# Estimation of impact severity in pedestrian accidents using accident investigation, computer simulation and physical reconstruction

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## Abstract

This paper presents current research where the investigation of actual pedestrian accidents is being used to estimate the levels of impact that are causing injury in those accidents. This is being done by reconstructing the impact that caused the injury. The reconstruction of each case begins by attendance at the scene of a pedestrian accident, which may be of any severity. Vehicle and scene investigations are used to determine the speed of the vehicle on impact, and to determine the contact points between it and the pedestrian. Interviews, hospital records, Coroner's files and Trauma Registry records are used to identify injuries suffered by the pedestrian. Computer simulation is used to reconstruct the sequence of impacts between the vehicle and the pedestrian, and the velocity of the parts of the pedestrian's body which come into contact with the car are determined. The simulation data is then used in the laboratory, where sub-system dummies representing the leg, upper leg and head are used to recreate the impact on the same make and model of car that was involved in the actual accident. The results of the impact reconstructions will be related to the type and severity of injuries sustained in the actual accident.

## Introduction

The principal aim of studies of the biomechanics of injury is to understand the way the body is injured in response to loads applied to it, and the limits of the body's endurance to those loads. Most research in this area examines the body's tolerance to impact loads, as impact injury is a leading cause of disablement and death in the community.

The study of the biomechanics of impact injury can be approached in several ways. Surrogates of the living human are often used. These include human cadavers, animals, and numerical models used in computer simulations. Experiments using human cadavers are useful where gross disruption to tissue is being studied. The disadvantages of human cadavers include the age of the subjects that are available, and the effects of death on the response of the tissues of the body to impact. In the study of brain injury, cadavers have the limitation that injuries that are caused by the physiological sequence of events that can occur after an impact to the head cannot be studied. This includes axonal injury (commonly referred to as DAI or diffuse axonal injury), which is one of the most common and serious forms of brain trauma.

Animal studies can overcome some of the limitations of cadaver research. Animals can be used to study the response of living tissue to impact, subject to ethical considerations. In brain injury research, they offer the only opportunity to study the biomechanics of brain injuries, such as DAI, using a controlled and measured insult to the head. In recent studies, the heads of animals have been instrumented to measure the dynamic characteristics of an impact, their brains have been examined for the presence of injury, and analyses have been used to relate the injury to the magnitude and characteristic of the loads (1, 2). The disadvantage of animal experiments is that assumptions must be made to allow the application of any findings to the human brain. Ultimately, these assumptions and the applicability of any findings from animal experiments to humans must be verified. Ethical considerations also prevent detailed study of the functional effects of the observed injury on functioning, so the observed injury cannot be related to any functional outcome.

The third commonly used surrogate is the numerical model, or computer simulation. The human body, or body part, can be modelled using techniques such as the finite element method. In the finite element method, the geometry of the structure being studied is dicretised into elements. Each element is assigned properties. These include material properties such as density, stiffness and damping. The boundary conditions on the elements in the model are specified, including the attachment between elements and their attachment to other structures. Injurious conditions can be simulated by providing the model with initial conditions and load/time histories. The simulation calculates stresses and strains in the structure over the simulation period. The advantage of such methods is that they can estimate stresses on the tissues of the body that are impractical to measure. Many simulations can also be run, to test different impact scenarios. However, the verification of finite element and other types of numerical model can pose a significant difficulty. Even if validity can be demonstrated, the load threshold for injury must be known beforehand, or determined by simulating impacts of known severity and known injury outcomes.

While human surrogate research is important in studying the injury response of human tissues to impact loads, any conclusions made from such research must be verified as being consistent with real life data. Real-life accidents are also a source of ‘natural experiments’ which can provide much information about the nature of impacts that cause injury to humans, being limited only by the evidence available to reconstruct the accident, and the techniques available to estimate the severity of the impact.

The Road Accident Research Unit has previously attempted to describe impact severity that caused fatal brain injuries in pedestrian accidents (3, 4). The brain injuries were recorded in detail by a neuropathologist and the nature and severity of the impact was estimated by several means, including categorising the impact location on the vehicle by its stiffness and using the velocity of the impact to provide an estimate of the impact force. Also, the Unit has recently developed a laboratory for evaluating the potential for vehicles to cause injury to pedestrians in an accident. The tests that are used to do this are based on the sub-system testing developed by the EEVC[1]. The tests consider the injuries to the tibia and knee in a legform test, femur fractures and pelvic injuries in an upper legform test, and head injuries in an adult and child headform test. The laboratory has provided us with a new tool for reconstructing the impacts and estimating the impact loads in the accidents that we have investigated.

## Aims

The aim of this research program is to use a physical reconstruction of the head impact in a series of real-life pedestrian accidents to estimate the severity of the impact in the accident, and relate this to the severity of any head injury. In the future we hope to extend this to the reconstruction of impacts to the lower extremities.

## Methods

Figure 1 illustrates the methodology that is being used in this study. The process of estimating the severity of the head impact comprises three phases, the first being the accident investigation phase. This is followed by the computer simulation of the collision, and finally the physical reconstruction of the head impact.

### THE DATA

The data for this study is drawn from two sets of accident records, both collected by the Road Accident Research Unit. The first set of data is from a study of fatal pedestrian accidents in Adelaide conducted over a period of ten years. Fifteen of 200 fatal accidents investigated in this period have been chosen, with the requirements that

- the impact speed could be accurately estimated from the forensic evidence of the collision,
- there was a single significant impact to the head of the pedestrian, and the struck object could be clearly identified.

The same requirements were applied to the second data set. These 80 accidents were collected from 1998 to 2000 in a study of pedestrian accidents in and around Adelaide, for the Commonwealth Department of Transport and Regional Services. The accidents investigated were of varying severity from almost no injury to fatal. Ten of these accidents are being reconstructed.

### ACCIDENT INVESTIGATION

The accident investigation typically began with notification from the South Australian Ambulance Service that they were to attend the scene of a pedestrian accident. In fatal cases, the investigation often began with a member of the Unit attending the autopsy at one of the metropolitan hospitals, or at the mortuary of the State Coroner. The scene of the accident was surveyed, and the lengths of any skid-marks left by the vehicle were measured, along with the location of the impact point and final position of the pedestrian, scuff marks on the road, debris, and any other feature of relevance. If the pedestrian was fatally injured, their injuries were recorded at the autopsy, along with their height, weight and the dimensions of various body segments. In non-fatal cases, the pedestrian was interviewed, to determine the nature and severity of their injuries, and the circumstances of the collision. Consent was sought for access to medical records, from which information on their injuries was

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[1] European Enhanced Vehicle-safety Committee

collected. The South Australian Trauma Registry was also consulted in cases where data on the pedestrian's injuries were not complete.

The vehicle involved in the accident was inspected, either at the scene of the accident, or if the accident was fatal, at the vehicle compound of the South Australian Police. The vehicle was inspected for signs of contact with the pedestrian, which could usually be identified by dents, scratches and scuffs in the body of the vehicle. The location of the head contact could be identified not only by a dent in a panel or crack in the windscreen, but also often by the presence of hair on the contact area. The dimensions of the front of the car were recorded so that these could be reproduced in the MADYMO simulation. The location of each contact location was also measured, so that the fidelity of the motion of the computer simulation could be verified.

The injuries to the pedestrian are used to determine their stance immediately prior to the collision. The impression of the bumper or grille, often indicated the orientation of the pedestrian, and the alignment of marks often indicate the position of limbs and torso as they were struck. This information is used to choose the initial position of the pedestrian model in the computer simulation of the accident.

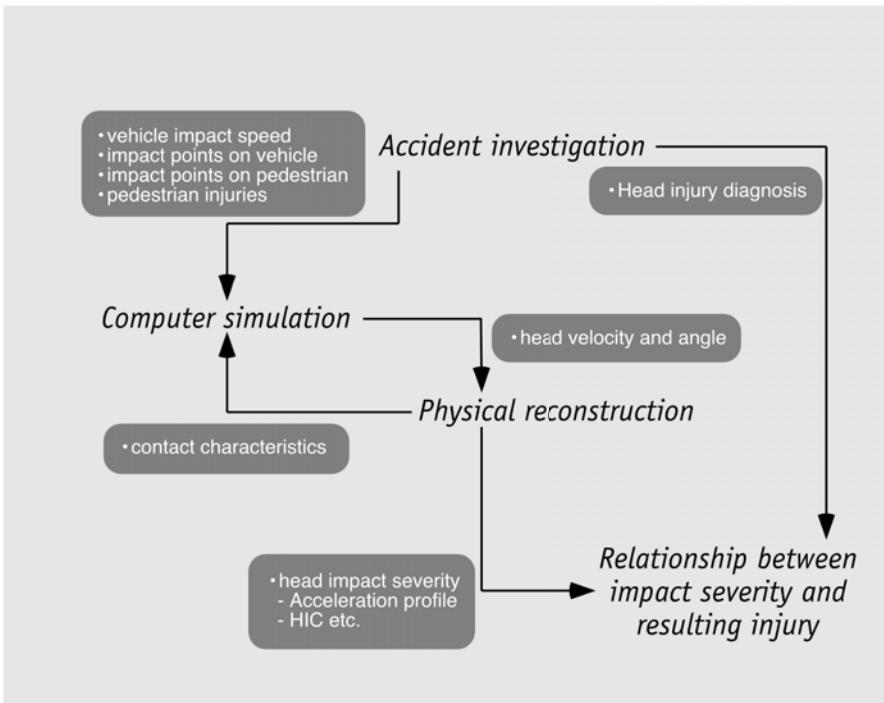


Figure 1 Methodology used to estimate impact severity in pedestrian accidents

## COMPUTER SIMULATION

The Unit has previously presented a MADYMO model of the human pedestrian that can be used to simulate a pedestrian-vehicle collision (5). This model is based on published anthropometric data on the human body. The mass and inertia of each segment of the human model is based on the GEBOD program (6). This program generates the required data using regression equations based upon a database of human measurements, using the person's height, weight, and sex. In fatal cases, these measurements were taken during autopsy. In the non-fatal cases, the pedestrian's weight and height is used, and is supplemented by body dimensions where these could be measured or supplied.

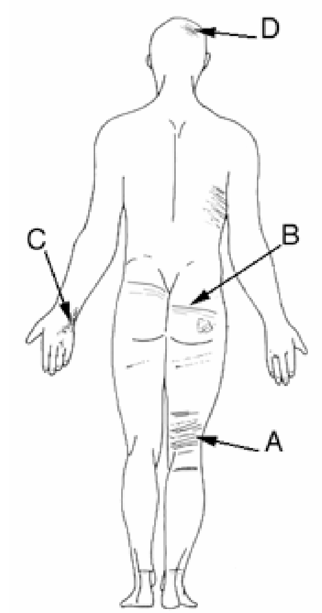


Figure 2 Matching contact points with the pedestrian's injuries is used with standard crash reconstruction techniques to determine the sequence of impacts between the pedestrian and the vehicle

The model of the pedestrian is positioned in front of the vehicle, in a position thought to be the most likely stance of the pedestrian immediately prior to the collision. The simulation is run and the location of contact points on the vehicle model is compared to the contacts noted at the time of the crash investigation. The simulation is then re-run, altering variables such as impact speed and the orientation of the pedestrian within the bounding limits of their likely values, as determined by the crash investigation. The aim of this is to match the results of the simulation to the forensic evidence of the crash.

The simulation is able to provide estimates of the forces placed on body segments throughout the collision. It is therefore theoretically possible to estimate the head impact severity from the simulation. The accuracy of this estimate would rely on the model reproducing the velocity of the head just prior to the collision, and defining the correct contact characteristic of the impact between the head and the car structure. The characteristic of this impact is often complicated by non-linear behaviour. For example, the presence of engine components close to the under-surface of the bonnet can stiffen the contact considerably if the bonnet deflects sufficiently during the impact. The dynamics of the car structure on impact can also be difficult to characterise in a simple manner. The realisation of such characteristics is impractical for the purposes of this study. Since the MADYMO model's kinematic behaviour has been previously validated against tests with human cadavers (5), we rely on the model to calculate the velocity of the impact immediately prior to the collision, and use a physical reconstruction to estimate the head impact severity in the actual accident.

## PHYSICAL RECONSTRUCTION

The physical reconstruction of the head impact is performed using the Pedestrian Impact Laboratory at the Road Accident Research Unit. This facility was originally constructed with the specific purpose of reconstructing real-life pedestrian accidents. Since the facility was first opened, the laboratory has been expanded so that, in addition to the reconstruction of head impacts, we are also able to perform the three EEVC sub-system tests for assessing the pedestrian protection afforded by a motor vehicle. These tests are now being used and reported on in the Australian New Car Assessment Program.

The headform launcher (Figure 4) is able to launch either the EEVC headform (as illustrated) or a headform designed by the Unit for impact reconstruction. The latter headform has a mass that can be altered, so that any additional effective inertia introduced by the mass of the rest of the body, which may act thought the neck, can be incorporated. The launcher is able to fire the headform at speeds of up to 70 km/h.

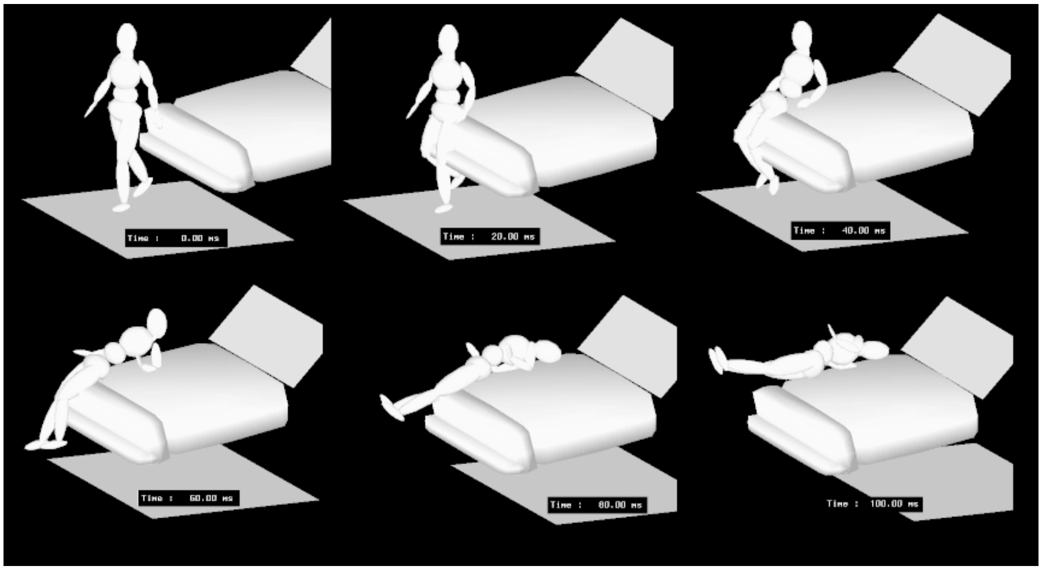


Figure 3 MADYMO simulation of the pedestrian accident

A vehicle of the same make and model as that involved in the accident is obtained for each reconstruction. The angle and velocity of the launcher is set according to the results of the simulation. As the vehicle is stationary for the test, the velocity of the head relative to the car must be extracted from the simulation. The components of the head's velocity immediately prior to the impact are used to determine the launch angle of the headform. The headform is aimed at the impact location identified in the crash investigation.

The headform contains a triaxial accelerometer that is used to measure its resultant acceleration throughout the impact. The acceleration is recorded according to the specifications of the SAE standard SAE J211/1 (Instrumentation for Impact Test - Part 1 - Electronic Instrumentation). The recorded acceleration is used to determine the head impact severity. Various measures of the severity are made, including the Head Injury Criterion.

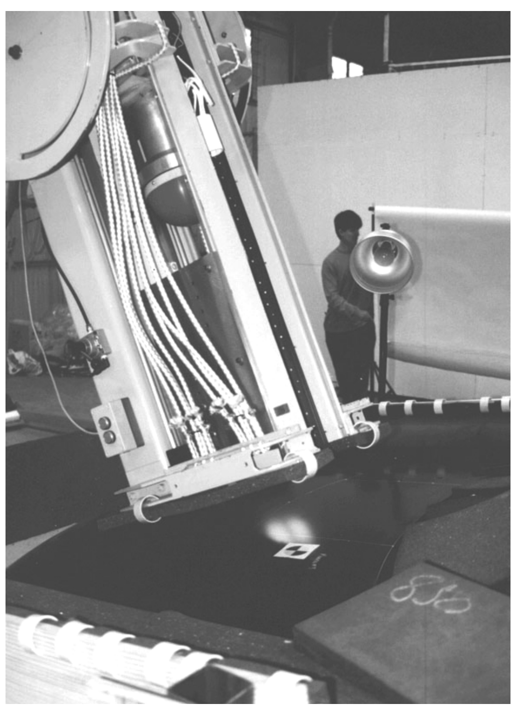

Figure 4 The impact is reconstructed using the EEVC headform fired from the headform launcher

## Status of the study

To date, 15 of the 25 simulations have been completed. Over the coming 12 months, the remaining simulation and physical reconstruction of these cases will be completed. It is our intention to have preliminary results available for presentation at the 2001 Enhanced Safety of Vehicles Conference in the Netherlands.

## Summary

This paper has presented an overview of the methods being employed in a study of the biomechanics of real-life human head injury. The study uses the crash investigation to determine the impact speed of the vehicle, and the position and potion of the pedestrian prior to the collision. A computer model is used to estimate the kinematics of the pedestrian throughout the collision, and to estimate the velocity of the head just prior to its contact with the car bonnet. A physical reconstruction of the impact is made with the same make and model of vehicle, using the results of the simulation to provide the correct impact conditions. The results of the reconstructions will be used to relate the severity of the head injury to the estimates of the head impact severity.

## Acknowledgments

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