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Executive Summary

The aim of this report is to consolidate all the valuable information found during the ADSEAT project into guidelines for reference when developing car seats that focus on safety and the protection from Whiplash Associated Disorders (WAD) in rear end crash scenarios for male and female occupants.

Main conclusions:

1.) Current car seat development
   a. Continue to use the currently applicable pulses for all testing
   b. Necessary to introduce occupant model diversity; a 50th percentile female model would best meet the requirements. More models would be better still e.g., a 5th percentile.
2.) Human anthropometry and diversity
   a. A 50th percentile female is not simply a scaled down 50th percentile male occupant model. Lengths, widths, weights, stiffness etc. must be adapted separately
   b. Based on statistical data, a set of data for a 50th percentile female occupant model has been generated.
   c. Human beings differ vastly from each other. Factors such as posture, different comfort levels and needs, leading to different seat settings etc., is behind the great variety in pre-crash situations and often the reason for WADs.
   d. A car seat delivering a high level of protection for a large variety of occupant sizes would be more beneficial than a car seat that is highly adaptable but poorly adjusted.
3.) A virtual female occupant model – EvaRID
   a. A first version of a female occupant model for finite element methods is now available and should be used when investigating loads on shorter and lighter car seat occupants when developing future car seats
   b. Since there is no female physical dummy available at present, using the virtual finite element dummy model is recommended.
   c. A detailed physical female dummy would be very beneficial for further investigations.
4.) Injury Criteria and thresholds
   a. The same criteria as for male occupants but adapted thresholds should be applied for female occupants. (NIC and Nkm in a first step)
   b. Other criteria need to be evaluated

5.) Seat settings, Seat Characteristics, Development Advice

a. Today´s car seats and their adjustability are designed for the 50^{th} percentile male occupant

b. Further occupant models, load cases and seat settings should be considered during development.

c. In the overall rating the worst scenario (setting, occupant) should be crucial.

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1 Current car seat development

Nowadays many car seats are developed to meet requirements according to Euro NCAP standards.

Figure 1: BioRID II dummy as used in Euro NCAP whiplash tests.

1.1 State of the art testing

Due to the lack of legislation with regards to rear end collision safety, the quasi standard for seat development is the Euro NCAP protocol [1, 2010].

Euro NCAP tests car seats in the course of consumer tests and the whiplash test is part of the overall rating. The whiplash score is calculated based on two different approaches. The first approach is a static, geometric test, where distances and adjustability are rated. Complementary to the static test, three independent sled tests applying three different pulses are conducted and evaluated. The occupant in these dynamic tests is represented by the BioRID II dummy, a model of a 50th percentile human male.

1.1.1 Pulses used in Euro NCAP

During this project accident statistics showed that most occupants suffering symptoms lasting longer than six months were found

a) at a change of velocity (delta-v) between 10 and 40 km/h and

b) at a mean acceleration between 2.5 and 10 g. [5, 2012] Sub-report 3, page 3

The average collision velocity of the bullet vehicle for females and males is roughly at 15.5 km/h.

[5, 2012]

The pulses used in Euro NCAP tests (see Figure 2) cover the relevant delta-vs (change of velocity) of most probable accident scenarios found in the ADSEAT project.

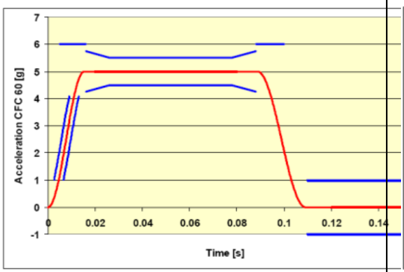
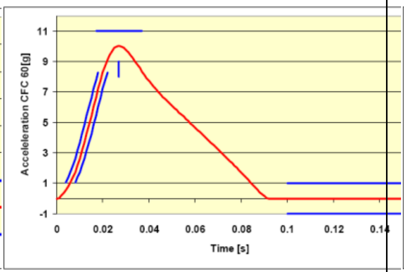
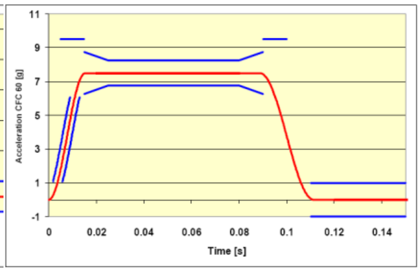
Low severity pulse	Medium severity pulse	High severity pulse
SRA 16 km/h	IIWPG 16 km/h	SRA 24 km/h
Peak ~ 5g	Peak ~ 10g	Peak ~8g
		
		Source: Euro NCAP Protocol

Figure 2: Comparison of the currently used Euro NCAP acceleration pulses for rear impact collision sled tests.

1.1.2 Anthropometry of occupant model

State of the art in whiplash testing is performed with a 50th percentile male occupant rear impact model, the BioRID II dummy. In addition to male occupants, the median female at risk has been identified to be approximately 36-39 years of age, 65kg of body weight and 165cm of body height. This data corresponds well with data from a number of other European countries; therefore a 50th percentile female occupant rear impact model should be implemented for additional testing. Using a 50th percentile male and a 50th percentile female would cover the majority of occupants at risk of being exposed to whiplash loads.

1.2 Conclusion of current car seat development

a) Continue to use currently applicable pulses for all testing

b) Necessary to increase occupant model diversity; a 50th percentile female rear impact model would best meet the requirements. Further models would be even better, i.e., 5th percentile.

2 Human Anthropometry and diversity

2.1 Anthropometry data

Human beings differ from each other and there is no simple way to cover all possible occupants. The most effective approach appears to be to select the most relevant portion, statistically, of occupant anthropometry. Thus, 50th percentile male and 50th percentile female occupants would be at the highest risk, since they represent the greatest portion of occupants. [5, 2012] An example of the distribution of whiplash injured female occupants in Switzerland and Sweden is shown in Figure 3.

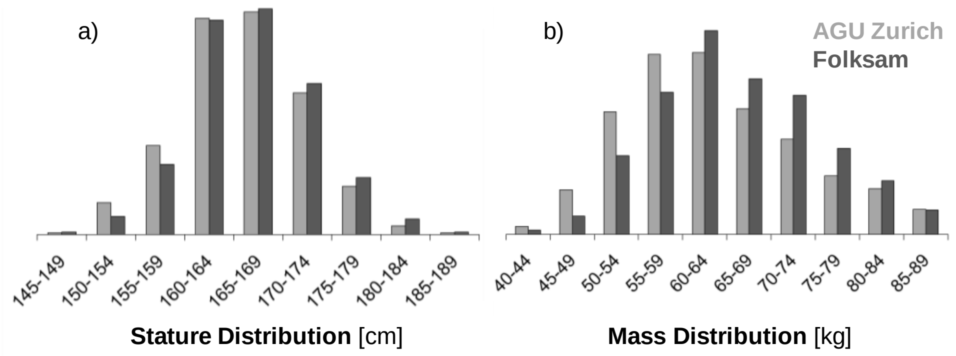


Figure 3 Stature and mass distributions of whiplash injured female occupants in Switzerland (AGU Zurich database) and Sweden (Folksam database) [2, 2013]

Table 1 "Average" female anthropometries of the general population for EU countries [2, 2013]

Country	Height [cm]	Weight [kg]	Age [years]
Austria[f, h]	167.0	67.0	43.2
Czech Republic[f, g]	167.3	-	41.9
Germany[d, f]	165.0	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]	162.0	-	44.8
Netherlands[e, f]	166.8	68.1	41.2
Norway[c, f, g]	167.2	-	40.2
Spain[f, g]	161.0	-	42.5
Sweden[f, j]	166.8	64.7	42.6
Switzerland[a, f]	164.0	49-67	42.0
United Kingdom[f, i]	161.6	67.0	41.3
Average	164.6	66.3	42.5

In order to identify anthropometric differences between a 50th percentile male and female, detailed data for all relevant body parts, such as weights, lengths, circumferences, centre of gravity etc., were gathered and compared with volunteer data, data from the University of Michigan Transportation Research Institute (UMTRI) database and other national and international data. [5, 2012] Figure 4 illustrates for instance, how mass distribution differ for different body parts between a male and female body.

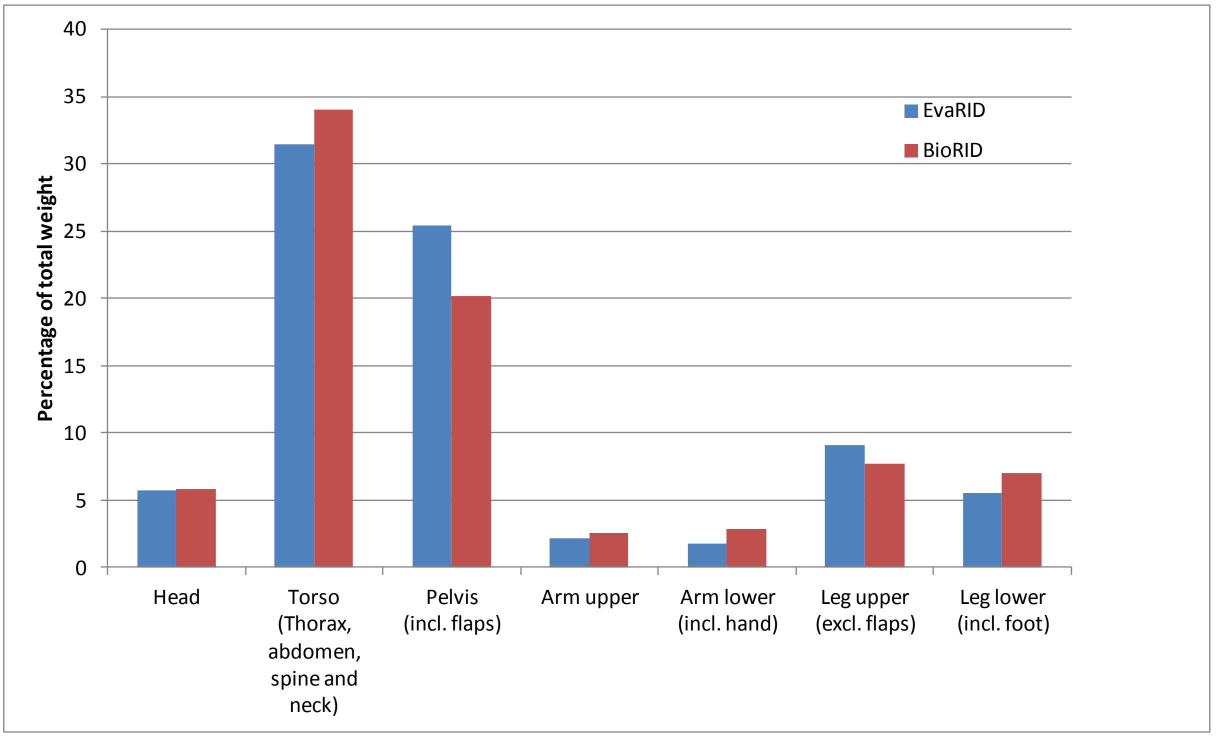


Figure 4 Comparison of mass distribution (in percentage of total weight) of the BioRID II and the EvaRID model [2, 2013]

2.1.1 Differences between male and female occupants

The obvious difference between male and female occupants is the variation of body measurements and shape. As an example, two volunteer candidates are displayed in Figure 5. They differ in head posture (♂upward, ♀ forward), upper body angle but also their upper leg and lower leg angles differ due to the different lengths. These anthropometric factors, alone, make it impossible to directly compare loads put on each of them during a crash.

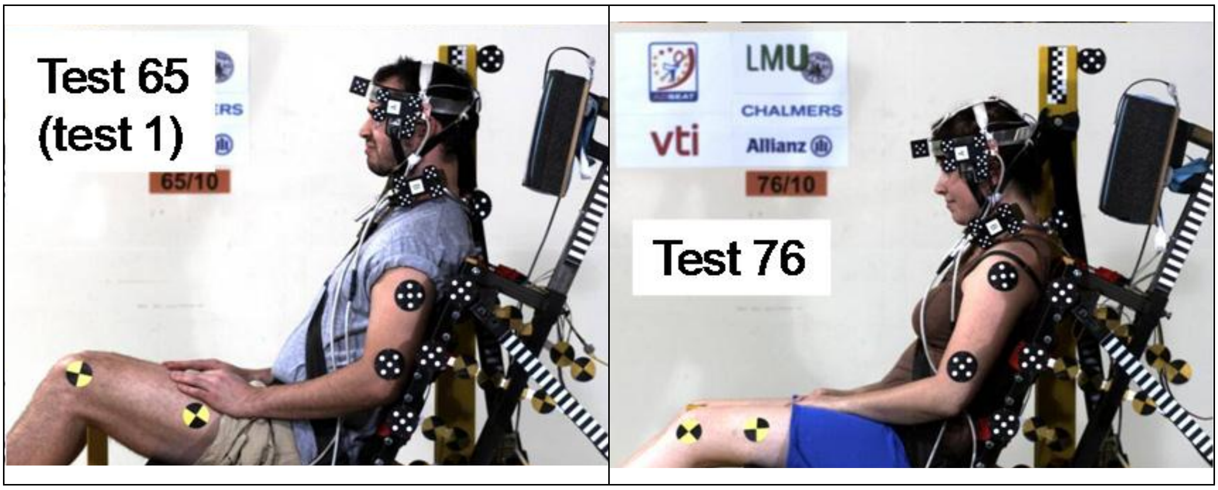


Figure 5: Different gender subjects in the same lab seat. The differing anthropometry leads to different seated postures. [4, 2010]

2.1.2 Differences between single subjects

Although the body shape of two different subjects appear to be alike in stature, weight etc. it must not be assumed that their seated posture or preferred seat adjustments will be the same. Due to the many different driving situations an occupant is confronted by in a single car journey or car seat, even the choices a subject makes can vary widely, i.e., relaxed or tired and changeable positions on highways to a more alert posture in busy traffic situations, etc. In Figure 6 one single subject is shown in subsequent tests. Even under lab-conditions, in which a generic lab-seat was used, the position of her head differs between the tests, thus it is impossible to expect the same results when conducting more than one of the same test.

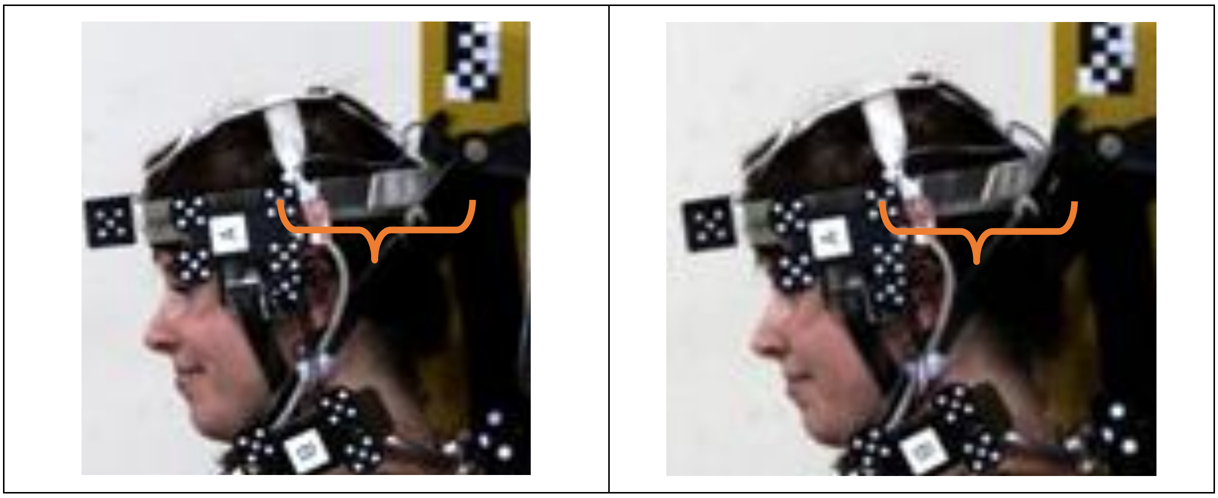


Figure 6: The identical subject in two subsequent tests. The bracket is the same size in the left and right picture. The head position differs even though the subject is the same person on an identical seat under lab-conditions. [4, 2010]

2.1.3 Differences between driver and passenger

A significant difference was identified in the volunteer tests when the subjects were positioned in a generic lab seat, once grasping a steering wheel, and once without the steering wheel. The positioning of the arms (mass – inertia) at the height of the steering wheel, as well as the grasp on the steering wheel seems to have a significant influence on behaviour during a rear impact collision. Figure 7 shows that the same subject seated on a passenger or driver seat adopts different postures. Raising the arms and holding on to the steering wheel does not only change the position and location of the arms, it also results in different upper body and head positions. This difference in posture, as well as the grip on the steering wheel influences the outcome in a whiplash sled test. Considering the low change in velocity (delta-v) in the volunteer tests, holding on to the steering wheel has an even greater influence on the outcome.

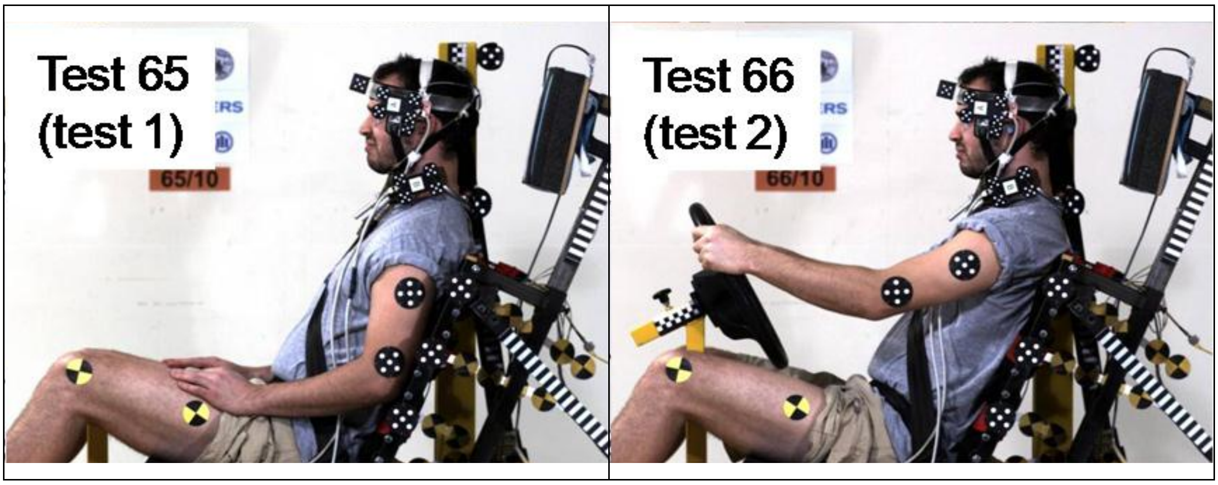


Figure 7: Different postures of one occupant seated on "driver" and "passenger" seat. [4, 2010]

2.2 Lack of adaption of protective equipment

Even high-end car seats do not always deliver sufficient protection if they are not adjusted well. Field studies show that this issue needs to be addressed since a large number of drivers and occupants seem to fail to adjust or modify their car seats to provide the best possible protection for themselves when driving shared cars and sometimes even when driving their own vehicle.

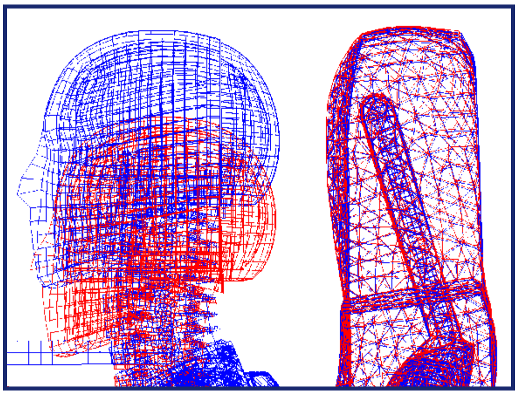


Figure 8: Approach to reduce adjustability increasing protection by supporting more than one size of occupant.

Some car manufacturers have addressed this issue by designing seats that are less adjustable but still provide better protection to a greater variety of occupant sizes. Unfortunately, the absence of a small, i.e., female occupant model leads to insufficient developments within this area, as shown in Figure 8. [3, 2013]

The seat shown in Figure 8 was tested in a real sled test and analysed using Finite Element Methods (FEM). While performing well in the physical test, scoring 3.41 points out of 4 according to the Euro NCAP protocol when loaded with the BioRID II dummy, in the Finite Element Analysis (FEA), loaded with the EvaRID model it was not awarded any points (0 points due to peaking above capping limits) during IIWPG 16km/h test pulse. The Neck Injury Criteria (NIC) of the EvaRID exceeded the capping limit of 27. Furthermore, the FEA for the BioRID dummy model scored well according to the Euro NCAP protocol and reached 2.3 points in this particular dynamic test.

2.3 Conclusion to human anthropometry and diversity

a) A 50th percentile female (occupant model) is not fairly represented by a scaled down 50th percentile male (occupant model). Lengths, widths, weights, stiffness etc. must be adapted separately

b) Based on statistical data, a set of data for a 50th percentile female occupant model has been generated.

c) Human beings differ vastly from each other. Factors such as posture, different comfort levels (leading to different seat settings) etc., is behind the great variety of pre-crash situations and often the reason for WADs.

d) A car seat delivering a high level of protection for a large variety of occupant sizes would be more beneficial than a car seat that is highly adaptable but poorly adjusted.

3 A virtual female occupant model – EvaRID

As mentioned earlier, to date only a male 50th percentile dedicated rear impact dummy is available for whiplash testing. The implication of such limitation is that even if a car or seat manufacturer would like to test their seats for a broader variety of occupants, there is simply no comparable dummy available representing a female occupant in rear end collisions. One option would be to use the HIII 5th percentile female, however it is not a rear impact dummy and thus not comparable with the BioRID.

Developing a complete dummy was outside the scope of the ADSEAT project. Therefore, a different approach was chosen and a finite element female dummy model was developed.

3.1 Lack of a female dummy and/or dummy model

Currently female dummies represent a 5th percentile female. This particular size of occupant however, does not represent the majority of women at risk in rear impact collisions. Due to the lack of a dummy representing the size of a 50th percentile female, anthropometry data had to be gathered and analysed within this project before it could be applied to a newly developed finite element model or even a physical dummy.

3.2 Development of a virtual female rear impact dummy model

One of the main objectives within the European Commission (EC) funded project ADSEAT was to develop a finite element female rear impact dummy model and the model was named EvaRID (Eva – indicating female, RID – Rear Impact Dummy). This dummy model is based on the (male) BioRID II finite element model, but it has been adapted to meet the anthropometry of a 50th percentile female. To verify its viability and bio fidelity, the finite element model has been compared with data from various volunteer tests. In the underlying project these tests have been conducted comprising female volunteers meeting the criteria (i.e. anthropometry) of a 50th percentile female in this project. It was found that the EvaRID model correlated very well with the volunteer data.

3.3 Conclusion to a virtual female occupant model - EvaRID

a) A first version of a female occupant rear impact dummy model for finite element methods is now available and should be used when investigating loads on shorter and lighter car seat occupants when developing future car seats

b) Since there is no female physical dummy available at present, using the virtual finite element dummy model is recommended.

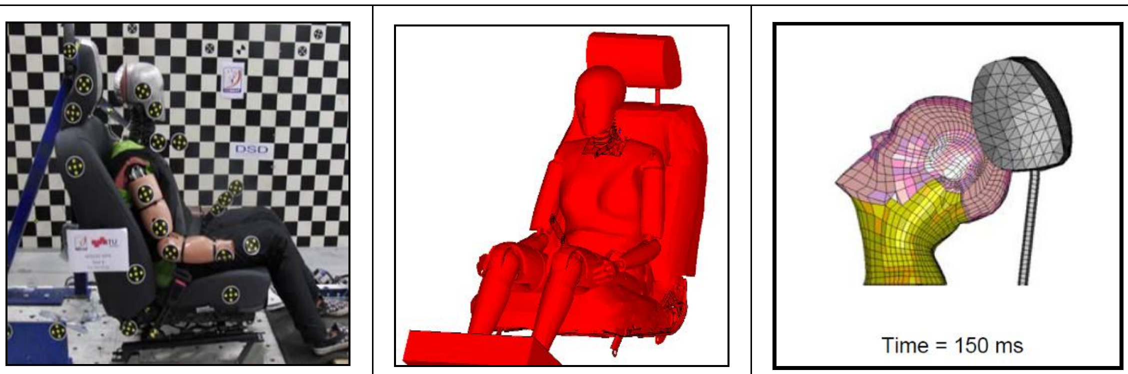
c) A detailed physical female dummy would be of great value for further investigations.

4 Injury criteria and thresholds

At present no specific injury criteria are available to assess the neck injury risk of a female. However, since the injury mechanisms, as well as the biomechanical behaviour of male and female occupants are similar leads to the assumption that the same criteria should be applied for injury mechanisms but for severity, different thresholds for males and females must be considered.

4.1 Present Injury criteria

The ADSEAT project addressed the issue of injury criteria and corresponding threshold values by analysing real-world data, performing computer simulations and conducting sled tests as well as physical testing with a modified BioRID II dummy called BioRID 50F loading device. Detailed information about this work can be found in [6, 2012].



a) BioRID 50 F loading device	b) EvaRID FEM	c) Female Head-Neck UdS FEM

Figure 9: Testing with a modified BioRID dummy, adapted to meet weight distribution and major sizes of a 50th percentile female (a), finite element method simulations with a dummy model (b) and a human finite element model (c).

There are several injury criteria available to indicate the severity of neck injuries. Amongst them are the Neck Injury Criterion (NIC), Nkm (a criterion based on neck forces and moments), Neck Displacement Corridor (NDC), Lower Neck Load (LNL) to name a few. [6, 2012]

In terms of practical impact / use it is first of all the NIC and Nkm criteria that are predominantly used today. NIC was defined based on animal experiments and Nkm considers the shear forces, i.e., both criteria are influenced by the occurrence of the S-shape. Furthermore, they are used as part of test procedures such as Euro NCAP.

4.2 *Adapted Thresholds*

Based on theoretical considerations it was particularly suggested to apply modified versions of the NIC and Nkm injury criteria although other injury criteria were also analysed, the main focus was put on criteria used in Euro NCAP tests.

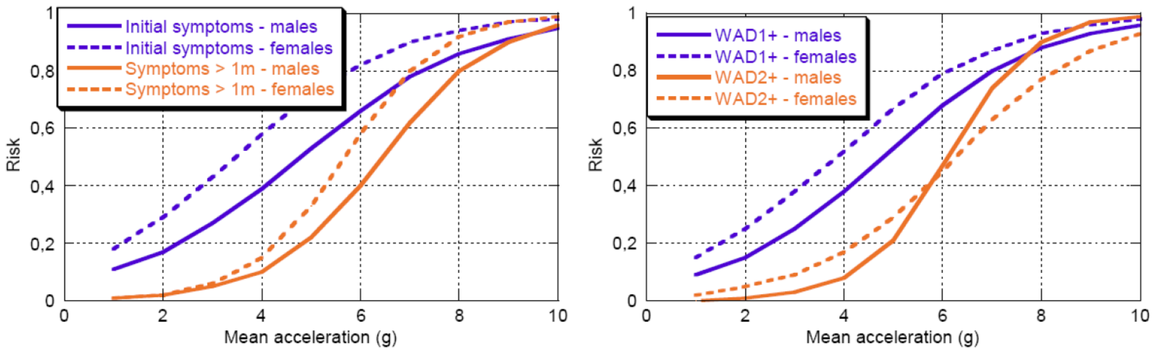


Figure 10 Injury risk vs. mean acceleration for male and female occupants [6, 2012]

4.2.1 NIC adaption

For NIC, a lower threshold value of 12 (instead of 15 as for males) was suggested. [6, 2012]

4.2.2 Nkm base value adaption

For Nkm different intercept values which are used to normalise the test data were defined. [6, 2012]

4.2.3 Other thresholds

Additional criteria, such as Neck Displacement Corridor (NDC), Lower Neck Load Index (LNL) or Normalised Neck Injury Criterion (Nij) were not addressed in the ADSEAT project.

Several criteria such as LNL for example are based on similar ideas to the Nkm in that the results obtained for Nkm might be useful with respect to other similar criteria. NIC and Nkm, however, are widely used which is why it seemed reasonable to focus on these two criteria.

4.3 *Conclusion to injury criteria and thresholds*

a) For female occupants, the same criteria as for male occupants with adapted thresholds should be applied. (initially NIC and Nkm)

b) Other criteria need to be evaluated

5 Seat Settings, Seat Characteristics, Development Advice

Just as different occupants will have a major impact on the level of safety and protection provided for occupants during a rear end impact, equally important to the outcome is how much the variety of different car seats, as well as the many adjustment options a seat has.

5.1 Benchmark

To gain a basic overview of different car seats and any possible potential for improvements, virtual investigations and real sled tests have been conducted. Four different currently available production seats have been tested with a male BioRID II dummy.

A further three of these production seats, one generic seat model and a specially developed prototype seat, have been investigated using FEM. The prototype seat was developed based on the information obtained in the ADSEAT project, especially with regards to the knowledge from the benchmark tests and simulations. The results indicate that a stiff connection between the head restraint and the backrest is beneficial. Furthermore, the adaptability of current seats appear to lack the possibility to adapt to female anthropometry, i.e., options to lower the head restraint.

These benchmark simulations and tests revealed that a seat model when loaded with a male or a female occupant may result in vastly differing Euro NCAP scores. The interactions and characteristics of the seats are well developed for the male, but not for the female occupant model.

Testing and simulation results have been compared and good correlation was found.

Moreover, the female occupant model, called EvaRID has been used in order to achieve a Euro NCAP-like rating for female occupants. [3, 2013]

5.2 Seat settings

To identify the influence of seat settings, e.g., backrest angle, headrest position etc., various simulations with a generic seat model have been computed and compared with each other. Parameters have been limited to the adjustability a consumer can influence, as displayed in Figure 11.

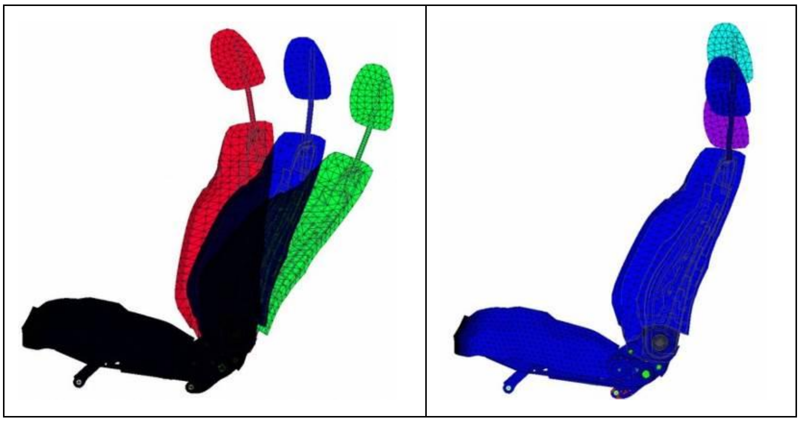


Figure 11: Suggestion for seat parameters to be investigated with respect to the influence on loads on occupants in future virtual consumer rating tests.

5.3 Development Advice – Summary Rating

Based on the work performed in this project, it is apparent that it would be generally beneficial to have a more versatile seat design suitable for all different occupant anthropometries. Seats should be easily adjustable for small and large occupants.

The incentive of using this approach is to achieve the best protection possible for all different sizes and postures of occupants in many different seat settings. To assure development of car seats aims at this target, more than one seat configuration with at least the three different Euro NCAP acceleration pulses should be taken into account. For this purpose, further testing is not necessary imminently as FEMs proved to be valuable tools in this field as it allowed a large number of variable parameters to be checked over in little time and with little financial effort.

A good rating will only be awarded if at least two different sized occupants (currently available EvaRID and BioRID) and at least nine different seat configurations are considered. As an example a simple virtual test matrix is shown in Table 2, with nine different seat configurations for each occupant model, and each pulse in the Euro NCAP protocol.

Within this study the focus was on variations in seat adjustments and two occupant sizes but always sitting "in position". A further step for increased robustness would be to consider various (realistic) types and degrees of “out-of-position”. This being outside the current scope can be a future extension, most likely by the use of virtual testing.

Table 2 Possible matrix for complementary virtual sled testing with different seat settings and two occupant models

Current Euro NCAP tests

Gender	Backrest	Headrestraint	IIWPG16	SRA 16	SRA 24	Average
m	forward	high	0,96	0,81	0,90	0,89
m		medium	0,65	0,63	0,67	0,65
m		low	0,47	0,56	0,64	0,56
m	middle	high	1,15	1,11	1,29	1,18
m		medium	1,00	0,84	1,20	1,02
m		low	1,20	1,05	1,46	1,24
m	backward	high	1,43	1,18	1,56	1,39
m		medium	1,16	0,98	1,49	1,21
m		low	1,05	1,10	1,78	1,31
f	forward	high	1,05	0,76	1,03	0,95
f		medium	0,89	0,64	0,85	0,79
f		low	0,66	0,36	0,59	0,54
f	middle	high	2,01	1,48	2,09	1,86
f		medium	1,52	1,10	1,62	1,41
f		low	1,14	0,74	1,38	1,09
f	backward	high	1,62	1,50	2,18	1,77
f		medium	1,37	1,07	1,79	1,41
f		low	1,07	0,72	1,65	1,15

Injury criteria used in the Euro NCAP ratings have been summarised and normalised by the value of the Euro NCAP IIWPG 16 km/h test in the matrix (Table 2). Also criteria values have been weighted in order of importance. A seat with a robust design would lead to a matrix with all cells showing values around 1.00. This outcome would represent a seat, which performs equally for all occupant sizes and seat configurations considered.

As a suggestion for overall rating is, that the worst single result should be crucial for the rating.

5.4 Conclusion to Seat Settings, Seat Characteristics, Development Advice

a) Today´s car seats and their design and adjustability are developed for the 50th percentile male occupant.

b) Further occupant models, load cases and seat settings should be considered during seat development.

c) In the overall rating the worst scenario (setting, occupant) should be crucial.

6 Discussion

A small number of car seats was selected for the initial investigations. To obtain a broader base of data, a larger number of different car seats, by different manufacturers and a variety of vehicle types (small, medium and large vehicles), as well as cars equipped with active, reactive and passive protection systems should be investigated. Additionally to standard sled testing, which usually is executed in the process of development, FEA should be used to verify the FE model and get comparisons between real sled testing and FE analysis. This may lead to an increase in the confidence for using FE methods more regularly in this area of development.

Until now, the EvaRID model was developed in one FE-code only. Therefore FEA was limited to LS-DYNA code. Seats which were unavailable in this code could not be computed. It is unfortunate that different car and car seat manufacturers use different FE codes as it makes it necessary to develop/transfer the occupant models needed into other FE codes. Thus a greater opportunity to increase the use of the occupant models can be achieved.

FEA using the current BioRID II dummy model and comparison with physical sled tests show deviations. These differences have to be limited / reduced, which can only be achieved by increasing the effort in developing FE models to represent the physical dummy better. Furthermore, a physical dummy model for the female occupant model is not available today. In order to validate and improve the FE model of the EvaRID dummy, such a loading device would be extremely valuable and would also lead to a more widespread acceptance, if FE simulations can be reproduced / validated by physical tests.

7 References

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8 List of Figures

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