Measurements for pregnant drivers' comfort and safety

B. Serpil Acar*

Research School of Informatics, Loughborough University, Leicestershire, LE11 3TU, UK
Fax: +44 1509 211586 E-mail: S.Acar@Lboro.ac.uk
*Corresponding author

Alix M. Weekes

Crash Department, Thatcham, Colthrop Way, Thatcham, Berkshire RG19 4NR, UK
Fax: +44 1635 871346 E-mail: AlixW@Thatcham.org

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.

Biographical notes: **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 the human spine, and system design processes. She works in close collaboration with engineering departments as well as clinical and academic members of the medical schools. Dr. Acar is the principal investigator of the two major Engineering and Physical Sciences Research Council funded projects investigating pregnant occupant safety.

Alix Weekes is currently based at Thatcham as a Research Engineer in the Crash department. She was the 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 is also completing a part-time PhD thesis concerned with Human Computer Interaction (HCI) for automotive designers and engineers. She graduated with honours from the Manufacturing Engineering department at Loughborough University in 2001 from the Product Design and Manufacture programme.

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 limbs.

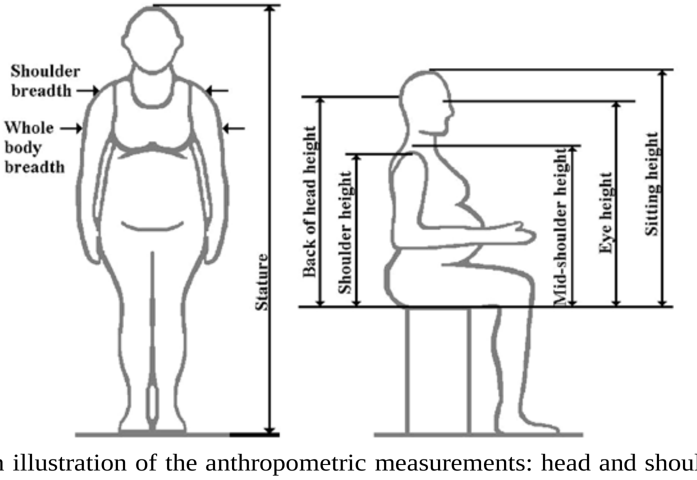

Figure 1 An illustration of the anthropometric measurements: head and shoulders region (measurements and figures adapted for pregnant women from standard measurements in Adultdata (DTI, 1998)

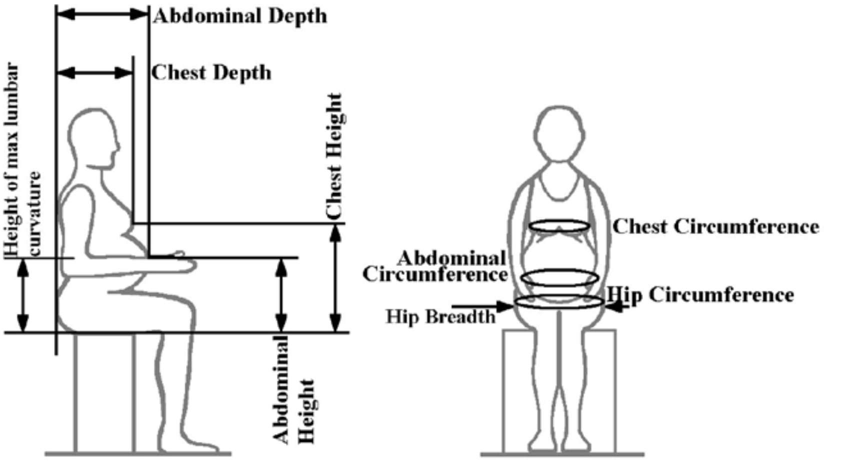

Figure 2 An illustration of the anthropometric measurements: trunk region (abdomen, chest and hips) (measurements and figures adapted for pregnant women from standard measurements in Adultdata (DTI, 1998)

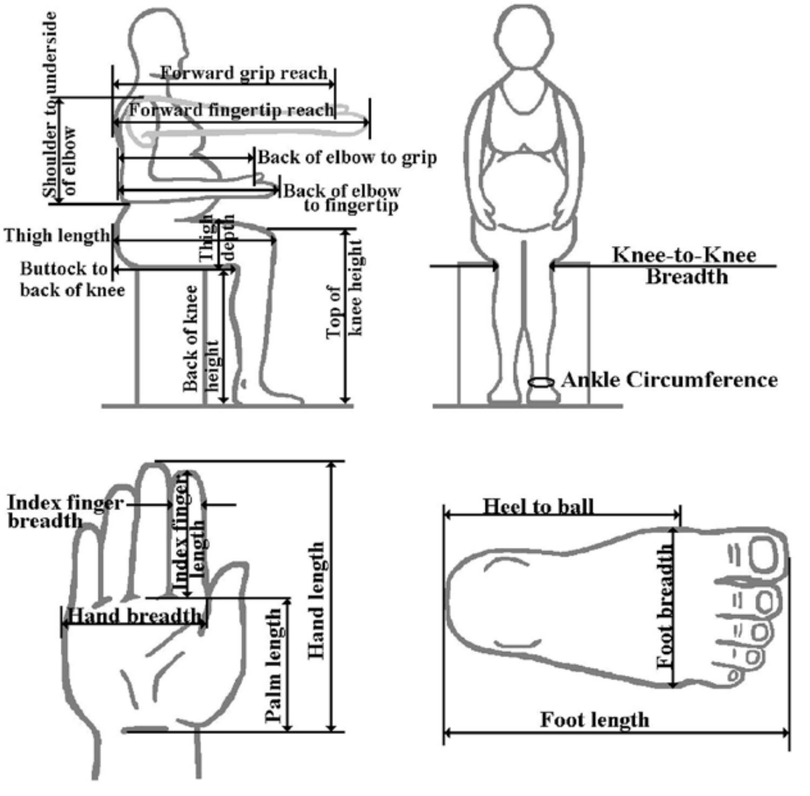

Figure 3 An illustration of the anthropometric measurements: limbs (arms and hands, legs and feet) (figures adapted for pregnant women from standard measurements in Adultdata (DTI, 1998)

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 1 Details of the sample of pregnant women

	Anthropometric measurements			*Pregnancy and driving questionnaire*		
	1st Tri	*2nd Tri*	*3rd Tri*	*1st Tri*	*2nd Tri*	*3rd Tri*
Number of women	0	36	71	48	226	285
Mean gestation (weeks)	n/a	21.4	35.4	8.4	21.2	35.0

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.

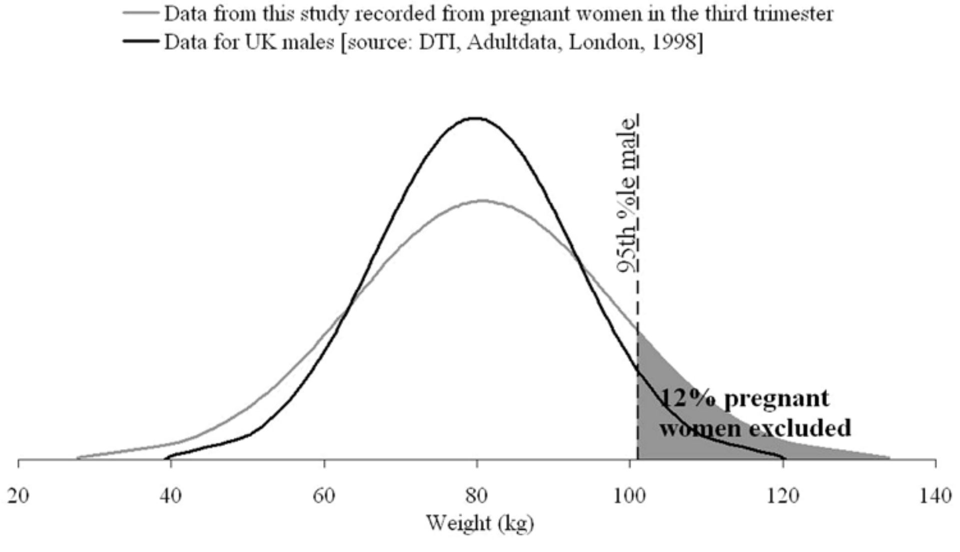

Figure 4 A design to accommodate the 95th percentile UK male might exclude 12% of pregnant women in the third trimester for weight

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.

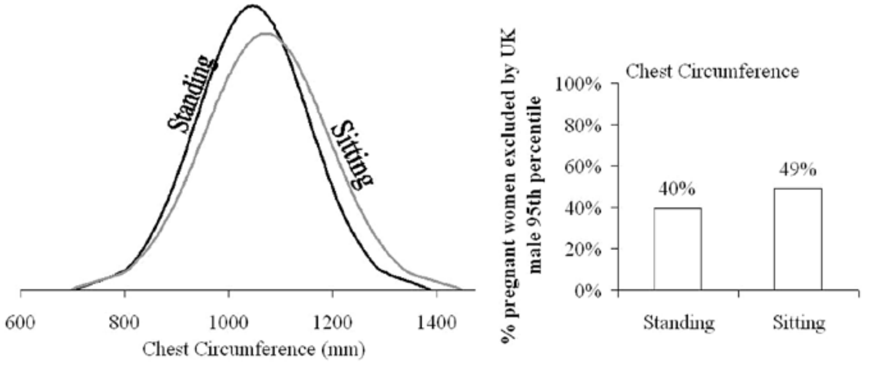

Figure 5 Chest circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 40% of pregnant women for the standing posture, and 49% for seated

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.

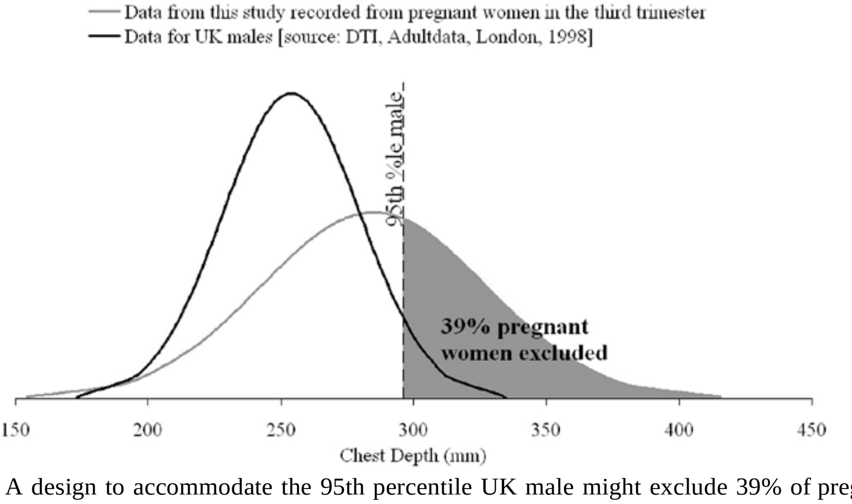

Figure 6 A design to accommodate the 95th percentile UK male might exclude 39% of pregnant women in the third trimester for chest depth

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 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.

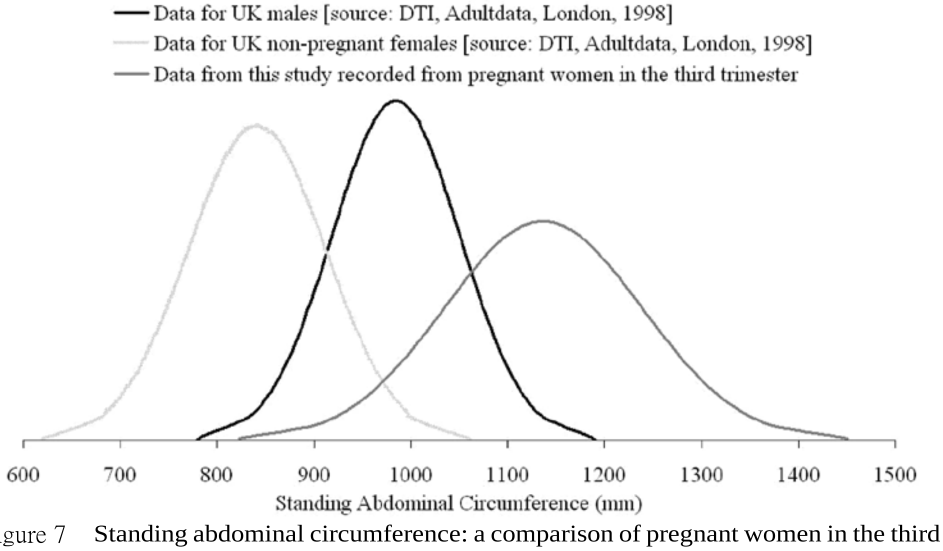

Figure 7 Standing abdominal circumference: a comparison of pregnant women in the third trimester against data for UK males and non-pregnant females

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 seated posture. 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.

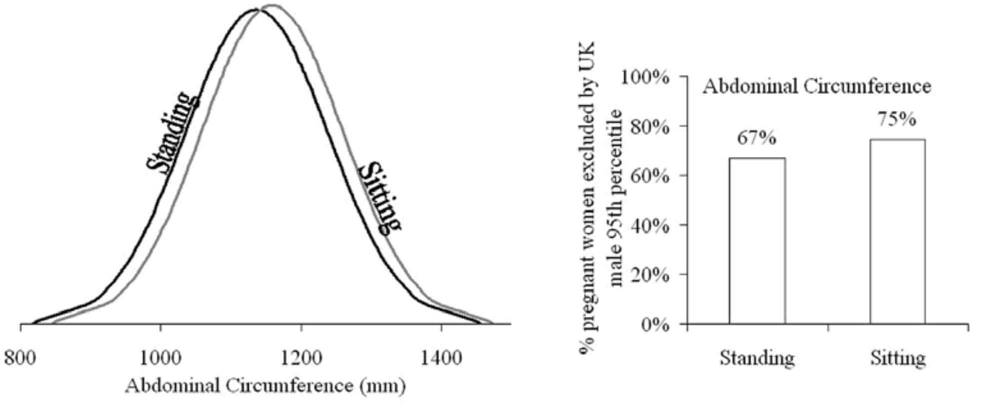

Figure 8 Abdominal circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 67% of pregnant women for the standing posture, and 75% for seated

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.

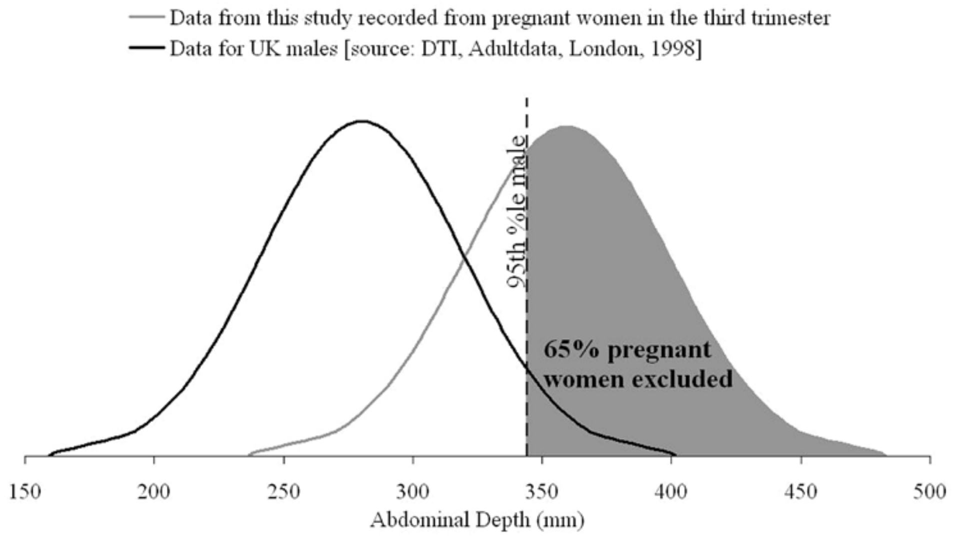

Figure 9 A design to accommodate the 95th percentile UK male might exclude 65% of pregnant women in the third trimester for standing abdominal depth

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.

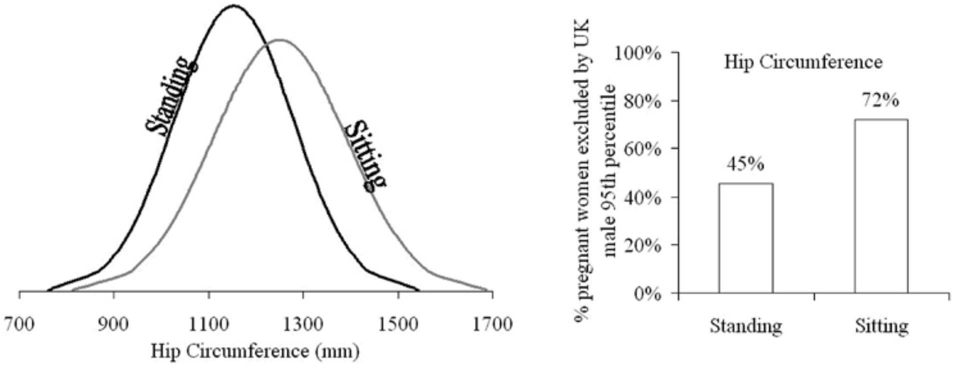

Figure 10 Hip circumference of pregnant women in the third trimester is larger in the seated posture than whilst standing. A design to accommodate the 95th percentile UK male might exclude 45% of pregnant women for the standing posture, and 72% for seated

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.

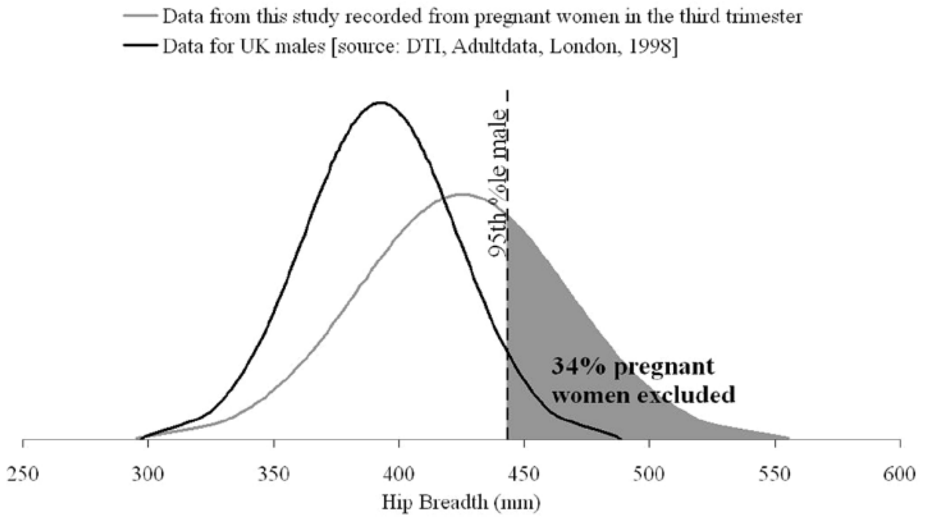

Figure 11 A design to accommodate the 95th percentile UK male might exclude 34% of pregnant women in the third trimester for hip breadth

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 compensate for 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.

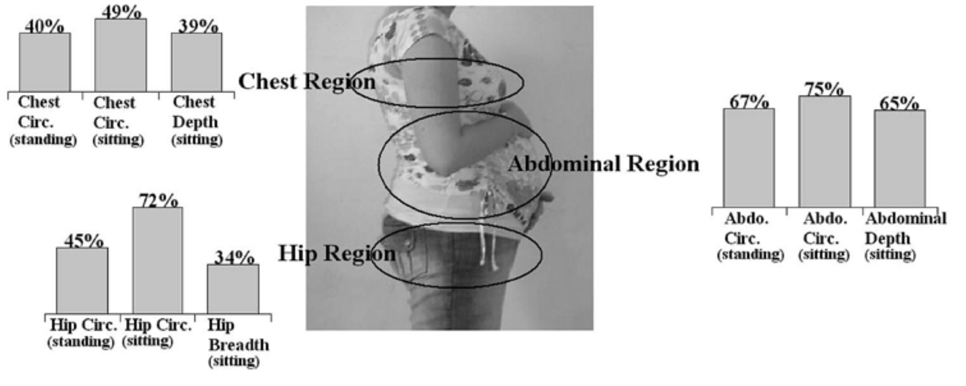

Figure 12 Pregnant women might be excluded by a design that accommodates up to the 95th percentile UK male anthropometry. Possible exclusion percentages for third trimester pregnant women by body region

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

The 'Automotive Design: Incorporating the Needs of Pregnant Women' project is funded by the EPSRC (Engineering and Physical Sciences Research Council, UK) GR/R13081 research grant of the Innovative Manufacturing and Construction Research Centre. The authors wish to express their thanks to sponsors, collaborating car manufacturers, consultant Obstetrician and Gynecologist M. Griffiths, and all pregnant women who have participated in this research. The authors would also like to thank the referees for their valuable comments on the earlier version of this paper.

References

Acar, S. and Weekes, A. (2003) 'Pregnant driver behaviour and safety', L. Dorn (Ed) *First International Con.ference on Driver Behaviour and Training*, 11-12 November 2003, Stratford-upon-Avon, UK, Ashgate, pp.125-133.

Acar, S. and Weekes, A. (2004a) 'Design guidelines for pregnant occupant safety', *Proceedings o.f the Institution o.f Mechanical Engineers Part D - Journal o.f Automobile Engineering*, Vol. 219, No. 7, pp.857-867.

Acar, S. and Weekes, A. (2004b) 'Designing for safety during pregnancy through a system for automotive engineers', *International Journal o.f Crashworthiness*, Vol. 9, No. 6, pp.625-632.

Acar, S. and Weekes, A. (2004c) 'Vehicle entry and egress: a systems approach', *ESDA 2004: 7th Biennial ASME Con.ference on Engineering Systems Design and Analysis*, 19-22 July, Manchester, UK.

Alvarez, R., Stokes, I.A.F., Aspirnio, D.E., Trevino, S. and Braun, T. (1988) 'Dimensional changes of the feet in pregnancy', *Journal o.f Bone and Joint Surgery* (American Volume), Vol. 70A, No. 2, pp.271-274.

American College of Obstetrics and Gynecology (ACOG) (1999) *Obstetric Aspects o.f Trauma Management*, Washington DC: ACOG (Report 251).

Department for Transport (DFT) (2003) *Seat Belts and Child Restraints*, London: Department for Transport (DFT) UK (T/INF/251).

Department of Trade and Industry (DTI) (1998) *Adultdata: The Handbook o.f Adult Anthropometric and Strength Measurements - Data .for Design Sa.fety*, London, UK: Department of Trade and Industry.

Klinich, K.D., Schneider, L.W., Eby, B. and Rupp, J.D. (1999) *Seated Anthropometry During Pregnancy*, Michigan: University of Michigan Transportation Research Institute (UMTRI-99-16).

National Highway Traffic Safety Administration (NHTSA) (2002) *Should Pregnant Women Wear Seatbelts?*, Washington DC: National Highway Traffic Safety Administration (NHTSA) USA (DOT HS 809 506).

Open Ergonomics (1998) *PeopleSize*, Loughborough: Open Ergonomics.

Pheasant, S. (1982) 'A technique for estimating anthropometric data from the parameters of the distribution of stature', *Ergonomics*, Vol. 25, pp.981-992.

Pheasant, S. (1986) *Bodyspace: Anthropometry, Ergonomics, and Design*, London: Taylor and Francis.

Pheasant, S. (1990) *Anthropometrics: An Introduction*, Milton Keynes: British Standards Institute.

Yamana, N., Okabe, K., Nakano, C., Zenitani, Y. and Saita, T. (1984) 'The body form of pregnant women in monthly transitions', *Japanese Journal o.f Ergonomics*, Vol. 20, No. 3, pp.171-178.