A PARAMETRIC ANTHROPOMETRIC MODEL OF THE PREGNANT WOMAN

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Abstract: The size, shape and anatomical changes of pregnant women throughout the gestational period pose a unique challenge in terms of safety and comfort during car travel. The specific needs of pregnant women have previously been of relatively low priority when compared to other safety issues in the automotive industry. This paper presents a parametric computer aided model of the pregnant occupant. The model can be scaled using anthropometric data from a sample of pregnant women to represent women of all sizes and shapes and at any stage of pregnancy. This model can be used in the evaluation of vehicle safety systems and interiors to ensure the accommodation of a broad population of pregnant women. This work is the first step toward a computational pregnant occupant model 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 many changes. These changes are wide ranging and can affect a woman's ability to complete everyday activities and can impact the comfort and safety of pregnant women when driving. Nicholls and Grieve [1] reported a series of common tasks that were found to be significantly more difficult to perform during pregnancy, from the top ten of this list, 3 were driving related. The specific needs of pregnant women as car occupants have largely been neglected to date; this is likely due to the temporary nature of pregnancy and the insufficient means of assessing current restraint systems and vehicle environments when being used by pregnant women. However, the anthropometric changes alone mean that pregnant women may be being excluded when it comes to car design, and with approximately 670,000 pregnant women each year in the UK alone [2], that is a significantly large user group being overlooked.

In practice young and able people can often 'adapt' to a bad design. In the case of pregnant women driving, although they can 'make do' and find a workable seating position, the resulting posture may lead to musculosceletal problems such as back and joint pain. Moreover a badly positioned seat belt may have much more serious implications in the event of an accident. It has been estimated that around 130,000 women in the second half pregnancy are involved in a car accident annually in the United States. Of these approximately 160 will die and a further 300-3800 will experience a fetal loss [3]. The results from an in-depth questionnaire in a previous study has shown that only 13% of pregnant woman are actually able to correctly position their seat belt [4]. Furthermore it was found that some women stop using their seatbelt completely due to safety concerns and discomfort.

Providing designers with the appropriate data about their target users is an important requirement if the users' needs are to be addressed. There is currently a lack of anthropometric data available for pregnant women, particularly for use with automotive design where a multivariate approach needs to be adopted to ensure the accommodation of pregnant women within today's automobiles. Typically 5th, 50th and 95th percentile dummies are used, with designers designing for the 5th percentile female to the 95th percentile male with the belief that they are satisfying 90% of the population. This may be the case for some dimensions but not where several critical dimensions exist, such as driving a car. For example, a pregnant woman with a 5th percentile stature may only have a 2nd percentile leg length and so have to position her car seat at its foremost position to reach the pedals. However, at a late stage of pregnancy the same woman may well have an abdominal circumference equal to or greater than that of a 95th percentile male and therefore have inadequate room between her abdomen and the steering wheel. Acar and Weekes [4] found that 11% of pregnant women were seated with less than 25mm between the abdomen and the steering wheel or with their 'bump' actually in contact with the steering wheel. This proximity with the steering wheel puts the fetus at increased risk of injury in the case of an accident due to direct fetal loading from the steering wheel or even airbag [5]. Without having access to data sets for real individuals it is very difficult to assess multivariate accommodation especially for the case of a pregnant woman who is constantly changing shape over the gestational period.

Acar & Weekes [6] have presented an anthropometry website for use by automotive designers so that pregnant occupant anthropometry can be incorporated into vehicle design. This data can be sorted by typical population data (percentile values) or by individual cases providing a holistic database of pregnant women's anthropometry. Although this data is accessible there is a need to provide designers with it in a more visual form that can be used efficiently in combination with existing design tools and practices. This paper presents a parametric anthropometric model developed within Solid Edge CAD software than can be scaled using the existing anthropometric data to represent pregnant women of any size and shape.

Anthropometric Measurements

A detailed study into the anthropometry of pregnant women has been conducted. A series of standard anthropometric measurements were collected in the first project associated with this research (Automotive Design: Incorporating the Needs of Pregnant Women). 48 measurements were taken from each case with a total of 100 cases. Standard anthropometric postures as presented by Pheasant [7] were adapted for pregnant women. Individual women were tracked through the course of their pregnancy where possible to document their anthropometric changes over the gestational period. The details of the sample of pregnant women are given in Table 1. The majority of the women in this study were drivers.

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 [8] 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 women as a seperate user group.

Table 1: Pregnancy and driving details of volunteers.

	2nd trimester (Week 13-28)	3rd trimester (Week 29-40+)
Number of volunteers.	35 women	65 women
Mean Pregnancy Week	21.6 weeks	35.5 weeks
Std. Dev. Pregnancy Week	4.5 weeks	2.8 weeks
Driver	34 women	52 women
Non-Driver & unknown	0 & 1 women	4 & 9 women

The physical growth during pregnancy is not limited to the abdominal region, but occurs throughout the body. There are other areas of significant change during pregnancy, e.g. 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 [8].

These anthropometric measurements are being used to define a parametric model of the pregnant occupant.

Anthropometric Model

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 [9]. 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 1 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.

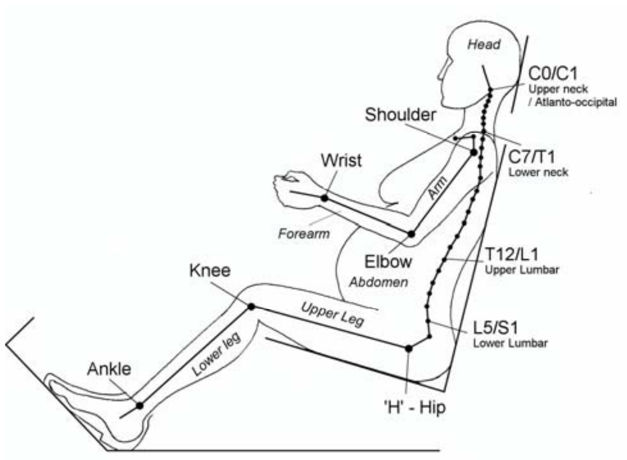

Figure 1: Diagram showing the kinematic linkage model with the various joints and body segments labeled.

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 front of knee and buttock to back of knee. Additional anthropometric data for 5th percentile UK females from the DTI's adultdata

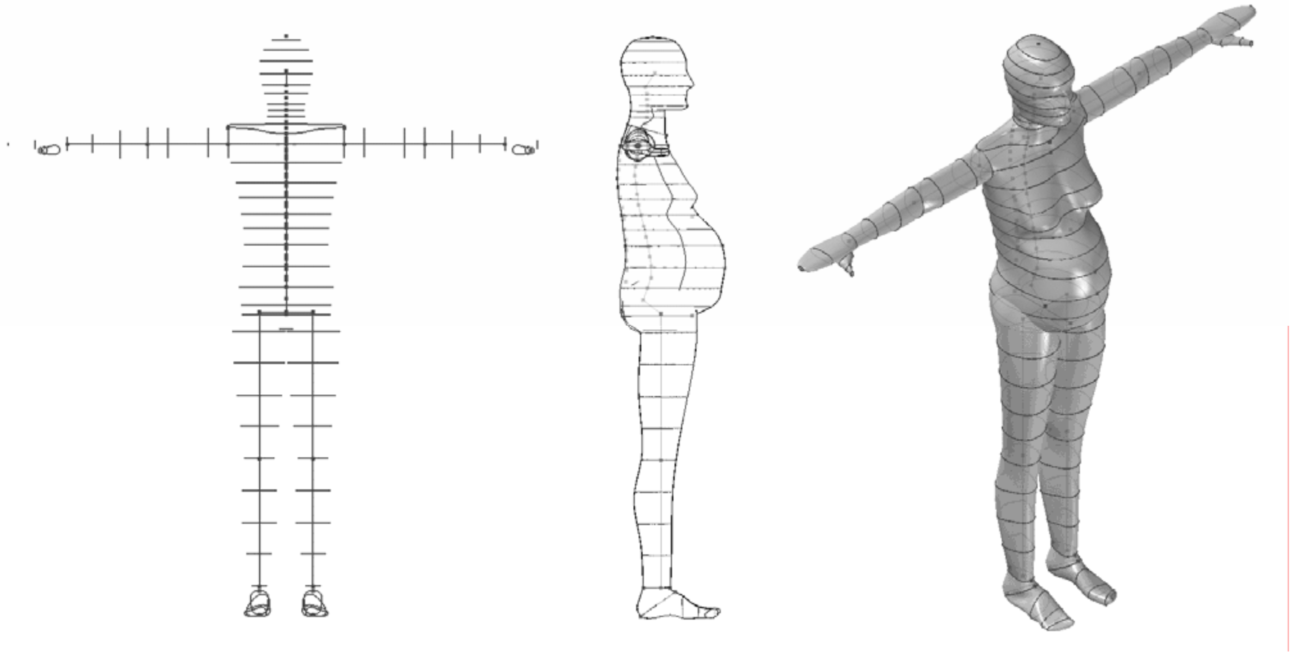

Figure 2. Front, side and isometric view of the pregnant female model. In the front view the body segment links and cross sections are shown. The side view shows the skin surface profile and the isometric view shows the complete 3D model.

handbook [8] 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 and enabling all the body cross sections to be orientated either horizontal or vertical. Figure 2 shows the preliminary model; all the cross sections used to define the geometric surface are shown along with the underlying segment linkages.

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 currently being undertaken to enable the scaling of the current model. Calculation methods as presented by Reed *et al* [10] can be 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) will be recorded, along with pelvic width and depth, to allow the positions of the knee, ankle and hip joints to be calculated. The positions of these joints in the model can then be adjusted to change the lengths of the upper and lower legs accordingly. A similar approach is applied to the upper extremities to adjust the upper and lower arm lengths 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 1. 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.

Another important part of the second phase of this study will be defining segment angles, including splay angles out of the sagittal plane, and spinal posture to correctly position the pregnant occupants in a realistic driving position.

Conclusions

A parametric model has been developed to allow the representation of pregnant women using specific anthropometric data. The model can be used to characterize women of all shapes and sizes and at any stage in the gestational period. Percentile models can be created as well as ‘one off’ individuals to allow designers to meet the needs of a broader range of the pregnant population.

The model is presented as a tool aimed at the automotive industry to aid in the evaluation of vehicle safety systems and car interiors for the pregnant occupants. 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 and seating position. 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 research project "Expecting: A pregnant occpunat model" is ongoing with the overall aim of the work being to create a computational model of the pregnant occupant for dynamic analysis of impacts.

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