Executive summary:

The overall objective of ADSEAT was to improve seat design to reduce whiplash injury and focus was on innovative adjustable adaptive seat design that can provide benefit for both male and female occupants. By focusing project resources on the latter group, what influence gender and additional factors have on whiplash injury risk has been highlighted. The project has established the properties for a model of an average female to be implemented into a finite element model (FEM), to provide an improved tool for use in the development and evaluation of adaptive systems, with special focus on protection against whiplash injuries.

Whiplash injuries sustained in vehicle crashes are a worldwide problem. It is estimated that, 800 000 EU citizens suffer whiplash injuries annually. 40 000 of these injuries result in long term suffering with an associated socio-economic impact of approximately 10 billion EUROS per annum and account for approximately 70 percent of all injuries leading to disability sustained in vehicle crashes. Injury statistics from the mid-1960's until today all show that females have a higher risk of sustaining whiplash injuries than males, ranging from 1.5 to 3 times higher.

The ADSEAT project has developed the world´s first virtual dummy model of an average female, called EvaRID (Eva female, RID – Rear Impact Dummy), and for the first time in the history of crash testing it is now possible to address occupant protection for both females and males. The anthropometry of the average female for a rear impact crash dummy model was established based on data found in scientific published literature. Male and female volunteer test data from identical test conditions were collected and analysed and corridors for dynamic female response were established. New volunteer tests in a seat with a larger head restraint gaps was conducted. The results have continually been made available to the general public in scientifically published articles, presentations, newsletters, TV programmes, and on the http://www.ADSEAT.eu website. License for the use of EvaRID is available from the ADSEAT partner Humanetics. An additional prototype dummy model of an average female, named BioRID 50F was also constructed.

The models were used in conjunction with the current available low severity rear impact model of an average male when assessing the safety performance of car seats. BioRID 50F was run in seats in equivalent test conditions as performed by Euro NCAP and the comparison shows that different seat designs can have a substantially different influence on the dynamic response of average sized male or female occupants in rear impacts. These results show how vehicle safety assessment can be improved and the potential such improvement have to influence consumer and legislation testing, and thus reduce the risk of soft tissue neck injuries in the future.

The socio economic impact of implementing adaptive seats as recommended by ADSEAT is estimated to address around 800.000 injuries, per annum, in the EU27 countries. By endorsing testing of all future seats with a female and a male dummy, apply injury criteria accordingly, and improve seat performance for both genders, the annual reduction of financial cost for the European society would be around 2 billion EUROS (between 1.6 to 2.6 billion EUROS). In comparison to current practice (male dummy only), ADSEAT can help the EU27 to save an additional 140 million EUROS (96 to 309 million EUROS) each year.

A design illustrator based on generic seat simulations with BioRID II, the dummy model of an average male, and EvaRID, the dummy model of an average female, has been developed. The Illustrator is available to the public on the ADSEAT website, http://www.ADSEAT.eu, to demonstrate the improved protection potential for male and female occupants involved in rear impact car crashes.

Project Context and Objectives:

The Adaptive Seat to Reduce Neck Injuries for Female and Male Occupants (ADSEAT) project is an EU funded project within the 7th Framework Programme which started on 1 October 2009 and ended on 31 March 2013. The overall objective of ADSEAT was to provide guidance on how to evaluate the protective performance of vehicle seat designs aiming to reduce the incidence of Whiplash Associated Disorders (WADs), also known as whiplash injuries. The work was concentrated on evaluating the protective performance of seats beneficial to female, as well as male motor vehicle occupants.

Whiplash injuries occur at relatively low velocity changes (typically less than25 km/h), and in impacts from all directions. Rear impacts, however, occur most frequently in crash statistics and it is firmly established that the whiplash injury risk is higher for females than for males, even in similar crash conditions. Epidemiological injury statistics from the mid 1960´s until today all show that females have a higher risk, ranging from 1.5 to 3 times higher, of sustaining these injuries than males. Real world data analysis revealed that existing whiplash protection concepts have a 45% risk reduction in permanent medical impairment for females and 60% for males. This analysis was published by Kullgren and Krafft, IRCOBI 2010. ADSEAT aimed at advancing seat designs to reduce whiplash injury in general, although adaptive seat systems beneficial to both male and female vehicle occupants, have received special focus. Considering that until now, biomechanics research into whiplash injury has predominantly been addressing the injury risk of males, ADSEAT particularly needed to extend the knowledge by also considering aspects of female occupants.

Females and males have different anthropometry and mass distribution. Crash test dummies used when developing and evaluating the occupant protection performance of a vehicle have only represented the 50th percentile male which correspond to a ~90th-95th percentile female with regards to stature and mass, resulting in females not being well represented by the existing low velocities rear impact male dummies: the Biofidelic Rear Impact Dummy (BioRID) and the RID3D. 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. Therefore, to address the lack of an equivalent crash test dummy that represents females, the anthropometry of the average sized female was established by the ADSEAT project. Furthermore, research into how the upper body of an average sized female interacts with the seat back rest and head restraint was also carried out, as well as establishing how such interaction influence the female injury risk. A new numerical research tool, a finite element model (FEM), representing the size of an average female was developed in the ADSEAT project. The FEM is called EvaRID (Eva – female / RID – Rear Impact Dummy) and was used in conjunction with the currently available rear impact dummy of an average male, the BioRID II, to evaluate enhanced whiplash injury protection for both genders.

Despite several precautionary approaches having been tried and tested to reduce the incidence rate, whiplash injuries are still the most commonly reported injury in the motor vehicle crash statistics of the insurance companies. For the victims, WAD can cause severe chronic pain and long term suffering, and thereby results in significant socio-economic

expense. Thus, it is important to recognise that whiplash injury is still a major traffic safety issue worldwide today.

Besides developing the above mentioned virtual dummy model, the EvaRID, for use in the design process and the assessment of new adaptive seat designs, injury criteria and thresholds appropriate for females, as well as a design illustrator and guidelines have been produced in the ADSEAT project. Such developments are very important with respect to seat design, but also in the scope of performance injury prevention assessment testing, i.e., Euro NCAP and similar tests. ADSEAT has, thus, prepared the framework and made recommendations for future safety assessment evaluations with regards to adaptive vehicle protection systems that will benefit both males and females.

It is estimated that more than 800 000 European Union citizens suffer whiplash injuries, sustained in vehicle collision, annually. 40 000 of these injuries result in long term residual effects (Whiplashkommisionen 2005) and the associated socio-economic impact of these injures, according to insurance estimations, is approximately 10 billion EUROS per annum and represent a major burden for the European society on a monetary, as well as a humane level.

That females have a greater risk of whiplash injuries resulting from vehicle crashes compared to males is shown in the published literature. However, little has been known about the differences between females and males in terms of their dynamic response until now.

The ADSEAT project has carried out research and established dynamic response rates for females by performing volunteer tests at low impact severities. Knowledge about the human dynamic response is needed in order to understand the biomechanics behind whiplash injuries to be taken into consideration when developing improved occupant models, i.e., crash dummies and computational models. As mentioned above, the only commercially available crash test dummy model for rear impact testing available on the market today is the BioRID and the RID3D, that represent an average male. Given the difference in injury risk between males and females, the availability of an average male dummy alone undoubtedly limit the assessment and development of whiplash prevention systems that adequately protect both male and female vehicle occupants.

Anti-whiplash systems for passenger vehicles available on the market today do have the potential to reduce the risk of whiplash injury. However, recent evaluations conducted by insurance companies have shown that it is nonetheless primarily males that benefit from seats equipped with anti-whiplash systems. As females belong to the part of the population most at risk of suffering WADs, such results are disturbing and against the EC work programme, http://ec.europa.eu/justice/gender-equality/index_en.htm, for 2010 – 2015, "The strategy for equality between women and men". As such, the work produced in ADSEAT contributes to closing the gender gap within the transport area.

The ADSEAT project initiated efforts to reduce the whiplash injury risk for females by establishing the anthropometry for, and developing a computational dummy model, the EvaRID. Making use of the EvaRID as well as the BioRID during the design process and safety evaluation of car seats, the safety of both males and females has been addressed.

The design illustrator developed within the project is published on the ADSEAT website, http://www.ADSEAT.eu/page/illustrator. The Illustrator gives users the opportunity to review what implication different seat settings and circumstances, such as gender, seat back angle and head restraint position, have in a rear end crash scenario. Evaluation guidelines to be used as a starting point for seat optimisation according to different occupant types (females and males) were also produced.

The overall objective of ADSEAT was to provide a protocol for guidance and evaluation of future seat designs to make sure that the whiplash injury risk is reduced for female, as well as male occupants. The project focused on creating a framework for innovative adaptive seat design that can be adjusted to provide benefit for occupants of both genders. By focusing project resources on the latter group, the current influence of gender and additional factors on whiplash injury risk was investigated and basic design guidelines for future adaptive seat systems were established.

The detailed objectives were:
- To analyse real world data (WP1) in order to Completed
i) assess actual risk of female injury Completed
ii) evaluate the effect of recently introduced whiplash systems for females and males Completed
iii) define crash pulse characteristics representing high and low risks for females and males Completed
iv) carry out statistical evaluation of the influence of anthropometric differences Completed
v) To estimate the expected socio-economic benefit. Completed
- To establish female biological data (WP2), in order to provide Completed
i) dynamic motion and acceleration data for evaluation of the computer model Completed
ii) data on injury mechanisms, injury sites and risk assessment parameters Completed
- To develop computational models of an average female dummy (WP3) Completed
i) as basis for dummy of an average female to serve as a design and test tool Completed
- To establish injury criteria and thresholds for females (WP4) Completed
- To develop a seat demonstrator illustrating how whiplash protection can be achieved for a wider population using adaptive seat design (WP5) Completed

Contributing towards the reduction of the number of whiplash related injuries and addressing the improvement of safety and security for rear end collision victims have formed part of the most significant objectives of the ADSEAT project, along with enhancing positive interaction between drivers and vehicles through implementation of adaptive seats.

In conclusion, ADSEAT has facilitated basic research in terms of creating new biomechanical knowledge that needs to be considered when addressing the whiplash injury risk of females, as well as applied research by developing a computational model of an average female dummy model, an adaptive design concept and a process to evaluate its benefits for both male and female car occupants.

Project Results:

The world´s first virtual dummy model, called EvaRID (Eva female, RID – Rear Impact Dummy) of an average female has been developed in the ADSEAT project. It is the first time in the history of crash testing that it is possible to address occupant protection for both males and females. For the development of the model, the anthropometry of the average female was established based on data found in the scientific published literature. Data from volunteer tests using male and female volunteers in identical test conditions were collected and analysed and corridors for dynamic female response were established. Based on the results of the analysis it was deemed necessary to perform new volunteer tests in a seat that allowed for larger head restraint gaps. These results have been scientifically published throughout the project, and thus made available to stakeholders and the general public through journal articles, presentations at conferences, newsletters, TV programmes and the ADSEAT website at http://www.ADSEAT.eu. License for the use of the EvaRID model is available from the ADSEAT partner Humanetics and their contact details can be found on said website. In addition, a prototype loading device dummy model of an average female, named BioRID 50F, was constructed on the advice of the Advisory Group (AG) to be included in the final test series with the prototype seat as they concluded that this would strengthen the output of the project.

These models have been used as research tools in conjunction with the current low severity rear impact model of an average male when assessing the safety performance of car seats. BioRID 50F was tested in seats in the same test conditions as performed by Euro NCAP. The comparison shows that different seat designs can have a substantial different influence on the dynamic response of average sized male or female occupants in a rear impact. These results show how vehicle safety assessment can be improved and have the potential to influence the consumer and legislation testing, and thus reduce the risk of soft tissue neck injuries in the future.

The socio-economic impact of the ADSEAT project has been examined. It is estimated that, 800 000 EU citizens suffer whiplash injuries annually. 40 000 of these injuries result in long term suffering with an associated socio-economic impact of approximately 10 billion EUROS per annum and account for approximately 70 percent of all injuries leading to disability sustained in vehicle crashes.. In monetary terms, a conservative estimate indicates that a saving of approximately 2bn EUROS per annum (between 1.6 to 2.6 billion EUROS) could be achieved by implementing the whiplash protection recommendations made by ADSEAT to test all future seats with both female and male dummies, apply appropriate injury criteria for each sex, and improve seat performance for both genders. The annual reduction of WAD victims would be around 450.000 less cases in the EU27. In comparison to currently available whiplash safety protection options, the annual additional saving would be approximately 140million EUROS (96 to 309m EUROS).

By improving safety for both male and female vehicle passengers, society as a whole will benefit from gender equality on account of the comparable reduced risk of WAD following a rear end impact. Consequently, reduced injury risk, less pain and suffering, loss of earning potential and less impairment which reduces the need for strong analgesics and other medication prescribed to constant pain sufferers will have a positive effect on society as a whole. Moreover, national economies will face less

loss of productivity due to illness and impairment and the development of new adjustable seats may also provide more job opportunities.

The development of the design illustrator based on generic seat simulations with BioRID II, the dummy model of an average male, and EvaRID, the dummy model of an average female, has been completed. The illustrator is available to the public on the ADSEAT website, http://www.adseat.eu/page/illustrator, and its purpose is to demonstrate how improved seats incorporating options to adjust the seats to benefit both genders will provide protection for male and female occupants in rear impact car crashes.

The results from the project has been extensively published, presented and well received by stakeholders and the general public during the duration of the project. In total, 27 presentations and publications have been made. Scientific publications have been made in Journal of Traffic Injury Prevention, Journal of Crashworthiness and Accident Analysis and Prevention. A PhD thesis based on part of the work carried out in the ADSEAT project was presented at Chalmers University in 2012 and the ADSEAT work has been presented at conferences such as IRCOBI 2010, 2011 and 2012, TRA 2012 and ESV 2011 and 2012. Additional papers have been accepted for presentation at the "Road Safety on 4 Continents" conference held in Beijing, May 2013, and the ESV conference in Seoul, also in May 2013. A further paper has been submitted for the IRCOBI conference 2013 and one journal paper discussing the socio-economic benefits of the ADSEAT project is currently under preparation. More publications and presentations are envisaged to present the final results of the project.

A number of scientific TV programmes have highlighted the EvaRID dummy model and the results achieved by ADSEAT; the science programmes Nano, broadcast to approximately 5 million viewers in Europe and Schrödingers katt in which is broadcast in Norway.

Results from each technical and the dissemination work package
Real world data, WP1

A literature review and analysis of databases, available within the consortium, was carried out. The results showed that weight and height close to the average female is appropriate for a dummy model representing females, as analysis of insurance data indicates that the average weight and height for females reporting whiplash injuries correspond quite well with the average sized female within the 27 European Union countries.

Records involving females who have sustained whiplash injuries in rear impacts were extracted from the AGU Zurich database, Switzerland (N=2,146), and from the Folksam database, Sweden (N=1,610). Basic anthropometric measures were then extracted from these records.

In the AGU Zurich database, the injured females had an average stature/mass of 165.3 cm/65.2 kg, which is close to the average size of the female population in Switzerland, 164.7 cm/63.4 kg. Correspondingly, in the Folksam database the average stature/mass was 165.3 cm/65.2 kg for the injured females, which correlate well with the average size of the female population in Sweden, 165.9 cm/65.9 kg. Thus, the 50th percentile female dummy would correlate in size to the females that are most frequently injured in rear impacts.

The anthropometry study of the WorldSID project concluded that the size of a world-harmonized 50th percentile adult male would correspond well with the size of the 50th percentile adult male as defined by the UMTRI project. Within the ADSEAT project the same conclusion regarding the 50th percentile adult female was drawn. Based on the above described findings, it was decided to base the EvaRID model on the anthropometric measures of the 50th percentile female from the UMTRI study (stature 161.8 cm, mass 62.3 kg).

A review on injury criteria shows that there are no gender specific injury criteria. No methods are validated to adequately scale proposed threshold values of postulated injury criteria. Real world data analysis showed that existing whiplash protection concepts are more effective for males than females. In the Driving Trials it was found that the head posture in driving situations most at risk for WAD lies in small ranges for lateral, longitudinal and rotational positions for about 50percent of the traceable time.

The socio-economic impact of the ADSEAT project has also been established. It is estimated that, 800 000 EU citizens suffer whiplash injuries annually. 40 000 of these injuries result in long term suffering with an associated socio-economic impact of approximately 10 billion EUROS per annum and account for approximately 70 percent of all injuries leading to disability sustained in vehicle crashes. In monetary terms, a conservative estimate indicates that a saving of approximately 2bn EUROS per annum (between 1.6 to 2.6 billion EUROS) could be achieved by implementing the whiplash protection recommendations made by ADSEAT to test all future seats with both female and male dummies, apply appropriate injury criteria for each sex, and improve seat performance for both genders. The annual reduction of WAD victims would be around 450.000 less cases in the EU27. In comparison to currently available whiplash safety protection options, the annual additional saving would be approximately 140million EUROS(96 to 309m EUROS). These figures are based on the calculated estimation of approximately 6bn EUROS for all cases while Euro NCAP already estimates a cost of 10 billion EUROS per annum for the EU27 (for all WAD cases). The effect of protection systems recommended by ADSEAT can be much more significant if the Euro NCAP estimates prove to be closer to the actual amount.

By improving safety for both male and female vehicle passengers, society as a whole will benefit from gender equality on account of the comparable reduced risk of WAD following a rear end impact and evaluation any negative impacts of implementing improved adjustable seats, especially on the environment, has not been found. Consequently, reduced injury risk, less pain and suffering, loss of earning potential and less impairment which reduces the need for strong analgesics and other medication prescribed to constant pain sufferers will have a positive effect on the whole population and the environment as the toxic waste excreted into the water supply will be reduced. Moreover, national economies will face less loss of productivity due to illness and impairment and the development of new adjustable seats may also provide more job opportunities.

Biological data,WP2

In WP2 the anthropometry of the 50th percentile female,for a rear impact crash dummy model, was established. The data was used as input for determining the size dimensions and seating for the BioRID 50F used in the WP4 sled testing, and the development of the EvaRID model in WP3.

In order to develop occupant models used in crash scenarios in depth knowledge of the dynamic response of humans is needed. In this work package such data have been generated. The differences between females and males in dynamic response in rear impacts have been quantified from volunteer tests. Also post mortem human subject (PMHS) tests have been carried out using female and male subjects. In addition possible injury sites and injury mechanisms in the neck have been further investigated.

A review of the test results from previous studies of was carried out. Further analysis of these previous test data was conducted. The differences between females and males in dynamic response in rear impacts were quantified using these volunteer test data. In addition, new volunteer sled tests were carried out at Allianz ZT in Ismaning, Germany, using both female and male volunteers in a new laboratory seat test set-up in conditions with known injury risk trends. The influence of various head-restraint gaps was investigated allowing for larger head excursions than in previous testing. In addition, the role of holding on to the steering wheel in guiding was tested.

The results quantified the differences in dynamic response between females and males in rear impacts and specified the potential protective effect for females and males attributed from recently introduced anti-whiplash systems that dynamically reduce the head-restraint gap and reduce the upper torso acceleration levels.

The geometry and mass distribution of a representative average female was established. This data has been used in WP3 in the definition of a new female size rear impact computational female dummy model, EvaRID.

New volunteer tests comprising eight male and eight female volunteers were performed in a new laboratory seat that allowed for larger and more representative head restraint gaps. In this series a rigid seat base and larger head to head-restraint distance was introduced.

The back of the seat consisted of four stiff panels, lined with a 20 mm thick layer of Tempur medium quality foam covered with a plush cloth. Panel and foam dimensions and stiffness's were derived from detailed measurements of each element. Furthermore, the stiffness of the supporting springs was derived from static measurements on each spring. The head-restraint consisted of a stiff panel and the initial Head Rest (HR) distance was adjusted to 15 cm by adding layers of padding.

The results of the volunteer test were presented as response corridors calculated ±1SD from the average response. The results added new and more comprehensive evaluation data for future crash dummies and models as the tests revealed the differences in dynamic response between women and men that distinguish between higher and lower whiplash injury risk. That it was necessary to increase the head restraint gap was established based on the result of the analysis of the published literature.

The analysis of the test results was later included in the second stage of the development and tuning of the finite element model (FEM), the EvaRID in WP3. The results gave new insights into differences between female and male occupants in terms of head and torso forward accelerations, and head relative to torso linear and angular displacements. A steering wheel was used in a subset of the volunteer tests as the whiplash injury risk is known to be significantly higher for drivers compared to front seat passengers. When the volunteers were

seated like a driver with the hands on the steering wheel, they instinctively adjusted their posture accordingly and displayed a more prominent kyphosis in the thoracic spine, as well as a greater head restraint gap. The volunteers tended to instinctively grab the steering wheel during the rear-impact test and the motion generated by the driver delayed contact with the head restraint. This was a valuable insight into the effect of driver posture on body dynamics that also provided valuable clues to the injury mechanism in a rear-end collision. In collaboration with WP3, an upgraded seat model was implemented and modifications to EvaRID were suggested by WP2, and implemented in WP3.

Post mortem human subject (PMHS) testing has been carried out in the form of sled tests with both male and female PMHS. High speed X-ray photography was applied. Differences in neck vertebral geometry and dynamic motion during staged rear impacts have been registered. Motion analysis and spinal canal pressure recordings has been provided from the tests.

Experimental whiplash testing on anaesthetised pigs included exposure in rearward, lateral and frontal direction collision scenarios. Variations in the acceleration pulse were used as means of illustrating the differences between female and male occupants. Pressure responses were found to be extremely sensitive to acceleration magnitude and may thus be a contributing factor to the higher injury risk in female occupants. The higher T1 acceleration recorded in female volunteers compared to males, has a direct influence on the spinal loading and on the pressure magnitudes that are believed to cause nerve cell dysfunction in the cervical posterior nerve root ganglia. The results support the recommendation by WP4 to decrease injury criteria levels for females. It demonstrates, in particular, the sensitivity of the Neck Injury Criterion (NIC) when predicting pressure transient magnitudes in the spinal canal. Pre- and post-trauma MRI analysis, in the same animal, revealed unique objective indications of muscle trauma. Pre-trauma MRIs are never available in whiplash patients but in the experimental animal model this was a unique possibility. These findings match the incidences of micro bleeding found in the present study during post mortem muscle tissue microscope analysis. The deeper posterior neck muscles had the most obvious incidences of bleeding, as well as the most prominent MRI signals. Post Mortem Human Subject (PMHS) tests comprising 4 individuals in a total of 16 tests were finalised. High speed X-ray movies and high speed video recordings were obtained together with pressure recordings of the spinal canal. The pressure time histories and magnitudes were close to those recorded in the animal tests. Pressure sensitivity to acceleration magnitude also showed the same trends as in the whiplash tests. In contrast, delta-v turned out to have no significant influence on the pressure magnitudes.

The present work thus used a unique combination of biological models including human volunteers, anaesthetised pigs, and PMHSs. This allowed us to make use of field accident data findings to propose probable explanations to injury mechanisms, injury criteria and differences in injury tolerance between men and women.

Field accident data from WP1 showed that females are at a higher risk than males in similar accident conditions and drivers are known to be at a higher risk than front seat passengers. Our volunteer tests showed that females are exposed to higher forward acceleration at torso level and score higher NIC values in cases with head restraint gaps that are

typical for the field situation. The head restraint contact for drivers tends to be delayed and upper torso acceleration is also likely to be higher which also increases the NIC value. The influence of acceleration was very clear on the pressure magnitudes and the retraction (s-shape) in the pig. Increased s-shape leads to higher strain in the deeper muscles and these findings correlate well with the injury findings in spinal ganglia and in the muscle tissue. The PMHS tests formed the link between the animal tests and the volunteer findings. Pressure magnitudes, as well as time histories were very similar between the animal and the PMHS. Both models indicated a high influence of forward torso acceleration magnitude on the neck tissue loading. These findings reflect back in consistence to the volunteer results and the field accident data.

Computational modelling,WP3

A numerical model of an average female, EvaRID, was produced in WP3.. Based on experience from previous research, it was known that the development and evaluation of a physical dummy require substantial efforts which were outside the scope of the ADSEAT project. Instead, undertakings to produce a numerical dummy model suitable for forming the foundation for future dummy model hardware development, based on specifications established in this project, was completed. Previous experience of developing dummy models such as theRID3D, has shown that a numerical dummy model is suitable as foundation when designing a hardware dummy. Hence, the work carried out in the ADSEAT project would be useful in future design processes when developing a FEM of an average sized female hardware dummy model

The FEM developed in this project was based on the same design concept as the 50th percentile male rear impact dummy, BioRID II in that the female dynamic response was defined and evaluated on the basis of non-injurious volunteer tests.

Approach

The approach used to develop the EvaRID model were as follows. Initially, the size for the model was identified (WP1). Injury statistics were extracted from insurance databases that revealed that a 50th percentile female dummy would correlate in size to the females most frequently suffering whiplash injury. Anthropometric data were then collected to define the geometry and mass (WP2). Based on these data an available BioRID II dummy FEM was scaled to build the EvaRID model of an average female(WP3). Extensive evaluations were made at volunteer impact level (WP3). Corridors from two datasets as provided by WP2 were used in an interactive procedure to fine tune and evaluate the model response.

Injury criteria and thresholds were then derived (see WP4) and the model and its thresholds were used in seat simulations (see WP5).

EvaRID model development

When developing the EvaRID model by scaling the BioRID II model, the goal was to make sure that mass, inertia and length data of each body segment matched the anthropometric data for the 50th percentile female as closely as possible. To meet anthropometric requirements in terms of mass and dimension, firstly the longitudinal dimensions and mass were scaled according to equations (1) and (2) below. Breadth (width) and depth dimensions for the different EvaRID body parts were established based on the most appropriate scaling method for each body segment. For the purposes of this report, SFL is the Longitudinal Scale Factor, SFB the Breadth Scale Factor, and SFD the Depth Scale Factor.

Extremities – It was assumed that SFB and SFD for the extremities / limbs are equal. SFB / SFD then follow as the square root of Mass Ratio over Scale Factor Length (volumetric relationship), see 2.2.

Head - For the head, all data for breadth and width scaling directions were available in the anthropometric specifications. Due to the head´s importance in terms of loading to the neck it was decided to apply direct scaling in all directions to meet all the dimensional requirements.
Neck – Adequate sources were not found when collecting input data for the anthropometry defining the skeleton. Of particular relevance are the spine and neck, and due to the lack of data it was decided that EvaRID would maintain the same spine and back profile as BioRID II. This was achieved by keeping the length and depth scaling factors, SFL and SFD, identical for both the neck and torso. Furthermore, it was assumed that breadth scaling factors SFBneck and SFBtorso are identical, concluded by comparing the shoulder joint distance of EvaRID to the shoulder joint distance of BioRID.
Torso - The upper torso was defined as the torso without the pelvis, running from the cervical to the iliac crest. The mass of the upper torso was derived by subtracting the mass of the pelvis from the mass of the torso. The breadth scale factor, SFB, was obtained by comparing the distance between shoulder joints in the female data (31.50 cm) and the value for the BioRID II (34.60 cm). SFD was then calculated.

The outer shape of the male and female torso and pelvis segment body parts differ significantly. Breasts were added to the female dummy and the shoulder/ waist ratio for both genders were quite different. Therefore, further refinements were made to the uniform scaling applying SFL, SFB and SFD. Using anthropometric data from Diffrient et al. and Young et al. the waist breadth was set at 310.5 mm, bust 288 mm; 10th rib 257 mm; buttocks 373 mm; and bust point distance 180 mm. Information on circumferences from these data sources was also used to further shape the geometry.

Pelvis - Although the outer shapes are different for the pelvis, no significant difference between the main dimensions of the 50th percentile female and the 50th percentile male pelvis were found in the anthropometric studies. Furthermore, the distance between the hip joints was similar for the 50th percentile female and the BioRID II. The pelvis mass was also found to be similar for the 50th percentile male (15.84 kg) and the 50th percentile female (15.80 kg). Consequently, the shape of this body part was the only one adjusted to match the breadth dimensions found in the literature. Finally, it was assumed that the EvaRID will maintain the same pelvis angle as the BioRID II at 26.5 degrees.

Based on information collected on muscle tension for males and females the stiffness and damping properties of discrete elements in neck and spine were scaled to a value of 70 per cent of the original values in the BioRID II model.

EvaRID model evaluation

Firstly, volunteer and BioRID II hardware tests were reproduced for the initial validation of the EvaRID model. A detailed description of the test set-up, volunteers and results was given. Both the EvaRID and the BioRID II model showed good to reasonable correlation with test data except for the T1 rotation which remains well below test data. It should

be noted that in this first evaluation, correction to the characteristics of discrete elements related to muscle tension had not yet been made.

To allow a more detailed analysis a new series of volunteer tests was performed in ADSEAT WP2. In this series a rigid seat base and larger head to head-restraint distance was introduced to eliminate some of the uncertainties for the correlation with the EvaRID model (see WP2 reporting).

A pre-simulation was conducted by dropping the dummy into the seat and letting it find its balanced position in the simulation through gravity. The seat was fixed to the ground and the only external force was the gravity. The influence of dummy positioning on the seat was studied by applying a shorter and a longer run time for the pre-simulations resulting in head-to-headrest distances of 144 and 158 mm respectively.

Good correlation was obtained for most signals. The T1 rotation, however, remains below the corridor for the first 160 ms. Compared to results from the initial validations, improved performance was found, which is explained by clearer definition of the test conditions. This allowed for a more detailed modelling of the seat and thereby for better conditions to fine tune the EvaRID model in terms of stiffness reduction related to muscle tension.

Simulations with head-neck human body model
In support of the EvaRID development, simulations with a detailed head-neck human model were performed to gain further insight into the dynamic response for usage in the EvaRID model refinements.

The previously developed head-neck human body model representing females was validated against volunteer data obtained in WP2. For this purpose recorded T1 accelerations and rotations as recorded in the volunteer tests were applied to the T1 vertebra of the model and resulting head accelerations, head displacements and NIC values were compared with experimental data.. Head kinematics appear to correlate well with test data, as does the NIC values, which provided confidence in the model as well as the test data collected. This study did not reveal any issues of consideration in the volunteer test data and the resulting corridors (WP2) as used for the EvaRID development. The simulations gave detailed insight into the neck kinematics and the response of individual vertebra's, which will be of relevance for future updates of the EvaRID model.

Injury Criterion WP4
WP4 addressed the topic of injury criteria and corresponding threshold values, to predict the injury risk in rear end collisions for female front seat drivers and passengers by analysing real-world data, performing computer simulations and conducting sled tests. Assessment into whether currently known injury criteria and threshold levels are appropriate to predict female injury risk was also performed. All parts of WP4 were carried out as intended and the results of WP4 have been widely disseminated in the scientific field, and also in general media (see WP7). It was the newly developed dummy prototype in particular that received considerable attention and was featured in several TV programmes.

Approach

To date no specific injury criteria are available to assess the female neck injury risk. Therefore modification of existing injury criteria, particularly the NIC and Nkm was recommended following investigation of various published injury criteria applicable for females. Based on theoretical considerations it was particularly suggested to use modified versions of the injury criteria NIC and Nkm. For NIC a lower threshold value of 12 (instead of 15 for males) was suggested; for Nkm different intercept values which are used to normalize the test data were defined.

The theoretical approaches considering the real-world injury risk were complemented by computer simulations and sled testing to investigate their practical applicability. Thereby the computer simulations made use of the EvaRID dummy model which was established in this project. Furthermore, computer simulations with a BioRID II dummy model, as well as, human body head-neck models of a male and a female were performed. For the performance of sled testing, a loading device representing the 50th percentile female anthropometry, called BioRID50F, was developed following advice received from the project AG that it would benefit the whole outcome of the ADSEAT project if such dummy model was included in the final test series with the prototype seat.

Computer simulations using finite element models of a female dummy (EvaRID, developed as part of the ADSEAT project), the BioRID as well as male and female (human) models of the head-neck system (provided by the project partner UdS) were conducted for different crash pulse severities. Generally the results confirm that a higher injury risk is to be expected for females and that the injury criteria under discussion reflect this. Furthermore, sled tests were performed using different seat models some of which were equipped with an anti-whiplash system. All tests were conducted according to Euro NCAP test procedure. To perform the tests a new loading device was developed. The device, called BioRID50F, represents the anthropometry of a 50%ile female. The development of this loading device seemed necessary and was thus included in the work package. Although the device needs further validation, it can be highlighted that a first step towards the development of a female rear-impact dummy was made. This represents a significant advancement achieved in this work package. BioRID50F complements the computer model EvaRID.

The sled tests clearly demonstrated differences in the seat performance when comparing the results obtained by BioRID50F and the (male) BioRID. Due to the underlying design, the performance of some seats changed significantly when loaded with a smaller and lighter "dummy". Consequently the rating of the seat performance as done, for example, in consumer tests must be expected to be different for male and female occupants. Additionally the test conditions need adjustments such that the sitting posture of a female occupant is considered. With regard to injury criteria a new NIC threshold value of 12 seems a reasonable starting point. For Nkm further analysis is needed; the data of the current tests indicate significantly higher Nkm values for females which can to some extent be explained by an inappropriate sitting posture and initial seat position as well as shortcoming of the loading device.

The different approaches used in this work package resulted in the following conclusions:
- Female neck injury criteria based on the same biomechanical principles as for males should be used. Particularly modified versions of NIC and Nkm are suggested for future investigation whereas a NIC threshold of 12 and reduced intercept values for Nkm are suggested.

- Sled tests indicate that such criteria/threshold values seem a reasonable starting point.
- A female rear-impact dummy is needed to evaluate the seat performance in sled tests. BioRID50F can serve as a first step in that respect.
- Standardized test procedures (both for simulations and sled tests) need adjustments to consider female sitting posture and related seat back/head restraint positions.

Sled testing with this device allowed direct comparison to the dynamic performance of the same seat models when loaded with the existing BioRID II. Eight sled tests were conducted in line with Euro NCAP test procedure, using the prescribed medium severity crash pulse. Generally, the results confirm that different kinematics is to be expected when a seat is loaded with a loading device representing a female instead of a male. Sled testing and computer simulations indicated that the suggested modifications for female NIC were a good starting point. The work of WP4 when presented to the public received considerable positive attention, particularly among car manufacturers.

Seat Evaluation, WP5

WP5 was divided into two parts. To begin, benchmark simulations of different serial production seats with EvaRID and BioRID were performed, secondly, sled tests with the loading device BioRID50F and the BioRID dummy model were carried out. Furthermore, FE model simulations with a generic seat model were performed to determine the influence of different seat configurations (robustness simulations) on both males and females. The findings resulted in a prototype seat, a design illustrator and seat evaluation guidelines.

Prototype seat

One of the objectives in WP5 was the development of a prototype seat that has the potential to protect male and female vehicle occupants. To achieve this benchmark, simulation of different serial production seats available to the consortium was performed using the EvaRID and BioRID models. Improvements to an existing seat were applied and a prototype seat was built. This prototype seat was tested with the physical BioRID dummy and BioRID50F loading device to evaluate what, if any changes resulted, when female, rather than male occupants were considered.

For comparison of different seats available to the consortium a set of 12 sled tests with the BioRID dummy model were performed. To ensure anonymity, the seats were labeled A, B, C, D. The Euro NCAP whiplash test rating rate the expected whiplash protection ranges from poor to good performance. Three different pulses (low, medium [IIWPG], high severity) were applied to the seats. These tests were used as a basis for a generic seat model for parameter studies e.g., backrest angle and head rest position. Furthermore the differences between physical tests and finite element simulations were compared.

In addition to the sled tests, finite element simulation of the chosen seats were performed in LS Dyna code with the BioRID50 F model and the EvaRID model developed in WP3. Out of the four seats, it was only possible to simulate three of the seats with the EvaRID model because the appropriate finite element of one seat model was not available in LS Dyna code. The benchmark of two different models highlighted the protection possibility and differences of current production seats with respect to females. Two of the seat models were fitted with adjustable head restraints and one was not. For the seats with adjustable head restraints

the head restraint was moved into the most downward position. Backrest angle was used based on the Euro NCAP whiplash test protocol. In total 18 simulations were completed.

The EvaRID model worked well within the simulations. The simulations provided good information about possible loads on female occupants. The EvaRID analysis has allowed identifying areas of improvement for the EvaRID dummy model and also which area the EvaRID worked well in. It is important to mention that fundamentally the head restraint adjusted to its lowest position must still be capable of catching the head of the EvaRID as quickly as possible. It is clear when evaluating the seats that the injury protection is increased in the seats having had the above rules applied when compared to seats that have not been made according to the rules above.

Design illustrator
For the content of the interactive seat configurator, 54 simulations and six physical sled tests were conducted. All simulations and sled tests were evaluated and analysed, and data has been processed to form the information presented on the ADSEAT website, http://www.ADSEAT.eu/page/illustrator. Simulation animations and high speed videos were created to complement the text on each page.

By publishing the Illustrator on the dedicated ADSEAT website it was made accessible to a broad and non-restricted audience and gives stakeholders and the general public easy access to necessary information when wanting to find out how seat adjustment can influence the protection performances during a rear impact. Integrating the Illustrator through scripting and programming was achieved without any issues and deciding to publish the Illustrator on the website also reduced the need for extensive distribution. Moreover, computer compatibility issues are avoided and distribution expenses are kept at a minimum. Additional to making the Illustrator available to an even wider audience than the stakeholders, it was decided to generate an offline version to distribute to a selected audience. For this purpose a USB based copy of the Illustrator, that is fully functioning offline was created. The offline version is a duplicate of the online version and users have access to video sequences of how the Illustrator works. However, any links to partners and other websites of other organisations mentioned on http://www.adseat.eu must still rely on being in possession of a working internet connection.

Brief information about the Illustrator:
- general information (brief introduction to the whiplash problem)
- interactive seat configurator (the user can change to different pre-defined seat settings and review its impact on load levels)
- seat evaluation guidelines (detailed information)
- further information (link to the Euro NCAP homepage for whiplash testing)
- available in several languages (English, Dutch, German, Spanish, and in the process of being translated into French and Swedish)

The selection of the configuration of the seat and the occupant model gives the visitor the option of selecting the desired seat setting and review what influence the selected settings may have on the chosen occupant model. As such, the visitor can select a scenario that suits his/her set of circumstances and review what implications the ticked choices may have on his/her injury risk at his/her driving (seat setting) habits. It was decided to keep the Illustrator as simple as possible and

narrow down the possible variation parameters for ease of use. Therefore, only settings which can be influenced by the occupant can be chosen: occupant type (male or female), backrest angle (forward, standard – Euro NCAP, backward) and head rest position (upper most, mid, lowest most position).

Seat evaluation guidelines

Based on the work performed in this project, it is apparent that it would generally be beneficial to make available a more versatile seat evaluation suitable for a wider range of occupant anthropometries. To increase whiplash injury protection, seats should be easily adjustable for small and large occupants.

The incentive of using this approach is to achieve the best protection possible for both genders, and all different sizes and postures of occupants in many different seat settings. To assure development of car seats aimed at the whole adult population, more than one seat configuration with at least the three different Euro NCAP acceleration pulses should be taken into account. For this purpose, FEMs have proven 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 of the different sexes (currently available EvaRID and BioRID II) and at least nine different seat configurations are considered

The main conclusions derived at from work in WP5 are summarised in the subsequent bullet points:

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 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 short and light 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. Similar criteria but with adapted thresholds should be applied for male and female occupants. (initially NIC and Nkm)

b. Other criteria need to be evaluated

5.) Seat settings, Seat Characteristics

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

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

c. For the overall rating the worst scenario (setting, occupant) is crucial for calculating a rating.

Dissemination, WP7

The results of the ADSEAT project have received extensive attention worldwide. Articles have been published in European and international scientific journals, presented at European and international conferences and received media attention in Europe continuously throughout the running of the project.

Publications and conference presentations

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Media attention

ADSEAT was singled out and presented as part of a documentary produced by the the journalist/author Jan Kerckhoff on behalf of ARD / Bayerischer Rundfunk, Germany, in the 30 minute science programme series Nano, broadcast to German and French speaking parts of Europe on main stream television and estimated to reach 5 million viewers. A shorter version of the programme has also being produced. The science documentary Schrödingers katt, produced by Norwegian Television and broadcast in Norway on 31 January 2013 also highlighted the work by the ADSEAT project.

Website

Today, the presence and reach of the worldwide web makes it essential to have a user friendly, engaging website that functions well in order to convey your message. With this purpose in mind, a website was built for the ADSEAT project and can be found at: http://www.adseat.eu. Interested parties are advised to visit the website, on which a project overview, guidelines for seat adjustment and the "Illustrator" (described in closer detail in WP5) are published. Each WP is described individually on the website and the consortium members and other invited parties, such as the AG and the project officer, have a secure platform accessible with personal login details to exchange knowledge and ideas on the website. The secure platform offers a facility to download reports, deliverables, milestones etc., whilst the general public has access to download documents such as newsletters and journal articles in the download section. Results, findings and other relevant information have been published on the website throughout the project.

Initially, a different version of the ADSEAT website was built but was re-designed as certain features such as a password restricted area for distributing documents to the members of the AG, the project officer and other invited parties.

The website allows visitors to gain insight into the problems ADSEAT have addressed by establishing the risk of sustaining WAD, as well as introducing the EvaRID model, for instance. The consortium regards the website as a living document and it has been updated as and when new information has been made available. It has been decided to keep the website alive for 5 years after the end of the project in order to make the findings easily accessible for future activities in the area of whiplash injury prevention.

The address of the project public website

http://www.adseat.eu

Newsletters

Two newsletters were produced describing the most recent results of the project. The newsletters were distributed to more than 600 email addresses predominantly collected from the Cover Dissemination Database (COVER – Coordination of Vehicle and Road Safety Initiatives, With a focus on Biomechanical coordination – a EU funded project within FP7) as well as to subscribers of the newsletter. The newsletters are available for download from the ADSEAT website on: http://www.ADSEAT.eu. ADSEAT Newsletter # 1 (4 pages) was distributed in November 2011 to 608 recipients of which 31.3 % opened the newsletter. The main article in this newsletter focused on when women are most at risk of sustaining soft tissue neck injuries. ADSEAT Newsletter # 2 (5 pages) was distributed in

June 2012 to 613 recipients of which 30.8 % opened the newsletter. The main article in this newsletter focused on different approaches when considering injury risk during test procedures.

Brochures
Two brochures were produced for the ADSEAT project. The first brochure was produced in the early stages of the project to have a brief introduction to the project easily accessible to distribute to the public at events attended by project members, and for all beneficiaries to display and distribute at their offices and any venues they attend.

It was deemed important to produce a further brochure towards the end of the ADSEAT project in order have at hand, material describing the main findings and results of the ADSEAT project that is also easy to distribute to stakeholders and the general public at conferences, beneficiaries´ offices and other venues attended by consortium members.

Advisory Group meetings
Four AG meetings were held to receive feedback on current work and take further steps to improve in accordance with experts' opinions and needs. The ADSEAT AG consisted of representatives from: Toyota Europe, Saab Automobile, IIHS (Insurers Institute for Highway Safety), JARI (Japan Automobile Research Institute), BASt (German Federal Highway Research Institute), pdb (Partnership for dummy technology and biomechanics), NHTSA (National Highway Traffic Safety Administration) and MAPFRE Insurers. Valuable advice received from the AG was taken into account and the production of the BioRID 50F was initiated following recommendation by the AG that such a loading device would enhance the outcome of the ADSEAT project.

Final Workshop
A final workshop was held in Brussels 14 February. The purpose of this one day workshop was to present the main work carried out in the ADSEAT project. The workshop was organised in five sessions and addressed the ADSEAT strategy and its justification based on accident data. During the day the developed model; EvaRID was presented, the results from seat tests with a scaled down hardware dummy was described and the ADSEAT seat evaluation guidelines was presented and discussed. In addition, future needs and trends in the virtual testing area addressing seat protective performances were discussed in a panel discussion with invited stakeholders. The final workshop was attended by 26 participants from industry, representatives from the European Commission, Euro NCAP, researchers and governmental agencies.

Potential Impact:

The overall objective of ADSEAT was to improve seat design to reduce whiplash injury. By focusing on innovative adjustable adaptive seat design to provide benefit for both male and female occupants, alike, a computational finite element model, a scaled down model of the 50th percentile male dummy model BioRID, to a female dummy model BioRID 50F representing a 50th percentile female, for use in seat evaluation processes were produced to achieve the overall objective. The work carried out in ADSEAT has significantly contributed to modernising technologies and methodologies for design with safety and security characteristics, with a special focus on adaptive vehicle safety systems. These activities support harmonisation and standardisation, due in particularly to consumer testing protocols such as the European New Car Assessment Programme (EuroNCAP). Fortunately, as the consortium had already established links to the European Enhanced Vehicle Safety Committee (EEVC), the US National Highway Traffic Safety Administration (NHTSA) and the Insurance Institute for Highway Safety (IIHS) and received offers of advice and support from those organisations, a broad international platform for future standardisation was established from the inception of the project.

Progress beyond state-of-the-art

Until now, the state-of-the-art dummy model used in seat design represents an average male. This dummy model, the BioRID II, is used for the development of measures to protect vehicle occupants from sustaining neck injury and was the starting point for work in the ADSEAT project. ADSEAT has advanced the state-of-the-art in dummy models by developing the first computational dummy model of an average female, the EvaRID (Eva – female / RID – Rear Impact Dummy) for low-severity rear impact testing. Not only is this model the first in the world, it is also the first dedicated female dummy model in the history of crash testing and it represents the part of the population with the highest risk of being victims of whiplash injuries in low velocity rear end impacts. Furthermore, the data needed in order to develop a computational model of an average female, such as defining size, weight, dynamic response properties, etc., was completed by the ADSEAT project. In addition, injury criteria and thresholds for females have been formulated and a seat demonstrator illustrating how whiplash protection can be achieved for both males and females using adaptive seat design has been developed. Until the ADSEAT project, such a seat demonstrator was not viable since the anthropometry of an average sized female had not been established and a model of the female part of the population was not yet produced.

In summary, the results of ADSEAT have contributed to the technological foundation in the area of biomechanics of user diversity by developing the first ever dynamic response corridors of females from low severity rear impacts. These corridors have been used within the project as a basis for the development of the computational model of an average female. With both males and females occupant models ready for use, it is now possible to further reduce the number of injuries caused in traffic collisions worldwide. The development of design solutions to improve seats to include cutting edge features to easily provide increased protection for males and females alike demonstrates the potential to reduce whiplash injury.

In-car protection systems to prevent whiplash injuries, i.e., re-active head restraint systems on the market to date have been developed to

different levels of sophistication in terms of protection for differing occupant characteristics, although the inherent disadvantage is that they can only be evaluated for one occupant size. The rear crash test dummy models that are available and used today to assess the benefit of such systems in crash testing only represent a 50th percentile male. This is in stark contrast to the fact that the majority of vehicle occupants suffering such injuries are female. Recent data from the insurance companies within the consortium and associated with the ADSEAT project indicates that these anti-whiplash systems only provide a limited benefit for females. Consequently, ADSEAT has extended today's knowledge with regard to the reduction of injury risk for females, whilst also taking into account and raising the male injury risk. This aspect has been largely underrepresented in the research performed in this area recently.

Corridors for female dynamic response have been established in this project and have been taken into consideration during the development of the EvaRID dummy model. The biomechanical basis for the analysis of the injury risk of humans travelling in a vehicle collision is formed by dynamic response data, i.e., data showing the behaviour of a human in an impact. However, until the research undertaken by the ADSEAT project, dynamic response data derived by volunteer tests was dominated by data on males. Volunteer studies that are published in English and consider females, are scarce. In these studies 159 volunteers were tested, 124 males and 35 females. The results indicate differences in the dynamic response between males and females but are – due to the lack of data – not at all conclusive.

In the studies where both male and female volunteers were exposed to rear impact (Siegmund et al. (1997), Hell et al (1999) and Ono et al (2006)) indications of differences in head and T1 acceleration between females and males have been reported. ADSEAT has filled the knowledge gap with regards to the dynamic response of females compared to males by performing additional volunteer tests to provide response corridors for females in low severity accidents.

In addition aspects of anthropometry and seated posture of different vehicle occupants have been investigated based on available data from literature, as well as on new measurements taken during the volunteer tests. Thus information needed for the design and development of adaptive seat design has been ascertained.

To further strengthen the foundation for future design approaches, additional biological tests were carried out to gain more detailed knowledge on the injury mechanism behind whiplash injuries. Since there are several hypotheses for the injury mechanism in discussion today, these experiments are necessary to elucidate the biomechanics in more detail and thus be able to assess the hypotheses on a better foundation. The results obtained from these tests are, of a more general nature and cover both females and males. Thus the current general understanding of the injury mechanism of whiplash injuries will benefit from these tests.

An important part of the ADSEAT project has been concerned with the development of the virtual dummy model taking into account the anthropometry of the population at highest risk. The aim was to have suitable models for seat development and testing.

The new virtual dummy model, EvaRID, is a powerful tool and has been used to assess whether currently used injury criteria (or modifications

thereof) can be applied to females as well. Combining results from the experiments and the computer simulations, injury criteria has been defined. This represents a considerable step forward in current procedures used to assess the whiplash injury risk since currently none of the known criteria and the related thresholds consider different risk for males and females. This is in contrast to what is known from accidentology and therefore considering different injury risk functions for male and female is a major advancement in the field and will have various consequences.

Bearing in mind that injury criteria are a key factor in all types of assessing the potential of injury by performance tests, e.g., crash tests, ADSEAT has a remarkable input to the on-going discussion on how such tests are best evaluated. Particularly thinking of consumer tests, the assessment scheme that is used in such tests needs a sound foundation to ensure that the test is robust and discriminating. Using the results established in ADSEAT will make sure that such testing is based on a solid scientific basis which in turn will be for the benefit of the consumers who rely on such tests.

Similarly the development of new anti-whiplash devices will be fostered by ADSEAT. By providing the necessary biomechanical background, as well as the necessary tools to assess the injury risk, e.g., response corridors, computer models, ADSEAT encourage improved seat design. Since current systems only evaluate the injury risk of the average male occupant, they can therefore be extended to also be designed and evaluated in their protection of females in a much better way. Thus the safety of a much larger portion of the population will significantly increase.

Related to seat design, adaptive systems to reduce whiplash injury were specifically addressed in this project. Different approaches to the design of such a seat that adapts to the occupant was be identified and evaluated. The head restraints are constructed such that they can follow the head of the occupant and thus ensure a reasonable head-to-head restraint distance all the time during driving.

Recognising the huge socio-economic costs associated with whiplash injury, the results of ADSEAT will also help to reduce society's burden on a higher level. A better understanding of the differences in male and female injury risk will allow more specific action, for example in terms of prevention strategies, and thus be of benefit to society at large.

ADSEAT comprises basic research, i.e., creating dynamic response corridors of females and applied research, i.e., the development of computational female models to be used in the design and evaluation process of whiplash countermeasures. Focusing not just on one area of research, but using a more holistic approach, is an ambitious goal. ADSEAT has taken advantage of the extensive research in the field of whiplash injury, which has predominantly focused on males that has already been carried out. With such a foundation significant advances in both basic and applied research has been obtained.

The ADSEAT project has built upon the knowledge gathered in the previous EU funded projects WHIPLASH I and II, expanded the scope and implemented the knowledge both in a virtual dummy model, as well as in seat evaluation guidelines. An updated assessment of the influence of individual factors on the risk of injuries has been conducted in a

comparable way with all available previous studies in order to establish the current situation. Real-world crash injury data, such as that gathered in the EU-funded projects Pendant and SafetyNet, as well as in national studies has been used to measure the protection of recently introduced anti-whiplash systems. Furthermore, the latest data collected at Folksam insurance has been available. The data was analysed in order to identify if any differences in the protection for females versus males from these systems occur. The analysis, indeed confirmed that females have an increased risk of sustaining whiplash injury in low velocity rear impacts by 1.5 – 3 times higher.

Results of the estimations of the socio-economic benefits of ADSEAT
The effect the ADSEAT project may have on society and the environment if measures recommended by the ADSEAT project were to be implemented in all seat design concepts has been estimated as part of the project. The result of this work is summarised below.

Initially, the qualitative value of EvaRID had to be established. It is well known from the published literature of injury statistics that females have a higher risk of sustaining WAD therefore it is necessary to ensure that seats are improved for this gender group as well. Furthermore, it is feasible to assume that improved seats would also offer protection for males at risk of sustaining WAD. Secondly, a quantitative approach to assess the expected injury reduction across the EU27 countries was applied. All front seat passengers involved in a rear impact who suffered WAD as a result were defined as a target group for analysis. As no official numbers for the EU27 exist, all reliable available information was gathered to estimate the size of this group. In addition, the latest estimates of costs for WAD in the EU27 for this target group, was collected.

These figures characterise the "baseline scenario" and refers to the year 2010, the EU27 and its current vehicle fleet. The majority of the seats in this vehicle fleet have not been improved for protecting passengers at risk of sustaining WAD. However, some manufacturers already provide seats with a prevention potential of 15% to 60%. It is also known that the protective effect is much higher for males than for females. These initial achievements are included in the baseline scenario.

The baseline scenario was compared to two different future scenarios: one scenario (Scenario 1) in which all seats were improved to the maximum of currently possible preventive potential and, a second "ADSEAT scenario" (Scenario 2) in which all seats were improved in accordance with recommendations defined in the ADSEAT project.

The data for the analysis were taken from the European Insurance Association (CEA) from 2002, the United Nations Economic Commission for Europe (UNECE) and the Organisation for Economic Co-operation and Development (OECD) (data from 2002 and 2010), from published literature and from the results of the ADSEAT project as presented in WP1 and developed in WP2-5. The data comprise numbers, costs, shares, and risk values for the EU27 population and WAD patients.

To calculate numbers and costs it was necessary to make the following assumptions and estimations:
CEA insurance data from 2002 are assumed to provide a picture of the whole EU27 (not only the countries, the data are derived from)

CEA insurance data from 2002 are assumed to capture the costs related to WAD in the EU27 (not only the countries, the data are derived from)
it was assumed that the discrepancies between reported injuries (UNECE data) and CEA insurance data from 2002 remained constant over the years until 2010
it was assumed that the development of WAD between 2002 and 2010 was either a proportional reduction in absolute numbers or the absolute WAD cases remained constant
it was estimated that the share of male and female WAD cases is 45%:55%
the share of WAD sustained in rear impact of all impact directions was estimated to be 65%
the share of rear seat passengers of all male and female WAD patients, following a rear end impact, was approximated by 3%.
the development of cost for WAD claims was assumed to rise by 3% per annum between 2002 and 2010. This figure is an estimate based on GNP development and consumer price index development for the EU27 countries who reported data (OECD).
the implementation of ADSEAT recommendations was assumed to reduce the risk of WAD in case of a rear impact by 50% for males and by 60% for females leading to an equal WAD risk for both genders.
Assumption 4 led to a range of numbers and costs. These were carried through the following calculations so that an average value and range are always presented. For validation reasons Assumptions 5 to 9 were varied according to given minimum and maximum values, e.g., from literature, in a sensitivity analysis to see what, if at all, the calculated effect depends on the assumptions.

Results:

It was calculated that the target group in 2010 comprised 794,717 (595,296 – 1,004,975) cases at 3.7 billion EUROS (2.8 – 4.7 billion EUROS) in the EU27.

Considering optimisation of current possibilities and improvement of all seats in the vehicle fleet (Scenario 1), only 383,451 (287,231-484,900) cases with costs of 1.8 billion EUROS(1.4 – 2.9 billion EUROS) will remain.

Finally, for the ADSEAT scenario only 353,649 (264907 - 447214) cases at a cost of 1.7 billion EUROS(1.2 – 2.1 billion EUROS) are to be expected.

By implementing the ADSEAT recommendations, the annual reduction of financial cost for the European society is calculated to be around 2 billion EUROS(between 1.6 to 2.6billion EUROS).

In comparison to current possible optimisation, ADSEAT can help the EU 27 to save an additionally 140 million EUROS(96 to 309 million EUROS) annually.

The variation in the share of female patients (Assumption 5) resulted in obvious changes based on our sensitivity analysis. The positive effect of the efforts made in ADSEAT will be much more prominent if the share of females is much higher than 55%. All other variations of the assumptions do not lead to any noteworthy changes.

Further potential beneficial effects of recommendations made by the ADSEAT project:

By improving safety for both male and female vehicle passengers, society as a whole will benefit from gender equality for society due to the comparable risk of WAD following a rear end impact for both genders, reduced injury risk, less pain and suffering, less loss of earning potential and less impairment. The cost of purchasing new cars may increase, although health and motor liability insurance rates may be reduced simultaneously.

To produce the improved cars, manufacturers will need to invest in seat development and production. They will have to carry out more tests on new cars/seats, however their profit will increase from more cars being bought by female customers and their image towards this gender group will improve.

Health and motor liability insurance companies will have to pay out less for WAD (1.6 billion EUROS to 2.6 billion EUROS per annum less), which will increase their profit margin and enable them to reduce insurance rates for clients.

National economies will face less productivity loss due to illness and impairment, and the income from tax will increase due to sold cars being more expensive. Furthermore, developing new seats will provide more job opportunities and increased employment security.

It is possible that there may be an environmental impact when producing new cars due to improved seats, although we estimate the effect to be negligible. The CO2 emission is predicted to be carbon neutral and no measurable effect on global warming is expected. Furthermore, the ADSEAT project does not envisage any negative effects on air, soil and/or water pollution due to manufacturing the seats, nor are any negative effects concerning noise, vibration, severance, visual intrusion, loss of important sites or impairment of landscape expected.

The ADSEAT reinforce the EC work programme, http://ec.europa.eu/justice/gender-equality/index_en.htm, for 2010 – 2015, "The strategy for equality between women and men", by closing the WAD gender gap whilst protecting males and females alike and promote of gender equality within the EU27. By reducing the number of WAD victims each year, automatically the amount of strong analgesics and other medication prescribed to constant pain sufferers would be significantly reduced. Consequently the amount of toxic waste excreted with the urine into the water supply would significantly reduce the level of toxic contamination in the water supply.

Discussion:
Although several assumptions were made when estimating the expected benefits of the implementation of the ADSEAT recommendations, the calculation is still very conservative. Due to different reasons the effect is expected to be higher than calculated. Our approach did not take differences in cost for severe and short-term WAD into consideration; however, WAD prevention systems are expected to be profitable, especially for the expensive long-term cases. The reduction in cost will be much more noticeable for the expensive long-term cases than for the short-term cases which would further increase the benefit. Also, Euro NCAP already estimates a cost of 10 billion EUROS per annum for the EU27 (for all WAD cases) while our calculations only estimate 5.9 billion EUROS(4.4 to 7.5 billion EUROS). The effect of protection systems

recommended by ADSEAT can be much more significant if the Euro NCAP estimates prove to be closer to the actual amount.

In conclusion, the socioeconomic benefit and the carbon neutral environmental impact favour implementing the recommendations made by the ADSEAT project, to improve the safety aspect of passenger car seats for males and females with regard to WAD risk in rear impacts.

List of Websites:

http://www.adseat.eu