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Systems for the Automotive Industry
for Improved Safety of Pregnant
Occupants

by

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(BEng hons)

A Doctoral Thesis
Submitted in partial fulfilment of the requirements
for the award of
Doctor of Philosophy of Loughborough University
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ABSTRACT

The thesis presents an investigation of pregnant women’s safety and comfort needs during car travel. A survey is used to investigate all aspects and problems of car travel. This survey is a comprehensive examination of the entire driving activity with much detail of reported difficulties from pregnant women that forms a novel resource for the automotive engineers. The survey results are used to generate guidelines for the automotive industry.

A series of sled tests are presented that investigate seat belt use in pregnancy including the use of lap belt positioners. The peak abdominal pressure results clearly agree with current guidelines that the lap belt should be positioned across the hips and not across the abdomen.

This research includes a novel anthropometric dataset for 107 pregnant women including measurements especially selected for the field of automotive design and to describe the changes of pregnancy. This includes investigation of pregnant driver’s proximity to the steering wheel. A novel measurement of ‘knee splay’ is used to define the pregnant women’s preference to sit with their knees widely spaced instead of knees together, in both normal sitting and in a car. Comparison is made between the pregnant women’s measurements and the available data in the literature for non-pregnant women and males, and this shows that pregnant women can be excluded from designs if the accommodation does not consider their needs.

The pregnant women’s anthropometric data is presented as a novel website in order to make the data available to the automotive industry. This website is generated for use by automotive engineers and is designed to suit their usability needs and the general trends within the industry, in order to make the site more user-friendly and more likely to be used as a reference for pregnant occupant’s needs.
ACKNOWLEDGEMENTS

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I would like to thank all the volunteers who have given their time for measurements and questionnaires, without whom this research would have been impossible. In particular I appreciate the time given by my sister Katie Davis, and by my cousin Lisa Lane, both of whom were extremely helpful with refining the anthropometric measurement procedures. I also thank Katie Davis for allowing the use of her photograph throughout this thesis.

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>ATD</td>
<td>Anthropomorphic Test Device</td>
</tr>
<tr>
<td>ARIS</td>
<td>Anthropometry Research Information System</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CAE</td>
<td>Computer Aided Engineering</td>
</tr>
<tr>
<td>CCIS</td>
<td>Co-operative Crash Injury Study</td>
</tr>
<tr>
<td>cm</td>
<td>Centimetre</td>
</tr>
<tr>
<td>CSCW</td>
<td>Computer Supported Collaborative Work</td>
</tr>
<tr>
<td>delta-v</td>
<td>Change in velocity</td>
</tr>
<tr>
<td>DMU</td>
<td>Digital Mock-Up</td>
</tr>
<tr>
<td>EPSRC</td>
<td>Engineering and Physical Sciences Research Council</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HCI</td>
<td>Human Computer Interaction</td>
</tr>
<tr>
<td>HTML</td>
<td>Hypertext Markup Language</td>
</tr>
<tr>
<td>Hybrid III</td>
<td>Type of Anthropomorphic Test Device first designed in 1976</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>km/h</td>
<td>Kilometres per hour</td>
</tr>
<tr>
<td>KPa</td>
<td>Kilopascal (unit of pressure)</td>
</tr>
<tr>
<td>MADYMO</td>
<td>MAthematical DYnamic Model</td>
</tr>
<tr>
<td>MAMA2B</td>
<td>Maternal Anthropometric Measurement Apparatus version 2B</td>
</tr>
<tr>
<td>MIRRC</td>
<td>Motor Insurance Repair Research Centre</td>
</tr>
<tr>
<td>mm</td>
<td>Millimetre</td>
</tr>
<tr>
<td>m.p.h.</td>
<td>Miles per hour</td>
</tr>
<tr>
<td>MySQL</td>
<td>Relational database management system (RDBMS)</td>
</tr>
<tr>
<td>PHP</td>
<td>PHP: Hypertext Preprocessor</td>
</tr>
<tr>
<td>UMTRI</td>
<td>University of Michigan Transportation Research Institute</td>
</tr>
<tr>
<td>VR</td>
<td>Virtual Reality</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Abruptio placentae</td>
<td>Detachment of the placenta from the uterus</td>
</tr>
<tr>
<td>Bump</td>
<td>Enlarged pregnant abdomen</td>
</tr>
<tr>
<td>Fetomaternal transfusion</td>
<td>Transfusion of fetal blood across the placenta into the maternal bloodstream</td>
</tr>
<tr>
<td>Fetus</td>
<td>The developing baby after the embryonic stage and before birth</td>
</tr>
<tr>
<td>Foetus</td>
<td>Earlier English spelling of fetus</td>
</tr>
<tr>
<td>Fundus</td>
<td>Top portion of the uterus</td>
</tr>
<tr>
<td>Infarction</td>
<td>Tissue death caused by blockage of the blood supply</td>
</tr>
<tr>
<td>Placental abruption</td>
<td>Detachment of the placenta from the uterus</td>
</tr>
<tr>
<td>Trimester 1</td>
<td>The first trimester of pregnancy lasting from week 0 to week 12</td>
</tr>
<tr>
<td>Trimester 2</td>
<td>The second trimester of pregnancy lasting from week 13 to week 28</td>
</tr>
<tr>
<td>Trimester 3</td>
<td>The third trimester of pregnancy lasting from week 29 onward</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

In England and Wales in 2008 there were 701,000 maternities (Office for National Statistics, 2009b) and a total of 888,000 conceptions (Office for National Statistics, 2010). In 2008 there were 709,000 babies born in England and Wales (Office for National Statistics, 2009a). All of these pregnant women are likely to be either drivers themselves, or regularly travel as a passenger in a car. Pregnancy changes the body in many different ways, and can cause problems with car travel, both in terms of safety and comfort. Whilst pregnancy is a temporary condition, these problems can severely affect women and their fetuses. Most women that have experienced pregnancy will have some problem or discomfort to report regarding car travel in pregnancy. This thesis aims to identify and address some of these issues of safety and comfort during car travel for pregnant women.

1.1 AIMS OF THE RESEARCH

The research aims to investigate the range of problems experienced by pregnant women during car travel. This investigation is not limited to the abdominal region only, but covers the entire body in a holistic and comprehensive approach. This information is then used to generate guidance for the vehicle manufacturers for how best to incorporate the needs of pregnant women. The research investigates the use and problems of seat belts in pregnancy in particular, including the use of after market seat belt positioners that are currently available as aids for pregnant women.

1.2 OBJECTIVES OF THE RESEARCH

One of the main objectives of the research is to investigate the needs of pregnant women for their safety and comfort during car travel. This includes data collection regarding their anthropometry as well as experiences and problems. This data collection is comprehensive covering all types of experiences and problems regarding both safety and comfort issues.

Another objective is the generation of guidelines for the automotive designers and manufacturers. These guidelines are generated from the information gathered from pregnant women.

There are after market devices (seat belt positioners) for pregnant women that are currently on sale globally. The third objective is to investigate whether these devices
are effective in improving pregnant women’s safety.
The final objective is to produce a novel website about the anthropometry (body measurements) of pregnant women. This site will be used to support the automotive design process to ensure that the needs of pregnant women are met.

1.3 THESIS OUTLINE
This research thesis aims to present information and data about pregnant women for the automotive designers and engineers, its organisation is now described.
Chapter 2 begins by reviewing the literature regarding the automotive safety needs of pregnant women. The chapter continues by reviewing Human Computer Interaction (HCI) and web usability for automotive designers and engineers, with a particular focus on their needs and characteristics.
In Chapter 3 the data collection from pregnant women is presented. This covers a questionnaire study to investigate the safety and comfort requirements of pregnant women for all aspects of car travel, including seat belts, airbags, seats, vehicle entry and exit, reaching controls, and using the boot. The physical and emotional symptoms of pregnancy are also investigated for their effect on driving.
In Chapter 4 the use of seat belt positioners for pregnant women is investigated in detail. This research begins by investigating their usage by pregnant women. A novel study is then presented which uses dynamic sled testing to investigate whether these devices offer pregnant women any safety benefit.
Chapter 5 discusses the anthropometry of pregnant women. The anthropometric changes are not limited to the abdominal region, and the changes over the entire body are presented. Analysis of the data is presented including comparison against data in the literature for males and non-pregnant females.
In Chapter 6 the anthropometric data from pregnant women is presented in website form. This website is designed for use by automotive designers and engineers during the vehicle design process, in order to ensure that the needs of pregnant women are met. The website is then developed further by improving the interface to be more suited to automotive engineers.
Conclusions and suggestions for further work are presented in Chapter 7.
CHAPTER 2: LITERATURE REVIEW

One of the aims of this thesis is to present data and guidelines for how to improve car travel for pregnant women to the automotive designers and engineers. This chapter begins by reviewing the safety needs of pregnant women in the automotive context, including all aspects of car travel. This chapter then continues by reviewing the characteristics of the automotive engineers, including their Human Computer Interaction (HCI) and web usability needs.

2.1 AUTOMOTIVE SAFETY NEEDS OF PREGNANT WOMEN

During the gestation period pregnant women experience a wide variety of physical and emotional changes. Not only do women gain weight, but they also undergo changes in size and shape throughout the entire body. The size increase may not be limited to the obvious abdominal protrusion. The size and shape changes can result in changes to women’s mobility and range of motion, with twisting, reaching and bending actions becoming particularly difficult. Women may also alter their posture to compensate for pregnancy, for example by leaning backwards to counterbalance the additional weight of the abdomen. The pregnant women may experience a wide variety of pregnancy related symptoms, which can be long lasting or sudden in occurrence. Long lasting symptoms might include back, hip, pelvic, stomach, and joint pain; exhaustion, haemorrhoids, swelling, varicose veins, and the baby’s head engaging with the pelvis. Symptoms that are sudden in occurrence can include leg cramp, heartburn, nausea, itching skin, Braxton Hicks contractions, and the need to urinate frequently. The hormone relaxin causes ligament laxity to help widen the pelvis in preparation for the birth. However its effect is not limited to the pelvis and can affect the entire musculoskeletal system. Furthermore, emotional changes caused under hormonal influence can mean that the pregnant women experience a wide range of emotions, ranging from depression, irritability and fear, through to excitement and pleasure.

All of these physical and emotional changes can cause pregnant women difficulty with carrying out everyday activities. Nicholls & Grieve (1992) found that 32 common tasks were more difficult during pregnancy. From this list of tasks, 3 driving-related tasks were in the top ten. These were: driving a car, getting in and out of a car, and using seat belts.
In 2008 there were 709,000 babies born in England and Wales (Office for National Statistics, 2009a). In England and Wales in 2008 there were 701,000 maternities (Office for National Statistics, 2009b) and 888,000 conceptions (Office for National Statistics, 2010). Consequently all of these pregnant women could have experienced some problem with driving or car travel.

2.1.1 Pregnant women’s anthropometric data

There is a lack of anthropometric data for pregnant women, and only a few sources were found, although little has relevance to the field of automotive design. For example, the study by Haslegrave (1979) involved measurements of British drivers’ anthropometry for both males and females, however this does not include any data for pregnant women.

The largest study of pregnant women's anthropometry is by Yamana et al. (1984), which includes 44 dimensions measured from 520 pregnant women from the second to tenth month of pregnancy. It is important to note that this sample is of Japanese women and due to national differences their anthropometric measurements might not be relevant to other populations, so this thesis will present a sample from the UK. The Yamana study was aimed at garment design, which means that few dimensions measured are applicable to the automotive design process. However there are 9 measurements that could be used in the automotive design process, and these include: chest circumference, abdominal circumference, hip circumference, stature, thigh length, breast depth, nipple height, abdominal circumference height, and weight. This is a small sample of measurements so this thesis will provide a more comprehensive set of measurements of pregnant women.

Pheasant (1986) then used the ratio scaling method (Pheasant, S., 1982) to modify the abdominal depth and forward grip reach dimensions from Yamana's data. This is based on the assumption that British women are of similar proportions to Japanese women and that pregnancy will cause them to change in a similar way, which is a potential limitation of Pheasant’s data. This thesis will present an anthropometric data set with a comprehensive list of measurements for a large sample size, so that scaling methods (with associated assumptions) are not required.

Culver and Viano (1990) have then used the data from Pheasant (1986) to produce a fetal ellipse. They represent body contact zones as 5 ellipses at the side and front, including the abdominal and pelvic ellipses for a normally seated woman. The fetal
ellipse is added to these by determining the centre and major axes of the fetal ellipse and superimposing it. This was an inexact approach because it relied upon subjective fit, but does offer some information to the automotive design process. Culver and Viano (1990) present the details of the ellipses, which are generated for the 5th, 50th, and 95th percentile females, for the 3rd, 6th and 9th months of pregnancy. A limitation of the method was that scaling based on stature was used to produce the ellipses, and the assumption that the abdominal size was proportional to stature. The data used to generate the fetal ellipse was taken from Stoudt et al. (1970) and Pheasant (1986). Stoudt et al. measured 203 pregnant occupants on 22 anthropometric dimensions, and included a measurement of H-point to the maximum forward protrusion of the abdomen.

Alvarez et al. (1988) investigated the dimensional changes of the feet during pregnancy. The study compared 17 pregnant women with 16 comparable non-pregnant women. The women were measured at 13 and 35 weeks, then at 8 weeks postpartum, and only 12 women attended all three measurement sessions. Only two dimensions, the foot length and width, are relevant to automotive design. There were not statistically significant changes in the foot length or width of the foot. However 14 women complained of tight shoes and 8 of these bought new shoes. There was an associated increase in foot volume, which Alvarez et al. conclude is due to increase in fluid or soft tissue. This thesis will include measurements of the pregnant women’s feet since these could be relevant to occupant packaging including the location of pedals. However this thesis will present a much larger sample, instead of the small sample from Alvarez.

Perkins (1999) studied a sample of 35 pregnant women at 5 times throughout pregnancy and at one month postpartum, but only 15 women completed all the sessions. These pregnant women were all military personnel, so this thesis will present a sample of pregnant women that is not limited by occupation. All of these pregnant women were Perkins studied both traditional anthropometric dimensions and the three-dimensional surface of the pregnant woman’s body. The 3D scans show that the pregnant woman’s body takes different shapes according to whether she is seated or standing. The scans also revealed that some women assumed a more lordotic posture in order to preserve their centre of gravity. Perkins presented only one anthropometric measurement, which was waist circumference at preferred level. This waist circumference at preferred level was found to move upwards throughout the
pregnancy. However the ‘preferred’ level of the waist is subject to the pregnant woman’s opinion and an improvement would be to measure the waist according to a physical landmark, e.g. the point of maximum circumference. This thesis will present a comprehensive set of anthropometric measurements that are defined according to landmarks using the standard methods. Klinich et al. (1999a; 1999c; 2005) measured the anthropometry of 22 pregnant women, in the 3rd, 5th, 7th, and 9th months of pregnancy. This study is also described in Pearlman et al. (2000) and Schneider et al. (2000), and these researchers are all from the University of Michigan Transportation Research Institute (UMTRI). However the full set of measurements was not recorded during all sessions, since Klinich et al. assumed that some measurements would not change during pregnancy. This thesis will present a set of anthropometric measurements for all stages of pregnancy to discover exactly which dimensions do (or do not) change with the effects of pregnancy. Only ten measurements applicable to the automotive design process, mainly concerned with the legs and abdomen, were recorded throughout the course of pregnancy by Klinich et al. This thesis will present the complete set of anthropometric measurements for all stages of pregnancy, and will include a greater number of measurements applicable to automotive design.

The Klinich study (1999a) also included measurements of pregnant women whilst seated in a driving simulator with adjustable seating buck. A number of landmark points were recorded on the pregnant woman’s body and well as on vehicle landmarks. These measurements were used to define the belt path across the woman’s body, as well as to record the distance between the steering wheel and abdomen. This thesis will present a similar study, but using a standard car (instead of a seating buck) in order to investigate different postures used by pregnant women in the real world. The study from Motozawa et al. (2007; 2008) presents measurements of 20 Japanese pregnant women seated in a sedan style car with a small set of measurements including height, stature, abdominal circumference, seat adjustment position and posture, position of the body in relation to the steering wheel, and relative position of the seat belt on the body. This set of measurements is only applicable to a sedan style car, and is also only useful for the Japanese population due to national differences in anthropometry. A similar study will be presented in this thesis for the UK sample of pregnant women seated in a supermini sized car as more commonly driven by females. Furthermore, by using a smaller car this will represent a higher risk scenario
due to the limited occupant space offered in smaller cars.

There are a few computational models of the pregnant women. One model is from Volvo (2003) and this can be used to investigate how the belt, fetus, uterus and placenta move in relation to the mother. The model represents a 50th percentile female, but it can be scaled up and down. A model representing the 5th percentile female would represent the greatest risk since the shorter stature would position the woman closer to the steering wheel. This model also does not appear to provide any facility to assess injury risk, only the relative motion of the mother and fetus and belt.

Another model is from Moorcroft et al. (2003), which is a model of the pregnant women within MADYMO that consists of a finite element uterus filled with amniotic fluid and with a placenta. This uterus and placenta is integrated into an existing 5th percentile female model available within MADYMO. The model is used to predict risk of injury with a range of restraint conditions and crash configurations. This model is based on the fetus and woman being in the 30th week of pregnancy, so does not represent the extreme case of abdominal enlargement that occurs at the end of pregnancy, and which would represent the stage of greatest risk. Moorcroft et al. have not included a fetus in the model, which is perhaps an important omission. This was based upon the work by Rupp et al, which found risk of fetal death to be independent of the fetus based on their five mechanisms of injury (2001). At a later stage of pregnancy than the 30th week the fetus is considerably larger. The fetus can move within the uterus which is more solidly filled by the fetus, and this could consequently affect the entire dynamic of the pregnant occupant in a collision. The model from Moorcroft et al. can only show the dynamic response of the amniotic fluid and uterus, and cannot replicate the more solid and heavier fetus.

Behr et al. (2009) have presented a finite element model by adding a pregnant uterus to the Radioss Humos full human body model. The internal organs of the abdomen were pushed back to make space for the uterus, which contained a fetus at 32 weeks gestation based on MRI images. Whilst this model does include a fetus, it is only at 32 weeks gestation, so does not represent the stage of pregnancy that is the greatest risk due to the greatest enlargement of the abdomen.

However the ‘Expecting’ model does include a fetus, with the placenta located in the fundal region of the uterus (Acar, B.S. and Van Lopik, D., 2009). This model also represents a later stage of pregnancy; the 38th week. It also incorporates the anthropometric measurements presented in this thesis that were taken from pregnant
women in the seated posture, so is most representative of an actual seated pregnant driver. The ‘Expecting’ model is capable of simulating the movement of the fetus within the uterus during a collision. However this thesis does not attempt to produce a model of the pregnant women, although the anthropometric data presented in this thesis was used in producing the ‘Expecting’ model (Acar, B.S. and Van Lopik, D., 2009).

### 2.1.2 Collisions involving pregnant women

During pregnancy a woman’s body undergoes a wide variety of physical changes and this can impact upon her safety during driving and car travel. Recent reports have shown that the biggest cause of abdominal trauma is the automotive collision.

The survey of 725 pregnant women (Hammond, T.L., Mickens-Powers, B.F. et al., 1990) revealed that 50 women were involved in a collision during their pregnancy (7%), and 86% of these women were wearing seat belts at the time.

It has been estimated by Klinich et al. (1999b) that around 130,000 women in the second half of pregnancy are involved in car accidents each year. Of these, around 30,000 will sustain treatable injuries, while approximately 160 will die. From those that survive, between 300 and 3800 will result in fetal loss.

Corsi et al. (1999) reported on 27 cases from a 9 year period. Blunt trauma was the cause of injury in 21 of the cases, and 7 of these cases were a result of a motor vehicle collision where the woman was inside the vehicle.

Baerga-Varela et al. (2000) presented 61 cases of trauma in pregnant women, and 64% of these were a result of a motor vehicle collision. Fetal death occurred in 15% of cases where the long-term outcome was available. They also noted that maternal injury severity was not necessarily correlated to fetal death.

Weiss et al. (2001) examined 240 traumatic fetal injury cases over a three year period. In 82% of cases the cause was a motor vehicle collision, and this equated to 2.3 fetal deaths per 100,000 live births. In 3 US States the rate of fetal death exceeded the rate of infant death in motor crashes.

In a later study Hyde et al. (2003) examined 322,704 births and found that 2.3% were involved in a car crash during pregnancy. 45 of 2,645 fetal deaths were caused by a crash.

Schiff et al. (1997) studied 97 deaths during pregnancy from 1986 to 1996 in New Mexico. They found that 47 deaths were injury related, and 33 (approximately 70%)
of these were related to motor vehicle crashes. Even in 1978 research was revealing that the motor vehicle crash was a major cause of fetal trauma. Rothenberger et al. (1978) presented a study of 103 cases of blunt abdominal trauma in pregnancy, 18% of which ended in fetal death. 54% of all injuries (all 103 cases) and 70% of major injuries were causes by car crashes. A much more recent study by Hitosugi et al. (2006) showed 135 women involved in motor accidents in eastern Japan from 1994 to 2003. 63 (46.7%) were drivers, 43 (31.9%) were front passengers, 8 (5.9%) were pedestrians, 8 (5.9%) were motorcyclists, 7 (5.2%) were rear seat passengers, and 6 (4.4%) were bicyclists. In the 113 collisions where the pregnant woman was inside the car, rear impacts were most common (42.7%), followed by front impacts (36.4%) and side impacts (20.9%). It should be noted that due to national motor park and road structure differences, these distributions of accident types might not be representative of other nationalities.

2.1.3 Fetal fatality and injury risk

2.1.3.1 Injury mechanisms

There are several causes of fetal injury and death as a result of a motor vehicle collision and these are reviewed as follows. Pepperell et al. reported in 1977 that the most common injury was placental abruption in their 27 cases of fetal death over three years in the state of Victoria, Australia (Pepperell, R.J., Rubenstein, E. et al., 1977). They also reported on three cases of uterine rupture. Pepperell et al. suggest that wearing the seat belt can offer protection against maternal death, but that risk of placental abruption or uterine rupture could be increased. Lane (Lane, J.C., 1977) counters this by citing the work of Crosby et al. (1968; 1971). Similarly to Pepperell et al, Chetcuti and Levene (1987) present a case of placental abruption in a woman wearing a seat belt, however it was only the lap belt. The guidelines from authorities are well established that the seat belt should be used and both parts correctly positioned in order to reduce the risk of injury to the mother and fetus, but since Pepperell et al. and Chetcuti and Levene do not give an indication of seat belt positioning it is impossible to establish whether this was a factor in their cases.

In a case from Cumming and Wren (1978) the cause of fetal death was a fetal skull fracture. Evrard (1989) also presents a case of fetal skull fracture from a collision where the mother was unbelted. Weinberg (2001) reports a case of uterine rupture,
placental abruption and fetal spine fracture where the fetus was completely ejected from the uterus.

Svendson and Morild (1988) reports on a case of fetal strangulation following uterine rupture where the 30 week pregnant mother was wearing a three point seat belt. Svendson and Morild suggested that usage of the three point belt is progress, but that more research is needed to design a belt to avoid forward flexion and to promote a more evenly distributed compression on the abdomen.

Agran et al. (1987) present a series of 9 cases of fetal death over 3 years. These cases were found to result from abdominal impact with the steering wheel during a collision, and in half the cases there was only minor injury to the mother. None of the women were wearing a seat belt.

Stafford et al. (1988) similarly present 8 cases of lethal fetal injury from 1979 to 1986. The causes of death were also placental abruption, infarction, and fetal injury including head injury.

Lane (1989) gives a study of 13 cases from 1982 to 1986, and there were serious injuries in 5 of these cases. Placental abruption, infarction, laceration, and uterine rupture were the causes of fetal death in these 13 cases, and 5 of the cases involved fetal head injury.

Pearlman et al. (1990) present a prospective controlled study of outcome after trauma during pregnancy. 85 pregnant women (12 to 41 weeks) who suffered trauma were compared with a control group of pregnant women matched by gestation age. This study revealed that fetomaternal transfusion occurred more frequently in the pregnant women who had suffered trauma. Furthermore they found that women with an anterior placenta were at greater risk, and that both of these findings were statistically significant. Placental abruption was also frequent in the study group.

Goodwin and Breen (1990) present a prospective study of 205 consecutive cases of non-catastrophic trauma during pregnancy. They revealed that 9% of cases lead to pregnancy complications, including: premature labour, placental abruption, fetal injury and fetal death. Complications were associated with uterine tenderness and bleeding, as well as fetomaternal transfusion.

Griffiths et al. (1991) present two cases of fetal death, both of which involve injury to the placenta that results in fetal death.

Pearlman (1997) suggests that a focus on monitoring of the uterus and fetus for women injured after 24 weeks’ gestation could be beneficial in treating the main
causes of injuries in pregnant women, namely placental abruption and uterine rupture. Corsi et al. (1999) reported on 27 cases from a 9 year period. Fetal mortality was 30.7%, with 37.5% of these deaths as a result of maternal death. The biggest cause of fetal death was placental abruption (50%).

Rainio and Penttilä (2003) presented a case report for a 38 week pregnant woman involved in a collision that lead to amniotic fluid embolism, which is a relatively rare complication of pregnancy, but with a high mortality rate. This case reported that the seat belt was not correctly used, since the lap portion was over the lower abdomen and the shoulder portion was unused behind the seat. This type of amniotic fluid embolism caused by blunt abdominal trauma in a motor vehicle collision was also reported by Olcott et al. (1973) and Judich et al. (1998).

In a study by Klinich et al. (1998) they present 120 cases, 93 of which are taken from the literature. The remaining 27 cases are from their own investigations. The main cause of fetal trauma was placental abruption, occurring in 1-5% of minor trauma and 20-50% of severe crashes during pregnancy. Uterine rupture and lacerations, and direct fetal injury were the other main causes of trauma. Other consequences were premature delivery, stillbirth, and brain damage to the fetus.

Weiss et al. (2001) examined 240 traumatic fetal injury cases over the period 1995 to 1997 and found that placental abruption was mentioned in 100 cases (42%). Maternal death was the cause of fetal death in 27 cases (11%).

Hitosugi et al. (2006) attempted to investigate the relationship between maternal injury severity (as determined by AIS and ISS scores) and fetal outcome. Their study found 32 cases of spontaneous abortion, 11 stillbirths and neonatal deaths, and 38 healthy fetuses, having discounted any cases that indicated an abnormality present before the collision. Nearly half the women had not sustained an injury, and 44% has sustained only AIS 1 injuries (e.g. abrasion or laceration to the skin, or spinal cord strain). The study used a t-test to determine whether death or abortion outcomes differed significantly to the healthy outcomes, but there were no significant differences found when considering the outcomes for the mother, or the presence of abdominal injury. Overall this study confirms that fetal injury can occur whether or not the mother is injured, and that it is difficult to predict the fetal outcome.

This thesis does not aim to investigate the causes of injury, since these are established in the literature above. Trauma during a motor vehicle collision can result in placental abruption, fetal injury and/or death, feto-maternal transfusion, and onset of labour.
The main causes of fetal death are placental abruption and uterine rupture. Injuries to the fetus or fetal death can occur with only minor injuries to the mother. However this thesis will present the use and misuse of seat belts since these are shown to have an influence on injury risk, as in the following section.

2.1.3.2 Injury risk and seat belt use

Rubovits (1964) presents a case of uterine rupture that resulted in fetal death. The mother was not using the seat belt and was thrown from the car and killed. Agran et al. (1987) has presented cases (above) of fetal trauma with associated lack of seat belt use. Lane (1989) gives a study of 13 cases, and in only 4 of these were the women wearing the seat belt.

Stafford et al. (1988) reported on 8 cases (above) of fetal death and at least 5 of the mothers were unrestrained at the time of the collision. The mothers sustained only minor injuries. In two cases the mothers were definitely wearing the seat belt; one was a 3 point belt and one was a lap belt only. However the positioning of the belt is not described.

The cases (above) from Hyde et al. (2003) showed that in a crash pregnant women not wearing the seat belt were twice as likely to experience bleeding than belted pregnant women. Furthermore they report that for unbelted pregnant women fetal death is 2.8 times more likely than for belted pregnant women in crashes, and both of these findings were statistically significant. Similarly Schiff et al. reported that the majority (77%) of the pregnant women killed in motor vehicle crashes were not wearing their seat belts.

Stuart et al. (1980) present two cases, both of which resulted in fetal death. In one case the woman was wearing only the lap belt, and in the second the woman was not using a seat belt at all. In a case from Cumming and Wren (1978) a women was not wearing her seat belt during a car crash, and this resulted in a fetal skull fracture and fetal death. Filardi and Weatherstone (2001) also present a case of fetal death where the mother was unrestrained during a crash at 28 weeks gestation.

Klinich et al. (2000) presented 43 case investigations of trauma during pregnancy, and this study is also described by Pearlman et al. (2000) and Schneider et al. (2000). The cases were divided into minor (<15 m.p.h.), moderate (15 ≤ 30 m.p.h.) and severe (>30 m.p.h.) cases according to change in velocity. The cases were divided by injury category and the study found 21 cases categorised as no problem, 6 cases as minor
problems (preterm uterine contractions and delivery at >32 weeks within 48 hours of crash), 8 cases as major fetal problems (compromising fetal survival, including placental abruption, uterine rupture, fetal injury and preterm delivery at >32 weeks within 48 hours of crash), and 8 cases as fetal loss (within 48 hours of crash without another explanation). Overall they reported that only 27% of properly restrained women wearing a three point seat belt had adverse fetal outcomes, compared to 62% of the improperly restrained women (including lap belt only). The study does not consider the positioning of the seat belt.

Fakhoury and Gibson (1986) report a case of pregnant woman in her 30th week that suffered abdominal trauma during a car collision. The woman’s abdomen showed bruising from the seat belt, and the fetus died as a result of placental abruption. Raney (1970) presents as case of a 28 week pregnant woman wearing a lap belt involved in a collision that resulted in bruising on the abdomen and placental abruption leading to fetal death. Bunai et al. (2000) present a case of a 24 week pregnant women that was shown to have an incorrectly positioned lap belt. Bruising was seen 5 days after the accident on the lower abdomen, and this resulted in placental abruption that caused fetal death. In these cases the actual belt positioning is not certain because it is not described, however the bruising on the abdomen suggests that the lap belt might have been incorrectly positioned.

Fries and Hankins (1989) reported a fetal death 5 days after a collision, however in their case the seat belt was used but the position was not defined.

In the case report from Rainio and Penttilä (2003) the seat belt was not correctly used, since the lap portion was over the lower abdomen and the shoulder portion was unused behind the seat. It was suggested that this incorrect positioning of the seat belt resulted in the fetal injury.

A case from (McCormick, R.D., 1968) shows a complete transection of the pregnant uterus and fetus. McCormick suggests that the lap belt should be positioned across the upper thighs. However van Enk and van Zwam (1994) showed a case of a 32 week pregnant woman who wore the lap belt across the upper thighs, instead of across the hips. During the collision she slipped under the lap belt, which moved upward on the abdomen. The result was uterine rupture and fetal death.

Crosby et al. (1968) completed 12 impacts using pregnant baboons. As with the human cases, the consequences included fetal death due to fetal head injury, placental abruption and maternal shock. The tests with just a lap belt showed that the baboon’s
upper torso tended to jackknife over the belt, which resulted in abdominal compression. Crosby et al. (1972) presented 22 impacts with pregnant baboons, with different conditions of seat belt use and positioning. The fetal death rate was established as 8% amongst the animals wearing a three point restraint, compared to 50% among the animals wearing only the lap belt. This high fetal death rate for the lap belted animals was due to the jackknife over the lap belt and not to deceleration alone. Crosby et al. suggest that the three point belt is recommended as being more protective for the fetus than a lap only belt.

Pearlman and Viano (1996) completed 39 tests using an ATD (Anthropomorphic Test Device) converted to represent pregnancy in a range of speeds from 10 to 25 m.p.h. The study is also described in Viano et al. (1996; 1996), and this ATD is described in more detail in Chapter 4. This testing revealed that greater speed resulted in a greater force transmission through the fetus. Pearlman and Viano also investigated belt positioning and showed that placing the lap belt over the uterus instead of underneath caused a three or four times greater force transmission through the uterus at all speeds tested.

Motozawa et al. (2007) used a Hybrid III 5th percentile female with MAMA2B conversion kit (described in greater detail in Chapter 4). This ATD was used to investigate use and non-use of the three point seat belt, as well as seating proximity to the steering wheel. Their study showed that pressure in the abdomen was greater in cases where the seat belt was not used, and that the pressure was also lower in the cases where the dummy was seated at a greater distance away from the steering wheel. This study by Motozawa et al. is more evidence showing that pregnant women should wear a three point seat belt. A related study by Hitosugi and Tokudome (2009) using the same test set up and ATD presents a novel study of the effect of the seatbelt pre-tensioner. This study reveals that a seat belt pre-tensioner could help to reduce the likelihood of fetal injury for pregnant drivers. However these two studies by Motozawa et al. and Hitosugi and Tokudome do have some limitations since the MAMA2B conversion only represents the 30th week of pregnancy. The two studies have used a rear-impact pulse with trapezoid waveform, with the delta-v of 24kph (mean acceleration of 6.5G), which is defined by the test protocol of Folksam (2005a; 2005b; 2005c). The decision to use the rear-impact pulse is based on the prevalence of the rear-impact injuries in Japan and that after the rear-impact the occupant moves forward in a rebound phase and this can result in steering wheel impact. However the
Hybrid III is most commonly used for frontal impacts and in a rear-impact situation could be limited by lack of biofidelity of the spine movements, and consequently this could cause the dummy to respond in an unrealistic manner. The study presented in this thesis will present testing using the Hybrid III 5th percentile female ATD with MAMA2B conversion to represent pregnancy, but in a frontal impact scenario and at a higher delta-v in order to represent a higher risk impact.

Newgard et al. (2005) present a study of 15,160 cases of injury from lateral motor vehicle crashes, of which 160 were for pregnant women. This provides a 1% frequency of occurrence of lateral crashes involving pregnant women. However the details of the injuries shown by the group of pregnant women are not discussed, so it is not possible to establish whether the injuries from side impacts differ from frontal impacts. However the study from Schiff et al. indicates that pregnant women are 1.5 times more likely to suffer a pelvic fracture in a lateral impact (Schiff, M.A., Tencer, A.F. et al., 2008). The study by Schiff compared 728 cases of occupant suffering a pelvic fracture in lateral impact against 5710 control cases without pelvic fracture. However the study was only focussed on pelvic fracture and did not offer an insight into other injuries sustained by pregnant women in lateral impact, and there were only 6 cases of pelvic fracture in pregnant women in the sample.

The aim of this thesis is not to investigate cases of fetal trauma during car crashes with regard to seat belt usage, since the literature has already established a consensus. Regarding the use of seat belts in pregnancy, research studies have shown that the pregnant woman and her fetus are at increased risk during a collision if the seat belt is not worn, or only the lap belt is used, or if it is incorrectly positioned (either over the abdomen or thighs). Many cases are presented of fetal death with an unrestrained mother by the authors above. Other studies show that fetal injury or death is more frequent if the mother is unbelted, or improperly belted. This thesis will present an investigation of the use of seat belt, and in particular their positioning over the pregnant woman’s body, in order to establish current practices on the road and any implications for automotive design.

2.1.3.3 Seat belt usage in pregnancy

In the study by Klinich et al. (1998) about half of the 120 cases showed the mother was unrestrained. In only 3% of cases the mother was confirmed to have the lap belt across the abdomen instead of across the hips. About 6% used a lap belt only, mainly
because historical cases were included from the literature. Klinich et al. (2000) reported only 31 of their 43 women (72%) were using the seat belt, but did not state how the seat belt was positioned. Klinich et al. report in both cases (1998; 2000) on seat belt usage in the pregnant population of drivers and passengers, but their involvement in a crash resulting in trauma could have some effect. Other studies involve surveys of reported belt usage by pregnant women in the normal driving activity. It should be noted that survey results asking about belt usage could be biased if women do not want to admit to breaking the law by not using the seat belt, or if they know the correct positioning and do not want to admit to not using it.

Arneson et al. used interviews with pregnant women to establish their seat belt usage. 40 of the 87 (46%) of the women were using the seat belt, but one third of them did not adjust it to the correct position. Phillips (1995) used a survey and found that seat belt usage increased in pregnancy, although 25% had the seat belt incorrectly positioned and nearly one third did not wear the seat belt.

Hammond et al. (1990) used a survey of 725 pregnant women attending a military medical clinic to assess seat belt use. Seat belt usage was 88% amongst drivers, and 90% amongst passengers. For 31% of the respondents being pregnant had caused a positive effect on restraint usage, and for 1.2% it caused a negative effect. 86% of the 50 pregnant women who were involved in crashes during their pregnancy were wearing the seat belt at the time.

Johnson and Pring (2000) surveyed 159 pregnant women attending UK antenatal clinic and found 98% were using seat belts in the front, and 48% in the rear. 48% correctly identified how to position the seat belt correctly. In another UK based study Shoesmith (2000) surveyed 100 pregnant women attending an antenatal clinic. 53% of the women wore the seat belt correctly. For the reasons given for non-use of the seat belt, 57% of the pregnant women stated discomfort, 15% stated fear of harming the baby, and 26% wore it incorrectly. Additional comments revealed an alarming practice by one woman of not wearing the seat belt because the baby travelled seated on her lap, which is dangerous to both mother and fetus, as well as being illegal. The survey by Brake (2005) showed that from 1,010 pregnant women 92% were using their seat belt. Nearly a quarter (23%) of the pregnant women did not know for sure that it was safer to wear a seat belt in pregnancy (both for the mother and the fetus), or that the lower part should sit underneath the bump. However it is not possible to separate the understanding of seat belt safety from the understanding of
how to position the lap belt, since the question put to the pregnant women grouped these two issues together. This study by Brake also did not directly question the pregnant women about how they actually positioned the seat belt.

A survey of 154 pregnant women by Jamjute et al. (2005) found that 75% of pregnant women wore seat belts as drivers, and 44% of the pregnant women indicated incorrect seat belt positioning.

In a large study of 880 pregnant women in Japan using a questionnaire at antenatal clinics Ichikawa et al. (2003) found that seat belt usage was reduced by about half in the 20th week of pregnancy. However the pregnant women were exempted from seat belt usage in Japan at the time. This study does not discuss seat belt positioning.

Filardi and Weatherstone (2001) reported on a small survey of 20 pregnant women, and revealed that only 80% were using seat belts. 36% of these women had the seat belt incorrectly positioned, although the exact positioning is not described.

Pearlman and Phillips (1996) found that 68% of pregnant women were using the seat belt correctly using a survey and with photographs as they arrived at the clinic. Nearly 20% were not using the belt at all.

McGwin et al. (2004) used a survey of pregnant women attending a clinic, and reported seat belt usage of 95% and correct positioning of 72.5%.

The seat belt usage in these reviewed studies ranges from 46% to 98%, and correct belt positioning ranges from 48% to 75%. This reveals an overall problem of how to increase seat belt usage, and its correct positioning. This thesis will not address how to achieve these goals, but will contribute a UK based survey of seat belt usage and positioning. The thesis will also investigate the problems of seat belt use in pregnancy including positioning.

2.1.3.4 Education about correct seat belt use

Various authors have presented data from surveys on the provision of information about seat belt use in pregnancy. In summary of the proportions of pregnant women that had received information about seat belt usage in pregnancy: Arneson (1986) reported 22.9%, Phillips (1995) reported two thirds, McGwin (2004) 36.9%, Pearlman and Phillips (1996) 55%, Hammond (1990) 42%, Johnson and Pring (2000) 37%, Ichikawa (2003) 20%, Jamjute (2005) 14%, and Shoesmith (2000) 23%. The range is from approximately one fifth to two thirds of pregnant women that had been informed, which reveals that in many cases the majority of pregnant women were
uninformed about seat belt use in pregnancy. The Brake survey (2005) also showed that 23% of pregnant women did not know that it was safer to use the seat belt in pregnancy. This thesis will not address education schemes for pregnant women, but will contribute a survey of information provision in the UK.

Analysis by Johnson and Pring (2000) and by Pearlman and Phillips (1996) revealed that those women who received information about correct belt usage in pregnancy were significantly more likely both to wear the belt and to have it correctly positioned. Shoesmith’s study (2000) also shows that correct seat belt usage is higher for those women who received information than for those who did not.

McGwin et al. (2004) have shown that educational intervention can increase correct seat belt usage. The intervention was dissemination of brochures and badges to medical staff and pregnant women attending an antenatal clinic. A pre- and post intervention questionnaire was used to establish that correct seat belt placement increased from 71% to 83% after the intervention.

The survey by Freeman and Wogalter (2002) takes a different approach. They sought to determine whether pregnant women would like to be informed of the risk of injury in car travel, specifically that seat belts could cause fetal injury in relatively minor crashes, and that lack of belt use in severe crashes could result in severe injury or death for the pregnant women and consequently to the fetus. 91% of the pregnant women said they would like to be informed about these risks. The women indicated that to deal with these risks they would either wear the seat belt, but some 15% would cease wearing it. Just over half the pregnant women said that they would try to reduce car travel during their pregnancy. The thesis author suggests that it is important to ensure that advice given to pregnant women will not cause them to take unsafe actions such as not wearing their seat belt. The guidelines regarding correct seat belt use and positioning should be clearly stated, and this could be combined with the suggestion that reducing car travel could help to reduce the risk of fetal injury.

Some studies have also investigated the education levels and practices of the medical practitioners, and shown them to be lacking. Griffiths et al. (1992) conducted a survey of teachers in maternity units and only 11 of 21 units gave any teaching on the use of seat belts in pregnancy. This survey revealed that the advice given to pregnant women can be incorrect and consequently affect women’s safety, since Griffiths et al. report that 7 of the 21 units advise pregnant women to travel unrestrained in the rear. One unit was advising women to pad the seat belt with a towel or foam, and one unit was
advising the use of the diagonal strap alone. One unit had been incorrectly advised by the local police that pregnant women are exempt from seat belt use. Griffiths suggests that these examples of incorrect advice mean that education is needed in the maternal units in order to improve the advice given to pregnant women and to ensure the correct information is given.

Chang et al. (1985) used a survey of 236 obstetrician-gynaecologists, the majority whom believed that pregnant women should be informed of safety issues by the obstetrician-gynaecologist. However one in four could not give an opinion or had doubts about the safety of seat belt use by pregnant women. Less than one in three actually discussed passenger safety with pregnant women.

The survey by Wallace (1997) showed that only 70% of general practitioners were aware that pregnant women are required by law to wear the seat belt. Only 30% provide regular advice to pregnant women, and less than 50% were aware of the correct advice to give. The thesis will not attempt to address the issue of education schemes neither for the medical practitioners, nor for the pregnant women. Although the author does suggest that information provision should be increased.

Nakahara et al. (2007) have used a survey of the content of maternity and baby magazines in order to assess the information given to pregnant women. They used 3 maternity and 3 baby magazines, including all issues from 2003 for each. Each page was assessed for its content regarding advice to pregnant women. There were only 0.17% of pages with articles on belt use in pregnancy, and only 2 of the 16 pages mentioned that the belt should also be worn in the rear seats. Only 5 pages (of 16) mentioned the correct lap and shoulder belt position, but there were no pages that gave incorrect written information on seat belt use in pregnancy. There were 30 depictions of pregnant women wearing a seat belt. 27 of the images showed the correct position of the seat belt, and 2 images showed incorrect positioning labelled (properly) as misuse. One depiction of a pregnant woman showed her seated in a car and holding a steering wheel without wearing the seat belt, and did not mention proper belt use in the text. Overall this magazine survey reveals that there is very little coverage given to the issue of seat belt use in pregnancy, although this could be because Japanese legislation makes pregnant women exempt from seat belt use. The thesis author suggests that it is important to increase information given to pregnant women, and particularly to ensure that depictions of pregnant women show the correct seat belt positioning. This thesis will not aim to address information provision
methods, but instead will survey the level of information provision to the pregnant women sampled from the UK.

2.1.4 Legal requirements and guidelines regarding pregnant women’s safety

The correct position for the seat belt in pregnancy is with the shoulder section passing across the shoulder, between the breasts, and around the abdomen, and the lap section passing across the hips and underneath the abdomen. This seat belt position is recommended by many authorities, including the UK Department for Transport (2007; 2009b), the American College of Obstetrics and Gynecology (1999) and the National Highway Traffic Safety Administration (2002). The correct position is shown below in Figure 1 diagrammatically, and in Figure 2 as photos of a pregnant woman in trimester 2 and trimester 3.

![Figure 1](image_url)

Figure 1. Diagram of correct lap and shoulder belt positioning during pregnancy.
Figure 2. Photos of correct lap and shoulder belt positioning during pregnancy for a pregnant woman in trimester 2 (top) and trimester 3 (bottom).

Some of the incorrect lap and shoulder belt positions are summarised in Figure 3. The lap belt can be incorrectly positioned across the thighs or laying over the abdomen instead of being correctly positioned over the hips. The shoulder portion of the seat belt is incorrectly positioned if it passes across the top of both breasts instead of between them, is off the shoulder, or if it passes across the abdomen. Both the lap and shoulder portions of the seat belt should be worn at all times, and it is incorrect if either or both is not worn. It is also important that these lap and shoulder belt positions can be in any combination. For example the lap belt could be incorrectly positioned across the abdomen, but the shoulder belt positioned correctly across the shoulder and between the breasts. Care should be taken with the correct positioning of both parts of the seat belt.
Chapter 2

2.1.5 Other issues of car travel in pregnancy

2.1.5.1 Proximity to the steering wheel

Another source of risk is proximity to the steering wheel through direct impact with the wheel (Klinich, K.D., Schneider, L.W. et al., 1998), or possibly a deployed airbag although the level of this risk is unproven. DeLeonardis et al. (1998) showed that shorter women are at increased risk of injury due to proximity to the steering wheel, and Dobson & Baird (1996) suggest that seat position is directly related to height. Welsh et al. have found that shorter drivers are seated in closer proximity to the steering wheel. Furthermore they report the drivers up to a little over 160cm in height had the highest rate of AIS 2+ injury across all body regions, and a significant increased risk of AIS 2+ head injury (Welsh, R., Clift, L. et al., 2003). UMTRI research showed that as pregnancy progresses the abdomen protrudes closer to the steering wheel (Klinich, K.D., Schneider, L.W. et al., 1998; Pearlman, M.D., Klinich, K.D. et al., 2000; Schneider, L.W., Klinich, K.D. et al., 2000). Hence risk is increased in pregnancy due to decreased distance from the steering wheel (Aschkenazi, S., Kovanda, J. et al., 1998). Klinich et al. (1999a; 1999c) showed that pregnant women
do not adjust their fore/aft seat position or seat back angle during pregnancy to compensate for increased abdominal protrusion. They also revealed by palpation of the fundus that there was an overlap of 26% between the fundus and the lower rim of the steering wheel, which means that contact between the pregnant abdomen and the steering wheel is possible.

In the work by Pearlman and Viano with the first design of pregnancy insert (described in greater detail in Chapter 4) there was also an investigation of the effects of the airbag. This work is described in several papers including Pearlman and Viano (1996) and Viano et al. (1996; 1996). The force transmission was similar whether the airbag was deployed or not in the 15 m.p.h. crash with the dummy belted properly in a three point belt. However when the dummy was unbelted there was an increase in fetal head injury criteria with airbag deployment, which confirms that the seat belt should always be worn. The dummy was also laid against the steering wheel without sled movement and the airbag deployed, and this also showed a substantial increase in fetal head injury criteria.

Motozawa et al. (2007) used the MAMA2B conversion kit with a Hybrid III 5th percentile female (described in greater detail in Chapter 4) to investigate use and non-use of the three point seat belt, as well as seating proximity to the steering wheel. Their study showed that pressure in the abdomen was lower in the cases where the dummy was seated at a greater distance away from the steering wheel. This thesis will present testing using a similar dummy; however the focus will be on seat belt positioning and not on proximity to the steering wheel.

2.1.5.2 Vehicle entry and exit

One of the major problems of car use in pregnancy is vehicle entry and exit. Nicholls and Grieve (1992) found nearly 70% of subjects reported difficulty in getting in and out of the car. In the study by Nicholls and Grieve the pregnant women reported that they perceived mobility to be the main cause of the vehicle entry and exit problems. They describe the difficulty of simultaneously bending, twisting and lifting the body weight against gravity in a constrained space as obvious, although they do not examine the precise nature of the problem in detail. Lou et al. (2001) investigated the sit to stand motion at different periods of pregnancy, and suggest that moving from sitting to standing posture takes longer toward the end of pregnancy. They suggest that in the third trimester of pregnancy the sit to stand motion becomes more difficult
because pregnant women are prevented from leaning forward by the enlarged abdomen. However Lou et al. only consider office chairs and not vehicle seats, and they also do not consider the opposite motion of moving from standing to sitting. The research to date has not yet comprehensively addressed the problem of vehicle entry and exit. This thesis will therefore present an investigation of vehicle entry and exit, in order to gain a thorough insight into the problems that occur. This will include a detailed examination of entry and exit problems to aid the understanding of automotive designers so that they could address the problem successfully.

2.2 HCI AND WEB USABILITY FOR AUTOMOTIVE ENGINEERS AND DESIGNERS

2.2.1 Human Computer Interaction (HCI) and web usability

Human Computer Interaction, or HCI, is the way in which humans (users) interact with computer applications. The Association for Computing Machinery define HCI as “a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them” (SIGCHI Curriculum Development Group, 1992). HCI occurs at the user interface, or simply the interface, and occurs with both software and hardware. For the purpose of this thesis hardware design is outside the scope of the research and will not be considered.

HCI is important in this thesis since the anthropometry of pregnant women will be presented as a website for use by the automotive industry. Therefore a good HCI can help to encourage increased usage of the site, whereas a poor HCI would discourage it. It is important to increase the use of the website in order to encourage the automotive engineers to consider and incorporate the anthropometric needs of pregnant women into automotive designs.

Siemieniuch and Sinclair have state that there is a need for engineering knowledge systems to be user-friendly, not just that they have good interfaces, but that knowledge is in a form usable and useful for its intended users. There are many publications of HCI design guidelines and rules. Some examples include Ask Tog (Tognazzini, B.), Brinck et al. (2002), Usability.gov (2009), W3C (1999), Nielsen (Nielsen, J.), and (Johnson, J., 2000). Some of these guidelines can be contradictory, but the overall trend can be identified. The aim of this thesis is not to generate new
HCI guidelines, or to evaluate the existing ones. This thesis will use these HCI guidelines in the production of the Pregnant Women’s Anthropometry website and will discuss how the guidelines are followed in its construction. The HCI guidelines are followed in order to provide a basic level of usability, and then further developments and features are provided on the website in order to suit the automotive industry specifically and these features are also discussed in this thesis.

Schneiderman has suggested that HCI can help to support creativity (Schneiderman, B., 2000). A four-phase framework for creativity is presented and the phases include: collect, relate, create and donate. The relevant point here is the activity of collecting and searching for data and past experiences, and the Pregnant Women’s Anthropometry website could be one resource for the automotive industry to inspire improved designs to accommodate the needs of pregnant women.

A vitally important aspect of HCI is that of website usability, and this is particularly relevant since this thesis is concerned with the production of a website. Jakob Nielsen is a usability expert who states that “on the Web, usability is a necessary condition for survival” (Nielsen, J.). Users will leave a website if it is not user-friendly, or if the home page does not make clear what the site can offer them, or if users get lost on the site (Nielsen, J.). Furthermore Kreitzberg and Schneiderman (2001) have argued that user difficulties can result in lost productivity for businesses. It is important for the Pregnant Women’s Anthropometry website to be usable in order to keep the automotive engineers using it, and not leaving it because of poor design. This thesis will present the methods by which the usability of the website has been addressed to ensure that automotive engineers will use the site, and hence make it more likely that they would use the anthropometric data in the automotive design process.

HCI is very much dependent on the human and in particular human behaviour and understanding. HCI is important because cases have shown that poor HCI can cost money and lives (Lee, L., 1992). It is important in this thesis that the interface is suitable for automotive engineers since if it were misunderstood and incorrect data used then this could potentially affect the safety of pregnant women and their fetuses. HCI often refers to usability, which is concerned with the user’s efficiency, ease and satisfaction with using the software. Some of the usability goals are efficiency, effectiveness, safety, utility, learnability and memorability (Preece, J., Rogers, Y. et al., 2002). Effectiveness is concerned with ensuring that the system will allow the user to achieve what they want to do, and efficiency is about ensuring the user can
achieve their goal in an efficient way and with a high level of productivity. Utility is concerned with letting the users carry out tasks in the way or using the method that they want to, and safety as a usability goal is concerned with reducing the occurrence of errors within a system and permitting users to recover from errors. Learnability is about whether a system is easy to learn and the length of time it takes for users to learn tasks, and finally memorability is concerned with aiding the user in remembering tasks. These usability goals are quite well defined, but since HCI and usability relates to human use there are many aspects of HCI that are much more difficult to define; these are the user experience goals (Preece, J., Rogers, Y. et al., 2002). Examples of these experience goals include: creativity support, helpfulness, pleasing aesthetics, emotional fulfilment, reward, motivation, entertainment, enjoyment, fun, and satisfaction. These experience goals are many concerned with how the system feels, which is why they are difficult to define and measure. For a technical information site such as the Pregnant Women’s Anthropometry website it is perhaps less relevant to provide some of the experience goals since many are focussed on the gaming industry, and consequently the focus of this thesis for an experience goal will be on helpfulness of the site.

Problems with HCI can be on the surface level, or can be deeper problems resulting from an incorrect view of the task. Deeper problems in HCI can be that the user is prevented from completing their task, or that users are prevented from going back to make changes or correction, or if they do go back then they have to start the entire task from the beginning (Brown, C.M., 1998; Johnson, J., 2000). A typical problem with the surface design of HCI can include requiring that the user has to remember too much for too long. Poor navigation is another common problem with HCI, as well as not using the right language for the user (Johnson, J., 2000) or using lots of annoying gimmicks or animation (Preece, J., Rogers, Y. et al., 2002). Inconsistency is another problem, for example using different names or different positions on screen can both be forms of inconsistency, as well as inconsistency in terminology (Johnson, J., 2000). Smith and Mosier (1986) have suggested that consistent organisation of layout, location of features, control options, instructions, error messages, and user command entry should be adopted. Another common problem is that an interface is too slow, or not responsive enough, and this can be caused either by too much text or images to download, or by slow processing. This thesis will present the Pregnant Women’s Anthropometry website, and discuss the steps taken to avoid these types of
problems with HCI.

The importance of consistency is further elaborated by Ehret (2002) in an empirical study of four different interfaces to assess how users learn locations. The findings support the positional constancy rule in HCI design since people can learn locations and use that knowledge to improve task performance. This learning of locations is actually unintentional, but can have a benefit to the user; conversely inconsistency can be a disadvantage by causing errors and confusion. This thesis will not investigate human location learning ability, but will discuss the steps taken to provide location constancy in the Pregnant Women’s Anthropometry website.

A highly cited paper by Miller (1956) found that the limit on the human ability to process information was seven (bits), plus or minus two. In terms of software this can include pieces of data, commands, codes, syntax or rules. This theory then relates to HCI not as a direct rule, but as a guideline to limit the amount of information that has to be remembered and/or processed by the user (Johnson, J., 2000). One example of how to achieve this is to provide summaries, or to use commonly held expectations in order to minimise mental processing. Therefore this thesis will not attempt to investigate human memory or processing of information, but will describe the design features of the Pregnant Women’s Anthropometry website that help to reduce the memory and processing requirement on the user.

Another important aspect of HCI is considering the errors that the user will inevitably make, and trying to reduce the errors where possible. It is also important to use clear error messages, with instructions on how to correct the error, and also to allow users to go back to correct mistakes without having to start the entire task from the beginning (Brown, C.M., 1998; Johnson, J., 2000). This thesis will discuss how the user errors are dealt with in the Pregnant Women’s Anthropometry website, and the steps taken to reduce the risk of errors occurring.

The language used is also an important aspect of HCI (Brown, C.M., 1998; Johnson, J., 2000; Preece, J., Rogers, Y. et al., 1994). For example the use of abbreviations should be avoided, unless the abbreviation is more well known that the full word(s). The language used should be appropriate to the user. Wording should be simple and instructions should be clear, and statements should be affirmative and active in nature (not negative or passive). Language should be standard informal language, polite, and without referring to the computer or system in the third person. This thesis will not present any analysis of language in use in today’s society, but the thesis will include
discussion on how the language needs of the automotive engineers are met when using the Pregnant Women’s Anthropometry website.

The use of colour is another important topic of HCI. Colour is important for providing contrast in order to make the content legible (Togazzini, B.). It is also important not to use too much colour because that could make the interface confused or messy; ‘colour pollution’ (Preece, J., Rogers, Y. *et al.*, 1994). Colour can be used to emphasise and show status, and to segment different sections of the interface (Preece, J., Rogers, Y. *et al.*, 1994), but since there are colour blind users it is important not rely on colour alone. There are also cultural issues with the use of colour that need to be considered (Noiwan, J. and Norcio, A.F., 2006). This thesis will discuss how the colour use on the anthropometry website was made suitable for the automotive engineers that will use it.

The navigation of a website is vital to whether the users will find the site usable, and therefore whether they will stay using the site (Nielsen, J.). The navigation structure should be consistent with users knowing clearly where they are, what they can do next at this current position, where they’ve been, and where they can go to next (Dix, A., 1999). This thesis will not present an investigation of website navigation structures and usability in general, but will present a focussed discussion on how the navigation of the Pregnant Women’s Anthropometry website navigation makes the site usable.

The homepage is crucial for the usability of a website since it often the first page that a user will see, and has the most frequent visits (Nielsen, J.). The homepage should include a clear description of the site and what the use can do on the site. It should also include a section that is ‘about you’ (i.e. about the website) and this should be easy to find either on or from the homepage. The homepage will often have a search box, and should have links with the keywords for the website and meaningful images. This thesis will discuss the homepage and the ‘about you’ section of the Pregnant Women’s Anthropometry website, and how these have been made suitable for the automotive engineers who will be using the site.

Schneiderman has suggested some practical design rules for menu systems to ensure the menu items are meaningful to the user so that the use of menus can result in a rapid, accurate and satisfactory approach (Schneiderman, B., 1987). This thesis will not attempt to evaluate the design rules, or to develop a new type of menu system. However this thesis will present the use of menus within the Pregnant Women’s Anthropometry website, and how these rules from Schneiderman are followed to aid
usability.

Another key aspect of HCI is to test a website (or piece of software) with the user group, in order to refine and improve the HCI based on user feedback. There are various methods of usability testing or evaluation and these can be applied during the design stages through to the final design definition. Usability evaluation techniques include: cognitive modelling methods, inspection methods, inquiry methods, prototyping methods, and testing methods, as well as others (Preece, J., Rogers, Y. et al., 1994; Preece, J., Rogers, Y. et al., 2002). The thesis does not attempt to assess the different types of usability testing methods, however this thesis will present the user testing of the Pregnant Women’s Anthropometry website, as well as the refinements made to the site in order to improve the HCI.

HCI is a fast developing field, and Raphael et al. have even presented a method to make the user interface adaptable by generating the interface dynamically from model fragments stored in a library (Raphael, B., Bhatnagar, G. et al., 2002). However this thesis is not a study of methods of HCI and interface development. This thesis will focus only on the production of the website, since a website in HTML is adaptable enough with other programs to suit the engineers.

### 2.2.2 The automotive design process

The process of design as an activity has been described by many authors, and this is briefly summarised. French described the design process as a flow diagram (French, M.J., 1971), and was the first to indicate the feedback that occurs between design stages. Other models have presented design as a systematic activity to optimum results, and have expanded upon the stages involved to developed different models (Cross, N., 1994; Pahl, G. and Beitz, W., 1977; Roth, K., Franke, H.J. et al., 1971). Hales (1987) completed an empirical study of the engineering design process in an industrial context, within three fields including the Company, the Market, and the Environment. Hales further introduces 20 categories of influence on the design process, in five levels including macroeconomic, microeconomic, corporate, project, and personal. Black (Black, I., 1990) showed the incorporation of Computer Aided Design (CAD) into the design process, and then Ainger presented the design process using a helical approach (Ainger, A., 1992). Konda et al. report on the influence of shared memories of design within industry and within design teams (Konda, S., Monarch, I. et al., 1992). Similarly Reddy et al. (1998) argue that design knowledge
is organised and re-used leading to artefact theory (interdisciplinary design knowledge and encapsulation involved in the design of that artefact). Acar presented the design process as a triple helix spiral to represent not only parallel design stages, but also the influence of environmental factors and that design is progressive because something is learnt at every stage and the designer never actually goes back to revisit a design (Acar, B.S., 1996). Ferguson argues that the design process is contingent, subject to unforeseen complications and influences as the design develops, or even chaotic (Ferguson, E.S., 1992). This thesis will not attempt to prescribe an automotive design process for including pregnant women. Although this thesis will present the information and data needed during the design process, at whatever stage, in order to incorporate the needs of pregnant women into the design.

Bouchard and Aoussat (2003) present a more specific model of the car design process, which represents the complex interrelationships and development stages and is shown in Figure 4. Computer-aided styling is reported to help earlier communication of data between design stages (former to latter). This thesis does not aim to present a model of the design process, and instead will provide information about the pregnant occupant that can be used throughout the car design process to improve their comfort and safety.
Concurrent engineering is prevalent in the automotive industry and involves a parallel approach instead of linear serial engineering (Prasad, B., 1999; 2000). This can mean that data must be available to the different design tracks at any time and often overlapping. May and Carter (2001) present a case study of how a software
demonstrator incorporating video conferencing, share whiteboard, application sharing and product data management tools can support concurrent engineering. The results showed potential time savings from 10 to 50%, and cost savings of 20%, which reveals that concurrent engineering can be effective. Prasad further describes the major vehicle design components as the outside body, styling, detail design, analysis and tooling and these can be worked on by staff or by outside contractors and suppliers. Specifically regarding the systems that the occupant has most interaction with, the interior systems (instrument panels, airbag, steering wheel, door trims and hardware, seat systems and seat belts) are often designed by suppliers (Prasad, B., 1999). 70-85% of the cost for a vehicle is attributed to the contracted out or outsourced products in the supply chain (Schweitzer, L., 2003). Not only is the production of parts outsourced, but also the design of those parts and even complete systems is given to the suppliers. Vehicle manufacturers are allowing Tier 1 suppliers greater design responsibilities and involving them earlier in the design process, e.g. during product definition (Chung, S. and Kim, G., 2003). This means that making the anthropometric data available globally is important since many different companies will require access to it. This thesis will not attempt to discuss the concurrent engineering processes, but will present the anthropometric measurements of pregnant women as a website that could support the concurrent engineering process by the vehicle manufacturers and its associated supply companies.

Pahl et al. (1999) presented work based on a 12-year empirical study of the engineers and the design process, and was mainly based on laboratory studies. The authors first discussed how engineers used different strategies in the design process. Initially the engineers identified and engaged with the task, and often reviewed the task description. Observations shows that successful problem-solvers are able to abstract and summarise the task, but engineers with little education of systematic design initially spend little time on the task, but were forced to repeat and intensify clarification of the problem during later stages of the design process.

The next stage was to divide the task into sub-problems, which was achieved using two methods. A step-by-step process oriented manner moves from an overall concept towards more detail, and considers the function of the entire product. A sub-problem oriented manner considers the separate functions of the product based on experience then aggregates them together, however this technique may result in late realisation that functions are missing or interacting incorrectly.
The third stage of design described was searching for a solution, and is mainly based on experience with or memory of similar products. The engineers dealt with multiple solutions in a generative search, or improved a single solution step-by-step in a corrective search. Designers that are methodologically experienced tend to use generative searches for the main function solution. Designers without academic education of the design process use the generative search through sub-problems. The authors then suggested that during the evaluation of design solutions, engineers tended to use qualitative rather than quantitative measures. They suggest that frequent evaluations of the solutions should use comprehensive criteria that relate to the overall task goals, and criteria should not emphasise personal preferences.

Secondly Pahl et al. (1999) investigated the significance of personal characteristics in design success using questionnaires on personal and education data, spatial imagination, and competence. They recommend that design methodologies are useful as a guideline to design work, but that flexibility is required to accommodate specific design barriers or situations. Successful methodological designers mainly concentrate on the main functions during search for solutions. They also develop ideas from very bad to very good so may possibly be slower to reach selection of the better ideas, however they are more effective at evaluating interim results and so effectively move from a divergent set of functional designs to convergence toward a good solution. Results showed that methodologists with higher education, but less experience take more time to reach a successful solution. However the methodologists can produce sub-function solutions more compatible to the overall solution, and produce better concept ideas for new problems.

Heuristic competence is defined as the candidate’s subjectively perceived problem-solving competence (Dömer, D., Kreuzig, H.W. et al., 1983; von der Weth, R., 1994). Results from Pahl et al. (1999) revealed a correlation between heuristic competence and design success, and over-estimation of competence was associated with less successful designs. Positive self-assessment can help to overcome setbacks, and can positively influence group dynamics.

Experience, both conscious and sub-conscious, allows much faster problem-solving and possibly better design solutions. However as experience can lead to deficient designs (Frankenberger, E., 1997) the authors recommend that experience should be complemented with a design methodology and correction where necessary. High motivation promotes good design results. However methodological designers
might spend too long searching for solutions creating time pressure, or resignative characters might abandon solution searches too early.

In terms of spatial (three-dimensional) imagination Pahl et al. (1999) found contradictory results from their tests, and could not confirm whether spatial imagination produced better designs or not.

Pahl et al. (1999) investigated the significance of group characteristics on design success. This involved investigation of routine work, and critical situations and the factors that influence them. Most frequently the critical situations were in goal analysis, solution analysis and decision making, with costs or deadlines being the most common negative factors. Availability of information is an influential factor, which highlights the need for provision of information in the correct format at the right time for increased usability of that information. This also includes requirements lists and access to existing solutions. Actual group working contributed less than thirty percent of time spent on design work, with the rest being individual work in order to support group meetings. Team management is therefore important to ensure comprehensive availability of information and processing in order to positively influence design success through the decision-making stages. Finally this thesis does not aim to study the engineering design process in the manner described by Pahl et al. or to study the engineers. This thesis will focus on the provision of information and data to support the engineering design process with the aim of improving vehicle safety for pregnant occupants.

The cognitive activities of the design process have also been modelled (Jin, Y. and Chusilp, P., 2006). Three distinct global iteration loops were identified as problem redefinition, idea stimulation, and concept reuse loops, and the local iteration loops within these global loops were also identified. The designers’ iteration behaviour varies according to the problem type and the constraint conditions, and the variation follows patterns, e.g. more skilful designers’ use more iteration loops, and need for creativity is associated with problem redefinition and idea stimulation loops. This thesis will not investigate the iteration loops of design, but it is useful to note that this looping occurs since any of these methods might lead designers and engineers to consider the needs of pregnant women.

Another increasing trend within the automotive industry is that of design optimisation, which can contribute to reduced product cost and increased performance (Chen, C.-J. and Usman, M., 2001). The Computer-Aided Design (CAD) and Computer-Aided
Engineering (CAE) tools are now embed design optimisation capabilities. Kodiyalam and Sobieszczanski-Sobieski (2001) even present a Multi-disciplinary Design Optimisation (MDO) that divides the design into sub-optimisations but maintains the linkages and the system-level optimisation. The example given is of optimisation of a vehicle for Noise, Vibration and Harshness (NVH) regulations and rollover roof crush regulations. Similarly O’Sullivan presents a design support tool that uses the knowledge available, the life-cycle environment of the product, the specification, and the structure of schemas by the designer. This constraint-aided conceptual design tool is used to support the design process. Another tool is presented by Kerr et al. (2004), which is a knowledge based tool for the selection of design options for the tendering from tier 1 suppliers for vehicle systems. This tool shows how the functionalities and features of a vehicle system can be selected and documented in order to streamline the process of contracting out designs to the supply chain. Susca et al. (2000) present a knowledge engineering tool that is capable of supporting the designer to automatically compute and evaluate the mass properties of a racing car. The model consists of the various parameters (part – subpart relationships, and independent design parameters) based on a tree structure, and the designer can edit these parameters. This thesis does not aim to address design optimisation, design generation or the development of design process tools. However it will make data available about the pregnant occupant, including anthropometric measurements that eventually could form part of the knowledge base or parameters that these tools and processes use.

Another feature of the current automotive industry is that of mergers and acquisitions (Wu, B., Kay, J.M. et al., 1999). According to Wu et al. the expected benefits are: shared research and development costs and competence, economies of scale in material costs, bargaining power against suppliers, increased manufacturing flexibility, reduced dependence on local economic cycles, and expansion of brand and market sector coverage. The relevant point here is the shared research and development costs and competencies, since merged companies are global and will have to share information. Calabrese (2001) reports that research and development activities had been internalised due to tradition and to security reasons, but that many car manufacturers are now introducing international processes as a result of mergers and acquisitions and this requires co-operation and free flow of information. Wu et al. also present a case study of Business Process Development (BPD) and how Manufacturing Systems Management (MSM) can be applied in practice to deal with a
range of issues related to the analysis, design and implementation of new manufacturing systems (Wu, B., Kay, J.M. et al., 2000). In order to maximise the benefit of such mergers the companies must undergo a reorganisation and convergence of processes, which is complex and requires a structured approach such as the MSM. There are various other tools presented for Computer Supported Collaborative Work (CSCW) and these all aim to share information and data for the design process across geographically dispersed companies and teams (Davis, J.G., Subrahmanian, E. et al., 2001; Huang, G.Q. and Mak, K.L., 1999; Huang, G.Q. and Mak, K.L., 2001; Lu, S.C.-Y. and Cai, J., 2001; Ranky, P.G., 2003; Ranky, P.G., Lonker, M. et al., 2003; Westerberg, A. and n-dim group, 1996). Specifically for the automotive industry Siemieniuch and Sinclair propose that culture and trust are important issues; that a culture of trust is needed if people are to operate based on materials passed along the supply chain (Siemieniuch, C.E. and Sinclair, M.A., 1999a; b). Bal and Foster present a guide to implementation of virtual team working (Bal, J. and Foster, P., 2000). This thesis will not discuss the trends in the automotive industry, nor try to prescribe management systems. The thesis will present findings about the pregnant occupant in a website format that will suit the global and changing nature of the automotive industry.

The World Wide Web is gaining use in product design and manufacturing since it is well suited to collaborative work over distributed geographical areas (Huang, G.Q. and Mak, K.L., 2001). Another benefit is that web applications require no installation or updating, so resources to maintain software are not required whilst still have the latest services on the internet. Howard et al. argue that for the automotive industry extra-organisational systems using electronic portals and hubs have enabled multiple firms to share industry-level systems, and that will help the automotive industry move from a ‘sell-from-stock’ to a more profitable ‘build-to-order’ business model (Howard, M., Vidgen, R. et al., 2003). Sung et al. have presented a web-based design and manufacturing system for automobile components, specifically lighting (Ahn, S.H., Bharadwaj, B. et al., 2002). The Smartlite tool was developed to help integrate the engineers with other parts of the process, such as marketing, since they do not traditionally have access to the same CAD software. A comparison was made between the CAD and web-based user interfaces, and for performance there was little difference although for accessibility the web-based interface was best. Andersson (2001) similarly presents a case study, but for sheet metal forming for car body
panels. Andersson states that appropriate viewers are required for workers that do not have the appropriate software, and as such the provision of a viewer will make information accessible. Brown et al. (2004) also present another web-based tool, and this one is a virtual repository for supporting distributed automotive component development called INTEREST. This repository can be used in conjunction with a Job Description system for capturing process information, and a Best Practice system for furnishing context-sensitive advice based on accumulated information stored in the repository. The advantages of the repository are easily access to relevant information, cost reduction by avoiding repeated mistakes and avoiding re-solving problems, general improved knowledge sharing, and support for technical auditing. Ozkaya and Akin (2006) describe the requirement-design coupling, which is another form of digital repository and tracks the designers processes and decisions. It enables searching and analysis of information to support design and by taking a requirement centred approach the authors argue that it will facilitate transition of design information between phases. Overall, there are web applications for the design process, knowledge management, and supply chain management, all of which are suited to the automotive industry, especially considering its increasingly global nature. This thesis will not present web based manufacturing systems, but instead will present data that can be used by the automotive industry via the internet to improve pregnant occupant safety.

Siemieniuch and Sinclair discuss knowledge lifecycle management from their projects mainly in the automotive industry (Siemieniuch, C.E. and Sinclair, M.A., 1999a). They point out that with Digital Mock-Up (DMU) technology there is a likelihood that ergonomics and engineering knowledge will be absorbed into the DMU, and for example there is no need for consumer testing of driver’s position or cabin layouts since judgements can be made from equations and tables instead. This thesis will not address the issue of knowledge management, but it will present how information about the pregnant occupant is presented in an accessible form as a website so that it could be used by any relevant DMU technology.

An important stage in the automotive design process is the concept design, which will usually involve a stylist who creates the overall design. Tovey describes the sketching process used by automotive designers and goes on to present methods to integrate the concept sketching and physical models into CAD systems (Tovey, M., 1992; 2002; Tovey, M., Porter, S. et al., 2002). Other authors have also presented a study of
sketching behaviour (McGown, A., Green, G. et al., 1998; Rodgers, P.A., Green, G. et al., 2000). Other authors have used the sketching study to generate prototype software to support sketching in CAD for supporting the design process (Fitzmaurice, G.W., Balakrishnan, R. et al., 1999; Landay, J.A. and Myers, B.A., 2001; Lim, S., Qin, S. et al., 2004; Lipson, H. and Shpitalni, M., 2000; Raisamo, R., 1999). Chu et al. present a multi-sensory user interface for a virtual reality based CAD system based on the typical activities in design (Chu, C.-C.P., Dani, T.H. et al., 1997). Sener and Wormald (2008) have investigated form creation and found that five concepts were particularly desirable for designers: immersive room, advanced wireless virtual reality, smart material, haptic hologram representation, and automated 2D to 3D translation. These use a variety of approaches and inputs from the designers to help support and automate the design process. Similarly Ye and Campbell (2006) present a virtual reality based concept design system named LUCID, and this integrates a two-handed interface, a stereoscopic display interface, a haptic interface, and a sound feedback interface, all of which are designed to better support the conceptual design process. Overall the relevance of the sketching of concept design process is that the sooner sketches and design ideas are incorporated into the CAD models, the sooner the engineers can begin to consider occupant packaging and particularly the accommodation of pregnant women’s needs.

2.2.3 Characteristics of automotive engineers and designers

It is also important to consider the characteristics of automotive designers and engineers. The information and data gathered about pregnant women’s needs is unlikely to be used unless it is presented in a format that is usable by the engineers and designers. Therefore this section will review the characteristics and traits of automotive engineers.

Park et al. (1997) review the use of team working in the Australian automotive industry using a survey of vehicle manufacturer and tier 1 supplier employees. Their study revealed an intention to use self-managed teams and many companies were still working to achieve this, but overall the most prevalent team type was directed (semi-autonomous). The industry is highly unionised, but union-management collaboration has helped to development the team working style. Previously the style had been for narrowly defined jobs with sharp distinction between management and production; however the trend is for wider control and flatter organisational structure with greater
involvement of all employees. Park et al. suggest that with the increase in just-in-time processes and lean working, that self-directed teams are perhaps less desirable since directed teams are most suited to lean production and assembly line operations. Training of employees has focussed on problem solving, technical multi-skilling, communication, and Total Quality Management skills that are needed for day-to-day work. The composition of the teams appears to have focussed on the requirements of day-to-day responsibilities, with less focus on inclusion of permanent ‘expert’ members of staff for indirect roles, and these roles are filled as needed. Finally Park et al. report that attitudes toward the team working were positive. However there could be some problems associated with directed teams in lean manufacturing plants such as job pressure, demanding standards, team peer pressure, which could all result in decreased morale and job satisfaction. This thesis does not aim to investigate team working in the automotive industry, but it is important to note these characteristics so that the information about the pregnant occupant is presented in a suitable manner. Reid et al. studied teams of engineering design students during team meetings and found three interaction patterns (Reid, F., Reed, S. et al., 1998). Firstly that the designers evolved specialisms, either being focussed on customer requirements and design constraints, or focussed on generating visual ideas. Secondly that design visualisation tended to happen in bursts from one individual, whereas non-visual design reasoning was highly interactive. Thirdly that conversational grounding was initiated by the speaker during visualisation sequences, but by the listener in non-visual sequences. Assuming that students reflect the practice of designers and engineers in industry, then this has implications for this thesis since these designers who focus on customer requirements and design constraints are the target group for the provision of the information and data about the pregnant occupant. Reid et al. argue that there are also implications for the design of virtual workspaces to support teams that are geographically separated. For example, video communication is required to support the gesturing and pointing at design drawings, as well as facial views to support conversation (attention focus, gaze, and eye contact). This thesis does not attempt to investigate team working in the automotive industry. However it will present pregnant women’s anthropometric measurements as a website so that this resource could be used in a virtual workspace by a design team if necessary.

James-Gordon and Bal (2003) suggest that in an organisation with the right learning climate and the right methods available, design engineers can engage in self-directed
learning. Self-directed learning can consist of work-based learning (learning on the job), book and manual references, peer and expert assistance, and computer-based learning. Given that engineers are engaging in activities of learning during their work, there is an opportunity for the engineers to learn about the needs of pregnant women. This can be achieved by providing the data regarding their needs in the suitable format to support engineer’s learning.

Both Ferguson and Holt argue that good engineering design depends upon the designer’s judgement, and this is difficult to define (Ferguson, E.S., 1992; Holt, J.E., 1997). Good judgement relies upon the understanding of the standards and the context of the design, and then expanding the limits of acceptability, but not by too much since design is dependent upon market forces. Holt argues that good judgement is not just common sense, but is firmly grounded in unique engineering heritage. The thesis is not aiming to assessing engineering judgement, rather it will support engineering designers in their judgement by providing data and information about the pregnant occupant.

Tovey (1997) argues that automotive stylists display characteristics described by Cross as the characteristics of designers (Cross, N., 1982). These include tackling ill-defined problems, solution-focussed methods of problem-solving, constructive thinking, only using codes that translate abstract requirements into concrete objects, and using codes to both read and write in object languages. A stylist is unlikely to have involvement with the detail design of making a vehicle suitable for a pregnant occupant, but these are characteristics to consider nonetheless. Therefore this thesis will not investigate the characteristics of designers, but instead will present the anthropometric measurements of pregnant women as a resource for designers so that they can consider pregnant women’s needs in their intuitive design process.

Kruger and Cross (2006) have investigated designers’ behaviour and the success of their designs. Their study revealed four types of design strategy: problem driven (focussed on defining and solving the problem only using information needed to solve the problem), solution driven (focussed on generating solutions using only information needed for further solutions), information driven (focussed on gathering external information for use in generating a solution), and knowledge driven (focussed on prior, structured, personal knowledge with only minimal external information). The majority of designers were problem or solution driven, and also tended to have less design iterations. The designers most frequently spend time on
gathering data and identifying constraints and requirements in order to generate potential solutions. However Restrepo (2004) argues that designers’ use and application of information is more important based on a study of students given a design task. Access to information was influence by a number of factors and it can have a positive impact on design results. Three major problems can occur with information processing whilst solving design problems: fixation (shrinking the space in which designs are considered), representation (poor or incorrect representation of the problem lead to inappropriate or no solution), and transfer problems (inability to translate knowledge from previous situations or new information to the current task).

Whilst these studies are not specific to automotive design and are based on general product design, it can help to inform about the methods that automotive designers might use. This thesis will not investigate the design strategies used by automotive designers, but will present information and data about pregnant women’s needs that will support the design process, particularly the features of the website that will help to improve the accessibility of the information.

Restrepo (2004) argues that design of information systems must consider not only the technical storage of the information, but also the method by which the designers will search and use the information. The most requested information is on users, and on the context of the task. The main criteria by which information is selected are topicality and accuracy. This thesis does not attempt to study designers as they access information. However it will support the designers by providing the information about the users (pregnant women) and the context (the problems encountered with driving), and will also explain how this information is made accessible to the engineers.

James-Gordon and Bal (2001) defined different learning styles from the literature: active learners, reflective learners, theorists, pragmatists, sensing learners, intuitive learners, visual learners, verbal learners, sequential learners, and finally global learners. Using two established questionnaires, the James-Gordon and Bal assessed the learning styles of design engineers, and project engineers and team leaders. The engineers provided feedback that some questions were perhaps poor, for example an engineer might consider himself to be both realistic and innovative, but at different stages of the design process. The engineers showed a very strong preference for visual rather than verbal learning styles, when compared to the wider population described in the literature. Visual learners learn best from what they see and absorb information easily from pictures, films, demonstrations and diagrams. They favour colour coding
for categorisation, and highlighting words and sentences for clarity. This means the engineers prefer learning from diagrams, sketches, charts, pictures, videos, computer graphics and demonstrations. It is therefore important that the information presented, for example the anthropometric measurements data, is in a visual style.

Ferguson (1992) sets forth an essay on engineering design and its need for non-verbal and intuitive thinking in combination with detail design in equations, calculations, and dimensions. The main method for engineers to convey their intentions is via drawings, and these mainly show the idea visually not verbally (apart from the notes that specify materials and dimensions). Ferguson argues that visual thinking is an intrinsic part of engineering. In this thesis the aim is not to analyse the engineering design process, but the thesis will explain how the findings of pregnant women’s anthropometry have been presented in a visual manner in order to support engineer’s thinking. Ferguson also states that engineers use both scientific and empirical knowledge, and this thesis is directly providing the automotive engineers with the empirical knowledge about the needs of pregnant women in order to support design that will include them.

Patel et al. report on two case studies within the automotive industry (2006). The first case was an investigation into the hardware needed for visualisation in virtual reality (VR) for PSA Peugeot-Citroën. A series of tests investigation perception of image quality, colour, contrast and depth, the number of projection walls, resolution, and projector brightness and contrast. The designers had a preference for contrast in the colour combinations. Whilst this study does reveal some preferences of the automotive designers, the focus is on viewing a car model so is not readily translated to the preferences of designers for working with data about occupant needs and anthropometry. The second case from Patel et al. concerned a need for Volvo to visualise different materials digitally. The materials were not reproduced accurately enough for them to be used in the vehicle interior selection process since there was a loss of colour and depth information resulting in generally dim images. This thesis will not address materials selection, but this case does inform us that design engineers value realism and detail for visualisations.

McAlpine et al. (2006) have investigated the use and content of the engineer’s logbooks, which are commonly used and contain a significant amount of design information and knowledge. Their survey of designers used a questionnaire to understand the background about why logbooks are used, and a sample of 16 paper-based logbooks (over 2000 pages) were also analysed. The most common reasons for
having a logbook were ‘a reminder of work in progress’ (72%) and ‘a personal work record’ (76%). The majority of engineers kept a single logbook (50%), although a large number kept a logbook per project (35%). The logbooks were mostly hardback books (61%) or loose sheets kept in a ringbinder. The majority of participants stated they located information by browsing through the pages (61%), or by recalling the approximate date of entry (22%). The logbooks currently in use were most frequently accessed daily, and the historical books were most frequently only accessed for specific events. There were 13 classes of information kept in the logbooks, and a few examples of the ones commonly used by designers and researchers were written notes, sketches, calculations, tables of figures, external documents, and component specification sheets. This investigation of logbooks is an interesting insight into the characteristics of designers and engineers. This thesis will not analyse the use of logbooks, nor produce an electronic version. However this thesis will present data about the pregnant women’s needs that could be used by the engineers and designers and kept in their logbooks, for example the data page from the Pregnant Women’s Anthropometry website could be printed and kept in the logbook as an external document. Furthermore McAlpine et al. argue that the design information held in logbooks should be recorded electronically for reference in other future projects within a company, and since the anthropometric data is already in electronic format on the website it will be easy to incorporate as a reference.

2.2.4 Review of existing software for automotive designers and engineers

It is also useful to review the existing software for automotive engineers and designers and particularly to set the Pregnant Women’s Anthropometry website into context of other resources that are available.

2.2.4.1 PeopleSize

There is a piece of software that presents anthropometric data for various populations. This is “PeopleSize” developed by Open Ergonomics (2008). The software uses graphics for selection of measurements, and is quite intuitive for selecting the correct dimensions. The first step is to select the posture (from which the measurement is taken) from a small grid of graphic buttons. Next a large image is displayed with the body (or body part) that is covered with arrows. These arrows turn green as the mouse is hovered over them to highlight the measurements that are available. The measurement data is then displayed in a dialog box for the measurements and
percentiles selected. The data can be adjusted for clothing, and any percentile can be selected (not just 5th or 95th). However only one measurement can be displayed at a time, so the process has to be repeated for each piece of measurement data required. The PeopleSize dataset covers 9 nationalities and all age ranges. It covers up to 289 different measurements, which is a large databank, however only one measurement covers pregnancy. The pregnant abdominal depth is recorded for different months of pregnancy, but only this one measurement is available and this cannot completely represent all of the changes that happen to a woman’s body throughout the course of pregnancy. There is a need for a resource of pregnant women’s anthropometry.

2.2.4.2 ARIS

Another source of anthropometric data is ARIS (Anthropometry Research Information System). This has many databases of anthropometric measurements within the search engine, so the first step for the user is to select the database that they require. Most of these databases are quite old, most being from the 1970’s or 80’s, so their relevance to today’s society may be limited. There is a long list of measurements, but not all measurements are available in each database. There is a facility to run mathematical computations with the data. It is also possible on the next page to select the target population group, for example only those subject over a certain age or height, or from a particular demographic. These functions are possibly useful to the automotive engineers, but their interface is not very usable or intuitive. The final step in using the ARIS database is to click the button to make the output file. The output of the search is given as a .csv file, and this simply gives the raw measurements for each subject. The automotive engineers then have to make their own calculations on the data, for example to establish the mean or the percentiles. This output is very lengthy, especially if a long list of databases and/or measurements are selected, and it could be improved if the summary calculations were given. Some of the measurements in the list could be used in automotive design, however some are related only to clothing and are not relevant to the automotive industry. Most importantly there are no measurements taken from pregnant women.

2.2.4.3 MADYMO

MADYMO (MAthematical DYnamic MOdel) is a piece of software that is widely used in the automotive industry for collision simulation, and evaluation of car safety and occupant dynamics. It comes complete with many models of dummy and human
models. Whilst the dummy model list does include the Hybrid III 5th percentile female dummy, it does not include its conversion kit MAMA2B that makes the dummy represent a pregnant occupant, so there is no possibility for MADYMO to represent an ATD that is capable of simulating pregnancy. Similarly the human models include a female model, but not a pregnant female model. This is probably due to the lack of anthropometric and material properties data for the pregnant woman, meaning that a model could not be developed and validated. This means there is a need for data and information about the pregnant occupant in order to represent their needs in the design process.

2.2.4.4 PC-Crash
Similarly the software PC-Crash is a collision and trajectory simulation tool for reconstruction and modelling of collisions. It can be used to analyse collisions in order to produce 3D animations, reports, tables and graphs. It does include a model of an occupant, but it is a model of the Hybrid III 50th percentile male dummy, and not a human. Furthermore, there is no female model or pregnant female model. Again, the lack of a model is possibly due to lack of data regarding pregnant women. However it is the aim of this thesis to begin to address this lack of data by contributing anthropometric measurements of pregnant women.

2.2.4.5 Beltfit
The Beltfit program can be used to assess the fit of a seat belt for both males and females (Haslegrave, C.M. and Searle, J.A., 1981; Searle, J.A., Hardy, R.N. et al., 1980). It uses a geometrical model of a person using cylinders and planes, and the belt is placed according to the shortest line. The models include the 50th and 95th percentile male, and the 5th percentile female, and it allows adjustment of the seat and the seat belt anchorages. However it does not include a model of a pregnant woman, so it is not possible to assess the fit of the seat belt around the pregnant woman’s altered body. This thesis does not aim to produce a tool to assess belt fit, but does aim to contribute pregnant women’s anthropometry so that such assessments can become possible in the future.
CHAPTER 3: DATA COLLECTION OF SAFETY AND COMFORT ISSUES FOR PREGNANT WOMEN

This chapter presents the problems that pregnant women experience during car travel using a questionnaire. The questionnaire comprehensively asked women about all of their experiences of driving and car travel. It covered all aspects of car usage, including both safety and comfort issues. Some of this work has also been published in the papers in Appendix F (Acar, B.S. and Weekes, A.M., 2003; Acar, B.S. and Weekes, A.M., 2004c; 2005).

3.1 PREGNANCY AND DRIVING QUESTIONNAIRE

The pregnancy and driving questionnaire was developed to gather a comprehensive dataset about pregnant women’s experience of car travel. The questionnaire is shown in Appendix A. In the questionnaire the pregnant women were reminded repeatedly to compare their experiences during pregnancy with when they were not pregnant. The reason for this was to isolate the problems associated pregnancy and to exclude any problems that were present before they were pregnant. Questions about all aspects of car travel both as drivers and as passengers were included in the questionnaire. The questionnaire was divided into sections according to the main activities of driving and using a car. It began with some general questions about the pregnant women, including establishing the stage of the pregnancy. The first section established whether women’s driving was being adversely affected by pregnancy, and this was asked for a number of factors including: comfort, safety, reaching controls, getting in and out of the car, using the boot, general driving ability, night driving and reversing. The next section of questions was concerned with the activity of getting in and out of the car, including the methods that women used and their main difficulties. Another section of questions asked about women’s ability to reach and operate the controls and whether this was easy or difficult in comparison to before they were pregnant. The controls and parts of the car listed were the: window controls, radio, dashboard controls, seat belt, wing mirrors, glove compartment, access to the rear seats, sun roof, gear stick, handbrake, pedals and rear view mirror. The section of questions about using the seat belt was extensive and covered whether the seat belt was being used and how it was positioned (using simple diagrams), the problems of seat belt use in pregnancy, and the safety advice received. The questions about the airbag covered
which airbags were fitted, and whether in the woman’s opinion the airbag might be a risk to the fetus or woman if it was deployed during a collision. The section of comfort related questions asked about the distance between the pregnant woman’s abdomen and the steering wheel, legroom, and the car seat cushions. The questions also covered the problems of using the boot and the head restraints, as well as the positioning of the head restraint (using simple diagrams) and whether the women had received any advice about head restraint positioning. The last sections of the questionnaire covered the physical and emotional changes experienced during pregnancy, and the extent to which these changes affected driving. The long lasting physical symptoms included stomach pain, hip pain, baby’s head in pelvis, pelvic pain, back pain, sore joints, haemorrhoids, oedema, and varicose veins. The women were also asked about the more suddenly occurring symptoms including leg cramp, heartburn, sickness, itchy skin, and a sudden need to urinate. The final section of physical symptoms covered the women’s movements including breathlessness, exhaustion, limited bending and limited reach. The emotional changes (pleasure, irritability, oversensitive, panic, fear, depression, and excitement) were also investigated in the same way to assess whether changed emotions had any affect on women’s driving.

The questionnaire was quite long, and took most women around 20 minutes to complete. However the questions were all designed with tick box answers for ease and speed of completion. All answers included an option to select ‘other’ and space for women to expand upon their answer, and it was these comments from the women that seemed to take the most time.

This questionnaire was administered using two different methods: as a survey or online.

3.1.1 Pregnant driver survey

The pregnant women answered a ‘Pregnancy and Driving Questionnaire’ in an interview or by self-completion. The interview sessions combined collecting the questionnaire responses with a series of anthropometric measurements, described in greater detail in Chapter 5. The survey responses were gathered from women at two different locations in the UK: Loughborough University in Leicestershire, and the Luton and Dunstable Hospital NHS Trust in Bedfordshire. The survey and measurements were prepared in accordance with Loughborough University Ethical
Advisory Committee guidelines, and permission was granted to carry out the study. Permission was also granted for the study by the South Bedfordshire Local Research Ethics Committee, and the research completed at the Luton and Dunstable Hospital was carried out under the supervision of Mr. Malcolm Griffiths (Consultant Obstetrician). The interview method gave a sample of 91 in-depth interviews with pregnant women.

### 3.1.2 Online method

The questionnaire was also available for online completion at [http://pregnantdriver.lboro.ac.uk](http://pregnantdriver.lboro.ac.uk) in four languages (English, Spanish, Italian and French). Screen prints of the online questionnaire are given in Appendix B.

### 3.1.3 Sample of pregnant women

There were 600 women in the sample and their details are summarised in Table 1. For 41 women their stage of gestation is missing from their questionnaire answer. Note that not all the pregnant women completed all questions so for some questions the sample size is sometimes lower than 600.

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<td>(Week 0-12)</td>
<td>(Week 13-28)</td>
<td>(Week 29-40+)</td>
</tr>
<tr>
<td>Number of volunteers</td>
<td>48 women</td>
<td>226 women</td>
<td>285 women</td>
</tr>
<tr>
<td>Mean Week of Pregnancy</td>
<td>8.4 weeks</td>
<td>21.2 weeks</td>
<td>35.0 weeks</td>
</tr>
<tr>
<td>Std. Dev. Week of Pregnancy</td>
<td>2.3 weeks</td>
<td>4.5 weeks</td>
<td>3.3 weeks</td>
</tr>
<tr>
<td>Driver</td>
<td>42 women</td>
<td>221 women</td>
<td>265 women</td>
</tr>
<tr>
<td>Non-Driver &amp; unknown</td>
<td>6 women</td>
<td>4 &amp; 1 women</td>
<td>6 &amp; 14 women</td>
</tr>
</tbody>
</table>

Table 1. Sample of pregnant women for Pregnancy & Driving Questionnaire.

Online questionnaire responses were received from around the world with the majority from Europe (73%), from which 84% of the responses were from the UK. The details of the sample are given in Table 2 for each of the three global regions: Europe, North America, and the ‘other countries’ of the world.
Table 2. Details of the sample of pregnant women by global region.

<table>
<thead>
<tr>
<th></th>
<th>Europe</th>
<th>North America</th>
<th>Other Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>440</td>
<td>118</td>
<td>42</td>
</tr>
<tr>
<td>% of total volunteers</td>
<td>73%</td>
<td>20%</td>
<td>7%</td>
</tr>
<tr>
<td>Mean gestation level (weeks)</td>
<td>27.1</td>
<td>27.9</td>
<td>25.3</td>
</tr>
</tbody>
</table>

The analysis of questionnaire responses includes replies from this entire sample of pregnant women, including those from outside the UK.

3.1.3.1 Sampling method and representivity

The aim of the research was to establish what types of problems occur during pregnancy. It is possible that the sample could be biased or unrepresentative in some way. For example participation in the survey could cause women to answer questions in an unrealistic way, if they think there is a ‘right’ or a ‘wrong’ answer. However care was taken in the design of the questions to avoid leading questions, and the questionnaire was reviewed and approved by two ethical advisory committees (Loughborough University, and South Bedfordshire).

There could also be a risk with this type of survey about experiences that only pregnant women with a complaint or problem would respond, and so this could possibly create a biased set of responses. There were 25 responses from women that could be seen as unbiased. These women were included in the sample because they were attending the antenatal clinic and their inclusion was therefore random and unlikely to be biased by the existence of problems with driving in pregnancy. The sample is described below in Table 3, and can be seen to be similar to the larger sample of 600 responses in Table 1.
A small investigation was therefore made to ensure that the larger sample was unbiased, by comparing this small sample of 25 responses against the larger sample of 600 responses. The aim of this investigation was to compare the occurrence of problems between the two samples to establish whether the frequency of problems was similar. A detailed summary of the 25 responses from the smaller sample is given in Appendix C.

Table 4 below summarises the comparison of frequency of occurrence of problems. Comparing the two samples shows there is no more than a 13% difference in occurrence of reported problems, and most areas have a difference of 10% or less. It is reasonable to expect that there is some slight difference between the two samples, but since this difference is relatively small it can be accepted that the two samples are similar. If the large sample of 600 responses were biased by inclusion of pregnant women who only participate due to their problems then trend would be for greater problems in this sample than in the small sample of 25 responses. However there is no clear pattern or trend when the frequency of occurrence of problems is compared; in some cases the problem frequency is greater in the small antenatal sample of 25 responses, and in some cases the problem frequency is greater in the larger sample of 600 responses. Furthermore it can be seen in Appendix C that the 600 responses from the large global sample of pregnant women often closely follow the pattern of responses given by the small sample of 25 responses from the antenatal clinic.

Overall the sample of 600 responses is similar to the smaller sample of 25 responses that are treated as unbiased. Therefore it can be assumed for the purpose of this research that the larger sample of 600 responses is unlikely to be biased by inclusion
of pregnant women that have volunteered to participate due to the presence of some problem with driving.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Small sample 25 responses (antenatal clinic)</th>
<th>Large sample 600 responses (global, interview &amp; online)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General driving</td>
<td>36.4%</td>
<td>49.4%</td>
</tr>
<tr>
<td>Safety</td>
<td>60.0%</td>
<td>54.3%</td>
</tr>
<tr>
<td>Using seat belt</td>
<td>64.0%</td>
<td>72.3%</td>
</tr>
<tr>
<td>Getting in and out car</td>
<td>88.0%</td>
<td>77.8%</td>
</tr>
<tr>
<td>Comfort</td>
<td>72.0%</td>
<td>76.3%</td>
</tr>
<tr>
<td>Car seat cushions</td>
<td>64.0%</td>
<td>56.8%</td>
</tr>
<tr>
<td>Using the boot</td>
<td>40.0%</td>
<td>34.2%</td>
</tr>
</tbody>
</table>

Table 4. Comparison of frequency of occurrence of problems with driving: Small sample 25 responses from antenatal clinic compared to large sample 600 responses.

The following data analysis throughout the rest of the chapter therefore deals with the large sample of 600 pregnant women. The small sample of 25 responses is only detailed in Appendix C, and is not described separately through the rest of this chapter. The data analysis following is concerned with the 600 responses from pregnant women via participation in the survey via the interviews and via online completion.

3.2 DRIVING AND SAFETY
The pregnant women were asked about how much they thought their driving ability was being adversely affected by their pregnancy, and their responses are shown in Figure 5. Around half of the women thought that their driving was unaffected, and 42% thought it was a little affected. Only a small number of women thought their driving was affected a lot by pregnancy (7%), and less than one percent thought their driving was so badly affected that they had ceased driving entirely.
How much is your driving being adversely affected by pregnancy?

- Not at all: 0.4%
- A little: 6.8%
- A lot: 42.2%
- So much I avoid driving: 50.6%

Figure 5. Summary of how much pregnant women think their driving is adversely affected by pregnancy (n= 561).

Similarly when asked the same question about their safety instead of their driving ability, around half the pregnant women thought that their safety was unaffected by their pregnancy. The responses are shown in Figure 6, and a similarly small group of women (less than 1%) felt their safety was so badly affected they had to stop driving entirely. 42% of women believed their safety was a little affected by pregnancy.

How much is your safety being adversely affected by pregnancy?

- Not at all: 12.3%
- A little: 0.3%
- A lot: 41.7%
- So much I avoid driving: 45.7%

Figure 6. Summary of how much pregnant drivers think their safety is adversely affected by pregnancy (n= 576).
Chapter 3   Data Collection of Safety and Comfort Issues for Pregnant Women

3.3 SEAT BELTS
Seat belts appear to be one of the biggest problem areas for women during pregnancy. This section discusses the use and misuse of the seat belt, along with the various problems experienced by pregnant women.

3.3.1 Legal requirements and guidelines for seat belt usage during pregnancy
The guidelines set out by the Authorities state that the seat belt should be worn during pregnancy. The shoulder section of the belt should pass across the shoulder, between the breasts, and around the abdomen, and the lap section should pass across the hips and underneath the abdomen (American College of Obstetrics and Gynecology, 1999; Department for Transport, 2007; 2009b; National Highway Traffic Safety Administration, 2002). Wearing the seat belt is a legal requirement during pregnancy, the same as for non-pregnant females and males. In certain medical circumstances a Doctor may decide that it is unsafe for the pregnant woman to use a seat belt, and will issue a medical exemption certificate. The seat belt is designed to protect pregnant women and should be worn at all times, unless women are certified medically exempt.

3.3.2 Safety and comfort issues for pregnant women using seat belts
3.3.2.1 Use of the seat belt
From the 584 responses from pregnant women, only 35 were not wearing their seat belt (7%). The Department for Transport (UK) states that 10% of people would admit to sometimes not wearing the seat belt in the front of the car (Department for Transport, 2009a). In comparison it seems the seat belt usage rate is higher for pregnant women.

From those women who admitted they were not using their seat belt, only 14% said it was because they do not usually wear it, so the majority had ceased using their seat belt due to pregnancy. There were two reasons given by the pregnant women for why they had chosen to stop wearing the seat belt. 37% had stopped wearing the seat belt because they believed it was a safety risk, and nearly half the women had stopped using the seat belt due to discomfort.

3.3.2.2 Positioning of the seat belt
Whilst the seat belt usage rate seems high for pregnant women, the correct positioning of the belt is fundamental to providing protection in a collision. The different seat belt positions used by the pregnant women are given in Figure 7.
### Correct Seat Belt Position

**Figure 7.** Diagrams of different shoulder and lap belt positions used by pregnant women (n=526) with correct positions highlighted according to the Department for Transport UK guidelines (Department for Transport, 2009, Seat Belts and Child Restraints).

Considering only those pregnant women who were wearing their seat belt, only 11% of them had their seat belt positioned correctly. This means 89% of the pregnant women had the seat belt positioned incorrectly, and this is due to two main reasons. One reason is because the pregnant women were unaware of the correct positioning. Another reason explained by many pregnant women was that the belt would not fit around the pregnant body correctly despite them understanding how the seat belt should be correctly positioned.

Considering only the shoulder section, the most common shoulder belt position was the correct one, with the belt passing between the breasts and around the abdomen.

<table>
<thead>
<tr>
<th></th>
<th>Shoulder Belt</th>
<th>Lap Belt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Above both breasts</td>
<td>Across upper thighs</td>
</tr>
<tr>
<td></td>
<td>Across one breast &amp; across abdomen</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Between breasts &amp; around abdomen</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Off shoulder &amp; around abdomen</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

- Correct Seat Belt Position

- Incorrect Seat Belt Position

Note: The table and diagram illustrate the varying belt positions and the correct positioning highlighted according to the Department for Transport UK guidelines.
This was used by 51% of the women. However a variety of other shoulder belt positions were reported, including across the breast and abdomen 19%, above both breasts and cutting the neck 16%, off the shoulder 14%. Around half of the women had the shoulder portion of the seat belt in the incorrect position.

Regarding the lap portion of the seat belt, only 21% of the women had the lap belt correctly positioned across the hips. Nearly half (49%) of the pregnant women had the lap belt over the bump, and 29% of the women had the lap belt across their thighs. Overall over three quarters of the pregnant volunteers were inadequately restrained by the lap belt.

3.3.2.3 Problems using the seat belt

The pregnant women were asked about the problems they experience with using the seat belt, and their responses are summarised in Figure 8. Note that they were allowed to give multiple problems and were not limited to just one problem, so the figure will not sum to 100%.

Only 28% of the pregnant women stated that they had no problem at all with the seat belt. The women reported three main problems with wearing the seat belts in pregnancy. These problems were:

- the belt won’t fit underneath the abdomen or tends to ride upward onto the abdomen (25%)
- the belt is too tight on the abdomen (21%), hips (7%) and/or breasts (12%),
- the belt cuts into the breasts (17%), shoulders and/or neck (16%).

The problems of tightness and cutting reveal that the seatbelts were not positioned according to the guidelines since the belt was not expected to be positioned on the breasts nor on the abdomen, but between the breasts and underneath the abdomen.

The other problems reported were difficulty with adjustment (19%) and fastening (10%), and the belt being too short (3%).
What are your problems with wearing a seat belt during pregnancy?

The tendency for the belt to ride upwards onto the abdomen is greatest in the second and third trimesters. Some pregnant women reported that there was increased contact between the abdomen and the upper thighs that caused them difficulty in sliding the seat belt between the thighs and abdomen, hence preventing them from putting the lap belt into the correct position across the hips. Other women in the third trimester reported that once they had positioned the lap belt across their hips and underneath the abdomen, their larger abdomen was beneficial in helping to hold the lap portion of the seat belt more securely in place and preventing it from sliding up onto the abdomen. Many pregnant women took action to prevent the belt riding upwards onto the bump with the purpose of protecting the fetus or improving comfort. One method was to use an after market device or seat belt positioner to hold the seat belt in position across their hips, and these are described in greater detail in Chapter 4. The other method...
was to hold the belt away from the bump with their hands or thumbs. Similarly, more women were holding the belt away from their neck because it was cutting or rubbing them. The women were not aware that slack in the belt could prevent it from functioning properly, hence increasing the risk of injury.

3.3.2.4 Awareness of seat belt safety

The pregnant women were asked if they felt safe wearing their seat belts. 456 of 580 pregnant women (79%) stated they felt safe wearing the seat belt, and the remaining 21% did not feel safe. The majority of women that felt unsafe wearing the seat belt were concerned about the seat belt harming the fetus in a crash, particularly because the seat belt has a tendency to ride up onto the abdomen. Some women were concerned about whether the belt could harm the fetus, but realised that wearing the belt was safer than to stop wearing it. Alternatively other women were wearing the seat belt because they were more concerned about the risk of an impact with the steering wheel.

From 578 pregnant women only 52% had received some advice or information about how to wear the seat belt during pregnancy. This advice was given from a variety of sources, including medical, friends and relatives, media etc.

3.3.3 Seat belt positioners

Seat belt positioners are add-on devices that are designed to position the seat belt correctly during pregnancy. There are several designs available, and pregnant women have commented on their experiences of using them. Chapter 4 describes the seat belt positioners in detail as well a novel study in Thatcham’s crash test facility of their effectiveness for the safety of the pregnant occupant and the fetus.

3.4 AIRBAGS

3.4.1 Guidelines for vehicle airbags during pregnancy

Current DFT guidelines recommend that the ‘distance between the centre of the steering wheel to the breast-bone should be at least 10 in (25 cm)’ (Department for Transport, 2009b). However, the advice given is not specific to pregnant women. The National Highway Traffic Safety Administration in the USA (2002) advise pregnant women to sit as far back as possible from the steering wheel or dashboard and recommends a distance between the breastbone and the steering wheel or dashboard
to be at least 10 inches in order to reduce the possibility of injury from an inflating airbag in an accident. No recommendations for pregnant women have been found to date for the side impact airbags.

### 3.4.2 Airbag safety and comfort issues for pregnant women

Both of the above recommendations measure between the breastbone and centre of the steering wheel, but the anterior point of the pregnant abdomen and the lower rim of the steering wheel can be in much closer proximity. The pregnancy and driving questionnaire revealed that many women could be sitting too close to the steering wheel and airbag. The pregnant women were asked how far their bump was from the steering wheel, and the women gave an estimated distance as shown in the distribution in Figure 9.

![Figure 9. Pregnant women’s estimated distance between their bump and the steering wheel (n=560).](image)

75% of the pregnant women reported that they were seated with their abdomen 15cm or less away from the steering wheel. 10% of the women said they were driving with their abdomen less than 3cm from the steering wheel or nearly touching. Some even confirmed that whilst they drove their abdomen was in constant contact with the wheel. This group is at greater risk of injury to the fetus in a collision because of their proximity to the steering wheel. The guidelines recommended 25cm distance (between the sternum and the centre of the steering wheel), but considering the abdominal region only 14% of the women were seated with their abdomen 25cm or
greater away from the wheel.

Considering the subset of pregnant women who were in their third trimester and who
gave this estimate of the distance between the bump and steering wheel, the effect of
pregnancy is greater. Only 10% of women are seated with a clearance distance of
25cm or greater, and 11% are seated with their abdomen nearly touching the wheel
whilst they are driving.

The pregnant women were also asked whether in their opinion they thought the airbag
could be a risk to the pregnant woman or fetus if it were activated in a collision, and
their responses are summarised in Figure 10.

![Figure 10. Pregnant women’s opinions whether airbag deployment could be a risk to the pregnant woman or fetus (n=557).](image)

Only 17% of the women believed the airbag did not pose a risk to the pregnant
woman or fetus. Just over half of the women believed the deployment of the airbag
during a collision could be a risk, and around one third were unsure. The main
concern for these pregnant women was about the force or impact of the airbag against
the abdomen and whether this would injure the child. Proximity to the steering wheel
and fear that the fetus could be injured in an accident had actually caused some
pregnant women to cease driving entirely. A large group of the pregnant women said
had moved the seat slightly rearward in order to increase the distance between their
abdomen and the steering wheel, and several participants also reclined their seat back
in addition; however, as expected, these women reported difficulty in reaching and
operating the pedals.

3.5 VEHICLE ENTRY & EXIT

‘Entry’ and ‘exit’ are the activities of getting into the car at the start of a journey and getting out the car at the end. When entering the car the pregnant woman is stood at the side of the car, opens the door and then takes a seat inside the car. The exit activity is the opposite of entry so the pregnant woman climbs out of the seat to move to stand beside the car again and shut the door. However these two activities are not necessarily the exact opposite of each other since they have different requirements and problems, so they are treated separately. For example a pregnant woman may choose pull on the inner handle above the door opening whilst exiting the car, but she might not use that handle whilst climbing into the car and instead chooses to lean on the steering wheel. Only 22% of the pregnant women reported no difficulty at all with getting in and out of the car. The main entry and exit problems that the women experienced are shown in Figure 11. Note that multiple responses were allowed for this question, since more than one problem could be experienced, so the total does not sum to 100%.

![What problems do you have getting in and out of the car?](image)

Figure 11. Problems that pregnant women encounter when entering or exiting the car.

During pregnancy the biggest problem was restricted movement (47%). For 26% of the pregnant women lack of space was a problem, and for 4% fear of overbalancing was a problem. Some pregnant women reported a problem with lowering themselves
into the car seat of lower cars. Others reported that they used a plastic bag on the seat to help them swivel around on the seat. These problems are described in more detail in the following sections.

The pregnant women response about the methods used entry and exit of the car are summarised in Figure 12 and Figure 13. Only 31% and 17% of pregnant women used no additional method to help them with getting in to and out of the car respectively. A variety of different actions were used to assist with entry and exit and some women used multiple methods, so the percentages in Figure 12 and Figure 13 will not sum to 100%.

![What methods or actions do you use to assist in getting in to the car?](chart)

**Figure 12. Methods used by pregnant women getting in to the car.**
What methods or actions do you use to assist in getting out of the car?

The pregnant women use a variety of methods for getting in and out of the car. These methods can include leaning, pushing and pulling on various parts of the car. Leaning on the seat and steering wheel are most common for pregnant women whilst climbing into the car. Pushing on the seat is the method used by the majority of pregnant women to help them get out of the car, but other methods included leaning forward and leaning and pulling on the door. Some pregnant women in taller vehicles experienced difficulty with climbing up to get into the car, or climbing or jumping down from the car. Many pregnant women also reported that they would move the seat rearward on the seat track before entering the car in order to allow the maximum available space for entry, and then slide the seat forward for driving (and the opposite action for exiting the car). These responses are described in fuller detail in the following sections.

3.5.1 Discussion of pregnancy related changes

3.5.1.1 Restricted movements

For the majority of pregnant women the biggest problem (40%) during entry and exit is that their movement is restricted. Specifically the term ‘restricted movement’ compares the physical movements and range of motion of the women during
pregnancy against before pregnancy, and women report that their movements and range of motion is reduced. Limited bending and limited reach were also reported 81% and 69% of pregnant women respectively, which confirms that restricted movements are a common side effect of pregnancy. This overall trend for restricted movements thus allows a greater understanding of more specific problems of entry and exit of the car. For example twisting and turning were particular problem reported by many women, which is not surprising given the size and shape changes occurring throughout the body. Pregnant women also reported difficulty in lifting their legs during car entry, and more specifically that restricted movement caused difficulty lifting their legs to move them into the car once they have sat down.

Another problem of restricted movement is that pregnant women are prevented from leaning forward whilst seated before and during their standing motion to get up and out of the car. The enlarged pregnant abdomen is touching the thighs whilst seated, which is a new interaction as a result of pregnancy and this consequently prevents the women from learning forward. Similarly this interaction between the abdomen and thighs causes pregnant women difficulty entering the car as women swing their legs in once seated.

It is common during pregnancy for women to experience restricted movements, and this causes women to change their method of getting in and out of the car. One common method of entry and exit is to separate the movement into two stages, and this is illustrated in Figure 14. For example when entering the car the woman would not use one continuous motion in the same way as non-pregnant women, but instead will use two motions: firstly to sit down on the seat whilst facing laterally out of the door opening, then secondly to swivel around whilst lifting their legs into the car and to face the front of the car.
For the exit of the vehicle the reverse two-stage method is used. The pregnant women will swivel around on the seat to face out the side of the car whilst lifting their legs out of the vehicle at the same time, then the second stage of the motion is standing up. Overall this shows that restriction of movement caused by pregnancy causes changes in the pregnant women’s vehicle entry and exit methods.

3.5.1.2 Pain
Pain is a common symptom of pregnancy and it can occur in many parts of the body including the back, pelvis, hips, abdomen, legs and joints. 75% of the pregnant women in the sample reported some back pain as a result of pregnancy. They also reported that the entry and exit activities of car travel cause pain to occur, or exacerbated pain that was already present. In order to reduce pain levels, or reduce the risk of pain occurring, some women altered their movements or restricted their range of motion. In turn, this lead to the problems associated with restricted movements and caused women to alter their methods of getting in and out of the car. This reveals that pain is indirectly causing problems with entry and exit, and also indirectly causing women to alter their methods of entry and exit.

3.5.1.3 Fear of overbalancing
The changes of pregnancy are not limited to physical changes, but can include emotional or psychological changes too. The additional mass of the enlarged abdomen alters the pregnant woman’s centre of gravity, and as a result she might feel a fear of overbalancing whilst she is getting in and out of the car. This can also cause women
to alter their method of vehicle entry and exit.

3.5.2 Discussion of changes in interactions between the pregnant occupant and the vehicle

3.5.2.1 Lack of space

26% of the pregnant women reported a problem of lack of space whilst getting in and out of the car (see Figure 11). This problem is a result of the changed relationship between the vehicle and the pregnant occupant as a result of the pregnancy. Pregnant women reported the problem of lack of space with regard to the space between the door, seat and steering wheel, as the woman moves through the door opening and into or out of the seat. The available space is not big enough because the pregnant woman has changed size and shape, and particularly that the abdomen has enlarged. The lack of space problem extends to fitting in between the seat and steering wheel whilst seated, and some women have a problem with this. Some pregnant women have to sit with their abdomen actually touching the steering wheel whilst driving, and others report that it bumps against the steering wheel as they get in or out of the car. A further explanation to the problem with fitting through the door opening and steering wheel distance is provided by the difference between standing and seated sizes when pregnant. The ‘spreading effect’ of being seated means that the abdominal region is larger when seated than when standing. For some pregnant women as they move between standing and seated posture whilst entering the car for example, this size increase is not accommodated.

3.5.2.2 Leverage points

The pregnant women need to lean, push, pull and hang on to various leverage points to help with entry and exit of the car. The leverage points are the door, the seat, the steering wheel, the car roof, the doorframe, the inner handle above the door opening, and the side of the car.

The pregnant women’s need to use these leverage points is explained by several reasons. For example the additional weight of the pregnant woman’s body means that a greater magnitude of force is needed to move the body. Using the leverage points gives the pregnant women the mechanical advantage needed to help with moving the additional mass.

Similarly, using the leverage points can help pregnant women to control and
manipulate their force direction whilst standing or sitting, which can help with women’s ability to turn and twist during the activity of getting in and out of the car. If the women are experiencing a fear of overbalancing then using a leverage point on the car can help with stability and maintaining control whilst getting in and out of the car.

3.5.2.3 Car door
Pregnant women’s strength is restricted during pregnancy. Some women reported difficulty with opening and closing the door because they felt weaker as a result of pregnancy. The car door needs a certain level of force to move it whilst opening and shutting, and this can be a problem if pregnant women are feeling weaker during their pregnancy.

3.5.2.4 Bucket seats
Bucket style seats were a problem for several pregnant women. The raised seat cushion bolsters interfered with entry and exit in two different ways. The first reason is that for pregnant women who preferred to use the two-stage exit method the swivelling was prevented by the raised edges of the seat. Secondly, the raised edges caused women to lift their legs over the cushion and this restricted the space available for the abdomen causing discomfort.

3.5.2.5 Seating aid
A few pregnant women who adopted the two-stage method of entry and exit chose to use a seating aid. Some pregnant women stated that they were helped in swivelling around on the seat by sitting on a plastic bag, which helped by reducing the friction between their bottom and seat surface.

3.5.3 External factors
These external factors are beyond the control of the vehicle designers or pregnant women however it is useful for them to be aware of these factors for more comfortable and safer entry and exit of the car during pregnancy.

3.5.3.1 Car parking spaces
Narrow car parking spaces are a common problem for the pregnant women. Due to the enlargement occurring in the body during pregnancy women need to open the door as wide as possible to allow enough space for entry and exit. However a narrow car parking space, especially when parked next to a wall or other cars, prevents
women from opening the door as wide as they need to. This was actually a serious problem since several women reported being unable to gain access to their car when they returned to find other cars parked in neighbouring spaces.

3.5.3.2 Roads
Getting in and out of the car is difficult in pregnancy, but women also reported that it was worse when parking on sloping roads. In particular, the door opening size is limited when a car is parked facing uphill and the car door swings shut.

3.5.3.3 Weather
Bad weather, particularly icy or windy conditions, makes getting in and out of the car even more difficult during pregnancy, and some pregnant women reported this problem.

3.5.3.4 Choice of vehicle
The choice of vehicle at the time of purchase determines its height. However women are unlikely to consider the problems of pregnancy during the car purchasing process unless they happen to be pregnant at the time of the decision.

The height of the vehicle can affect pregnant women’s entry and exit in two ways. Firstly if the seat is low it is difficult for pregnant women to lower themselves down to the seat when getting in to the car. Secondly, if the seat is high it forces women to climb or jump up into the seat, or jump down from the seat, which could potentially pose a risk of injury.

3.5.3.5 Help
Sometimes pregnant women will have someone to help them to get in or out of the car.

3.6 SEATS
The pregnant women were asked about the problems that they experience with seating in their cars. Initially they were asked to decide whether their comfort was adversely affected by pregnancy, and their responses are summarised in Figure 15. Only about a quarter of the pregnant women said that they had no problem at all with car travel comfort during pregnancy compared to when they were not pregnant. Over half of the pregnant women said that comfort was a little affected by pregnancy, and 21% said it was a lot affected. 1% of the pregnant women reported that their comfort during car travel was so adversely affected that it had caused them to avoid driving at all during
pregnancy.

**Figure 15. Summary of how much pregnant drivers think their comfort is adversely affected by pregnancy (n= 577).**

The women were also asked more specific questions about the car seat cushions and their comfort during pregnancy and Figure 16 summarises their responses. 320 of the 563 (57%) women reported that they had no problem at all with the car seat cushions. 43% of the pregnant women reported a variety of problems (and in many cases multiple problems so the percentages in Figure 16 will not sum to 100%) with the car seat during pregnancy. 51 of 563 women reported that the car seat cushions were too hard, but 10 women reported the cushions were too soft. Another problem (22 of 563 pregnant women) was that the seat cushions were too high under the knees and restricting the space available for the enlarged abdomen. However, a few women also reported the seat was too low beneath their knees.
However the biggest problem was the lack of back support (196 of 559 pregnant women), which affected over one third of the pregnant women (35%). In the additional comments about other problems some women additionally reported that the problem was the lumbar curve being too shallow, thought the curve was positioned too high up their back, or thought it was too low. This is a clear indication that there is a problem with the lumbar section of the seat for pregnant women.

One woman praised her car seat which had an adjustable lumbar curve that could be adjusted both horizontally and vertically. Several women reported using an additional pillow. Another woman suggested that a heated lumbar section of the seat would be an improvement.

Several women reported difficulty in reaching the seat controls, specifically the fore/aft seat track adjustment lever when located under the front of the seat. Similarly women reported difficulty with adjusting the seat back recliner to suit them in a comfortable position. Some women also reported that the angle between the seat back and the seat pan was too small. Several women complained that their seats were too low, and one woman also stated that her seat was too high. Some women reported pain (back or hip pain) during long journeys. A few women reported difficulty fitting into bucket seats. Finally a few women stated discomfort or back pain as a result of the alignment between the seat and steering wheel and pedal controls, i.e. that feeling
of a misalignment caused them to sit twisted or leant toward the centre of the car. In general additional comments about comfort in the car, there were more problems and opinions raised by the pregnant women. Several women praised the air conditioning systems in their cars and said that were using them more during their pregnancy. Several women also commented that speed bumps and pot holes were extremely uncomfortable in pregnancy.

3.7 USING THE BOOT

The pregnant women were also asked questions about using the boot. The initial question was used to assess the overall impact of pregnancy upon using the boot. The women were asked to consider how much pregnancy was adversely affecting their driving, and their responses are summarised in Figure 17. Using the boot does not seem to be a major problem for the pregnant women, since two thirds of them reported that pregnancy was not adversely affecting their ability to use the boot. For 26% of the pregnant women using the boot was a little affected by pregnancy, and for 6% it was a lot affected. There was even one woman who reported that using the boot was so badly affected by pregnancy that she had chosen to avoid driving or travelling by car altogether.

![How much is using the boot being adversely affected by pregnancy?](image)

Figure 17. Summary of how much pregnant drivers think they are adversely affected by pregnancy when using the boot (n= 571).

Later in the questionnaire the pregnant women were asked a more detailed question
about their experience of using the boot. This question asked what problems they have with using the boot and they were given a number of options: that the edge is too high so they can’t lift items in or out, their bump gets in the way so they can’t reach far enough into the boot, or that they can’t reach high enough to shut the boot. The responses from the pregnant women are summarised in Figure 18, and the women gave multiple responses since they often experienced combinations of problems, which means that Figure 18 will not sum to 100%.

![Figure 18. Problems that pregnant women encounter using the boot.](image)

Reaching into the boot is the biggest problem during pregnancy because of the enlarged abdomen. In additional comments other women said that the parcel shelf got in the way, and that the boot is too deep, or that they stand facing to the side so that the bump doesn’t get in the way of reaching. The next biggest problem is reaching up to shut the boot lid (10%). One woman additionally reported that even though she has a strap to help pull down the boot lid, she still cannot reach it. Another problem is lifting items in and out of the boot, reported respectively by 9% and 8% of pregnant women. It is interesting to note here that the pregnant women who have a problem lifting items into the boot do not necessarily have the opposing problem with lifting
items out of the boot. For example, from those 49 women who do have a problem with lifting items into the boot, 19 women (39%) don’t have the opposing problem with lifting items out of the boot. 27% of women that have a problem with lifting items out of the boot do not have a problem with lifting them into the boot. This indicates that the problem is varied according to the pregnant woman and the car she is using, and it is incorrect to make the assumption that pregnancy affects the activity of lifting items in and out of the boot equally.

6% of the pregnant women reported other problems with using the boot. Some of their comments have already been described above, but more of these other problems are now described in more detail. Several women stated that they actually had to climb into the boot in order to use it. This is quite an extreme course of action as a result of pregnancy and is potentially unsafe because of the risk of slipping or falling, which highlights the importance of making the boot easy to use for pregnant women to avoid risk of injury. Many women reported a lack of strength for opening or closing the boot in comparison with before they were pregnant. Some women reported standing at the side of the car to shut the boot. Several women reported a fear of straining muscles so they avoid stretching whilst using the boot. Another woman said that she had hurt her back lifting heavy items, so asked her husband to be responsible for lifting items in and out of the boot in order to avoid injury.

### 3.8 REACHING CONTROLS

The pregnant women were asked about how easy it was for them to reach and to use and operate various controls and parts of the car, and their answers are summarised in Figure 19.

The biggest problems seem to be reaching the glove compartment and the rear seats. However this is to be expected since these are hard to reach for any non-pregnant person in the driver’s seat. Reaching to the rear seats could be of importance for pregnant women with previous children that are seated in the rear.

Reaching the seat belt is another big problem in pregnancy, particularly with twisting around to reach it when it is hanging at the side of the seat, which is difficult due to the enlarged abdomen and restricted range of motion.

For controls that are in front of the pregnant occupant (e.g. radio, window buttons, dashboard control etc), the pregnant women mainly have difficulty leaning forward, either because of the enlarged abdomen restricting their motion, or because the
abdomen touches the steering wheel.

There are some controls that are vital for the activity of driving, but few women have serious difficulty in reaching these.

![How easy is it for you to reach and use/operate the following parts of the car?](image)

3.9 PHYSICAL AND EMOTIONAL CHANGES AND THEIR EFFECT ON DRIVING

The pregnant women were asked about the physical changes and symptoms of pregnancy and how these affect their driving and car travel. These physical changes were divided into three groups; longer lasting, sudden in occurrence, and movement changes.

From the longer lasting symptoms summarised in Figure 20, back pain was the biggest problem. Only a quarter of the pregnant women did not experience any back pain, and half of the women felt their driving was affected in some way. 40% of the women reported discomfort caused by their back pain. Other types of pain associated
with pregnancy were also causing discomfort and distraction for the pregnant women, and these included pain in the stomach, hips, pelvis, and joints. For a small group of women this pain actually caused women to avoid driving entirely. Figure 20 describes the longer lasting physical symptoms of pregnancy reported by the pregnant women, and how these impact upon driving.

![Figure 20. Problems of long lasting physical symptoms for pregnant women.](image)

There are also some suddenly occurring symptoms of pregnancy, and these include: a sudden need to urinate, itchy skin, sickness, heartburn and leg cramp.

Considering the suddenly occurring symptoms as summarised in Figure 21, a sudden need to urinate was the biggest problem affecting the pregnant women’s driving. Need to urinate is increased in pregnancy due to pressure applied to the bladder by the baby. 10% of the women reported unpredictable driving as a result of the sudden need to urinate, and 13% of the women were distracted. The biggest problem that caused women to avoid driving entirely was sudden feeling of sickness (5%). Braxton Hicks contractions were another physical symptom of pregnancy that affects the pregnant
women’s driving style, causing distraction or forcing women to avoid car travel. Sudden hunger also caused distraction for a few women. Figure 21 below summarises the pregnant women’s responses about the suddenly occurring symptoms of pregnancy.

Figure 21. Problems of suddenly occurring physical symptoms for pregnant women.

The women were also asked about how their movements were affected by pregnancy and their responses are given in Figure 22. The biggest problem is with exhaustion in pregnancy, and for some women it caused them to avoid driving entirely. 24% of the women reported slower movements because of their exhaustion, and 4% were distracted because of their exhaustion. Limited reach and bending, and slower movements also caused the women to have slower responses whilst driving.
In which ways is your movement affected during pregnancy?

<table>
<thead>
<tr>
<th>Movement</th>
<th>Percentage of Pregnant Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited reach</td>
<td>20%</td>
</tr>
<tr>
<td>Limited bending</td>
<td>40%</td>
</tr>
<tr>
<td>Slower movements</td>
<td>60%</td>
</tr>
<tr>
<td>Exhaustion</td>
<td>80%</td>
</tr>
<tr>
<td>Breathlessness</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure 22. Problems of altered movements as physical symptoms for pregnant women.

There were also some emotional changes as a result of pregnancy that caused some effects on pregnant women’s driving, and women’s responses are given in Figure 23.

<table>
<thead>
<tr>
<th>Emotional Symptoms</th>
<th>Percentage of Pregnant Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleasure / pride</td>
<td>0%</td>
</tr>
<tr>
<td>Irritable</td>
<td>20%</td>
</tr>
<tr>
<td>Oversensitive / tearful</td>
<td>40%</td>
</tr>
<tr>
<td>Panic / anxiety</td>
<td>60%</td>
</tr>
<tr>
<td>Fear</td>
<td>80%</td>
</tr>
<tr>
<td>Depression / feeling down</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure 23. Problems of emotional symptoms for pregnant women.
Feeling oversensitive and tearful or feeling irritable seem to be the biggest causes of distraction for pregnant drivers. It is revealed that it is not only difficult to predict the pregnancy related emotional changes, but also it is very difficult to reach a conclusion on the affect of these emotions on driving. Many women felt very happy and calm. Other women became more alert and the main cause was excitement, irritability or pleasure. Alertness is a positive impact of pregnancy on driving style. On the other hand numerous women felt distracted during driving, and irritability and tearfulness were the main causes of this. A few women chose to avoid driving as a result of emotions in pregnancy such as pleasure, irritability, tearfulness, panic, fear and depression. Additional information given by women described how their driving style had changed. Firstly, feelings of calmness caused women to reduce their risk-taking behaviour and decrease their speed. Secondly, vulnerability made women more alert and reduce their risk-taking behaviour. The last group described aggressive feelings that increased their risk-taking behaviour and made them impatient drivers.

3.10 DISCUSSION OF PREGNANT WOMEN’S NEEDS

The needs of pregnant women revealed by the questionnaire responses are now discussed. The discussion is divided into the different areas of the vehicle design.

3.10.1 Automotive design implications for seat belts for pregnant women

Comparing the seat belt usage rates for this sample of pregnant women against the national average it seems the seat belt usage rate is higher for pregnant women. This is perhaps because they have become more safety conscious due to the pregnancy, or because they do not want to admit that they are breaking the law by not using the seat belt.

Seat belts are the biggest problem for pregnant women and their lack of use or incorrect positioning is a safety risk. Automotive engineers can design specific adaptable, integrated seat belts to make certain that the seat belt is more suitable for the pregnant body, so that pregnant women can comfortably fit the belt and are safely restrained during all stages of pregnancy. This would help to increase the number of women wearing the seat belt in the correct position.

One particular problem highlighted is that the lap portion of the seat belt tends to ride upward onto the abdomen into a dangerous position. Engineers should consider this and use pregnant women’s anthropometry to ensure that the belt will fit correctly
throughout the course of pregnancy.

The increased abdominal depth of pregnancy causes the base of the abdomen to make contact with the upper thighs in seated posture, as shown in Figure 24. This could be part of the problem for wearing the lap belt in the correct position across the hips.

![Figure 24. Illustration of increased area of contact between the thighs and lower abdomen whilst seated as pregnancy progresses from the first trimester to the third trimester.](image)

The use of anthropometric measurements from pregnant women can also be used to define the necessary belt length in order to ensure that the seat belt can accommodate the enlarged hips, abdomen and chest area during all stages of pregnancy.

The evidence from the questionnaire responses shows that women modified their seat belt behaviour for protection or comfort, for example by holding the seat belt. However in reality these women actually put themselves at greater risk of injury, which reinforces the need to provide comfort for pregnant women to ensure their safety. The capacity of the seat belt to accommodate the changing size and shape of pregnant women comfortably can become an important safety issue since this can be the determining factor for women and their fetuses to be protected by the seat belt.

Poor geometry and a slack seat belt were found in 74% of submarining cases in a study by Leung et al. (1982). So any action by pregnant women that introduces slack or any incorrect positioning of the seat belt could contribute to the risk of abdominal injuries caused by submarining.

It is surprising that only around half the women had received advice when all women are expected to attend a clinic with their GP or specialist regarding their pregnancy, and this is a prime opportunity to inform women of this important safety advice.

Information provision about correct seat belt use and positioning in pregnancy to both the medical practitioners and the pregnant women should be improved.
3.10.2 Automotive design implications for airbags for pregnant women

Pregnant women are advised to leave as much space as possible between themselves and the steering wheel. The pregnant women are not sitting with their abdomen close to the wheel deliberately; it is a case of necessity in order to reach the controls and due to the changes in anthropometry during pregnancy. For example the women may be seated with 25cm between their breastbone and the steering wheel normally, but during pregnancy the abdomen enlarges and grows close to toward the steering wheel. The women cannot however counteract this growth by moving the seat rearward because they still have to reach the pedals with their feet and the steering wheel with their hands, meaning that rearward movement away from the controls is limited. In order to better accommodate this enlargement of the abdomen toward the steering wheel there are several things that automotive engineers can do. Engineers should use anthropometric measurements from pregnant women (such as those given in this study) to give practical advice on keeping a safe distance away from the steering wheel in order to reduce the impact of the steering wheel or deployed airbags in case of an accident. Secondly vehicles should provide a greater range of fore and aft seat adjustments. This would allow pregnant women to move their seats rearward to compensate for the enlarging abdomen. However it is important to consider the pregnant woman and the car environment as a system and hence providing fore and aft adjustable pedals or pedal extenders would greatly benefit pregnant women. Adjustable pedals have been found to be effective in increasing both chest-to-steering wheel and abdomen-to-steering wheel distances (Parenteau, C.S., Shen, W. et al., 2000) in a sample of males and non-pregnant females. Adjustable or extendable pedals would allow pregnant women to move their seats rearward but also be able to comfortably reach and operate the pedals to drive. This will also benefit the group of small stature people. Another suggestion for automotive designs is the provision of a retractable steering wheel to move the steering wheel further away from the abdomen as it enlarges. Automotive designers could check reach capabilities of pregnant women, using the anthropometric data provided, for all parts of the car with the seat in all fore and aft positions to ensure pregnant women can reach the pedals, and all other controls.
3.10.3 Automotive design implications for entry and exit of the car for pregnant women

The method of vehicle entry and exit can be altered as a result of pregnancy. For example pregnant women often separate what is usually one continuous movement into two separate motions; termed the two-stage method. For example when women are getting in to the car, the two separate motions are first to sit down on the seat whilst facing laterally out of the door opening, then secondly to swivel to face the front of the car whilst lifting their legs in. The exit method is the opposite. This two-stage method has automotive design implications. It is important to ensure that pregnant women are able to swivel on the seat unobstructed (for example by steep sided bucket seats), and to ensure they have enough space in the door aperture when stood facing laterally out of the drivers seat.

It is important for automotive designers to check the accommodation of pregnant women’s anthropometry as they move in and out the car. For example checking the space through the door aperture, and checking the space for fitting in between the seat and steering wheel (while still being able to reach the pedals and controls). Not only must the increased sizes of pregnant women be considered, but also the changes in size as they move between standing and seated postures. It is important to use the correct anthropometry and to consider the difference between sitting and standing posture because in seated posture the abdomen and breast sizes of pregnant women are larger than in standing posture.

Leverage points on the car are used by many pregnant women as an aid to help them move or twist. There are various leverage points, including the door, the seat, the steering wheel, the car roof, the doorframe, the inner handle above the door opening, and the side of the car. Automotive designers could provide such leverage points and handles as an aid to pregnant women to lean, push, pull and hang on to.

The car door should not be too heavy since some women feel weaker than usual during pregnancy. The door should also open wide enough for pregnant women allowing for their enlarged abdomen. The car seat could be height adjustable to help women who experience difficulty in lowering themselves into the seat.

Some pregnant women choose to slide their seat rearward to increase the space available between the seat and steering wheel whilst getting in and out of the car. However if the seat track control is positioned under the front edge of the seat it can be difficult to reach, particular with the enlarged pregnant abdomen preventing
women from leaning forward. Positioning the seat track control on the side of the seat, on the door or dashboard could help, but it is most important to make sure that the seat is easy to adjust and that the control is within reach.

Some pregnant women reported using a plastic bag on the seat in order to help them swivel around on the seat pan for getting in and out of the car. They stated that it seemed to be a harmless, yet effective, method of helping them get in and out of the car. However this plastic bag method has dangerous implications since the seat is carefully designed for safety, in particular to prevent submarining under the lap belt. By using the plastic bag these women could be unintentionally putting themselves and their fetuses at increased risk of injury in a collision. Automotive engineers could consider the need of pregnant women to swivel on the seat pan surface and consider how to make this easier for pregnant women, and so prevent them using the plastic bag method.

The author recommends that pregnant women should be allowed to use parking spaces designated for families with children that are commonly seen in supermarket car parks. Other infrastructure designers, town planners etc that control the layout of car parks should consider providing extra wider spaces to allow pregnant women safe and comfortable entry and exit of their vehicles.

If there are other people travelling in the car with them, then pregnant women should consider asking for help. If the pregnant woman is travelling as a passenger they should ask the driver to park safely with a wide space to allow for a wide door opening to help them with entry and exit.

3.10.4 Automotive design implications for car seats for pregnant women

The biggest recommendation for automotive engineers for the design of car seats it to provide adjustability in the seat in order to incorporate the needs of pregnant women. This includes adjustments in the height, seat back angle, seat pan tilt, and lumbar curve fore/aft and vertical positioning. Some women also reported problems being able to adjust the seat back angle to a comfortable position, and others reported discomfort because the angle between the seat back and pan was too small. A solution is to offer a greater range of adjustability in the seat back and the seat pan. One possible solution is to offer continuous adjustment rather than notched positions on the seat back recliner, however the seat back recliner also should be carefully engineered with the requirements for providing protection against whiplash injury in a
rear impact. Automotive engineers could check that the full range of anthropometry of pregnant women is covered by their seat designs. This adjustability in the seat will also help the group of women who suffer discomfort or pain during long journeys. It is also important to put the controls for these seat adjustments within easy reach of the pregnant occupant and their limited range of motion should be considered. Some women reported difficult reaching forward to operate the seat track control if it was located underneath the front edge of the seat. One solution to this is to provide a larger handle, or to provide an electric adjustment with the button located within reach.

Several women reported a problem of feeling twisted in the seat, and that there was a misalignment between the seat and the steering wheel and pedals. The solution to this problem is to ensure that the seat is alignment with the steering wheel and pedals central to the seat.

One improvement could be to offer air conditioning in all cars as standard since there is slight rise in body temperature in pregnancy, and many women reported using the air conditioning more often during pregnancy. Some women also reported additional discomfort caused by speed bumps and pot holes during driving, and suspension systems that provide more cushioning would be an improvement for these women.

3.10.5 Automotive design implications for using the boot in pregnancy

Pregnant women have a variety of difficulties with using the boot, and automotive engineers have some possible solutions that might help. The problem of reaching items within the boot space could be addressed by providing a shelf or sliding floor in the boot to help move items around inside the boot space. One of the problems for pregnant women is reaching up to shut the boot lid, and a boot with a self-closing mechanism or providing a pull strap on the boot lid could be a solution to this problem. For women who feel weaker due to their pregnancy and have difficult with opening or closing the boot, boot lids with self-opening and self-closing mechanisms could be a solution.

3.10.6 Automotive design implications for reaching controls in pregnancy

For controls that are in front of the pregnant occupant (e.g. radio, window buttons, dashboard control etc), the pregnant women mainly have difficulty leaning forward, either because of the enlarged abdomen restricting their motion, or because the
abdomen touches the steering wheel. For these types of controls that are mounted in front of the pregnant woman it might help if they were mounted on the steering wheel, or on stalks behind the steering wheel, so they were in easier reach. The main recommendation for automotive engineers is to use pregnant women’s anthropometry to ensure that pregnant occupants can easily reach all the control and parts of the car, particularly those that are vital for the driving activity. Another suggestion is to mount dashboard controls (e.g. radio) controls on the steering wheel, or on stalks behind the steering wheel, so they were in easier reach. For women who have difficulty reaching the pedals, fore/aft adjustability might help. Providing a hook or method of pulling the belt forward so that it is easier to reach could also help pregnant occupants.

Reaching to the rear seats could be of importance for pregnant women with previous children that are seated in the rear, so perhaps providing a child view mirror as an accessory could help. Alternatively attachments for children’s toys to be hung or stored within the car could also help with keeping the children occupied, so automotive engineers could consider this need.

**3.10.7 Automotive design implications of changed emotions or physical symptoms in pregnancy**

Whilst it might seem that the physical symptoms of pregnancy are not related to automotive design, there are some things that can be done to help reduce the problems for pregnant women. For example reducing discomfort by providing adjustable seats and lumbar support could help to reduce discomfort and distraction during driving and so improve safety. Reducing driver error by ensuring that all controls and driving operations are simple and easy to use will make all drivers including pregnant women safer, by helping their concentration.

The limitations on mobility could be reduced by positioning all the relevant controls within easy reach so that the pregnant women do not have to stretch, twist, or bend. This will potentially improve pregnant women’s physical response times and hence their safety. Positioning all controls within easy reach could also help to avoid driver errors if the pregnant driver is temporarily distracted by some physical symptom or emotion.
Chapter 4

CHAPTER 4: SEAT BELT POSITIONERS

4.1 USE OF SEAT BELT POSITIONERS DURING PREGNANCY

A number of seat belt positioners are available on sale as aftermarket products. As reported in the previous chapter some pregnant women are using these positioners. These seat belt positioners generally claim to be able to hold the lap belt in the correct position and prevent it from rising up onto the abdomen, which is a common problem reported by the pregnant women. In the previous chapter the survey results have revealed that some pregnant women do not use the seat belt at all, and that many have the lap belt incorrectly positioned across the abdomen instead of across the hips. This can be due to lack of awareness of the correct position, or due to discomfort or belt fitting problems. The aim of this study is to establish the use of lap belt positioners, and whether they can contribute to pregnant women’s safe seat belt use.

4.1.1 Legal requirements and guidelines for seat belt positioners

The seat belt restraint system is a system for a specific vehicle type consisting of a seat and a belt fixed to the vehicle, and consisting of all elements which are provided to diminish the risk of injury to the wearer, in the event of an abrupt vehicle deceleration, by limiting the mobility of the wearer's body (United Nations Economic Commission for Europe, 2009a).

There are legislative requirements for the safety of seat belts, such as ECE Regulation 14 concerning seat belts anchorages (United Nations Economic Commission for Europe, 2009b), Regulation 16 concerning seat belts (United Nations Economic Commission for Europe, 2009a), and Regulation 94 concerning frontal impacts (United Nations Economic Commission for Europe, 2008). ECE R14 is concerned with seat belt anchorages and defines the minimum number of belt anchorages to be provided, their location, dimensions of holes, and the tests and inspection requirements. ECE R16 is concerned with seat belt restraint systems. It defines the rigid parts of the seat belt, the buckle, belt adjustment devices, retractors, pre-loading device, and straps. It also defines the tests, including tests for corrosion, micro-slip, conditioning of straps and breaking strength (static), belt assembly, retractor, dynamic, buckle-opening, and for pre-loading devices. R16 also defines the installation of seat belts and belt reminder systems into the vehicles. ECE R94 is
concerned with occupant protection in frontal impacts. It defines the performance limits for values recorded by test dummies, and the instructions for users of vehicles with airbags, as well as the test procedure, instrumentation, dummies, performance criteria and other relevant requirements.

However the legislation regarding seat belts only affects new systems. Any aftermarket products, such as seat belt positioners, are not considered in the regulations, even though the positioners might be marketed as though they could help to improve safety. Chapter 3 has established that many pregnant women are not wearing their seat belt in the correct position, and some are concerned about this issue. The regulations define the requirements for seat belts, but during pregnancy some women are unable to use the seat belt in the position in which it is intended to be used. Therefore for some pregnant women, a belt positioner can seem like a sensible and helpful device to ensure correct positioning. However these seat belt positioners are not tested as part of the regulations in the way that a seat belt system is. These after-market belt positioners are not subject to the regulations. The aim of this chapter is to investigate the use of belt positioners for whether they can affect pregnant women’s safety in comparison to the normal use of the seat belt.
4.1.2 Seat belt positioners available

The seat belt positioners are described below in Table 5.

<table>
<thead>
<tr>
<th>Device</th>
<th>Method of operation</th>
<th>Illustration of device</th>
<th>Country on sale</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Sit on small pad. Pad fastened by strap around back of seat. Pair of buckled straps holds lap belt down between legs.</td>
<td><img src="image1.png" alt="Image" /></td>
<td>USA</td>
</tr>
<tr>
<td>B</td>
<td>Sit on pad. Pad fastened by strap around back of seat. Velcro strap holds lap belt down between legs.</td>
<td><img src="image2.png" alt="Image" /></td>
<td>UK</td>
</tr>
<tr>
<td>C</td>
<td>Sit on pad. Pad fastened by strap around back of seat. Pair of Velcro straps holds lap belt down at either side of the hips.</td>
<td><img src="image3.png" alt="Image" /></td>
<td>UK</td>
</tr>
</tbody>
</table>

Table 5. Details of seat belt positioners.

4.1.3 Frequency of seat belt positioner use amongst pregnant women

Seat belt positioners are used by some women during car travel. From the survey, 17 women reported that they were using a lap belt positioner. The most common reason given by these women for their decision to use the positioner is to help hold the lap portion of the belt down across the hips and below the abdomen, in order prevent it from riding upward onto the abdomen during the journey and this is either due to the discomfort of the belt laying on the abdomen, or more commonly due to awareness that the lap belt should be placed across the hips and not across the abdomen. The positioners in use were type B and type C, and no women reported they were using type A. They reported that the positioners (types B and C) were comfortable and effective for holding the lap belt below the bump as it should be, although some women complained that wearing skirts was difficult when using positioner B because
it fastens between the legs. Many women also stated that they felt safer during car travel when using the belt positioner. One woman using a belt positioner did raise the concern that the positioners are not widely used or promoted, and consequently questioned whether there was a safety problem with them, although she kept using the positioner despite this concern. This is the aim of this chapter, to establish whether the positioners are effective in use.

4.2 DYNAMIC SLED TESTING METHOD TO INVESTIGATE THE EFFECTIVENESS OF LAP BELT POSITIONERS FOR PREGNANT WOMEN

This section will describe the development of the ATD (Anthropomorphic Test Device) with conversion to represent a pregnant female. A description of the test methodology will follow.

4.2.1 Hybrid III 5th percentile female ATD with MAMA2B conversion

This type of investigation into the use of lap belt positioners has not been possible until now, due to the lack of an ATD that is capable of representing a pregnant female.

The first design of ATD representing a pregnant female involved a pregnancy insert for the 5th percentile female Hybrid III ATD (Pearlman, M.D. and Viano, D.C., 1996). This represented pregnancy at 28 weeks and was a vinyl-covered foam casting. Inside the casing was a soft urethane gel ellipsoid to represent the uterus, and this contained a fetus, but no placenta. The insert was instrumented with triaxial accelerometers in the fetal head and thorax, and there was also a reaction plate behind the insert with four load-bolts that measured the pressure through the uterus. This device was not commercially available. It did not include a placenta so could not represent the risk of placental abruption which is the biggest cause of fetal trauma. However the MAMA2B conversion kit is now sold by First Technology Safety Systems and this was selected for use in the testing. The dummy is a standard Hybrid III 5th percentile female dummy, with a MAMA2B pregnancy conversion kit used to make it represent a pregnant female instead of the standard non-pregnant female ATD. The ATD that is capable of representing a pregnant female based on the MAMA2B conversion kit is still a prototype design, and still undergoing research and development. It was developed in 2001 by UMTRI and FTSS (Klinich, K.D., Rupp,
J.D. et al., 2005; Pearlman, M.D., Klinich, K.D. et al., 2000; Rupp, J.D., Schneider, L.W. et al., 2001). The version used contains only a single pressure sensor mounted at the front of the uterus with no other uterine instrumentation. The ATD converted with the MAMA2B kit to represent the pregnant female is shown in Figure 25.

4.2.1.1 Injury reference values
The MAMA2B conversion includes a replacement pelvis and lower spine. The pregnant abdomen assembly uses a fluid-filled silicone rubber bladder to represent the uterus at 30 weeks gestation. A pressure sensor is mounted at the anterior point of the uterus to measure the pressure response of the fluid filled uterus. This is based on the hypothesis the uterine pressure could be related placental abruption. Placental abruption has been shown in the research to be the primary cause of fetal loss. Peak intra-abdominal pressures are related to both the peak force applied to the abdomen and the peak accelerations of the abdomen, and have been suggested as potential predictors of injury. The theory is that the uteroplacental interface fails due to either shear strain or tensile failure. Since uterine strain and pressure are proposed to be direct causes of abruption, the pregnant uterus is a fluid-filled bladder to measure pressure caused by inertial loading of the uterus. The ATD with conversion to represent a pregnant female can not represent other injury mechanisms to the fetus, and only aims to measure uterine pressure in relation to placental abruption and consequent fetal loss.
UMTRI did develop an equation to calculate ‘risk of adverse fetal outcome’ (Rupp, J.D., Schneider, L.W. *et al.*, 2001), which includes both fetal loss and other major complications to pregnancy regardless of the injury mechanism. The risk was developed from the outcome of real world crashes involving pregnant occupants. However there were only 43 crashes in the dataset, and they were all located in the US rather than the UK. The risk curves generated were then related to the peak anterior pressure measured by the pressure sensor in KPa, to produce an equation to calculate risk of adverse fetal outcome from the peak pressure. This risk equation was developed based on a series of sled tests using the ATD with conversion kit to represent a pregnant female on a rigid seat, with a range of belt and airbag loading scenarios. The tests were run at 13-55 km/h to approximate to risks of 10-90%. However the calculation of risk is only valid for the range of sled tests from which it was calculated, and for the dataset of 43 US real world crashes, hence it is difficult to apply this calculation for the sled tests in this investigation with certainty of its validity, especially for real car seats (not a rigid seat). There are no regulatory requirements, nor established criteria for what is an acceptable level for risk of adverse fetal outcome. The user manual supplied with the ATD conversion kit contains no discussion of injury reference values (First Technology Safety Systems Inc, 2005). As discussed above, the proposed estimate for risk of adverse fetal outcome is based upon real world cases and test set ups that are not comparable to the testing set up used in this research, therefore calculation of the risk of adverse fetal outcome would not be representative or realistic for the test series described in this chapter. Therefore the calculation of risk of adverse fetal outcome is not discussed in this analysis due to its limitations, and due to the lack of regulatory requirements or established criteria.

Furthermore, other authors have not used the calculation for risk of adverse fetal outcome, and have only reported the pressure sensor values. Motozawa *et al.* (2007) and Hitosugi and Tokudome (2009) have used a 5th percentile female Hybrid III ATD with MAMA-2B conversion kit, however they have used both the anterior pressure sensor, and a posterior pressure sensor located at the rear of the bladder assembly. Motozawa *et al.* and Hitosugi and Tokudome have only reported the pressure sensor values, and have not used the estimate for risk of adverse fetal outcome proposed by Rupp *et al.* (2001).

The ATD with conversion kit to represent a pregnant female is suited to comparative
testing scenarios, such as this comparison of belt positioning and the use of lap belt positioners. Comparative testing allows differentiation between higher and lower pressures, which can be related to higher and lower risk regardless of injury criteria. Conclusions are drawn simply from comparison of the uterine pressure responses.

4.2.2 Test methodology
A series of Hyper-G sled tests were performed using a Hybrid III 5th percentile female ATD with the MAMA2B pregnancy conversion, since it was the only device available capable of representing the pregnant female. The tests were used to assess the effectiveness and safety of three seat belt positioners available commercially as after market aids for pregnant women.

The tests used a sinusoidal pulse with a delta-v of 50km/h, similarly to the regulatory requirements for seat belts (National Highway Traffic Safety Administration, 1993; United Nations Economic Commission for Europe, 2009a). The test matrix used is given below in Table 6. Two types of test were completed, and these were a seat only style test and a buck style test. For the seat tests, just the car seat and seat belt system were used, with no pre-tensioners fired on the seat belts. For the buck style tests a vehicle buck was mounted on the sled for the dummy to be seated in. In these buck tests the airbag was deployed, as were the pre-tensioners (double). In all tests, the driver’s seat was used.

For each of the test types (sled and buck), five tests were completed with only the lap belt positioning altered. Two tests had the lap portion of the seat belt positioned correctly (across the hips and underneath the abdomen) and incorrectly (across the middle of the abdomen). The other three tests were a comparison of each of the three seat belt positioners. The position of the diagonal torso portion of the seat belt was not varied for each test.
### 4.3 CORRECT AND INCORRECT LAP BELT POSITIONING DURING PREGNANCY

#### 4.3.1 Correct versus incorrect lap belt positioning across the hips

The traces for abdominal pressure are shown in Figure 26 and Figure 27, and these traces show a comparison between the lap belt correctly positioned across the hips according to the guidelines, and incorrectly positioned across the abdomen. It is clear that having the lap belt positioned across the abdomen appears to give a much higher pressure than with it positioned across the hips. The peak abdominal pressures recorded are also summarised in Table 7. The peak pressure for the incorrectly positioned lap belt over the abdomen was one third greater for the seat tests, and just over one quarter greater for the buck tests in comparison to the correctly positioned lap belt over the hips.
Figure 26. Abdominal pressure (KPa) traces for seat tests: Comparison of correct lap belt position across the hips versus incorrect lap belt position across the abdomen.

Figure 27. Abdominal pressure (KPa) traces for buck tests: Comparison of correct lap belt position across the hips versus incorrect lap belt position across the abdomen.
Table 7. Summary of peak abdominal pressures: comparison of correct and incorrect lap belt positioning.

<table>
<thead>
<tr>
<th>Test</th>
<th>Lap belt position</th>
<th>Peak Abdominal Pressure (KPa)</th>
<th>Test type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Correct lap belt over hips</td>
<td>84.1</td>
<td>Seat</td>
</tr>
<tr>
<td>5</td>
<td>Incorrect lap belt over abdomen</td>
<td>112.0</td>
<td>Seat</td>
</tr>
<tr>
<td>6</td>
<td>Correct lap belt over hips</td>
<td>60.2</td>
<td>Buck</td>
</tr>
<tr>
<td>10</td>
<td>Incorrect lap belt over abdomen</td>
<td>76.2</td>
<td>Buck</td>
</tr>
</tbody>
</table>

4.3.2 Agreement with current guidelines
For both the seat and buck style of tests, the result was clear that the lap portion of the seat belt should be positioned over the hips, and not across the abdomen, in order to reduce the pressure in the abdominal assembly. This result agrees with established research from Crosby et al. (Crosby, W.M., King, A.I. et al., 1972), and with the guidelines from the UK Department for Transport (2007; 2009b).

4.4 LAP BELT POSITIONERS DURING PREGNANCY
The next comparison is between the use of the seat belt only (correctly and incorrectly positioned), and the use of the seat belt positioners. The traces (KPa) from the abdominal pressure sensor in the abdomen of the ATD representing pregnancy are given in Figure 28 for the seat tests and in Figure 29 for the buck tests. The peak abdominal pressures recorded are given in Table 8.
Figure 28. Abdominal pressure (KPa) traces for seat tests: Comparison of correct lap belt position across the hips, all three lap belt positioners tested, and incorrect lap belt position across the abdomen.

Figure 29. Abdominal pressure (KPa) traces for buck tests: Comparison of correct lap belt position across the hips, all three lap belt positioners tested, and incorrect lap belt position across the abdomen.


<table>
<thead>
<tr>
<th>Test</th>
<th>Lap belt position</th>
<th>Peak Abdominal Pressure (KPa)</th>
<th>Test type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Correct lap belt over hips</td>
<td>84.1</td>
<td>Seat</td>
</tr>
<tr>
<td>2</td>
<td>Positioner A</td>
<td>86.9</td>
<td>Seat</td>
</tr>
<tr>
<td>3</td>
<td>Positioner B</td>
<td>85.9</td>
<td>Seat</td>
</tr>
<tr>
<td>4</td>
<td>Positioner C</td>
<td>85.5</td>
<td>Seat</td>
</tr>
<tr>
<td>5</td>
<td>Incorrect lap belt over abdomen</td>
<td>112.0</td>
<td>Seat</td>
</tr>
<tr>
<td>6</td>
<td>Correct lap belt over hips</td>
<td>60.2</td>
<td>Buck</td>
</tr>
<tr>
<td>7</td>
<td>Positioner A</td>
<td>69.4</td>
<td>Buck</td>
</tr>
<tr>
<td>8</td>
<td>Positioner B</td>
<td>59.6</td>
<td>Buck</td>
</tr>
<tr>
<td>9</td>
<td>Positioner C</td>
<td>59.0</td>
<td>Buck</td>
</tr>
<tr>
<td>10</td>
<td>Incorrect lap belt over abdomen</td>
<td>76.2</td>
<td>Buck</td>
</tr>
</tbody>
</table>

Table 8. Summary of peak abdominal pressures: comparison of correct and incorrect lap belt positioning against the use of 3 different lap belt positioners sold as aftermarket products.

The peak pressures felt for each of the tests are summarised below in Figure 30. In this case the bars represent the positioners, and the lines are where only the lap belt (with no positioner) was used. The lower line represents the correct position across the hips, and the upper line is the incorrect position across the abdomen.

Figure 30. Summary of peak abdominal pressures (KPa): comparing use of seat belt with lap belt positioners, against the seat belt (no positioners) with lap belt used correctly over the hips and incorrectly over the abdomen.
It is clear that for both the seat and buck style tests, the correct lap belt positioning gives a lower abdominal pressure than incorrect positioning. However, regarding the use of lap belt positioners in pregnancy, the result is less clear than the comparison of the correct and incorrect lap belt positions. It appears that for the seat tests the peak measurements of abdominal pressure are higher for the tests where a positioner was used, than for when just the lap belt was used in the correct position over the hips.

The peak pressure values are also lower than when the lap belt was positioned incorrectly over the abdomen. For the seat tests, the results for positioners A, B and C are only up to 3.3% greater than the result using the lap belt correctly positioned over the hips. The research study developing the design for the dummy had two identical tests (Rupp, J.D., Schneider, L.W. et al., 2001), which revealed differences of up to 4% for any point in the trace, and 1% at the peak. The peak abdominal pressures for tests with the positioners are compared to the test with lap belt correctly positioned, and this is summarised in Figure 31. There is only 3.3% difference from the peak pressure recorded with the lap belt correctly positioned, so the results for the positioners A, B and C, are within this bound of 4% for the entire trace. Therefore little clear conclusion can be drawn as to whether using positioners give a higher or lower abdominal pressure than using just the lap belt in the correct position over the hips within the bounds of the published repeatability of the ATD.

Figure 31. Comparing seat belt positioner tests against using the correctly positioned lap belt: Percentage difference in abdominal pressure, with 4% dummy repeatability bounds marked.
This pattern of results for the seat tests is not repeated for the buck tests. For two of these buck tests, using positioners B and C, the peak abdomen pressure values were lower than using the lap belt correctly positioned over the hips. However one point to note is that the pressure sensor was broken and had to be replaced with an identical sensor prior to the last three tests. This means that the buck tests using positioners B and C, and the one using the incorrectly positioned lap belt (over the abdomen), used a different pressure sensor to all the other tests, and therefore it is unclear whether the replacement of the pressure sensor may have influenced the result. Similarly to the seat tests, the peak abdomen pressure results for positioners B and C are within 2% of the result for the correctly positioned lap belt over the hips, and since this is within the repeatability of the dummy it is difficult to draw a clear conclusion from these test results for positioners B and C. However the result for Positioner A is more different with a peak pressure 15% greater than the correctly positioned lap belt, which is very different to the result for the seat test where positioner A had a peak pressure only 3.3% greater. It is difficult to draw a clear conclusion about the use of lap belt positioners from the buck test results, especially since the peak pressures from positioners B and C are within the 4% bounds of repeatability of the dummy, as shown in Figure 31. This figure shows the percentage difference of the peak pressure for the positioner when compared to the baseline of the lap belt being correctly positioned across the hips.

Overall it seems that the tests reveal that the lap belt positioners offer no particular safety advantage in terms of a reduced peak abdominal pressure. However it is possible to surmise that in the real world if the positioners help to encourage pregnant women to use a seat belt instead of not wearing a seat belt at all, then that might be a positive influence on their safety since the guidelines are clear that the seat belt should be worn at all times. Secondly, considering the real world influence of the aftermarket seat belt positioners, if they could help to increase the correct positioning of the lap belt across the hips instead of across the abdomen, then this might also be a positive influence on the safety of pregnant women. Pregnant women are clearly advised in the guidelines that the lap belt should pass across the hips and underneath the abdomen. It is not possible to assess the actual real world influence of the seat belt positioners until there is some crash data evidence of real world accidents involving women using these positioners.
4.5 REPEATABILITY
The published research study for the dummy development reports a 4% difference in abdominal pressure at any point in time, and 1% difference at the peak, based upon two identical tests (Rupp, J.D., Schneider, L.W. et al., 2001). This repeated test used the dummy in the driver’s seat of a rig wearing a 3 point belt at 34km/h with a peak acceleration of 12g, which is a different condition to the tests in this research.

The seat test with the lap belt correctly positioned over the hips of the dummy was actually run twice, which gives a rough indication of repeatability of the dummy for this research. The comparison between two identical tests is shown in Figure 32. This comparison reveals a 10% difference between the two peak abdominal pressures for two identical tests. The difference in abdominal pressure at other regions was greater, for example at 135 ms the difference was 73.9%, which is greater in comparison with the 4% difference reported in the development of the dummy.

![Figure 32. Repeated seat test with lap belt positioned correctly over hips.](image)

The buck tests with the lap belt correctly positioned across the hips was also repeated, and the only difference was that the repeat test re-used a seat that had been previously tested. This repeated buck test revealed a 3.6% difference in the peak abdominal pressure recorded, and is shown in Figure 33. Considering the whole trace for abdominal pressure there was a difference of 18.75% at 116.6 ms. It should be noted that re-using the seat might affect the result for the pressure sensor in some way, although inspection revealed no damage resulting from the previous test.
This repeatability analysis therefore reveals a need to better understand the repeatability of the dummy, since this may have a bearing on the test analysis for the comparison of the lap belt positioners. However the differences may be attributable to some other factor that is not accounted for in the set up.

4.6 SUMMARY OF DYNAMIC TESTING OF LAP BELT POSITIONERS FOR PREGNANT WOMEN

4.6.1 Summary of dynamic testing
It would seem that the intention of the positioners is to help pull the lap belt down across the hips and into the correct position. They are also, according to the sample of 17 pregnant women in this study, comfortable in use. If the devices are marketed as comfort aids, then the positioners are effective products for comfort according to the feedback from the pregnant women. However, if the positioners are marketed and sold as safety aids then it has been unclear whether this is realistic, since there has been no testing to establish the voracity of the claim due to lack of a suitable test device. The aim of this research was to use the Hybrid III 5th percentile female dummy with MAMA2B pregnancy conversion kit to investigate whether the positioners offer an improved or decreased protection, represented as a lower or higher pressure felt in the abdominal assembly. It is not possible to assess the safety effect of the positioners for risk of injury caused by the straps passing between the...
legs since the dummy is not instrumented in this region. The dynamic tests clearly support the correct positioning of the lap belt over the hips rather than on the abdomen. The tests also suggest that the use of the aftermarket seat belt positioners offer no obvious disadvantage (higher abdominal pressure) compared to use of the lap belt in the correct position across the hips. Considering the real world impact of positioners then it can be surmised that if their use encourages pregnant women firstly to use the seat belt, and secondly to position it correctly across the hips, then this might possibly offer benefit by encouraging properly positioned use of the seat belt. However given the different result for Positioner A between the sled test and the buck test, further tests are needed to define clearer conclusions as to whether positioners repeatably offer an improvement in safety or not. Real world evidence is required to help investigate the safety effect of the seat belt positioners in the real world.

4.6.2 Limitations of MAMA2B
The ATD that is converted to represent a pregnant female does have some limitations in its design, and these have some impact on this study and should be taken into consideration when interpreting the results. The ATD only tries to represent the pregnant uterus, and has an amount of additional weight to represent the additional body mass. The pregnancy conversion does not contain a placenta or fetus. There is no other attempt to replicate the changes and effects of pregnancy elsewhere in the body, such as changes in the anthropometry, spinal posture changes, changes to the pelvis etc. There is no facility to measure loads felt by a fetus with regard to direct impact injury, which is a common cause of fetal injury. Some of the lap belt positioners use a strap (or straps) between the legs to pull the lap belt downward, and there is no possible instrumentation on the ATD that could measure whether these straps might cause injury, either to the pelvic structure or to the soft tissues. The standard (non-pregnant) ATD does not have a fluid filled bladder representing the uterus, so there is no way to measure the uterine pressure in the standard ATD without conversion to represent a pregnant female. It is therefore impossible to make a comparison as to the effect of the pregnancy compared to a non-pregnant person for uterine pressure.
As stated above, the previously published repeatability of the ATD is not well established, since it is based on only one repeated sled test. Repeated tests from this series reveal differences in abdominal peak pressures could be as great as 10%. A further study of ATD repeatability is required before accurate conclusions can be drawn from any testing using the ATD with conversion kit to represent a pregnant female.

There is a lack of established injury criteria or performance limits for the ATD with MAMA-2B conversion. Rupp et al. have proposed a calculation for risk of adverse fetal outcome (Rupp, J.D., Schneider, L.W. et al., 2001). However as discussed in 4.2.1.1 this is based upon real world data and test set ups that are not comparable to this test series. Motozawa et al. have also not used the risk of adverse fetal outcome, and have only reported pressure sensor values. Further research is needed for this prototype ATD to establish injury reference values that are accepted by industry and regulation. The ATD is therefore limited to comparative testing scenarios, such as that used in this study comparing the use of belt positioners against the use of a standard seat belt. Without injury reference values and criteria the dummy cannot be used to indicate real world risk of injury.

The conclusions drawn in this study must be qualified by the above limitations. However the tests were completed using the ATD with conversion kit to represent a pregnant female since it was the only available test device at the time of testing that could represent pregnancy.
CHAPTER 5: ANTHROPOMETRY OF PREGNANT WOMEN

The design process relies upon the use of anthropometric data to determine the portion of the user population that will be accommodated by the design. This chapter investigates the physical changes during pregnancy and their resultant effect upon the safety of pregnant car occupant and her fetus. Some of this work has also been published in the papers in Appendix F (Acar, B.S. and Weekes, A.M., 2005; 2006a; b; Acar, B.S., Weekes, A.M. et al., 2009).

The anthropometric data sets are collected with a broad vision that physical changes to a pregnant woman may not be limited to the abdominal region. These data sets are compared with non-pregnant data to study possible exclusion percentiles. Two main safety issues have been focused on: the use and positioning of the seat belt during pregnancy, and the proximity to the steering wheel.

There has been a dearth of anthropometric data for pregnant women that are pertinent to automotive design and safety testing. The safety and comfort considerations for pregnant occupants have subsequently been largely neglected. The study presented in this paper has addressed this problem by recording 48 anthropometric measurements selected specifically for their applicability to the vehicle design process. Previous research has tended to focus solely on the abdomen, and has not considered the changes occurring throughout the rest of the body. This thesis presents the first comprehensive analysis of the anthropometry of pregnant women throughout the entire body, specifically for the automotive industry, and can help us to understand pregnant women's needs in a holistic manner.

5.1 ANTHROPOMETRIC DATA SOURCES

There is a lack of research investigating anthropometric changes during pregnancy to all body parts, or how different regions of the body interact.

Lenard and Welsh discuss women’s travel patterns and behaviours, including women’s tendency to drive smaller and lighter cars (Welsh, R. and Lenard, J., 2001). In terms of crash involvement, female drivers account for one third of drivers in the CCIS study, and outnumber men as passengers despite constituting only 40% of the overall sample, and have a different pattern of susceptibility to injuries (Lenard, J. and Welsh, R., 2001). In neither of these papers are any anthropometric data for women given, and no specific discussion of pregnancy is included. However Lenard and
Welsh make the point that women are poorly represented in testing that uses 50th percentile male dummies, since this equates to a 90-95th percentile female, and therefore suggest that only the extremes of female anthropometry are being considered (Welsh, R. and Lenard, J., 2001).

Hill and Mackay discuss the safety and security issues for women, including a little detail on pregnant women. Discussion of the altered anatomy during pregnancy is given, but no anthropometric measurements are included (Hill, J. and Mackay, M., 1997).

Welsh et al. report on the needs of shorter drivers and make an anthropometry study of 100 shorter drivers and their driving posture. Whilst the sample does include 96 women, there are no pregnant women included (Welsh, R., Clift, L. et al., 2003).

5.1.1 Adult data

Adultdata (Department of Trade and Industry, 1998) is a compilation of anthropometric data. It is the most recent source of data for the UK, but also covers various other nationalities. The UK source of data is PeopleSize (Open Ergonomics, 1998). PeopleSize takes its data from a UK government survey in 2005. That survey covered all incomes and all ages, and using validated scaling techniques the survey data is scaled up to match the latest heights and weights. The anthropometric data from PeopleSize (Open Ergonomics) does not include a full set of anthropometry of pregnant women. However it does include one measurement of abdominal depth at different stages of pregnancy. This is of limited use for vehicle design since it is not a comprehensive dataset covering the entire set of anthropometric measurements that are relevant to vehicle occupant accommodation.

5.1.2 Pregnant women’s anthropometric data

5.1.2.1 Yamana data

Yamana et al. (1984) present a large study of pregnant women’s anthropometric data. This includes 520 pregnant women who were measured for 44 dimensions from the second to tenth month of pregnancy. Few dimensions measured are applicable to the automotive design process since the study was aimed at garment design.

Using Pheasant’s ratio scaling method (1982) Pheasant then modified the abdominal depth and forward grip reach dimensions (1986) from Yamana's data. This is based on the assumption that British women are of similar proportions to Japanese women and
that pregnancy will cause them to change in a similar way.

5.1.2.2 UMTRI data
The UMTRI data set presented in Klinich et al. (1999a) presents the anthropometry of 22 pregnant women. Only ten measurements applicable to the automotive design process were recorded throughout the course of pregnancy, and these were mainly concerned with the legs and abdomen. This study included other measurements, but these were not recorded throughout the entire course of pregnancy since it was assumed that certain measurements would not be affected by pregnancy.

5.1.2.3 Alvarez data
The dimensional changes of the feet during pregnancy were investigated by Alvarez et al. (1988). 17 pregnant women were compared with 16 comparable non-pregnant women. Only two dimensions measured in this study are relevant to automotive design and these are the foot length and width.

5.1.2.4 Perkins data
Perkins (1999) studied the three-dimensional surface of the pregnant woman’s body as well as the traditional anthropometric dimensions. The sample included 15 pregnant women who were measured 5 times throughout pregnancy and at one month postpartum. Perkins study examined the waist circumference at preferred level, as selected by the pregnant woman instead of using a physical landmark.

5.1.2.5 Motozawa data
The study from Motozawa et al. (2007; 2008) presents measurements of 20 Japanese pregnant women seated in a sedan style car. The measurements include height, stature, abdominal circumference, seat adjustment position and posture, position of the body in relation to the steering wheel, and relative position of the seat belt on the body. These Motozawa measurements are only applicable to a sedan style car, and are also only useful for the Japanese population due to national differences in anthropometry.

5.2 ANTHROPOMETRIC DATA COLLECTION METHOD
There were different methods of data collection for the size and shape of pregnant women. The first was anthropometric measurements, and the second was measurements of pregnant women whilst seated in a car.
5.2.1 Anthropometric measurement method
A series of anthropometric measurements were recorded from pregnant women. The equipment used included weight scales, a stadiometer, a digital vernier calliper, a tape measure and an anthropometer. Volunteers wore light clothing and removed their shoes.

5.2.1.1 Anthropometric measurements
The anthropometric measurements recorded in the study were selected for their applicability to the vehicle design process. The measurements were also selected to help understand the changes in physical size and shape that occur during pregnancy. The measurements used the standard postures and procedures, as in Adultdata (Department of Trade and Industry, 1998) and Pheasant (1986; 1990). Where necessary the measurements were adapted to suit the pregnant body. For example during pregnancy the waistline (point of minimum circumference) is difficult to locate and eventually disappears. Instead of using the waistline the abdominal circumference was recorded at the point of maximum circumference.

The measurements are illustrated according to the four groups: weight and stature (Figure 34), head and shoulders region (Figure 34), trunk region (Figure 35), and limbs (Figure 36). The full list of anthropometric measurements is also given in Appendix D.

The anthropometric changes occurring during pregnancy might occur in the head and shoulders region since the changes might not be limited to the abdominal region. Sitting height, eye height and back of head height are all measurements of head height that were recorded as shown in Figure 34. These head height measurements are needed to define the head position in order to provide an adequate field of vision for the occupant. The head height is also required in order to position the head restraint correctly in relation to the head, in particular for prevention of whiplash injury (Avery, M. and Weekes, A.M., 2006; Farmer, C., Wells, J. et al., 1999; O’Neill, B., Haddon, J.W. et al., 1972). In order to position the seat belt so that it passes over the occupant’s shoulder the location of the shoulder is also required. The shoulder and mid-shoulder heights shown in Figure 34 were also recorded for the pregnant women.
Figure 34. An illustration of the anthropometric measurements: Head and Shoulders region. [Measurements and figures adapted for pregnant women from standard measurements in DTI, Adultdata, London, 1998]

There were many measurements recorded in the trunk region, including the chest, abdomen and hips, since this is the area where the seat belt passes around the body. The measurements of the trunk region are shown in Figure 35. The increase in breasts size during pregnancy is one of the first changes in the pregnant body in preparation for breast-feeding. The measurements recorded for the breast region (shown in Figure 35) were the chest depth and height whilst seated, and chest circumference in standing and seated posture. The chest height measurement helps to locate the bustpoints within the vehicle. The chest depth and circumferences give an understanding of the breasts enlargement during pregnancy. The measurements of the breast region are important because the increasing size of the breasts can affect how the seat belt fits around the breasts, and lead to the problems with the seat belt as reported in the questionnaire responses from pregnant women in Chapter 3. The increased breast size could prevent the seat belt from protecting the pregnant women and fetus as intended if it causes women difficulty with positioning the shoulder portion of the belt correctly. It can also mean the seat belt cuts into the breasts or is too tight. The seat belt might also slip out of position during a journey and cut into the neck, or it might be difficult to fit between the breasts. The discomfort of the seat belt in pregnancy can cause some pregnant women to take actions such as holding the seat belt away from
the neck in order to relieve the discomfort, and they do not realise that holding the belt and introducing slack might result in reducing the protection effectiveness of the seat belt during a collision. The chest depth increases also mean that the breasts are closer to the steering wheel. Overall the questionnaire discussed previously in Chapter 3 reveals that anthropometric changes occurring to the breasts can greatly influence pregnant women’s comfort and safety in the car, so the measurements of the breast region are of importance.

Figure 35. An illustration of the anthropometric measurements: Trunk region (Abdomen, chest and hips). [Measurements and figures adapted for pregnant women from standard measurements in DTI, Adultdata, London, 1998]

The abdomen is greatly enlarged during the gestation period and is the site of greatest change. From the questionnaire responses in Chapter 3 there are two main problems for pregnant women as a result of the enlarged abdomen; firstly the correct positioning of the seat belt around the abdomen. The seat belt can cause discomfort by cutting into the abdomen or becoming tight. Fitting the lap belt underneath the abdomen and across the hips (as per the guidelines) can be difficult, and the lap belt can tend to ride upward onto the enlarged pregnant abdomen. Pregnant women might try to prevent the lap belt from lying over the abdomen by holding the belt, which causes slack in the belt and might consequently affect their safety. Secondly the proximity of the abdomen to the steering wheel means that pregnant women are often concerned for the safety of their fetus. The measurements of abdominal depth and circumferences are used to quantify the large increase in size of the abdomen during
pregnancy. The measurement of abdominal depth is particularly important for the occupant package and position the seat in relation to the steering wheel. The abdominal point was defined as the anterior point of the abdomen at the point of maximum circumference. Since the waistline disappears in pregnancy the abdominal point was used for abdominal height and was therefore defined as the height of abdominal point from the seat surface. The abdominal height measurement was used to describe the location of the abdominal point, which is important for its interaction with the steering wheel during a vehicle collision. The height of maximum lumbar curvature was recorded because it is relevant to the position of the lumbar cushions on the seat back. From the questionnaire responses in Chapter 3 the pregnant women reported discomfort when the point of maximum curve of the lumbar cushions on the car seat back did not align well with the point of maximum lumbar curvature on the pregnant woman’s spine. This discomfort and any associated back pain could distraction that may affect pregnant women’s safety whilst driving.

Any change in hip size as a result of pregnancy is important to the design of car seats and in particular to the design of seat belts. The lap portion of the seat belt should pass across the hips during pregnancy according to guidelines (American College of Obstetrics and Gynecology, 1999; Department for Transport, 2007; 2009b; National Highway Traffic Safety Administration, 2002). Therefore any increase in hip size might affect pregnant women’s comfort with the seat belt. Change in the hip breadth measurement could affect seated comfort because the hip breadth has to be accommodated in the seat pan breadth. The hip circumference and hip breadth measurements were therefore included in the measurements dataset for the sample of pregnant women.

The trunk region, particularly the abdomen, is the greatest area of physical change in pregnancy. However it is crucial not to neglect any changes that may occur throughout the rest of the body during pregnancy. Therefore measurements of the pregnant women’s limbs were also included in this study and are illustrated in Figure 36. For the following comfort and safety reasons it is important to check these measurements for accommodation during the design process.
Pregnant women’s reach capabilities are defined by the arm dimensions. From the questionnaire responses in Chapter 3 pregnant women report difficulties with reaching the vehicle controls on the dashboard, radio, heating and air-conditioning systems, sunroof, mirrors and storage compartments. Pregnant women report that stretching and reaching actions can be uncomfortable. Pregnant women also complain of difficulty with using controls and pressing buttons on the vehicle dashboard. The operation of controls can be difficult if there are any changes in the hand dimensions during pregnancy, and gripping the steering wheel or gear stick could become more difficult for example. If pregnant women having difficulty reaching and operating controls they may become distracted or have slower response times as a result, and this might consequently affect their safety.

For the specification of the pedals, and the distance from the pedals to the seat the leg
dimensions are important. The dimensions of the legs are also involved in specifying the seat position within the vehicle and seat track length. Questionnaire responses from Chapter 3 show that a common problem for pregnant women is difficulty in reaching and operating the pedals. This problem occurs because the women try to move their seat slightly rearward in order to keep the distance between the abdomen and the steering wheel as large as possible and compensate for the protruding abdomen. Rearward movement of the seat on the seat track is limited by leg dimensions, particularly leg length, and by the pregnant women’s ability to fully depress the pedals. Similarly, some pregnant women report reclining the seat backrest in order to better allow for the enlarged abdomen. Reclining the seat backrest is limited by the arm lengths. Furthermore during pregnancy any changes in feet dimensions might result in problems with operating the pedals, and a common symptom experienced during pregnancy is swollen ankles. There are several reasons that the ankles swell in pregnancy including water retention and oedema, and this might cause discomfort for pregnant women when depressing the pedals.

5.2.1.2 Sample of pregnant women for anthropometric measurements
The gestation levels of the pregnant women recruited to this study are summarised in Table 9.

<table>
<thead>
<tr>
<th></th>
<th>First trimester (Week 0-12)</th>
<th>Second trimester (Week 13-28)</th>
<th>Third trimester (Week 29-40+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of women</td>
<td>0</td>
<td>36</td>
<td>71</td>
</tr>
<tr>
<td>Mean gestation (weeks)</td>
<td>n/a</td>
<td>21.4</td>
<td>35.4</td>
</tr>
</tbody>
</table>

Table 9. Details of the sample of pregnant women for anthropometric measurements.

107 sets of measurements were recorded. The majority of pregnant women in the sample normally occupy the driver's seat, and occasionally use the front or rear passenger seats, and in a few cases the normal occupant position is unknown.

5.2.2 In-vehicle driver posture measurements
A series of measurements were recorded from pregnant women whilst seated in a car. Women were recruited at Thatcham. Volunteers wore light clothing and removed
their shoes, and the equipment used included a FaroArm\(^1\), weight scales, a stadiometer, a digital vernier calliper, a tape measure and an anthropometer. Note that these women were only measured for their driver posture whilst seated in a car, and not measured for the anthropometric measurement set described in the previous section.

### 5.2.2.1 Driver posture measurements method

The car used for measurements was selected as one commonly used by pregnant women. It was a supermini sized hatchback, and which was three years old at the time of the study. The measurements are illustrated in Figure 37.

![Figure 37. Driver Posture Measurements.](image)

The measurements were selected for their applicability to the vehicle design process, and for understanding the changes in physical size and shape that occur during pregnancy. The measurements were used to locate the pregnant occupant within the vehicle and define distances from the occupant to the vehicle hard points in the abdominal region and chest regions. The coordinate reference frame for measurements is as follows: +X forward (i.e., direction of driving), +Y right, +Z

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\(^{1}\) The FaroArm is a three-dimensional co-ordinate measuring machine manufactured by Faro Technologies Inc.
Chapter 5

Anthropometry of Pregnant Women

5.2.2.2 Sample of pregnant women for driver posture measurements
There were 16 pregnant women measured in the car to record their driver posture, and their mean gestation was 34 weeks. All participants were from the third trimester of pregnancy. 16 non-pregnant women and 16 men were also measured for comparison.

5.3 PREGNANT WOMEN’S ANTHROPOMETRY COMPARED TO MEN’S AND NON-PREGNANT WOMEN’S ANTHROPOMETRY
The data from pregnant women in the third trimester is presented, since this is the period when the body is most altered by pregnancy. The data presented refers only to the sample of UK pregnant women that participated in the study.

The data is concerned with comparison against the non-pregnant UK females and male anthropometric data given in Adultdata (Department of Trade and Industry, 1998). The study measurements were recorded from UK pregnant women so the data comparisons against males and non-pregnant females are been concerned with the UK population, and not any other nationality. Any cases of extreme physical changes that occur during pregnancy are also examined.

Typical design practice is to accommodate the 5th percentile female up to the 95th percentile male, i.e. to accommodate 90% of the population overall. The physical changes during pregnancy could result in pregnant women also being unintentionally excluded and smaller portion of the population being accommodated. Hence the exclusion rate is calculated as the percentage of pregnant women that might be excluded by a design that accommodates the 5th percentile non-pregnant UK female size up to the 95th percentile UK male size as defined by anthropometric data currently available in the literature. The exclusion rate is investigated for each measurement. The exclusions are only considering one tail of the population distribution, i.e. the measurements are found to either increase or decrease (never both), and so the exclusion is found either for the 5th percentile or 95th percentile non-pregnant UK female data according to a decrease or increase respectively. These calculations of exclusion rates are important since they reveal the difference between the anthropometry of the sample populations. The exclusion rates show that many pregnant women could unintentionally be excluded from accommodation in a design simply because their proportions are altered by pregnancy to such an extent that they...
are no longer covered by the typical range. Calculations for statistical significance of the difference between the samples were also carried out. These were comparing pregnant women’s anthropometry against male and non-pregnant female anthropometry. If a statistically significant difference was found between the populations (p<0.05 or less) then this is indicated in the text, including the value of p. If there was no statistically significant difference then it is not given.

5.3.1 Weight and stature
Pregnant women’s weight increases during pregnancy due to growth of the fetus, placenta, umbilical cord, amniotic and other body fluids. The mean weight recorded was 80.8kg for the pregnant women in the third trimester. This is 14.1kg greater than the mean weight for non-pregnant females of 66.7kg, and 1kg greater than the mean weight for males as given in Adultdata. The exclusion rate for weight was 12% as shown in Figure 38. This means that a design that accommodates up to the 95th percentile male weight might exclude 12% of women by the third trimester of their pregnancy.

![Figure 38. A design to accommodate the 95th percentile UK male might exclude 12% of pregnant women in the third trimester for weight.](image)

Even an average woman’s pregnancy can result in extreme weight gain. For example the mean weight for non-pregnant females is 66.7kg, and the sample included a woman with self-reported (from the questionnaire response) pre-pregnant weight of
70kg, which is close to the mean for non-pregnant females. This particular woman had the greatest weight increase of 35 kg, which was the greatest increase recorded from the sample. For the sample of pregnant women the maximum weight recorded was 128.5kg, and this is greater than the 95th percentile male weight by 27.4kg. Compared to the mean stature for non-pregnant females in Adultdata the pregnant women had a mean stature that was slightly greater by 8mm.
The pregnant women’s anthropometry (weight and stature) was not statistically significantly (p<0.05) different to the anthropometry for males or for non-pregnant females.

5.3.2 Head and shoulders region
The pregnant women measured in the sample seem to have a slightly lower head position whilst seated than the non-pregnant female data as given in Adultdata. Respectively the mean sitting, eye, and back of head heights are 35mm, 25mm, and 17mm lower.
If a design accommodated the range down to the 5th percentile UK non-pregnant female only, it might exclude some of the pregnant women since the head positioning measurements of the pregnant women measured are actually lower than the values for the non-pregnant women given in Adultdata. This is a case where the measurements are getting smaller as a result of pregnancy, where in most other regions of the body the measurements are increasing. Using the 5th percentile non-pregnant UK female data in Adultdata would effectively limit the range of accommodation to for sitting height, eye height and back of head height. This might exclude third trimester pregnant women at a rate of 32%, 23%, and 16% percent respectively.
The shoulder heights show a similar pattern to the head heights. For the sample of pregnant women measured these locations (the mid-shoulder and the bony tip of the shoulder) were slightly lower during pregnancy than the UK non-pregnant female data in Adultdata. The mean mid-shoulder height was 21mm lower and the mean shoulder height was 39mm lower. Similarly to the head heights a design with accommodation limited to 5th percentile non-pregnant female data might exclude 21% and 39% of the pregnant women respectively for the mid-shoulder and shoulder height.
The whole body breadth and mean shoulder breadth measurements showed only a small difference between the measurements of non-pregnant females compared to the
sample of pregnant women measured.
The pregnant women’s anthropometry for the head and shoulders region was not statistically significantly (p<0.05) different to the anthropometry for males or for non-pregnant females.

5.3.3 Trunk region: breasts, abdomen and hips
The measurements of the trunk region including the abdomen, breasts and hips, are described in this section and these measurements are illustrated in Figure 35.

5.3.3.1 Breast measurements
Pregnancy also causes the chest depth to increase. The mean chest depth for pregnant women in the third trimester was 13mm greater than the mean for non-pregnant UK females. Figure 39 shows that a design based upon accommodating up to the 95th percentile male (from Adultdata) would exclude 39% of pregnant women according to this sample’s measurements of chest depth. The 95th percentile non-pregnant female value in Adultdata is greater and therefore only 17% of pregnant women might be excluded by a design that accommodates up to the 95\textsuperscript{th} percentile non-pregnant female. For chest depth the maximum recorded value for pregnant women was 417mm. Compared to the UK male 95th percentile in Adultdata this maximum chest depth for pregnant women is 121mm larger.

Figure 39. A design to accommodate the 95th percentile UK male might exclude 39% of pregnant women in the third trimester for chest depth.

Compared to the mean for non-pregnant UK females mean standing chest
circumference was 92mm larger for the sample of pregnant women. The only data available in Adultdata for mean chest circumference is recorded in standing posture so the mean chest circumference in seated posture for the pregnant women had to be compared against standing posture for the non-pregnant UK females. The mean chest circumference in seated posture for pregnant women was 117mm greater than the mean for non-pregnant females in standing posture. Figure 40 shows the large difference between standing and sitting chest circumferences of pregnant women. For chest circumference the exclusion rate for a design that accommodates up to the 95th percentile male is 40% for pregnant women in standing posture and 49% in seated posture. In Adultdata the 95th percentile chest circumference is smaller for males than for non-pregnant females. Even using the non-pregnant female 95th percentile data as the limit for accommodation might still exclude 26% and 36% respectively for standing and seated pregnant women. The pregnant women’s maximum chest circumference recorded in standing posture was 1388mm, which is 313mm greater than for the 95th percentile value for males in Adultdata. The same pattern is shown for the chest circumference in seated posture, but to an even greater extent. The maximum recorded chest circumference for seated pregnant women was 1430mm, which is 355mm greater than the 95th percentile value for males in Adultdata.

![Figure 40](Image)

**Figure 40.** Chest circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 40% of pregnant women for the standing posture, and 49% of seated pregnant women.

Adultdata does not include chest height data in seated posture. Therefore chest height comparisons between the pregnant women’s measurements and the non-pregnant UK females or males are not possible.
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The pregnant women’s anthropometry in the breast region was not statistically significantly (p<0.05) different to the anthropometry for males or for non-pregnant females.

5.3.3.2 Abdominal measurements

During the gestation period the abdominal depth is greatly increased. The difference between the mean abdominal depth for pregnant women in the third trimester and the mean for non-pregnant females was statistically significant (p<0.03) and was 90mm greater for the pregnant women. The difference was slightly less when compared to the male mean abdominal depth in Adultdata, but was still 79mm greater for the pregnant women measured and was similarly statistically significant (p<0.03).

If the accommodation limit was the 95th percentile male data in Adultdata the exclusion rate for abdominal depth is 65%. A design that accommodates up to the 95th percentile female data might however exclude slightly less pregnant women since the exclusion rate is 63%. Figure 41 illustrates the measurements of abdominal depth and shows that 65% of the pregnant women could be excluded.

Figure 41. A design to accommodate the 95th percentile UK male might exclude 65% of pregnant women in the third trimester for abdominal depth.

Figure 42 illustrates the differences in standing abdominal circumference between the three populations: Pregnant women in the measurement sample, non-pregnant females and males from Adultdata.
Comparing the mean abdominal circumference in standing posture for pregnant women of 1136.6mm to values from Adultdata shows that it was greater than the mean for males by 318.3mm, which was statistically significant (p<0.02). It was also greater than the mean for non-pregnant females by 296.0mm, and again the difference was statistically significant (p<0.00002). If the 95th percentile male value is used as the accommodation limit then the exclusion rate is 67%. The maximum value recorded for standing abdominal circumference was 1410mm, which is 317mm larger than the 95th percentile male value.

The pregnant women’s seated abdominal circumference for follows a similar pattern to the standing abdominal circumference. The mean sitting abdominal circumference is 1159mm and compared to the same measurement in standing posture is even larger. The difference in the measurement of abdominal circumference between standing and seated posture is shown in Figure 43. In Adultdata only standing abdominal circumference is available in the literature for comparison against the pregnant women’s seated abdominal circumference, and the differences were found to be statistically significant for both non-pregnant females (p<0.000004) and males (p<0.004). A 75% exclusion rate was found for sitting abdominal circumference of pregnant women if a design was based upon accommodating up to the 95th percentile male standing abdominal circumference. 1454mm was the maximum abdominal circumference recorded in seated posture, which is 361mm greater than the 95th percentile value for male standing abdominal circumference.
Figure 43. Abdominal circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 67% of pregnant women for the standing posture, and 75% of seated pregnant women.

The measurements of height of maximum lumbar curvature for pregnant women revealed that the mean was 18mm lower than the mean for non-pregnant female value in Adultdata. If the accommodation range were to use the 5th percentile non-pregnant female value in Adultdata this would exclude 27% of pregnant women.

The abdominal height data for pregnant women uses the point of maximum abdominal circumference because the waistline disappears during pregnancy. This means that the abdominal height measurements for pregnant women cannot be compared to waist height in non-pregnant females or males as given in Adultdata because the measurements use different locations based on different physical landmarks.

5.3.3.3 Hip measurements

For pregnant women the measurements of hip circumference follow a similar pattern to the measurements of chest and abdominal circumferences. In standing posture the mean hip circumference for pregnant women was statistically significantly (p<0.06) larger than the mean for non-pregnant females in Adultdata, and the difference was 116mm. Compared to the mean standing hip circumference males the mean for pregnant women was 107mm greater. The maximum pregnant women’s standing hip circumference recorded was 1475mm and this is 307mm greater than the male 95th percentile value in Adultdata. Up to 45% of pregnant women could be excluded by using an accommodation range up to the 95% percentile male standing hip circumference for a design. The measurements of standing hip circumference are
illustrated in Figure 44.

![Figure 44. Hip circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 45% of pregnant women for the standing posture, and 72% of seated pregnant women.](image)

In seated posture the hip circumference of pregnant women is even greater than in standing posture. The mean hip circumference for seated pregnant women is 97mm greater than for standing pregnant women as shown in Figure 44. Adultdata does not give a seated hip circumference so that comparison cannot be made, but using an accommodation range up to the 95th percentile male value for standing hip circumference might exclude up to 72% of seat pregnant women for seated hip circumference. The most extreme value of seated hip circumference recorded from the sample of pregnant women was over half a metre greater than the 95th percentile male value.

Hip breadth is greatly enlarged during pregnancy. 34% of pregnant women might be excluded for hip breadth from a vehicle that is produced to accommodate only up to the 95th percentile male, and this is illustrated in Figure 45. In Adultdata the 95th percentile non-pregnant female value is greater than the male value, so if the accommodation range used the non-pregnant female value instead of the male value it might actually only exclude 10% of the pregnant women. The maximum hip breadth for pregnant women was 518mm, which is 75mm larger than the male 95th percentile value.
5.3.4 Limbs: arms and hands, legs and feet

The limb dimensions were recorded in this study in order to assess whether any dimensional changes occurred during pregnancy. The measurements included arm, hand, leg and foot dimensions of pregnant women. The 5th percentile female to male 95th percentile data range for these limb measurements will be adequate for accommodating the anthropometric needs of the pregnant women since there was little or no difference between the measurements from pregnant women in this sample and the non-pregnant female data in Adultdata.

5.4 PREGNANT DRIVER POSTURE

The measurement of pregnant driver posture was an investigative study and has provided a set of valuable data. However the emphasis for analysis was on two aspects: the relationship between the pregnant occupant and the steering wheel (and its airbag), and defining knee splay. Knee splay is described in full in the following section of this chapter.

The focus of this section is on defining the relationship between the pregnant occupant and the steering wheel and airbag. This is because the anthropometric measurements have established that the abdomen is the area of greatest change. Also the pregnancy and driving questionnaire has shown that this is an area of concern for pregnant women, and that they may be seated extremely close to the steering wheel or even touching it.
DFT guidelines recommend that the ‘distance between the centre of the steering wheel to the breast-bone should be at least 10 in (25 cm)’ (Department for Transport, 2009b). However, the advice given is not specific to pregnant women. For the purpose of this research this guideline is used, and an equivalent measurement is made for the sample of pregnant women to record the distance between the sternum and the centre of the steering wheel. Two additional measurements were made: the abdominal point to steering wheel centre, and the abdominal point to steering wheel lower rim measurements. The measurement from abdominal point to the centre of steering wheel is selected to describe the proximity between the pregnant abdomen and the deployment of an airbag. The measurement of abdominal point to the lower rim of the steering wheel was selected to describe the proximity between the pregnant abdomen and the closest hard point of the car in a frontal impact.

There is no current guideline regarding the distance required between the pregnant abdomen and the steering wheel (centre or lower rim). However the National Highway Traffic Safety Administration in the USA (2002) advise pregnant women to sit as far back as possible from the steering wheel or dashboard. The measurements in this section are used to describe the proximity of pregnant women to the hard points of the car to provide an understanding of real world situations.

The measurements recorded from the group of pregnant women are given in the X axis only, representing the horizontal distance in the fore/aft direction. The measurements are summarised in Table 10, and normal curves are constructed from this data and are given in Figure 46.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sternum to steering wheel centre (mm)</td>
<td>371.9</td>
<td>50.1</td>
</tr>
<tr>
<td>Abdominal point to steering wheel centre (mm)</td>
<td>161.1</td>
<td>47.0</td>
</tr>
<tr>
<td>Abdominal point to steering wheel lower rim (mm)</td>
<td>83.7</td>
<td>46.6</td>
</tr>
</tbody>
</table>

Table 10. Steering wheel clearance dimensions measured from pregnant occupants seated in a car.
It is evident that the distance between the steering wheel and the sternum is much greater than for the abdomen for this sample of pregnant women. The Department for Transport guideline states that the distance between the sternum and the centre of the steering wheel should be 25cm. The pregnant women measured in this sample are seated in accordance with this guideline, since according to the normal curves only 1% of the pregnant women would be seated closer than the recommended 25cm.

The guideline measurement is between the sternum and the steering wheel centre, but it is also possible to consider the distance from the abdominal point (instead of the sternum) to the wheel centre. Using the normal curves and considering the abdominal point to the centre of the steering wheel, only 3% of the pregnant women would have a clearance of greater than 25cm. This reveals that nearly all the pregnant women were sat with their pregnant abdomen closer than 25cm to the steering wheel. It is established in the literature that pregnant women are at risk of injury due to proximity to the steering wheel and risk of direct impact with the wheel (Klinich, K.D., Schneider, L.W. et al., 1998), or possibly a deployed airbag although the level of this risk is unproven. Risk is increased in pregnancy due to decreased distance from the steering wheel (Aschkenazi, S., Kovanda, J. et al., 1998). Therefore it is important to consider the proximity between the abdomen and the steering wheel lower rim. Using the normal curves for the abdominal point to the steering wheel rim, all the pregnant women had a clearance less than 25cm. The pregnant women are seated with a small clearance between the abdominal point and the steering wheel, only 8.4cm on average.
and some are even seated with the abdomen in contact with the wheel. Overall the driver posture study shows that pregnant women are seated close to the steering wheel, which might be putting them at increased risk of injury, but they have to be able to reach the pedals and other controls.

It is possible to compare the measurements against the study by Klinich et al. (1999a) that found the mean abdomen to wheel clearance to be 58.5mm in the last month of pregnancy. Considering only the 8 pregnant women in the sample that are in the last month of pregnancy, the mean abdominal point to steering wheel lower rim distance is 84mm, which is similar to the 59mm reported by Klinich et al.

Considering the abdominal point to steering wheel rim distance as a straight line in three dimensions, instead of just the X axis, the mean distance measured from this sample of pregnant women was 97mm. For the group of women in the sample that were in the last month of pregnancy, the mean distance was 84.7mm. This is a little greater than the distance of 59mm reported by Klinich et al.

Figure 47 and Figure 48 show the relationship between stature and abdomen to wheel clearance for the sample of pregnant women’s measurements presented in this thesis. These figures show the measurements recorded, the linear regression line of best fit, and upper and lower bounds of +/- 1 standard deviation. Figure 47 uses the abdominal point to lower rim of steering wheel as a straight line distance and has a correlation of 0.807 with stature.

![Figure 47. Abdomen to lower rim of steering wheel vs. stature for sample of 15 pregnant women.](image)
Figure 48 uses the abdominal point to lower rim of steering wheel, but only the X direction (fore/aft). This has a correlation of 0.841 with stature for this sample.

This correlation between stature and clearance between the lower rim of the steering wheel and the abdominal point is also shown by Motozawa et al. (2008) and Klinich et al. (1999a).

The data presented by Motozawa et al. (2008) presents the measurement between the pregnant abdomen and the lowest part of the steering wheel for their sample of 20 Japanese pregnant women. The mean abdomen to lower steering wheel measurement was 146mm for their sample of pregnant women with mean gestation of 31 weeks, which is greater than the 59mm reported by Klinich et al. for their subjects in the last month of pregnancy, or the 84mm found in this thesis study for subjects with mean gestation of 34 weeks. The difference in the measurements is explained by the different gestation levels of the sample populations. For example the Japanese study has mean gestation of 31 weeks, which is earlier in the pregnancy than the other samples from the US and the UK. Therefore since the Japanese measurements are taken at an earlier stage of pregnancy the abdomen has not had the same amount of time to enlarge a grow closer to the steering wheel, and consequently is at a greater distance from the steering wheel despite the generally smaller stature of the Japanese population. In the same way, the measurements taken from women in the US study...
were from the last month of pregnancy, whereas the UK sample of pregnant women were measured at a slightly earlier stage with mean gestation of 34 weeks. Therefore the US women are seated with a smaller distance between the abdomen and wheel than the UK women, based on the later stage of pregnancy of the US women. Motozawa et al. (2008) also argues that the difference between the Japanese horizontal clearance between abdomen and steering wheel, compared to the US clearances, can be explained by greater body weights and greater abdominal circumferences in the American sample of pregnant women. This is based on the assumption that measurements in the first trimester as the same as pre-pregnancy measurements inferring that the US sample of women had greater weight and abdominal circumference prior to pregnancy, and this trend is then reflected in the pregnancy measurements revealing that the US women had smaller clearances than the Japanese women.

5.5 KNEE SPLAY DURING PREGNANCY

5.5.1 Knee splay
In the standard anthropometric procedures the seated posture requires the seat height to be adjusted for the women could sit with their feet flat on the floor with knees together and bent at 90°, and with the upper leg parallel to the floor (Pheasant, S., 1986). The standard anthropometric measurements include the knee breadth, which is normally taken with knees together as described by Adultdata. However the author noted that the pregnant volunteers tended to sit with their knees apart during normal sitting in preferred posture, and this was noted during the interview part of the sessions. Therefore a measurement termed ‘Knee splay’ was introduced and defined as the distance between the outer borders of the knees whilst seated in the preferred posture. As with the standard anthropometric measurement the feet remained flat on the floor with knees bent at 90° and the upper leg parallel to the floor, but for knee splay the preferred posture for angle between thighs and distance between the knees was allowed. The size and shape changes associated with pregnancy may influence women’s comfort and safety during car travel. This also means that the knee splay of pregnant women is of importance for investigation. This section presents the findings based on measurements of knee splay, and its design implications. The literature does not provide any data regarding any other measurements attempting
to describe seated leg posture that pregnant women adopt by preference, and knee splay has not been described in previous research. Detailed knee splay findings from the anthropometric measurements are presented for the sample of pregnant women, as well as for men and non-pregnant women in order to make the comparison between the populations. Knee splay measurements taken whilst seated in a car in driving posture are given.

5.5.2 Measurements of knee splay

Measurements of knee splay were recorded using standard anthropometry methods, as well as measurements of the pregnant women whilst seated in a car as the driver. Both methods are now described.

5.5.2.1 Anthropometric measurements of knee splay

The measurements used the standard procedures and postures as in Adultdata (Department of Trade and Industry, 1998) and Pheasant (Pheasant, S., 1986; 1990). Adaptations to the measurements were made to suit pregnancy, i.e. the measurement of knee splay was introduced to record pregnant women’s preference of sitting with knees splayed apart. The measurements taken to describe anthropometric posture, knee breadth and knee splay are shown below in Figure 49 (A), (B) and (C) respectively.

![Figure 49. Standard sitting anthropometric posture (A), knee to knee breadth (B), and knee splay (C)](image)
5.5.2.2 Driver posture measurements of knee splay

Measurements of men, non-pregnant and pregnant women were taken at Thatcham (UK), in order to investigate knee splay in driving postures. The statures of the sample of men, non-pregnant and pregnant women were representative. The sample sizes were 16 men, 16 non-pregnant women, and 16 pregnant women. Since the third trimester is the period when the body is most altered by pregnancy the sample of pregnant women included only the ones in their third trimester. The vehicle used was a small car typically driven by women during pregnancy based on findings from the questionnaire.

The relaxed knee splay measurements were recorded first with participants seated on a comfortable office chair, using an anthropometer. Participants were then asked to sit in the car and make themselves comfortable for driving, and to fasten the seat belt. A Co-ordinate Measuring Machine (Faro Arm) was used to record landmark points describing knee splay in driving posture.

5.5.3 Anthropometric versus. driver posture for knee splay

Throughout this section the data refers only to the sample of pregnant females, males, and non-pregnant females that were participants in this study. Comparison is made against Adultdata (Department of Trade and Industry, 1998) as the literature source unless stated otherwise. The measurement recorded from the sample of pregnant women, non-pregnant women and men are given in Table 11 below.

<table>
<thead>
<tr>
<th></th>
<th>Pregnant women</th>
<th>Non-pregnant women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of volunteers</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Mean height (SD)</td>
<td>1644 (70)</td>
<td>1612 (142)</td>
<td>1744 (58)</td>
</tr>
<tr>
<td>Knee breadth</td>
<td>209</td>
<td>201 (^2)</td>
<td>203 (^2)</td>
</tr>
<tr>
<td>Knee splay: Relaxed</td>
<td>353</td>
<td>242</td>
<td>463</td>
</tr>
<tr>
<td>Driving</td>
<td>366</td>
<td>309</td>
<td>470</td>
</tr>
</tbody>
</table>

Table 11. Summary of sample details and measurements for knee splay.

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The measurements of mean knee breadth show that pregnant women’s knee breadth is not significantly different to the knee breadth for non-pregnant women given in Adultdata (Department of Trade and Industry, 1998). When asked to sit with their knees together the pregnant women’s measurements are not significantly different from non-pregnant women’s or men’s measurements. In a relaxed posture however the men and pregnant women preference choose a significantly different position and sit with their knees widely spaced apart by preference. By preference pregnant women choose to adopt a greater knee splay instead of simply sitting with their knees together in the traditional posture. The range of pregnant women’s knee splay measurements is from 229 to 500mm. Non-pregnant women’s knee splay is significantly different in relaxed and driving positions, whereas pregnant women’s and men’s driver and relaxed knee splays are very close.

5.6 SUMMARY OF PREGNANT WOMEN’S ANTHROPOMETRY AND ASSOCIATED AUTOMOTIVE DESIGN IMPLICATIONS

The study has provided an insight into the anthropometric needs of pregnant women as well as an analysis of their needs for use during the vehicle design process. A major advantage of this study is that the anthropometric measurements were selected specifically for use by the automotive industry, whereas other studies have been more focussed on measurements for garment design. The full data is available in the form of a website (see Chapter 6) in order to help accommodating pregnant women’s anthropometric needs, during all stages of pregnancy and in all postures. This will hopefully help to improve both comfort and safety for the pregnant occupant during car travel.

Pregnancy is a natural process that women experience involving inevitable size and shape changes. Overall, it is desirable to include the pregnant population in designs in order to maintain the same safety and comfort standards for pregnant women as the rest of the population.

5.6.1 Key regions of change: chest, abdomen and hips

During the gestation period the key regions of physical change are the chest, abdominal, and hip regions. Assuming that the anthropometry of a large male (the 95th percentile male) will accommodate the enlargement associated with pregnancy is inadequate. The measurements from the sample of pregnant women have revealed
that the size of the chest, abdomen and hips of a pregnant woman can be so enlarged during gestation that the equivalent 95th percentile male measurements are greatly exceeded. Common practice in design is to accommodate up to the 95th percentile male anthropology, and there has also been a lack of data for pregnant women that has meant that their needs are not considered. However this study has shown that large portions of the pregnant women population in their third trimester could be excluded. The exclusion rates for these key regions (chest, abdomen and hips) are summarised below in Figure 50. These high exclusion rates for the trunk region measurements highlight that it is important to consider the dimensions of pregnant women carefully in the vehicle design process. For example to lower the risk of impact with the steering wheel during a collision whilst ensuring the pregnant women can easily reach and operate the pedals it is important to accommodate the abdominal depth of pregnant women combined with their lower limb dimensions in order to provide sufficient clearance between the abdomen and steering wheel.

![Figure 50. Pregnant women might be excluded by a design that accommodates up to the 95th percentile UK male anthropology. Possible exclusion percentages for third trimester pregnant women by body region.](image)

For certain regions non-pregnant females have larger dimensions than males in Adult data, including the chest circumferences and depth, abdominal depth and hip breadth. This is an important point because in these cases considering the non-pregnant female anthropology rather than male anthropometric data from the
literature will help to meet the needs of a larger range of the pregnant population. However in the trunk region the non-pregnant female and male data in the literature will always be exceeded by the measurements for pregnant women. The author therefore believes that incorporating the anthropometry of pregnant women into designs will be most effective for meeting pregnant women’s safety and comfort needs.

The dimensional increases can be very extreme during pregnancy, particularly around the chest, hips and abdomen. The maximum or extreme cases that occur during pregnancy were also presented in order to demonstrate the extent of the size and shape changes, and the author suggests that these extreme cases should also be considered. The increased weight during pregnancy might affect collision dynamics of a pregnant occupant particularly if the centre of gravity is altered and for the enlarged abdomen. In terms of vehicle dynamics in a collision it could be critical to accommodate the altered anthropometry of pregnant women.

A problem for pregnant women is positioning the seat belt correctly and accommodating the pregnant women’s anthropometry in the trunk region might help women to use their seat belt in the correct position according to guidelines, which can help to ensure it will operate as intended to provide protection during a vehicle collision. Particular problems are fitting the seat belt between and around the breasts, and underneath the abdomen and across the hips, so accommodating the trunk region anthropometry is of key importance.

5.6.2 Standing versus sitting: the spread effect

Another key finding was the difference between standing and seated sizes, which is shown where measurements were recorded in both postures e.g. for the circumferences. In particular this means that there are greater exclusion rates for the seated posture than standing, especially if only standing data is available in the literature. The greater sizes, particularly for circumferences, in seated posture are due to the ‘spread’ effect. The ‘spread effect’ of being seated means that the abdominal region is larger when seated than when standing. The reason for the increased sizes of pregnant woman is explained by examining the interactions of the body parts in seated posture. In standing posture the pregnant abdomen has a large space around it and it can take its natural size and shape under the influence of gravity. However when seated the space available below the abdomen is limited by the upper thighs.
This is particularly problematic in car seats where the seat slopes upwards under the knees so it is higher under the knees than under the bottom, because the angle between the legs and trunk is even further decreased. The thighs therefore apply an upward pressure on the abdomen, which pushes and squashes it upward and outwards. In turn the abdomen can also push the breasts upwards and outwards. Hence in seated posture the abdomen and breast sizes of pregnant woman are larger than in standing posture. The spreading occurs in everyone when in seated posture, but seems to be substantial in pregnant women. Vehicle designs might better accommodate the anthropometric needs of pregnant women if based upon their anthropometric measurements recorded from the seated posture, instead of from the standing posture.

5.6.3 Proximity to the steering wheel
The measurements of driver posture clearly reveal that some pregnant women are seated with their abdomen very close to the steering wheel. Impact with the steering wheel could be a source of injury risk for the mother and the fetus. The guidelines prescribe a distance of 25cm between the sternum and the centre of the steering wheel. As yet there are no equivalent guidelines for the abdomen in relation to the steering wheel and in particular there is no guideline for the distance of the pregnant abdomen away from the steering wheel centre or lower rim. Automotive engineers are recommended to consider these measurements of driver posture, along with the anthropometric measurements, and ensure that an adequate clearance can be maintained between the abdomen and wheel even during the course of pregnancy.

The measurements presented in this thesis are in agreement with Klinich et al. (1999a) and Motozawa et al. (2008) that the abdomen of the pregnant women is in close proximity to the lower rim of the steering wheel. The distance between the abdomen and the lower rim of the steering wheel was a little greater in this study than in Klinich et al; however the difference could be due to their use of a seating buck instead of a real vehicle. The distance between the abdomen and the lower steering wheel is small in all cases, from the data measured in this thesis and that presented by Klinich et al. and Motozawa et al, which confirms that steering wheel clearance is a problem during pregnancy.

Both this study and the studies by Klinich et al. and Motozawa et al. have shown that proximity to the steering wheel is correlated to stature, which is not a surprising result. However the data from Motozawa et al. for Japanese women shows a greater
distance between the abdomen and the steering wheel lower rim, than this study for UK women or for the US pregnant women in Klinich et al. The mean distance from the lower rim of the steering wheel to the abdominal point was 146mm for the Japanese sample of pregnant women with mean gestation of 31 weeks. For the UK sample in this thesis study the mean distance was 84mm for the pregnant women with mean gestation of 34 weeks. Finally the sample of US women measured in the last month of their pregnancy had a mean distance of 56mm. Therefore when comparing these different studies the gestation level of the pregnant women must be accounted for. Motozawa et al. also discuss the difference between the US and Japanese samples of pregnant women, and highlight that body weight could be a factor, as well as the national differences in anthropometry and the different configurations of the vehicle buck used by Klinich et al. and the typical vehicle configuration in Asian countries. In any case it is clear that during pregnancy the abdominal enlargement means that the abdomen and fetus are close to the steering wheel, and that this enlargement should be considered so that the distance between the wheel and abdomen can be safely maintained during pregnancy. The study presented in this thesis is an important contribution to consider the UK seated anthropometry of pregnant occupants with regard to proximity to the steering wheel.

5.6.4 Knee splay

There is strong evidence from the knee splay measurements that by preference pregnant women choose a different posture and sit with their knees widely spaced, instead of with knees together. It is clear that pregnancy can result in changes in other parts of the body and does not just affect the abdomen. These changes can interact causing an alteration in posture such as knee splay. If the abdominal enlargement is considered in isolation then this significant change in pregnant women’s posture is neglected, which could impact upon the safety and comfort of pregnant women. This trend for wide knee splay in pregnancy could have several causes. Contributing factors could include the abdominal enlargement, gain in weight and increase in soft tissue, and the spreading of the pelvis in preparation for birth. For example, in seated posture the horizontal upper legs apply an upward pressure and restrict the space available for the enlarged pregnant abdomen, which may be uncomfortable for pregnant women. Secondly, during gestation the pelvis widens under the influence of the hormone relaxin to allow the fetus to pass through the birth canal. The spreading
of the pelvis possibly combined with engagement of the baby’s head in the pelvis could cause the pregnant women to sit with their knees more widely separated. Finally increases in soft tissue mean that the thighs could increase in size. In seated posture the seat applies an upward pressure on the thighs and spreads the soft tissue horizontally; the spread effect. This means the thighs could increase in size horizontally and could prevent the pregnant women from putting their upper legs together, and consequently causing the increase in knee splay.

Pregnant women often reported discomfort sitting in bucket seats in the questionnaire responses (Chapter 3). According to measurements take from a sample of seats the mean non-pregnant women knee splay is less than the mean pan breadth of 334 mm (between the bolsters of the seat pan). Pregnant women’s knee splay measurements suggest that their thighs are positioned over the protrusion of the bolsters of the seat pan, which could partly explain the discomfort. However this all depends on the stature of the pregnant women and the size of the seats.

Knee splay should be considered during automotive design with regard to the design of car seats. The author suggests that the seat pan could be wider at the front to allow women to sit with their knees more widely spaced and be more comfortable, whilst still providing adequate support under the knees. The car seat cushion bolsters are a particular problem for some pregnant women. Some car seats have the bolsters raised steeply at the side in ‘bucket’ style. Since pregnant women show this trend to sit with their knees widely spaced the bucket style cushions may interfere with their posture and cause the reported discomfort. Pregnant women may prefer to avoid this type of bolster. Another alternative could be to provide cushion bolsters that could be adjusted up and down at the sides (within safe limits) according to preference.

Pregnant women still have to be able to reach and operate the pedals for driving. Due to the abdominal enlargement pregnant women often adjust their seat to allow the maximum possible space for the abdomen, which can mean setting the seat as rearward as possible in order to decrease proximity to the steering wheel. If fore/aft adjustable pedals and steering wheels are incorporated into car designs, pregnant women might be able to sit further away from the steering wheel and still have their knees in a comfortably splayed position as is their preference. This could consequently benefit women’s safety by reducing the risk of impact with the steering wheel on the pregnant abdomen.
5.6.5 Other anthropometric issues

The hip, shoulder and whole body breadths, and the height of maximum lumbar curvature, are particularly important for providing comfortable car travel for pregnant women.

The head and shoulder height measurements indicates that in sitting upright posture the women have their head and shoulders positioned slightly lower during pregnancy. This altered sitting posture could be caused by a more lordotic spinal shape associated with pregnancy that results in the overall head and shoulder heights being lower. This is also confirmed by the lower height of maximum lumbar curvature measured for the sample of pregnant women, which could indicate a more lordotic spinal curve in sitting posture, in agreement with the slightly lower head and shoulder heights. It is important to consider the altered head and shoulder heights to accommodate pregnant women’s comfort and safety needs. With a slightly lower head position pregnant women may experience a restricted field of vision, particularly for seeing out of the front windscreen over the dashboard and steering wheel. Pregnant women might also experience difficulty when turning around to see out the rear of the car during reversing manoeuvres. The range of anthropometry for pregnant women should be accommodated in the design of relevant car features such as seat height adjustments. The height position of the pregnant occupant’s shoulder is important for positioning of the shoulder portion of the seat belt across the shoulder and clavicle. The correct positioning of the seat belt during pregnancy could be critical to ensure the safety of the pregnant woman and the fetus.
CHAPTER 6: PREGNANT WOMEN’S ANTHROPOMETRY WEBSITE

This chapter describes the development of a website that presents the anthropometric data gathered from measurements of pregnant women. This anthropometric data was specifically selected for use with the automotive industry to help accommodate the needs of pregnant women and to improve both comfort and safety. The data is presented as a website and the features of the website and its interface that make it suited for use by the automotive engineers are also described. Some of this work has also been published in the papers in Appendix F (Acar, B.S. and Weekes, A.M., 2004a; Acar, B.S. and Weekes, A.M., 2004b).

6.1 INTRODUCTION TO THE PREGNANT WOMEN’S ANTHROPOMETRY WEBSITE

The main aim of the research is to present the anthropometric dataset in a form that could be easily used by the automotive industry. Since the automotive industry is global, the data was presented in the form of a website. May et al. (1998) have also given a guideline that advice to the automotive industry should have easy access, be widely available throughout a development team, and should it should be web-based. The website format was also selected so that all parts of the automotive industry could access the data regardless of particular software systems used for their design process internally.

The aim of the site is providing this anthropometric data to automotive designers for the assessment of designs for accommodation of pregnant occupants. By making this data available to the automotive engineers it will consequently help to incorporate the altered anthropometric needs of pregnant women into vehicle designs, for example to ensure that seat belts can be correctly and comfortably worn. This is the first anthropometry website to be produced and is especially unique in providing anthropometric measurements of pregnant women specifically selected for use in vehicle design. The site is principally aimed at automotive designers and engineers, but the anthropometric data for pregnant women may also be useful to other areas of design.

The design of the site is now discussed in the following sections, including discussion of how the site was made suitable for use by the automotive engineers. The general
HCI and usability principles and guidelines were followed, and the incorporation of these features will be discussed. In addition some features were built into the site specifically for the aid of the automotive engineers, and these will also be described.

6.2 HOME PAGE

The site begins with a home page divided into three sections, and this is shown in Figure 51. The heading bar runs along the top, has a logo on the left hand side and the heading of the page is clearly given in the middle of this heading bar (for the home page this is also the heading of the entire site). The provision of a site logo in a consistent position is in accordance with the guidelines (Usability.gov, 2009).

Figure 51. Screenshot of Pregnant Women’s Anthropometry website: Homepage.

On the left hand side there is a panel that is marked by a darker grey colour than the title bar and this is the space for the navigation menu. The menu has links that operate with a rollover function that changes the background colour around the link to white in order to highlight it.

The rest of the screen forms the main panel of information, including introductory text explaining the website and its purpose. The text explains the key pages of the website, and includes embedded links that duplicate the links given in the menu in order to help the user understand their way around the site very quickly.

Schenkman and Jönsson (2000) have stated that from their survey of users’ preference of web pages the ‘beauty’ of the webpage was the most important factor compared to mostly illustrations versus mostly text, and overview and structure. The study found that beauty was the most important factor for first impressions of a site and suggested
this is linked to increased use of images, but warned that use of images should be balanced against download time and speed (Schenkman, B.N. and Jónsson, F.U., 2000). The image on the homepage is of a pregnant woman seated in a car and was selected as a meaningful image about the content of the website (Nielsen, J.). There is also only one image on the page so that it is not cluttered or slow to download (Johnson, J., 2000; Nielsen, J.; Schenkman, B.N. and Jónsson, F.U., 2000).

Nielsen states that it is important for homepages to include a section that is about the site (Nielsen, J.). The homepage of the site not only clearly describes the content of the website, but also has specific text with links that will take the user to the ‘About the research’ page that gives more detail about the research.

Each section of the homepage (title bar, left-hand navigation menu, and main information panel) is marked in a different colour, as Preece et al. suggest for marking different sections (1994). The colour contrast of the black text on the blue background should also help the site be legible for the users, and the number of colours on the site are limited in order to avoid confusion and cluttering, and both of these design features are as per the principles from Preece (1994).

6.3 SITE STRUCTURE

Every page in the Pregnant Women’s Anthropometry website has a distinct and descriptive page title as per the guidelines (Usability.gov, 2009). This is so that users can easily distinguish between pages, and so that the ‘Favourites’ and ‘History’ features of web browsers can identify the pages separately.

The navigation menu is short since the website as a whole is small. The site has a total of 7 pages in total, and is never more than 3 pages deep. This small structure is in keeping with the theory from Miller (1956) that human processing is limited to 7 plus or minus 2 chunks, and the guideline that the mental processing by the user should be kept to a minimum (Johnson, J., 2000). Furthermore Catledge and Pitkow, and Perzel and Kane have both reported that essential information must be accessible within two or three jumps of the initial homepage, and again the website structure conforms to this guideline (Catledge, L.D. and Pitkow, J.E., 1995; Perzel, K. and Kane, D., 1999).

The site includes a page ‘About the research’ that describes the project aims and objectives so automotive designers can understand the research project and background.

A Contact page is provided so automotive designers can request modifications to the
site if necessary. The users are also invited to provide feedback and comments about
the Pregnant Women’s Anthropometry website, to ensure it meets their needs. The
inclusion of the Contact page helps to convey the ‘real world’ aspects of the research
work because it includes physical addresses, contact details, and photographs.
Similarly the ‘About the research’ also provides real world context for the research, as
well as markers of expertise. By providing these real world aspects and the markers of
expertise the website will have increased credibility with users according to the design
rules from Fogg et al. (2001).

The site structure is very consistent since every page has the same layout as the
homepage, with the title bar at the top, and logo on the left hand side of that title bar;
the navigation menu on the left; and the main panel forming the remainder (majority)
of the screen. The menu choices for navigation on the left hand panel are the same on
every screen, but the user cannot select the page that they are currently on since this
would be a redundant link. This consistency in the page layout and site structure
conforms with the HCI principles (Johnson, J., 2000; Preece, J., Rogers, Y. et al.,
1994; Smith, S. and Mosier, J., 1986) and will help the automotive engineers to find
their way around the site easily. Furthermore, Brinck et al. (2002) advise that a link to
the contact information should be provided on every web page, and the consistent
navigation menu and site structure provide this HCI feature. This consistency in
location of key features of the site will also help the users to learn their location and
consequently improve task performance as suggested by Ehret (2002).

6.4 ENGINEERING TERMINOLOGY

The general language of the site is English and sentences are kept concise. The text is
in accordance with the guidelines in terms of language and font (Plain English
Campaign, 2001). May et al. (1998) have stated that advice to the automotive industry
should use industry terminology, and also be as quantitative as possible, both of
which features are incorporated into the site.

The website uses engineering terminology so that the automotive designers and
engineers feel familiar with the terms. For example, the obstetrics terms are defined
so the engineers can understand them. On the search page the stage of pregnancy is
given in trimesters, but the week of pregnancy is displayed alongside in parentheses
for clarification.

The anthropometric measurements were selected from the standard measurements that
the automotive designers are also familiar with since they are depicted in the literature (Department of Trade and Industry, 1998; Pheasant, S., 1986). For a few of the measurements they were either a new measurement, or a measurement adapted from the standard measurement, in order to better define the pregnant form. In order to ensure that automotive designers and engineers can be aware of the exact detail of the measurement data recorded from the pregnant women a full description of every measurement (including the new and adapted ones) is given. The terminology used is consistent throughout the site, including consistent terms for the measurements in order to reduce the risk of confusion. Overall this use of engineering terminology and familiar anthropometric measurements is in accordance with the HCI principles that the language should be in keeping with that of the users (Brown, C.M., 1998; Johnson, J., 2000; Preece, J., Rogers, Y. et al., 1994; Schneiderman, B., 1987).

### 6.5 SEARCH PAGE

The anthropometric data of the pregnant women is stored in a MySQL database and this database is queried using PHP code. Using the PHP code directly would not be user-friendly since it is unlikely that most engineers and designers would be familiar enough with the code to use it, and could not know the structure of the database. Therefore an interface page is provided to enable the users to easily use the PHP code. This interface page is an HTML webpage and this allows the engineers to interface with the PHP code and control exactly which data is retrieved from the database according to their need.

This interface page is the ‘Search page’ as shown in (Figure 52). The search page has simple radio buttons, checkboxes, and lists to aid the users’ choices. The search process is divided into three steps, each of which is clearly labelled with a heading and instruction of how to proceed. The three steps of the search are:

- Choosing the stage of pregnancy.
- Choosing the statistics about the measurements.
- Choosing the anthropometric measurements.
The first step for the automotive designer in selecting the set of anthropometric data to be displayed is to choose the stage of pregnancy. The user can choose the stage of pregnancy by selecting a radio button for the trimester(s) of interest, and these radio buttons work as a ‘one from n’ choice as recommended by Johnson (2000). As an aid to understanding images of a pregnant woman with a small bump for Trimester 2, and a much larger bump for Trimester 3 are used to visually represent the stages of pregnancy. These images act like icons for the user, and the representative nature of the images will help the ‘guessability’ for first time users (McDougall, S.J.P., Curry, M.B. et al., 1998), then for experienced users their consistency will help the users to learn the location (Ehret, B.D., 2002). The automotive designers are given the choice (Figure 53) to display data for women measured in the:

- Second trimester,
- Third trimester,
- Or both second and third trimesters together.
Anthropometric data for pregnant women in the first trimester is not provided on the site because there is little physical change during the first three months of pregnancy so data for non-pregnant females that is already available in the literature (Department of Trade and Industry, 1998) is adequate.

This choice of different stages of pregnancy is given in order to encourage automotive designers to consider the entire gestation period. Since the abdominal enlargement is greatest during the third trimester this is the period of greatest risk of injury; however the second trimester is also a time of great change. The second trimester also has particular problems associated with it including the problem of the lap belt riding up onto the abdomen, which is greatest in the second trimester. Furthermore if the data for the pregnant women were given only as one group (with women from both second and third trimesters) then this would have an averaging effect overall and the greater size of pregnant women in the third trimester might still not be accommodated. This makes it important to give the data for the pregnant women in separate groups, especially to have measurements for women in the third trimester separately.

Automotive designers should be encouraged to accommodate women’s changing physical needs throughout pregnancy since they will have the data available for both periods separately.

The second step the user makes in choosing the dataset to display is choosing which statistics to display about the measurements of pregnant women. Users can either choose to display all the statistics, or make their own personalised selection of the statistics by ticking the checkboxes in the list. The choice of statistics is shown in Figure 54 and includes the:

- Minimum, maximum and range,
- Sample size,
- Mean and standard deviation,
- 5th, 50th, and 95th percentiles.

![Figure 54. Search page: Choosing the statistics.](image-url)
These selections of statistics have also been aimed at the automotive industry. In typical design practice the 5th, 50th, and 95th percentiles are the statistics used for accommodating 90% of the population, and therefore these calculations of percentiles are also given for the pregnant women’s dataset. To encourage the automotive engineers to accommodate an even larger portion of the pregnant population the minimum and maximum data are given to provide information about extreme cases occurring in pregnancy, and this could also benefit obese people. The sample size data provides understanding of how many women’s measurements are included in the sample, which was 100 at the time of original development, but has now extended to include the full 107 datasets.

In accordance with the design rules from Johnson (2000) the radio buttons work as a ‘one from n’ choice, i.e. that only one button can be selected when choosing the statistics. If the ‘choose your own group’ option is selected, then the user can select the group(s) of statistics by ticking the checkboxes, which again work properly as a multiple selection in accordance with Johnson (2000).

The third and final step for automotive designers when choosing the dataset to display is to choose which anthropometric measurements to display. The user may choose the measurements by using one of three methods (Figure 55), including:

- Choose the entire list of 48 measurements,
- Make a personalised selection of measurements from the list,
- Choose by the vehicle part they are designing.

The user can select to display all the different measurements of pregnant women (for the stage of pregnancy and with the statistics as already selected). However the user can also select to display a set of measurements that they have selected specifically to suit their need. To make their own personalised selection of measurements the user simply clicks on the measurements in the list, as shown in Figure 55 at the bottom. The engineers are helped in selecting the measurements from the list since the measurements are listed in a logical order, working down the body from the head to the feet. Furthermore the measurements from a region of the body are all grouped together. This ordering and grouping of the measurements will help the automotive engineers in making selections, as per Schneiderman’s design rule (Schneiderman, B., 1987). Figure 55 shows the three methods by which the automotive designers and
engineers can select their choice of measurements to display from the pregnant women’s data.

Entire list of 48 measurements:

Vehicle part:

Personalised selection of measurements from the list:

Figure 55. Three methods to choose measurements: entire list (top), by vehicle part (middle), or by personalised selection (bottom).

Underneath the list of measurements is a link to a page providing the full details of every measurement so that automotive engineer can be sure they have selected the measurement that they want. This page with the full measurements list opens as a separate browser window to enable easy referencing between measurement details and the search page and this use of another browser window to allow referencing between the two is in accordance with HCI guidelines (Perzel, K. and Kane, D., 1999). This allows the automotive designers to know the exact details of the measurements so they can make a fully informed choice.
A screenshot of the Measurements List page is shown in Figure 56 below, and this page includes details about the measurement as follows:

- A diagram providing a visual representation as an aid to understanding,
- The measurement name,
- The body landmarks between which the measurement is recorded,
- The posture (either standing or seated),
- The equipment used.

Figure 56. Screenshot of the Anthropometric Measurements List page displaying details of the measurements recorded.

To support the engineering design process the measurement descriptions include a diagram of the measurement recorded, in order to illustrate it visually. The literature revealed the importance of visual thinking for engineers, and hence this feature is built into the design of the website in order to aid the engineers (Ferguson, E.S., 1992; James-Gordon, Y. and Bal, J., 2001). Another feature of the Measurements List page is the ‘jump to’ box where the user can select the region of the body according to the measurement they are looking for. When the body region is selected, the page will automatically scroll to the correct point for the measurements associated with that
body region, and hence save the user a lot of time and effort in scrolling and searching for the items. This box also has an associated ‘back to top’ link that will automatically return the user to the top of the page. This ‘jump to’ box feature is provided at each new section of measurements associated with a new body region. This ‘jump to’ box is provided in accordance with Schneiderman’s menu selection design rules, that suggest short-cuts are beneficial to the user (Schneiderman, B., 1987), and the ‘jump to’ box is shown in Figure 57.

![Figure 57. ‘Jump to’ box for selecting body region from Measurements List page with associated ‘back to top’ link.](image)

When selecting the measurements to display the automotive designers also have the option to choose measurements to display according to the part of the vehicle. Only the measurements of any body part making contact with that particular vehicle part are presented. Any measurements that are not relevant to the selected vehicle part are excluded from the display which give the engineer are more concise set of data. For example, if they are designing the seat belt specification for the car, then they could select ‘seat belt’ and this would display on those measurements relevant to the design of the seat belt. For the seat belt option the measurements of the abdomen, hips, breasts, and shoulders are displayed, and as an indication of overall size the weight and stature of pregnant women are also given. Any dimensions that are useful for defining locations of vehicle parts in relation to the occupant are also given. A separate page defining which of the anthropometric measurements are associated with which of the different vehicle parts is given as a reference page for the automotive engineers and this is shown in Figure 58. A link to this ‘Vehicle parts’ reference page is given underneath the vehicle parts list and the page opens a new browser window so the user can easily get access to the page, and can also make references against it whilst making choices on the search page. The ability to choose the measurements according the vehicle part is advantageous to the designers and engineers, and it saves time.
Figure 58. Screenshot of the Vehicle Parts page displaying which measurements are associated with different parts of the vehicle.

For both the vehicle parts list and the measurements list the user makes the selections from a list box, and there are different methods of select these list items. The user can select just one individual list item (either a measurement or a vehicle part). Alternatively by holding the control key whilst clicking on the items they can make multiple selections. The user can also select a group of consecutive items by clicking the first item in the group then holding the shift key and clicking the item at the end of the group. The ability to make multiple selections in these lists is shown in Figure 59. This feature of multiple selections will help automotive designers to make their own personalised selections to suit their particular aspect of vehicle design.

Figure 59. Making multiple selections: multiple selections using control key (left), and grouped selections using shift key (right).

To ensure the user completes all the required sections of the search page in order to
get the anthropometric data to display, the website has an error checking facility, as shown in Figure 60. An error message will be displayed if the user leaves any, or all, of the sections (stage of pregnancy, statistics, or measurements) blank. The error message informs the user of the incomplete section, and also gives an instruction on how to correct the error so the user knows exactly how to make the correction and successfully display the anthropometric data. This is in accordance with the HCI design principles (Brown, C.M., 1998; Johnson, J., 2000). Furthermore by using the ‘back’ link provided the user will not have to go back and enter the selections again from the beginning since their previous selections are saved, which is also in agreement with the design guidelines of HCI (Brown, C.M., 1998; Johnson, J., 2000).

![Image](image.png)

**Figure 60. Example of error message and instructions for how to go back to search page and make selections.**

There is another feature of the website that is engineered for errors, as per the HCI design principles (Johnson, J., 2000). When the user clicks a statistics checkbox or a measurement item from the list, then the associated radio button for that choice is automatically selected. For example if the automotive designer wishes to select the sample size check box they do not have to select the ‘choose your own group(s)’ radio button because it will be automatically selected. In this way the error of selecting a checkbox or measurement list item without selecting the radio button is prevented, and consequently the error is prevented. This is an error prevention feature, rather than error checking, and this also saves the user time since they do not necessarily have to click the radio button.

### 6.6 DATA PAGE

The automotive engineer has to complete the three steps of the search by choosing the stage of pregnancy, statistics, and measurements to display. Once the selections are made the user can display the anthropometric data by clicking on the “Display
Anthropometric Data” button.

The data page displays a table of anthropometric data according to the selections that were made in the search page, and an example is shown in Figure 61. Each different anthropometric measurement has one row of the table that is labelled clearly in the left-hand column with the measurement name. In the top row of the table the statistics that are selected are labelled, and each different statistic is given a column each. According to the number of measurements and the number of statistics that are selected the table resizes, with more or less rows and columns according to the measurements and statistics respectively.

![Figure 61. Screenshot of the data page: Example measurement of abdominal depth for pregnant women in the third trimester.](image)

The user is reminded of their selection for the stage of pregnancy in the heading above the table. For example heading clearly states “Trimester 3 (weeks 29-40+)” if the user selected ‘trimester 3’ to display measurements from women in the third trimester of pregnancy. This helps to reduce the mental processing load of the user, as recommended in the guidelines (Johnson, J., 2000).

The user is provided with a button to press to go back to the search page, and this is in addition to the normal back button in the browser. This button is positioned both above and below the data table, so that if there is a long list of measurements it is easy to find the nearest button (either at the top or bottom of the page) without a lot of scrolling up and down the page. This button means that when the user returns to the search page then the choices from their previous search are displayed, and this has two benefits; firstly that the user is able to make modifications based on the previous search, and secondly that the user does not have to remember the previous choices. This is also a feature of the website that helps to reduce the mental workload of the automotive engineer that is using the site, and this is in agreement with the HCI
principles (Johnson, J., 2000). Furthermore Resnick et al. (2005) state that it is useful for creativity to allow exploration, i.e. the provision of a facility to try things out and then go back.

The data table produced on the data page can be copied from the webpage for use in other programs and software. This feature makes the data page flexible for use by the engineers, who might be using a variety of different programs to handle the data.

In the data table on the data page each of the measurement labels is a hypertext link. When the user clicks on the measurement name in the data table the full details about that particular measurement are displayed. The details of the measurement are displayed in a pop-up window so that both the measurement details and the anthropometric data statistics can be viewed simultaneously, and the pop-window is shown in Figure 62. The measurement details include the name of the measurement, a diagram to illustrate the measurement, and the description of the measurement; and all of these details correspond to the measurements list page as mentioned above and in Figure 56. One of the HCI guidelines states that multiple pop-up windows should be avoided, and with over 40 measurements available in the dataset, this could cause confusion for the user. However if the user wishes to display details for another measurement then these details are displayed in the same pop-up window. This reduces the risk of confusion for the use that could be caused by multiple pop-up windows, and is in accordance with the guideline (Johnson, J., 2000).

Figure 62. Screenshot of pop-up window displaying reference details of measurement.
6.7 RESPONSIVENESS
Responsiveness has been stated as an important HCI principle since users will feel frustrated in the website is not responsive enough. The Pregnant Women’s Anthropometry website is fast to download since there is only one photo on the homepage, and all the measurement images are very small sized .gif files. Even the Measurements List page that has the greatest number of images (an image for every different anthropometric measurement) takes around 10-15 seconds to download on average. The data page is virtually instantaneous in its response when displaying the selected set of pregnant women’s anthropometric data and this is due to the speed of the calculations in PHP code. The speed of the site and its small size will help the users to feel that it is responsive, in agreement with the HCI principles (Johnson, J., 2000; Preece, J., Rogers, Y. et al., 1994).

6.8 SURVEY OF TECHNICAL AUTOMOTIVE RESOURCES

6.8.1 Technical automotive resources
One method to improve the usability of a website is to make it look and feel familiar, and this relates to the HCI principle of consistency (Johnson, J., 2000; Preece, J., Rogers, Y. et al., 1994; Smith, S. and Mosier, J., 1986). The automotive engineers will find the website more user-friendly if it is consistent with other sites of its type and so a survey of technical automotive resources was undertaken, in order to investigate the common trends in interface design within the automotive industry. The resources reviewed were technical websites from a range of different vehicle manufacturers. These websites provide data and information from vehicle manufacturers for the sales and repair networks around the world.

6.8.2 Survey method
A typical page of technical information was selected from the information resource. The font and colour details were recorded, along with the structure of menu navigation for the site. Any details about the user feedback were also noted, such as how a menu item selected was indicated, or how a ‘rollover’ was highlighted. Once all of these details were recorded for each of the information resources, the data was compiled in order to examine the common trends amongst the different interfaces, which is summarised in the following analysis of page layout, font, menu structure, and user feedback details.
6.9 GUIDELINES FOR WEBSITE INTERFACES FOR AUTOMOTIVE DESIGNERS AND ENGINEERS

6.9.1 Page layout
The majority of the pages were divided into three main panels. The upper panel ran horizontally across the top of the page. A left hand panel then ran down the left-hand side of the page below the upper panel. The remaining area of the page formed the main body of the page used for content.

The manufacturer’s logo was positioned at the top left-hand corner on all of the technical information sites. 10 of the 12 technical resources had their own branding, i.e. the resource was given its own name, rather than the name of the vehicle manufacturer. For 4 of these sites which had their own branding, the logo and/or name was positioned in the top corner in the opposite corner to the main vehicle manufacturer logo. For another 5 sites the technical site branding was positioned close to the vehicle manufacturer logo, for example just to the right hand side.

The page background colour was white for 11 of the 12 technical sites, with only one site having a grey background.

6.9.2 Font
The most common font types used for the technical resources were Arial and Verdana. Arial was the font used for 8 of the 12 technical information sites. The body text of the pages the font colour was black for all of the technical sites.

In the majority of sites, for a main heading the normal font type was made bold. For 5 of the 12 sites, for a main heading, the normal font type was not only made bold, but also made a larger size. For half of the sites the heading font was also made a different colour, most commonly grey.

For the menu items, the fonts were most commonly put into a different colour. In this case, the most common colours were grey and blue. 4 of the 12 sites used grey, and 4 used blue.

6.9.3 Menu structure
For 10 of the 12 technical sites the main menu options were listed running down the left-hand side of the page in the left-hand panel.

There were two types of menu used: a simple list, and a tree menu. The most commonly used menu was the simple list, used in 8 of the 12 technical sites.
6.9.4 User feedback
In 11 of the 12 technical sites some type of user feedback was given to indicate when a menu item was rolled over or selected. Most commonly this meant that the menu item was highlighted by underlining (3 of 12 sites), or by changing font colour (7 of 12 sites), or by changing the background colour of the menu (5 of 12 sites). The most common combination was to change the background colour to make it darker with the font colour changed to white.

6.9.5 Summary of guidelines
The information gathered from this survey is useful in indicating the common interface trends used by the vehicle manufacturers in conveying technical information. Based on this survey, it is possible to recommend the following for design of an interface to communicate technical automotive information:

1. Page layout:
   a. Title panel across the top of the page, left hand panel to provide menu options, and the main body of the window to provide the data.
   b. Logo in the top left hand corner.
   c. White background.

2. Font:
   a. Body text: Arial, black.
   b. Main heading text: bold.

3. Menu structure:
   a. Left hand panel of the page.
   b. Simple list.

4. User feedback for menu navigation:
   a. Change background colour (darker).
   b. Change font colour (white).

6.10 MODIFICATION OF THE PREGNANT WOMEN’S ANTHROPOMETRY WEBSITE
Based on the examination of the technical information websites from the vehicle manufacturers it is now possible to modify the Pregnant Women’s Anthropometry website to make its appearance and interface more similar to the technical sites. The aim of modifying the anthropometry website is to mirror the technical sites to make it
more familiar for automotive designers and engineers who would be using the site. If the site is consistent in appearance and interface with other sites then it will be more intuitive to use. The original anthropometry website is shown in Figure 63.

Figure 63. Screenshot of the Pregnant Women’s Anthropometry website.

Following the trends of the technical information sites from the vehicle manufacturers, the modified anthropometry website is shown in Figure 64.

Figure 64. Screenshot of the Pregnant Women’s Anthropometry website: modified interface.
6.10.1 Page layout
For the page layout few changes were needed. The title panel of the page did not need any changes, nor did the location of the logo or the menu panel on the left hand side. The overall structure of each page (title bar at the top, navigation menu on the left and main information panel in the remainder of the screen) was already consistent with the other technical automotive resources. However the page background was changed from blue to white. Not only did this change make the site more consistent with the other technical resources, but it also increased the contrast between the white background and black text, which will help legibility. Both of these principles of consistency and colour contrast are in accordance with the HCI guidelines (Johnson, J., 2000; Preece, J., Rogers, Y. et al., 1994; Smith, S. and Mosier, J., 1986).

6.10.2 Font
For the font of the body text, it was already Arial and coloured black so no change was needed. However to make it more consistent with the technical information sites the text was made one size smaller.

6.10.3 Menu structure
The menu items were already given on the left hand side of the page and as a simple list, so no change was required to the structure of the menu.

6.10.4 User feedback
The user feedback for the menu items needed some changes. The original anthropometry website had a rollover on the menu items which highlighted them with a white background colour. This was changed to give the items a dark blue background colour to highlight, and to change the font colour to white. The HCI guidelines give quite specific advice for navigation (Johnson, J., 2000; Preece, J., Rogers, Y. et al., 1994). It is important that the user knows where they are, what they can do next at this current position, where they’ve been, and where they can go to next. The menu options provide this functionality in the original design of the site, although the menu did not clearly show which page the user was currently on. In the new design of the site this was updated so that the current page was highlighted in the menu, so that user would clearly know where they were in accordance with the guidelines.
6.11 PREGNANT WOMEN’S ANTHROPOMETRY WEBSITE USER TESTING

HCI design principles state that testing by the users is important (Johnson, J., 2000; Preece, J., Rogers, Y. et al., 1994), so a survey was then used to investigate the usability of the Pregnant Women’s Anthropometry website. This test two aspects: firstly the usability of the website for automotive engineers, and secondly which design of website was most suitable.

6.11.1 User testing method

The first version of the website as shown in Figure 63 was termed Site A, and the second modified version as shown in Figure 64 was termed Site B. The survey used is given in Appendix E.

There were 13 participants who were all automotive engineers. It has been shown that only a small number of participants are required for user testing (Nielsen, J. and Landauer, T.K., 1993). Nielsen and Landauer propose that a no user testing offers zero insight into usability, so ever a user test with one user is better than none. The number of new insights decreases with increasing numbers of participants, so only a small number of participants, and a minimum of 5 is required. Therefore this small sample of 13 participants was deemed to be adequate for the user testing.

The participants were given two tasks. The first task was completed only on one website, and either Site A or B was used alternately (n=7 starting on Site A, and n=6 starting on Site B). This first task was to familiarise themselves with the site and to locate measurements of pregnant women related to seat design. After this the participant was asked to complete the first set of questions (“Website Questions”). The second task was to locate measurements related to maximum abdominal size, but this task was carried out on both versions of the site, each one in turn, and then the second set of questions about comparison of the sites were completed (“Website Comparison Questions”). The main focus of the survey was on this second set of questions, to determine which site design the engineers preferred, but the first task and set of questions was used as a familiarisation exercise and to gather general feedback. The questions (both sets) are given in Appendix E.

The first set of questions was the Website Analysis and Measurement Inventory (WAMMI) survey (Claridge, N. and Kirakowski, J.). This is a set of 20 statements and a unique international database, from which an electronic report is automatically
generated. It is based on a comparison of users’ expectations against what they actually experience when using the site. WAMMI compares the satisfaction of the engineers using the site against values from the reference database, so overall it gives a comparison against other sites. WAMMI was selected for use because it is a questionnaire that is specific to website design, and not a general software HCI questionnaire.

The second set of questions was designed with the aim of making a comparison between the two different designs of website. The questions were designed in a similar style to WAMMI with a five point scale for each factor. The factors used included: attractiveness, information on screen, interface, characters, and colour scheme. Two additional factors were used to directly assess the engineering aspects of the site, namely its professionalism, and its consistency with other engineering websites. These questions were completed twice, once for each version of the website (A and B), in order to gather a direct comparison between the sites. The final question was a simple choice as to whether the engineer would prefer to use either Site A or Site B.

6.11.2 User survey

All participants managed to successfully complete the both tasks. The raw responses to the usability questions are summarised in Table 12, including the average score for each question. Overall it is clear that the participants were positive about the website. In particular there was strong disagreement with the statement that the site was difficult to learn their way around, and similarly strong disagreement that it was difficult to move around the site. Similarly, there was agreement with the statements that they can quickly find what they’re looking for and the site helps them find it, the site is logical, and they get what they expect when they click on a link. These sets of statements therefore indicate that the menu and navigation structure is effective, and the site is quick and easy to use for automotive engineers.
Table 12. Summary of website usability questions. (1 = strongly agree, 5 = strongly disagree)

<table>
<thead>
<tr>
<th>Question</th>
<th>Participant 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>This website has much that is of interest to me</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>It is difficult to move around this website</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4.3</td>
</tr>
<tr>
<td>I can quickly find what I want on this website</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>This website seems logical to me</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>This website needs more introductory explanations</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>The pages on this website are very attractive</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>I feel in control when I’m using this website</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>This website is too slow</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4.2</td>
</tr>
<tr>
<td>This website helps me find what I’m looking for</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Learning to find my way around this website is a problem</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4.3</td>
</tr>
<tr>
<td>I don’t like using this website</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>3.8</td>
</tr>
<tr>
<td>I can easily contact the people I want to on this website</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>I feel efficient when I’m using this website</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.9</td>
</tr>
<tr>
<td>It is difficult to tell if this website has what I want</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3.8</td>
</tr>
<tr>
<td>Using this website for the first time is easy</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>This website has some annoying features</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4.2</td>
</tr>
<tr>
<td>Remembering where I am on this website is difficult</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Using this website is a waste of time</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>I get what I expect when I click on things on this website</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Everything on this website is easy to understand</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1.8</td>
</tr>
</tbody>
</table>
able to locate the information quickly and the response time of the site. The helpfulness factor assesses whether the site corresponds with user expectation on content and structure. A high learnability refers to users being able to start with minimum introductions and that it is easy to understand. A low learnability refers to a site with unfamiliar concepts or terminology, and that needs more explanation. Finally there is also a global score for how well the site is rated overall. This concept requires that users can access what they want easily, that the site is organised in an understandable manner, and that language and terminology are suited to the users. The global score was 67 out of 100, where a score over 70 would represent an exceptional website. A score of over 50 is above average, and the scores for the site are shown in Figure 65. This graphs shows that the site scored above average for every factor, and scored exceptionally well for controllability, efficiency, and helpfulness. This relates to the HCI design principles (Preece, J., Rogers, Y. et al., 2002) that require effectiveness (the system will allow the user to achieve what they want to do), efficiency (user can achieve their goal in an efficient way and with a high level of productivity), and utility (letting the users carry out tasks in the way or using the method that they want to). The user experience goal of helpfulness (Preece, J., Rogers, Y. et al., 2002) also scores well in the WAMMI questionnaire, which assesses user experience against expectation for content and structure of the site.

![Figure 65. Graph of WAMMI results based on 13 automotive engineers’ responses to the 20 statement WAMMI questionnaire.](image-url)
Note that the attractiveness score is irrelevant in this exercise, because two visually different sites were used (A and B) with differences in colour and font size. However since the navigation and content and all other aspects of the site were unchanged, the questions and their scores can be deemed representative.

The WAMMI report also generates a statement analysis, as shown in Figure 66, which again shows the site favourably against the WAMMI database of user satisfaction values. The most positive comment related to the contact page on the website, and the statement that users could easily contact the people they wanted to.

Figure 66. WAMMI statement analysis.
Another HCI principle (Preece, J., Rogers, Y. et al., 2002), that of safety (reducing the occurrence of errors within a system and permitting users to recover from errors) is also achieved by this website, although this principle is not directly measured in the WAMMI questionnaire.

6.11.2.1 User preference for Site A or B

However the main focus of the survey was on determining which site design the engineers preferred, which used the second set of questions specifically about the comparison between the two site designs, A and B. The responses of the 13 participants are summarised below in Table 13.
Figure 67 shows that overall Site B scored higher than Site A for all points, which means the group of participants preferred it. Both versions of the site scored over 3 for the majority of questions, meaning that all participants viewed both sites positively, however B was preferred overall. The only point that scored below 3 at any time was the question about how easy the characters were to read; in this case Site A scored under 3 meaning that the characters were difficult to read. The majority of participants commented that the blue background made the contrast between the background and the letters poor, and so they preferred Site B.
When asked to choose which site they would prefer to use, 9 of the 13 participants chose Site B, which is a clear majority, and this is summarised in Figure 68 below.

6.11.2.2 General feedback on site
The general feedback and comments about the sites were positive. There was a clear majority of participants who preferred Site B with the higher contrast between the black text characters on the white background.

There was some confusion about the selection of stage of pregnancy, and two participants mistakenly thought that the ‘Trimesters 2&3’ choice was actually ‘Trimester 1’ because of its position on the left before the choices for trimester 2 and
trimester 3. Therefore this selection has now been moved to the right hand side, in order to avoid confusion. The order now reads: Trimester 2, Trimester 3, Trimester 2&3.

Another two participants questioned whether the data produced in the table related to the group of pregnant women, or to the published data for males and non-pregnant females (e.g. that data used to develop Hybrid III crash dummies). To clarify this point a line of text was added above the table stating “All dimensions relate to the group of pregnant women measured (not to other published male or non-pregnant female data).”

The updated website design that incorporates these few feedback points from the participants is shown in Figure 69, and this is taken as the final design.

Figure 69. Final design of Pregnant Women’s Anthropometry website.
6.12 SUMMARY OF PREGNANT WOMEN’S ANTHROPOMETRY WEBSITE

A Pregnant Women’s Anthropometry website was generated to present the anthropometric data gathered in this research. This novel website displays measurements specifically selected for use in vehicle design. Incorporating the needs of pregnant women and modifying automotive design accordingly can help to improve safety and comfort for the pregnant population. The anthropometry website is provided for automotive designers and engineers with the aim of enhancing pregnant occupant protection through improved automotive design. The site was designed in accordance with the general HCI principles and guidelines, but in addition the site was designed for use by engineers and designers to suit their needs, in order to encourage consideration of the pregnant occupant during the design stages. The website has many features to aid the user, in particular the ability to select the anthropometric measurements according to the vehicle part being designed. Another major advantage of the site is the ability to display multiple measurements, rather than just a single measurement as in PeopleSize. This feature of the site will help the automotive engineers in finding the complete set of data required; whether that be just one measurement, a specific selected group of measurements, or a group of measurements for a vehicle part. Another feature of the site is the provision of diagrams representing the anthropometric measurements. James-Gordon and Bal (2001) showed that engineers tend to be visual learners, so these diagrams will help the engineers to learn more easily about the measurement details and reduce the need to repeatedly look up the details. The use of engineering terminology throughout the site combined with the use of the diagrams will make the website approachable to automotive engineers around the globe. The visual nature of the search page and the use of the engineering terms should mean that an engineer that is not familiar with the English language could make an attempt at using the site. However, should an engineer experience any difficulty with using the website they are invited to provide feedback so that the site could be developed further. A survey of technical information websites from vehicle manufacturers was undertaken. These websites provide technical information and data for the international network of vehicle dealerships and bodyshops. The trends in appearance
and interface have been summarised as recommendations. These recommendations include page layout, font, menu structure, and user feedback.

The anthropometry website has been modified according to the recommendations where necessary. These changes to the anthropometry website make it appear much more similar to the technical information websites provided by vehicle manufacturers. By making the anthropometry website appear similarly and have a similar interface the site will be more intuitive and familiar to automotive engineers.

The new design of website was assessed by automotive engineers who compared the new Site B, to the original Site A. Their survey responses revealed a strong preference (9 of 13 participants) for the new design, Site B, with its higher contrast between the black text and white background. The survey responses showed that the automotive engineers found the site quick and easy to use, in particular that the structure and navigation were suited to them. Other general feedback on the site revealed the need for a few small changes, and these were incorporated into the site for the final design.
CHAPTER 7: DESIGN GUIDELINES

7.1 DESIGN GUIDELINES FOR THE PREGNANT OCCUPANT
The questionnaire responses and anthropometric data have been used to generate guidelines for the automotive engineers so that they may better accommodate the needs of pregnant women. It should be noted that these are not meant to be comprehensive, and are not necessarily the ideal solution. These guidelines are intended to outline the key points for consideration of pregnant women’s needs to enable the automotive engineers to integrate the pregnant occupant into the design, and with further development and resolution they could achieve solutions satisfactory for the comfort and safety of pregnant women. These novel recommendations and suggestions for automotive designers to incorporate the needs of pregnant women into car design are summarised below. These recommendations are an important contribution to pregnant occupant safety and believed that they will help to change the quality of life for pregnant women if they were incorporated into automotive designs.

7.1.1 Seat belts
- Design specific adaptable, integrated seat belts to make certain that the seat belt is more suitable for the pregnant body, so that pregnant women can comfortably fit the belt and are safely restrained during all stages of pregnancy.
- Ensure that pregnant occupants can correctly position the seat belt during the course of pregnancy.
- Consider that the lap portion of the seat belt tends to ride upward onto the abdomen into a dangerous position, and use pregnant women’s anthropometry to ensure that the belt will fit correctly and remain in position.
- Anthropometric measurements from pregnant women can also be used to define the necessary belt length in order to ensure that the seat belt can accommodate the enlarged hips, abdomen and chest area during all stages of pregnancy.

7.1.2 Steering wheel clearance
- Engineers should use anthropometric measurements from pregnant women to define the occupant space to maintain a safe distance away from the steering wheel in order to reduce the risk of injury from impact of the steering wheel or deployed airbags in case of a collision.
• Provide a greater range of fore and aft seat adjustments.
• Consider providing fore and aft adjustable pedals or pedal extenders to allow pregnant women to move their seats rearward, but also be able to comfortably reach and operate the pedals to drive.
• Consider providing a retractable steering wheel to move the steering wheel further away from the abdomen as it enlarges.
• Check reach capabilities of pregnant women, for all parts of the car with the seat in all fore and aft positions to ensure pregnant women can reach the pedals, and all other controls.

7.1.3 Entry and exit of the vehicle
• Be aware that pregnancy causes some women to alter their method of entry and exit from the car, for example by separating it into two separate motions instead of one fluid movement. For example when women are getting in to the car, the two separate motions are first to sit down on the seat whilst facing laterally out of the door opening, then secondly to swivel to face the front of the car whilst lifting their legs in. (Getting out of the car is the reverse of this two-stage method).
• Ensure that women are able to swivel around on the seat unobstructed.
• Ensure women have enough space in the door aperture when stood facing laterally out of the driver’s seat.
• Check that anthropometry of pregnant women is accommodated in all stages as they move in and out the car. It is also important to consider the difference between sitting and standing posture and use the correct anthropometry because in seated posture the abdomen and breast sizes of pregnant woman are larger than in standing posture. Not only must the increased sizes of pregnant woman be considered, but also the changes in size as she moves between standing and seated postures.
• Consider that many pregnant women also need to lean, push, pull and hang on to various leverage points, including the door, the seat, the steering wheel, the car roof, the doorframe, the inner handle above the door opening, and the side of the car. A suggestion is to provide such leverage points and handles as an aid to pregnant women.
• Check the car door can open wide enough for pregnant women, and is not too heavy for those women who feel weaker during pregnancy.
• Adjustability in the car seat height could help women who experience difficulty in lowering themselves into the seat.

7.1.4 Seats
• Provide adjustability in the seat, including adjustments in the height, seat back angle, seat pan tilt, and lumbar curve fore/aft and vertical positioning.
• Position the controls for seat adjustments within easy reach of the pregnant occupant and their limited range of motion should be considered.
• Provide air conditioning, preferably as standard.
• A suggestion is to give a smoother ride by providing softer suspension.

7.1.5 Boot space
• Consider providing a shelf or sliding floor in the boot to help move items around inside the boot space.
• One of the problems for pregnant women is reaching up to shut the boot lid, and a boot with a self-closing mechanism or providing a pull strap on the boot lid could be a solution to this problem. A self-opening boot could also be helpful.

7.1.6 Reaching controls
• Use pregnant women’s anthropometry to ensure that pregnant occupants can easily reach all the controls and parts of the car, particularly those that are vital for the driving activity.
• Position all the relevant controls within easy reach so that the pregnant women do not have to stretch, twist, or bend.
• Another suggestion is to mount dashboard controls (e.g. radio) controls on the steering wheel, or on stalks behind the steering wheel, so they are in easier reach.
• Consider providing a hook or method of pulling the belt forward so that it is easier to reach.
CHAPTER 8: CONCLUSIONS

8.1 THE NEEDS OF PREGNANT WOMEN IN AUTOMOTIVE DESIGN

The thesis has presented the first comprehensive study of the needs of pregnant women in the automotive context. This study was completed using two methods: a questionnaire and anthropometric measurements.

The questionnaire responses have revealed a wide range of problems experienced during pregnancy, and the extent of the problem for this occupant group. The main problem areas are using the seat belt, proximity of the abdomen to the steering wheel and getting in and out of the car.

It could be argued that by the third trimester of pregnancy many pregnant women may choose to travel as passengers and not to drive. However, the safety and comfort issues for example wearing a seat belt in pregnancy are not limited to only car drivers, but also passengers, and hence it is still important to consider the needs of pregnant women. Furthermore, only a few of the pregnant women who completed the questionnaire had reported that they had started travelling as passengers rather than drivers in the third trimester despite their concerns and complaints.

An important point is that pregnant women to try and ease their comfort problems, which resulted in them possibly compromising their safety. For example, some women held the seat belt during travel, or other women who used a plastic bag on the seat to help them swivel around for getting in and out of the car. This highlights the importance of providing comfort for the pregnant women so that there is no risk of discomfort impacting on their safety.

The questionnaire responses also revealed that some pregnant women are using devices to position the lap belt. These lap belt positioners were assessed in a novel sled test study at Thatcham. The comparative test series used a Hybrid III 5th percentile female ATD with a MAMA2B conversion kit to make represent pregnancy. The kit consisted of a fluid filled bladder representing the uterus with a pressure sensor at the abdominal point to represent the pressure felt at the utero-placental interface. It is important to note the limitations of the dummy, in particular that there is no method of assessing risk of injury caused by the positioner straps passing between the legs. The main finding from the study was that positioning the lap belt correctly across the hips, instead of over the abdomen, results in a lower peak
pressure. There was little difference found between the use of aftermarket lap belt positioners and the use of the correctly positioned three-point seat belt, which suggests that these positioners offer little advantage or disadvantage in terms of the crash forces experienced. However if pregnant women choose to use the aftermarket lap belt positioners then this might have a positive influence on increasing seat belt usage and correct positioning. Real world accident data cases involving pregnant women using the positioners is needed to assess the effect of the seat belt positioners in the real world.

The anthropometric measurements are a novel dataset, produced for the first time with a focus on automotive design. Previous anthropometry of pregnant women has focussed on clothing. This new dataset is a valuable resource for the automotive designers and engineers in providing an occupant package that accommodates pregnant women more safely and comfortably.

During the course of the measurement sessions the author noted that pregnant women tended to sit with their knees spread more widely apart than usual. A novel measurement was introduced and termed ‘knee splay,’ which is defined as the distance between the outer borders of the knees whilst seated in the preferred posture. The pregnant women’s position is not significantly different from non-pregnant women’s position or men’s position when asked to sit with their knees together, however in a relaxed posture by preference men and pregnant women choose a significantly different position and sit with their knees widely spaced apart. By preference pregnant women choose to adopt a greater range of knee positions than simply sitting with their knees together. If automotive engineers use this information and incorporate the altered anthropometry of pregnant women into vehicle designs then it could help to improve both comfort and safety for pregnant women.

All of the data from the anthropometric measurements and questionnaire responses of the pregnant women has been compiled in this thesis to generate a set of design guidelines, as given in Chapter 7. These design guidelines are recommendations for the automotive industry to consider how to incorporate the needs of pregnant women into vehicle design, in order to offer them an improved safety and comfort package.

### 8.2 WEBSITE INTERFACES FOR AUTOMOTIVE DESIGNERS AND ENGINEERS

The anthropometric data for pregnant women has been presented as a website, which
is novel resource for the automotive industry. The site was designed for use by automotive engineers, in order to encourage consideration of the pregnant occupant during the design stages. The ability to select a group of measurements according to the part of the vehicle is a major feature designed to help the automotive engineers find the data quickly.

The website was then updated to have a similar interface as other technical websites within the automotive industry, so that it will be more intuitive and familiar to the automotive engineers who use it. This new design was assessed by a group of engineers who compared the new Site B, to the original Site A, and they preferred the new design. The automotive engineers also gave some suggestions for improvement, which were incorporated so that the final design is intended to be user-friendly to the automotive engineers. If the automotive engineers use the website to gain access to this novel resource of pregnant women’s anthropometric data and use the data to better accommodate pregnant occupants then the quality of life for pregnant women will be improved. This will have benefits particularly for pregnant occupant safety, but also for their comfort and overall driving experiences.

8.3 RELATED AND FUTURE WORK
The research work described in this thesis has helped contribute to other research projects in related areas. In some cases these further projects have specifically used the findings or methods described in this thesis as a foundation for the new project. For example the anthropometric data presented in this study was used in the “EXPECTING – A Pregnant Occupant Model” project that produced a pregnant occupant model capable of simulating the dynamic response to impact and predicting the risk of injury in automobile crashes (Acar, B.S. and Van Lopik, D., 2009).

Another example is the completion of the Research Assistant Industrial Secondment (RAIS) project by the Author. This 1 year secondment to Thatcham resulted in the investigation of the effectiveness of lap belt positioners for pregnant women as described in full in Chapter 4. The anthropometric data and questionnaire data from pregnant women about their experiences of seat belt use was used in the ‘Development of an Improved Seat Belt Design with Particular Emphasis on the Needs of Pregnant Women’ project.

There are many ways in which the research can be extended. One example is the use of the Pregnancy and Driving questionnaire for other markets, and one such study is
already in progress in Israel. By using the questionnaire in other markets it could be possible to account for any national differences in the population and whether this affects driving experiences in pregnancy. A further extension could be then to incorporate these needs into the automotive designs of cars available in that market, since there could also be national differences in the configuration of vehicles. A piece of further development of the Pregnant Women’s Anthropometry website could be to produce it in multiple languages to suit the global nature of today’s automotive industry. This would probably require multiple versions of the site in order to meet the varying cultural needs of different nationalities (Smith, A., Dunckly, L. et al., 2004).

The research presented in the thesis can also help the automotive sector and wider society in many others ways. For example by incorporating the anthropometry of pregnant women into automotive design obese people could also be better accommodated, especially in today’s society that is increasingly obese. The automotive industry can therefore begin to consider the needs of the obese population more comprehensively, and the research could even be extended using similar methods to cover this group of obese people.

An extension to the work could be to investigate the issue of proximity to the steering wheel with a study of testing using MAMA2B conversion with the Hybrid III 5th percentile female. An investigation of a range of seating positions with various horizontal positions away from the steering wheel could reveal whether there is possibility to make a recommendation about safe seating position for pregnancy to reduce risk of injury from impact with the steering wheel. Given the concern shown by pregnant women about the risk of injury to the fetus posed by a deployed airbag, a useful contribution of further research could be a study using the ATD representing the pregnant female in order to investigate the effect of the airbag. This could be particularly useful if combined with the study about seating position, since this might reveal evidence about a safe seating position away from the steering wheel to reduce risk of injury from a deployed airbag. This investigation using the ATD could be compared to the results using the ‘EXPECTING’ model of a pregnant occupant to analyse whether the results give the same conclusions.

A further extension of the research could be to investigate the risk of submarining injuries specifically since submarining under the lap belt in a collision is associated with abdominal injury (Leung, Y.C., Tarrière, C. et al., 1982). This could be done
using the ATD converted to represent pregnancy, but further modifications might be required in order to replicate the proper biomechanical responses of submarining as well as additional instrumentation of the ATD to allow assessment of the injury risk. An investigation of submarining of the pregnant occupant could be a valuable contribution to pregnant women’s safety. This would be especially valuable if it were compared to results using the ‘EXPECTING’ pregnant occupant model.

Another useful investigation with the ATD that is capable of representing pregnancy would be to examine the safety impact of sitting on a carrier bag. This use of a carrier bag was reported by pregnant women in the survey, and they are using it as an aid to help with swivelling around on the seat pan aid entry and exit of the car. The contribution of this extension of the research would be to provide evidence of whether or not the use of the carrier bag affects the interface between the occupant and the seat and whether this has an adverse effect on the occupant biomechanics. This aim would be to specifically investigate the risk of excessive forward motion and impact with the steering wheel, or risk of submarining injury to the abdomen. The tests using the ATD could be compared to the results of simulations using the ‘EXPECTING’ pregnant occupant model. This evidence would be beneficial not only for informing pregnant women, but also other sectors of society since the author also has anecdotal evidence of other sectors of the population similarly using a carrier bag to aid in swivelling on the seat.

Another useful extension to the research would be to develop a new design of ATD that could represent a later stage of pregnancy where there is the greater level of risk posed by the more greatly enlarged abdomen in closer proximity to the steering wheel. It would also be useful if this new ATD could be used for a range of impacts including front, rear and side, and for a range of seated postures as used by pregnant women. This new ATD design could be used in the automotive design process to investigate seat belt positioning, submarining, and steering wheel proximity issues for vehicle designs in order to improve safety for pregnant women yet further by considering different impact types and a later stage of pregnancy. Another development to the ATD could be to develop a method to measure and assess the risk of injury caused by the straps of seat belt positioners that pass between the legs when seated, since injury in this region could have consequences for the birth process. However the ability to develop such a new ATD (including capabilities to represent a later stage of pregnancy, a range of impact types, and/or assessing risk of injury
caused by straps passing between the legs) depends on available ATD technologies and the availability of biomechanical data to inform its design.

Another piece of further work could be to carry out a study of seated driver posture of pregnant women as they drive. The advantage of this study would be to examine driver posture measurements in a dynamic driving situation i.e. the realistic driving environment. In particular measurements could be used to record the relationship of the pregnant occupant to the various hard points of the vehicle, including the proximity to the steering wheel, and the backset measurements of the head restraint. This study could provide a valuable resource of data that would reveal the main issues for pregnant occupants in their seating posture. This study would be particularly valuable if it covered a range of gestation levels, and a variety of vehicle types. Any out-of-position postures used by the pregnant women could also be recorded, and these could help to inform testing using an ATD capable of representing pregnancy and hence establish any particular postures that should be avoided during pregnancy if they increase risk of injury to the mother or fetus. This study of pregnant occupants during driving could provide a valuable resource of data to help further inform the automotive design process.
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APPENDICES

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APPENDIX A: PREGNANCY & DRIVING QUESTIONNAIRE

PREGNANCY & DRIVING QUESTIONNAIRE

Information
My name is Alix Weekes and I work for Loughborough University under the direction of Dr B S Acar. The aim of this questionnaire is to understand how you feel during pregnancy and any problems that you are experiencing with driving. The information from this survey will be used to compile a set of guidelines for the automotive companies to use, in order to design cars more suited to the needs of pregnant women. The results of the project will be published as academic papers and presentations, and as a website. The “Automotive Design: Incorporating the Needs of Pregnant Women” Project is funded by the Engineering and Physical Sciences Research Council in collaboration with Ford, Jaguar, Nissan, Autoliv, MIRA, and the Luton and Dunstable Hospital.

The information you provide is entirely confidential and your identity will not be disclosed to any third parties. The data will be held at Loughborough University. You can withdraw from the research at any time. This research will not impact on your medical care.

This questionnaire will take approximately 20 minutes.

Date and Number: .................................................................
About You

W1) What week of your pregnancy are you at now? ________________________

W2) How many babies are you carrying? (Please tick)
   1   2   more ________________________________

W3) How many pregnancies have you previously had? (Both viable and non-viable) (Please tick)
   0  1   2   3   4   more _______

W4) How many children do you have aged: (please tick)
   0 to 3 years old?   0   1   2   more ______
   4 to 7 years old?   0   1   2   more ______
   8 to 12 years old?   0   1   2   more ______
   13 and older?   0   1   2   more ______

W5) How tall are you? _______________________________________________

W6) How old are you? _______________________________________________

W7) What was your average weight before pregnancy? _____________________

W8) How much do you weigh now? _____________________________________

W9) What is your highest completed level of education?
   School leaver   GCSE or equivalent   A levels or equivalent
   higher education   other _______________________________

W10) What is your average household gross income (£) per year? (Please tick)
    Below 10,000   10,000 to 20,000   20,000 to 30,000
    30,000 to 50,000   50,000 to 70,000   over 70,000
About the Cars

V1) Do you drive? (Please tick)  Yes  No

V2) Please give details of the cars you travel in. Start with the car you travel in most often and fill in row 1, then in row 2 answer for the car you travel in next most often.

<table>
<thead>
<tr>
<th>Brand (e.g. Ford)</th>
<th>Make (e.g. Focus)</th>
<th>Year (e.g. 2001)</th>
<th>2 door or 4 door</th>
<th>Manual or Automatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

V3) Please indicate whether you are most often a driver, a front passenger, or a rear passenger in each of the cars you travel in. Please refer to the previous question for the car numbers. (Please tick)

<table>
<thead>
<tr>
<th>Car 1</th>
<th>Car 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td></td>
</tr>
<tr>
<td>Front Passenger</td>
<td></td>
</tr>
<tr>
<td>Rear Passenger</td>
<td></td>
</tr>
</tbody>
</table>
For the rest of the Questionnaire, please think about the cars you listed. Tick number 1 for the number one car, and tick number 2 for the car you listed as number 2.

**Driving/Car Travelling**

D1) How much is your driving/travelling being adversely affected by pregnancy?

<table>
<thead>
<tr>
<th></th>
<th>not at all</th>
<th>a little</th>
<th>a lot</th>
<th>so much, I now avoid driving/travelling</th>
<th>I don’t drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfort</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Safety</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Reaching controls</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Getting in &amp; out of car</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Using the boot</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Driving ability in general</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Night driving</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Reversing</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
<tr>
<td>Other ___________</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
</tbody>
</table>

**Getting in and out of the car**

G1) What methods or actions do you use to assist in getting out of the car?

1 2 lean forward 1 2 lean on the door 1 2 pull on the door
1 2 push against the seat 1 2 someone helps 1 2 nothing
1 2 other ____________________________________________

G2) What methods or actions do you use to assist in getting in to the car?

1 2 lean on the door 1 2 lean on the seat
1 2 lean on steering wheel 1 2 someone helps 1 2 nothing
1 2 other ____________________________________________

G3) What is the main difficulty in getting in and out of the car?

1 2 fear of overbalancing 1 2 there is not enough space
1 2 movement is restricted 1 2 no difficulty
1 2 other ____________________________________________

G4) Is there anything else that makes getting in and out of the car difficult for you?
Reaching and operating controls

*Remember you are comparing whilst you are pregnant with when you were not pregnant.*

**R1)** How easy is it for you to reach and use/operate the following parts of the car?

<table>
<thead>
<tr>
<th>Part of Car</th>
<th>Very Easy</th>
<th>Easy</th>
<th>Difficult</th>
<th>Very Difficult</th>
<th>I Don’t Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window buttons/handle</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Radio</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Controls on dashboard</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Seat belt</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Wing mirrors</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Glove compartment</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Access to rear seats</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sun roof</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Gear stick</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Handbrake</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Pedals</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Rear view mirror</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Other ___________________________</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**R2)** For the items that you listed above as being difficult/very difficult to reach or use, please explain why, or the particular problem associated with that activity.
**Seat Belts**

S1) Are you wearing a seat belt whilst you are pregnant? 1 2 Yes  1 2 No

S2) If you are not wearing a seat belt at this time, please tick a reason why:
   1 2 don’t usually wear a seat belt   1 2 it is uncomfortable
   1 2 I think it might be safety risk   1 2 no reason
   1 2 not applicable 1 2 other _____________________

S3) How do you position the shoulder section of your seat belt over your chest?
(Please choose the picture that best describes how you wear your belt across your chest for each car)

- 1 2 Across the top of the chest above both breasts
- 1 2 Across one breast and over the bump
- 1 2 Between the breasts and around the bump
- 1 2 Off the shoulder and around the bump
- 1 2 I don’t wear the shoulder section of the belt

S4) How do you position the lap belt over your abdomen? (Please choose the picture that best describes how you wear your belt over your abdomen for each car)

- 1 2 Across the top of the thighs
- 1 2 Across the hips underneath the bump
- 1 2 Over the bump
- 1 2 I don’t wear the lap section of the belt
S5) What are your problems with wearing a seat belt during pregnancy?

- [ ] it is difficult to adjust
- [ ] the belt won’t fit under my bump
- [ ] the belt is not long enough to fasten
- [ ] the belt is too tight on my hips
- [ ] it is too tight on my chest
- [ ] it cuts into my shoulder
- [ ] it is difficult to fasten and unfasten
- [ ] it cuts into my breasts
- [ ] it is too tight on my abdomen
- [ ] it is tight on my abdomen
- [ ] it is difficult to fasten and unfasten
- [ ] there is no problem
- [ ] other ________________________________

S6) Do you feel safe when wearing your seat belt?  

- [ ] Yes
- [ ] No

If you don’t feel safe in your belt, please state why.

S7) Have you received any advice about how to wear your seat belt during pregnancy?

- [ ] Yes
- [ ] No

S8) If yes, where did you receive this advice from?

- GP
- midwife
- leaflet
- book
- friend
- relative
- radio
- nurse
- television
- internet
- magazine
- other ________________________________

S9) Are you aware that there are leaflets available that specifically provide advice on how to wear seat belts during pregnancy?

- [ ] Yes
- [ ] No

Airbag

A1) Which airbags does the car have?

- [ ] driver
- [ ] driver and passenger
- [ ] driver and side
- [ ] driver and passenger and side
- [ ] don’t know
- [ ] none

A2) Does the airbag where you sit have an on/off switch?

- [ ] Yes
- [ ] No
- [ ] Don’t know

A3) In your opinion might an airbag be a risk to the fetus or pregnant woman if it is activated during an accident?

- [ ] Yes
- [ ] No
- [ ] Don’t know
Comfort

Remember that you are comparing your pregnancy with when you are not pregnant.

C1) Approximately how far is your bump from the steering wheel?

- [ ] nearly touching
- [ ] 1” or 3cm
- [ ] 2” or 5cm
- [ ] 3” or 8cm
- [ ] 4” or 10cm
- [ ] 6” or 15cm
- [ ] 8” or 20cm
- [ ] 10” or 25cm
- [ ] more __________

C2) Is there enough legroom for you in the car when you sit:

- In the driver’s seat?
  - [ ] Yes
  - [ ] No
  - [ ] don’t know
- In the front passenger seat?
  - [ ] Yes
  - [ ] No
  - [ ] don’t know
- In a rear passenger seat?
  - [ ] Yes
  - [ ] No
  - [ ] don’t know

C3) What problems do you have with the car seat cushions?

- [ ] too hard
- [ ] too soft
- [ ] not enough back support
- [ ] too high under knees
- [ ] no problem
- [ ] other ________________________

C4) Please describe any other problems you have with comfort in the car.

Boot

B1) What problems do you have with using the boot?

- [ ] edge is too high so can’t lift items in
- [ ] edge is too high so can’t lift items out
- [ ] bump gets in the way so can’t reach far enough into the boot
- [ ] can’t reach up high enough to shut the boot
- [ ] there is no problem
- [ ] other ____________________________
**Head Restraint**

H1) What is the worst problem with the head restraint?
1 2 can’t adjust the height properly
1 2 can’t get it close enough to my head
1 2 it gets in the way
1 2 it blocks the view out the rear windscreen
1 2 none
1 2 other ______________________________________________________

H2) How is your head restraint positioned? Please choose the picture that best describes how your head restraint is positioned for each car.

- [ ] Away from the head
- [ ] Close to the head
- [ ] Tilted away from the head
- [ ] Tilted toward the head
- [ ] High above the head
- [ ] Low down at neck level
- [ ] don’t know
- [ ] other (please sketch or describe)

H3) Have you received any advice about how to position your head restraint?
Yes    No
If yes, where was the advice ____________________________________________

What exactly was the advice? ____________________________________________
Physical Changes in Pregnancy

P1) Which of these general or longer lasting physical changes are you experiencing? Consider the way that this physical change due to pregnancy affects your driving in general, and tick the statements that you agree with.

No  Yes, but doesn’t affect my driving  Yes, it makes me uncomfortable  Yes, it makes me distracted  Yes, it makes me avoid driving

Stomach pain
Hip pain
Baby’s head in pelvis
Pelvic pain
Back pain
Sore joints
Haemorrhoids (piles)
Oedema (swelling)
Varicose veins
Other ____________

P2) Which of these physical changes are you experiencing? These occur more suddenly i.e. you don’t feel it all the time.

No  Yes, but doesn’t affect my driving  Yes, it makes my driving unpredictable  Yes, it makes me distracted  Yes, it makes me avoid driving

Leg cramp
Heartburn
Sickness
Itchy skin
Need to urinate
Other ____________

P3) In which ways is your movement affected during pregnancy?

No  Yes, but doesn’t affect my driving  Yes, it slows my responses  Yes, it makes me distracted  Yes, it makes me avoid driving

Breathless
Exhaustion
Slower movements
Limited bending
Limited reach
Other ____________
**Emotions in Pregnancy**

*(Remember that you are comparing now when you are pregnant, with when you are not pregnant)*

E1) What feelings are you having during your pregnancy? Please think about how your emotions may affect your driving during pregnancy, and tick the statement that you agree with for each item below.

<table>
<thead>
<tr>
<th></th>
<th>No</th>
<th>Yes, but doesn’t affect my driving</th>
<th>Yes, it makes me more alert</th>
<th>Yes, it makes me distracted</th>
<th>Yes, it makes me avoid driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleasure/prise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irritable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oversensitive/tearful</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panic/anxiety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depression/feeling down</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excitement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other ___________</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Do you have anything you would like to add? Please comment on any problems that you have with car travel during your pregnancy, compared to when you are not pregnant.

If you have any questions, or any further information, please don’t hesitate to contact me. Please return this questionnaire to the desk.

Thank you for your time and co-operation.
APPENDIX B: PREGNANTDRIVER ONLINE QUESTIONNAIRE

Pregnantdriver site in English.

Pregnantdriver site in English: Example of questionnaire page.
Pregnantdriver site in Turkish.

Pregnantdriver site in Spanish.
Appendix B

Pregnantdriver: Online Questionnaire

**Un questionnaire qui mesure les effets de la grossesse sur la conduite**

Ce questionnaire est part d’un travail de recherche intitulé “L’influence des biais des anciens conducteurs”, effectué par Dr. Sariel Acar et l’équipe de Loughborough. L’objectif de ce questionnaire est de comprendre les sentiments connus par une personne enceinte et aussi les problèmes que les enquêtes confrontent pendant quelle conducteur.

L’information que vous fournissez est entièrement confidentielle et votre identité ne sera pas révélée au tiers personne. Les données seront gardées à l’université de Loughborough.

Veuillez compléter ce questionnaire seulement vous êtes enceinte ou vous avez été enceinte.

Il y a plusieurs méthodes pour compléter ce questionnaire. Vous pouvez le compléter en ligne ou le télécharger.

**Cliquez ici à fin de compléter le questionnaire en ligne.**

**Cliquez ici pour télécharger le questionnaire.**

Si vous téléchargez le questionnaire, veuillez le remplir par la poste à Miss Alx Wielies, Research School of Informatics, (Department of Computer Science), Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

Cliquez ici pour nous contacter si vous avez des questions.

**Les informations qui figurent sur ce site sont l’objet d’une clause de non-responsabilité et d’une déclaration concernant les droits d’auteur.**

**Gravidanza e Guida - Questionario**

Questo questionario è parte di un progetto di ricerca intitolato “Design automatico: includere i biaisi della donna incinta” diretto dal Dr. Sariel Acar con l’aiuto di Miss Alx Wielies presso l’Università di Loughborough. Lo scopo di questo questionario è quello di stabilire i problemi associati con la guida al momento della gravidanza.

Le informazioni fornite attraverso il questionario saranno usate per compilare linee guida da fornire a case automobilistiche per il design di autoveicoli che si aspettano ai biaisi della donna incinta. I risultati del progetto verranno pubblicati sotto forma di pubblicazioni accademiche e presentazioni. Il progetto ”Design automatico: includere i biaisi della donna incinta” e sponsoziorizzato dal Consiglio Italiano della Ricerca per l’Ingegneria e la Scienza Pubblica.

L’informazioni fornite sono interamente confidentiali e l’identità della persona rimarrà anonima. I dati verranno conservati presso l’Università di Loughborough.

Rispondi a questo questionario solo nel caso in cui tu sia incinta o, nel rispondere, tu faccia riferimento ad una tua precedente gravidanza.

Ci sono due modi per completare questo questionario: puoi completarlo online oppure completarlo dopo averlo scaricato.

**Clicca qui per completare il questionario online.**

**Clicca qui per scaricare il questionario.**

Se scelgono il questionario, una volta composta, posta a questa indirizzo per favore: Miss Alx Wielies, Research School of Informatics, (Department of Computer Science), Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

Se tu vuoi chiedere qualunque cosa in merito a questo questionario, clicca qui per contattarci.

**Pregnantdriver site in French.**

**Pregnantdriver site in Italian.**
# Pregnancy & Driving Questionnaire

This questionnaire is part of a research project entitled "Automotive Design: Incorporating the Needs of Pregnant Woman," directed by Dr. Serpil Acar assisted by Miss Aix Weekes at Loughborough University. The aim of this questionnaire is to establish problems associated with driving during pregnancy.

The information from this study will be analysed and used to generate a set of guidelines for the automotive companies to use, in order to design cars more suited to the needs of pregnant women. The results of the project will be published as academic papers and presentations, and as a website. The "Automotive Design: Incorporating the Needs of Pregnant Woman" project is funded by the Engineering and Physical Sciences Research Council.

The information you provide is entirely confidential and your identity will not be disclosed to any third parties. The data will be held at Loughborough University.

Please only answer this questionnaire if you are pregnant, or thinking about a previous pregnancy.

There are two methods for completing the questionnaire. You can either complete it online, or download it.

**Click here to complete questionnaire online.**

**Click here to download the questionnaire.**

If you download the questionnaire, please post it to Miss Aix Weekes, Research School of Informatics, Department of Computer Science, Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

If you have any questions about this questionnaire, click here to contact us.

**Copyright and disclaimer:**

Last modified by Aix Weekes 04/02/2005 12:59:45

Pregnantdriver site in English text only.
APPENDIX C: SUMMARY OF 25 RESPONSES FROM THE SMALL SAMPLE OF PREGNANT WOMEN

This is the sample of 25 responses from pregnant women attending the antenatal clinic. These 25 responses can be assumed to be unbiased since the inclusion of these women into the sample is random according to their attendance at the clinic. This sample of 25 responses is used in section 3.1.3.1 describing comparison against the larger sample of 600 responses. The responses in both samples reflect a similar pattern of answers, the percentages are similar, and there is no clear pattern of higher occurrence of problems between the two samples. Therefore the larger sample of 600 responses is accepted as unlikely to include any bias caused by women only volunteering to participate because they are experience some problem(s). The large sample of 600 responses is the main finding of the research and is reported in Chapter 3. This summary of responses from the smaller sample of 25 responses from the women attending antenatal clinic is only included in this appendix to support the investigation into whether the large sample might include bias.

A summary of the small sample of 25 responses from women attending antenatal clinic follows below:

<table>
<thead>
<tr>
<th>Problem</th>
<th>Small sample 25 responses (antenatal clinic)</th>
<th>Large sample 600 responses (global, interview &amp; online)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General driving</td>
<td>36.4%</td>
<td>49.4%</td>
</tr>
<tr>
<td>Safety</td>
<td>60.0%</td>
<td>54.3%</td>
</tr>
<tr>
<td>Using seat belt</td>
<td>64.0%</td>
<td>72.3%</td>
</tr>
<tr>
<td>Getting in and out car</td>
<td>88.0%</td>
<td>77.8%</td>
</tr>
<tr>
<td>Comfort</td>
<td>72.0%</td>
<td>76.3%</td>
</tr>
<tr>
<td>Car seat cushions</td>
<td>64.0%</td>
<td>56.8%</td>
</tr>
<tr>
<td>Using the boot</td>
<td>40.0%</td>
<td>34.2%</td>
</tr>
</tbody>
</table>

Table C1. Comparison of frequency of occurrence of problems with driving: Small sample 25 responses from antenatal clinic compared to large sample 600 responses.
Appendix C

Summary of 25 responses from the small sample of pregnant women

How much is your driving being adversely affected by pregnancy?

- 63.6% Not at all
- 31.8% A little
- 4.5% A lot
- 0.0% So much I avoid driving

Figure C1. Summary of how much pregnant women think their driving is adversely affected by pregnancy (n=25).

How much is your safety being adversely affected by pregnancy?

- 52.0% Not at all
- 40.0% A little
- 8.0% A lot
- 0.0% So much I avoid driving

Figure C2. Summary of how much pregnant drivers think their safety is adversely affected by pregnancy (n=25).
Appendix C

Summary of 25 responses from the small sample of pregnant women

Figure C3. Summary of how much pregnant drivers think their comfort is adversely affected by pregnancy (n=25).

Figure C4. Summary of how much pregnant drivers think they are adversely affected by pregnancy when using the boot (n=25).
# APPENDIX D: ANTHROPOMETRIC MEASUREMENTS

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Definition</th>
<th>Posture</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight</strong></td>
<td>Measured to the nearest 0.5kg. The person wears indoor clothing and no shoes</td>
<td>Standing</td>
<td>Weight Scales</td>
</tr>
<tr>
<td><strong>Stature</strong></td>
<td>Measured vertically from the floor to the top of the head. The person stands erect, looking ahead, the arms hanging loosely at the side.</td>
<td>Standing</td>
<td>Stadiometer</td>
</tr>
<tr>
<td><strong>Sitting Height</strong></td>
<td>Measured vertically from the seat surface to the top of the head, compressing the hair. The person sits erect, looking straight ahead, hands in lap. The feet are supported at a level that ensures the thighs are horizontal.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Eye Height</strong></td>
<td>Measured vertically from the seat surface to the outer border of the eye socket. The person sits erect, looking straight ahead, hands in lap. The feet are supported at a level that ensures the thighs are horizontal.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Back of head height</strong></td>
<td>Measured vertically from the seat surface to the protruding back of the head (occiput). The person sits erect, looking straight ahead, hands in lap and with the feet supported at a level that ensure the thighs are horizontal.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Mid Shoulder Height</strong></td>
<td>Measured vertically from the seat surface to a point midway between the bony tip of the shoulder (acromion) and the neck. The person sits erect, looking ahead with the arms relaxed at the side and the hands resting in the lap.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Shoulder Height</strong></td>
<td>Measured vertically from the seat surface to the bony tip of the shoulder (acromion). The person sits erect, looking straight ahead, hands in lap. The feet are supported at a level that ensures the thighs are horizontal.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Shoulder Breadth</strong></td>
<td>Measured horizontally between the bony tips of the shoulders. The person stands or sits erect with arms at the sides. The shoulders should be relaxed so that they slope down and forward. Measured from behind the person.</td>
<td>Standing &amp; Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Measurement</td>
<td>Definition</td>
<td>Posture</td>
<td>Equipment</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Whole Body Breadth</td>
<td>Measured horizontally across the whole breadth of the body. The person stands or sits erect with the arms hanging loosely at the sides. Measured from behind the person.</td>
<td>Standing &amp; Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Chest Depth</td>
<td>Measured horizontally from the rear vertical plane to the bustpoint. The measure is taken at the end of quietly breathing out, without compressing the breast.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Chest Height</td>
<td>Measured vertically from the seat surface to the height of the bustpoint. The person sits erect.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Chest Circumference</td>
<td>The maximum circumference, measured horizontally around the chest at the level of the bustpoints. The person stands or sits erect, looking forwards, with shoulders relaxed and breathing quietly.</td>
<td>Standing &amp; Seated</td>
<td>Tape Measure</td>
</tr>
<tr>
<td>Abdominal Depth</td>
<td>Measured horizontally from the rear vertical plane to the maximum protrusion on the front of the relaxed abdomen. The person sits erect with the arms hanging relaxed by the side.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Waist Height</td>
<td>Measured vertically from the seat surface to the point of maximum circumference of the abdomen. The person sits erect, hands in lap, the feet are supported at a level that ensures the thighs are horizontal.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Abdominal Circumference</td>
<td>Measured horizontally at the level of the waist or at the level of maximum abdominal protrusion. The person stands or sits erect with the arms held slightly away from the sides of the body.</td>
<td>Standing &amp; Seated</td>
<td>Tape Measure</td>
</tr>
<tr>
<td>Height of Maximum Lumbar Curvature</td>
<td>Measured vertically from the seat surface to the point where the lumbar spine is most inwardly curved. The person sits erect, hands in lap. The feet are supported at a level that ensures the thighs are horizontal.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Hip Circumference</td>
<td>Measured horizontally around the hips at the point of maximum protrusion. The person stands or sits erect, feet together, arms held away from the sides.</td>
<td>Standing &amp; Seated</td>
<td>Tape Measure</td>
</tr>
<tr>
<td>Measurement</td>
<td>Definition</td>
<td>Posture</td>
<td>Equipment</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Hip Breadth</td>
<td>Measured horizontally across the widest part of the hips. The person sits erect and with the legs and feet supported.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Thigh Depth</td>
<td>Measured vertically from the seat surface to the upper, uncompressed, surface of the thigh where the thigh depth is greatest. The seat is adjusted so that the person can sit with the lower legs vertical, thighs horizontal and feet flat.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Buttock to Front of Knee</td>
<td>Measured horizontally from the most posterior part of the buttock to the front of the knee. The seat is adjusted so that the person can sit with the lower legs vertical, thighs horizontal and feet flat.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Buttock to Back of Knee</td>
<td>Measured horizontally from the most posterior part of the buttock to the underside of the knee. The seat is adjusted so that the person can sit with the lower legs vertical, thighs horizontal and feet flat.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Knee Splay</td>
<td>Measured horizontally between the outer borders of the knees. Person sits erect with legs in comfortable normal seated position and knees at 90 degrees.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Knee to Knee Breadth</td>
<td>Measured horizontally between the outer borders of the knees. Person sits erect with legs together and knees at 90 degrees.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Top of Knee Height</td>
<td>Measured vertically from the floor to the top of the knee. The seat is adjusted so the person can sit with the lower legs vertical, thighs horizontal, and feet flat.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Back of Knee Height (Popliteal)</td>
<td>Measured vertically from the floor to the popliteal tendon which extends back from the knee along the lower, outer part of the thigh. The seat is adjusted so the person can sit with lower legs vertical, thighs horizontal and feet flat.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Ankle Circumference</td>
<td>Measured around the ankle at the level of the inner ankle bone. The person stands or sits with weight evenly distributed on both legs.</td>
<td>Standing &amp; Seated</td>
<td>Tape Measure</td>
</tr>
<tr>
<td>Measurement</td>
<td>Definition</td>
<td>Posture</td>
<td>Equipment</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<td>-----------------</td>
</tr>
<tr>
<td><strong>Foot Length</strong></td>
<td>Measured horizontally from the tip of the longest toe to the back of the heel. The person stands or sits with their weight evenly distributed on both feet.</td>
<td>Standing &amp; Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Rear of Heel to Joint at Base of Big Toe</strong></td>
<td>Measured horizontally from the rearmost part of the heel to the protrusion at the base of the 1st toe on the inner (medial) border of the ball of the foot.</td>
<td>Standing &amp; Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Foot Breadth</strong></td>
<td>Measured horizontally across the widest point of the foot, perpendicular to the length of the foot.</td>
<td>Standing &amp; Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Forward Fingertip Reach</strong></td>
<td>Measured horizontally from the wall to the tip of the middle finger. The person sits erect, the arm and hand stretched horizontally in front of them.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Forward Grip Reach</strong></td>
<td>Measured horizontally from the wall to the centre of a rod gripped in the hand. The person sits erect, the arm stretched horizontally in front of them.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Shoulder (Acromion) to Underside of Elbow</strong></td>
<td>Measured vertically from the bony tip of the shoulder (acromion) to the underside of the elbow. The person sits with the upper arm vertical and the elbow flexed to 90 degrees.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Back of Elbow to Tip of Middle Finger</strong></td>
<td>Measured from the back of the elbow to the tip of the middle finger. The person sits with the upper arm vertical and the elbow flexed to 90 degrees. The hand and fingers are held straight and in alignment with the forearm.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Back of Elbow to Grip</strong></td>
<td>Measured from the back of the elbow to the centre of a rod gripped in the hand. The person sits with the upper arm vertical and the elbow flexed to 90 degrees. The hand is held in alignment with the forearm.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td><strong>Hand Length</strong></td>
<td>Measured from the wrist crease directly below the pad of muscle at the base of the thumb to the tip of the middle finger. The hand and fingers should be held straight and flat, palm uppermost.</td>
<td>Seated</td>
<td>Anthropometer</td>
</tr>
<tr>
<td>Measurement</td>
<td>Definition</td>
<td>Posture</td>
<td>Equipment</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Index Finger Length</td>
<td>Measured from the tip of the index finger to the base of the finger. Finger held straight.</td>
<td>Seated</td>
<td>Vernier</td>
</tr>
<tr>
<td>Hand Breadth across knuckles</td>
<td>Measured across the palm of the hand at the junction between the palm and fingers, not including the thumb. The hand and fingers should be held flat, palm uppermost.</td>
<td>Seated</td>
<td>Vernier</td>
</tr>
<tr>
<td>Index Finger Breadth</td>
<td>Measured across the broadest part of the joint toward the tip of the index finger, from the side nearest the thumb to the side nearest the middle finger. Finger held straight.</td>
<td>Seated</td>
<td>Vernier</td>
</tr>
<tr>
<td>Seat Height</td>
<td>Measured vertically from the floor to the seat surface. The seat should be adjusted so the person can sit with the lower legs vertical, thighs horizontal and feet flat.</td>
<td>Seated</td>
<td>Adjustable seat with anthropometer</td>
</tr>
</tbody>
</table>
# APPENDIX E: USABILITY SURVEY

## Website Questions

**Name:** _____________________________________________________________

**Date:** ______________________________________________________________

Site A[ ] or B[ ]

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>This website has much that is of interest to me</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>It is difficult to move around this website</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>I can quickly find what I want on this website</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>This website seems logical to me</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>This website needs more introductory explanations</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>The pages on this website are very attractive</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>I feel in control when I’m using this website</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>This website is too slow</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>This website helps me find what I’m looking for</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Learning to find my way around this website is a problem</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>I don’t like using this website</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>I can easily contact the people I want to on this website</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>I feel efficient when I’m using this website</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>It is difficult to tell if this website has what I want</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Using this website for the first time is easy</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>This website has some annoying features</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Remembering where I am on this website is difficult</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Using this website is a waste of time</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>I get what I expect when I click on things on this website</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Everything on this website is easy to understand</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

Do you have any additional comments about the website’s ease of use?

Is there anything you think is missing from this website?

What help or support have you needed in using this website?

Which part of this website do you find most interesting or useful?
### Website Comparison Questions

<table>
<thead>
<tr>
<th></th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attractiveness of pages</strong></td>
<td>Unattractive</td>
<td>Unattractive</td>
</tr>
<tr>
<td><strong>Information on screen</strong></td>
<td>Disorganised</td>
<td>Disorganised</td>
</tr>
<tr>
<td><strong>Interface</strong></td>
<td>Unpleasant</td>
<td>Unpleasant</td>
</tr>
<tr>
<td><strong>Characters on screen</strong></td>
<td>Hard to read</td>
<td>Hard to read</td>
</tr>
<tr>
<td><strong>Colour scheme</strong></td>
<td>Unpleasant</td>
<td>Unpleasant</td>
</tr>
<tr>
<td><strong>Professionalism of site</strong></td>
<td>Unprofessional</td>
<td>Unprofessional</td>
</tr>
<tr>
<td><strong>Consistency with image of other engineering websites</strong></td>
<td>Inconsistent</td>
<td>Inconsistent</td>
</tr>
</tbody>
</table>

**1 2 3 4 5**

Attractiveness of pages: Unattractive ↔ Attractive
Information on screen: Disorganised ↔ Organised
Interface: Unpleasant ↔ Pleasant
Characters on screen: Hard to read ↔ Easy to read
Colour scheme: Unpleasant ↔ Pleasant
Professionalism of site: Unprofessional ↔ Professional
Consistency with image of other engineering websites: Inconsistent ↔ Consistent

I would prefer to use: (choose only one)

- **Site A**
- **Site B**

Please give any additional comments about either/both sites:

**Site A:**

**Site B:**
APPENDIX F: PUBLISHED PAPERS

This Appendix F provides copies of the published journal and conference papers that are related to this thesis. Each paper has a title page to locate it using the page numbering of the thesis. Note that papers may also include their own page numbers where they were published as part of another journal or book.

Journal Papers:


Conference Papers:


ICrash2004: International Crashworthiness Conference, San Francisco, USA, 14th-16th July. 


‘Expecting’: occupant model incorporating anthropometric details of pregnant women

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Abstract: This study reports the research for a design tool related to pregnant women’s safety during car travel. Anthropometric measurements are taken to generate an occupant model incorporating pregnancy related changes. These anthropometric changes mean that a pregnant occupant may be excluded by the designs, based upon non-pregnant female anthropometry. The paper explains the generation of a comprehensive parametric computer aided model of a pregnant occupant, ‘Expecting’. The model can represent different size pregnant occupants as well as the size differences occurring in standing and seated postures. This model can be used as a design tool for automotive designers to help ensure that vehicle designs can accommodate the anthropometric needs of pregnant occupants.

Keywords: pregnant; occupant; model; driver; safety; comfort; anthropometry; design.


Biographical notes: B. Serpil Acar is a Senior Lecturer at the Department of Computer Science at Loughborough University. After completing her PhD in Mathematics, she worked as a Researcher in engineering departments. Her current research interests include engineering design for women, mathematical modelling of human spine and system design processes. She works in close
‘Expecting’: occupant model incorporating anthropometric details

collaboration with engineering departments as well as with clinical and academic members of the medical schools. She is the Principal Investigator of several major Engineering and Physical Sciences Research Council funded projects investigating pregnant occupant safety.

Alix Weekes is a Research Associate for the EPSRC funded ‘Automotive Design: Incorporating the Needs of Pregnant Women’ project based in the Department of Computer Science at Loughborough University, UK. She graduated with honours from the Manufacturing Engineering Department at Loughborough University from the Product Design and Manufacture programme. She is currently based at Thatcham, the Motor Insurance Repair Research Centre as a Safety Research Engineer. She is also completing a part-time PhD thesis concerned with human computer interaction (HCI) for automotive designers and engineers.

David Van Lopik is a Research Associate for the EPSRC funded ‘Expecting: A Pregnant Occupant Model’ project based in the Department of Computer Science at Loughborough University, UK. He completed his PhD thesis concerned with head and neck modelling and whiplash injuries in the Department of Mechanical Engineering at Loughborough University before he was employed as an RA of the ‘Expecting’ project. He is currently based at Atkins Aviation and Defence Systems.

1 Introduction

Every year, there are approximately 670,000 pregnant women in the UK (Office for National Statistics, 2000), the majority of whom are likely to be car occupants during some or all stages of their pregnancy. More women are driving today and driving longer distances than ever before (Haapaniemi, 1996) and consequently, increasing numbers of pregnant women are being exposed to automobile accidents. It has been estimated that around 130,000 women in the second half of pregnancy are involved in car crashes annually in the USA (Klinich et al., 1999). Of these, around 30,000 will sustain treatable injuries, while approximately 160 will die. Of those that survive, between 300–3,800 will experience a fetal loss (Klinich et al., 1999) making motor vehicle crashes the leading cause of traumatic fetal mortality (Weiss et al., 2001). Placental abruption, uterine rupture, direct fetal injury and maternal mortality have been identified as the main causes of immediate fetal death. Placental abruption has been shown to account for 50% to 70% of all fetal losses following motor vehicle crashes (Pearlman et al., 1990). Little is known about the delayed effects of car accidents on pregnant women and on adverse fetal outcomes.

The safety of pregnant women can be compromised due to the changes of body size and shape that occur during pregnancy. Anthropometric changes occur throughout the body and are not limited to the abdominal region (Acar and Weekes, 2005). Changes in the abdomen, chest and hip regions are particularly important because they can influence the fit and positioning of the seat belt during pregnancy (Acar and Weekes, 2005). The correct position for the seat belt has been established so that the shoulder section passes between the breasts and around the abdomen and the lap section passes across the hips and underneath the bump (Crosby et al., 1972). This position has been adopted by governmental safety guidelines, both in the UK (DFT, 2003) and the USA (NHTSA,
However, only 13% of pregnant women are actually able to position their seat belt correctly (Acar and Weekes, 2005, 2003). Some pregnant women do not use the seat belt due to safety concerns and discomfort and others may take unsafe actions such as holding the belt away from the body during car travel, which may prevent it from functioning correctly (Acar and Weekes, 2003). Pregnant women and their fetuses may not be adequately protected by their seat belt if it is incorrectly positioned or not used.

Another cause of concern in pregnancy is increased abdominal protrusion toward the steering wheel. Acar and Weekes (2005) found that 11% of pregnant women were seated with less than 2.5 cm between the abdomen and the steering wheel or with their bump actually in contact with the steering wheel. This proximity to the steering wheel may put the placenta at increased risk of abruption from direct impact with the steering wheel (Aschkenazi et al., 1998). Abdominal depth is defined as the ‘maximum horizontal distance from the vertical reference plane to the front of the abdomen in standard sitting position’ (Pheasant, 1996). The abdominal depth data can be used to define the clearance between the steering wheel and the occupant. Pheasant (1996) suggests that adequate clearance is defined by lower limb length and abdominal depth. He states that 95th percentile abdominal depth with the seat in the foremost position should be used, but states that it is even better to use abdominal depth of a pregnant woman (Pheasant, 1996). However, Pheasant only provides abdominal depth and forward grip reach data for pregnant women, without providing data for the rest of the body, making it difficult to accurately represent the needs of the pregnant occupant since the size of the fetus and hence the abdomen is not necessarily related to pregnant woman’s stature.

It is important for automotive designers to consider the changed shape and size of pregnant women to ensure that the pregnant occupant is not excluded from designs. This is particularly imperative if the type of car is designed and marketed for women of child-bearing age. Acar and Weekes (2004a) introduced an anthropometry website for use by automotive designers, so that pregnant occupant anthropometry can be incorporated into vehicle design. This anthropometric data has been collected as part of the ‘Automotive Design: Incorporating the Needs of Pregnant Women’ project based at Loughborough University. The pregnant anthropometry has been used to generate the pregnant occupant model presented in this paper. The model is a design tool for automotive designers to help ensure that vehicle designs can accommodate the anthropometric needs of the pregnant occupant.

2 Method

In this study, 48 anthropometric measurements were taken from 100 pregnant women. The details of this sample of pregnant women are provided in Table 1. The measurements recorded were adapted by the authors for pregnant women based on standard anthropometric postures (Pheasant, 1996). Women were recruited in two locations in the UK: Loughborough University and the Luton & Dunstable Hospital National Health Service Trust. Volunteers removed their shoes and wore light clothing. The equipment used included weight scales, an anthropometer, a digital vernier calliper, a stadiometer and a tape measure.
Table 1

<table>
<thead>
<tr>
<th></th>
<th>Second trimester (Weeks 13–28)</th>
<th>Third trimester (Weeks 29–40+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of volunteers</td>
<td>35 women</td>
<td>65 women</td>
</tr>
<tr>
<td>Mean week of pregnancy</td>
<td>21.6 weeks</td>
<td>35.5 weeks</td>
</tr>
<tr>
<td>Std. dev. week of pregnancy</td>
<td>4.5 weeks</td>
<td>2.8 weeks</td>
</tr>
<tr>
<td>Driver</td>
<td>34 women</td>
<td>52 women</td>
</tr>
<tr>
<td>Non-driver and unknown</td>
<td>0 and 1 women</td>
<td>4 and 9 women</td>
</tr>
</tbody>
</table>

The first comprehensive analysis of the anthropometry of pregnant women throughout the entire body, specifically for the automotive industry, is presented in an *International Journal of Vehicle Design* paper by Acar and Weekes (2006). The paper classified the measurements in four groups: weight and stature, head and shoulders region, trunk region and limbs. The analysis of every parameter is given in detail in the paper and it was concluded that the whole body measurements provide an insight to the changes, however, the most significant changes during pregnancy occur in the chest, abdominal and thigh areas.

The relevant trunk region measurements (i.e., chest, abdominal and thigh area) which are illustrated in Figure 1 are incorporated in the generation of ‘Expecting’: the Pregnant Occupant Model.

Figure 1  An illustration of the trunk region anthropometric measurements

### 3 Exclusion from design

The typical engineering practice involves producing designs to accommodate 90% of the population by accommodating people between the 5th and 95th percentiles. However, the
anthropometric data available for UK females in Adultdata by DTI (1998) does not include measurements of pregnant women. If this data for non-pregnant women is used in a design and no consideration of pregnant women is made, then the design will not accommodate the changed anthropometry of pregnant women. For example, the abdominal depth of pregnant women is greatly increased by pregnancy. The mean abdominal depth of pregnant women measured in the third trimester is 359.5 mm. This is significantly (p<0.03) larger than the mean abdominal depth for non-pregnant women given by Acar and Weekes (2006) of 269.9 mm. The impact of this difference between the abdominal depths of pregnant and non-pregnant women is clearly illustrated by the difference of the two curves in Figure 1. The mean abdominal depth of non-pregnant females corresponds to the 1st percentile for pregnant women in the third trimester. This means that 99% of third trimester pregnant women might be excluded by a design based on the 50th percentile non-pregnant female anthropometric data, as shown in Figure 2.

Figure 2  Abdominal depth distribution of non-pregnant UK female data* and that of pregnant women in third trimester**

- Pregnant women in third trimester
- Non-pregnant UK females

Source: *DTI, Adultdata, London (1998) and **measurements from this study

Even if a design is produced to accommodate the 95th percentile large female, it still may not accommodate up to 62% of pregnant women in the third trimester, as shown in Figure 3.

Furthermore a design produced to accommodate a large 95th percentile male might not accommodate 65% of pregnant women in the third trimester, as shown in Figure 4. Using the 95th percentile male anthropometry as the upper limit might be inadequate for accommodating pregnant women because the women are so physically altered by pregnancy.

Abdominal depth is not the only example of analysed anthropometric data. Similar to the abdominal differences, a change in the chest circumferences and chest depth give an understanding of how much the breasts enlargement can potentially affect the comfort and safety of pregnant women. The increasing size of the breasts can affect how the seat belt fits around the breasts and stays in position to avoid cutting into the neck during car
travel. The increasing chest depth also means that the breasts are closer to the steering wheel. The exclusion rate for a design that accommodates up to the 95th percentile male is 49% in seated posture. Using the non-pregnant female 95th percentile data as the limit for accommodation might still exclude 36% of pregnant women.

**Figure 3** Abdominal depth distribution of non-pregnant UK female data* and that of pregnant women in third trimester**

- Pregnant women in third trimester
- Non-pregnant UK females

Source: *DTI, Adultdata, London (1998) and **measurements from this study

**Figure 4** Abdominal depth distribution of UK male data* and that of pregnant women in third trimester**

- Pregnant women in third trimester
- UK males

Source: *DTI, Adultdata, London (1998) and **measurements from this study
Automotive designers can avoid excluding pregnant women from designs by incorporating pregnant occupant anthropometry into the designs. Detailed description of the generation of ‘Expecting’, Loughborough University Pregnant Occupant Model is given in the following sections.

4 Pregnant occupant model

The unique anthropometric measurements from pregnant women, collected in the first stage of this research, are used to develop a parametric model of the pregnant female occupant. The aim is to produce a tool that will facilitate the production of a three-dimensional model of a pregnant woman of any size and at any stage of gestation.

The underlying structure of the model is based on the kinematic linkage model of the MADYMO 5th percentile female facet occupant, developed by TNO Automotive (2003). The positions of the various kinematic joint centres, representative of actual joints in the human body, are positioned relative to the hip joint centre or ‘H’ point. Corresponding joint centres are connected by a rigid link, which can be thought of as the ‘bones’ of the model. The basic arrangement of the linkage model is depicted in Figure 5 showing how the joint centres are connected to form the body.

Figure 5  Kinematic linkage model of the MADYMO 5th percentile female facet occupant model (see online version for colours)

The three-dimensional geometric surface of the model is constructed from a series of cross sections that are positioned relative to their parent ‘bone’ linkage and derived from the anthropometric measurements of pregnant women. For example, the cross section of
the knee, positioned at the knee joint, has a width equal to half the measured knee to knee breadth and a depth equal to the difference between the measured sitting distance for buttock to the front of the knee and buttock to the back of the knee. The model has been developed in an upright standing position with arms horizontal and out to the sides, allowing for easy application of standard anthropometric measurements and enabling all the body cross sections to be orientated either horizontally or vertically.

To describe the pregnant abdomen, the sagittal plane abdomen contour is defined by three points positioned relative to the ‘H’ point, they are: the pubic symphysis, the point of maximum abdominal height and depth, and the xiphoid process (bottom of sternum). For the initial model, the point of maximum abdominal height and depth representative of a 5th percentile woman in her 30th week of pregnancy has been used. Figure 6 shows the model; all the cross sections used to define the geometric surface are shown along with the underlying segment linkages.

Figure 6  Side and front view of the pregnant female model

Note: In the side view, the points defining the abdomen contour are labelled.

The pregnant female model can be easily scaled to represent women of different statures and to embody the unique changes experienced at any stage of the gestational period. A second anthropometric study measuring a series of bony landmarks of pregnant women in driving postures is undertaken to enable the scaling of the current model. Calculation methods as presented by Reed et al. (1999) are used to determine joint locations from measured exterior landmarks. For the legs, the positions of the lateral femoral condyle (bony surface on the outside of the knee) and the lateral malleolus (bony surface on the outside of the ankle) are recorded, along with pelvic width and depth, to allow the positions of the knee, ankle and hip joints be calculated. The positions of these joints in the model can be adjusted to change the lengths of the upper and lower parts of the legs.
accordingly. Similarly, the positions of the joints of the upper extremity can be determined from the measured positions of the wrist, lateral humeral condyle (bony surface on the outside of the elbow), and acromion landmarks and used to adjust lengths of the upper and lower parts of the arm of the model.

To adjust the length of the spine, a series of measurements are required to determine the positions of important transitional joints as shown in Figure 5. The position of the upper neck joint, C0-C1, also known as the atlanto-occipital joint, can be determined from two measured landmarks on the head. The lower neck joint, C7-T1 is calculated using the measured positions of the suprasternale and C7 spinous process surface landmarks. The relative positions of these two joints thus define the length of the neck. The length of the thorax is defined as the distance between the lower neck joint, C7-T1, and the upper lumbar joint, T12-L1. The position of the upper lumbar joint can be found by using the measured position of the spinous processes of T8 and T12. Finally, the lower lumbar joint, L5-Sacrum can be calculated using the measured pelvis width and depth. Pelvis width is defined as the distance between the left and right anterior superior iliac spines (ASIS) and pelvic depth as the distance between the left (right) ASIS and the left (right) posterior superior iliac spine.

In order to take into account the various size changes experienced during pregnancy, the individual cross sections of the model can be scaled to change the circumferences of any body element as required. In particular, the size and shape of the abdomen can be altered by moving the point of maximum abdominal height and depth accordingly.

5 Sitting and standing

Pregnant women may be inappropriately represented if the anthropometric data is taken from an unrepresentative posture. For example, for pregnant women in the third trimester, the mean ‘seated hip circumference’ is 1,249.8 mm, which is 94.6 mm larger than the ‘standing hip circumference’. It is important to use anthropometric data measurements taken from the seated posture in designs where the user will be seated. The abdominal and chest sizes are also greater in seated position than in standing, which reinforces the importance of using the appropriate anthropometry from a relevant position.

The difference in standing and seated anthropometry occurs because the soft tissue spreads outward from the body in the seated position. The seat applies pressure to the buttocks causing the hip tissues to spread. The thighs make contact with the base of the abdomen in the seated posture (Acar and Weekes, 2005), which reduces the space available for the abdomen and causes the abdomen to spread outward from the body. The abdomen is pushed upward and outward from the body, which applies pressure on the breasts and causes the soft tissue around the chest region to spread. Pregnancy exaggerates this spreading effect in seated position and using the anthropometric data recorded from a relevant position is even more important when the subjects are pregnant.

Automotive designers can accommodate the difference between seated and standing sizes by using the anthropometric data of the pregnant occupant in the appropriate positions. For example, only the seated anthropometry should be used in the design process of vehicle interiors.
‘Expecting’: occupant model incorporating anthropometric details

Figure 7  Pregnant occupant model in driver position (see online version for colours)

Note: Dimensions are changed according to the seated anthropometric data of pregnant women.

Acar and Weekes (2004b) analysed 450 questionnaire responses filled in by pregnant women and concluded that the restricted movement that women experience during pregnancy causes them to alter their method of vehicle entry and egress. For example, when women are getting in to the car, they tend to separate the movement into two stages. The two separate motions are first to sit down on the seat whilst facing laterally out of the door opening, then secondly, to swivel to face the front of the car whilst lifting their legs in. This is a different technique compared to before pregnancy, when women would normally move from standing to seated in the car in one fluid motion. The reverse of the two-stage entry method is used for vehicle egress.

Hence, during entry into the vehicle and egress out of the vehicle, the occupant moves between the standing and seated postures so the body undergoes transition between sizes. This transition between postures should be accommodated during the design of door openings and for determining the clearance between the seat and the steering wheel. The cross sections in the model can be altered to take into account the size changes between standing and sitting postures and the deformation of the buttocks when sitting.

6 Discussions and conclusions

This paper presents the importance of considering pregnant occupant anthropometry for vehicle designers. Using anthropometric data for males or non-pregnant females might exclude pregnant women from being accommodated in the automotive interior designs. Even using large male (95th percentile) data can be inadequate for this purpose. It is also important to consider the difference in size for seated and standing positions that occurs during pregnancy.

The most important recommendation to automotive designers and motor manufacturers is using appropriate anthropometric and geometric models of pregnant women, which incorporate anthropometric data taken from the relevant positions, if they
would like to include pregnant occupants in their design. General recommendations such as availability of adaptable integrated seat belts, adjustable pedals, retractable steering wheels including the pregnant population as discussed by authors in detail (Acar and Weeks, 2005) would not exclude the non-pregnant and male populations and may also include further populations such as overweight occupants whose numbers are increasing all over the world and also small-stature occupants.

Furthermore, cars are usually the second most expensive items bought by families. Considering the comfort and safety issues for pregnant occupants without affecting the comfort and safety of non-pregnant occupants might be expected as a bonus and a selling point of family-friendly cars since more women are travelling today and travelling longer distances than ever before and a subsequently increasing number of pregnant women are being exposed to automobile accidents.

A comprehensive parametric pregnant occupant model representing pregnancy is presented as a design tool that can be used to evaluate vehicle safety systems and interiors to help improve the pregnant occupants’ safety.

The model has the ability to be scaled between the standing and seated posture sizes of the pregnant occupant. This is particularly advantageous to designers to help meet the anthropometric needs of the pregnant women in both positions. Other examples of specific safety concerns that can be addressed using the pregnant occupant model include the seat belt positioning, steering wheel clearance and head restraint geometry.

The work described in this paper is part of a comprehensive research program at Loughborough University to improve pregnant occupant safety using a computational pregnant occupant model for crash protection. The overall aim is to produce a pregnant occupant model capable of simulating the dynamic response to impact and predict the risk of injury in automobile crashes.

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**References**


‘Expecting’: occupant model incorporating anthropometric details

Measurements for pregnant drivers’ comfort and safety

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Abstract: Pregnant women experience many different problems and difficulties with comfort and safety during car travel, which can be alleviated by accommodating pregnant women’s anthropometry. There has been a dearth of information about pregnant anthropometry and subsequently women’s needs have been neglected. This paper addresses the problem by presenting a detailed analysis of the anthropometric changes occurring throughout the body. The measurements have been selected for use in the vehicle design process, in order to best meet the needs of the automotive industry. The paper investigates the size and shape changes in pregnant women to calculate the possible exclusion rates for designs based on male and non-pregnant female data in order to help improving pregnant drivers’ safety and comfort. The paper points out the importance of changes not only in the abdomen but also the chest and hip regions.

Keywords: anthropometry; comfort; design; driver; measurements; occupant; pregnant; safety.


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1 Introduction

During pregnancy women experience a wide range of physical changes and symptoms, many of which can affect their car travel experience. In a previous study by the authors it was found that 99% of pregnant women experience some difficulty or problem with car travel (Acar and Weekes, 2003). These problems are concerned with both comfort and safety and the ‘Automotive Design: Incorporating the Needs of Pregnant Women’ project based at Loughborough University has provided a comprehensive analysis of pregnant women’s needs. For example, getting in and out of the car during pregnancy can cause great discomfort and difficulty due to the enlarged abdomen and restricted mobility (Acar and Weekes, 2004c). A specific safety issue for pregnant women is the proximity of their abdomen to the steering wheel as it enlarges, since many women are seated with their abdomen less than one inch away from the steering wheel or actually touching it, which puts them at increased risk of impact with the steering wheel during a collision (Acar and Weekes, 2004a). Many women have difficulty using the seat belt, particularly with positioning it correctly, due to the physical size and shape changes that occur and due to discomfort (Acar and Weekes, 2003, 2004a,b). The correct position for the seat belt in pregnancy is with the shoulder section passing across the shoulder, between the breasts, and around the abdomen, and the lap section passing across the hips and underneath the abdomen (American College of Obstetrics and Gynecology, 1999; Department for Transport, 2003; National Highway Traffic Safety Administration, 2002). However Acar and Weekes (2003) also established that as little as 13% of pregnant women are wearing their seat belts correctly, and that some women may also cease to use their seat belts during pregnancy. The comfort and fit of the seat belts are important to pregnant women’s safety. The discomfort currently experienced by pregnant women using today’s car seat belts could be due to lack of available anthropometric data and information about pregnant women for use during automotive design.

The design process relies upon the use of anthropometric data to determine the portion of the user population that will be accommodated by the design. The largest study of pregnant women’s anthropometry is by Yamana et al. (1984), which includes 44 dimensions measured from 520 pregnant women from the second to tenth month of pregnancy. The study was aimed at garment design, which means that few dimensions measured are applicable to the automotive design process. Pheasant (1986) then used the ratio scaling method (Pheasant, 1982) to modify the abdominal depth and forward grip reach dimensions from Yamana’s data, which is based on the assumption that British women are of similar proportions to Japanese women and that pregnancy will cause them to change in a similar way. Klinich et al. (1999) measured the anthropometry of 22 pregnant women, although the full set of measurements was recorded at the first session (approximately the 3rd/4th month). Only ten measurements applicable to the automotive design process, mainly concerned with the legs and abdomen, were recorded throughout the course of pregnancy so this provides a limited understanding of the changes occurring during
pregnancy. Finally, Alvarez et al. (1988) investigated the dimensional changes of the feet during pregnancy. The study compared 17 pregnant women with 16 comparable non-pregnant women. Only two dimensions, the foot length and width, are relevant to automotive design. There has been a dearth of anthropometric data for pregnant women that are pertinent to automotive design and safety testing. The safety and comfort considerations for pregnant occupants have subsequently been largely neglected. The study presented in this paper has addressed this problem by recording 48 anthropometric measurements selected specifically for their applicability to the vehicle design process. Previous research has tended to focus solely on the abdomen, and has not considered the changes occurring throughout the rest of the body. This paper presents the first comprehensive analysis of the anthropometry of pregnant women throughout the entire body, specifically for the automotive industry, and can help us to understand pregnant women’s needs in a holistic manner.

The methods of data collection and analysis are described in the following sections. The measurements and their possible effects upon pregnant women’s comfort and safety are presented in four groups: weight and stature, head and shoulders region, trunk region, and finally the limbs. The paper concludes with the discussion section.

2 Data collection method

A series of anthropometric measurements were recorded from pregnant women. All of the anthropometric measurements were selected for their applicability to the vehicle design process, and for understanding the changes in physical size and shape that occur during pregnancy. The measurements used the standard postures and procedures, as in Adultdata (DTI, 1998) and Pheasant (1986, 1990), but were adapted where necessary to suit the pregnant body. For example the waistline disappears during pregnancy so the abdominal circumference was recorded at the point of maximum circumference, rather than at the waistline (point of minimum circumference). The measurements are illustrated in Figures 1 to 3, according to the four groups: weight and stature, head and shoulders region, trunk region, and finally the limbs. The paper concludes with the discussion section.

Figure 1 An illustration of the anthropometric measurements: head and shoulders region (measurements and figures adapted for pregnant women from standard measurements in Adultdata (DTI, 1998)
Figure 2  An illustration of the anthropometric measurements: trunk region (abdomen, chest and hips) (measurements and figures adapted for pregnant women from standard measurements in Adultdata (DTI, 1998)

Figure 3  An illustration of the anthropometric measurements: limbs (arms and hands, legs and feet) (figures adapted for pregnant women from standard measurements in Adultdata (DTI, 1998)
Women were recruited in two locations in the UK: Loughborough University, and the Luton and Dunstable Hospital National Health Service Trust. The gestation levels of the pregnant women recruited to this study are summarised in Table 1. Over 550 pregnant women also completed a questionnaire for this project. The questionnaire findings are not explained in this paper although they are used to understand the need for specific measurements and interactions. The majority of pregnant women in the sample normally occupy the driver’s seat, and occasionally use the front or rear passenger seats, and in a few cases the normal occupant position is unknown. Volunteers wore light clothing and removed their shoes, and the equipment used included weight scales, a stadiometer, a digital vernier caliper, a tape measure and an anthropometer. At the time of writing 107 sets of measurements were recorded.

<table>
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<tr>
<th>Table 1</th>
<th>Details of the sample of pregnant women</th>
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<td><strong>Anthropometric measurements</strong></td>
<td><strong>Pregnancy and driving questionnaire</strong></td>
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3 Data analysis method

Throughout this paper the data analysis refers only to the sample of pregnant women that participated in this study. The data analysis focused on the pregnant women in the third trimester of pregnancy, since this is the period when the body is most altered by pregnancy. The data analysis is concerned with comparison against the non-pregnant UK females and male anthropometric data given in the literature, and with examining any extreme cases of physical changes that occur during pregnancy.

The exclusion rate is also investigated for each measurement, and is calculated as the percentage of pregnant women that might be excluded by a design that accommodates the 5th percentile non-pregnant UK female size up to the 95th percentile UK male size as defined by anthropometric data currently available in the literature.

The measurements were recorded from pregnant women within the UK so the data comparisons against non-pregnant females and males have only been concerned with the UK population. Throughout this study the measurements were compared against Adultdata (DTI, 1998), unless stated otherwise, which is the most recent published collection and uses PeopleSize (Open Ergonomics, 1998) as the source of the UK anthropometric measurements.

This study has found that some physical changes occurring during pregnancy are very important, and that some are less significant, but in all cases the comfort and safety of pregnant women may be affected.
3.1 Weight and stature

During pregnancy the weight increases not only due to growth of the foetus, but also due to the placenta, umbilical cord, amniotic and other body fluids. The mean weight recorded for the pregnant women in the third trimester was 80.8 kg, which is 14.1 kg greater than the mean weight for non-pregnant females of 66.7 kg as given in Adultdata. It was also 1 kg greater than the mean weight for males. The exclusion rate for weight was 12% as shown in Figure 4, so a design that accommodates up to the 95th percentile male weight might exclude 12% of pregnant women by the third trimester.

Extreme weight gain in pregnancy can occur in average women. For example the woman with the greatest weight increase of 35 kg had pre-pregnant weight of 70 kg, which is only slightly more than the mean for non-pregnant females of 66.7 kg. The maximum weight recorded for pregnant women was 128.5 kg, which is 27.4 kg greater than the 95th percentile male weight. The pregnant women had a mean stature that was slightly greater (8 mm) than the mean value for non-pregnant females in the literature.

3.2 Head and shoulders region

The anthropometric changes occurring during pregnancy are not limited to the abdomen and some may occur in the head and shoulders region. The measurements of this region are illustrated in Figure 1, and their analysis and implications for pregnant women’s comfort and safety are described in this section.

The head height measurements recorded were: sitting height, eye height and back of head height, as shown in Figure 1. These are needed to define the head
position in order to position the head restraint correctly in relation to the head, and to provide an adequate field of vision. The location of the shoulder is also needed to position the seat belt so that it passes over the occupant’s shoulder, so the shoulder and mid-shoulder heights shown in Figure 1 were also recorded for the pregnant women.

When compared to the non-pregnant female data in Adultdata the pregnant women seem to have a slightly lower head position whilst seated. For example the mean sitting, eye, and back of head heights are 35, 25 and 17 mm lower respectively. It is also interesting to note that if a design only accommodated the range down to the 5th percentile UK female, the head positioning measurements are actually lower than these values and so the design might exclude some of the pregnant women. Limiting the range of accommodation to the 5th percentile UK female data for sitting height, eye height and back of head height might exclude 32, 23, and 16% percent of third trimester pregnant women respectively. The mean mid-shoulder height and shoulder height (see Figure 1) for the pregnant women were also slightly lower, 21 and 39 mm respectively, than the values for non-pregnant females in Adultdata. Furthermore, a design with accommodation limited to 5th percentile female data might exclude 21 and 39% of the pregnant women respectively. This shows a similar pattern to the head heights, whereby during pregnancy these locations (the mid-shoulder and the bony tip of the shoulder) are slightly lower. All of this evidence indicates that in sitting upright posture the women have their head and shoulders positioned slightly lower during pregnancy. This altered sitting posture could be caused by a more lordotic spinal shape associated with pregnancy that results in the overall head and shoulder heights being lower. It is important to consider the altered head and shoulder heights to accommodate pregnant women’s comfort and safety needs. With the head position slightly lower pregnant women may experience a restricted field of vision, particularly for seeing over the dashboard and steering wheel out of the front windscreen, unless this range is accommodated in the design of relevant car features such as seat height adjustments. The lower head position could also mean the pregnant women have difficulty seeing past the head restraint whilst turning around to see out of the rear windscreen during reversing manoeuvres. The position of the pregnant occupant’s shoulder is important for positioning of the shoulder portion of the seat belt across the shoulder and clavicle. The correct positioning of the seat belt during pregnancy could be critical to ensure the safety of the pregnant woman and the foetus.

The mean shoulder breadth and whole body breadth measurements could be important for the car seat design, however the difference between the measurements of pregnant women and non-pregnant females was small and insignificant.

### 3.3 Trunk region: breasts, abdomen and hips

This study has taken a holistic approach to provide a comprehensive analysis of the changes occurring throughout the entire body. The abdomen is the area where the greatest physical change occurs during pregnancy although it is important to remember that the enlargement is not limited to the abdominal region. The breasts and hips also increase considerably in size, so the trunk region is the region of
greatest anthropometric change during pregnancy. Neglecting the changes occurring in the breasts and hips can result in comfort (and hence safety) problems for pregnant women. The anthropometry changes and their implications for the breasts, abdomen, and hips are described in detail in this section. All of the measurements recorded for this region are illustrated in Figure 2.

3.3.1 Breasts

The breasts increase in size during pregnancy in preparation for breast-feeding. This is one of the first changes in the pregnant body, noticeable even in the first trimester. The measurements recorded (shown in Figure 2) were the chest circumference in standing and seated posture, and chest depth and height whilst seated. The chest circumferences and chest depth give an understanding of how much the breasts’ enlargement affects the chest region during pregnancy. The chest height measurement helps the location of the bustpoints within the vehicle. The increasing size of the breasts can affect how the seat belt fits around the breasts, and can cause women difficulty with positioning the shoulder portion of the belt correctly, which could prevent the seat belt from protecting as intended (Acar and Weekes, 2004a). The enlarged breasts can mean that the seat belt is too tight or that it cuts into the breasts. The seat belt may also be difficult to fit between the breasts, or may slip out of position and cut into the neck during car travel. Some pregnant women take actions such as holding the seat belt away from the neck in order to relieve discomfort, but do not realise that the slack in the belt could result in reducing the protection of the seat belt during a collision (Acar and Weekes, 2003). The increasing chest depth also means that the breasts are closer to the steering wheel. Overall the anthropometric changes occurring to the breasts can greatly influence pregnant women’s comfort and safety during car travel.

The mean standing chest circumference in standing posture was 92 mm larger than the mean for non-pregnant UK females. The mean chest circumference in seated posture had to be compared against standing posture for the non-pregnant UK females, since the only data available are recorded in standing posture. In this case the difference is 117 mm between the mean for pregnant women in seated posture and the mean for non-pregnant females in standing posture. The larger chest circumference in seated posture during pregnancy is due to the spreading effect that occurs due to upward pressure applied by the abdomen to the base of the breasts. This ‘spreading’ effect causes the large difference between standing and sitting chest circumferences of pregnant women as shown in Figure 5. The exclusion rate for a design that accommodates up to the 95th percentile male is 40% for pregnant women in standing posture and 49% in seated posture. It should also be noted that the 95th percentile chest circumference is greater for non-pregnant females than for males (Pheasant, 1990). Consequently using the non-pregnant female 95th percentile data as the limit for accommodation might still exclude 26 and 36% respectively for standing and seated pregnant women. The maximum chest circumference recorded in standing and seated postures respectively were 1388 and 1430 mm. These values are both much greater than the 95th percentile value for males in (Pheasant, 1990), by 313 and 355 mm each.
Figure 5  Chest circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 40% of pregnant women for the standing posture, and 49% for seated posture.

The chest depth also increases during pregnancy, and the mean for pregnant women in the third trimester was 13 mm greater than the mean for non-pregnant UK females. For a design based upon accommodating up to the 95th percentile male the exclusion rate is 39% for chest depth, as shown in Figure 6. It is interesting to note that only 17% of pregnant women might be excluded by a design that accommodates up to the 95th percentile female value for chest depth of 324.8 mm. The maximum recorded value for pregnant women was 417 mm, which is 121 mm larger than the UK male 95th percentile.

It is clear that the increase in breast size during pregnancy is considerable in comparison to the non-pregnant females and male data, and that many pregnant women might be excluded from designs as a consequence. Chest height data is not available in the literature in seated posture and consequently no comparisons can be made for this dimension between the pregnant women’s measurements and the non-pregnant UK females or males.

Figure 6  A design to accommodate the 95th percentile UK male might exclude 39% of pregnant women in the third trimester for chest depth.
3.3.2 Abdomen

The abdomen is the area of greatest change during pregnancy and undergoes dramatic enlargement. The abdominal circumferences and abdominal depth provide a clear indication of the large increase in size of the abdomen during the gestation period. This growth of the abdomen not only means that the abdomen is closer to the steering wheel and at greater risk of impact during a collision, but also the seat belt is more difficult to fit around the altered abdomen. The seat belt can become too tight or cut into the abdomen causing discomfort. The abdominal enlargement can make it difficult to fit the lap portion of the seat belt underneath the abdomen and across the hips, and the lap belt often tends to ride upward onto the abdomen (Acar and Weekes, 2003, 2004a). Pregnant women are often concerned for the safety of their foetus and may take action to prevent the lap belt from laying over the abdomen by holding the belt, causing a slack in the belt which could, as a consequence, affect their safety.

The mean abdominal circumference in standing posture was 1136.6 mm, which is larger than the mean for non-pregnant females and males by 296.0 mm and 318.3 mm respectively. The differences were also statistically significant when comparing the pregnant women’s standing abdominal circumference against data for non-pregnant females ($p < 0.00002$) and males ($p < 0.02$). The differences in standing abdominal circumference between these three populations are illustrated in Figure 7. The exclusion rate is 67% if the anthropometric accommodation limit is set at the 95th percentile male. The maximum value recorded was 1410 mm and this is 317 mm larger than the 95th percentile male value.

![Figure 7](image-url) Standing abdominal circumference: a comparison of pregnant women in the third trimester against data for UK males and non-pregnant females

The sitting abdominal circumference for pregnant women in the third trimester follows a similar pattern to the abdominal circumference whilst standing. The mean of 1159 mm is even larger than for standing posture, due to the spreading effect in
The ‘spreading’ occurs for everyone whilst seated, but the effect is considerable during pregnancy hence causing the large difference between standing and sitting shown in Figure 8. Only standing abdominal circumference for non-pregnant females and males is available in the literature for comparison against the pregnant women’s seated abdominal circumference. The differences are statistically significant between the pregnant women’s seated abdominal circumference and standing abdominal circumference for non-pregnant females (p < 0.000004) and males (p < 0.004). For sitting abdominal circumference 75% of pregnant women might be excluded by a design based upon accommodating up to the 95th percentile male standing abdominal circumference. The maximum abdominal circumference recorded in seated posture was 1454 mm, which is 361 mm greater than the male 95th percentile value for standing abdominal circumference.

Figure 8 Abdominal circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 67% of pregnant women for the standing posture, and 75% for seated

The abdominal depth also increases greatly during pregnancy. The mean abdominal depth for pregnant women in the third trimester was 90 mm greater than the mean for non-pregnant females and the difference is also statistically significant (p < 0.03). In comparison to the male data the pregnant women’s mean abdominal depth was 79 mm greater and similarly statistically significant (p < 0.03). The exclusion rate for abdominal depth is 65% if the accommodation limit was the 95th percentile male data in the literature, instead of accommodating pregnant women’s data as shown in Figure 9. A design that accommodates up to the 95th percentile female data might however exclude a slightly less 63%.

The abdominal height was defined as the height of abdominal point (point of maximum circumference) from the seat surface. The abdominal point was used because the waistline disappears during pregnancy. The abdominal height data for pregnant women cannot be compared to waist height in non-pregnant females or males because the measurement uses different locations. The abdominal height measurement was used to describe the location of the abdominal point, which is important for its interaction with the steering wheel during a vehicle collision.
A design to accommodate the 95th percentile UK male might exclude 65% of pregnant women in the third trimester for standing abdominal depth. The height of maximum lumbar curvature was also recorded from the sample of pregnant women because it is relevant to the position of the lumbar cushions on the seat back. Discomfort can be a problem if the point of maximum curve of the lumbar cushions on the car seat back does not align well with the point of maximum lumbar curvature on the pregnant woman’s spine, and back pain is associated with driver distraction that may affect pregnant women’s safety (Acar and Weekes, 2003). For pregnant women, the mean height of maximum lumbar curvature was 18 mm lower than the mean for non-pregnant females. This could indicate a more lordotic spinal curve in sitting posture, in agreement with the head and shoulder heights as mentioned previously. Twenty-seven percent of pregnant women in the third trimester might be excluded by a design with an accommodation range limit set at the 5th percentile female, and this indicates the importance of considering the altered spinal posture during pregnancy.

3.3.3 Hips
The hip circumference measurements follow a similar pattern to the abdominal and chest circumferences of pregnant women. The increase in hip size is important to the design of car seats and in particular seat belts. The lap portion of the seat belt passes across the hips during pregnancy according to guidelines (American College of Obstetrics and Gynecology, 1999; Department for Transport, 2003; National Highway Traffic Safety Administration, 2002) therefore considering any increase in hip size might help pregnant women’s comfort with the seat belt. The hip breadth also increases greatly during pregnancy, and this is important to the specification of car seat breadth.

The mean hip circumference for pregnant women in standing posture was 116 mm larger than the mean for non-pregnant females, and the difference was also statistically significant ($p < 0.06$). The mean standing hip circumference for pregnant
women was 107 mm greater than the mean for males. The maximum value recorded for pregnant women’s standing hip circumference was 1475 mm, which is 307 mm greater than the male 95th percentile value in Adultdata. Using an accommodation range up to the 95% percentile male standing hip circumference for a design for seated pregnant women might in fact exclude up to 72% of pregnant women. This is because the hip circumference of pregnant women is even greater in seated posture than in standing posture, for example the mean is 97 mm greater as shown in Figure 10. The most extreme value of seated hip circumference recorded from pregnant women was over half a metre greater than the 95th percentile male value.

Figure 10 Hip circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 45% of pregnant women for the standing posture, and 72% for seated.

For hip breadth Figure 11 illustrates that 34% of pregnant women might be excluded from a vehicle that is produced to accommodate only up to the 95th percentile male, since the hip breadth is so greatly enlarged during pregnancy. In fact the 95th percentile female value in Adultdata is greater than the male value and might actually only exclude 10% of the pregnant women, so the range up to the 95th percentile female data would accommodate a greater portion of the pregnant women. The maximum hip breadth for pregnant women was 518 mm, which is 75 mm larger than the male 95th percentile value.

From the hip measurements of pregnant women in this study it is apparent that the hip region enlarges considerably during pregnancy in comparison with the non-pregnant females and male data, and that many pregnant women might be excluded from designs as a consequence. It is therefore important not to neglect the changes in hip size of pregnant women.

3.4 Limbs: arms and hands, legs and feet

Despite the trunk being the region of greatest change it is essential not to neglect changes that may occur throughout the rest of the body during pregnancy, hence the limbs were also included in this study. The measurements recorded from pregnant women’s limbs are illustrated in Figure 3. These measurements are important to check for the following comfort and safety reasons.
A design to accommodate the 95th percentile UK male might exclude 34% of pregnant women in the third trimester for hip breadth. The arm dimensions define pregnant women’s reach capabilities. Pregnant women often experience difficulties with reaching the vehicle controls on the dashboard, radio, heating/air-conditioning systems, sunroof, mirrors and storage compartments. Pregnant women may become distracted or have slower response times as a result of difficulty in reaching parts of the car, and hence their safety may be affected. Stretching and reaching actions can also be uncomfortable during pregnancy. If there are any changes in the hand dimension during pregnancy this might affect pregnant women’s comfort during operation of controls, for example gripping the steering wheel or gear stick could become more difficult. Pregnant women might also have difficulty with pressing buttons and controls on the vehicle dashboard.

The dimensions of the legs are particularly important for the specification of the pedals, and the distance from the pedals to the seat. The leg dimensions are also involved in specifying the seat track length and seat position within the vehicle. A common problem for pregnant women is difficulty in reaching and operating the pedals. This problem occurs because the women try to move their seat slightly rearward in order to accommodate the protruding abdomen and keep the distance between the abdomen and the steering wheel as large as possible. Any rearward movement of the seat is limited by leg length and the pregnant women’s ability to fully depress the pedals. Similarly, some pregnant women recline the seat backrest in order to allow more space for the enlarging abdomen, and this reclining of the seat backrest is limited by the arm lengths. Furthermore any dimension changes in the feet during pregnancy may result in difficulty with operating the pedals during driving. For example a common symptom experienced during pregnancy is swollen ankles. The ankle circumference is enlarged during pregnancy because the ankles tend to swell up due to water retention and oedema. This ankle swelling might mean that pregnant women have difficulty depressing the pedals comfortably.

This study has recorded the arm, hand, leg and foot dimensions of pregnant women since any changes might affect women’s ability to reach and operate the
steering wheel and pedals, and other driving controls. However there was little or no difference between the measurements from pregnant women in this sample and the non-pregnant female data in Adultdata. The 5th percentile female to male 95th percentile data range for these limb measurements will be adequate for accommodating the anthropometric needs of the pregnant women.

4 Discussion and conclusions

The ‘Automotive Design: Incorporating the Needs of Pregnant Women’ project has provided an insight into the anthropometric needs of pregnant women. This paper presents an analysis of their needs for use during the vehicle design process. The anthropometric measurements were selected specifically for use by the automotive industry, which is a major advantage of this study. The full data will be available in the form of a website in order to help accommodating pregnant women’s anthropometric needs, during all stages of pregnancy and in all postures. This will hopefully help to improve both comfort and safety for the pregnant occupant during car travel.

In terms of vehicle dynamics in a collision accommodating the altered anthropometry of pregnant women could be critical. The increased weight during pregnancy may affect how the pregnant occupant moves during a collision. A benefit of accommodating pregnant women’s enlarged abdominal depth, combined with their lower limb dimensions, can be used to provide increased clearance between the steering wheel and the abdomen. This might help to reduce the risk of impact with the steering wheel during a collision whilst ensuring the pregnant women can easily reach and operate the pedals. Accommodating the pregnant women’s anthropometry in the trunk region might help women to use their seat belt, in the correct position according to guidelines, so that it can operate as intended to provide protection during a vehicle collision. This could be particularly helpful for fitting the seat belt between and around the breasts, and underneath the abdomen and across the hips. The hip, shoulder and whole body breadths, and the height of maximum lumbar curvature, are particularly important for providing comfortable car travel for pregnant women. Finally it is important to accommodate the slightly lower head and shoulder position of pregnant women in order to provide an adequate field of vision that is unobstructed, and to check the shoulder portion of the seat belt passes correctly across the shoulder.

The key regions of physical change during pregnancy are the chest, abdominal, and hip regions. For these regions it is not adequate to assume that a large male, represented by the 95th percentile anthropometric data, would accommodate the anthropometric needs of a pregnant woman simply because the 95th percentile male has a greater stature. The size of the chest, abdomen and hips of a pregnant woman can be so enlarged during pregnancy that these measurements exceed the equivalent measurements of the large 95th percentile male by a considerable amount. Hence if a vehicle design is produced to accommodate the range up to the 95th percentile male, and does not consider the anthropometry of pregnant women, many women may be excluded from the design by their third trimester of pregnancy. The rates of exclusion in these key regions (chest, abdomen and hips) are summarised below in Figure 12.
These exclusion rates for regional measurements highlight the fact that it is important to consider the dimensions of the vehicle, for example accommodating the abdominal depth of pregnant women to provide sufficient clearance between the abdomen and steering wheel to lower the risk of impact with the steering wheel during a collision. It is also worth noting that in the literature for certain regions non-pregnant females have larger dimensions than males, such as for the chest circumferences and depth, abdominal depth and hip breadth. In these cases the needs of a larger range of the pregnant population will be met by considering the non-pregnant female anthropometry rather than male anthropometric data. However in the key trunk region the sizes of pregnant women will always exceed the non-pregnant female and male data in the literature. The authors, therefore, think that designs that incorporate the anthropometry of pregnant women will be the best for meeting pregnant women’s comfort and safety needs.

**Figure 12** Pregnant women might be excluded by a design that accommodates up to the 95th percentile UK male anthropometry. Possible exclusion percentages for third trimester pregnant women by body region.

It could be argued that by the third trimester of pregnancy many pregnant women may choose to travel as passengers and not to drive. However, the safety and comfort issues, for example wearing a seat belt in pregnancy, are not limited only to car drivers, but also to passengers, and hence it is still important to consider the needs of pregnant women. Furthermore only a few of the pregnant women who completed the questionnaire as part of the project had reported that they had started travelling as passengers rather than drivers in the third trimester despite their concerns and complaints. In addition, accommodating the enlarged anthropometry of pregnant women may also benefit overweight male or female occupants.

Another key finding is the difference between standing and seated sizes, which can also be seen in Figure 12, where there are greater exclusion rates for the seated posture than standing. For the circumferences, where measurements were recorded in both postures, the seated sizes are much larger than the standing sizes due to the ‘spread’ effect. The spreading occurs in everyone when in seated posture, but seems to be substantial in pregnant women. This consequently means that vehicle designs might accommodate the altered needs of pregnant women better if based upon their anthropometric measurements recorded from the seated posture.
The maximum or extreme cases that occur during pregnancy are also important to demonstrate the extent of the size and shape changes. The physical enlargement, particularly around the chest, hips and abdomen, during pregnancy can be very extreme.

The anthropometric data presented in this paper are also being used in the ‘EXPECTING – A Pregnant Occupant Model’ project. This project aims to produce a pregnant occupant model capable of simulating the dynamic response to impact and predicting the risk of injury in automobile crashes.

Pregnancy is a natural process that women experience involving inevitable size and shape changes. It is desirable to offer the same safety and comfort standards for pregnant women, by including the pregnant population in designs.

Acknowledgements

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References


Design guidelines for pregnant occupant safety

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Abstract: During pregnancy a woman's body undergoes a considerable change in size and shape, and this can impact upon her safety during car travel. The two main issues are proper seat belt use and positioning, and steering wheel clearance. A comprehensive analysis of the questionnaire responses by pregnant women and anthropometric measurements demonstrates that the difficulties experienced can be explained by the physical changes and interactions throughout the body during gestation. Analysis of the anthropometry of pregnant women highlights that many pregnant users could easily be excluded from designs inadvertently if the design is based on males or non-pregnant females. Thus incorporation of pregnant women's anthropometry into automotive design could reduce the exclusion rates and alleviate problems. This paper presents guidelines for the automotive industry generated from experiences and anthropometry of pregnant women, with the aim of improving safety for pregnant car occupants.

Keywords: pregnant, occupant, safety, automotive design, guidelines

1 INTRODUCTION

During pregnancy a woman's body undergoes a wide variety of physical changes and this can impact upon her safety during driving and car travel. Recent reports from the USA have shown that the biggest cause of abdominal trauma is the automotive collision. Baerga-Varela et al. [1] and Cosi et al. [2] found that automobile trauma was the maternal trauma mechanism for 64 and 65 per cent respectively of cases. Abdominal trauma caused by impact to the abdomen can result in placental abruption, fetal injury and/or death, feto-maternal transfusion, and onset of labour [3–6].

The correct seat belt position for pregnant women described by the Department for Transport (DFT) in the UK [7], and the National Highway Traffic Safety Administration (NHTSA) in the USA [8], is that ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. Regarding the use of seat belts in pregnancy, research has shown that the pregnant woman and her fetus are at increased risk during a collision if the seat belt is not worn [9], or only the lap belt is used [10, 11], or if it is incorrectly positioned [10, 12].

Klinich et al. [13] reported that only 31 of their 43 women (72 per cent) were using the seat belt in their study entitled ‘Investigations of crashes involving pregnant occupants’, but did not state how the seat belt was positioned. Johnson and Pring [14] reported that in 1998, from 200 women attending an antenatal clinic in York (UK), 98 per cent were wearing the seat belt, but only 48 per cent had it correctly positioned.

There is a lack of research into why pregnant women do not position the belt correctly. Improving seat belt use and its safe positioning can help to improve the safety of pregnant women, and many papers have called for provision of information about seat belt legislation and guidelines for pregnant women to be increased [14–17]. However, these are all focused on disseminating information through medical channels, and this approach will be more effective if combined with driver behaviour [18].

Another source of risk is proximity to the steering wheel through direct impact with the wheel [19], or possibly a deployed airbag although the level of this risk is unproven.

DeLeonardis et al. [20] showed that shorter women are at increased risk of injury owing to proximity
to the steering wheel, and Dobson and Baird [21] suggest that seat position is directly related to height. University of Michigan Transport Research Institute research showed that, as pregnancy progresses, the abdomen protrudes closer to the steering wheel [19, 22, 23]; hence risk is increased in pregnancy because of the decreased distance from the steering wheel [24]. Klinich et al. [25] showed that pregnant women do not adjust their fore/aft seat position or seat back angle during pregnancy to compensate for increased abdominal protrusion.

There is a dearth of research investigating anthropometric changes to all body parts, or how different regions of the body interact. The study by Yamana et al. [26] was originally aimed at garment design, and it includes few measurements that are applicable to automotive design. Yamana et al. measured 44 dimensions of 520 pregnant women from the second to tenth month of pregnancy.

A project funded by the Engineering and Physical Sciences Research Council, UK (EPSRC), entitled ‘Automotive design: incorporating the needs of pregnant women’ started in 2001 at Loughborough University. This research addresses the problems associated with changes during pregnancy on the entire body and driving. The data set collected in this research was selected specifically for use in automotive design. The aim of this project is to provide pregnant women’s anthropometric measurements and guidelines to designers in automotive industry.

This paper investigates the physical changes during pregnancy and their resultant effect upon the safety of pregnant car occupant and her fetus. The data sets are collected with a broad understanding that physical changes to a pregnant woman are not limited to the abdominal region. These data sets are compared with non-pregnant data to study possible exclusion percentiles. In particular, two main safety issues, namely the use and positioning of the seat belt during pregnancy and the proximity to the steering wheel, have been focused on and the guidelines for the automotive industry are generated.

2 METHOD

Two methods of data collection were used in this study: a questionnaire and anthropometric measurements.

The pregnant women answered a ‘pregnancy and driving questionnaire’ in an interview or by self-completion. At the time of writing, 450 sets of questionnaire responses had been processed. The questionnaire can be found for online completion at http://pregnantdriver.lboro.ac.uk in five languages (English, Spanish, Italian, Turkish, and French). Responses have been received from around the world with the majority being from the UK (63 per cent), and the remainder from the USA and Canada (19 per cent), from other European countries (10 per cent), and from other countries of the world (8 per cent). The pregnant women were reminded repeatedly to compare their experiences during pregnancy with when they were not pregnant. Questions about all aspects of car travel both as drivers and as passengers were included in the questionnaire. In particular, the questions about seat belt use, and steering wheel clearance, were asked to gain understanding in trends in driving during pregnancy.

The standard anthropometric postures [27] were adapted for pregnant women by the present authors and a series of anthropometric measurements were taken. At the time of writing, 100 sets of measurements were recorded. Volunteers wore light clothing and removed their shoes, and the equipment used included weight scales, a stadiometer, a digital vernier calliper, a tape measure, and an anthropometer. Women were recruited in two locations in the UK: Loughborough University, and the Luton and Dunstable Hospital National Health Service Trust. The measurements of the hip, abdominal, and chest regions (illustrated in Fig. 1) were taken. At the time of writing, 100 sets of measurements were recorded. Volunteers wore light clothing and removed their shoes, and the equipment used included weight scales, a stadiometer, a digital vernier calliper, a tape measure, and an anthropometer. 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3 USE AND POSITIONING OF SEAT BELTS

Research has proven that wearing the seat belt and ensuring that it is correctly positioned are of vital importance to the safety of pregnant women and...
their fetuses [11–13]. It was found that 5 per cent of the pregnant women that participated in this research were not wearing their seat belt at all during pregnancy. These women felt unsafe or vulnerable using the seat belt during pregnancy; so they took uninformed action and stopped using the seat belt. Previous research [9, 12] suggests that not wearing the seat belt increases women’s risk of injury, which is the opposite of their intentions. The capacity of the seat belt to accommodate the changing size and shape of pregnant women comfortably is an important safety issue since this can be the determining factor for women and their fetuses to be protected by the seat belt.

3.1 Problems identified through the questionnaire

The DFT UK guidelines state that ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. The

Table 1  Pregnancy and driving details of the sample of pregnant women: first, second, and third trimesters

<table>
<thead>
<tr>
<th></th>
<th>First trimester (weeks 0–12)</th>
<th>Second trimester (weeks 13–28)</th>
<th>Third trimester (weeks 29–40 +)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pregnancy and driving questionnaire</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of volunteers</td>
<td>34 women</td>
<td>159 women</td>
<td>257 women</td>
</tr>
<tr>
<td>Mean week of pregnancy</td>
<td>8.5 weeks</td>
<td>21.6 weeks</td>
<td>35.2 weeks</td>
</tr>
<tr>
<td>Standard deviation week of pregnancy</td>
<td>2.3 weeks</td>
<td>4.4 weeks</td>
<td>3.3 weeks</td>
</tr>
<tr>
<td>Driver</td>
<td>32 women</td>
<td>156 women</td>
<td>243 women</td>
</tr>
<tr>
<td>Non-driver and unknown</td>
<td>2 women</td>
<td>2 and 1 women</td>
<td>5 and 9 women</td>
</tr>
<tr>
<td><strong>Anthropometric measurements</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of volunteers</td>
<td>0</td>
<td>35 women</td>
<td>65 women</td>
</tr>
<tr>
<td>Mean week of pregnancy</td>
<td>N/A</td>
<td>21.6 weeks</td>
<td>35.5 weeks</td>
</tr>
<tr>
<td>Standard deviation week of pregnancy</td>
<td>N/A</td>
<td>4.5 weeks</td>
<td>2.8 weeks</td>
</tr>
<tr>
<td>Driver</td>
<td>N/A</td>
<td>34 women</td>
<td>52 women</td>
</tr>
<tr>
<td>Non-driver and unknown</td>
<td>N/A</td>
<td>0 and 1 women</td>
<td>4 and 9 women</td>
</tr>
</tbody>
</table>

N/A, not applicable.
women reported three main problems with wearing the seat belts in pregnancy. These problems were as follows.

1. The belt will not fit underneath the abdomen or tends to ride upwards on to the abdomen (24.4 per cent).
2. The belt is too tight on the abdomen, hips, and/or breasts (26.2 per cent).
3. The belt cuts into the breasts, shoulders, and/or neck (26.2 per cent).

The problems of tightness (problem 2) and cutting (problem 3) reveal that the seat belts were not positioned according to the guidelines since the belt was not expected to be positioned on the breasts nor on the abdomen, but between the breasts and underneath the abdomen [7]. This fact is further supported by women’s choice of seat belt positioning later in the questionnaire. The other problems reported were difficulty with adjustment (13.7 per cent) and fastening (7.3 per cent), and the fact that the belt is too short (2.2 per cent). Figure 2 provides a summary for these ratios.

The tendency for the belt to ride upwards on to the abdomen is greatest in the second and third trimesters. This problem represents 5, 29, and 24 per cent of all the reported seat belt problems in the first, second, and third trimesters respectively. In the seated posture the increased abdominal depth of pregnancy causes the base of the abdomen to make contact with the upper thighs. Some pregnant women reported that this contact caused them difficulty in sliding the seat belt between the thighs and abdomen, hence preventing them from putting the lap belt into the correct position across the hips. Other women in the third trimester reported that, once they had positioned the lap belt across their hips and underneath the abdomen, their larger abdomen was beneficial in helping to hold the lap portion of the seat belt more securely in place and preventing it from sliding up on to the abdomen. Many pregnant women took action to prevent the belt riding upwards on to the bump with the purpose of protecting the fetus or improving comfort. One method was to use an add-on device to hold the seat belt in position across their hips and the other method was to hold the belt away from the bump with their hands or thumbs. Similarly, more women were holding the belt away from their neck because it was cutting or rubbing them. The women were not aware that slack in the belt could prevent its proper functioning, hence increasing the risk of injury. Women modified their seat belt behaviour for protection or comfort but in reality put themselves at greater risk of injury, reinforcing the need to provide comfort for pregnant women for their safety.

The pregnant women were asked how they position the shoulder and lap sections of the seat belt. It has been revealed that only 13 per cent of the pregnant women had the entire seat belt correctly positioned in accordance with the DFT guidelines. The high level of incorrect belt positioning during pregnancy arises in some cases because the pregnant women are unaware of the correct positioning. Alternatively many pregnant women explained that they understood how the seat belt should be positioned, but that it would not fit around the pregnant body correctly. The various seat belt positions are shown in Fig. 3 with the correct positions highlighted for both the shoulder and the lap portions of the belt.

Considering only the shoulder section, over half of the women had the seat belt in incorrect positions. The belt passing between the breasts and around the abdomen, i.e. the correct position, was used by 49 per cent of the women. However, a variety of other shoulder belt positions were reported, including across one breast and over the abdomen 19 per cent, above both breasts and cutting the neck 15 per cent, off the shoulder 12 per cent, and not worn 5 per cent.

![Fig. 2 Seat belt problems experienced by pregnant women](image-url)
Regarding the lap portion of the seat belt, only 23 per cent of the women were wearing the lap belt correctly positioned across the hips; 45 per cent of the pregnant women had the lap belt over the bump, 26 per cent of the women had the lap belt across their thighs, and 6 per cent were not wearing it at all.

### 3.2 Anthropometric measurements and needs identification

The comfort and fit problems with the seat belt were also explained by the changing size and shape of the pregnant women. These problems can be addressed by ensuring that the needs of the pregnant women of all shapes and sizes are accommodated by the seat belt through all stages of pregnancy. This is particularly important in the third trimester when the size and shape of pregnant women are transformed to a great extent. Values for hip, abdominal, and chest region measurements are given for pregnant women in the third trimester in Table 2.

The abdominal region is where the most dramatic and obvious physical changes occur during pregnancy. Initial uterine growth is mainly in the lower abdomen; so the lower abdomen may contact with the upper thighs as it grows, causing difficulty for pregnant women in fitting the lap belt between the lower abdomen and upper thighs into the correct position across the hips. As the abdomen enlarges, it grows in many directions: out from the body in an anterior direction, lateral growth at either side of the abdomen, and upward growth as the enlarging fetus pushes the internal organs upwards. As pregnancy progresses, the multi-directional growth means that the abdominal point moves upwards as in Fig. 4. However, the increased abdominal protrusion in the anterior direction means that the lower abdomen still remains in contact with the thighs, and the region of contact may increase, as shown in Fig. 5. The multi-directional growth also means that the abdomen will stretch the seat belt further than normal, particularly at the side and top of the abdomen, and extra belt length may be needed.

It is also important to consider the often ignored facts such as increase in hip size and the chest region (due to preparation for the birth and breast feeding). Some pregnant women reported that the seat belt was painfully tight on the breasts or was not long enough to fasten. The breasts are also pushed upwards (until the very last stages of pregnancy) by the enlarging

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**Fig. 3** Diagrams of different shoulder and lap belt positions with correct positions highlighted according to reference [7]
Table 2 Percentages of the sample of pregnant women measured in the third trimester who would be excluded by a design based on the 95th percentile UK anthropometric data for females (non-pregnant) and males

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Non-pregnant UK females [28] and [31]</th>
<th>Excluded by DBF (%)</th>
<th>Excluded by DBM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip circumference standing</td>
<td>1037</td>
<td>1155.1</td>
<td>49</td>
</tr>
<tr>
<td>Hip circumference sitting</td>
<td>*</td>
<td>1249.8</td>
<td>73†</td>
</tr>
<tr>
<td>Abdominal circumference standing</td>
<td>840.6</td>
<td>1136.7</td>
<td>95</td>
</tr>
<tr>
<td>Abdominal circumference sitting</td>
<td>*</td>
<td>1161.3</td>
<td>97†</td>
</tr>
<tr>
<td>Abdominal depth</td>
<td>269.9</td>
<td>359.5</td>
<td>62</td>
</tr>
<tr>
<td>Chest circumference standing</td>
<td>1007.8</td>
<td>1046.5</td>
<td>9</td>
</tr>
<tr>
<td>Chest circumference sitting</td>
<td>*</td>
<td>1072.3</td>
<td>16†</td>
</tr>
<tr>
<td>Chest depth</td>
<td>271.8</td>
<td>284.0</td>
<td>16</td>
</tr>
</tbody>
</table>

DBF, design based on the 95th percentile data for non-pregnant UK females; DBM, design based on the 95th percentile data for UK males.
*UK data not available in references.
†UK data are not available for sitting posture in references and so comparison is made against data for the standing posture instead.

**Fig. 4** Diagram showing abdominal growth pushing the breasts upwards as pregnancy progresses from the first trimester to the third trimester

abdomen, which decreases the space between the top of the abdomen and the base of the breasts. This introduces difficulty in fitting the seat belt between the breasts and abdomen.

Pregnant women experience size changes that make it vital to consider their needs as a separate user group, as proven by the marked size increases. For example the mean standing abdominal circumference for the pregnant women in the third trimester is 1136.7 mm and is significantly larger \((p < 0.00002)\) than the value for non-pregnant women given in reference [28], and the mean abdominal depth of 359.5 mm is also significantly \((p < 0.03)\) larger. Increases in size in the chest and hip regions are also large. For example the mean standing hip circumference is 1155.1 mm for women in the third trimester and is 118.1 mm larger than for anthropometric data on non-pregnant women.

Comparison on the standing and seated measurements of the abdomen, hip, and chest circumferences reveals that seated sizes are much larger, and therefore using standing measurements is inadequate in vehicle design where the occupant is seated. For example the mean sitting hip circumference is 1249.8 mm, which is 94.6 mm larger than the standing posture. This is also true for measurements of abdominal and chest circumferences.

It is particularly important that these physical changes do not take place in isolation, and the interactions between the abdomen and breasts, and
between the abdomen and thighs, must be checked in detail during seat belt design to ensure correct fit of the seat belt.

The waistline disappears as the abdomen grows. Instead of the standard anthropometric measurement of waist height (the point of minimum circumference), the abdominal height (height of maximum abdominal circumference) was measured since this point could be at greatest risk of injury in a collision.

4 STEERING WHEEL CLEARANCE PROBLEMS

Current DFT guidelines recommend that the ‘distance between the centre of the steering wheel to the breastbone should be at least 10 in (25 cm)’ [7]. However, the advice given is not specific to pregnant women. The NHTSA in the USA [8] advises pregnant women to sit as far back as possible from the steering wheel or dashboard and recommends a distance between the breastbone and the steering wheel or dashboard to be at least 10 in to reduce the possibility of injury from an inflating airbag in an accident. No recommendations for pregnant women have been found to date for the side impact airbags.

The significant abdominal protrusion occurring during pregnancy (as described in section 3.2) means that a large proportion of the pregnant women currently have their abdomen very close to the steering wheel; 86 per cent of the pregnant participants were seated at less than 25 cm away from the steering wheel, and this increased to 92 per cent for women in the third trimester. Some of the pregnant women were seated with less than 2.5 cm between their

bump and the steering wheel, or with their bump in contact with the steering wheel during driving. The proximity of the enlarged abdomen to the steering wheel should be addressed since it is experienced by a large majority of the pregnant drivers.

Half of the pregnant women who completed the questionnaire believed that they or their fetus were at risk of injury from a deployed airbag. The majority of these women stated that they were concerned about the force or impact of the airbag against the abdomen and whether this would injure the child. Further research and data are needed to establish the level of risk to a pregnant woman and her fetus from deployed airbags. Some pregnant women had chosen to cease driving in pregnancy because of proximity to the steering wheel and fear that the fetus could be injured in an accident. A large group of the pregnant women said they increase the distance between their abdomen and the steering wheel by moving the seat slightly rearwards, and several participants also leant their seat back rearward in addition; however, as expected, these women reported difficulty in reaching and operating the pedals.

5 ANALYSIS OF THE DATA

Statistical analysis of the anthropometric measurements of pregnant women confirms that the changes in pregnant women are not limited to the abdominal area. Significant increments are noted during pregnancy in hip circumference, chest depth, and chest circumference, as well as abdominal depth and the more commonly measured parameter of abdominal circumference.

The relevant anthropometric data in Table 2 reveals that any design based on the non-pregnant data available in the literature could ignore the physical features of a large proportion of pregnant women in the third trimester. The questionnaire results showed that a large group of pregnant women modify their use of seat belt behaviour because of fear and discomfort, hence putting themselves at greater risk of injury. Integrating these two sets of evidence suggests that it would be a valuable contribution to provide specific design for pregnant women for their assurance and comfort, and hence for their safety.

The 95th percentile value of non-pregnant female data and 95th percentile male data are compared with the pregnant women data measured in third trimester. A design that uses 95th percentile non-pregnant female data or male anthropometric data would exclude 45–97 per cent of pregnant women in the third trimester of pregnancy for all the hip and
abdomen dimensions listed in Table 2. For example, the 95th percentile value for standing abdominal circumference of a non-pregnant female is 957.2 mm [28]. This is equivalent to only the fifth percentile abdominal circumference value for the pregnant women measured in the third trimester of pregnancy. Thus 95 per cent of pregnant women in the third trimester would not be accommodated by a design that used anthropometric data of a non-pregnant female for the abdominal circumference. More crucially the 95th percentile abdominal circumference value for UK males is only equivalent to the 34th percentile abdominal circumference for pregnant women measured in the third trimester. Therefore even the design for large men using the 95th percentile might not accommodate the enlarged abdomen of the pregnant women, and two-thirds of this sample of pregnant women would be excluded. The exclusion rates are given in Table 2 for the other dimensions, including hip circumference, abdominal depth, chest depth, and chest circumference.

The concern is even greater when the measurements in the relevant seated posture for automotive design are considered. The sitting abdominal circumference data are not available in reference [28]. Any designs that use the standing abdominal circumference data for a non-pregnant female or male would exclude 97 per cent and 89 per cent respectively of pregnant women measured in the third trimester.

Comparing the maximum values, or extreme cases, against typical non-pregnant measurements gives far more dramatic results. The maximum standing hip circumference of 1475 mm is 317.7 mm larger than the 95th percentile value for non-pregnant UK females in reference [28]. In seated posture the difference is even greater at 516.7 mm.

Similarly the maximum standing abdominal circumference measured was 1410 mm from a woman in her third trimester. This is 452.8 mm larger than the 95th percentile value for a non-pregnant female. The maximum sitting abdominal circumference of 1454 mm was nearly half a metre larger than the 95th percentile value for a non-pregnant woman, demonstrating the remarkable range in abdominal size in the pregnant population.

6 DESIGN GUIDELINES

Comparing the anthropometry of pregnant women against the data for non-pregnant females and males shows the significance of considering pregnant women as a separate user group. Anthropometric data from a relevant posture, e.g. sitting sizes rather than standing, is important. The awareness of the extreme cases that can occur because of growth during pregnancy is also essential.

This study reveals that, because of the incorrect seat belt positioning rate, 87 per cent of the pregnant women in our sample could be inadequately protected by their seat belt and 92 per cent of them in their third trimester were sitting close to the steering wheel.

The analysis of the questionnaire and the anthropometric measurements are used to generate the following guidelines for the designers in the automotive industry to assist them in considering the features of pregnant women at the design stage.

The authors recommend the following.

Accommodating pregnant occupant anthropometry

A1. Anthropometric measurements of the pregnant population, similar to those provided in this research, should be included as opposed to non-pregnant population anthropometry. As represented by this sample, the bodies of pregnant women are significantly different from those of non-pregnant females and therefore have different geometric considerations during design. This could be especially important if the type of car is designed for and expected to be used by women of childbearing age.

A2. Pregnant women should be considered as a separate user group during vehicle design in order to attend to their particular safety needs and requirements.

A3. Women from various stages of pregnancy should be considered, especially anthropometric measurements of the pregnant women from the last trimester of pregnancy when the abdomen is at greatest risk of injury.

A4. Anthropometric measurement data should be taken from the relevant posture, i.e. specifically seated posture measurements for use in car design. The standing and seated measurements taken from this sample show large differences, and using standing data in seat design could exclude larger portions of the seated population than intended.

Seat belt design

B1. A specific adaptable integrated seat belt should be designed to make certain that it is more suitable for the pregnant body, so that pregnant women can comfortably fit the belt and are safely restrained during all stages of pregnancy.
This could help to increase the number of women wearing the seat belt in the correct position.

B2. Specific areas of concern for the seat belt are the changes in the hips, abdomen, and chest regions. Also the region between 'the breasts and the top of the pregnant abdomen' and the interactions between 'the base of the abdomen and upper thigh area' should be checked in detail.

B3. Anthropometric measurements from pregnant women for the necessary belt length should be used in order to ensure that the seat belt accommodates the enlarged hips, abdomen, and chest area during all stages of pregnancy. (This will also benefit the group of obese people.)

Steering wheel clearance provision

C1. Anthropometric measurements from pregnant women should be used to give practical advice on keeping a safe distance away from the steering wheel in order to reduce the impact of the steering wheel or deployed airbags in case of an accident.

C2. A greater range of fore and aft seat adjustments should be provided. This would allow pregnant women to move their seats rearwards to compensate for the enlarging abdomen. However, it is important to consider the pregnant woman and the car environment as a system and hence the provision of fore and aft adjustable pedals or pedal extenders would greatly benefit pregnant women. Adjustable pedals have been found to be effective in increasing both chest-to-steering-wheel and abdomen-to-steering-wheel distances [29] in a sample of males and non-pregnant females. Adjustable or extendable pedals would allow pregnant women to move their seats rearwards but also be able comfortably to reach and operate the pedals to drive. (This will also benefit the group of small-stature people.)

C3. A retractable steering wheel should be provided so that the steering wheel can be moved further away from the abdomen as it enlarges. Automotive designers could check reach capabilities of pregnant women, using the anthropometric data provided, for all parts of the car with the seat in all fore and aft positions to ensure that pregnant women can reach the pedals, and all other controls.

Vehicle design

D1. The possibility of new and alternative methods of driving, such as drive-by-wire, should be considered to remove the risk of impact with the steering wheel.

D2. Pregnant women (ideally from various stages of pregnancy) should be involved in user comfort tests with prototype vehicles to check that pregnant women are accommodated in reality.

Educating pregnant women

E1. A broad publicity campaign of advice should be undertaken to target pregnant women. The automotive industries could help by providing leaflets or information in car manuals about seat belt position in pregnancy to help to increase awareness levels about belt positioning and consequently to provide better protection against injury. Automotive industries could also train all staff in contact with the public to advise pregnant women correctly about seat belt positioning.

E2. The publicity campaign could be supported by inclusion of the DFT [7] or NHTSA [8] guidelines into road regulations by the appropriate transport authorities. For example, seat belt requirements and advice about children in cars are currently included in The Highway Code [30] for the UK, and seat belt positioning information for pregnant women would complement these instructions. Similarly all learner drivers must learn the guidelines and consequently improve awareness about seat belts in pregnancy and increase numbers of pregnant women that use the seat belt in the correct position.

E3. Pregnant women are advised to travel as a passenger instead of driving, or to choose alternative means of transport, if they feel that their car safety is compromised by pregnancy. Women should consider their proximity to the steering wheel and whether they are able to position the seat belt correctly according to government guidelines [7].

E4. Women should be advised about the safety tests and any possible changes in insurance cover for all the products marketed for a pregnant occupant.

8 CONCLUSIONS

This research identified the problems of pregnant car occupants through 450 responses to a questionnaire and 100 sets of anthropometric measurements from pregnant women. The analysis of measurements data is used to confirm the problems by identifying
excluded populations during a typical design process. The design guidelines are drawn up to assist automotive designers and hence to improve the quality of life of pregnant women. The focus of this paper is on automotive design, and improvements for the safety of pregnant car occupants; however, as a by-product it may also be useful in other areas of product design for pregnant women in general and contribute to improving design for obese people too.

This research has shown that a wide variety of physical changes that women undergo during pregnancy can have an impact upon the safety of pregnant women during car travel. Because of the anthropometric changes during pregnancy the two major areas of concern for the safety of pregnant vehicle occupants are seat belt positioning and steering wheel clearance. Some pregnant women ignore the benefits of wearing the seat belts properly because of discomfort and fear. However, some were unaware of the recommended positioning during pregnancy. Most feared proximity to the steering wheel and could not do anything about it.

This research revealed that only 13 per cent of the pregnant women who took part in this study had the entire seat belt correctly positioned in accordance with the DFT guidelines. Similarly 92 per cent of the pregnant participants in the third trimester were seated less than 25 cm away from the steering wheel in contrast with the recommendations.

The most important recommendation to automotive designers is to use anthropometric data of pregnant women, similar to the data provided in this research, to check that designs can accommodate pregnant women safely and to address the problems identified through the questionnaire.

The present authors’ general recommendations included the design of new adaptable integrated seat belts, and the use of anthropometric measurements of pregnant women to ensure comfort issues. The capacity of the seat belt to accommodate the changing size and shape of pregnant women comfortably is an important safety issue since this can be the determining factor for women and their fetuses to be protected by the seat belt.

Specific recommendations included the attention required in changes in hip, abdominal, and chest areas, the related length of the seat belts, the provision of a greater range of fore and aft seat adjustments, adjustable or extendable pedals, drive-by-wire, and retractable steering wheels. Comfort tests with pregnant women and broad publicity for the proper use of seat belts and safe sitting positions are also recommended.

The high level of significance in the difference between pregnant and non-pregnant women meant that it is crucial to consider pregnant women as a separate user group during vehicle design in order to attend to their particular safety needs. This research also revealed that any design based on the non-pregnant data available in the literature could ignore the physical features of a large proportion of pregnant women in the third trimester. Consideration of the interaction between local changes in the pregnant body is also highlighted for better designs.

In this research it has been shown that a majority of the pregnant population in the third trimester can be excluded in designs based on a typical 95th percentile of male or non-pregnant female populations. The exclusion was much more dramatic in extreme cases of measurements. This provided understanding of the complaints and discomfort of pregnant women. The research also highlighted the difference between measurements taken from the standing and seated postures of pregnant women for use in vehicle design.

Road traffic accidents form the largest cause for accidental death for pregnant women and their fetuses. Earlier research has proven that wearing the seat belt and ensuring that it is correctly positioned are of vital importance to the safety of pregnant women and their fetuses. Therefore evidence suggests that following the DFT advice and placing the lap strap across the hips, fitting under the bump, while placing the diagonal strap between the breasts and around the bump even if it is not comfortable, seems to be the best available advice to take until new adjustable integrated designs are available.

ACKNOWLEDGEMENTS

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Designing for safety during pregnancy through a system for automotive engineers

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Abstract: Pregnant women in the UK are legally required to wear seatbelts both as drivers and passengers. This paper considers fitting the seat belt correctly around the pregnant woman’s altered body and explores the ways of providing data to automotive engineers. The paper presents the difficulties experienced during pregnancy resulting from women’s altered shape and size. Accommodation of pregnant occupant anthropometry is key to improving seat belt use and positioning. An anthropometry website is presented with the aim of enhancing pregnant women’s quality of life through an improved seat belt design. The website has been designed to suit the needs of automotive designers and engineers to encourage them to consider pregnant occupant protection.

Key words: Pregnant, occupant, safety, automotive design, website.

INTRODUCTION

Road traffic accidents are one of the leading causes of death, with 1.3 millions deaths worldwide in 2000 [1]. World Health Organisation predictions suggest road traffic accidents will rise from 9th rank to 3rd by the year 2020 [2, 3]. The largest cause of accidental death and disability in pregnancy is automobile collisions [4]. The Royal Society for the Prevention of Accidents safety publications report that seat belts and air bags prevent tens of thousands of deaths and serious injuries in the UK each year [5]. It is a legal requirement in the UK to wear seatbelts both as drivers and passengers [6, 7], and pregnant women are not exempt to this rule.

Crash test research [8] has shown the effectiveness of seat belts in reducing injury risk for pregnant women and their fetuses, and has focussed on establishing the correct position for seat belts in pregnancy in order to reduce the risk of abdominal trauma. Current safety guidelines from the UK Department of Transport [7] and the National Highway Traffic Safety Administration in the USA [9] describe the correct position such that ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. However Acar and Weekes [10] also reported that only 13% of pregnant women are actually wearing their seat belt in the correct position.

During pregnancy a woman’s body undergoes significant changes in size and shape. These changes are not limited to the abdominal region, since the hips and breasts also increase in size. In this paper we focus on the ability of fitting the seat belt correctly around the pregnant woman’s altered body and investigate the ways of providing data to automotive engineers.

The design process relies upon the use of anthropometric data to determine the portion of the user population that will be accommodated by the design. There is currently little data available for pregnant women, and the published data dimensions are often not relevant to automotive design. The study of the dimensional changes of the feet during pregnancy by Alvarez et al. [11] compares a sample of 17 pregnant women with 16 comparable non-pregnant women. This data is of little use for vehicle design since the sample size is extremely small, and only dimensions for foot length and width are given that are relevant to automotive design. The study by Yamana et al. [12] presents measurements of 520 pregnant women from the second to tenth month of pregnancy for a total of 44 dimensions. However very few measurements are applicable to automotive design since the paper was originally aimed at garment design. Pheasant [13] modified the data from Yamana et al. [12] for the abdominal depth and forward grip reach dimensions. Pheasant used a scaling method based on the assumption that pregnancy will cause British and Japanese women to change in a similar way, and that they are of similar proportions. The anthropometric data generated using the scaling method is therefore less reliable than real anthropometric measurements. Klinich et al.
[14] present measurements of 22 pregnant women. 10 measurements pertinent to automotive design were recorded throughout the course of pregnancy. Therefore in general the availability of pregnant women’s anthropometric data is limited, and little is relevant to vehicle design. It has also been difficult for designers to assess the suitability of their designs for the pregnant occupant, since there has been a lack of anthropometric data measured from pregnant women.

Recently, Acar and Weekes [15] presented analysis of a comprehensive set of 48 anthropometric measurements selected specifically for use in vehicle design as a contribution towards the solution of this problem. In this paper the Pregnant Women’s Anthropometry Website is used to display this data in a user-friendly manner for automotive designers and engineers after a brief introduction of the measurement methods and analysis.

METHOD

Two data collection methods were used in this study, the first being a series of anthropometric measurements. 100 sets of measurements were recorded at the time of writing. The measurements recorded were adapted by the authors for pregnant women based on standard anthropometric postures [13]. Women were recruited in two locations in the United Kingdom: Loughborough University, and the Luton & Dunstable Hospital National Health Service Trust. Volunteers wore light clothing and removed their shoes. The equipment used included an anthropometer, weight scales, a digital vernier calliper, a tape measure and a stadiometer. The abdominal, hip and chest region measurements (illustrated in Figure 1) were particularly useful in understanding how physical changes impact upon seat belt safety in pregnancy.

Figure 1 Anthropometric measurements with particular relevance to seat belt design.

The second data collection method was a ‘Pregnancy and Driving Questionnaire’ that was answered during an interview or by self-completion. 450 sets of questionnaire responses were processed at the time of writing. The questionnaire was also available for online completion in five languages (English, Spanish, Italian, Turkish and French) at the Pregnant Driver website [16]. Responses have been received from around the world with the majority being from the UK (63%), and the remainder from the rest of the world (37%). The pregnant women were reminded repeatedly to compare their experiences when they were not pregnant against their experiences during pregnancy. The questions about seat belts included issues of seat belt use and positioning, and attitudes and information received about seat belts in pregnancy.

Table 1 provides a summary of the gestation levels of the pregnant women recruited to this study. The majority of these women normally occupy the driver’s seat. Occasionally they use the front or rear passenger seats, and in a few cases the normal occupant position is unknown.

SEAT BELTS

Fitting and positioning
The DFT and NHTSA advise pregnant women that the correct seat belt position is as follows: ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. 95% of the pregnant volunteers who responded to the questionnaire reported that they were wearing their seat belt during pregnancy. However only 13% of pregnant women using their seat belt actually had their seat belt correctly positioned according to the guidelines.

It is not surprising that the pregnant women report problems with seat belt positioning when they are physically altered. The anthropometric measurements recorded show that the pregnant woman’s body undergoes dramatic transformation during pregnancy [15]. For example the biggest changes occur in abdominal circumference where pregnant women’s abdominal circumference may be up to 1410 mm, which is 452.8 mm larger than the 95th percentile value for non-pregnant UK females. The changes are not limited to the abdominal region, but occur throughout the body. The breasts and hips also enlarge notably due to pregnancy, as well as the abdominal protrusion.

For pregnant women measured in the third trimester the lower bound of the 95% confidence interval of the mean for the standing abdominal circumference is greater than the 95th percentile value for UK non-pregnant females given in [17]. The lower bound of the confidence interval is also larger than the male 95th percentile [17] so even using data for large males might be inadequate. These confidence intervals lie completely outside the 5th to 95th percentile range of currently available data. This highlights the importance of considering the pregnant occupant as a separate user group in order to accommodate their particular physical sizes.

However the most important change for seat belt fitting is the increment in hip circumference because the lap belt is supposed to pass across the hips. Changes to hip
circumference in pregnancy illustrate the importance of considering pregnant women’s full anthropometry.

Figure 2 shows how much larger pregnant women’s hip circumference is in the third trimester, when compared to non-pregnant UK female or male data currently available in [17]. The mean standing hip circumference is 1155.1 mm for the women in the third trimester, which is 118.1 mm larger than for non-pregnant women’s anthropometric data given in [17]. Similarly it is 108.6 mm larger than the mean male standing hip circumference. This suggests that a woman nearing the end of pregnancy would need an approximately 12 cm longer seat belt.

Even if seat belt designs were based on the 95th percentile male value for hip circumference of 1168.2 mm, they would still exclude many pregnant women. This is because the 95th percentile for male standing hip circumference in [17] is equivalent to only the 53rd percentile value for measurements recorded from pregnant women in the third trimester. Hence 45% of pregnant women would be excluded by a design based on currently available data, even if the male 95th percentile is used as shown in Figure 3.

Use of pregnant women’s anthropometric data during the design stages might help to reduce seat belt discomfort problems, which is particularly important since some pregnant women are discouraged from using the seat belt due to discomfort [10]. It is important for the automotive industry to accommodate the pregnant women’s anthropometric needs throughout the entire course of pregnancy, because the seat belt positioning may change as body shape alters. For example the tendency for the lap portion of the seat belt to ride up onto the abdomen is highest in the second trimester, whereas in the third trimester the enlarged abdomen helps to hold down the lap belt more securely across the hips [10]. The authors not only recommend that the anthropometric data be used to check seat belt fit for the pregnant occupant, but also at least static user testing with pregnant volunteers. This will help the designers and engineers gain further insight into the notable physical changes occurring throughout the body during pregnancy, and how these changes affect seat belt positioning.

ANTHROPOMETRY WEBSITE AND INTERFACE

A website presenting the anthropometric measurements of pregnant women was produced, and is illustrated in

Table 1 Pregnancy and driving details of the sample of pregnant women

<table>
<thead>
<tr>
<th>No. volunteers (women)</th>
<th>Week of pregnancy</th>
<th>Women’s usual driving activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (weeks)</td>
<td>Std. dev. (weeks)</td>
</tr>
<tr>
<td><strong>Anthropometric measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second trimester(^b)</td>
<td>35</td>
<td>21.6</td>
</tr>
<tr>
<td>Third trimester(^c)</td>
<td>65</td>
<td>35.5</td>
</tr>
<tr>
<td><strong>Pregnancy and driving questionnaire</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First trimester(^a)</td>
<td>34</td>
<td>8.5</td>
</tr>
<tr>
<td>Second trimester(^b)</td>
<td>159</td>
<td>21.6</td>
</tr>
<tr>
<td>Third trimester(^c)</td>
<td>257</td>
<td>35.2</td>
</tr>
</tbody>
</table>

\(^a\)The first trimester lasts until the 12th week of pregnancy.

\(^b\)The second trimester is from the 13th to the 28th week of pregnancy.

\(^c\)The third trimester is from the 29th week of pregnancy until the birth (40+weeks).
Figure 4. The aim of the site is providing this anthropometric data to automotive designers for assessment of designs for accommodation of pregnant occupants. This will subsequently help to incorporate the altered physical needs of pregnant women into vehicle designs. The web format was selected so all parts of the automotive industry could access the data regardless of particular software systems used for design. This is the first anthropometry website to be produced and is especially unique in providing anthropometric measurements of pregnant women specifically selected for use in vehicle design. The site is aimed at automotive designers and engineers, but the measurements may also be useful to other areas of design.

The site includes a page describing the project aims and objectives so automotive designers can understand the research project and background. The target user group is automotive designers and engineers, so the entire site has been designed to suit their human-computer interaction and usability needs. A contact page is provided so automotive designers can request modifications to the site if necessary. The users are also invited to provide feedback and comments about the pregnant women’s anthropometry website, to ensure it meets their needs.

The website uses engineering terminology so the automotive designers and engineers feel familiar with the terms. The anthropometric measurements were selected from the standard measurements depicted in the literature [13, 17], which the automotive designers are also familiar with. In a few cases the authors either added new measurements or adapted the standard measurement in order to better define the pregnant form. A full description of every measurement (including the new and adapted ones) is given so that automotive designers and engineers can be aware of the exact detail of the data recorded. Any gynaecological terms are defined, for example on the search page the stage of pregnancy is given in trimesters, but the week of pregnancy is displayed alongside in parentheses for clarification.

The anthropometric data is stored in a MySQL database, which is queried using PHP code. The engineers and designers use a simple HTML search page to interface with the PHP code and control exactly which data is

Figure 4 A screenshot of the Pregnant Women’s Anthropometry Website data search page.
Designing for safety during pregnancy through a system for automotive engineers

The percentile calculations are provided because the 5th, 50th, and 95th percentiles are the statistics used in typical design practice for accommodating 90% of the population. The minimum and maximum data are given to provide information about extreme cases occurring in pregnancy, and so automotive designers could aim to accommodate a larger portion of the pregnant population. This could also benefit obese people. The sample size data provides understanding of how many women's measurements are included in the sample, which is 100 at the time of writing.

The third and final step for automotive designers is choosing which anthropometric measurements to display. The user may choose the measurements by using one of three methods, including:
- choose the entire list of 48 measurements,
- make a personalised selection of measurements from the list,
- choose by the vehicle part they are designing.

If the user is making their own personalised selection of measurements they simply click on the measurements in the list. There is a link underneath the list to a page providing the full details of every measurement, and this page opens as a separate browser window to enable easy referencing between measurement details and the search page. This allows the automotive designers to know the exact details of the measurements so they can make a fully informed choice. The details provided in the reference page about each individual measurement include:
- a diagram providing a visual representation as an aid to understanding,
- the measurement name,
- the body landmarks between which the measurement is recorded,
- the posture (either standing or seated),
- the equipment used.

The automotive designers also have the option to choose measurements to display according to the part of the vehicle they are designing, for example the seat belt. In this case all measurements of any body part making contact with that particular vehicle part are presented. For the seat belt option the measurements of the abdomen, hips, breasts, and shoulders are displayed. The weight and stature of pregnant women are also given providing an indication of overall size. Any dimensions useful for defining locations of vehicle parts in relation to the occupant are also given. For reference purposes there is a separate page defining which anthropometric measurements are associated with different vehicle parts, shown in Figure 5. A link to this reference page is given underneath the vehicle parts list so the user can easily get additional information about this feature. The reference page opens a new browser window so the user can make references whilst making choices on the search page. The ability to choose the measurements according to the vehicle part is advantageous to the designers and engineers, and it saves time.

For both the vehicle parts list and the measurements list the user can select just one individual list item (either a measurement or a vehicle part). Alternatively they can make multiple selections by holding the control key whilst clicking on the items. The user can also select a group of consecutive items by clicking the first item in the group then holding the shift key and clicking the item at the end of the group. The ability to make multiple selections in these lists helps automotive designers to make their own personalised selections to suit their particular aspect of vehicle design.

Once the automotive designer has completed the three
steps of the search and made their choices of the stage of pregnancy, statistics, and measurements to display, they simply display the anthropometric data by clicking on the “Display Anthropometric Data” button.

The data page displays a table of anthropometric data, according to the selections made in the search page. Each measurement has one row of the table, and is clearly labelled in the left-hand column with the measurement name. The statistics selected are given a column each and are also labelled clearly in the top row of the table. The table resizes according to the number of measurements and statistics that were selected. Above the table is a heading to identify the stage of pregnancy so the user is reminded of their selection. For example if the user selected ‘trimester 3’ to display measurements from women in the third trimester of pregnancy, the heading clearly states “Trimester 3 (weeks 29–40+)”.

Also above the table a button to return to the search page can be used, as well as the back button in the browser. When the user returns to the search page the choices from their previous search are displayed. This has two benefits, first that the user does not have to remember the previous choices, and secondly that the user is able to make modifications based on the previous search.

The user can click on the measurement name in the data table, which is a hypertext link, to display the full details about that particular measurement. The details including a diagram are displayed in a pop-up window so that both the measurement details and the anthropometric data statistics can be viewed simultaneously. If the user wishes to display details for another measurement, these details are displayed in the same pop-up window so there is no risk that multiple pop-up windows would confuse the user.

The website has an error checking facility to ensure the user completes all the required sections of the search page. If the user leaves any or all of the sections (stage of pregnancy, statistics, measurements) blank, an error message will be displayed. The error message informs the user of the incomplete section, so the user knows exactly how to correct the error and successfully display the anthropometric data. An additional feature is that the user can click a statistics checkbox or measurement item to make a selection without necessarily having to click the associated radio button because the radio button will be automatically selected for them. For example if the automotive designer wishes to select the sample size check box they do not have to select the ‘choose your own group(s)’ radio button because it will be automatically selected. This not only prevents errors on the search page, but also helps to save automotive designers’ time.

CONCLUSION

This study reveals that only 13% of pregnant women actually had the seat belt correctly positioned according to current safety guidelines. The correct position for the seat belt is ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. Since many seat belt fit and positioning problems experienced by pregnant women are caused by alterations in size and shape, accommodating women’s altered anthropometry will be of greatest benefit. Pregnant women’s physical size and shape changes require that the pregnant occupant should be considered as a separate user group in order to meet their specific needs. The pregnant occupant anthropometry could be used during
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the design stages to check the fit and positioning of the seat belt. Designers are also recommended to consider both the second and third trimesters of pregnancy because the fit of the seat belt is constantly changing as pregnancy progresses.

A pregnant women’s anthropometry website was generated to present the anthropometric data gathered in this research. This website displays measurements specifically selected for use in vehicle design, and is the first such resource of its kind. The site was designed for use by engineers and designers to suit their needs, in order to encourage consideration of the pregnant occupant during the design stages. The website has many features to aid the user, in particular the ability to select the anthropometric measurements according to the vehicle part being designed. Incorporating the needs of pregnant women and modifying seat belt design accordingly can help to improve seat belt fit and use for the pregnant population. The anthropometry website is provided for automotive designers and engineers with the aim of enhancing pregnant occupant protection through an improved seat belt design.

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Pregnant Driver Seating Position

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Abstract - Pregnant women often experience discomfort and difficulties during driving due to their altered physical form, and it may also force them to adopt different positions. A study was undertaken to examine the posture of pregnant women, both in standard anthropometric, and in driver seating position in a car, with a particular focus on knee splay. Knee splay was defined as the distance between the outer borders of the knees in preferred posture. Analysis of the measurements reveals that pregnant women adopt a different posture in the car when compared to non-pregnant females. Considering the pregnant driver posture presented in this paper may provide a safer and more comfortable driving experience for pregnant women.

INTRODUCTION

Nicholls & Grieve [1] found that driving a car, getting in and out of a car, and using seat belts were all in the top ten tasks that are more difficult in pregnancy, yet previous research has not considered all aspects of driving and has focussed only on abdominal trauma. However changes to a pregnant woman are not limited to the abdominal region, and may occur throughout the body including the abdomen, chest and hip regions [2]. An EPSRC funded project entitled “Automotive Design: Incorporating the Needs of Pregnant Women” at Loughborough University addressed the problems associated with changes in pregnancy on the entire body and driving. Only one percent of over 600 volunteers who took part in this study experienced no car travel difficulties or changes arising from pregnancy [3].

The standard seated anthropometric posture requires the seat height to be adjusted so that the women could sit with their feet flat on the floor with knees together and bent at 90°, and with the upper leg parallel to the floor [4]. The knee breadth is a standard anthropometric measurement normally taken with knees together as described by Adultdata [5]. However during normal sitting in preferred posture the pregnant volunteers tended to sit with their knees apart. ‘Knee splay’ is defined for the purposes of this research as the distance between the outer borders of the knees whilst seated in the preferred posture. The feet remained flat on the floor, knees bent at 90°, with the upper leg parallel to the floor, but the angle between thighs and distance between the knees was increased. This paper presents the findings based on measurements that were introduced to investigate this trend, and its design implications.

Knee splay has not been described in previous research and the literature does not provide any data regarding any other measurements that attempt to describe seated posture that pregnant women tend to adopt by preference. The detailed knee splay findings from the anthropometric measurements for men, pregnant and non-pregnant women are presented, in addition to knee splay measurements taken whilst seated in a car in driving posture.

The knee splay of pregnant women is of concern since posture can influence safety and comfort during car travel. The size and shape changes associated with pregnancy may influence women’s comfort and safety during car travel [6]. By allowing for pregnancy and the associated knee splay automotive designers may help reduce risk and increase comfort for pregnant occupants. Every year there are approximately 670,000 pregnant women in the United Kingdom alone [7], who could potentially benefit from information regarding this alternative posture.

METHOD

Anthropometric posture measurements

A series of anthropometric measurements were recorded from pregnant women. All of the anthropometric measurements in this study were selected for their applicability to the vehicle design process, and for understanding the changes in physical size and shape that occur during pregnancy. The measurements used the standard postures and procedures, as in Adultdata (DTI, 1998) and Pheasant (1986, 1990), but were adapted where necessary to suit the pregnant body. The measurements taken to describe anthropometric posture, knee breadth and knee splay are shown below in Figure 1(A), 1(B) and 1(C) respectively.
Women were recruited in two locations in the United Kingdom: Loughborough University, and the Luton & Dunstable Hospital National Health Service Trust. The mean gestation level of these pregnant women was 35. Volunteers wore light clothing and removed their shoes, and the equipment used included weight scales, a stadiometer, a digital vernier caliper, a tape measure and an anthropometer. 29 sets of knee splay measurements were recorded from women in the third trimester. Furthermore, over 600 pregnant women also completed a questionnaire. The questionnaire findings are not explained in this paper although they are used to understand the need for specific measurements and interactions.

**Driver posture measurements**

Additional measurements of men, non-pregnant and pregnant women were taken at Thatcham MIRRC, in order to make inferences on driving postures and knee splay. The stature of the sample of men and non-pregnant and pregnant women were representative. The pregnant women were all in the third trimester, and the data sets are presented in Table 1 below. The vehicle used was a small car typically driven by women during pregnancy based on findings from the questionnaire. The measurements were taken where participants were first asked to sit in a comfortable office chair and the relaxed knee splay measurements then they were asked to sit in the car and make themselves comfortable for driving, and to fasten the seat belt.

A Co-ordinate Measuring Machine (CMM) was used to record landmark points over the body in order to describe the driver posture in three-dimension. Features of the vehicle interior were also recorded to locate the driver within the occupant space. From the co-ordinates recorded lengths and angles were calculated to describe the size, shape and position of the drivers. The focus of this paper is on the measurements describing knee splay in driving posture.

**DATA ANALYSIS**

Throughout this paper the data analysis refers only to the sample of males, non-pregnant females and pregnant females that participated in this study. All pregnant women were chosen from the population in their third trimesters, since this is the period when the body is most altered by pregnancy. All measurements were recorded within the UK. Throughout this study the measurements were compared against Adultdata [5], unless stated otherwise, which is the most recently published collection and uses PeopleSize [8] as the source of the UK anthropometric measurements.

The measurements of knee breadth and knee splay are summarised below in Table 1.
Table 1. Summary of Sample details and measurements

<table>
<thead>
<tr>
<th></th>
<th>Pregnant women</th>
<th>Non-pregnant women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of volunteers</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Mean height (SD)</td>
<td>1644 (70)</td>
<td>1612 (142)</td>
<td>1744 (58)</td>
</tr>
<tr>
<td>Knee breadth</td>
<td>209</td>
<td>201(^a)</td>
<td>203(^a)</td>
</tr>
<tr>
<td>Knee splay: Relaxed</td>
<td>353</td>
<td>242</td>
<td>463</td>
</tr>
<tr>
<td>Driving</td>
<td>366</td>
<td>309</td>
<td>470</td>
</tr>
</tbody>
</table>

\(^a\) Data taken from the literature: Adultdata, DTI [5]

**Anthropometric versus driver position**

The mean knee breadth for pregnant women is not significantly different to the knee breadth for non-pregnant women given in [5]. The pregnant women’s position is not significantly different from non-pregnant women’s position nor men’s position when asked to sit with their knees together, however in a relaxed posture by preference men and pregnant women choose a significantly different position and sit with their knees widely spaced apart.

Pregnant women’s knee splay measurements range between 229 and 500mm. By preference pregnant women choose to adopt a greater range of knee positions than simply sitting with their knees together. There are several causes that might contribute to women sitting with their knees splayed apart during pregnancy. The effect of the enlarging abdomen size and shape, gain in weight and soft tissue, and the spreading of the pelvis in preparation for birth could all be factors that contribute. For example, in seated posture the horizontal upper legs restrict the space available for the enlarged pregnant abdomen and apply an upward pressure, which may be uncomfortable for pregnant women. Secondly, during the course of pregnancy the pelvis widens under the influence of the hormone relaxin to allow the fetus to pass through the birth canal. The spreading of the pelvis possibly combined with the fetus moving to engage its head in the pelvis could cause the pregnant women to sit with their knees widely separated. Finally, the thighs increase in size during pregnancy due to an increase in soft tissue. In the seated posture the seat applies an upward pressure on the thighs and spreads the soft tissue horizontally. This horizontal increase in the size of the thighs could prevent the pregnant women from putting their upper legs together, so causing the increase in knee splay.

One of the pregnant women’s leading comments about the car seats in the questionnaire was the discomfort caused by the bucket seats. Non-pregnant women’s knee splay is significantly different in relaxed and driving positions whereas pregnant women’s and men’s driver and relaxed knee splays are very close. However the mean non-pregnant women knee splay is still under the mean pan breadth of 334 mm (between the wings of the seat pan). Pregnant women’s knee splay measurements suggest that their thighs are positioned over the protrusion of the wings, which partly explains the discomfort. Further clarification depends on the depth of the seat pan, which may force pregnant women to sit not right at the back of the seat in order to support back of the knees. This may have implications such as not taking the full advantage of the restraints available in cars, for example seat belts and head restraints. This may also mean sitting even closer to the steering wheel. However this all depends on the stature of the pregnant women and the size of the seats.

**DISCUSSION**

There is strong evidence from the measurements that by preference pregnant women choose a different posture and sit with their knees widely spaced. Knee splay increases as pregnancy progresses. This is caused by a combination of factors including: the enlarging abdomen, the widening pelvis, and the larger thighs that are caused by pregnancy. The combination of changes that could cause knee splay during pregnancy emphasises the need to consider the entire body as a system during design. It is clear that pregnancy can alter many parts of the body and not just the abdomen, and that these changes can interact causing an alteration in
position such as knee splay. If only the abdominal changes are considered then this significant change to posture is neglected, which could impact upon the safety and comfort of pregnant women.

Knee splay is important to automotive design with regard to the design of car seats. The authors suggest that the seat pan could be wider at the front, or made adjustable to provide extra width at the front, to provide adequate support under the knees. Knee splay is relevant to the design of car seat cushion mouldings. Some car seats have the mouldings raised at the side in ‘bucket’ style. Given the trend for pregnant women to sit with their knees widely spaced the bucket style cushions may interfere with their posture and result in discomfort. It may therefore be beneficial to pregnant women to avoid this type of moulding. Another alternative could be to provide cushion mouldings that could be adjusted up and down at the sides (within safe limits) according to preference.

For automotive design the knee splay data may also be relevant to the seat belt and head restraint use. Depending on the seat pan depth, pregnant women may need to sit forward in order to support the knees at the back, leaving a gap at the back of the seat. This would mean reduced proximity to the steering wheel and inappropriate use of seat belts and may bring about further difficulties of positioning the seat belts correctly, which might increase the risk of abdominal injuries. This would also mean increasing the distance between the head restraint and the head and increasing the risk of whiplash injuries in case of an accident.

The knee breadth for pregnant women is not greatly different to that of non-pregnant women or of men. However the anthropometric measurement of knee splay in pregnant women, where women could position their legs unrestrained, was different to that of men and non-pregnant women. Pregnant women still have to be able to reach and operate the pedals. Pregnant women often adjust their seat to allow the maximum possible space for the abdomen, and this can mean setting the seat as rearward as possible in order to decrease proximity to the steering wheel. If fore/aft adjustable pedals and steering wheels were incorporated into automotive designs, pregnant women might be able to sit further away from the steering wheel. This could consequently benefit women’s safety by reducing the impact of the steering wheel on pregnant abdomen. The findings suggest that the compatibility between the body and the seat is even more important during pregnancy.

Crandall et al. [9] and Parenteau et al [10] observed shorter drivers and use of pedal extenders respectively to reduce the risk of injuries. Similar observations of pregnant women using car pedals could also be useful to reduce the risk of injury.

Pregnant women can experience a wide range of symptoms during pregnancy including hip, pelvic, joint, and back pain, leg cramp and the baby’s head engaging with the pelvis. These symptoms, both long lasting and sudden in occurrence, can cause women to temporarily lose concentration whilst driving. Any pregnancy-related symptoms that cause discomfort can also cause distraction as the pregnant women tries to adjust herself or the vehicle to find a more comfortable posture. Driver distraction can put pregnant drivers, their fetuses and other road users at increased risk. Reducing driver error by ensuring that all controls and driving operations are simple and easy to use will make all drivers including pregnant women safer, if they have temporary difficulty concentrating on driving.

The “Automotive Design: Incorporating the Needs of Pregnant Women” research project aimed to consider the needs of pregnant women for all aspects of driving as well as behaviour and driving style. The information about the characteristics of pregnant women has been used in automotive design recommendations and an electronic information catalogue. This will allow designers to incorporate the changes resulting from pregnancy to improve both safety and comfort for pregnant drivers.

ACKNOWLEDGEMENTS

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Safety of Pregnant Drivers in the United Kingdom

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It is widely accepted that women have a different driving style and travel patterns from those of men, whereas pregnant women have yet again a different set of travel patterns and preferences. Pregnancy can cause a wide range of symptoms and physical changes that are not limited to the abdominal region. Research to date has not considered the real-life experiences and problems of car travel during pregnancy. The project Automotive Design: Incorporating the Needs of Pregnant Women at Loughborough University addresses issues such as seat belt safety, behaviors, and needs in a holistic manner for the first time and provides explicit information about pregnant women. A pregnancy and driving questionnaire is used to investigate how U.K. women's experiences of driving and using passive safety systems (seat belts, airbags, and head restraints) are affected during car travel. The main safety concerns found in 450 completed questionnaires were low levels of correct seat belt and head restraint positioning and proximity to the steering wheel and airbags. The correct position for the shoulder section of the seat belt is between the breasts and for the lap section around the abdomen and across the hips underneath the abdomen. Some U.K. pregnant women used the correct position for the shoulder belt, and others positioned the lap belt correctly across the hips. However, the seat belts are designed to protect the car occupant when used correctly, not correctly in part. Therefore this study is focused on correct usage of the entire seat belt. Certain factors seem to influence correct seat belt positioning positively, and this information could be used to target schemes to provide seat belt information. Targeting information to women in their first pregnancy will improve seat belt positioning for that first pregnancy and will help in subsequent pregnancies. Pregnant women commonly reported concern that the seat belt was incorrectly positioned, and they felt unsafe while using the seat belt. In some cases women took action to alleviate this fear, for example, by ceasing to use the seat belt or by holding it. This is evidence that women modify their seat belt behavior for protection during pregnancy but may actually put themselves at greater risk of injury. The majority of women in their third trimester of pregnancy were seated with their abdomen less than 25 cm from the steering wheel because of abdominal protrusion. This problem is counteracted by moving the seat rearward, but that results in difficulty reaching the pedals. More suitable designs would help women to increase their steering wheel clearance while maintaining their ability to reach the pedals. All the information about pregnant women's experiences of using passive safety systems is presented as an information catalog for automotive designers as part of this project. This catalog includes guidelines to aid future vehicle design concepts with the aim of improving car travel for pregnant women. Detailed findings of this project have been submitted for publication or can be obtained from the authors.
Designing for Safety During Pregnancy

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Abstract
Pregnant women in the UK are legally required to wear seat belts (if fitted) both as drivers and passengers. This paper focuses on the ability of fitting the seat belt correctly around the pregnant woman’s altered body and investigating the ways of improving the seat belts. The paper presents analysis of anthropometric measurements and questionnaire responses from pregnant women. The difficulties experienced during pregnancy result from women’s altered shape and size, hence accommodation of pregnant occupant anthropometry is key to improving seat belt use and positioning. An anthropometry website and guidelines are presented with the aim of enhancing pregnant women’s quality of life through an improved seat belt design. The site has been designed to suit the needs of automotive designers and engineers to encourage them to consider pregnant occupant protection.

INTRODUCTION

Road traffic accidents are one of the leading causes of death, with 1.3 millions deaths worldwide in 2000 [1]. World Health Organisation predictions suggest road traffic accidents will rise from 9th rank to 3rd by the year 2020 [2,3]. The largest cause of accidental death and disability in pregnancy is automobile collisions [4]. The Royal Society for the Prevention of Accidents safety publications report that seat belts and air bags prevent tens of thousands of deaths and serious injuries in the UK each year [5]. It is a legal requirement in the UK to wear seatbelts (if fitted) both as drivers and passengers [6,7], and pregnant women are not exempt to this rule. Crash test research [8] has shown the effectiveness of seat belts in reducing injury risk for pregnant women and their fetuses, and has focussed on establishing the correct position for seat belts in pregnancy in order to reduce the risk of abdominal trauma. Current safety guidelines from the UK Department of Transport [7] and the National Highway Traffic Safety Administration in the USA [9] describe the correct position such that ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. However Acar and Weekes [10] also reported that only 13% of pregnant women are actually wearing their seat belt in the correct position, and many are therefore inadequately protected.

During pregnancy a woman’s body undergoes significant changes in size and shape. These changes are not limited to the abdominal region, since the hips and breasts also increase in size. In this paper we focus on the ability (or inability) of fitting the seat belt correctly around the pregnant woman’s altered body and investigate the ways of improving the design of seat belts.

The design process relies upon the use of anthropometric data to determine the portion of the user population that will be accommodated by the design. There is currently little data available for pregnant women, and the published data dimensions are often not relevant to automotive design. The study of the dimensional changes of the feet during pregnancy by Alvarez et al. [11] compares a sample of 17 pregnant women with 16 comparable non-pregnant women. This data is of little use for vehicle design since the sample size is extremely small, and only dimensions for foot length and width are given that are relevant to automotive design. The study by Yamana et al. [12] presents measurements of 520 pregnant women from the second to tenth month of pregnancy for a total of 44 dimensions. However very few measurements are applicable to automotive design since the paper was originally aimed at garment design. Pheasant [13] modified the data from Yamama et al. [12] for the abdominal depth and forward grip reach dimensions. Pheasant used a scaling method based on the assumption that pregnancy will cause British and Japanese women to change in a similar way, and that they are of similar proportions. The anthropometric data generated using the scaling method is therefore less reliable than real anthropometric measurements. Finally Klinich et al. [14] present measurements of 22 pregnant women. 10 measurements pertinent to automotive design were recorded throughout the course of pregnancy. Therefore in general the availability of pregnant women’s anthropometric data is limited, and little is relevant to vehicle design. It has also been difficult for designers to assess the suitability of their designs for the pregnant occupant, since there has been a lack of anthropometric data measured from pregnant women.
This paper presents analysis of a comprehensive set of 48 anthropometric measurements selected specifically for use in vehicle design as a contribution towards the solution of this problem. A Pregnant Women’s Anthropometry Website is then used to display this data in a user-friendly manner for automotive designers and engineers.

METHOD

Two data collection methods were used in this study, the first being a series of anthropometric measurements. 100 sets of measurements were recorded at the time of writing. The measurements recorded were adapted by the authors for pregnant women based on standard anthropometric postures [13]. Women were recruited in two locations in the United Kingdom: Loughborough University, and the Luton & Dunstable Hospital National Health Service Trust. Volunteers wore light clothing and removed their shoes. The equipment used included an anthropometer, weight scales, a digital vernier calliper, a tape measure and a stadiometer. The abdominal, hip and chest region measurements (illustrated in Figure 1) were particularly useful in understanding how physical changes impact upon seat belt safety in pregnancy.

![Figure 1. Anthropometric measurements with particular relevance to seat belt design.](image)

The second data collection method was a ‘Pregnancy and Driving Questionnaire’ that was answered during an interview or by self-completion. 450 sets of questionnaire responses were processed at the time of writing. The questionnaire was also available for online completion in four languages (English, Spanish, Italian and French) at [http://pregnantdriver.lboro.ac.uk](http://pregnantdriver.lboro.ac.uk). Responses have been received from around the world with the majority being from the UK (63%), and the remainder from the rest of the world (37%). The pregnant women were reminded repeatedly to compare their experiences when they were not pregnant against their experiences during pregnancy. The questions about seat belts included issues of seat belt use and positioning, and attitudes and information received about seat belts in pregnancy.

Table 1 provides a summary of the gestation levels of the pregnant women recruited to this study. The majority of these women normally occupy the driver’s seat. Occasionally they use the front or rear passenger seats, and in a few cases the normal occupant position is unknown.
Table 1 Pregnancy and driving details of the sample of pregnant women.

<table>
<thead>
<tr>
<th></th>
<th>No. Volunteers (women)</th>
<th>Week of Pregnancy</th>
<th>Women’s Usual Driving Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (weeks)</td>
<td>Std. Dev. (weeks)</td>
<td>Drivers (women)</td>
</tr>
<tr>
<td><strong>Anthropometric Measurements</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second trimester (^b)</td>
<td>35</td>
<td>21.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Third trimester (^c)</td>
<td>65</td>
<td>35.5</td>
<td>2.8</td>
</tr>
<tr>
<td><strong>Pregnancy &amp; Driving Questionnaire</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First trimester (^a)</td>
<td>34</td>
<td>8.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Second trimester (^b)</td>
<td>159</td>
<td>21.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Third trimester (^c)</td>
<td>257</td>
<td>35.2</td>
<td>3.3</td>
</tr>
</tbody>
</table>

\(^a\) The first trimester lasts until the 12\(^{th}\) week of pregnancy.

\(^b\) The second trimester is from the 13\(^{th}\) to the 28\(^{th}\) week of pregnancy.

\(^c\) The third trimester is from the 29\(^{th}\) week of pregnancy until the birth (40+weeks).

SEAT BELTS

Fitting and positioning

The DFT and NHTSA advise pregnant women that the correct seat belt position is as follows: ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. 95% of the pregnant volunteers who responded to the questionnaire reported that they were wearing their seat belt during pregnancy. However only 13% of pregnant women using their seat belt actually had their seat belt correctly positioned according to the guidelines. This means that a huge portion of pregnant women are inadequately restrained by the their seat belt during car travel, and potentially at greater risk of injury.

It is not surprising that the pregnant women report problems with seat belt positioning when they are physically so altered. The anthropometric measurements recorded show that the pregnant woman’s body undergoes dramatic transformation during pregnancy. For example the biggest changes occur in abdominal circumference where pregnant women’s abdominal circumference may be up to 1410mm, which is 452.8mm larger than the 95\(^{th}\) percentile value for non-pregnant UK females. The changes are not limited to the abdominal region, but occur throughout the body. The breasts and hips also enlarge notably due to pregnancy, as well as the abdominal protrusion.

For pregnant women measured in the third trimester the lower bound of the 95\(^{th}\) confidence interval of the mean for the standing abdominal circumference is greater than the 95\(^{th}\) percentile value for UK non-pregnant females given in [15]. The lower bound of the confidence interval is also larger than the male 95\(^{th}\) percentile [15] so even using data for large males might be inadequate. These confidence intervals lie completely outside the 5\(^{th}\) to 95\(^{th}\) percentile range of currently available data. This highlights the importance of considering the pregnant occupant as a separate user group in order to accommodate their particular physical sizes.

However the most important change for seat belt fitting is the increment in hip circumference because the lap belt is supposed to pass across the hips. Changes to hip circumference in pregnancy illustrate the importance of considering pregnant women’s full anthropometry.

Figure 2 shows how much larger pregnant women’s hip circumference is in the third trimester, when compared to non-pregnant UK female or male data currently available in [15]. The mean standing hip circumference is 1155.1mm for the women in the third trimester, which is 118.1mm larger than for non-pregnant women’s anthropometric data given in [15]. Similarly it is 108.6mm larger than the mean male standing hip circumference. This suggests that a woman nearing the end of pregnancy would need an approximately 12cm longer seat belt.
Figure 2. Pregnant occupants have approximately 12cm larger standing hip circumference during the third trimester.

Even if seat belt designs were based on the 95th percentile male value for hip circumference of 1168.2mm, they would still exclude many pregnant women. This is because the 95th percentile for male standing hip circumference in [15] is equivalent to only the 55th percentile value for measurements recorded from pregnant women in the third trimester. Hence 45% of pregnant women would be excluded by a design based on currently available data, even if the male 95th percentile is used as shown in Figure 3.

Figure 3. Pregnant occupants have a larger standing hip circumference so even designs using UK male 95th percentile data could exclude 45% of pregnant women in the third trimester.
The automotive industry could use pregnant women’s anthropometric data during the design stages to ensure that pregnant women are able to wear a correctly positioned seat belt. This should also help to reduce seat belt discomfort problems, which is particularly important since some pregnant women are discouraged from using the seat belt due to discomfort [10]. It is important for the automotive industry to accommodate the pregnant women’s anthropometric needs throughout the entire course of pregnancy, because the seat belt positioning may change as body shape alters. For example the tendency for the lap portion of the seat belt to ride up onto the abdomen is highest in the second trimester, whereas in the third trimester the enlarged abdomen helps to hold down the lap belt more securely across the hips [10]. The authors not only recommend that the anthropometric data be used to check seat belt fit for the pregnant occupant, but also at least static user testing with pregnant volunteers. This will help the designers and engineers gain further insight into the notable physical changes occurring throughout the body during pregnancy, and how these changes affect seat belt positioning.

ANTHROPOMETRY WEBSITE AND INTERFACE

A website presenting the anthropometric measurements of pregnant women was produced, and is illustrated in Figure 4. The aim of the site is providing this anthropometric data to automotive designers so assessment of designs for accommodation of pregnant occupants. This will subsequently help to incorporate the altered physical needs of pregnant women into vehicle designs, to ensure seat belts can be correctly and comfortably worn. The web format was selected so all parts of the automotive industry could access the data regardless of particular software systems used for design. This is the first anthropometry website to be produced and is especially unique in providing anthropometric measurements of pregnant women specifically selected for use in vehicle design. The site is aimed at automotive designers and engineers, but the measurements may also be useful to other areas of design.

The site includes a page describing the project aims and objectives so automotive designers can understand the research project and background. The target user group is automotive designers and engineers, so the entire site has been designed to suit their human-computer interaction and usability needs. A contact page is provided so automotive designers can request modifications to the site if necessary. The users are also invited to provide feedback and comments about the pregnant women’s anthropometry website, to ensure it meets their needs.

The website uses engineering terminology so the automotive designers and engineers feel familiar with the terms. The anthropometric measurements were selected from the standard measurements depicted in the literature [13,15], which the automotive designers are also familiar with. In a few cases the authors either added new measurements or adapted the standard measurement in order to better define the pregnant form. A full description of every measurement (including the new and adapted ones) is given so that automotive designers and engineers can be aware of the exact detail of the data recorded. Any gynaecological terms are defined, for example on the search page the stage of pregnancy is given in trimesters, but the week of pregnancy is displayed alongside in parentheses for clarification.

The anthropometric data is stored in a MySQL database, which is queried using PHP code. The engineers and designers use a simple HTML search page to interface with the PHP code and control exactly which data is retrieved from the database. The search page (Figure 4) has simple radio buttons, checkboxes, and lists to aid the users’ choices. The search process is broken into three steps, each of which is clearly labelled with a heading and instruction of how to proceed. The three steps of the search are:

1. Choosing the stage of pregnancy.
2. Choosing the statistics about the measurements.
3. Choosing the anthropometric measurements.

The first step for the automotive designer is choosing the stage of pregnancy. The user can choose the stage of pregnancy by selecting a radio button for the trimester(s) of interest. Images of a pregnant woman with a small bump for Trimester 2, and a much larger bump for trimester 3 are used to visually represent the stages of pregnancy as an aid understanding. Anthropometric data is not provided for
pregnant women in the first trimester because there is little physical change during the first three months of pregnancy so data for non-pregnant females is adequate. The automotive designers are given the choice to display data for women measured in the:

- second trimester,
- third trimester,
- or both second and third trimesters together.

This choice is given because the authors wish to encourage automotive designers to consider the entire gestation period, and not just the third trimester. The third trimester is the period of greatest risk of injury because the abdominal enlargement is greatest, however the second trimester is also a time of great change and has particular problems associated with it. For example the problem of the lap belt riding up onto the abdomen is greatest in the second trimester. Providing data for the women in the second and third trimesters separately should encourage automotive designers to accommodate women’s changing physical needs throughout pregnancy.

Figure 4. A screenshot of the Pregnant Women’s Anthropometry Website data search page.
The second step the user makes is choosing which statistics to display about the anthropometric data. These selections have also been aimed at the automotive industry. Automotive designers can either choose to display all the statistics, or make their own personalised selection by ticking the checkboxes in the list. The choice of statistics includes the:

- minimum, maximum and range,
- sample size,
- mean and standard deviation,
- 5th, 50th, and 95th percentiles.

The percentile calculations are provided because the 5th, 50th, and 95th percentiles are the statistics used in typical design practice for accommodating 90% of the population. The minimum and maximum data are given to provide information about extreme cases occurring in pregnancy, and so automotive designers could aim to accommodate a larger portion of the pregnant population. This could also benefit obese people. The sample size data provides understanding of how many women’s measurements are included in the sample, which is 100 at the time of writing.

The third and final step for automotive designers is choosing which anthropometric measurements to display. The user may choose the measurements by using one of three methods, including:

- choose the entire list of 48 measurements,
- make a personalised selection of measurements from the list,
- choose by the vehicle part they are designing.

If the user is making their own personalised selection of measurements they simply click on the measurements in the list. There is a link underneath the list to a page providing the full details of every measurement, and this page opens as a separate browser window to enable easy referencing between measurement details and the search page. This allows the automotive designers to know the exact details of the measurements so they can make a fully informed choice. The details provided in the reference page about each individual measurement include:

- a diagram providing a visual representation as an aid to understanding,
- the measurement name,
- the body landmarks between which the measurement is recorded,
- the posture (either standing or seated),
- the equipment used.

The automotive designers also have the option to choose measurements to display according to the part of the vehicle they are designing, for example the seat belt. In this case all measurements of any body part making contact with that particular vehicle part are presented. For the seat belt option the measurements of the abdomen, hips, breasts, and shoulders are displayed. The weight and stature of pregnant women are also given providing an indication of overall size. Any dimensions useful for defining locations of vehicle parts in relation to the occupant are also given. For reference purposes there is a separate page defining which anthropometric measurements are associated with different vehicle parts, shown in Figure 5. A link to this reference page is given underneath the vehicle parts list so the user can easily get additional information about this feature. The reference page opens a new browser window so the user can make references whilst making choices on the search page. The ability to choose the measurements according the vehicle part is advantageous to the designers and engineers, and it saves time.

For both the vehicle parts list and the measurements list the user can select just one individual list item (either a measurement or a vehicle part). Alternatively they can make multiple selections by holding the control key whilst clicking on the items. The user can also select a group of consecutive items by clicking the first item in the group then holding the shift key and clicking the item at the end of the group. The ability to make multiple selections in these lists helps automotive designers to make their own personalised selections to suit their particular aspect of vehicle design.

Once the automotive designer has completed the three steps of the search and made their choices of the stage of pregnancy, statistics, and measurements to display, they simply display the anthropometric data by clicking on the “Display Anthropometric Data” button.
Figure 5. A screenshot of the Vehicle Parts page displaying which measurements are associated with different parts of the vehicle.

The data page displays a table of anthropometric data, according to the selections made in the search page. Each measurement has one row of the table, and is clearly labelled in the left-hand column with the measurement name. The statistics selected are given a column each and are also labelled clearly in the top row of the table. The table resizes according to the number of measurements and statistics that were selected. Above the table is a heading to identify the stage of pregnancy so the user is reminded of their selection. For example if the user selected ‘trimester 3’ to display measurements from women in the third trimester of pregnancy, the heading clearly states “Trimester 3 (weeks 29-40+)”. Also above the table a button to return to the search page can be used, as well as the back button in the browser. When the user returns to the search page the choices from their previous search are displayed. This has two benefits, first that the user does not have to remember the previous choices, and secondly that the user is able to make modifications based on the previous search.

The user can click on the measurement name in the data table, which is a hypertext link, to display the full details about that particular measurement. The details including a diagram are displayed in a pop-up window so that both the measurement details and the anthropometric data statistics can be viewed simultaneously. If the user wishes to display details for another measurement, these details are displayed in the same pop-up window so there is no risk that multiple pop-up windows would confuse the user.

The website has an error checking facility to ensure the user completes all the required sections of the search page. If the user leaves any or all of the sections (stage of pregnancy, statistics, measurements) blank, an error message will be displayed. The error message informs the user of the incomplete section, so the user knows exactly how to correct the error and successfully display the anthropometric data. An additional feature is that the user can click a statistics checkbox or measurement item to make a selection without necessarily having to click the associated radio button because the radio button will be automatically selected for them. For example if the automotive designer wishes to select the sample size check box they do not have to select the ‘choose your own group(s)’ radio button because it will be automatically selected. This not only prevents errors on the search page, but also helps to save automotive designers’ time.
CONCLUSION

This study reveals that only 13% of pregnant women actually had the seat belt correctly positioned according to current safety guidelines. The correct position for the seat belt is ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump’ [7]. Since many seat belt fit and positioning problems experienced by pregnant women are caused by alterations in size and shape, accommodating women’s altered anthropometry will be of greatest benefit. The authors following recommendations are based on 48 anthropometric parameters of 100 pregnant women and 450 questionnaire responses. Pregnant women’s physical size and shape changes require that the pregnant occupant should be considered as a separate user group in order to meet their specific needs. The pregnant occupant anthropometry could be used during the design stages to check the fit and positioning of the seat belt. Designers are also recommended to consider both the second and third trimesters of pregnancy because the fit of the seat belt is constantly changing as pregnancy progresses.

A pregnant women’s anthropometry website was generated to present the anthropometric data gathered in this research. This website displays measurements specifically selected for use in vehicle design, and is the first such resource of its kind. The site was designed for use by engineers and designers to suit their needs, in order to encourage consideration of the pregnant occupant during the design stages. The website has many features to aid the user, in particular the ability to select the anthropometric measurements according to the vehicle part being designed. Incorporating the needs of pregnant women and modifying seat belt design accordingly can help to improve seat belt fit and use for the pregnant population. The anthropometry website is provided for automotive designers and engineers with the aim of enhancing pregnant occupant protection through an improved seat belt design.

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VEHICLE ENTRY AND EGRESS IN PREGNANCY: A SYSTEMS APPROACH

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Keywords: Systems, Pregnant, Entry, Occupant, Automotive Design, Driver.

ABSTRACT

Women experience a range of physical and emotional changes in pregnancy, which can impact upon their car travel. A major problem is vehicle entry and egress. This paper presents the systems approach used to gain insight into getting in and out of the car during the gestation period. The systems approach involves defining the system in terms of its objectives, subsystems, environment and interactions. A model of a vehicle system is used to interpret the problems and experiences of entry and egress reported by pregnant women. The analysis is based upon a questionnaire and anthropometric measurements. Understanding the vehicle system helps to identify both how the changed attributes of pregnant women can affect the interactions of the system, and the influence of the system environment. The systems approach is used to present an analysis of vehicle entry and egress so that automotive designers can make informed design decisions.

INTRODUCTION

During the gestation period pregnant women experience a wide variety of physical and emotional changes. Not only do women gain weight, but they also undergo changes in size and shape throughout the entire body. The size increase is not limited to the obvious abdominal protrusion, since the hips, thighs and breasts also increase greatly in size. The size and shape changes can result in changes to her mobility and range of motion, with twisting, reaching and bending actions becoming particularly difficult. She may also alter her posture to compensate for pregnancy, for example by leaning backwards to counterbalance the additional weight of the abdomen. The pregnant women may experience a wide variety of pregnancy related symptoms, which can be long lasting or sudden in occurrence. Long lasting symptoms might include back, hip, pelvic, stomach, and joint pain; exhaustion, haemorrhoids, swelling, varicose veins, and the baby’s head engaging with the pelvis. Symptoms that are sudden in occurrence can include leg cramp, heartburn, nausea, itching skin, Braxton hicks contractions, and need to urinate. The hormone relaxin causes ligament laxity to help widen the pelvis in preparation for the birth. However its effect is not limited to the pelvis and can affect the entire musculoskeletal system. Furthermore, emotional changes caused under hormonal influence can mean that the pregnant women experience a wide range of emotions, ranging from depression, irritability and fear, through to excitement and pleasure.

All of these physical and emotional changes can cause pregnant women difficulty with carrying out everyday activities. Nicholls & Grieve [1] found that 32 common tasks were more difficult during pregnancy. From this list of tasks, 3 driving-related tasks were in the top ten. These were: driving a car, getting in/out of a car, and using seat belts. Acar & Weekes [2] found that 99% of pregnant women experience a wide range of difficulties with car travel during pregnancy. The “Automotive Design: Incorporating the Needs of Pregnant Women” project is implementing a systems approach to examine the changed driving experiences of pregnant women. This project examines all aspects of car use and travel in a comprehensive and holistic manner.

One of the major problems of car use in pregnancy is vehicle entry and egress. Nicholls & Grieve [1] found this difficulty to be reported by nearly 70% of subjects. However the questionnaire results from this study indicate that 81% of pregnant volunteers experience entry/egress difficulty, which confirms the extent of the problem and suggests that the problem is increasing. Nicholls & Grieve [1] state that pregnant women perceived mobility to be the main cause of entry/egress difficulty.
problems. They describe the difficulty of simultaneously bending, twisting and lifting the body weight against gravity in a constrained space as obvious. However they do not examine the problem in detail. Lou et al [3] investigated the sit to stand motion at different periods of pregnancy, and suggest that it takes longer toward the end of pregnancy. They highlight that the sit to stand movement becomes more difficult in the third trimester of pregnancy because the enlarged abdomen prevents women from leaning forward. However Lou et al [3] do not consider the opposite motion of stand to sit, and the focus is on office chairs rather than vehicle seats. The research to date has not yet fully addressed the problem of vehicle entry and egress in a comprehensive manner. This paper focuses on the entry/egress function of car travel by using a systems approach. The systems approach is needed to better understand the current experiences of pregnant women, to help make informed design decisions.

Traditional engineering practice involves dividing a design problem into sub-problems or components, and solving each of these sub-problems in turn, whereas the systems approach involves considering a design problem in a broad and holistic manner. The design solution is then conventionally a combination of these sub-solutions. In the systems approach every function, objective, and subsystem of the system is considered, similar to the conventional engineering approach. However within the systems approach the system environment and the interactions (between the subsystems and between the environment and the system) are considered thoroughly.

The system environment consists of everything outside of the system boundary that can affect the system functionality and that is beyond the control of the system. One common cause of system failure is poor consideration of environmental factors and their interactions with the system. The interactions within the system between the subsystems also have to be studied carefully. Acar [4] suggests that the interactions are the most difficult part of successful design since possible inputs to and outputs of subsystems and their effect on the other subsystems must be considered to minimise system failure. This includes people, either as part of the system or as part of its environment. Their decisions, errors and use/abuse of the system could affect the interactions.

Systems are most vulnerable at times of change according to Acar [5]. Changes can include change in the objectives, subsystems, interactions, or environment of the system. Since pregnancy is a period of great change within the body, the systems approach is the best method of understanding these changes, and how they impact upon pregnant women’s normal activities and associated systems.

This paper therefore presents a systems approach to vehicle entry and egress, in order to gain a thorough insight into the system and the problems that occur. This comprehensive systems approach enables detailed analysis of entry/egress problems to aid understanding of automotive designers so that they could address the problem successfully.

METHOD

The comprehensive systems approach used two methods to investigate how car entry and egress is affected by pregnancy. These methods include a questionnaire, and anthropometric measurements. Women were recruited in two locations in the United Kingdom: Loughborough University, and the Luton & Dunstable Hospital National Health Service Trust. At the time of writing 100 sets of anthropometric measurements and 450 questionnaire responses had been processed. The majority of these women normally occupy the driver’s seat. Occasionally they use the front or rear passenger seats, and in a few cases the regular occupant position is unknown. The details of the sample of pregnant women are given in Table 1.

Table 1. Pregnancy and driving details of volunteers.

<table>
<thead>
<tr>
<th></th>
<th>Tri 1</th>
<th>Tri 2</th>
<th>Tri 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Weeks 0-12)</td>
<td>(Weeks 13-28)</td>
<td>(Weeks 29-40+)</td>
</tr>
<tr>
<td>Pregnancy &amp; Driving Questionnaire.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of women.</td>
<td>34</td>
<td>159</td>
<td>257</td>
</tr>
<tr>
<td>Gestation: Mean weeks</td>
<td>8.5</td>
<td>21.6</td>
<td>35.2</td>
</tr>
<tr>
<td>Gestation: Std. dev. weeks</td>
<td>2.3</td>
<td>4.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Drivers (women)</td>
<td>32</td>
<td>156</td>
<td>243</td>
</tr>
<tr>
<td>Non-Driver &amp; unknown (women)</td>
<td>2</td>
<td>2 &amp; 1</td>
<td>5 &amp; 9</td>
</tr>
</tbody>
</table>

Anthropometric Measurements.

<table>
<thead>
<tr>
<th></th>
<th>Tri 1</th>
<th>Tri 2</th>
<th>Tri 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of women.</td>
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<td>35</td>
<td>65</td>
</tr>
<tr>
<td>Gestation: Mean weeks</td>
<td>n/a</td>
<td>21.6</td>
<td>35.5</td>
</tr>
<tr>
<td>Gestation: Std. dev. weeks</td>
<td>n/a</td>
<td>4.5</td>
<td>2.8</td>
</tr>
<tr>
<td>Drivers (women)</td>
<td>n/a</td>
<td>34</td>
<td>52</td>
</tr>
<tr>
<td>Non-Driver &amp; unknown (women)</td>
<td>n/a</td>
<td>0 &amp; 1</td>
<td>4 &amp; 9</td>
</tr>
</tbody>
</table>

The measurements used were based upon standard anthropometric postures, and where necessary measurements were modified or introduced by the authors to incorporate the changes associated with pregnancy. Since the process of getting into and out of the car involves moving between standing and seated postures, measurements (such as abdominal circumference) were recorded in both these postures. Volunteers wore light clothing and removed their shoes. The equipment used included an anthropometer, weight scales, a digital vernier calliper, a tape measure and a stadiometer.

The ‘Pregnancy and Driving Questionnaire’ was used to investigate women’s experiences. It was answered in an interview or by self-completion, and was also made available for online completion in four languages (English, Spanish, Italian and French) at [pregnantdriver.lboro.ac.uk](http://pregnantdriver.lboro.ac.uk). The pregnant women were repeatedly reminded to compare their pregnancy experiences with when they were not pregnant. Responses have been received from around the world with the majority being from the UK (63%), and the remainder from the rest of the world (37%). Questions were asked about all aspects of car travel, both as drivers and as passengers. The questionnaire included a section specifically to investigate issues and experiences of getting in and out of the car.
The data analysis focused on using the systems approach to examine the problems reported by pregnant women, and the possible causes of these problems.

**THE VEHICLE SYSTEM**

The first step in using the systems approach to understand the vehicle entry and egress problems experienced by pregnant women was to define the vehicle as a system. This vehicle system is illustrated below in Fig. 1. The objective of this vehicle system is to transport the pregnant woman in safety and comfort. For the purposes of this paper the vehicle is a car.

The process of completing a car journey can be divided into functions:

1. Load the car (if necessary).
2. Enter the vehicle.
3. Drive the car to destination.
4. Exit the vehicle.
5. Unload the car (if necessary).

By breaking a journey up into functions the different subsystems of the car system can be identified. The most obvious subsystem is ‘driving’ i.e. the process of actually traveling in the vehicle, be this as the driver or a passenger. This can be divided into sub-systems of motion and control. The driving subsystem and its sub-systems are systems beyond the scope of this study and have not been investigated.

The ‘occupancy’ subsystem consists of three sub-subsystems. Firstly there is the occupant that is a pregnant woman in this case. The second sub-subsystem of occupancy is safety because the occupant must be kept safe during the car journey. This can include both active and passive safety systems, such as seat belts, air bags, and head restraints. Comfort is the final sub-subsystem, which is important for an enjoyable and user-friendly car travel experience. This can include many aspects such as the ‘fit’ of the car and being able to reach the required parts of the car, as well as the comfort of all five senses.

‘Loading’ and ‘unloading’ are two more subsystems, but these only occur when the driver and/or passengers have bags, luggage or packages that also need transporting. Loading and unloading can involve any of the storage spaces within the car, including the car seats, boot, floor space, glove compartment, and pockets.

The ‘entry’ and ‘egress’ subsystems are the activity of getting into the car at the start of a journey, and getting out the car at the end. The entry subsystem is when the occupant opens the car door and moves from standing posture beside the car to sitting in the car seat. The egress subsystem is when the occupant climbs out of the car seat to standing posture beside the car, and then shuts the car door. The entry and egress subsystems are the focus of this paper. These two motions are treated as two separate subsystems because whilst they are quite similar, they are not necessarily the exact opposite of each other. For example a pregnant woman may choose to lean on the steering wheel whilst entering the car, but chooses to pull on the inner handle above the door opening whilst she gets out of the car. This is because the motions of sitting and standing during entry and egress have different system inputs and outputs, such as force magnitude and direction.

All the environmental factors lie outside the system boundary. The vehicle system environment can include the road surface, signs, journey start point and destination, number of car passengers, frequency of vehicle use, weather, help, roads, the pregnant woman’s choice of vehicle, and car parking spaces. Environmental factors can interact with the vehicle subsystems, and more specifically the entry and egress subsystems that are the centre of this paper.

![Figure 1. Vehicle System Diagram.](image)

The entry and egress subsystems are the focal point of this paper, and the entire vehicle system is used to analyse the problems of entry and egress during pregnancy. The main problems with getting into and out of the car experienced by pregnant women are illustrated in Fig.2.

![Figure 2. Problems experienced by pregnant women during entry and egress.](image)
These problems are explained by using the vehicle system model. Defining the vehicle system enables a deeper understanding and analysis of how pregnancy can affect the system functionalities, its subsystems and interactions. In order to understand how vehicle entry and egress subsystems are affected the different types of changes caused by pregnancy are investigated in turn.

**CHANGED ATTRIBUTES OF THE PREGNANT OCCUPANT**

**Restricted movement**

The biggest problem (48%) for pregnant women during entry and egress is that their movement is restricted. Restricted movement is a common side effect of pregnancy, and 82% and 70% of pregnant women respectively also reported limited bending and limited reach. Specifically the term ‘restricted movement’ means the physical movements and range of motion of the women being decreased in comparison with when they are not pregnant; hence the movement and mobility attributes of the pregnant occupant are changed. Having understood this general problem of restricted movement, it can then be used to analyse more specific problems reported by pregnant women. For example many women commented that twisting and turning were particularly a problem. This is not surprising when put into context against the size increases throughout the body, not only in the abdomen, but also in the hips and breasts. The pregnancy-related size and shape changes cause restricted movement, which in turn causes women difficulties with twisting during entry and egress.

Restricted movement can also cause pregnant women difficulty with lifting their legs. When getting into the car women have difficulty lifting their legs to move them into the car once they have sat down.

Restricted movement also prevents women from leaning forward whilst seated before they stand up to get out of the car. The women cannot lean forward whilst seated because the large abdomen is touching the thighs. Hence the problem occurs because of a new interaction that is introduced during pregnancy i.e. the interaction between the abdomen and thighs whilst seated. Similarly this interaction causes difficulty when women are getting in to the car, as the abdomen and thighs interact as women swing their legs in once seated.

The restricted movement that women experience during pregnancy causes them to alter their method of entry and egress. For example when women are getting in to the car, they tend to separate the movement into two stages, as shown in Fig.3. The two separate motions are first to sit down on the seat whilst facing laterally out of the door opening, then secondly to swivel to face the front of the car whilst lifting their legs in. This is a different technique compared to before pregnancy, when women would normally move from standing to seated in the car in one continuous motion. Since pregnant women are using different motions in this two-stage method of entry they have different requirements of the vehicle system. This has design implications such as ensuring women are able to swivel on the seat unobstructed, and ensuring they have enough space in the door aperture when stood facing laterally out of the drivers seat.

The reverse of the two-stage entry method is used for vehicle egress. Pregnant women tend to swivel round to face laterally out of the car door whilst lifting their legs out of the car as the first motion, then standing up is the second separate motion. Hence the restricted movements experienced by the pregnant occupant sub-subsystem causes alterations in the entry and egress subsystems by making pregnant women change their entry/egress method.

**Figure 3. The two-stage vehicle entry method. (The egress method is the reverse process.)**

**Pain**

A common symptom of pregnancy is pain. This pain can occur in many parts of the body including the back, pelvis, hips, abdomen, legs and joints. Back pain was the biggest problem for this sample of pregnant women, with 74% of women reporting back pain during pregnancy.

The pain described by pregnant women is a change within the pregnant occupant sub-subsystem because the pain attribute is added. The activity of getting into or getting out of the car can cause pain to occur, or may exacerbate pain levels. The pain may then cause the pregnant women to alter their movements or restrict their range of motion in order to avoid the occurrence of pain or to reduce pain levels. Hence as pregnant women choose to restrict their range of motion to avoid pain, this in turn can lead to the problems associated with restricted movement mentioned previously. Thus the pain attribute of the pregnant occupant can indirectly cause alterations to the entry and egress subsystems.
Fear of overbalancing

It is important to remember that the pregnancy related changes are not just physical ones, but are also emotional or psychological too. For example some pregnant women may experience a fear of overbalancing because their centre of gravity is altered due to the additional abdominal body mass. This fear of overbalancing is a new attribute of the pregnant occupant. It can cause alterations with the entry and egress subsystems, such as using a different method/technique for entry and egress.

Changes in Interactions.

Lack of space

The problems of entry and egress during pregnancy are caused by changes in the interactions between the pregnant occupant and the subsystems. Some of the problems are caused by changes in interactions between the pregnant occupant and the vehicle subsystems, and the lack of space is one of these. Lack of space is the second biggest problem and was reported by 27% of pregnant women. The lack of space is defined specifically as the space available between the door, the seat and the steering wheel, as the pregnant woman moves through the door opening into the car seat. The problem occurs because the pregnant occupant has changed size and shape, and the door opening is no longer sufficiently large. When getting in or out of the car a pregnant occupant will mentally check whether there is sufficient space and because she is larger in pregnancy her space requirement input is larger. This changes the interaction between the pregnant occupant sub-subsystem, and the door opening that is a part of the entry and egress subsystems.

The physical changes that women undergo during pregnancy explain the problem. Firstly there is the abdominal enlargement, meaning that the pregnant woman can no longer fit through the door opening easily. For the women measured in the third trimester the mean abdominal depth is 359.5mm, which is significantly (p<0.05) larger than the mean abdominal depth for males given in [6]. Hence if a design is based upon accommodating the 95th percentile male abdominal depth, as in typical design practice, this will still exclude 65% of pregnant women in the third trimester. This highlights the importance of using a systems approach to consider all possible changes to the user population, including when women become pregnant, in order to consider significant user groups.

The lack of space problem also includes fitting between the seat and the steering wheel. As the abdomen enlarges it protrudes forwards closer to the steering wheel. Pregnant women however cannot compensate by moving further rearward because they must still be able to reach the pedals in order to drive. Current guidelines [7,8] recommend a 25cm clearance between the breastbone and the steering wheel, but 86% of the pregnant women stated they were seated with their abdomen closer than 25cm from the steering wheel. 11% of the pregnant women were seated with less than 2.5 cm between their bump and the steering wheel, or with their bump in contact with the steering wheel during driving. So for these women a new interaction is introduced during pregnancy, whereby the abdomen is touching and interacting with the steering wheel. This causes problems for them during entry and egress because they have to carefully fit their abdomen in between the seat and steering wheel. Some women have reported that their abdomen is bumped against the steering wheel during entry and egress.

In some cases pregnant women choose to slide their seat rearward to increase the space available between the seat and steering wheel. This action can help to counteract the problem of fitting the enlarged abdomen between the seat and steering wheel, but it is limited by women’s leg length, as they must still be able to reach the pedals. It can also introduce another problem, since women’s ability to lean forward is reduced in pregnancy because of the enlarged abdomen. Therefore if the lever that controls the seat track position is underneath the front of the seat women may experience difficulty reaching this lever.

A further explanation to the problem with fitting through the door opening and steering wheel distance is provided by the difference between standing and seated sizes when pregnant. For example the mean standing abdominal circumference is 1136.68mm for women in the third trimester, but when seated this is 24.57mm larger at 1161.25mm. The difference is much larger for the hip circumferences, with the seated circumference 94.64mm larger than the standing circumference of 1155.14mm. The reason for the increased sizes of pregnant woman whilst seated is understood by examining the interaction of the body parts. In standing posture the pregnant abdomen has a large space around it and it can take its natural size and shape under the influence of gravity. However when seated the space available below the abdomen is limited by the upper thighs. This is particularly problematic in car seats where the seat slopes upwards under the knees so it is higher under the knees than under the bottom, because the angle between the legs and trunk is even further decreased. The thighs therefore apply an upward pressure on the abdomen, which pushes and squashes it upward and outwards. In turn the abdomen can also push the breasts upwards and outwards. Hence in seated posture the abdomen and breast sizes of pregnant woman are larger than in standing posture. So as the pregnant woman moves between standing and seated posture as she enters the car for example, this size increase must also be accommodated. Not only must the increased sizes of pregnant woman be considered, but also the changes in size as she moves between standing and seated postures.

Leverage points

There are new interactions introduced during pregnancy, as the pregnant women need to lean, push, pull and hang on to various leverage points. The leverage points are the door, the
seat, the steering wheel, the car roof, the doorframe, the inner handle above the door opening, and the side of the car.

There are several reasons why pregnant women need to use these leverage points. For example the additional weight of the pregnant body means that a greater force magnitude is needed to move the body, so a greater force input is needed to the entry and egress subsystems. So women may need to use leverage points to give them mechanical advantage to help themselves move their additional weight and meet this additional force requirement.

An important input to the entry and egress subsystems is the ability to turn whilst moving in/out of the car. Pregnant women may also use the leverage points as an aid to controlling and manipulating their force direction whilst standing or sitting.

Women may also feel the need to use leverage points for stability if they are experiencing a fear of overbalancing. Difficulties with entry and egress can occur as a consequence of changes within the pregnant occupant sub-system. This in turn can cause women to take actions to try and overcome their difficulties, hence resulting in the new interactions between the pregnant occupant and various other parts of the vehicle system.

**Car Door**
Not only is pregnant women’s movement restricted during pregnancy, but also their strength. Some women reported difficulty with opening and closing the door because they felt weaker during pregnancy. The door needs a certain force magnitude to move it whilst opening and shutting. Since pregnant women feel weaker they have difficulty in providing this input force magnitude to open/shut the door, hence the interaction is changed. Thus a change within the pregnant occupant can cause an alteration in the interaction between the pregnant occupant and the door.

**Bucket seats**
Several pregnant women reported problems with the bucket style seats. In particular that the raised cushion mouldings at the sides of the seat interfered with their entry and egress, for two different reasons. Firstly the raised cushion forced women to lift their legs and reduce the angle between their trunk and thighs when seated. This restricted the space available for the large abdomen and was uncomfortable. The second reason was that women who preferred to use the two-stage egress method (swivel round then stand up as in Fig.3) found that the raised cushion moulding prevented them from swiveling around. Hence the pregnant woman reported this bucket seat problem because the interaction between their legs and the seat cushions was altered, which impeded their entry and egress.

**SYSTEM FAILURE PREVENTION**
System failure occurs when the system is no longer able to complete its functions within acceptable limits. The following method (as described by some pregnant women) to ease entry and egress provides a very good example for how a solution in isolation can lead to a system failure.

Pregnant women often tended to adopt the two-stage method of entry and egress, as described previously and in Fig.3. This is where the women separate entry/egress into two separate motions of swiveling around, and sitting/standing. Some pregnant women reported sitting on a plastic bag in order to help them with swiveling around on the seat. So pregnant women sit on the bag in order to reduce the friction between their bottom and seat surface.

For some pregnant women this must seem to be a perfectly harmless, yet effective, method of helping entry and egress. However this plastic bag method has dangerous implications. Automotive engineers carefully design the seat surface, along with every other part of the car, for maximum safety. The seat surface is angled upwards underneath the knees to prevent ‘submarining’ underneath the lap section of the seat belt in a collision. Also the seat surface texture is carefully chosen to help prevent sliding and submarining in a collision. Introducing the plastic bag unintentionally puts the pregnant women and their fetuses at increased risk of injury in a collision.

The plastic bag method used to alleviate problems with the entry/egress subsystems also alters the safety subsystem of the occupant package. This demonstrates the importance of using the systems approach and considering all aspects of change and interactions within the vehicle system. Within the systems approach finding a solution to a problem in isolation is not sufficient, because it will usually create other problems by changing the interactions with other subsystems. The solution should address all possible interactions and environmental factors to avoid system failure.

**ENVIRONMENTAL FACTORS & INTERACTIONS**
The following environment entities specifically affect pregnant women’s entry and egress and are therefore explained in detail. These factors are beyond the control of the system however it is useful for pregnant women to be aware of these for more comfortable and safer entry and egress.

**Car parking spaces**
A common problem for the pregnant women is that of narrow car parking spaces. In order to accommodate their increased size, pregnant women need to open the car door as wide as possible. However a narrow car parking space, especially when parked next to other cars or walls, prevents women from opening the door as wide as they need to. This can actually be quite a serious problem as several women reported being unable to gain access to their car when they returned to find other cars parked in neighbouring spaces.
Roads
The roads can affect entry and egress of pregnant women specifically because being parked on a slope can make it more difficult to manoeuvre into and out of the car. In particular, when a car is parked facing uphill it can cause the car door to swing shut and hence limit the size of the door opening.

Weather
The weather is also in the environment of the vehicle system, since it can influence pregnant women’s entry and egress in bad weather. Especially icy and windy conditions could make entry and egress even more difficult.

Choice of vehicle
The height of the vehicle can affect pregnant women’s entry and egress in two ways. Firstly if the seat is low, pregnant women have difficulty in lowering themselves down to the seat when getting in to the car. Secondly, if the seat is high it forces women to climb or jump up into the seat, or jump down from the seat, which could potentially pose a risk of injury.

However the height of the vehicle depends upon the pregnant women’s choice of vehicle. In choosing a vehicle women may consider a wide variety of factors, including the model, price, manufacturer etc, but are unlikely to consider the possibility of travelling in the car when pregnant unless the woman is purchasing a new car whilst she is pregnant.

Help
Sometimes pregnant women will have someone to help them to get in or out of the car. However since the vehicle system cannot control if there is someone available to help, or the type of help given, the help is part of the environment of the system.

CONCLUSION
This paper presents the systems approach used to gain insight into getting in and out of the car during the gestation period. The questionnaire responses show that pregnancy can cause a wide variety of problems and different levels of difficulty with entry and egress. The experiences reported by pregnant women also highlight the need to use the systems approach in order to encompass the wide range of physical tasks in pregnancy, and the interaction changes that pregnancy can cause have not been considered. Hence the systems approach is recommended so that designers can make informed design decisions, and so help to improve the quality of life during car travel for pregnant women.

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ANTHROPOMETRIC MODELLING OF THE PREGNANT OCCUPANT

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Keywords: Anthropometry, Pregnant, Occupant, Modelling, Automotive Safety.

ABSTRACT

A parametric anthropometric model of a pregnant woman has been produced for use in crash protection research. The model is based on anthropometric measurements of pregnant women, with the initial model representing a 5th percentile woman in her 30th week of gestation. The model has been developed to be easily scaleable so women of different sizes can be modeled and adapted to simulate any stage of pregnancy. Previous research has simply added an enlarged abdomen to existing females models. However the model presented describes a comprehensive depiction of the altered pregnant form by incorporating the anthropometry of the entire body. This paper presents the pregnant occupant model for use in evaluation of safety systems and vehicle interiors. This work is the first step toward a computational pregnant occupant for crash protection research, capable of simulating dynamic impact response and predicting injury risk in automobile crashes.

INTRODUCTION

During pregnancy a woman’s body experiences not only an increase in body mass, but also undergoes a series of physiological changes and symptoms. These changes are wide ranging, and can affect a woman’s ability to complete everyday activities including driving. Acar and Weekes [1] found that only 1% of women are unaffected by pregnancy during driving and car travel. All aspects of driving and car travel are affected, for example 81% of women have difficulty with vehicle entry and egress during pregnancy [2].

Pregnant women also experience safety problems during car travel in today’s automobiles. The risks to the fetus are described by medical studies as placental abruption [3,4], maternal death [5], direct injury or death [6], fetomaternal transfusion [7], onset of labour and preterm delivery [8]. Such injuries can occur through a variety of mechanisms, including direct impact with the vehicle interior such as the steering wheel. The impact of an airbag could also cause an injury to the fetus, however this risk is unproven as yet due to lack of data. Current UK Department for Transport [9] guidelines and US National Highway Traffic Safety Administration (NHTSA) [10] guidelines recommend the distance between the centre of the steering wheel to the breastbone should be at least 10 inches (25cm) [9]. No recommendations for pregnant women have been found for the side impact airbags.

The seat belt may apply pressure to the abdomen in a collision and cause injury to the uterus as described by Rubovits [11], or direct injury to the fetus as reported by Fakhoury and Gibson [12]. Klinich et al. [13] reported that injuries could be prevented by using the seat belt properly. Crosby et al. [14,15] established the correct position for the seat belt in pregnancy, in order to minimise risk of injury. This is adopted in current guidelines in the UK [9] and USA [10], which state that pregnant women should use the seat belt, and that three-point belts are preferable. The seat belt position is described as ‘the lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts around the bump’ [9], and this is shown in Fig.1. However Acar & Weekes [1] also established that as little as 13% of pregnant women are wearing their seat belts correctly. Some pregnant women may also cease to use their seat belts during pregnancy. In some cases this is due to misguided safety concerns, and nearly half of the women say this is due to discomfort. Hence the comfort and fit of the seat

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belts is important to pregnant women’s safety. The discomfort currently experienced by pregnant women using today’s car seat belts could be due to lack of available anthropometric data and information about pregnant women for use during automotive design.

![Correct seat belt position during pregnancy](image)

**Figure 1. Correct seat belt position during pregnancy as advised by DFT and NHTSA.**

There is a lack of anthropometric data available for pregnant women that are suitable for use in vehicle design and safety evaluation. The study by Yamana et al. [16] measured 44 dimensions of 520 pregnant women from the second to tenth month of pregnancy. However it was originally aimed at garment design, and includes few measurements that are applicable to automotive design. Pheasant [17] used scaling to modify the data from Yamama et al. [16] for two dimensions: abdominal depth and forward grip reach. However Pheasant notes that the scaling is based on the assumption that British women are of similar proportions to Japanese women and that pregnancy will cause them to change in a similar way, so this scaling method is not as reliable as real measurements. Alvarez et al. [18] studied the dimensional changes of the feet during pregnancy by comparing a sample of 17 pregnant women with 16 comparable non-pregnant women. However this data is of limited use because only two dimensions relevant to automotive design are given (foot length and width), and the sample size is small. Finally Klinich et al. [19] measured 22 women, but only provide data for 10 measurements through the course of pregnancy that are of use in vehicle safety testing. Therefore there is currently a deart of anthropometric data for pregnant women, and little of the available data is pertinent to automotive design and safety testing. Given the lack of data about pregnant women, the safety and comfort considerations for pregnant occupants are subsequently largely neglected. This paper addresses this problem by providing analysis of a comprehensive set of 48 anthropometric measurements selected expressly for their relevance to vehicle design. This anthropometry is then used to produce a pregnant occupant model for safety evaluations.

### ANTHROPOMETRIC MEASUREMENTS METHOD

The standard anthropometric postures in Pheasant [17] were adapted for pregnant women by the authors and a series of 48 anthropometric measurements were taken. Women were recruited in two locations in the United Kingdom: Loughborough University, and the Luton & Dunstable Hospital National Health Service Trust. Volunteers wore light clothing and removed their shoes, and the equipment used included weight scales, a stadiometer, a digital vernier calliper, a tape measure and an anthropometer. At the time of writing 100 sets of measurements were recorded.

The details of the sample of pregnant women are given in Table 1. The anthropometric data analysis focused on comparing the UK pregnant women in the sample against data from the literature [20] for UK males and non-pregnant females. The majority of the pregnant women normally occupy the driver’s seat. They occasionally use the front or rear passenger seats, and in a few cases the normal occupant position is unknown. For both the anthropometric and questionnaire data the overall trends and extreme cases were examined.

<table>
<thead>
<tr>
<th>Table 1. Pregnancy and driving details of volunteers.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd trimester (Week 13-28)</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Number of volunteers.</td>
</tr>
<tr>
<td>Mean Pregnancy Week</td>
</tr>
<tr>
<td>Std. Dev. Pregnancy Week</td>
</tr>
<tr>
<td>Driver</td>
</tr>
<tr>
<td>Non-Driver &amp; unknown</td>
</tr>
</tbody>
</table>

### PREGNANT ANTHROPOMETRY

The most obvious area of change during pregnancy is the abdomen, which enlarges and protrudes. The mean abdominal depth is 359.5mm for pregnant women measured in the third trimester. This is significantly larger than the mean abdominal depth [20] for non-pregnant females (p<0.03), and even for males (p<0.05). Since the size increases occurring during pregnancy make women significantly different to non-pregnant females and males, this demonstrates the importance of considering the pregnant occupant’s needs.

The physical growth during pregnancy is not limited to the abdominal region, but occurs throughout the body. There are two other main areas of change during pregnancy, which are the hips and breasts. For the women measured in the third trimester the mean standing hip circumference is 1155.1mm, and the mean standing chest circumference is 1046.5mm. These are 118.1mm and 38.7mm larger respectively than for non-pregnant women’s anthropometric data [20].

Previous research has tended to focus only on the enlarging abdomen. For example Viano et al. [21] and Rupp et al. [22] have developed the first and second generations of a pregnant abdomen to add to a 5th percentile small female crash...
test dummy. However this work does not incorporate the other physical changes that occur throughout the pregnant woman. The advantage of the model presented in this paper is that it is based on the wide series of 48 measurements covering the entire pregnant woman’s body, so incorporates all of the changes.

An important finding from the anthropometric measurements is how different women are during pregnancy compared to when they are not pregnant. The dimensions of the abdomen, chest and hips can enlarge dramatically in comparison to non-pregnant female and male data, as mentioned previously. This is important to pregnant occupant safety because pregnant women may no longer be safely accommodated in a vehicle. Thus if a vehicle is designed as in typical engineering practice to accommodate a 95th percentile male, the altered measurements of a pregnant woman may exceed the dimensions accommodated in the design. For example the 95th percentile male abdominal depth is 280.4mm. This is equivalent to only the 35th percentile value for pregnant women measured in the third trimester. Consequently 65% of pregnant women would be excluded by a design based on using the 95th percentile male anthropometry. This situation is worsened if a design is based upon accommodate the 50th percentile male instead of the 95th, because 97% of pregnant women would be excluded. This demonstrates the importance of considering pregnant women’s particular accommodation requirements based upon their altered anthropometry. A brief summary of examples of exclusions is given in Table 2.

Table 2 Percentages of the sample of pregnant women measured in the third trimester who would be excluded by a design based on UK male anthropometric data [20]. All dimensions are in mm.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>UK males mean</th>
<th>Pregnant women mean (tri 3)</th>
<th>% excluded</th>
<th>50th %le</th>
<th>95th %le</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip circ. standing</td>
<td>1046.5</td>
<td>1155.1</td>
<td>45%</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>Abdomen depth</td>
<td>280.4</td>
<td>284.0</td>
<td>38%</td>
<td>76%</td>
<td>76%</td>
</tr>
<tr>
<td>Chest depth</td>
<td>254.0</td>
<td>284.0</td>
<td>38%</td>
<td>76%</td>
<td>76%</td>
</tr>
</tbody>
</table>

Some of the increases in anthropometric measurements of pregnant women can be extreme. The maximum standing abdominal circumference of 1410mm was 452.8mm larger than the non-pregnant women’s 95th percentile value in [20]. This shows the remarkable increase in abdominal size that can occur during pregnancy. The maximum abdominal circumference in seated posture was 1454mm, which is nearly half a metre greater than the 95th percentile for non-pregnant women. This demonstrates the importance of using anthropometric measurements recorded in the relevant posture in order to avoid the possibility of unintentional exclusions from a design.

It is important to consider the anthropometric needs of pregnant women throughout the entire course of pregnancy. The period of greatest risk is the third trimester, because the abdominal sizes are at their greatest putting the abdomen closest to the steering wheel. However the second trimester is just as important because the abdomen is enlarging throughout this period too. One particular problem of pregnancy is that the lap belt tends to ride up off the hips and onto the abdomen. This problem is at its worst during the second trimester. In the third trimester the larger abdomen helps to hold the lap belt more securely across the hips and so reduces the problem of it riding upward. Consequently it is vital to incorporate the needs of pregnant women during all stages of pregnancy.

During pregnancy the interactions between the parts of the body are also affected. For example when a pregnant woman is seated her upper thighs apply an upward pressure on the base of the abdomen. This pressure from the thighs causes the abdomen to spread upward and outward from the body. Hence the mean abdominal circumference of 1161.3mm is 24.6mm larger when seated than when standing. Since the abdomen is spreading upward and outward, this also pushes the breasts upwards too. This is confirmed as both the abdominal height and chest height increase as pregnancy progresses, by 17.8mm and 12.8mm respectively. Furthermore there is a significant (p<6*10^-11) correlation between the abdominal and chest height measurements. So interactions are introduced during pregnancy between the thighs and abdomen, and between the abdomen and breasts. These interactions are particularly important for seat belt positioning and length. Firstly, the abdominal, hip and chest sizes are increased during pregnancy, but are even greater in seated position due to the interaction between the thighs, abdomen and chest. The belt length must accommodate all of these changes to fit around the enlarged pregnant body according to the guidelines. Secondly, since there is contact between the thighs and abdomen this can cause difficulty in putting the seat belt correctly into position across the hips. Similarly, the contact between the abdomen and breasts can prevent the seat belt from laying between and around the breasts, hence forcing it into a dangerous position across the abdomen or cutting into the neck. Thus it is important not only to consider the anthropometric changes during pregnancy, but also how these changes affect interactions between parts of the body.

ANTHROPOMETRIC MODEL

One of the major difficulties faced by the automotive industry in developing safety systems for the pregnant occupant is evaluating their designs. This is due to a lack of any form of three-dimensional anthropometric model of the pregnant body, either physical or computational.

The data collected in the first stage of this research has been used to develop a parametric anthropometric model of a female occupant. The aim is to be able to generate a three-dimensional model of a pregnant woman of any size at various stages of gestation.
The ultimate goal of the project is to develop a computational model of the pregnant female body capable of simulating the dynamic response to impacts. It was therefore important to consider the underlying skeletal structure when developing the three-dimensional skin surface of the model. By doing so, important body landmarks will be correctly positioned relative to the kinematic joints of the model. As a starting point the core kinematic linkage of the MADYMO 5th percentile female facet occupant model has been used [23]. The positions of the various kinematic joint centres, representative of actual human joints, are positioned relative to the hip joint centre or ‘H’ point. Figure 2 shows the basic arrangement of the linkage model and its relationship to the various body segments. Corresponding joint centres are connected by a rigid link, which can be thought of as the ‘bones’ of the model. For example the right hip and knee joints are connected and the resulting linkage represents the right upper leg of the model. As well as the joints of the upper and lower limbs, the linkage model also includes individual joints between vertebrae of the entire spinal column; from the sacrum-L5 joint up-to and including the atlanto-occipital joint connecting the head and cervical spine.

The three-dimensional skin surface of the model is constructed from a series of cross sections that are positioned relative to their parent ‘bone’ linkage and derived from the anthropometric measurements of pregnant women. Additional anthropometric data for 5th percentile UK females from the DTI’s adult data handbook [20] have been used to further define the 3D surface. The model has been developed in an upright standing position with arms horizontal, and out to the sides, allowing for easy application of standard anthropometric measurements.

The sagittal plane abdomen contour is defined by three points positioned relative to the ‘H’ point, they are; the pubic symphysis, the point of maximum abdominal height and depth, and the xipoid process (bottom of sternum). The position of the pubic symphysis was calculated using the procedure described by Reed et al. [24] as a function of pelvic depth and height. For the initial model the point of maximum abdominal height and depth representative of a 5th percentile woman in her 30th week of pregnancy has been used. The sagittal plane contour of the back is dependant on the spine posture and is defined by the tips of the spinous processes of each of the thoracic and lumbar vertebrae.

The resulting model, shown in figure 3, is easily scalable to represent different sized women at different stages of pregnancy. The underlying body segment linkages can be extended or shrunk to specific values or scaled by an overall scaling factor. The individual cross sections can also be scaled and changed enabling the body elements to be adjusted as required. The size and shape of the abdomen is easily modified by moving the point of maximum abdominal height and depth to represent the size changes throughout pregnancy. The trunk and neck of the model can be adjusted by scaling the spinal column between segment joint positions that can be determined from measurable bony landmarks. For instance using the
methods described by Reed et al. [24] the thorax length can be calculated. The thorax length is defined as the distance between the lower neck joint (C7-T1) and upper lumber joint (T12-L1), the positions of which can be easily calculated based on the measured position of the spinous processes of C7, T8 and T12 and the position of the suprasternale. The model can then be scaled between these two joints to match the calculated length of the thorax. Comparable methods can be used to adjust the lumbar and neck lengths. Similarly the shoulder width can be scaled based on the measured distance between the acromion landmarks. A second anthropometric study measuring a series of bony landmarks of pregnant women in driving postures is currently being undertaken to enable the scaling of the current model.

Figure 3. Front, side and isometric view of the pregnant female model. In the front view the body segment links and cross sections are shown. The side view shows the skin surface profile and the isometric view shows the complete 3D model.

CONCLUSION

This paper presents a parametric pregnant occupant model for use in automotive design and safety evaluation. The advantage of this model is that it is based entirely upon pregnant women’s anthropometry. Previous models have only focused on the abdominal region by simply adding an enlarged abdomen to an existing female model. The model presented describes the changes throughout the entire body hence providing a more comprehensive depiction of the altered pregnant form.

The pregnant occupant model presented will be able to be used for the evaluation of safety systems and vehicle interiors. The model can be easily adapted to represent progressive stages of gestation and so can be used to ensure the safety of pregnant women through the entire course of pregnancy. Furthermore the model can be scaled to represent pregnant women of any size and shape.

The anthropometric models will also be of use to designers in checking that designs are not excluding pregnant women. In addition the models should help to highlight areas of concern including any interactions between body parts. The interactions between the upper thighs and the base of the abdomen, and the top of the abdomen and the breasts are of particular importance to seat belt fit and positioning.

Some examples of specific safety concerns that can be addressed using the models are the steering wheel clearance, head restraint geometry, and seat belt positioning. Firstly the clearance between the enlarged abdomen and the steering wheel can be assessed to ensure that the abdomen remains at a safe distance as it grows and protrudes. Secondly the head restraint geometry is important because pregnancy can cause women to alter their posture. Finally the correct fit and positioning of the seat belt can be maintained throughout the course of pregnancy, so that women and their fetuses are not put at increased risk of injury. By ensuring the correct
positioning of the belt pregnant women will feel more comfortable and confident whilst wearing the seat belt. This will consequently reduce the risk that women are discouraged from using the seat belt, and reduce the need for them to take unsafe action such as holding the belt during car travel.

The work described in this paper is the first step in the development of a computational pregnant occupant for crash protection research. The overall aim of the study is to produce a pregnant occupant model capable of simulating the dynamic response to impact and predicting the risk of injury in automobile crashes.

ACKNOWLEDGMENTS

Both the “Automotive Design: Incorporating the Needs of Pregnant Women” and “EXPECTING: A Pregnant Dummy Model” projects are funded by EPSRC (Engineering and Physical Sciences Research Council, UK) research grants from the Innovative Manufacturing and Construction Research Centre. The authors wish to thank the sponsors, collaborating car manufacturers, consultant Obstetrician and Gynaecologist M. Griffiths, and all the pregnant women who have participated in this research.

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Chapter 13

Pregnant Driver Behaviour and Safety

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Loughborough University, UK

Abstract

Previous research has focussed on the risk of abdominal trauma to the pregnant woman and foetus during a collision. The importance of seat belt use and correct positioning around the pregnant abdomen is well established. During pregnancy women undergo many physical and emotional changes. However research has not yet investigated the effect of pregnancy upon other aspects of driving such as driving style or behaviour. Behavioural changes are of concern because they may put pregnant women, foetuses or other road users at increased risk. This chapter presents information based on analysis from 268 volunteers’ questionnaire answers. The questions about driving, seat belt use, and how physical and emotional changes affect car travel revealed interesting changes to driver behaviour/style that impact upon safe driving in pregnancy. The paper concludes with a summary of suggestions that incorporate the behavioural changes to enhance the safety of pregnant women during car travel.

Introduction

Previous research has focussed on the safety of pregnant women during collisions and the risks to the foetus that are associated with abdominal trauma. Research has shown that the pregnant woman and her foetus are at increased risk during a collision if the seat belt is not worn or only the lap belt used (Crosby, Snyder, Snow and Hanson, 1968), or if it is incorrectly positioned (Viano, Jedrzejczak, Deng, Smrcka, Kempf and Pearlman, 1996). The correct belt position for pregnant women described by the Department for Transport, is that the 'lap strap should go across the hips, fitting comfortably under the bump, while the diagonal strap should be placed between the breasts and around the bump' (DTLR, 1999). Griffiths (1992) suggests that pregnant women are often poorly or incorrectly informed. Nicholls and Grieve (1992) found that driving a car, getting in and out of a car, and using seat belts were all in the top ten tasks that are more difficult in pregnancy, yet previous research has not considered all aspects of driving and has focussed only on abdominal trauma. However changes to a pregnant woman are
both physical and emotional, and are not limited to the abdominal region. An EPSRC funded project entitled ‘Automotive Design: Incorporating the Needs of Pregnant Women’ started in July 2001 at Loughborough University. The results presented here are derived from the completed analysis forming the first part of the project. This research addresses the problems associated with changes in pregnancy on the entire body and driving. Only 1 per cent of the volunteers who took part in this study experienced no car travel difficulties or changes arising from pregnancy, which means that 99 per cent of the pregnant volunteers experienced a wide range of changes with varying levels of difficulties with driving as a result of pregnancy.

As driving style or behaviour may be altered during pregnancy, this paper aims to investigate possible behavioural changes and their resultant effect upon the safety of pregnant women. This is of particular concern because driving style alterations could put the pregnant women at increased risk during driving. This may also put the foetus and other road users at risk. By allowing for pregnancy and the associated behavioural differences automotive designers can help reduce risks for both the pregnant mother and her foetus. Every year there are approximately 665,000 to 670,000 pregnant women in the United Kingdom alone (Office for National Statistics, 2000). Improving automotive design for pregnant women could also benefit other relevant user populations, such as obese people.

Method

A total of 268 pregnant women, described below in Table 13.1, were recruited to the study. The majority of these women normally occupy the driver’s seat, and occasionally use the front or rear passenger seats. Women were recruited from two locations in the United Kingdom, Loughborough University, and the Luton and Dunstable Hospital NHS Trust. Participants responded to the questionnaire either in an interview or by self-completion.

The questionnaire was also available in four languages (English, Spanish, Italian and French) for online completion at http://pregnantdriver.lboro.ac.uk.

Table 13.1 Pregnancy and driving details of the sample of pregnant women: first, second and third trimesters

<table>
<thead>
<tr>
<th>Trimester</th>
<th>First (Week 0-12)</th>
<th>Second (Week 13-28)</th>
<th>Third (Week 29-40+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of volunteers</td>
<td>16</td>
<td>106</td>
<td>159</td>
</tr>
<tr>
<td>Week of pregnancy</td>
<td>Mean</td>
<td>8</td>
<td>22.1</td>
</tr>
<tr>
<td></td>
<td>Std deviation</td>
<td>2.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Driver</td>
<td>15</td>
<td>101</td>
<td>138</td>
</tr>
<tr>
<td>Non-driver</td>
<td>1</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>
Questions about all aspects of car travel both as drivers and as passengers were included in the questionnaire. The topics that gave insight into the behavioural changes caused by pregnancy were:

- Driving/car travel experience
- Physical change and affect on driving
- Restraint systems
- Emotional change and affect on driving

The pregnant women were reminded repeatedly to compare their experiences during pregnancy with when they were not pregnant in both the questionnaire and during the interview.

Analysis of questionnaires

Driving and car travel experiences

The trend was for increasing difficulty with driving ability as pregnancy progressed, and by the third trimester 39 per cent of women were adversely affected. 25 and 32 per cent of women in the third trimester had difficulty with night driving and reversing, respectively. It is clear, then, that the changing characteristics caused by pregnancy adversely affect a large portion of the pregnant population.

One per cent of the women in all three trimesters avoided driving and car travel as a result of the physical and emotional problems caused by pregnancy. As pregnancy changes women's physical and emotional characteristics, their driving experiences are altered, forcing this behavioural change of ceasing car travel.

Many women provided additional information about their driving experiences, in particular how their vision was affected. Some women said spatial awareness and blurred vision were causing difficulty. Others said that pregnancy prevented them from twisting around to see out of the rear windscreen when reversing. A few volunteers mentioned difficulty bending forward to see around corners when pulling out at junctions.

Pregnancy also seemed to cause an increase in driver error according to specific comments from the volunteers. One woman described driving in the wrong direction around a roundabout en route to a meeting at Loughborough University. Another woman forgot to turn to look out of the rear windscreen when reversing, and reversed into another driver causing damage to both cars. Both of these women said that their concentration was affected due to pregnancy. Another woman described her tendency to have accidents when pregnant, as proven in each of her three previous pregnancies. Many women explained they wanted to protect the safety of their unborn child and other road users so had ceased driving entirely. Reducing driver error by ensuring that all controls and driving operations are simple and easy to use will make all drivers, including pregnant women, safer, especially if they have temporary difficulty concentrating on driving.
Restraint systems

The use and correct positioning of seat belts in pregnancy is vital to reduce risk of injury in a collision. Seven and three per cent of the women in the second and third trimesters respectively never used a seat belt during pregnancy. One group who were not using the belt said it was because they thought it was a safety risk. Some women felt unsafe or vulnerable using the seat belt during pregnancy and took uninformed action to stop using seat belts. This would increase their risk of injury in the event of an accident, which was the opposite of their intentions.

Other groups of women said they were not using seat belts because it was uncomfortable, or because it was too short. Another group did not wear seat belts so had not changed their behaviour. The last group did not provide a reason why they were not using seat belts.

Only 43 per cent of women had received some advice about seat belt use during pregnancy. Of these women 28 per cent received information from an official or medical source (e.g. GP, nurse or midwife). The remaining 72 per cent of women received information from other sources (e.g. books, Internet) where they voluntarily researched information due to safety concerns. Of the women 18 per cent said they did not feel safe using the seat belt due to fear of abdominal impact in a collision.

The authors recommend that more information be made available to pregnant women. The advice could be given at the start of pregnancy to reduce the risk throughout the entire pregnancy. The information could be provided through medical channels (doctors, midwives etc) in the form of leaflets, posters, videos, and spoken advice. The automotive industry may also distribute information by providing leaflets or information in car manuals.

<table>
<thead>
<tr>
<th>Second trimester (Weeks 13-28)</th>
<th>Third trimester (Weeks 29-40+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder belt across shoulder, between breasts and around bump (safe).</td>
<td>Shoulder belt across shoulder, between breasts and around bump (safe).</td>
</tr>
<tr>
<td>Lap belt over bump (unsafe).</td>
<td>Lap belt across hips and underneath bump (safe).</td>
</tr>
</tbody>
</table>

Figure 13.1 Most frequent combination of shoulder belt and lap belt position for the first, second and third trimesters

The pregnant women were asked how they positioned the shoulder and lap portions of the seat belt. The only safe positioning (DTLR, 1999) would be to have
the shoulder belt across the shoulder, between the breasts and around the abdomen, and the lap belt underneath the bump across the hips.

Overall only 13 per cent of pregnant women had the belt correctly positioned before the researchers made the DTLR information available to them.

The trend through pregnancy, illustrated in Figure 13.1, suggests that women position the belt differently as pregnancy progresses. In the early stages of pregnancy the volunteers most often have the lap belt across their bump, but in trimester three it is most often placed safely across the hips.

One of the reasons for the change as pregnancy progresses from having the lap portion across the bump, to underneath the bump and across the hips, is the result of receiving information whilst participating in this research. Another reason is the increasing size of the abdomen i.e. in the final weeks of pregnancy the bump holds the belt across the hips more securely.

Several women said they were not wearing the seat belt because it was uncomfortable. This shows that seat belt comfort is extremely important because it affects whether women use seat belts and influences her safety during car travel.

Approximately 86 per cent of the pregnant women had comfort problems with seat belts during pregnancy, and the range of problems is illustrated in Figure 13.2.

According to the figures the most revealing pattern is that 26 per cent of these women felt that seatbelts are too tight on the abdomen, breasts or hips. This is an interesting result especially when the seatbelt is not expected to be positioned on the breasts nor on the abdomen but between the breasts and underneath the abdomen (DTLR, 1999). Of women in the sample 17 per cent reported that the lap belt would not fit underneath the bump so they could not position the belt correctly across their hips. Another main problem (13 per cent) was that the belt tended to ride upwards onto the bump, and many women took action to prevent this. One group chose to use a belt device to hold the seat belt in position across their hips. Automotive designers could modify seat belts so they can fit comfortably underneath the bump to remove the need for such devices, or could incorporate a means/device as part of the restraint system.

The other method that women used to prevent the lap belt from contacting the abdomen was to hold the belt away from the bump with their hands or thumbs. These women said they were trying to protect the foetus or to make themselves more comfortable.

Similarly, more women were holding the belt away from their neck because it was cutting/rubbing them. The women were not aware that holding the belt could prevent it from deploying correctly, hence it increases the risk of injury. This is further evidence that women modify their seat belt behaviour for protection, but actually put themselves at greater risk of injury in the event of an accident.

There were other problems with seat belts during pregnancy such as difficulty with fastening the belt (7 per cent), or that it cut into the breasts (11 per cent) or shoulders (11 per cent). All of these problems contribute to the discomfort that can cause some women to cease using seat belts during pregnancy, or to hold it preventing proper deployment.
Figure 13.2 Pregnant women’s problems with seat belt comfort

Physical changes and their effect upon driving

The physical changes were grouped according to whether they were long-lasting or sudden in occurrence, or a change in mobility. Overall, 21 per cent of women experienced long-lasting physical symptoms that affected their driving. Of these women 1 per cent chose to avoid driving during pregnancy as a result of pain in the back and pelvis.

The long-lasting symptoms included stomach, hip, pelvic, back and joint pain, the baby’s head in the pelvis, haemorrhoids and swelling, and all of these caused discomfort and distraction for pregnant women. Back pain was the biggest cause of discomfort, which could be alleviated by adjusting the lumbar support if possible. Supplementary information showed several women found back pain more severe in cars, particularly on long journeys, and a few women had sciatica during pregnancy. Reducing discomfort by adjusting seats and lumbar support could help to reduce discomfort and distraction during driving and so improve safety.

Hip and pelvic pain were the main causes of distraction. Possible reasons for this are the foetus engaging in the pelvis, or widening of the pelvis under the hormonal influence of relaxing in preparation for birth. Allowing more space between the trunk and thighs by leaning the seat back to increase the space available to the pregnant abdomen could reduce this. A few women had Symphysis Pubis Dysfunction (SPD) that caused pelvic pain and made them uncomfortable.

Overall 13 per cent of women experienced sudden physical symptoms that affected their driving ability. These included leg cramp, heartburn, sickness, itchy skin and the need to urinate. Need to urinate is increased in pregnancy due to pressure applied to the bladder by the baby. Some women explained that they changed driving style in pregnancy to stop regularly for breaks to accommodate this need. Sickness and need to urinate were the biggest causes for women to avoid driving.

Numerous women said that the sudden occurrence of leg cramp, sickness and need to urinate caused them to become distracted and their driving to become
unpredictable. A few women reported that leg cramp was more severe when driving because the feet are in a fixed position for using the pedals. Increasing the angle between the trunk and thighs could increase the space available for the pregnant abdomen and might reduce the internal pressure.

Several women reported other sudden physical changes caused by pregnancy that had an effect upon their driving and car travel. Sudden baby movements made some women distracted or avoid driving entirely. One woman explained that her baby’s movements were specifically a response to music or to changes in volume from the stereo speakers at abdominal level.

Braxton Hicks contractions were another physical symptom of pregnancy that affects the pregnant women’s driving style, causing distraction or forcing women to avoid car travel. Sudden hunger also caused distraction for a few women.

By ensuring that all controls and driving operations are simple and easy to use will make all drivers, including pregnant women safer, by increasing their concentration and reducing driver error.

The last group of physical symptoms investigated were changes to movements or mobility. Nineteen per cent of women experienced these symptoms and felt that they affected their driving. Many women were distracted or chose to avoid driving as result of breathlessness, slower movements, limited bending and limited reach, with exhaustion being the main cause.

Of women 17 per cent said their physical responses were slower when driving during pregnancy. This was caused by the changes to mobility including limited bending and reach, slower movement and exhaustion. This problem of slower physical responses gets worse as pregnancy progresses from the first trimester (eight per cent) to the third (22 per cent), since the increasing size of the pregnant abdomen limits range of motion. The limitations on mobility could be reduced by positioning all the relevant controls within easy reach so that the pregnant women do not have to stretch, twist, or bend. This will potentially improve pregnant women’s physical response times and hence their safety.

_Emotionally changes and their effect upon driving_

Overall, 52 per cent of pregnant women did not experience any emotional changes, and 32 per cent said the emotions did not affect their driving. However the remaining 16 per cent of women said that pregnancy-related emotions affected them in different ways. This study revealed that it is not only difficult to predict pregnancy-related emotional changes but also very difficult to reach a conclusion on the effect of emotional state on driving. Many women felt very happy and calm. Other women became more alert due to excitement, irritability or pleasure. Whilst on the one hand alertness is a positive impact of pregnancy on driver style, numerous women felt distracted during driving, due to irritability and tearfulness. A few women chose to avoid driving due to emotions in pregnancy, such as pleasure, irritability, tearfulness, panic, fear and depression.

Additional information given by women described how their driving style had changed. Firstly, feelings of calmness caused women to reduce their risk-taking behaviour and decrease their speed. Secondly, vulnerability made women more
alert and reduced their risk-taking behaviour. The last group described aggressive feelings that increased their risk-taking behaviour and made them more impatient drivers.

Conclusion

Pregnant women experience a wide variety of changes due to pregnancy. There are women who feel that none of the physical or emotional symptoms they experience affect their driving. However for some women changes in driver behaviour caused by pregnancy can put the pregnant woman, her foetus or other road users at increased risk of an accident.

The symptoms of pregnancy can cause a range of behavioural changes in some pregnant women, and the authors recommend that pregnant women be advised of this. According to the survey some women feel distracted, have slower physical responses, or wish to avoid driving entirely. Some pregnant women also change behaviour and cease to use seat belts, or hold the belt, preventing it from proper deployment. However, a positive influence of pregnancy on driving is that many women feel more alert during driving.

For women who do experience behavioural changes there are some methods to reduce the potential risk. Women who are concerned about seat belt safety in pregnancy should seek information. The correct shoulder belt position is across the shoulder, between the breasts and around the bump, while the lap belt should pass across the hips and underneath the bump.

The authors recommend that more information be made available to all pregnant women regarding correct seat belt positioning in pregnancy. The advice should be given at the start of pregnancy to reduce the risk of injury in the event of an accident throughout the entire pregnancy. The information could be provided through medical and automotive manufacturer channels.

Pregnant women may be able to reduce seat belt discomfort problems by spending more time adjusting the car seat, its fore/aft position as long as the pedal controls permit, and the seat back angle, the mirrors and the seat belt itself. Such adjustments could also help to alleviate other physical symptoms such as back pain, and pelvic/hip pain. Leaning the seat back will mean the pregnant abdomen has more space available and the internal organs will be less constricted. This might help reduce distraction.

Planning a journey in advance could also help by ensuring that there are enough facilities on the route for regular breaks to alleviate hunger or the need to urinate. Breaking a journey into short sections could also ease the aches and pains of pregnancy, particularly back pain.

A pregnant driver may also be less distracted if most controls are ideally located within easy reach of the driver. Alternatively, if possible, the front passenger could be responsible for any controls such as the heater/air conditioning and radio. This will also help to improve response times for pregnant women with difficulty reaching controls due to limited mobility.
If a woman is purchasing a new car she could consider the symptoms of pregnancy and their impact upon safe driving, especially if she is currently pregnant or likely to have a child in the future. Clearly adjustability is an important feature, particularly for the seat belt and car seat. It is fortunate that nowadays most motor manufacturers do care about drivers and passengers of all shapes.

The ‘Automotive Design: Incorporating the Needs of Pregnant Women’ research project aims to consider the needs of pregnant women for all aspects of driving as well as behaviour and driving style. The information about the characteristics of pregnant women will be used in automotive design recommendations and an electronic information catalogue. This will allow designers to incorporate the changes resulting from pregnancy to improve both safety and comfort for pregnant drivers.

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