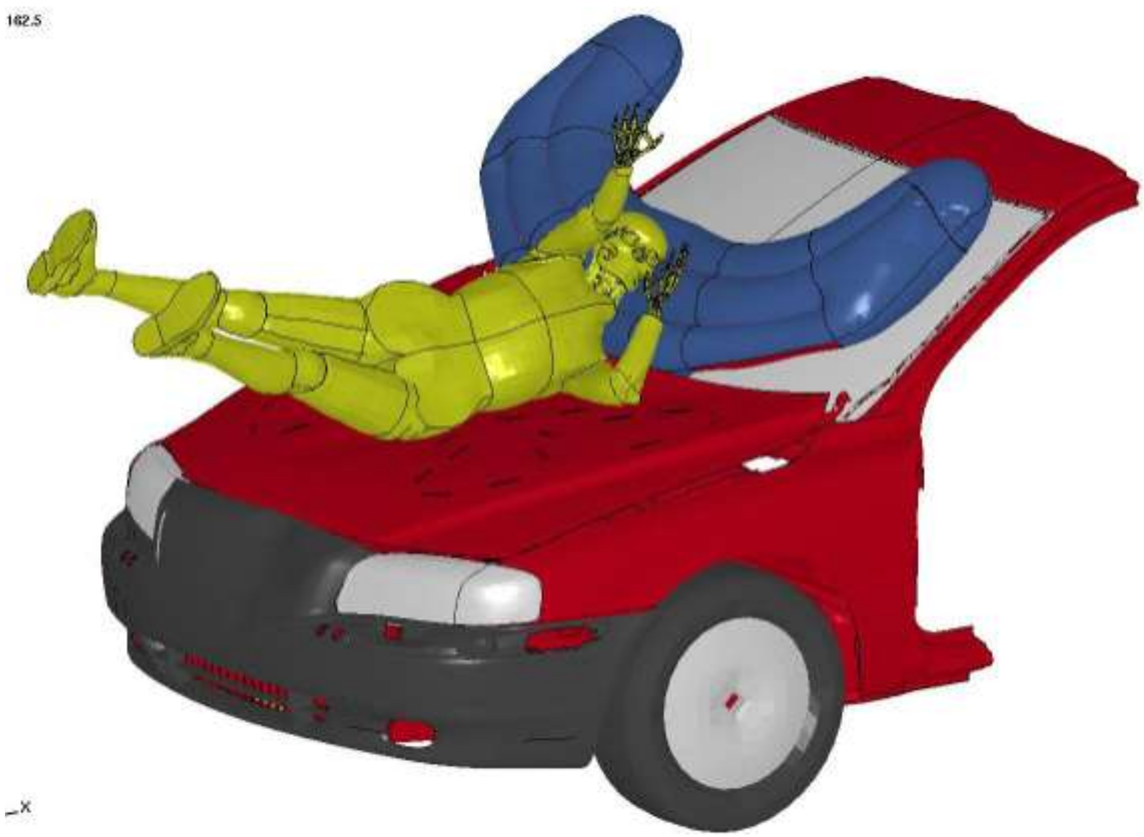
FFI

# Human Model with Active Neck and Detailed Head (Brain) for Pedestrian Protection

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**FFI in short**

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

**For more information:** www.vinnova.se/ffi

# 1. Executive summary

A mathematical human model with active neck and detailed brain was developed and validated in the project. The goal with the project was to develop a unique tool that can be used to develop and evaluate pedestrian injury countermeasures for pedestrian impacted by passenger vehicles. The model was validated by comparing predictions from the model with results from corresponding post mortem human subject (PMHS) tests. Reasonable validation of the model was reached. In addition the model was validated by reconstructing a number of pedestrian to vehicle impacts. The model was used to study the influence of neck muscles on the motion of the head in a collision between a vehicle and a pedestrian. Small influence of tensed neck musculature on the impact velocity and impact point for an impacted pedestrian was found.

The model has also been used to study the influence of shoulder and lumbar motion on head kinematics. The neck kinematics when impacted on the shoulder was found to correspond to a human with tensed neck musculature.

The risk for a pedestrian to sustain brain injuries was evaluated with the detailed head model. An inflatable head protection system for pedestrians was found to significantly reduce the risk for brain injury.

The model has also been used to study the risk of damage by reconstructing a number of passenger vehicles to pedestrian accidents.

The project has resulted in one licentiate thesis and five scientific publications.

# 2. Background

Pedestrian accidents are frequent and commonly cause injuries due to the combination of vehicle properties and that the pedestrian is unprotected. The probability for a pedestrian to be injured or killed is much higher than that for a vehicle occupant; 6.7 % of vehicle-pedestrian impacts in the US were fatal, whereas the corresponding fatality rate for occupants in crashes only was 1.3 % (NHTSA, 2009). For these two reasons pedestrian related fatalities comprise a considerable percentage of total traffic fatalities in industrialized nations: from 11 % in USA (NHTSA 2009) to nearly 50 % - South Korea (Youn et al. 2005). In pedestrian injuries the most frequently injured body part is the head followed by the chest (Yang 1997, Otte 1999).

Few legal requirements exist to date in which the pedestrian injury risk is assessed. However, there exist rating tests carried out to evaluate the level of safety a car offers in pedestrian-to-car accident. These tests do not fully represent a typical car-to-pedestrian accident; rather evaluate the properties of the hood, windshield etc. One reason for this short coming is the lack of readily available mechanical and mathematical tools. Mainly the test tools are components representing human body regions, e.g. models of the head, upper leg and lower leg, and not complete crash test dummies representing the complete human and its motions and contacts with the car. There is a mechanical crash test dummy developed by Honda to be used for pedestrian testing but it is not publicly available.

There are finite element human body models (HBM) on the market to evaluate pedestrian protection. However, these models do not include muscle tonus and there is a need for evaluation of the capability of such models to predict the kinematics of a pedestrian in a car-to-pedestrian accident. The commercial available human FE-models do need a better control of the head kinematics. One of the most important boundaries of the head motions is the neck. None of the commercial human FE models have a validated neck including the muscle activation.

There is a lack of knowledge about the kinematics of the pedestrian when impacted by a car. The impact point and the impact velocity are not well known. For development of countermeasures these parameters are crucial. A significant number of the accidents occur at low impact velocity for which the influence of muscle action can significantly influence the head impact velocity to the car.

In addition there is a significant influence on neck and head kinematics by the shoulder properties. That body region of the human is complex. The shoulder is only connected to the rib cage and spine by ligaments, muscles and indirectly by means of the clavicle bone. This connection is very moveable and the resistance to shoulder relative thorax and spine motions is highly dependent on muscle tonus.

In a previous project (IVSS AL80 A 2005 15805) a number of finite element HBM:s and mathematical models of crash test dummies were evaluated for impact loads from the side; lateral loading when the posture simulates that of an occupant in a car seat (Pipkorn et al., 2008; Lanner et al., 2009). One of the main efforts in the project was to evaluate the behaviour of the shoulder during lateral loading. The models were validated by means of PMHS pendulum impact tests. In the tests the PMHS were loaded on the shoulder and the kinematics of the shoulder was recorded. In addition, in this validation project, data for volunteers exposed to lateral loads on the shoulder were made available and obtained. The data from these studies and ongoing studies at Chalmers will be used to develop a shoulder model that can predict the behaviour of a human shoulder when loaded from the side.

Injuries to the head are the most common fatal injury in a pedestrian accident. The resulting head kinematics in such an accident is a combination of translational and rotational acceleration. The Head Injury Criteria (HIC) is the only criterion used today to predict head injuries, is insufficient as it only includes translational acceleration and do not take the direction of the impulse into consideration. Hence, means to assess head injury risk is a necessity to successfully predict pedestrian injury risk in the near future. The development of an improved head injury criterion, global head injury criteria or local brain tissue response limits, requires parallel research activities, such as detailed accident reconstruction, material property testing, and the use of animal models and FE-models of these animal experiments in order to be successful. Funding for an improved global head and local brain tissue injury criteria will be submitted in parallel with this application.

Both KTH and Chalmers have extensive knowledge and tools to introduce active muscles in HBM:s and to improve their kinematics. KTH has a unique FE model of the human head and neck and the important surrounding tissues. Chalmers have experience using mathematical modeling to reconstruct pedestrian injuries and are modeling humanlike pre-crash activated muscles. Both academic partners have extensive experience in neck modeling. Further, Chalmers and KTH have the experience of experimental biomechanics and the design of shoulder models. KTH has extensive experience in developing and using detailed FE models of the human head for traffic injury prevention. Using the KTH head model, it was suggested that variations in head size should be considered when developing new head injury criteria (Kleiven and von Holst, 2002). Also, the change in angular velocity has shown to correspond well with the injury level and strain levels in reconstruction of pedestrian head to windshield accidents (Mordaka et al., 2007). Recently, it has been found that even though the HIC reached acceptable levels for both perpendicular and oblique impacts towards an interior automotive padding, the maximum strain in the human head model for the oblique impact was almost twice suggested allowable levels (Kleiven, 2007).

# 3. Objective

The objective of the project is to:

1. Add the detailed and validated active neck developed by KTH on the Total Human Model for Safety (THUMS).
2. Add the detailed and validated brain model developed by KTH on THUMS
3. Validate the whole body kinematics of the combined model by means of published PMHS test results
4. Validate the whole body kinematics of the combined model by means of accident reconstruction
5. Evaluate and improve the shoulder model of THUMS
6. Use the combined method to evaluate current rating and test standards
7. Use the combined model to evaluate pedestrian impact countermeasures

# 4. Project realization

Both KTH and Chalmers have extensive knowledge and tools to introduce active muscles in HBM:s and to improve their kinematics. KTH has a unique FE model of the human head and neck and the important surrounding tissues. KTH has extensive experience in developing and using detailed FE models of the human head for traffic injury prevention Adding the head and neck model on the THUMS model will be carried out by KTH.

Chalmers has experience using mathematical modeling to reconstruct pedestrian injuries and are modeling humanlike pre-crash activated muscles. Chalmers and KTH have the experience of experimental biomechanics and the design of shoulder models. Chalmers has the experience of experimental biomechanics and the design of shoulder models. Therefore Chalmers will evaluate and improve the shoulder model of THUMS.

Autoliv have plenty of experience of developing restraints to reduce the injury outcome of pedestrian accidents. VCC and Autoliv have vast understanding of the pedestrian collisions from many years of accident analysis, mechanical testing and test methodologies. Volvo and Autoliv will use the modified and validated THUMS model to evaluate countermeasures and current test methods.

SAFER has ongoing activities on accident investigations and reconstructions and has developed technologies for those activities. The methods will be applied on accidents occurring in the Göteborg region and where the victims with moderate brain injuries are or have been treated at hospitals in the region. The results from the accident analysis and reconstruction will be used as input for a detailed brain injury modeling task at KTH.

# 5. Results and deliverables

## 5.1 Delivery to FFI-goals

FFI program's specific goal to develop technologies with the potential to reduce the number of traffic fatalities by one third by 2020 has been addressed in the project. The goal has been addressed by developing mathematical models that can be used to predict and evaluate head injuries sustained by pedestrians impacted by passenger vehicles. Head injury is dominating injury among pedestrians impacted by passenger vehicles. In this project, a prototype pedestrian impact protection system aimed at reducing head injuries was evaluated with the model with positive results. The model can be used to refine the existing system of protection for pedestrians and also to develop new systems.

The second of the FFI program's specific goals that have been addressed is that the Swedish automotive and supplier companies are to remain world leader in the development of safe vehicles and vehicle safety. One way to remain world leader in the development of safety products is to have a process for rapid development and testing of new concepts. In this project the goal to develop tools for rapid development and evaluation of new concepts has been achieved by developing virtual tools. These virtual tools allow development of new protection systems in a very cost and time efficient way.

# 6. Dissemination and publications

## 6.1 Knowledge and results dissemination

The pedestrian airbag presented by Volvo Cars in 2013 has received an enormous publicity. Therefore the bag is well known by the general public. The results from this project confirms the potential injury reducing benefits by such a protection system and can therefore lead to a wide spread of the project results.

## 6.2 Publications


Paas, R., ”Pedestrian Shoulder and Spine Kinematics and their Influence on Head Kinematics”  Licentiate Thesis Chalmers University of Technology 2013

Victor S. Alvarez, Madelen Fahlstedt, Peter Halldin, Svein Kleiven
Importance of Neck Muscle Tonus in Head Kinematics during Pedestrian Accidents
IRCOBI 2013.

Paas R, Davidsson J, Masson C, Sander U, Brolin K, Yang J
Pedestrian Shoulder and Spine Kinematics in Full-Scale PMHS Tests for Human Body Model Evaluation
IRCOBI 2012

Importance of Neck Muscle Tonus in Head Kinematics during Pedestrian Accidents
Alvarez V, Fahlstedt M, Halldin P, Kleiven S
IRCOBI 2013

Paas R, Brolin K, Davidsson J (2013) Evaluation of THUMS head and shoulder response in view of application for pedestrian accident analyses
To be submitted to Traffic Injury Prevention

Pipkorn B, Fredriksson R, Östling M, Ericsson M,
Pedestrian head injury protection by means of inflatable protection systems
To be submitted to AAAM 2014

# 7. Conclusions and future research

The conclusions from the study were:

- The developed human body model is unique
- The combined human body model was partially validated
- The shoulder kinematics of the combined model was validated
- Minimum influence of active neck musculature on head impact velocity was found in impacts at 40 km/h
- Influence of active neck musculature on head impact velocity was found in impacts at 20 km/h
- THUMS predicted shoulder deflections appear to be biofidelic
- The predicted head displacement when loaded on the shoulder correspond to humans with tensed neck muscles
- The correspondence between the full body vehicle to pedestrian impact results and a sub system test method using and impactor results was very limited
- An inflatable pedestrian head impact protection system significantly reduces the risk for an impacted pedestrian to sustain a brain injury

There is additional research needed to find a theoretical maximum level of steady state constant activation to determine the possible influence of muscle activation on head kinematics and impact velocities, to be compared to the differences between dummies and PMHS. But also see the influence strain in the brain and compare to same or more other parameters.

Additional work is also needed to study the dynamic muscle activation during pedestrian collision based on some optimization routine to determine if, the muscles have time to do any notable adjustment that differ considerable from a static activation. Should it start with static baseline activation, or a relaxed neck? How can this activation scheme be validated?

More detailed study of the effect of increased neck stiffness due to activation during the impact and impact rebound of the head.

Future work on how shoulder impacts influence head kinematics in pedestrian accidents should therefore include

- model validation against higher severity shoulder impacts, where the head and vertebrae linear and angular displacements can be evaluated
- further investigation on head rotations as a function of modelling refinements

In addition, the following topics should be studied, which have not yet been addressed:

- shoulder injuries, e.g. clavicle fractures, acromioclavicular joint sprains, and humerus fractures
- experiments with volunteers and PMHS regarding pedestrian-like shoulder impacts, where the impactor surface orientation and impactor velocity are changed such that they compare to pedestrian shoulder impacts on a vehicle; this should include changing the shoulder posture
- shoulder range of motion during elbow impacts to the vehicle

This study has been limited to one vehicle geometry and two pedestrian gaits. The study should include several different vehicle geometries and pedestrian gaits to give more knowledge concerning the difference in kinematics between the two models.
In this project a limited of parameters, pedestrian size and vehicle models have been evaluated. More simulations should be performed with larger variation to give a more general conclusion if a combination MADYMO and THUMS could be used in accident reconstruction to save time. The method is been evaluated against one accident case more accident cases should be tested. The results from the reconstruction of the kinematics should also be evaluated by comparing the injury and the effect on the brain tissue.
The sensitivity to vehicle geometry has initially been investigated in this project more can be done and also evaluate the influence of the stiffness on the head kinematics until initial contact.

Additional work is also needed to make the detailed head model a useful tool for the industry. In addition there is a need for a method to assess the level of injury risk the head model predicts.

# 8. Participating parties and contact person

This project was carried out by Autoliv Research, Volvo Car Corporation, Royal Institute of Technology (KTH) and Chalmers University of Technology (CTH). The contact person is Bengt Pipkorn (bengt.pipkorn@autoliv.com) at Autoliv Research.

# 9. References

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