EvaRID - ANTHROPOMETRIC AND BIOMECHANICAL SPECIFICATION OF A FINITE ELEMENT DUMMY MODEL OF AN AVERAGE FEMALE FOR REAR IMPACT TESTING

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Paper Number 11-0374

ABSTRACT

Neck injury due to low severity vehicle crashes is of worldwide concern and it is well established that the risk of such injuries are higher for females than for males, even in similar crash conditions. In addition, recently developed protective systems have shown to be less protective of females than males. Hence there is a need for improved tools when developing and evaluating the performance of protective systems for occupants.

The objective of this study was to develop a finite element model of a 50th percentile female rear impact crash dummy model. The anthropometry of the 50th percentile female was specified based on data found in the scientific published literature and is called EvaRID (Eva - female/RID - Rear Impact Dummy). EvaRID is based on the same design concept as the 50th percentile male rear impact dummy, the BioRID. A first version, EvaRID V1.0, was developed in LS-Dyna. The dynamic response of EvaRID V1.0 was compared to data from rear impact tests with female volunteers. It was found that it is necessary to further adjust the stiffness of the joints in the spine in order to fully mimic the motion of the volunteers. In future, the EvaRID dummy model has the potential to be a valuable tool when evaluating and developing seats and whiplash protection systems.

INTRODUCTION

Whiplash Associated Disorders (WAD), so called whiplash injuries, sustained in vehicle crashes is a worldwide problem. In Sweden, such injuries account for ~70% of all injuries leading to disability due to vehicle crashes (Kullgren et al. 2007). The majority of those experiencing initial neck symptoms recover within a week of a car crash, however, 5–10% of individuals experience different levels of permanent disabilities (Nygren et al. 1985; Krafft 1998; the Whiplash Commission 2005). Whiplash injuries occur at relatively low velocity changes (typically <25 km/h) (Eichberger et al. 1996; Kullgren et al. 2003), and in impacts from all directions. Rear impacts, however, occur most frequently in accident statistics (Watanabe et al. 2000).

It is well established that the whiplash injury risk is higher for females than for males, even in similar crash conditions (Narragon 1965; Kihlberg 1969; O'Neill et al. 1972; Thomas et al. 1982; Otremski et al. 1989; Maag et al. 1990; Morris recover & Thomas 1996; Dolinis 1997; Temming & Zobel 1998; Richter et al. 2000; Chapline et al. 2000; Krafft et al. 2003; Jakobsson et al. 2004; Storvik et al. 2009). These studies concluded that the female injury risk was 1.5 to 3 times higher than the male injury risk.

It has been shown that existing concepts for whiplash protection seats in general are more effective for males than females (Kullgren and Krafft 2010). The risk reduction regarding permanent medical impairment was approximately 45% for females and 60% for males, Figure 1. These results suggest that the difference in effectiveness between males and females could differ for various seat concepts. It is important to further validate these differences and to understand the reason behind them in order to achieve better protection for females, but also for males.

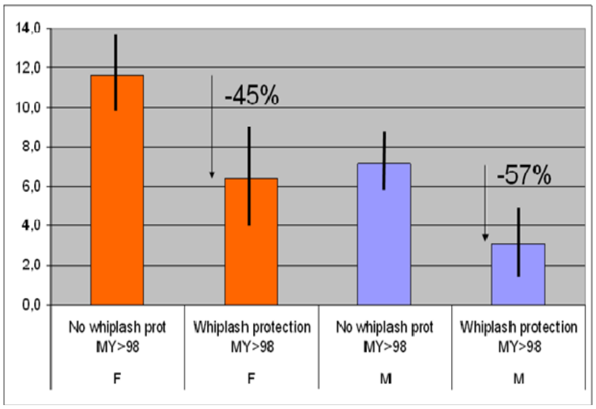


Figure 1. Whiplash injury reduction for females (F) and males (M) including 95% CI (based on the results from Kullgren and Krafft (2010)).

Females and males have different anthropometry and mass distribution, which may influence the interaction of the upper body with the seatback and head restraint and thus the injury risk. For example, the deflection of the seat frame, back rest padding and springs may depend on the mass and/or the centre of mass of the upper body with respect to the lever about the seatback hinge. The deflection of the structures of the back rest affects the plastic deformation, energy absorption and the dynamic head-to-head restraint distance as well as the rebound of the torso (Svensson et al. 1993; Croft 2002; Viano 2003). The motion of the head relative to the head restraint may be affected by seated height in relation to the head restraint geometry. It has been reported that females have a somewhat different dynamic response in rear volunteer tests, such as a higher head x-acceleration, a higher (or similar) T1 x-acceleration, a lower (or similar) Neck Injury Criterion (NIC) value and a more pronounced rebound (Szabo et al. 1994; Siegmund et al. 1997; Hell et al. 1999; Welcher & Szabo 2001; Croft et al. 2002; Mordaka & Gentle 2003; Viano 2003; Ono et al. 2006; Carlsson et al. 2008; Linder et al. 2008; Schick et al. 2008, Carlsson et al. 2010) than males.

Crash test dummies are used when developing and evaluating the occupant protection performance of a vehicle. The 50th percentile male crash test dummy correspond to a ~90th–95th percentile female with regards to stature and mass (Welsh & Lenard 2001), resulting in females not being well represented by the existing low velocity rear impact male dummies: the BioRID and the RID3D. Consequently, the current seats and whiplash protection systems are primarily adapted to the 50th percentile male without consideration for female properties, despite higher whiplash injury risk in females.

In view of the above, a European research effort was initiated under the ADSEAT (Adaptive Seat to Reduce Neck Injuries for Female and Male Occupants) project. The overall objective of ADSEAT is to provide guidance on how to evaluate the protective performance of vehicle seat designs aiming to reduce the incidence of whiplash injuries. The work concentrates on evaluating the protective performance of seats beneficial to female as well as male motor vehicle occupants. For this purpose a finite element crash dummy model of an average female is being developed. This new research tool will be used in conjunction with the BioRID II dummy model when evaluating enhanced whiplash injury protection.

This paper present the background research leading to the development of the first version of a finite element dummy model of an average female, called EvaRID, as well as the data used to develop the model. EvaRID is based on scaling an existing BioRID II dummy model in LS-Dyna. Background information on the size selection, anthropometry and the scaling method used, is described as well. The performance of the EvaRID V1.0 release is shown by comparing simulation results with volunteer data. This study was carried out within the ADSEAT project.

METHOD

EvaRID - Selection of size

Several sources were evaluated within the scope of the ADSEAT project to establish the size of female model to develop. One source used was the AGU Zurich database which records technical and medical information of persons who have suffered WAD. 2,146 data sets of females were analysed. It was found that the median height and weight of those females were 165 cm and 65 kg, respectively. The data sources contained basic measurements such as whole body height and weight. More specific measurements such as seated height or the dimension of individual body parts were not available.

Comparing these measurements with data of the female population in different European countries showed that the weight and height found for the female most at risk correspond quite well with the average weight and height of females in the European countries; that is 165 cm and 66 kg, Table 1.

Table 1.
"Average" female anthropometries of the general population in different European countries

Country	Height [cm]	Weight [kg]	Age [years]
Austria[f, h]	167	67	43.2
Czech Republic[f, g]	167.3	-	41.9
Germany[d, f]	165	67.5	45.2
Finland[f, g, i]	164.7	69-83	43.7
France[b, f, g]	161.9	62.4	40.9
Italy[f, g]	162	-	44.8
The Netherlands[e, f]	166.8	68.1	41.2
Norway[c, f, g]	167.2	-	40.2
Spain[f, g]	161	-	42.5
Sweden[f, j]	166.8	64.7	42.6
Switzerland[a, f]	164	49-67	42
United Kingdom[f, i]	161.6	67	41.3
Average of the above given measures	**164.6**	**66.3**	**42.5**

[a]http://www.statistikbs.ch/kennzahlen/integration/A/a2
[b] http://www.insee.fr/fr/ffc/docs_ffc/es361d.pdf
[c] http://www.ssb.no/english/yearbook/tab/tab-106.html
[d]http://www.wissen.de/wde/generator/wissen/ressorts/bildung/index,page= 3496378.html
[e] http://dined.io.tudelft.nl/en,dined2004,304
[f] https://www.cia.gov/library/publications/the-world-factbook/fields/2177.html
[g] http://www.disabled-world.com/artman/publish/height-chart.shtml
[h]http://www.imas.at/content/download/329/1288/version/1/file/05-03%5B1%5D.pdf
[i] http://psychology.wikia.com/wiki/Body_weight
[j] http://www.nordstjernan.com/news/sweden/776/

Additionally, the documentation regarding choice of crash dummy size in the WorldSID project was studied (Moss et al. 2000) in order to evaluate if that data could give guidance when selecting the size for the 50th percentile female model. When establishing the anthropometry of the WorldSID midsize male crash dummy (Moss et al. 2000) the average weight and height of the average occupant was similar to that of Schneider et al. (1983).

Another source of data for the distribution of weight and size of the occupants sustaining whiplash injuries can be seen in the insurance company Folksam´s database that include vehicle occupants reporting injuries in car crashes. The data include 1,610 female occupants in total, aged 18 and above at an average age of 46 years. The average stature was 165.9 cm and the average weight was 65.9 kg, which correspond relatively well with the average European results presented above.

Anthropometry specifications

As an initial input to the development of the EvaRID model the following data were collected:

- Dummy (model) total weight and if possible, each assembly weight
- Seated height
- All related chest dimensions (depth and width)
- All related pelvis dimensions (depth and width)
- Lengths of limbs (distance between joints)

The data for the 50th percentile female was mainly collected from the following references:

1. Schneider et al. (1983): The goal of this study was to define the anthropometry of a crash test dummy family. Initially, this dummy family consisted of two female dummy members (5th and 50th percentiles), and two male dummy members (50th and 95th percentiles). In the first part of the project, data was collected and analysed for all four dummy members, but it was later decided that the 50th percentile female dummy member should be dropped. The statures, seated heights and weights of the dummy family members were defined based on the National Health and Nutrition Examination Survey (HANES) of 1971–1974 by Abraham et al. (1979). According to Young et al. (1983), the HANES survey provides the most current and appropriate general population model available for US adult females. The HANES data was collected on 13,645 individuals representing the 128 million persons aged 18–74 in the US population.

2. Diffrient et al. (1974): This reference "incorporates extensive amount of human engineering data compiled and organised by Henry Dreyfuss Associates over the last thirty years, including the most up-to-date research of anthropologists, psychologists, scientists, human engineers and medical experts."
3. Young et al. (1983): This research was part of a series of studies designed to obtain information about mass distribution characteristics (including moment of inertia and centre of volume) of the living human body and its segments, and to establish reliable means of estimating such properties from easily measured body dimensions. The study was based on 46 adult female subjects, selected to approximate the range of stature and weight combinations found in the general U S female population. The sampling plan for this study was to achieve a stature and weight distribution comparable to that found in the civilian female US population as reported in the HANES of 1971–1974 by Abraham et al. (1979).

Both Young et al. and Schneider et al. derived stature, weight, and seated height for the 50th percentile female from the HANES data. However, as Young only considered a limited age range (21–45 years) compared to Schneider et al. (18–74 years), the latter source was used for extracting the anthropometric data.

In addition to the above sources, anthropometric data taken from the ergonomic programmes GEBOD and RAMSIS was used to validate the collected data. Product Information from Humanetics (previously FTSS) was also used to collect information on the BioRID II hardware dummy model for direct comparison of anthropometry data. Finally, for comparative purposes, part of the 50th percentile male data was based on McConville et al. (1980).

RESULTS

Schneider et al. (1983) described in detail how the anthropometry was defined for the 5th percentile female as well as the 50th and 95th percentile male crash test dummies. The same method was used, when appropriate, in order to establish the anthropometry of EvaRID. The stature, weight and seated height of EvaRID were based on Schneider et al. (1983) since this data set has defined the sizes of the existing dummies.

Table 2 summarizes the dimensions of the EvaRID model in comparison to the existing BioRID II model hardware. The stature, total weight and seated height were derived from Schneider et al. (1983). The assembly weights for the females are based on data reported by Young et al. (1983). The statures for the male was derived from Schneider et al. (1983), whereas the weights of each body part is based on data from McConville et al. (1980) or Schneider et al. (1983).

Table 2.
Stature, weights, seated height of EvaRID and 50th percentile male by Schnieder et al. (1983) and BioRID II.

Variable	50th percentile Female EvaRID	50th percentile Male	
		Schneider et al. (1983)	BioRID (FTSS)
Total stature [cm]	161.8	175.3	177
Total weight [kg]	62.3	77.3	78.24
Head [kg]	3.53	4.14	4.54
Thorax [kg] (including neck/spine)	17.06	24.73	26.61
Abdomen [kg]	2.56	2.37	
Pelvis [kg] (including flaps)	15.72	17.98[1)]	15.80
Arm upper [kg]	1.39	1.77	2.02
Arm lower [kg] (including hand)	1.15	2.02	2.23
Leg upper [kg] (excluding flaps)	5.71	5.33[2)]	5.99
Leg lower [kg]	2.84	3.59	5.44
Foot [kg]	0.62	0.98	
Seated Height [cm]	84.4	90.1	88.4

1) McConville et al. (1983): Flap: 3440 cc => Pelvis incl. flaps: 11964+3440=18844 cc (=17,98 kg, Volume*0.954)
2) McConville et al. (1983): Flap: 3440 cc => Upper leg excl flap: 9029-3440=5589 cc (=5332 kg, Volume*0.954)

The weight of body parts, absolute and relative compared to overall weight is provided in Table 3 and Figure 2 of the EvaRID and BioRID II dummy models.

Table 3.
Comparison of mass distribution (in percent of the total weight) of the BioRID II and the EvaRID

Body Part		EvaRID Mass [kg]	EvaRID % of total	BioRID II Mass [kg]	BioRID II % of total
Head	x1	3.5	5.7	4.54	5.8
Torso[1)] (incl. neck/spine)	x1	19.6	31.5	26.61	34.0
Pelvis (incl. flaps)	x1	15.7	25.2	15.80	20.2
Arm upper	x2	1.4	2.2	2.02	2.6
Arm lower (incl. hand)	x2	1.2	1.9	2.23	2.9
Leg upper (excl. flaps)	x2	5.7	9.2	5.99	7.7
Leg lower (incl. foot)	x2	3.5	5.5	5.44	7.0
TOTAL		**62.3**	**100**	**78.24**	**100**

1) The torso consists of the thorax, the abdomen and the spine (including the neck).

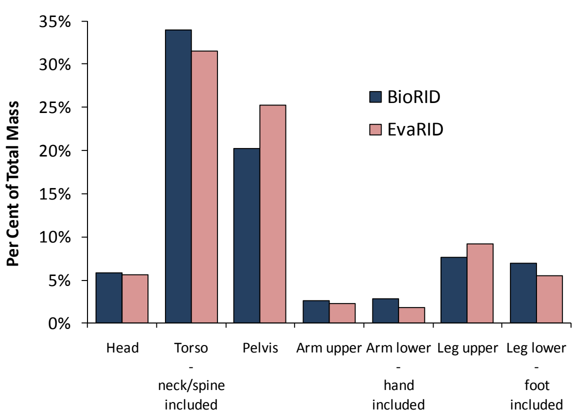


Figure 2. Comparison of mass distribution (in percent of the total weight) of the BioRID II and the EvaRID.

Table 4-6 provide remaining anthropometric data for the various body segments. The data was obtained from either Young et al. (1983) or Diffrient et al. (1974) since Schneider et al. (1983) only provided stature, weight and the seated height for the 50th percentile female**.**

Table 4.
Chest dimensions of EvaRID based on Diffrient et al. (1974) and Young et al. (1983)

Chest dimensions of EvaRID	Dimension [cm]
Parts of chest	
Shoulder (Diffrient et al. 1974)	
- Circumference	98.0
- Breadth	40.6
Armpit (Diffrient et al. 1974)	
- Circumference	89.2
Bust height (Young et al. 1983)	**116.4**
- Circumference	95.4
- Breadth	28.8
- Depth, mid-sagittal	17.8
- Depth, bust point (maximum protrusion of bra cup) (Diffrient et al. 1974)	23.1
- Distance, bust point – bust point	18.0
Chest below bust (Diffrient et al. 1974)	
- Circumference	79.0
10th rib height (Young et al. 1983)	**102.5**
- Circumference	75.9
- Breadth	25.7
- Breadth (Diffrient et al. 1974)	25.4
- Depth (Diffrient et al. 1974)	16.5
Waist	
- Circumference (Diffrient et al. 1974)	74.2
- Breadth (Young et al. 1983)	30.34

Table 5.
Pelvis dimensions of EvaRID based on data reported by Young et al. (1983)

Pelvis dimensions of EvaRID	Dimension [cm]
Part of pelvis	
Iliac crest height	**97.6**
Omphalion height	**95.9**
- Circumference	86.7
- Breadth	31.1
Buttocks	
- Circumference (standing)	100.1
- Breadth (standing)	37.3
- Depth (right buttock, standing)	24.1

Table 6.
Leg dimensions of EvaRID derived from Diffrient et al. (1974) and Young et al. (1983)

Variable	Dimension [cm]
“Inseam” height (Diffrient et al. 1974)	**75.2**
- Circumference	59.2
Gluteal furrow height (Young et al. 1983)	**71.7**
- Circumference	59.4
Mid-thigh height (Young et al. 1983)	**62.2**
- Circumference	51.9
- Depth	16.5
Knee height (Diffrient et al. 1974)	**45.7**
- Circumference (over the middle of the patella) (Young et al.1983)	37.0
- Breadth (across the femoral epicondyles) (Young et al. 1983)	8.8
Calf (Young et al. 1983)	
- Circumference (the maximum circumference of the calf)	35.6
- Depth (at same height as maximum circumference of calf)	10.8
Ankle height (Diffrient et al. 1974)	**8.1**
- Circumference (maximum circumference of ankle) (Young et al. 1983)	21.4
- Breadth (minimum breadth above medial & lateral malleoli) (Young et al. 1983)	5.4

EvaRID V1.0 – Model development

Since the EvaRID V1.0 model was based on the existing BioRID II model, the mass and dimensional ratios of the 50th percentile female should be used instead of the BioRID II. To meet the anthropometric requirements in terms of mass and dimension, the longitudinal dimensions and mass were initially scaled to obtain values related to the 50th percentile female. Breadth and depth dimensions were then established based on the scaling method of each body segment in detail, described in (Chang et al. 2010). The method was applied to all body parts.

Basic Scaling Methodology used to establish the Scale Factor Length (SFL), Scale Factor Breadth (SFB) and Scale Factor Depth (SFD) were calculated as follows. Firstly, the mass ratio of the EvaRID over BioRID II was calculated. Secondly, the SFL of EvaRID over BioRID II was determined based on the 50th percentile female data reported by Diffrient et al. (1974) and the dimensions of the BioRID II model. The SFB and SFD were then derived by taking the square root of mass ratio over SFL. Below are some general remarks related to the scaling of specific body parts:

The size of the head was scaled to meet all three dimensional requirements in depth, width and length. The mass requirement was met by adjusting the density of the skull.

The neck height was defined as the mastoid height less the cervical height. Considering the complexity of the neck modelling, the SFD was selected to be the same as the SFL. The SFB was assumed to be the same as the SFB for the torso, which was established by comparing the shoulder joint distance of EvaRID to the shoulder joint distance of BioRID II. Due to the lack of an accurate landmark of the mastoid and the cervical spine, the 50th percentile male data from McConville et al. was used for the neck height. The mass ratio of 0.664 was derived from SFL*SFB*SFD and was slightly less than the mass ratios of the head (0.778) and the torso (0.737).

It should be noted that the longitudinal dimension of the limb is different from the total length of the limb. The longitudinal dimensions were measured as follows: The upper arm was measured from shoulder joint to elbow joint; the lower arm was measured from the elbow joint to the end of middle finger tip; the upper leg was measured from the hip joint to the knee joint; the lower leg was measured from the knee joint to the bottom of the heel.

The torso was divided into two sections; the upper torso and the pelvis. The upper torso in this study was defined as the torso without the pelvis and it extends from the cervical to the iliac crest. The EvaRID maintain the same back profile as the BioRID II due to the scaling factors used for the SFL and SLD being the same. The upper torso mass was derived by subtracting the pelvis mass from the torso mass. The breadth was defined as the distance between shoulder joints. The Scale Factor Depth was then derived as follows:

$$SFD_{Upper\ Torso} = \frac{Mass\ Ratio_{Upper\ Torso}}{SFL_{Upper\ Torso} \times SFB_{Upper\ Torso}} \quad (1)$$

Regarding the pelvis, no major difference was found between the dimensions of 50th percentile female and 50th percentile male pelvis. From the data published by Diffrient et al. (1974), the 50th percentile female has a distance of 180 mm between the hip joints, which matches the hip joint distance (179.6 mm) of BioRID II. Furthermore, the articles of Young’s et al. and McConville’s et al. indicate that there is little difference between the 50th percentile female pelvis and the 50th percentile male pelvis. With regards to the pelvis angle the EvaRID maintains the same pelvis angle of 26.5 degrees as the BioRID II.

Finite element model of the seat

A seat model representing the test set-up was constructed for the initial evaluation of the dynamic response of the EvaRID V1.0 model. A Volvo 850 seat base dating from the early 90's was used as a seat in the tests. Differences in the seat base were considered to have negligible influence on the validation and therefore an available Taurus seat base was used during the evaluation. The seat back consisted of four stiff panels which were covered in a 20 mm thick layer of medium quality Tempur foam and lined with plush fabric (Volvo 850, year model 1993). The panels and foam were fitted according to the specified dimensions of the Volvo seat. The stiffness of the supporting springs on the seat were measured from and implemented in the finite element model. The head-restraint consisted of a stiff panel which was covered by 20 mm thick soft and 20 mm thick medium Tempur foam.

Dynamic data for model evaluation

The EvaRID V1.0 model was exposed to the same impact conditions as that of the volunteers in the test at 7 km/h in Carlsson et al. (2008). The dynamic response of the EvaRID V1.0 model was reproduced and compared to the responses in the volunteer tests. In Carlsson et al. a series of rear impact sled tests with eight female volunteers, representing the 50th percentile female, were performed at a change of velocity of 5 km/h and 7 km/h. The volunteer data is summarized in Table 7.

Table 7.
Volunteer data in Carlsson et al. (2008)

Female volunteers		Average
Age	[years]	24
Stature	[m]	1.66
Weight	[kg]	60
Seated height	[m]	0.88
Neck circumference	[m]	0.33

In the tests, the head of the volunteers were equipped with a harness with tri-axial accelerometers mounted on the left side and an angular accelerometer mounted on the right side, approximately at the centre of gravity on each side of the head. Two linear accelerometers, in x and z direction, were placed on a holder attached to the skin at four points near the spinal process of the T1. The upper body was equipped with a harness with tri-axial accelerometers mounted on the chest. Linear accelerometers were placed on the bullet sled and on the target sled. The test setup and the position of markers and instrumentation of the volunteers are shown in Figure 3 and 4. Additionally, the head-to-head rest distance and contact time and Neck Injury Criteria (NIC) were extracted from the data set. The volunteers wore a lap belt during the test.

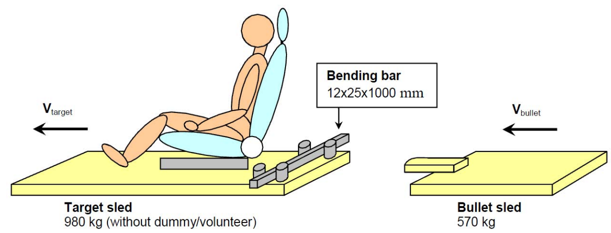


Figure 3. Sled set-up in the tests by Carlsson et al. (2008).

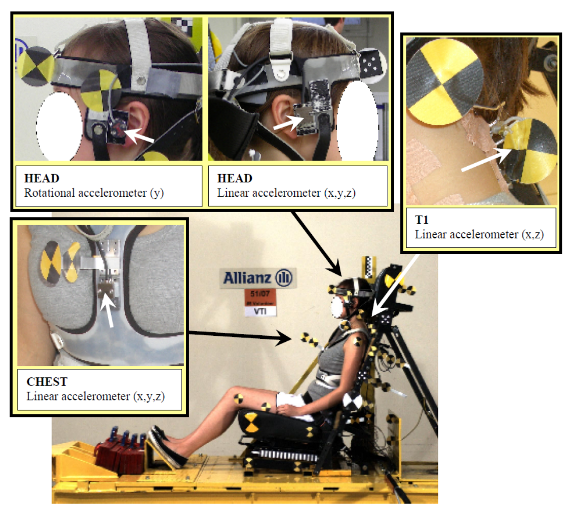


Figure 4. Position of markers and instrumentation on the volunteers in the tests by Carlsson et al. (2008).

Dynamic response corridors for the x-accelerations, the x-displacements and the angular displacements of the head, T1, and head relative to T1 were generated. Resulting corridors were created by +/-1SD from the average response of the volunteers from the tests and are depicted in Figure 5.

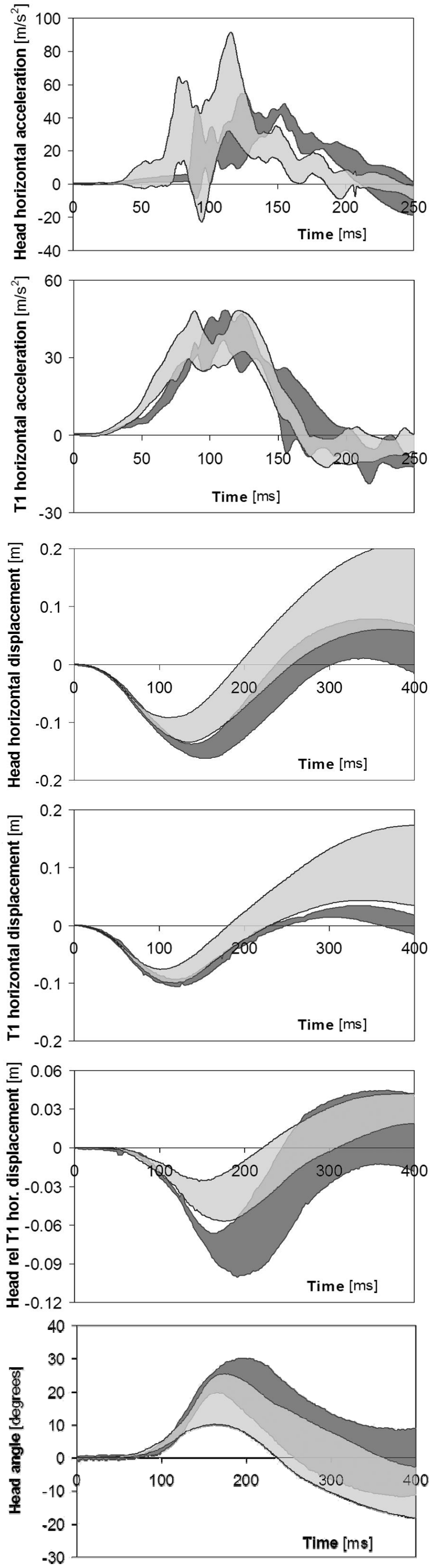


Figure 5. Examples of response corridors from Carlsson et al. (2008). The dark corridors represent tests with males and the light corridors represent tests with females.

RESULTS

Joint properties for the EvaRID V1.0 dummy model were adopted from the BioRID II dummy model. The curvature of the neck, spine etc. were the same for both models. A comparison between the EvaRID V1.0 and the BioRID II model is shown in Table 8 and Figure 6.

Table 8.
Comparison between the EvaRID VI.0 and the BioRID II

	Model	
	BioRID II (mm)	EvaRID (mm)
Head Total Height (top of head to chin)	215.9	203.0
Head Length	199.9	186.9
Head Breadth	157.6	145.8
Neck (C0-C1 joint to C7-T1 joint)	120.4	102.8
Torso (C7-T1 joint to Mid-point of hip joints)	526.5	479.4
Distance between shoulder joints	346.0	315.2
Upper Arm (shoulder joint to elbow joint)	261.4	264.0
Lower Arm (elbow joint to tip of middle finger)	248.8	234.0
Upper Leg (hip joint to knee joint)	405.5	389.6
Lower Leg (knee joint to bottom of heel along tibia)	495.5	457.0
Shoe Length	322.6	271.6

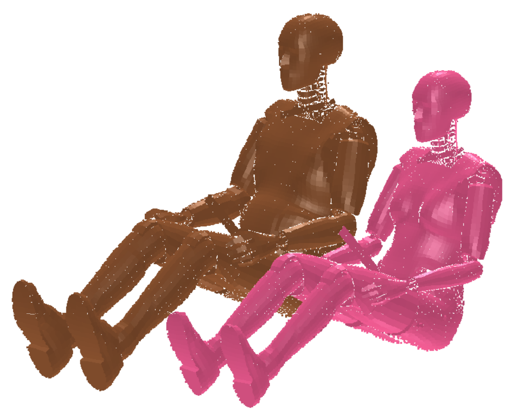


Figure 6. Comparison of EvaRID and BioRID II models.

Dynamic response

A pre-simulation positioning of the dummy model was conducted by dropping the EvaRID V1.0 model into the seat, allowing gravity to find its balanced position in the simulation. The seat was fixed to the ground with gravity as the only external force. Correlation of the initial position of the EvaRID V1.0 model with a volunteer was ensured by carefully checking each position. A representative example is shown in Figure 7. Once a balanced position was achieved by pre-simulation, the head panel was adjusted to equal the initial head-to-head rest distance, based on film analysis estimation measurements and a seatbelt was fastened before simulating the impact tests

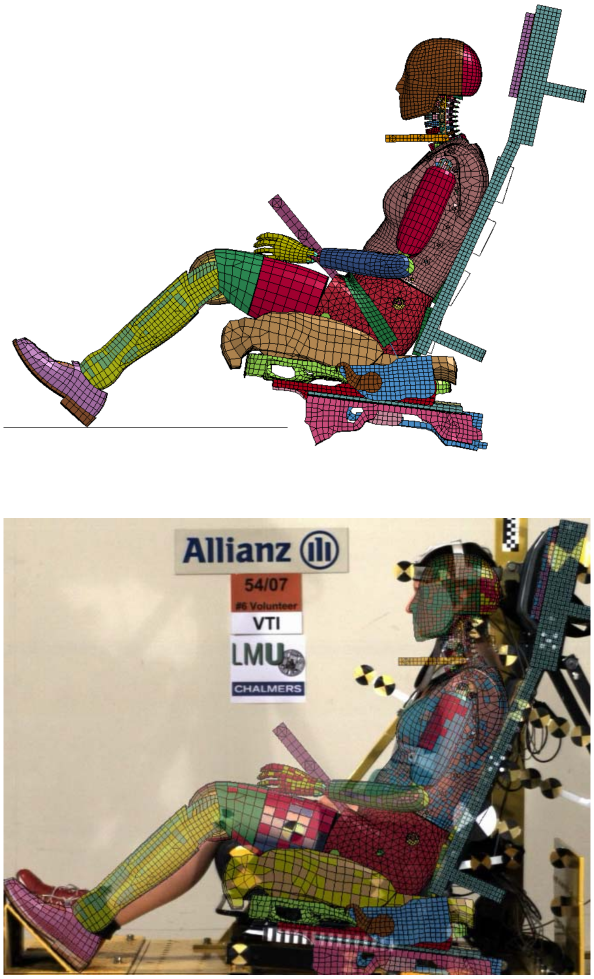


Figure 7. The EvaRID V1.0 finite element model seated in the seat and comparison of the initial posture with one of the volunteers.

The 7 km/h was used in simulations with the EvaRID V1.0. The results are shown in Figures 8-10, which compares simulated results using the EvaRID V1.0 model with response corridors and volunteer #50 who most resembled the EvaRID dummy model in terms of mass and initial position. Figures 8-10 shows the Head & T1 x-acceleration, Head & T1 x-displacement and the angular displacement of the Head & T1. T1 is the first thoracic vertebra and x-direction is in the horizontal plane.

Head and T1 x-accelerations

The head and T1 x-accelerations were mostly close to the test results and close to or within the test corridors.

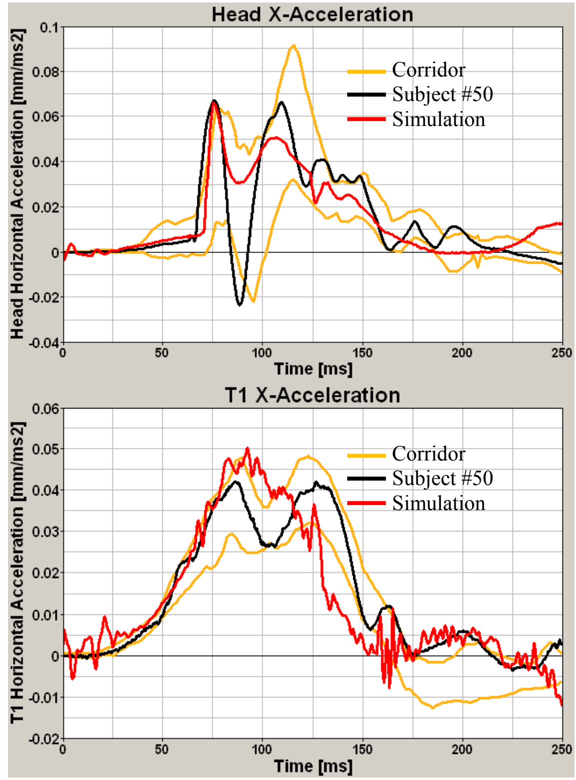
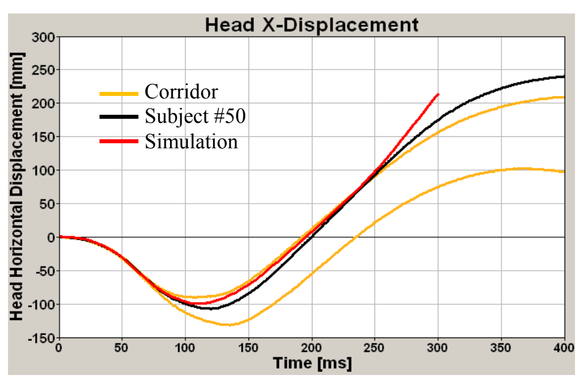


Figure 8. Comparison of head and T1 x-acceleration of the EvaRID V1.0 model response (red) with corridors constructed from all volunteer test data (orange lines) and volunteer #50 (black).

Head and T1 Displacements

The head and T1 x-displacements were close to the volunteer test results before the rebound at around 95 ms, Figure 9. From the T1 rebound and the simulation animation, it was observed that the EvaRID V1.0 model by design had a torso with much stiffer properties in extension than in flexion.



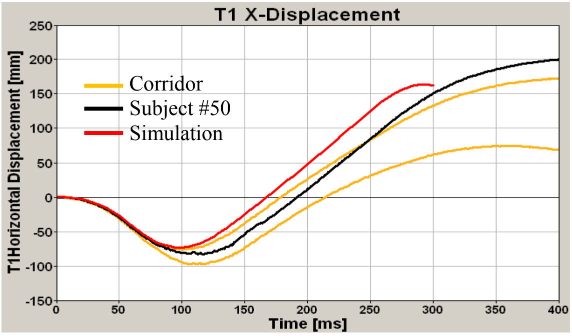


Figure 9. Comparison of head and T1 x-displacement of the EvaRID V1.0 model response (red) with corridors constructed from all volunteer test data (orange lines) and volunteer #50 (black).

Head and T1 angular displacement

The angular displacement of the head was within the corridor for the first 250 ms, however the angular displacement of T1 rotation response was not within the corridor for the first 240 ms, Figure 10. Thus the torso EvaRID V1.0 model has considerably stiffer properties in extension than flexion. The properties of the finite element model of the seat and seatbelt may also contribute to some of this discrepancy.

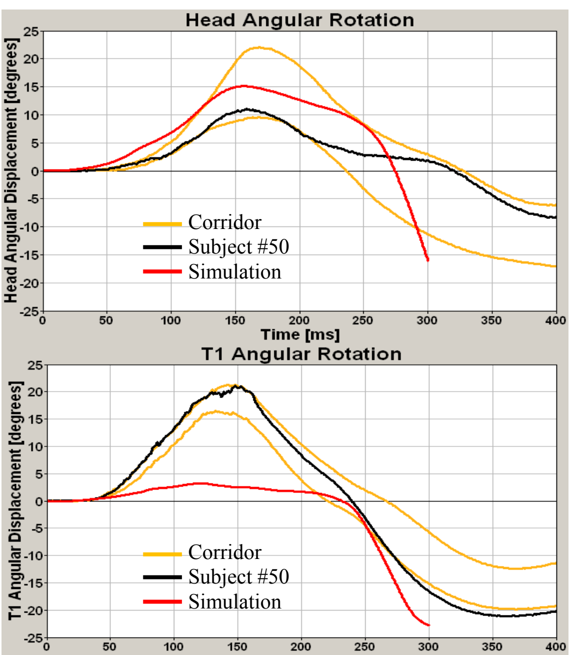


Figure 10. Comparison of head and T1 angular displacement of the EvaRID V1.0 model response (red) with corridors constructed from all volunteer test data (orange lines) and volunteer #50 (black).

Additional volunteer tests

Additional rear impact sled tests were performed in November 2010 with eight female volunteers at the change of velocity 7 km/h. The purpose was to receive input data for further improvements of the EvaRID mathematical model. The test setup was basically the same as in the previous volunteer test series (Carlsson et al. 2008), Figure 3 and 4, except for some changes to the design of the seat base and head rest to simplify the mathematical modelling of the seat. The head-to-head rest distance was increased to ~15 cm to delay headrest contact and improve the possibility of studying the retraction phase. Due to the increased head-to headrest distance the average acceleration was reduced to ~2g to ensure the safety of the volunteers. For comparison, the test series also included tests with eight male volunteers in the same test setup. The increased head-to-headrest distance allowed for more detailed comparison of the neck injury criteria such as NIC and neck loads for females and males.

The volunteers were selected based on their statures and masses being close the 50th percentile female and male, respectively, according to the University of Michigan Transportation Research Institute (UMTRI) study (Schneider et al. 1983). For the female volunteers, the stature range was 161–166 cm with an average of 163 cm, and the mass range was 54.5–66.8 kg with an average of 59 kg. In comparison to the UMTRI data, the female volunteers were on average 1% taller and 4% lighter. For the male volunteers, the stature range was 171–179.5 cm with an average of 176 cm, and the mass range was 69.8–81.0 kg with an average of 75 kg. In comparison to the UMTRI data, the male volunteers were on average 0.5% taller and 3% lighter.

The new headrest base consisted of plywood that was covered with foam blocks (polyethylene 220-E, 35 kg/m^3), and firmly attached to the stiff seat frame, Figure 11. The headrest was adjustable in height. The new seat base consisted of a rigid frame and was covered by plywood. The seatback (headrest excluded) was identical to the one used in the previous test series (Carlsson et al. 2008). In recent test series, two layers of Lycra fabric covered the seat back and seat base.

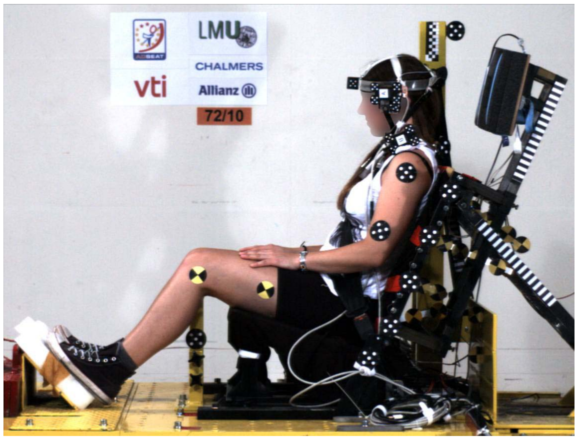


Figure 11. Test setup in voluteer tests run in November 2010.

The volunteers wore a pair of shorts and a T-shirt designed as a vest during the tests. The volunteers were seated, restrained by a three-point seatbelt and instructed to obtain a normal sitting posture, face forward, position their feet on an angled foot plate, place their hands on their lap and relax prior to the impact, Figure 11. Each female volunteer underwent two tests. By adding padding to the headrest, the headrest distance was 10 cm in the first test and 15 cm in the second. The males were only exposed to tests with a head-to-headrest distance of 15 cm.

The analysis of the data from these tests is ongoing and will be used to validate and further improve joint stiffness properties of the EvaRID mathematical model.

DISCUSSION

Based on real-world crashes it is well known that females have a higher risk of whiplash than males. A study has also shown that anti-whiplash concepts are more effective for males than females (Kullgen and Krafft 2010). Studies have shown many differences between males and females that may influence the difference in risk, for example differences in seated posture (Jonsson et al. 2007) and differences in muscle activity (Foust et al. 1973) and head to neck size (States et al. 1972) to mention just a few. In this study it is shown that females on average are 18% lighter and 7% shorter than males. In order to improve whiplash protection concepts for both males and females, but especially for females, it is important to better understand what influences the dynamic response and the risk of injury.

As a first step in the process of developing a finite element model of an average female the EvaRID V1.0 was created. The EvaRID V1.0 model was developed by scaling anthropometry, geometry and mass properties on the BioRID II dummy model. The weight distribution of EvaRID is somewhat different from the BioRID. EvaRID has a slightly lighter torso, a heavier pelvis and somewhat heavier upper legs. The joint stiffness properties of the spine, torso and neck were the same as that of the BioRID. In order to obtain a T1 angular motion as reported from volunteer tests, the stiffness of the EvaRID model will need to be tuned.

During the evaluation it was observed that the EvaRID V1.0 model showed less angular motion of the torso/spine in extension in comparison to the subjects, Figure 9. Due to having inherited the design and properties of the BioRID II dummy model, adjustments in joint characteristics were not made in the V1.0 model. Consequently, the T1 rotation is expected to be considerably less compared to the response of the real subjects during the extension motion. The rotation of the head relative to the T1 suggests that further improvement on the T1 (or spine) flexibility is important to correct the neck motion.

The next step in the process of developing the EvaRID model, tuning of the stiffness of the spine will be made. However, it may be the case that the construction of the BioRID II model does not contain the components needed to mimic the dynamic response of both males and females. In such case, new design features will be taken into consideration.

It was noted that the headrest was relatively close to the head in volunteer tests by Carlsson et al. (2008), which indicate that the head response is largely governed by the headrest properties and not entirely by the neck properties. Thus, these volunteer tests are less suitable for fine tuning the neck parameters, stressing the importance of using a greater headrest gap in the upcoming volunteer tests.

In this study, initial evaluation of the EvaRID V1.0 model was based on tests with one set of female volunteers. Additional test results from female volunteers that can be reproduced as finite element simulations are needed in order to further evaluate and develop the dynamic response of the EvaRID model.

CONCLUSIONS

A computational dummy model, called EvaRID, of a 50th percentile female to be used in rear impact tests was developed in the ADSEAT project based on anthropometry data found in the literature. Geometry and mass data was taken from sources serving as basis for the anthropometry of previous crash dummies. The model was obtained by scaling anthropometry, geometry and mass properties of an existing BioRID II model. Stiffness and damping properties of materials and discrete elements were kept in accordance with the BioRID II model in the initial EvaRID model version.

To evaluate how close the dummy model´s response was to that of a human, the EvaRID V1.0 was compared to the corridors and response curves gained in volunteer tests with females. Further work on the joint stiffness properties was found to be needed for the model to achieve a response fully within the corridors in the volunteer tests. Furthermore, additional volunteer data with a greater initial gap between the head and the headrest would be valuable to further improve the dynamic response of the dummy model. Such studies are included in the ADSEAT project. Once fully validated, the dummy model will be utilised in the design and evaluation of adaptive seat systems in order to provide enhanced neck injury protection for female occupants.

ACKNOWLEDGEMENT

This study is part of the ADSEAT (Adaptive Seat to Reduce Neck Injuries for Female and Male Occupants) project funded by the European Commission within the 7th Framework Programme. Additional funding has been received from the Swedish Transport Agency.

The authors would like to thank DynaMORE GmbH for providing the BioRID II dummy model as basis for the EvaRID model developments.

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