TECHNISCHE UNIVERSITÄT WIEN

Diploma Thesis

Crash Test Dummies – How realistic are currently used Dummies?

carried out for the purpose of obtaining the degree of Master of Science (MSc or Dipl.-Ing. or DI), submitted at TU Wien, Faculty of Mechanical and Industrial Engineering, by

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Affidavit

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

Vienna, 27th of March 2019

Signature

Abstract

This diploma thesis analyses in how far currently used crash test dummies are realistic. The analysis primarily focuses on the Žilina Dummy and the Biofidelic Dummy, as those two are used by DEKRA for accident reconstructions.

Nine crash tests with the Biofidelic Dummy were conducted by DEKRA and AXA Insurance in June 2018 in Wildhaus, Switzerland, while crash tests with the Žilina Dummy have been conducted in earlier years. Four of those crash tests were chosen for further analysis.

The analysis of the dummy trajectories highlights that the Žilina Dummy behaves in an unrealistic way, while the Biofidelic Dummy's trajectory is comparable to those of cadavers. It is also shown that the vehicle damages produced by the Žilina Dummy are too severe, whereas the ones caused by the Biofidelic Dummy are more realistic. The C-ratios obtained with both dummies are good and they only deviate from each other slightly. The analysis of the throw distances further shows that both crash test dummies perform well in this regard.

A unique feature of the Biofidelic Dummy is the ability to suffer damages that are comparable to injuries a pedestrian would sustain in a pedestrian-vehicle accident of similar severity. It is shown that the "injuries" of the Biofidelic Dummy are quite realistic and the underlying injury mechanisms are the same as for pedestrians. Three of the five injuries that can be used for reconstruction purposes are well mimicked by the Biofidelic Dummy.

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Acknowledgment

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Contents

Nomenclature

Acronyms

ADR accident data recorder

ATD anthropomorphic test device

PMHS post mortem human subject

THOR Test device for Human Occupant Restraint

Symbols

C ratio between closing speed and collision speed (analytical C-ratio)

$C(t)$ dynamic, time-dependent C-ratio

$C(t)_P$ dynamic, time-dependent C-ratio of the pelvis

$C(t;P)$ dynamic, time-dependent C-ratio relative to the pelvis

$C(t;P)_F$ dynamic, time-dependent C-ratio of the foot relative to the pelvis

$C(t;P)_H$ dynamic, time-dependent C-ratio of the head relative to the pelvis

C_g geometrical C-ratio

C_{gx} geometrical C-ratio with a correction factor of x % applied to it

CoM centre of mass

e coefficient of restitution

$s(x)$ distance in x-direction

$s(y)$ distance in y-direction

$v(res)$ resultant velocity

ΔC difference between analytical and geometrical C-ratio

ΔC_x difference between analytical C-ratio and geometrical C-ratio with a correction factor of x % applied to it

$\Delta C\%$ percentage-wise difference between analytical C-ratio and geometrical C-ratio

$\Delta C\%_x$ percentage-wise difference between analytical C-ratio and geometrical C-ratio with a correction factor of x % applied to it

1. Introduction

Walking can probably be considered as the most common mode of transportation, as every driver has to be a pedestrian at least twice. In 1896, the first ever pedestrian fatality in a pedestrian-vehicle collision was reported in the United Kingdom (Ashton, 1989), while nowadays roughly 1.2 million people across all modes of transport are killed worldwide in road traffic accidents every year (Organisation for Economic Co-operation and Development - International Transport Forum, 2017).

Compared to other road users, pedestrians lack a protecting and energy absorbing structure, and are hence referred to as "vulnerable road users". This comes along with an elevated injury likelihood, oftentimes resulting in severe or even fatal injuries.

While vehicle-vehicle accidents can cause distinctive scratch marks on the road surface, which can be used for reconstruction purposes, pedestrian-vehicle accidents lead to hardly any traces on the road surface. This lack of evidence often complicates the work of experts reconstructing the accident. As such, for reconstructing the pedestrian-vehicle accident and narrowing down the possible collision speed, the expert frequently has to deal with scarce evidences. One such evidence is the throw distance, i.e. the distance between the known point of collision and the final position of the pedestrian, given that both are determinable. Furthermore, the collision speed can be calculated by assuming a certain deceleration and considering the relative distance between the point of collision and the final position of the vehicle. However, as the point of collision can hardly be determined and the exact deceleration is mostly unknown, the injuries of the pedestrian as well as the vehicle damages are also of interest to narrow down the collision speed.

In order to narrow down the collision speed based on the pedestrian's injuries and the vehicle damages, however, the expert should be able to access a database with a large set of reference cases with different vehicles and impact constellations and known collision speeds as a basis of comparison. The quantity of such reference cases, where the collision speed is known sufficiently enough or was determined precisely enough, is limited though, as a precise determination of the collision speed is not yet possible considering the current reconstruction tools, unless data from surveillance cameras and/or data recorders is available.

But for court proceedings, it is necessary to determine the exact collision speed even in cases with limited evidences. Thus, full-scale pedestrian-vehicle crash tests are often indispensable, in order to gather comparable evidence to reconstruct the accident. However, these gathered data must be as realistic as possible, in order to avoid erroneous conclusions, i.e. the vehicle damages caused by the dummy in the crash test must match those caused by a pedestrian under the same impact conditions. Therefore, the employed dummies must be as human-like as possible to render realistic evidences such as throw distance and vehicle damages.

Currently used crash test dummies, though, can hardly be employed for reconstruction purposes in a satisfactory way. The available dummies are either too expensive due to their sophisticated instrumentation, and/or they are too stiff and cause unrealistic damages when compared to real-world accidents with known collision speeds. Therefore, a biofidelic dummy has been developed by the "Bureau for Accident Reconstruction Berlin" under the guidance of Dr. Michael Weyde. This dummy was designed to sustain damages comparable to the injuries sustained by a pedestrian and to also cause realistic vehicle damages, in order to use the data gathered by conducting crash tests to reconstruct a pedestrian-vehicle accident.

The objective of this diploma thesis is therefore to analyse, in how far currently used dummies are realistic, paying special attention to the newly developed Biofidelic Dummy.

First, a market study will be performed and an overview of the currently used pedestrian dummies will be presented in chapter 2. For accident reconstruction purposes, however, DEKRA primarily conducts crash tests with the Žilina and Biofidelic Dummy, as the costs for the more sophisticated ATDs are too high. Therefore, the diploma thesis will primarily focus on these two dummies.

In the third chapter, a short introduction into the theory and biomechanics of the pedestrian accident will be given. These include the underlying principles, injury mechanisms, biomechanical thresholds, kinematics and dynamics, which vehicle structures are hit and what kind of injuries prevail.

Chapter four deals with the analysis of pedestrian-vehicle crash tests which have been conducted by DEKRA in conjunction with AXA Insurance in Wildhaus, Switzerland, and their comparison with real-world cases with respect to vehicle damages and dummy damages/pedestrian injuries. Internally used throw distance charts will be supplemented and adapted accordingly.

Based on the findings, the advantages and disadvantages of the different dummies will be presented and it will be determined, which dummy is best suited for what kind of experiment in chapter five. An evaluation matrix was created for this purpose.

Chapter six will finally analyse how the Biofidelic Dummy can be made even more biofidelic.

Figure 1.1 shows the structure of the diploma thesis.

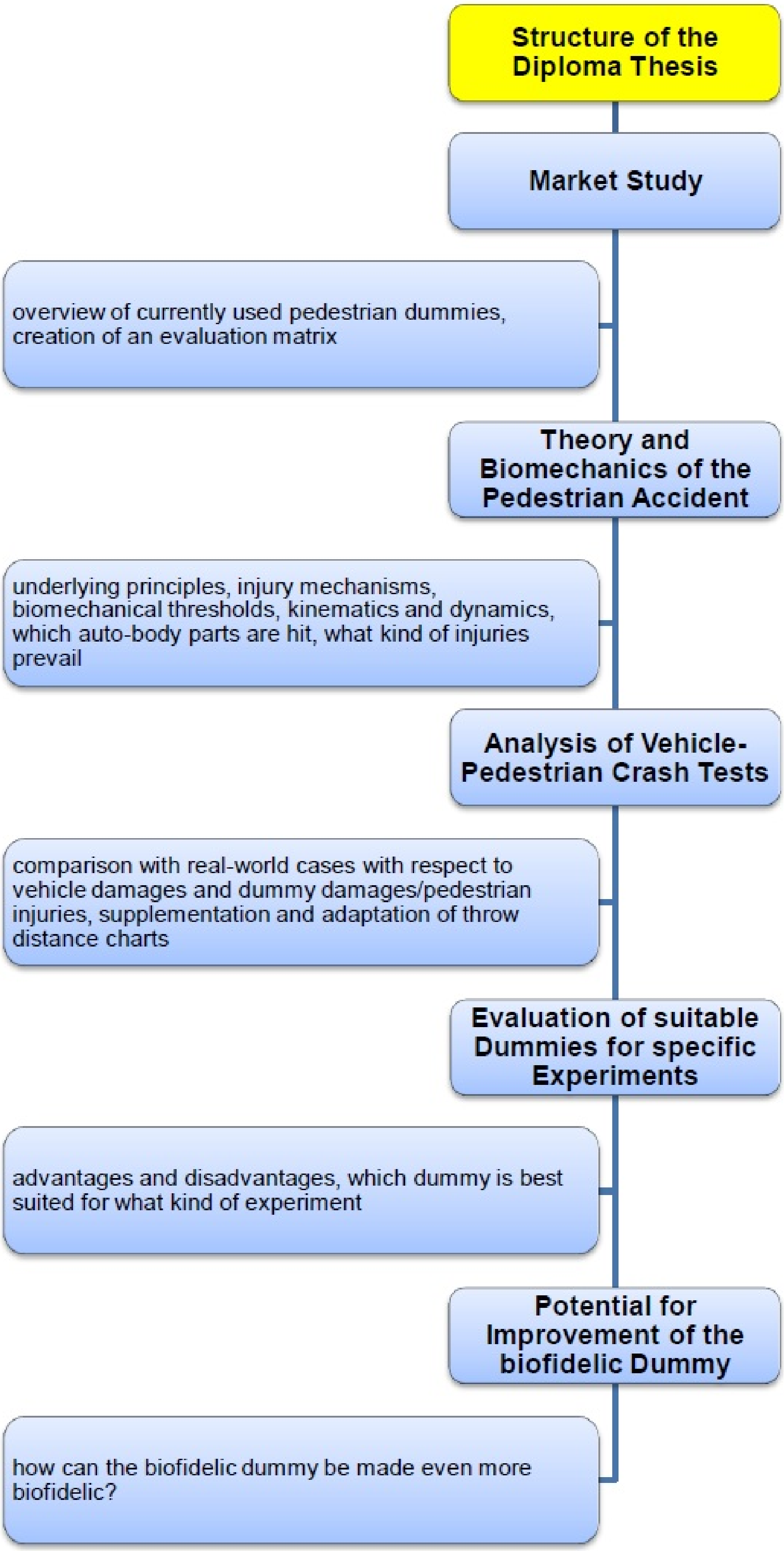


Figure 1.1.: Structure of the diploma thesis

2. Market Study: Currently used Pedestrian Dummies

Crash test dummies, also called anthropomorphic test devices (ATDs), are used as human surrogates in crash tests. ATDs are humanoid mechanical models primarily used in the automotive industry to evaluate the effectiveness of passive safety systems. They are designed to measure mechanical loading parameters like acceleration, force and deformation (Schmitt et al., 2010). Their skeleton is usually made of steel or aluminium, while polymers are used to represent joint surfaces and the skin, and foam as a surrogate for human flesh. ATDs can be equipped with instrumentation such as accelerometers and load cells.

Nowadays, there exists a whole family of ATDs. The most common are the 5th percentile female, the 50th percentile male and the 95th percentile male. The percentile value designates here the percentage of the population being smaller than the respective ATD; e.g. the 5th percentile female represents the height and weight of the female population, where $5\,\%$ of the female population is smaller (Kramer, 2009). Child ATDs representing a 3, 6 and 10 year old child are also available.

ATDs must fulfill certain requirements (Schmitt et al., 2010):

- Anthropometry and biofidelity: In terms of size, mass distribution, moments of inertia and posture, ATDs should properly represent a human, while their biomechanical response to impact loading should be humanoid.

- Instrumentation: ATDs should be able to measure the mechanical loading parameters pertaining to the injuries or the injury mechanisms to be examined.

- Repeatability, reproducibility and durability: ATDs should be designed in such a way that they behave similarly when the same crash test is conducted repeatedly. Moreover, the obtained data should be comparable when the same crash test is conducted using different ATDs of the same kind. An ATD should also be robust and should not or hardly be damaged even when critical biomechanical thresholds are exceeded.

Depending on the application, different kinds of ATDs need to be employed, as no ATD which can be used universally has been developed yet. These different dummy types include frontal impact, lateral impact, rear-end impact, pedestrian, child, belt and impactor dummies.

2.1. The Hybrid-III Dummy

Figure 2.1.: Hybrid-III 50th percentile male pedestrian dummy (Humanetics, 2018a)

The 50th percentile male hybrid-III dummy is the most widely used ATD for frontal impact crash testing, and is defined in the respective European and US-American regulations (Schmitt et al., 2010). In the early 1970s, however, Humanetics already developed a pedestrian dummy based on the hybrid-II, the predecessor of the current dummy.

The hybrid-III pedestrian dummy family comprises a 5th percentile female, a 50th percentile male and a 95th percentile male dummy.

The hybrid-III 50th percentile male pedestrian dummy is based on the hybrid-III 50th percentile male dummy with changes to its lower torso and knee regions (Humanetics, 2018a). The anthropometry of this ATD is based on the US male adult population.

The head is made of a one-piece aluminium skull and a one-piece skull cap which is removable to enable access to the head's instrumentation. The head assembly is covered by a vinyl skin. The neck is made of rubber and aluminium segments, enabling an anthropomorphic neck response in dynamic flexion and extension in terms of angle versus moment. Neck stretching is limited by means of a cable running along the axis of the neck. This cable further controls responses and increases the durability of the neck assembly. The chest comprises six spring steel ribs and a polymer-based damping material, in order to resemble the force-deflection characteristics of the human chest. The knee joint differs in so far as that the knee slider mechanism has been removed, enabling rotation only. While the standard hybrid-III dummy has a curved lumbar spine, the pedestrian version has a straight lumbar spine to enable an erect posture. The leg assemblies are made of steel tubes which are covered with vinyl foam and skin.

The hybrid-III 50th percentile male pedestrian dummy can be equipped with 21 different sensors and has a total body weight of $78.15\,kg$, and is shown in figure 2.1 (Humanetics, 2018b,a).

2.2. The THOR Dummy

The THOR (Test device for Human Occupant Restraint) dummy is a 50th percentile male frontal impact ATD exhibiting an improved biofidelity and expanded instrumentation in com-

Figure 2.2.: THOR dummy (Humanetics, 2018c)

parison with the hybrid-III 50th percentile male dummy, and is shown in figure 2.2 (Humanetics, 2018c). Apart from the arms, which are identical to those of the hybrid-III, all other components have been improved, in order to obtain an enhanced anthropometry and biofidelity (Schmitt et al., 2010).

The facial region is equipped with load cells to determine the probability of facial skull fractures. The new neck design permits a more accurate mimicry of head trajectories, velocities and accelerations under frontal, lateral and rear-end impact loading (GESAC, 2005). Rib design has been improved by using elliptical ribs, enhancing the biofidelity and geometry of the rib cage. The new abdominal assembly enables the measurement of belt intrusion and compressive displacement in the upper abdominal region. Sensing capabilities were improved by changes made to the pelvis and lower limbs, while the new ankle joint is more humanoid.

2.3. The POLAR Dummy

The POLAR dummy is a modified THOR dummy, and has been designed to better mimic the human kinematics during pedestrian-vehicle collisions (Akiyama et al., 2001; Schmitt et al., 2010). Like the THOR dummy, the POLAR dummy represents a 50th percentile US-American male adult, and is displayed in figure 2.3. One of the main design requirements

Figure 2.3.: POLAR dummy (Akiyama et al., 2001)

of the POLAR-II was its response at collision speeds of $32\,km/h$ and $40\,km/h$.

The most important features of this ATD are a more anthropomorphic knee and tibia design. The POLAR's knee structure comprises condyles, a meniscus, and cruciate and collateral ligaments just like the human knee. The tibia is fabricated from urethane and exhibits the same bending characteristics like the human tibia. As the lateral bending and shearing responses are more anthropomorphic, the kinematics of the whole ATD become more biofidelic.

2.4. The Žilina Dummy

The Žilina Dummy was developed at the University of Žilina in the Slovak Republic, and represents a 50th percentile male (see figure 2.4).

In contrast to the more sophisticated ATDs used by the automotive industry, instrumentation is limited to the chest (Knape, 2016). This ATD is based on a metal skeleton covered by hard plastic, and the joints can be fastened to enable an upright posture.

The primary application of this cost-efficient ATD is in the area of accident reconstruction

Figure 2.4.: Žilina Dummy (Knape, 2016)

and research, as the lack of sophisticated instrumentation impedes the usage in research and development in the automotive sector.

2.5. The Biofidelic Dummy

The Biofidelic Dummy was developed by the “Bureau for Accident Reconstruction Berlin” under the premise to sustain damages comparable to the injuries sustained by a pedestrian, and to also cause realistic vehicle damages.

The first prototype had a wooden skeleton, which was held together by stapled straps, covered by a tissue surrogate made of a mixture of silicone and acrylic. The special feature of this ATD tissue are the pseudoelastic properties similar to human tissue. Under the application of an external force, the tissue behaves plastically, while its properties are elastic as soon as the force is removed. Thus, the lower extremities can cling to the vehicle’s front-end more human-like during the primary and secondary impacts, thereby increasing the contact area and hence lowering the local impact forces, leading to less severe vehicle damages. The skin is represented by a $3\,mm$ thick wet suit, which is covered by latex to increase the elasticity and tensile strength. Moreover, the wet suit is not only used as a skin surrogate, but also as a means of additional fixation of the tissue parts.

In order to further improve the anthropometry and biofidelity of this 50th percentile male ATD, the current version has no longer wooden bones, but a mixture of epoxy resin and aluminium powder is used. This mixture allows the fabrication of ATD bones which better resemble human bones in their shape and mechanical properties. The tissue parts are now made of a two-component-silicone instead of a mixture of silicone and acrylic. A wet suit, covered with latex, is still used as the skin surrogate. The design of the current Biofidelic Dummy is shown in figure 2.5.

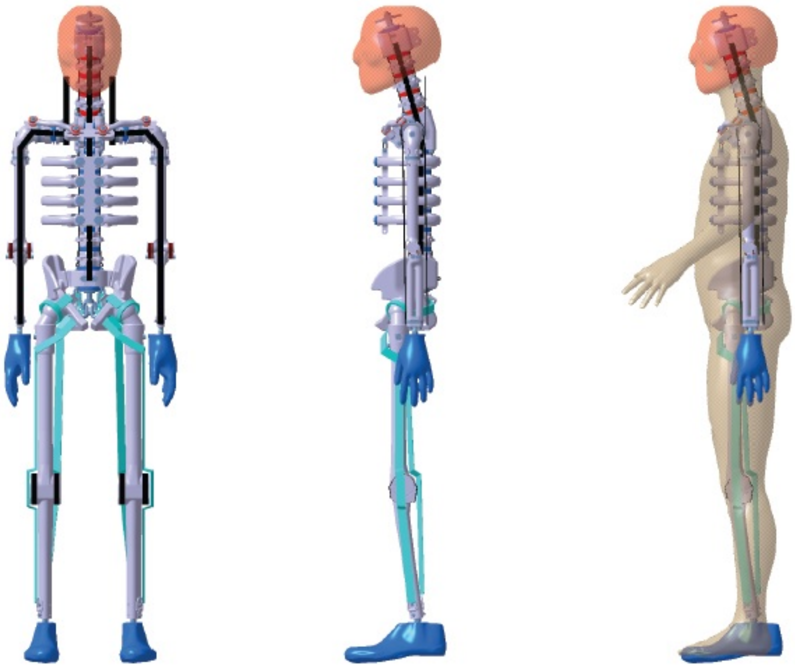


Figure 2.5.: Biofidelic Dummy (Knape, 2016, p. 65)

3. Theory and Biomechanics of the Pedestrian Accident

In order to evaluate the biofidelity of the currently used dummies, it is important to have an understanding of the theory and biomechanics of the pedestrian accidents. The following chapter provides a short overview detailing the underlying principles, injury mechanisms, biomechanical thresholds, kinematics and dynamics, which vehicle strcutures are hit and what kind of injuries prevail. The overview is based on Schäuble (2018), the present author's project report which can be regarded as preparatory work for this thesis.

3.1. Theory of the Pedestrian Accident

Four different time stages define the pedestrian accident as depicted in figure 3.1. With regard to the pedestrian's injury patterns, solely the in-crash phase is of significance.

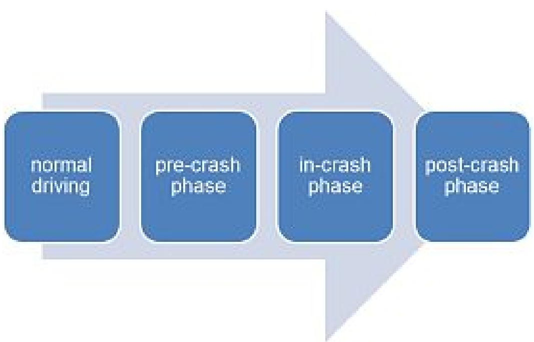


Figure 3.1.: Time stages of the pedestrian accident according to Kühn et al. (2007)

The following parameters primarily determine the severity of the pedestrian accident:

- impact constellation
- front-end geometry
- collision/closing speed
- local vehicle stiffness
- biomechanics

3.1.1. Impact Constellation

The impact constellation is a decisive factor when it comes to the injuries sustained by the pedestrian, as it determines the closing speed of the pedestrian in conjunction with the collision speed. Impacts with the front-end structure are statistically most common, as depicted in figure 3.2.

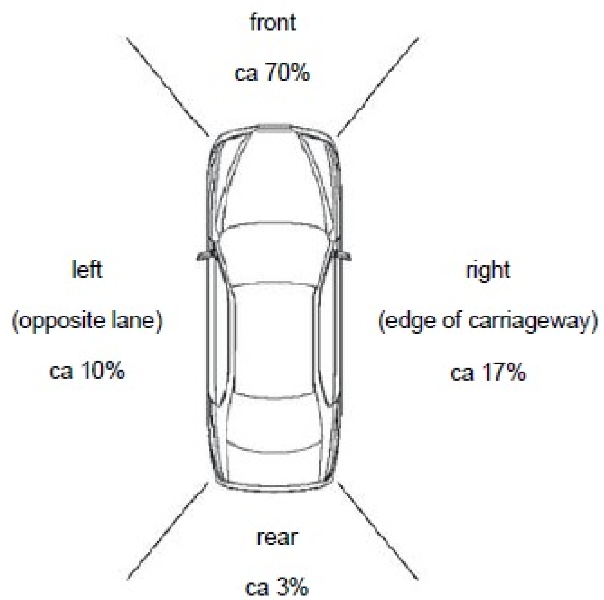


Figure 3.2.: Statistics of impact area (Lauer, 2012, p. 13)

Hence, solely impacts with the front of the striking vehicle will be considered. Those are further distinguished between three different kinds of hit.

3.1.1.1. Complete Hit

The pedestrian is completely hit by the vehicle's leading edge (see figure 3.3). The front-end geometry has an impact on the pedestrian kinematics, but generally the bumper strikes the lower extremities, inducing an angular momentum causing the pedestrian to roll onto the bonnet, before the pedestrian is either catapulted over the vehicle or ejected frontwards depending on the braking characteristics of the vehicle.

Figure 3.3.: Complete hit. 1: The lower leg impacts the bumper. 2: The upper thigh/hip impacts the bonnet leading edge. 3: The thorax impacts the bonnet. 4: The shoulder impacts the bonnet rear edge. 5: The head impacts the windscreen (DEKRA, n.d.)

As the pedestrian undergoes several changes in speed, it is helpful to further divide the pedestrian accident into hit stages as shown in figure 3.4.

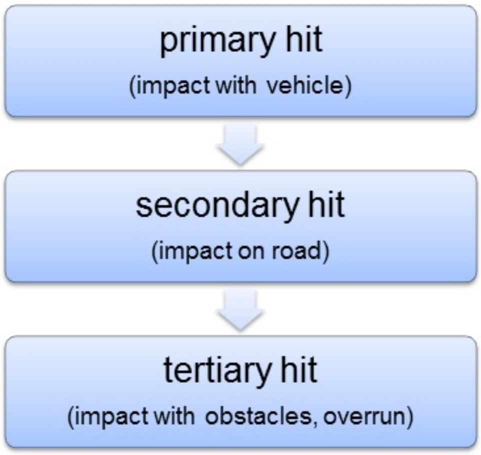


Figure 3.4.: Hit stages of the pedestrian accident

The impact with the vehicle is defined as the primary hit. Here, the pedestrian gains energy which has to be dissipated subsequently. The secondary hit is defined as the following impact on the ground. During the flight phase or subsequent skidding, the pedestrian may strike obstacles. The pedestrian may also be overrun. These impacts are classified as the tertiary hit. These phases, except for the tertiary hit, are depicted in figure 3.5.

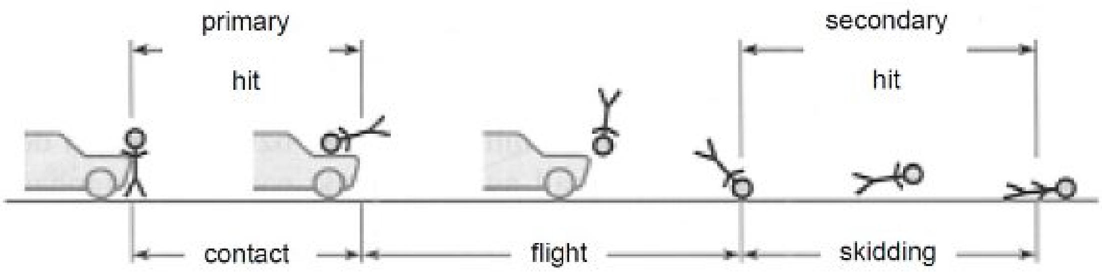


Figure 3.5.: Phases of the pedestrian-vehicle collision (Kühn et al., 2007, p. 75)

The primary hit is further subdivided into three impact stages. The impact of the lower extremities with the vehicle's leading edge is defines as the primary impact, while the secondary impact is defined as the impact of the thigh or hip with the bonnet leading edge. The head's impact is defines as the tertiary impact.

3.1.1.2. Partial Hit

The pedestrian is only partially struck by a vehicle corner as can be seen in figure 3.6. The boundaries between a complete and partial hit are fluent.

Figure 3.6.: Partial hit (DEKRA, n.d.)

3.1.1.3. Streaking Hit

The pedestrian is only struck by side structures as shown in figure 3.7. There is no impact between the pedestrian and the vehicle leading edge, bonnet, windscreen or roof. Relatively high collision speeds are survivable as barely any impact energy is induced.

Figure 3.7.: Streaking hit (DEKRA, n.d.)

3.1.2. Front-end Geometry

The front-end geometry has an impact on the injuries sustained by the pedestrian (Schmitt et al., 2010).

There have been various scientific works to classify different front-end geometries. DEKRA defines four different geometries, namely trapezium, pontoon, wedge and box form (see figure 3.8).

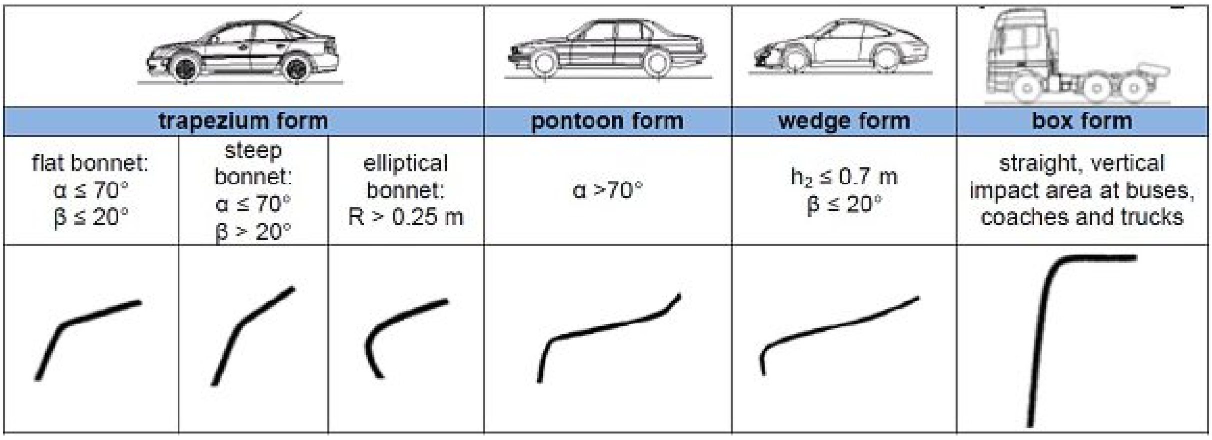


Figure 3.8.: Front-end geometry classification according to Dettinger (Schreiner, 2011)

3.1.3. Collision Speed / Closing Speed

The collision speed directly affects the injury likelihood. However, the front-end geometry has an impact on the pedestrian's kinematics and dynamics. While certain body parts are hit with collision speed, other body parts impact with the vehicle structure after a time offset. In these cases, the actual impact speed of the body parts is different to the collision speed. This impact speed is defined as the closing speed.

Hence, collision speed is the speed with which the striking vehicle hits the pedestrian, and is therefore a property of the vehicle. Closing speed is the speed with which the pedestrian's body part to be analysed impacts with the striking vehicle, and is therefore a property of the pedestrian.

These relations have been analysed by Kühnel (1980), who defined a ratio between the closing speed and collision speed (see equation 3.1).

$$C = \frac{closing\,speed}{collision\,speed} \tag{3.1}$$

3.1.4. Local Vehicle Stiffness

The local vehicle stiffness is another important parameter determining the injury likelihood. Kühnel (1980) revealed that an increase in local vehicle stiffness has a larger detrimental effect on the injury likelihood than an increase of the collision speed.

The local vehicle stiffness determines the detaching speed, which links the secondary and tertiary hits with the primary hit (Schäuble, 2014). By lowering the detaching speed, the impact energy of the secondary and tertiary hits are lowered too, consequently leading to a reduced injury likelihood. The detaching speed and contact time between the pedestrian and the vehicle are inversely proportional to each other. The contact time can be increased by providing a longer deformation path, which depends on the local vehicle stiffness.

3.2. Biomechanics of the Pedestrian Accident

3.2.1. Analysis of real-world Pedestrian Accidents

A total of 21 real-world pedestrian accidents has been analysed in depth in terms of pedestrian injuries and vehicle damages.

Spec sheets outlining which injury was caused by what vehicle structure were created for every single accident and can be found in appendix A.

However, the analysis of these data only provides guiding values, as it would be necessary to analyse a much larger sample size, in order to draw scientifically sound conclusions. Moreover, there is a selectivity bias towards more severe accidents, as the analysed dataset primarily contains pedestrian accidents with a severe injury outcome. The vehicles are also of older model years. These limitations must be taken into account.

3.2.1.1. Injury vs. Vehicle Structure

The pedestrians suffered 334 injuries altogether.

It was possible to assign the injury-causing vehicle structure to 250 injuries, whereas it was not possible to ascertain exactly which vehicle structure has caused the injury in 83 cases. These injuries were either caused by multiple vehicle structures or several different vehicle structures may have caused the injury. The cause of injury was not determinable in a single case. Further analysis will limit itself on the 250 injuries assigned to a single vehicle structure.

The vehicle structures have been bundled into three groups based on the pedestrian kinematics and dynamics during the contact phase, i.e. during the primary, secondary and tertiary impacts. These groups are the bumper, bonnet and windscreen area. However, the pedestrians also sustained some injuries solely caused by the secondary hit, i.e. by the impact with the ground. No injuries were caused by the tertiary hit. The distribution of the 250 injuries in respect to these three vehicle structure groups plus the ground is depicted in figure 3.9.

Impact Area The distribution of the injury severity caused by the impact area is depicted in figure 3.10.

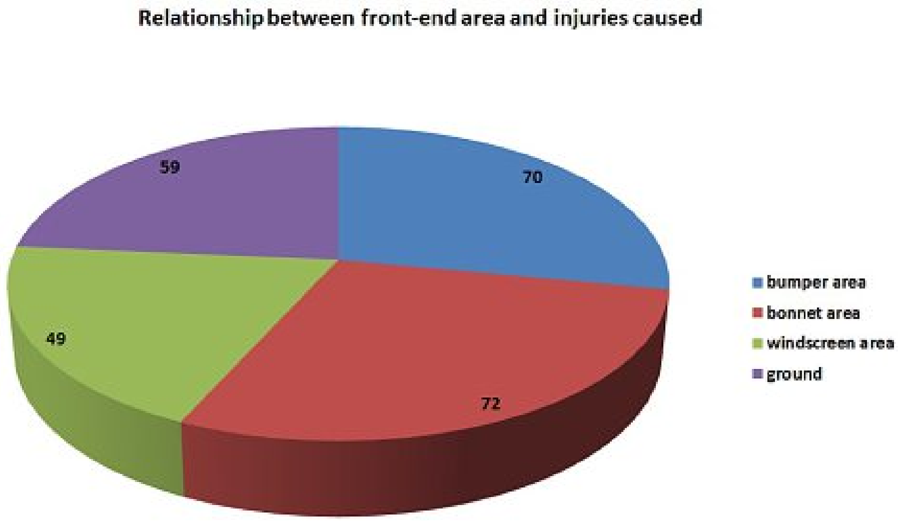
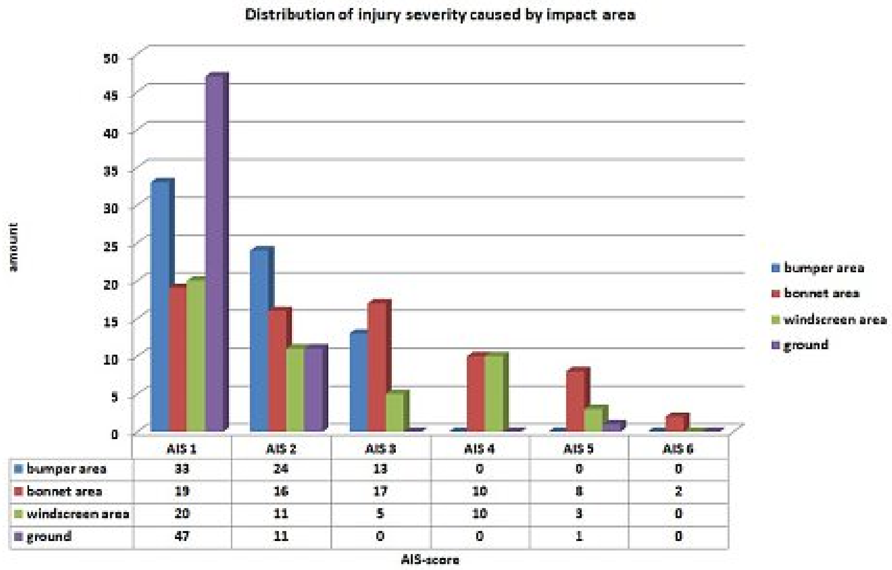


Figure 3.9.: Relationship between front-end area and injuries caused



	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6
bumper area	33	24	13	0	0	0
bonnet area	19	16	17	10	8	2
windscreen area	20	11	5	10	3	0
ground	47	11	0	0	1	0

Figure 3.10.: Distribution of injury severity caused by impact area

The bumper and front spoiler have been grouped into the category “bumper area”. The pedestrian’s legs are also included in this category, as the leg directly hit by the bumper hit the other leg in some cases, which resulted in injuries to the far side leg. Solely AIS 1 to AIS 3 injuries are caused by this group. The distribution of the types of injuries caused by the bumper area is displayed in figure 3.11.

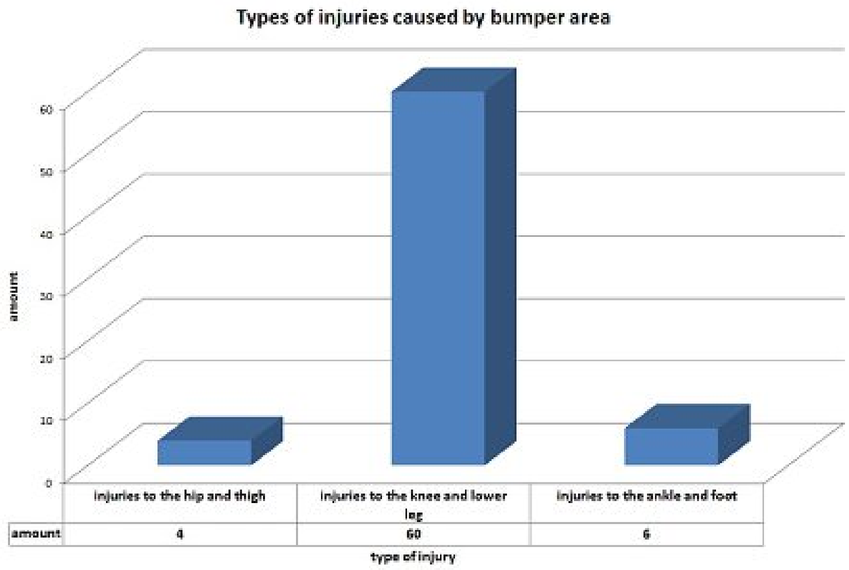


Figure 3.11.: Types of injuries caused by bumper area

The bonnet, bonnet leading edge, bonnet rear edge, edge between bonnet and fender, front panel and the radiator grill have been grouped into the category "bonnet area". Injuries ranging from AIS 1 to AIS 6 were caused by this group. The distribution of the types of injuries caused by the bonnet area is displayed in figure 3.12.

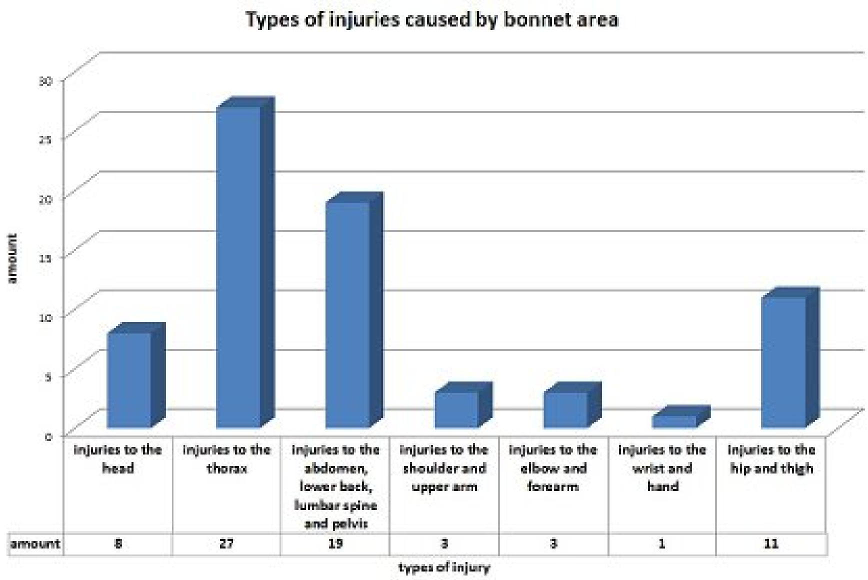


Figure 3.12.: Types of injuries caused by bonnet area

The A-pillar, roof leading edge, windscreen and windscreen wiper have been grouped into the category “windscreen area”. The sustained injuries range from AIS 1 to AIS 5. The distribution of the types of injuries caused by the windscreen area is displayed in figure 3.13.

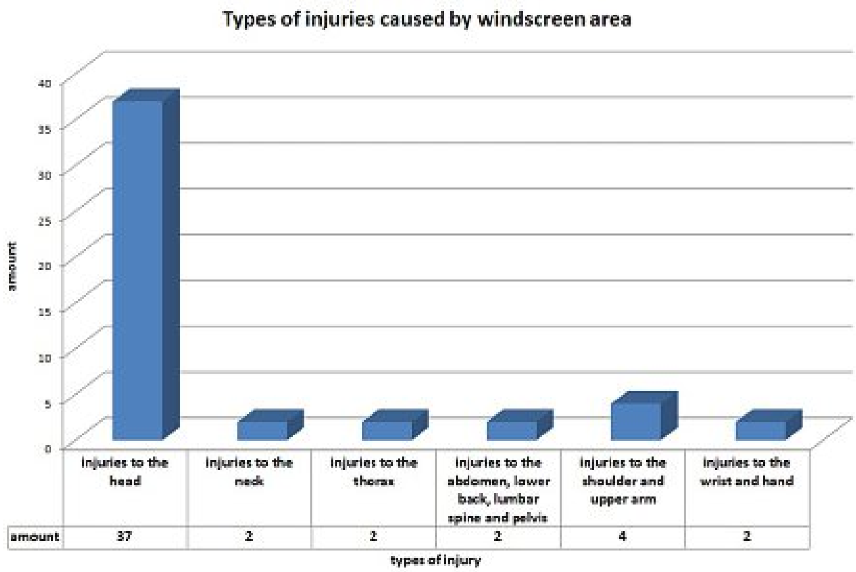


Figure 3.13.: Types of injuries caused by windscreen area

The ground and kerbstone have been grouped into the category “ground”. AIS 1 to AIS 2 injuries have been primarily caused by this group. In a single case, however, an AIS 5 injury resulted from the hard impact with the road surface. The distribution of the injuries caused by the ground is displayed in figure 3.14.

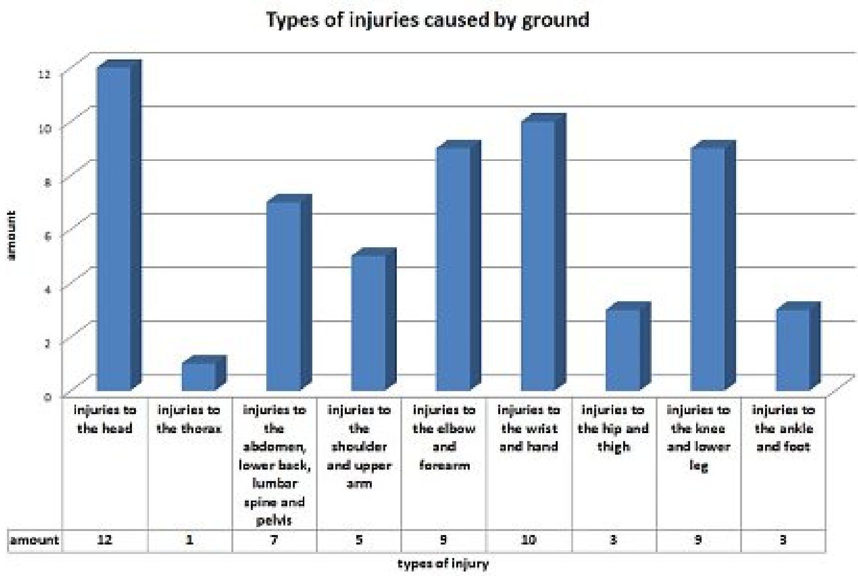


Figure 3.14.: Types of injuries caused by ground

Schäuble (2018) concluded that the fracture patterns of long bone fractures in the lower limbs, knee joint injuries, injuries to the ankle, pelvic injuries and head injuries can be used for reconstruction purposes. The biomechanics of these injuries will be presented in the following chapter and these injuries will further serve as the benchmark for the determination of the ATDs' biofidelity.

3.2.2. Injury Biomechanics

3.2.2.1. Thorax Injuries

Anatomy of the Thorax The rib cage and the soft tissue organs protected by the former make up the thorax. The diaphragm, the lower boundary of the thorax, separates the thoracic cavity from the abdominal cavity. The upper boundary is the base of the neck.

Twelve pairs of ribs form the rib cage. While all those twelve ribs are connected to the thoracic vertebrae posteriorly, solely the top seven are connected to the sternum anteriorly. Ribs 11 and 12 are referred to as the "floating ribs", because they are only connected to muscles and the abdominal walls, while the costal cartilage of ribs 8 to 10 articulates with the costal cartilage of rib 7.

The left and right outer region as well as the mediastinum subdivide the thoracic cavity into three regions. While the two outer regions host the two lung lobes, the mediastinum hosts the heart, trachea and large vessels among others.

Two layers of membranes surround the lung. The visceral pleura encloses the lung tissue, while the parietal pleura covers the interior side of the rib cage. The pleural cavity separates both membranes.

The thoracic anatomy is depicted in figure 3.15.

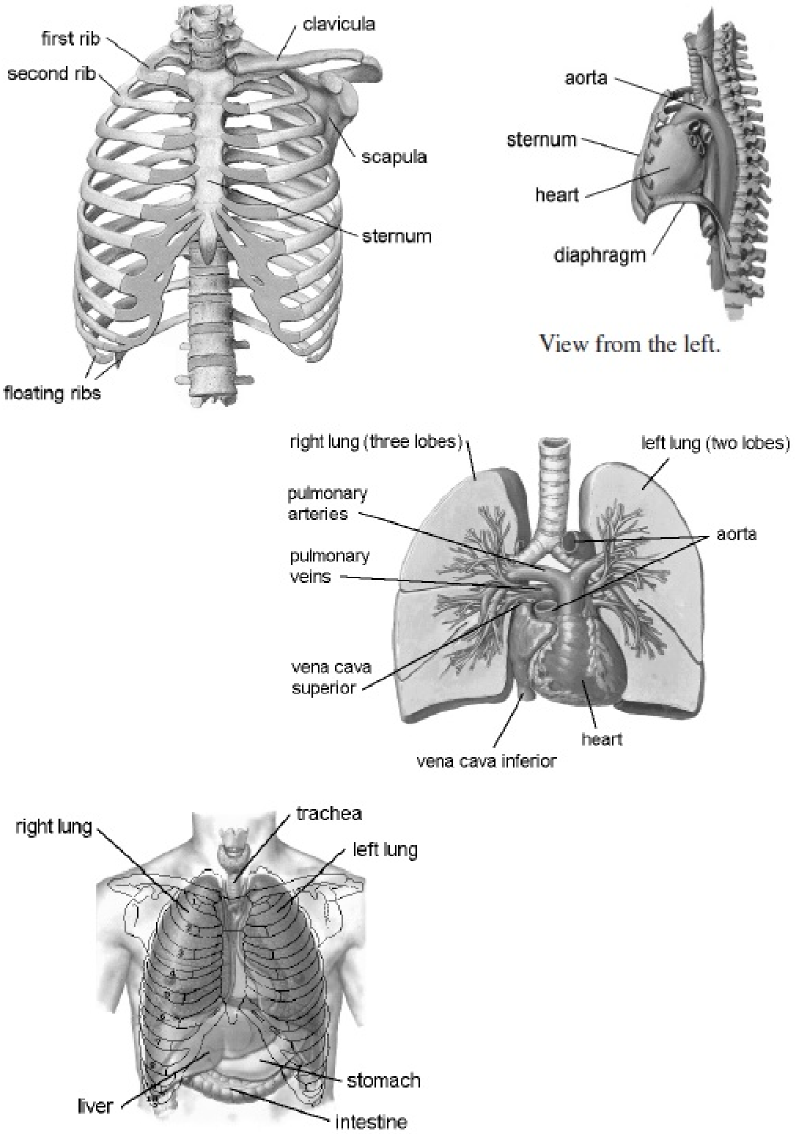


Figure 3.15.: The thoracic anatomy (Schmitt et al., 2010, p. 144)

Injury Mechanisms Blunt impacts are most likely in road traffic accidents, and hence only the injury mechanisms related to those will be covered, while those caused by penetration will be ignored.

Three different injury mechanisms or a combination of those can arise when the thorax is loaded due to a blunt impact such as with the bonnet (Schmitt et al., 2010). The mechanisms are compression, viscous loading and inertia loading of the internal organs, leading to either skeletal or soft tissue injuries. Possible soft tissue thoracic injuries are depicted by figure 3.16.

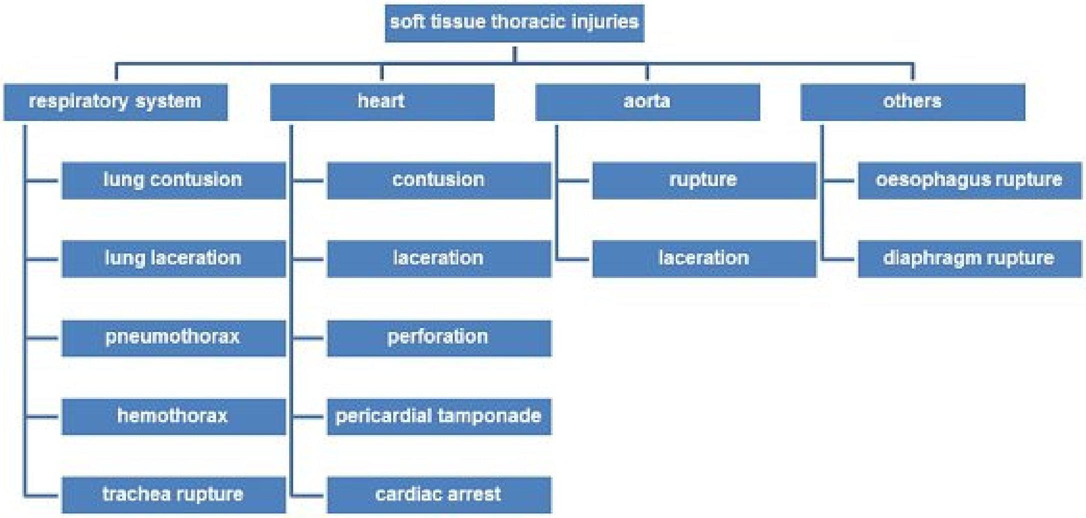


Figure 3.16.: Possible soft tissue thoracic injuries (own work according to Schmitt et al., 2010, p. 147)

Single rib fractures are more likely to occur under sagittal loading, whereas multiple rib fractures occur more frequently under lateral loading. Rib fractures can occur at any point along their length. However, fractures most likely occur at the point of maximum curvature or at the site of force application. Thus, lateral rib fractures are more common, as this is the site of maximum curvature. According to Schmitt et al. (2010), there appears to be a correlation between the force and number of rib fractures for a given loading rate.

3.2.2.2. Fracture Patterns of the Lower Leg's Long Bones

Anatomy of the Lower Leg The lower leg is formed by two long bones, the tibia and fibula (Schmitt et al., 2010). The tibia, the stronger and larger bone, is proximally connected to the knee and distally to the ankle bones. The fibula is connected to the tibia via the interosseous membrane. The fibula does not directly form part of the knee joint itself, but forms the lateral part of the talocalcanean joint. However, others argue that the fibula is part of the knee joint, as the lateral collateral ligament attaches to the former's head.

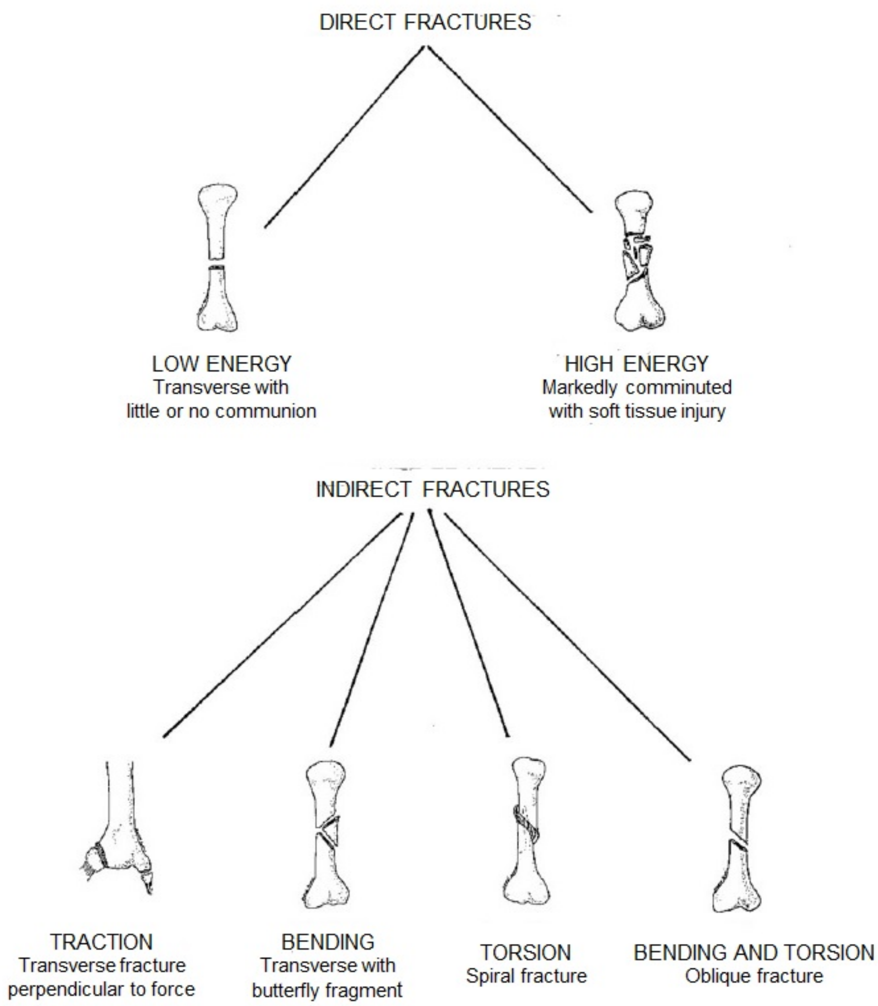


Figure 3.17.: Fracture patterns arising from direct and indirect loading. It should be noted that fractures due to bending may also arise as direct fractures (Schmitt et al., 2010, p. 189)

Injury Mechanisms Fractures are most common, and can either be classified as open or closed.

Four different fracture mechanisms can be distinguished based on the type of loading. These are direct loading, indirect loading, repetitive loading and penetration (see figure 3.17). Direct and indirect loading are the most important mechanisms in road traffic accidents.

When a pedestrian is hit by a vehicle, direct loading and bending occur. The Messerer's wedge fracture, a characteristic wedge-shaped fracture pattern, can be often found in pedestrians. The apex points in the direction of the vehicle's velocity vector (see figure 3.18).

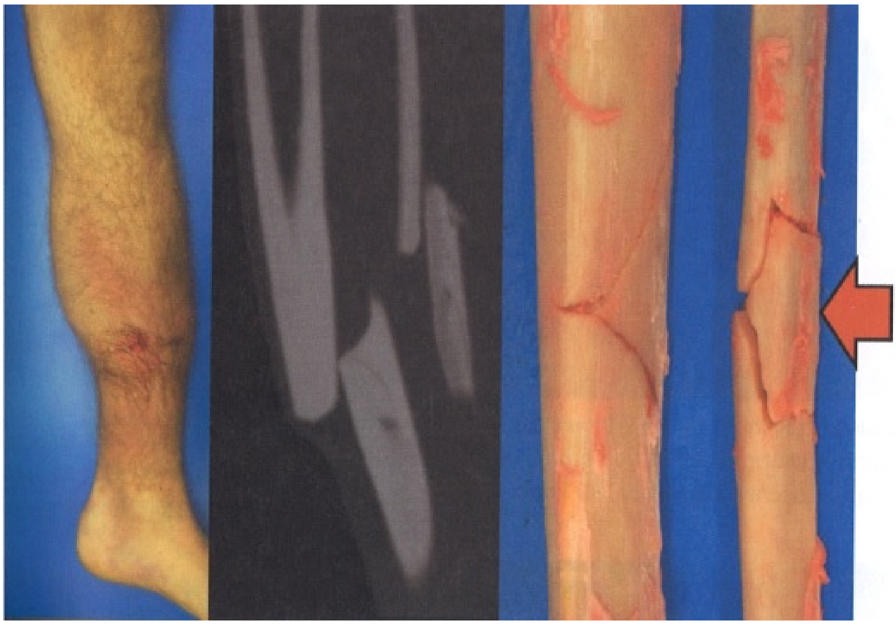


Figure 3.18.: Messerer's wedge fracture: Marks on the skin, CT-scan and autopsy preparation. The arrow indicates the impact direction (Hartwig, 2016, p. 457)

When the pedestrian rotates over the concerning limb, a torsional fracture may occur (Eubanks & Hill, 1998).

Low energy impacts primarily cause transverse fractures with little or no communion, whereas high energy impacts rather cause comminuted fractures with soft tissue injuries.

3.2.2.3. Knee Joint Injuries

Anatomy of the Knee The knee joint, which links the thigh to the lower leg, is made of four different bones, namely the femur, patella, tibia and proximal part of the fibula (see figure 3.19) (Traina et al., 2013).

The knee joint is stabilised by ligaments and tendons, the most important of which are the anterior and posterior cruciate ligaments, and the internal and external collateral ligaments. The knee's ligaments and tendons are displayed in figure 3.20.

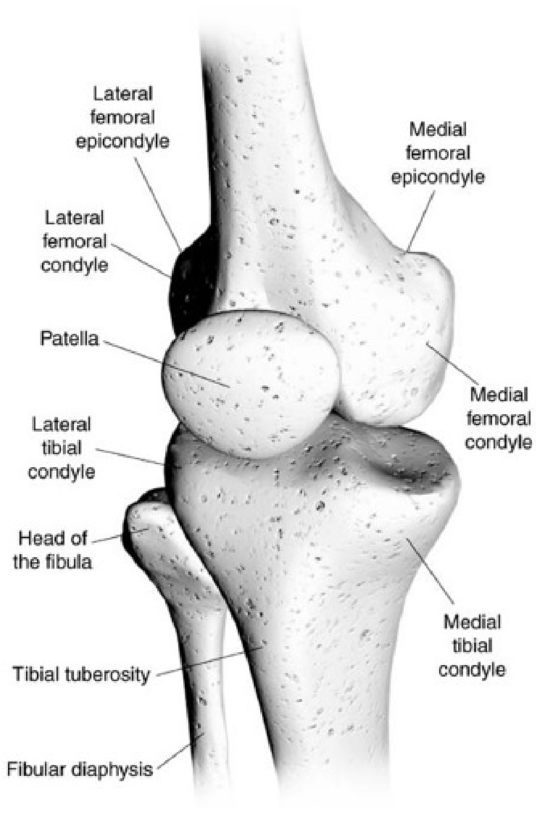


Figure 3.19.: The knee joint (Traina et al., 2013, p. 119)

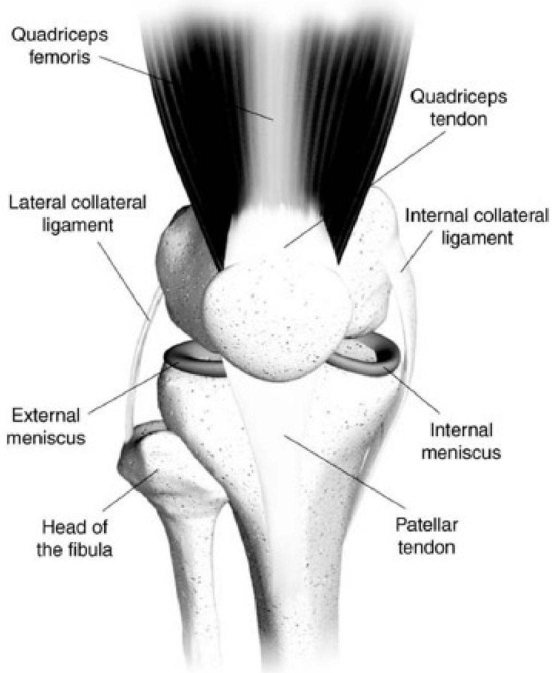


Figure 3.20.: Ligaments and tendons around the knee (Traina et al., 2013, p. 120)

Injury Mechanisms The impact parameters determine the underlying mechanisms of knee injuries (Teresinski & Madro, 2001b). Depending on their mechanism, knee injuries are classified as avulsive or compressive (see figures 3.21, 3.22 and 3.23).

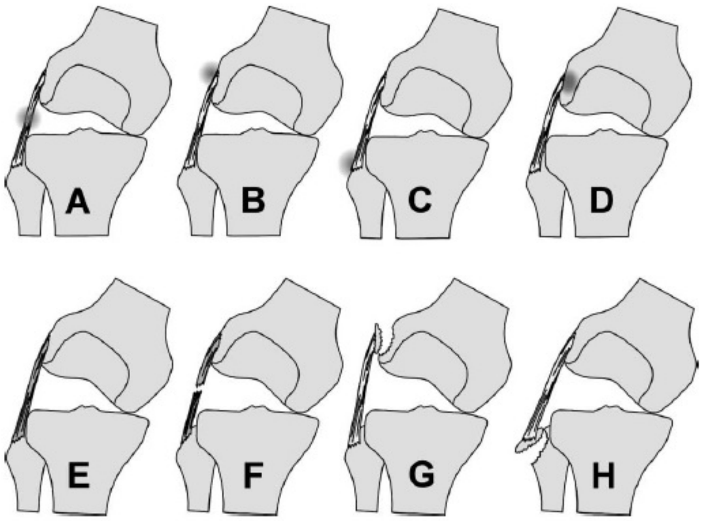


Figure 3.21.: Forms of injuries resulting from the avulsive mechanism presented on the example of the lateral collateral ligament. (A-C) Bruises along and at the sites of attachments with possible lengthening; (D) Bone bruise at the attachment site; (E) Lengthening; (F) Disruption; (G, H) Bone fragment avulsion Teresinski & Madro (2001b, p. 77)

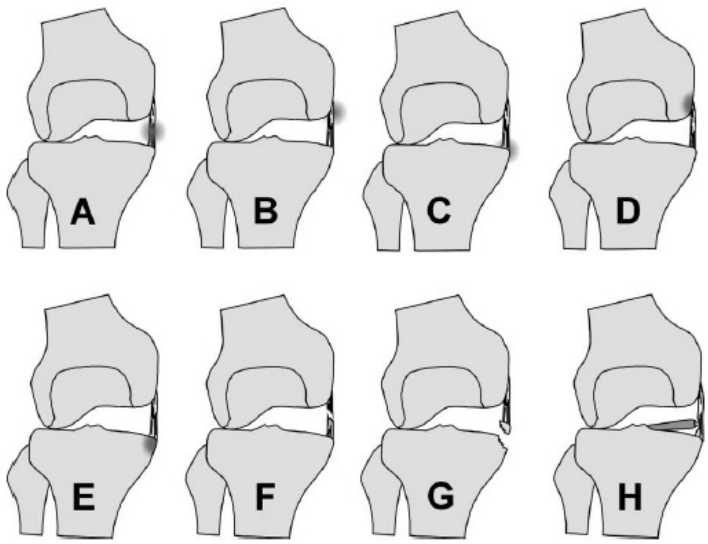


Figure 3.22.: Forms of injuries resulting from the avulsive mechanism on the example of the medial knee capsule. (A-C) Bruises along and at the sites of attachments with possible lengthening; (D,E) Bone bruises at the attachments; (F) Disruption; (G) The Segond's fracture; (H) Marginal meniscus separation (Teresinski & Madro, 2001b, p. 77)

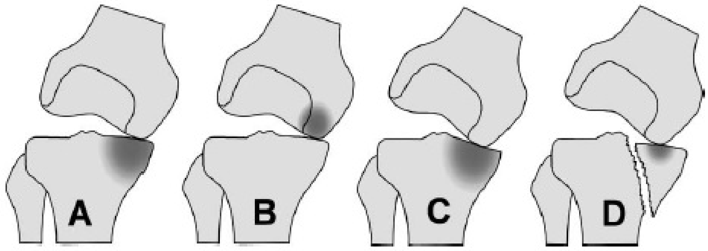


Figure 3.23.: Forms of injuries resulting from compression on the example of the mechanism varus flexion of the knee. (A,B) Bone bruises in the central parts of condyles and under the capsular surface; (C) Lowering of the condyle; (D) Tibial condyle fracture (Teresinski & Madro, 2001b, p. 78)

The different injury patterns caused by the avulsive and compressive injury mechanism can be used to determine the underlying mechanisms leading to the knee joint damage as displayed in figures 3.24, 3.25, 3.26 and 3.27.

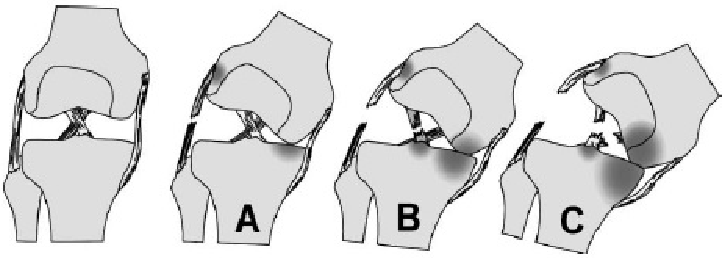


Figure 3.24.: Stages of the right knee injury (frontal view) in the mechanism of varus flexion. (A) Avulsion of the lateral collateral ligament; (B) Avulsion of the anterior cruciate ligament; (C) Avulsion of the posterior cruciate ligament. A → C increasing compression of the medial tibial and femoral condyles (Teresinski & Madro, 2001b, p. 78)

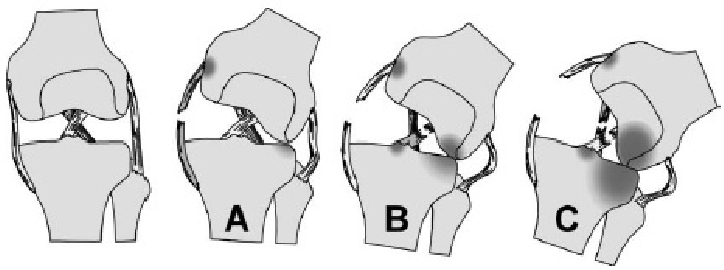


Figure 3.25.: Stages of the left knee injury (frontal view) in the mechanism of valgus flexion. (A) Avulsion of the medial collateral ligament; (B) Avulsion of the anterior cruciate ligament; (C) Avulsion of the posterior cruciate ligament. A → C increasing compression of the lateral tibial and femoral condyles (Teresinski & Madro, 2001b, p. 78)

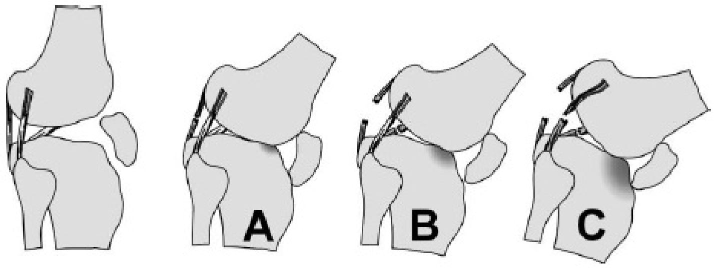


Figure 3.26.: Stages of the right knee injury (end view) in the hyperextension mechanism. (A) Avulsion of the posterior articular capsule; (B) Avulsion of the cruciate ligaments; (C) Avulsion of the collateral ligaments. A $\rightarrow$ C increasing compression of the anterior tibial margin (Teresinski & Madro, 2001b, p. 78)

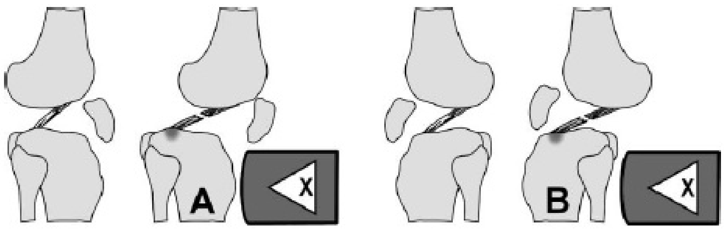


Figure 3.27.: Avulsion of the posterior cruciate ligament (A) of the right knee joint (end view) in the posterior dislocation and of the anterior cruciate ligament (B) in the anterior dislocation of the proximal tibial epiphysis in relation to the femoral condyles (X: force application) (Teresinski & Madro, 2001b, p. 79)

Under certain conditions, however, the injuries are caused by the opposite mechanism to the expected one Teresinski & Madro (2001b). Vehicles whose front-end geometry induce a negative angular momentum, i.e. box-shaped type 2 vehicles, were found responsible for most of these “reversed” mechanisms (see figures 3.28, 3.29 and 3.30, parts D). Vehicles with very low front-end structures, i.e. wedge-shaped vehicles, were found to be responsible for the remaining “reversed” mechanisms (see figures 3.28, 3.29 and 3.30, parts A). The pedestrian kinematics and dynamics during the primary impact primarily resemble the ones shown in figures 3.28, 3.29 and 3.30 parts B, and rarely those in parts C.

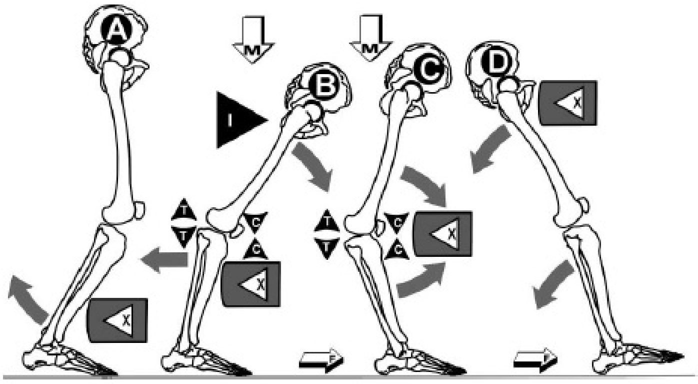


Figure 3.28.: Compressive (C) and tensile (T) forces at the knee level and directions of thigh and shin dislocation depending on the site of force application (X) in front impacts of pedestrians caused by various vehicles (M: body mass; F: friction force; I: inertia force) (Teresinski & Madro, 2001b, p. 80)

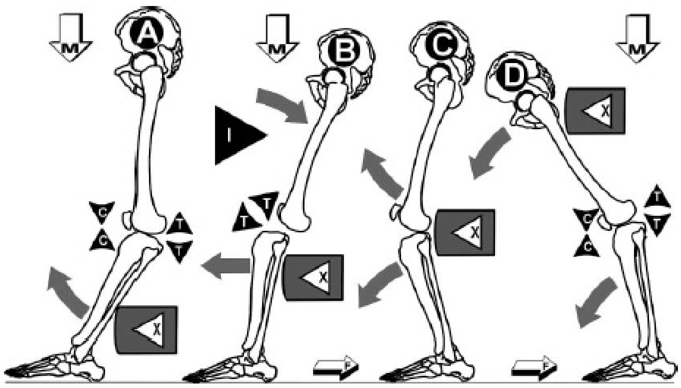


Figure 3.29.: Compressive (C) and tensile (T) forces at knee level and directions of thigh and shin dislocation depending on the site of force application (X) in back impacts of pedestrians caused by various vehicles (M: body mass; F: friction force; I: interia force) (Teresinski & Madro, 2001b, p. 80)

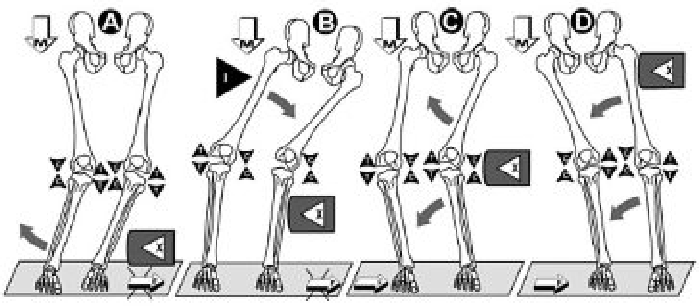


Figure 3.30.: Compressive (C) and tensile (T) forces at the knee level and directions of thigh and shin dislocation depending on the site of force application (X) in lateral impacts of pedestrians caused by various vehicles (M: body mass; F: friction force; I: inertia force) (Teresinski & Madro, 2001b, p. 80)

3.2.2.4. Injuries to the Ankle

Anatomy of the Ankle The lower leg is linked to the foot by the ankle joint, which is a synovial joint. The lower leg's tibia and fibula and the foot's talus form the ankle as depicted in figure 3.31. The medial and lateral ligaments stabilise the ankle joint as shown in figures 3.32 and 3.33. Figure 3.34 displays the key anatomical ankle motions.

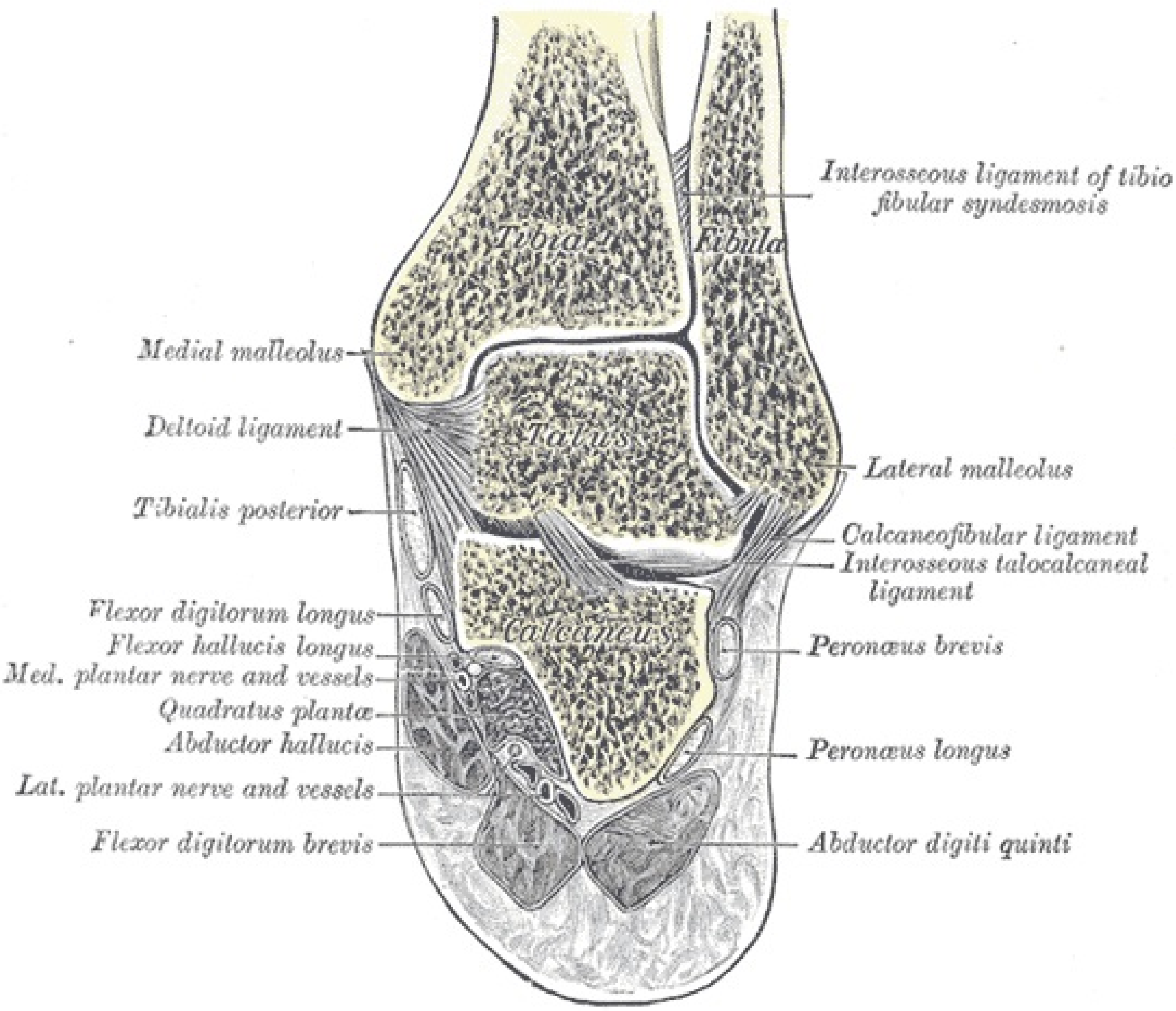


Figure 3.31.: Schematic of ankle joint (Gray, 1918c)

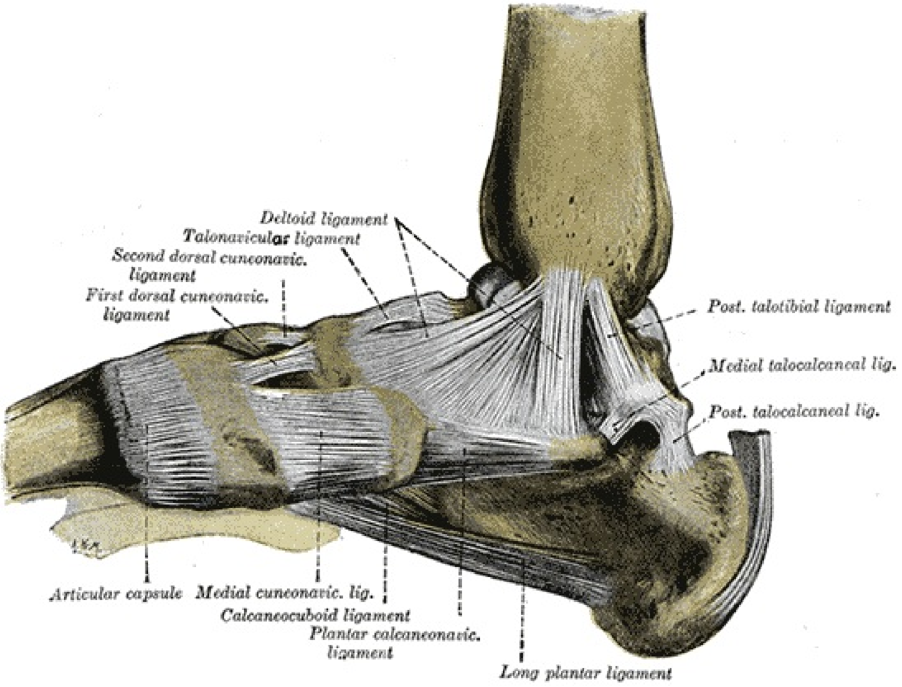


Figure 3.32.: Medial ligament of ankle joint (Gray, 1918a)

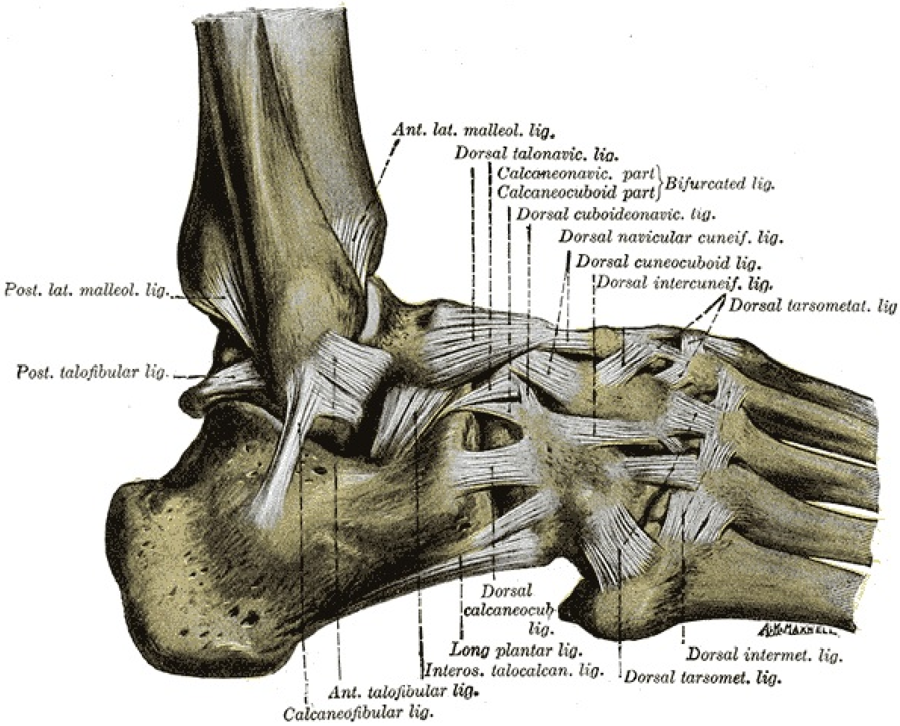


Figure 3.33.: Lateral ligament of ankle joint (Gray, 1918b)

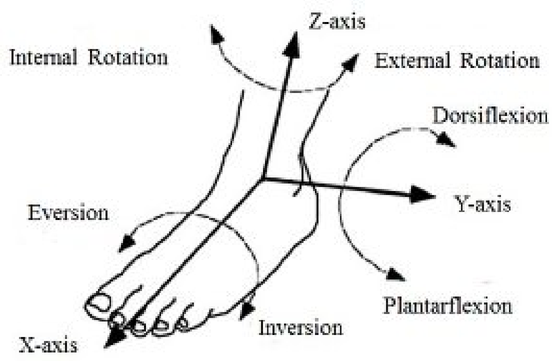


Figure 3.34.: Anatomical motions of hindfoot joints (Schmitt et al., 2010, p. 193)

Injury Mechanisms Ankle joint injuries can be distinguished between four different injury mechanisms with different stages as displayed in table 3.1. The first part of the name indicates the position of the foot while the injury occurs, whereas the second part indicates the direction of force application and foot dislocation. Interestingly, injuries occurring in stage I of all fractures are caused by tensile forces, while the injuries in stages II to IV are caused by compressive forces. In order for this to occur, the limb needs to be loaded with the body weight.

Table 3.1.: Classification of malleolar fractures according to Lauge-Hansen (own work according to Teresinski & Madro, 2001a, p. 67)

	Type of fracture	Stage I	Stage II	Stage III	Stage IV
A	Supination-adduction	Horizontal fracture of lateral malleolus at or below the level of ankle joint or rupture of lateral malleolus ligaments	Vertical fracture of medial malleolus	Not appears	Not appears
A'	Supination-rotation	Rupture of anterior tibio-fibular ligament	Spiral or oblique fracture of lateral malleolus	Fracture of posterior tibial margin	Fracture of medial malleolus or rupture of deltoid ligament
B	Pronation-abduction	Horizontal fracture of medial malleolus or rupture of deltoid ligament	Rupture of anterior and posterior tibio-fibular ligaments (often with fracture of posterior tibial margin)	Oblique fracture of lateral malleolus just above the level of ankle joint, often with displacement of a triangular fragment from the lateral surface of fibula	Not appears
B'	Pronation-rotation	Horizontal fracture of medial malleolus or rupture of deltoid ligament	Rupture of anterior tibio-fibular and interosseous ligaments	Fracture of fibula high above the level of ankle joint	Fracture of posterior tibial margin

Teresinski & Madro (2001a) also analysed ankle joint injuries depending on the direction of impact. Considering impacts from the lateral side, damages to the medial malleolus and the medial malleolus ligaments occurred the most often, while damages to the medial malleolus ligaments occurred the most often in impacts from the medial side. Impacts from the front only resulted in five damaged joints in the cadavers they analysed, while impacts from the rear resulted primarily in damages to the anterior part of the joint capsule.

Considering the ankle joint injury complexes depending on the direction of impact, Teresinski & Madro (2001a) established that pronation is the primary injury mechanism in impacts from the lateral side, while it is supination in impacts from the medial side. Regarding impacts from the front or rear, there is no distinct injury mechanism.

"Reversed complexes" can occur likewise to knee injuries. These complexes arise when the pedestrian is struck above the crus level. For such impacts, figures 3.35, 3.36, 3.37 and 3.38 display the injury mechanism for medial, lateral, front and rear impacts, respectively.

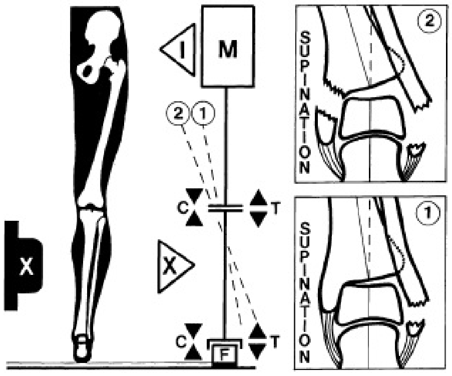


Figure 3.35.: The mechanism of the onset of the upper ankle joint injuries in the case of car impact on the lower extremity from the medial side (X: Place of impact application; M: Body weight; I: Direction of the inertia force; C: Compressive forces; T: Tensile forces; F: Force of friction and $0, 1, 2$: Degree of pathological dislocation) (Teresinski & Madro, 2001a, p. 72)

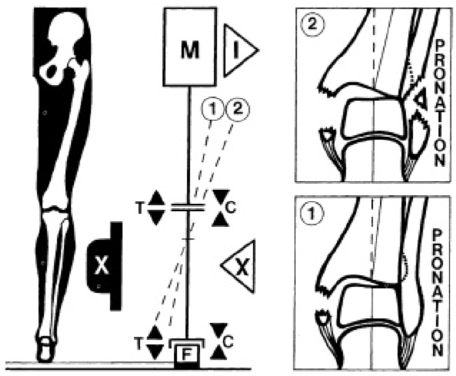


Figure 3.36.: The mechanism of the onset of the upper ankle joint injuries in the case of car impact on the lower extremity from the lateral side (abbreviations as in figure 3.35) (Teresinski & Madro, 2001a, p. 72)

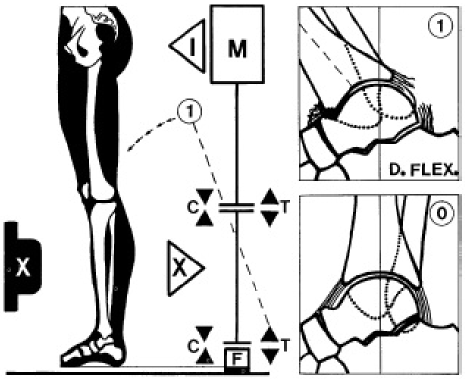


Figure 3.37.: The mechanism of the onset of the upper ankle joint injuries in the case of car impact on the lower extremity from the front (abbreviations as in figure 3.35) (Teresinski & Madro, 2001a, p. 72)

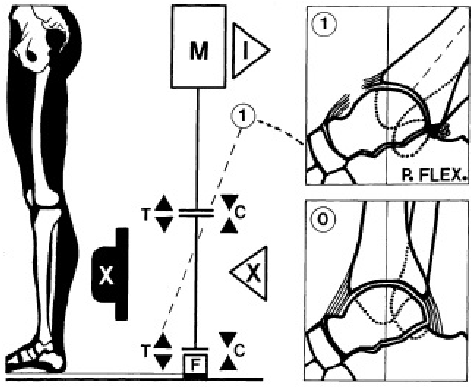


Figure 3.38.: The mechanism of the onset of the upper ankle joint injuries in the case of car impact on the lower extremity from the rear (abbreviations as in figure 3.35) (Teresinski & Madro, 2001a, p. 73)

3.2.2.5. Pelvic Injuries

Anatomy of the Pelvis and Hip Joint The pelvis is made up of basically four bones (Schmitt et al., 2010). Two hipbones form the side and front walls, while the sacrum and coccyx form the rear wall as shown in figure 3.39. The hipbones are formed by the ilium, ischium and pubis, which are fused bones. The acetabulum, which forms part of the hip joint, is further hosted by the hipbones. The right and left pubic bones form the frontal part of the pelvis. The pubic symphysis joins these bones together. The pelvis is moreover the only load path transmitting the torso's weight to the ground by linking the spinal column to the lower extremities.

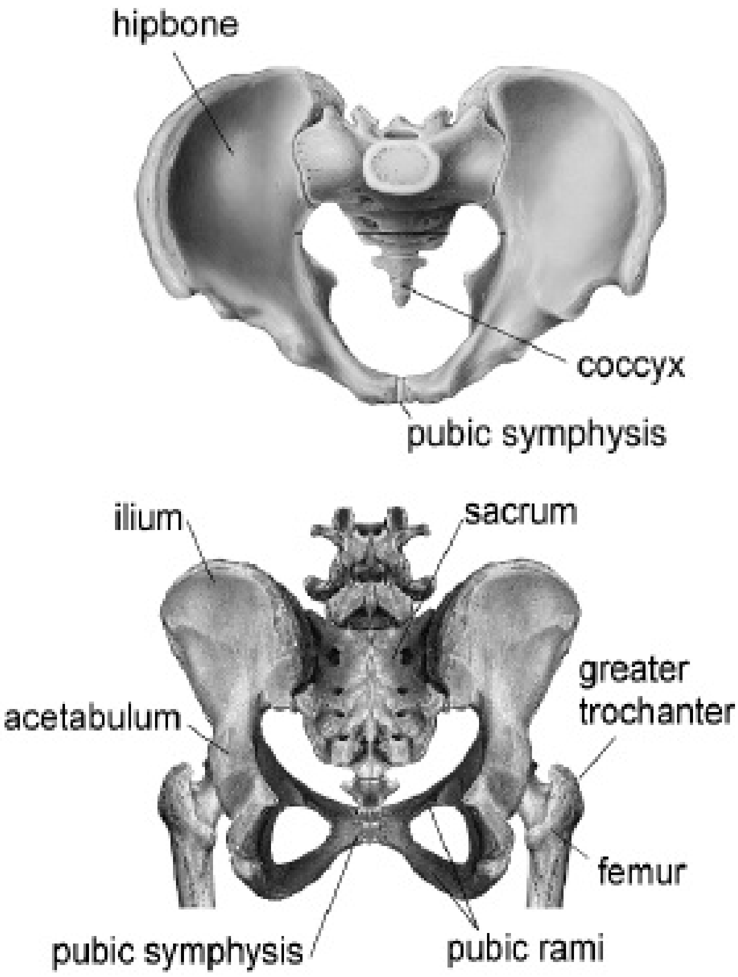


Figure 3.39.: The bony structures of the pelvic girdle (Schmitt et al., 2010, p. 184)

Injury Mechanisms Direct, indirect and avulsion-like are the three injury mechanisms related to hip girdle injuries (Teresinski & Madro, 2001c). The direct mechanism causes the injuries to occur at the site of force application, whereas the indirect mechanism causes the injuries to occur at the site of greatest tension caused by the deformation. Rapid muscle strain causes bone fragments to break off at the location of tendon attachment in the avlusion-like mechanism. While the former two mechanisms occur in pedestrian accidents, the latter mechanism is primarily related to sports injuries.

Figure 3.40 displays the pelvic injuries which can be found in lateral impacts, while figure 3.41 depicts the mechanisms of central fracture or dislocation of the hip acetabulum.

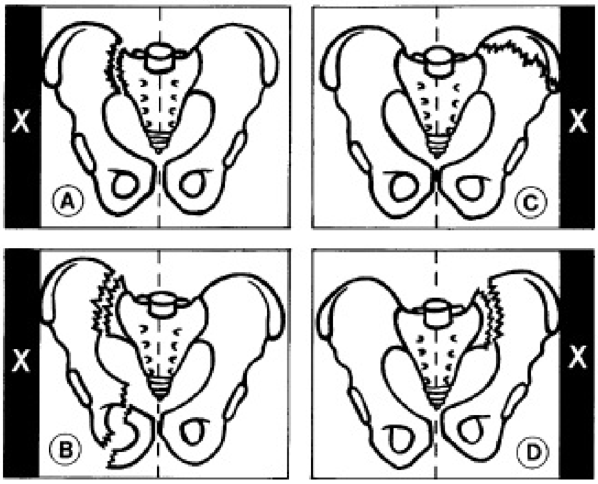


Figure 3.40.: Pelvic injuries found in lateral impacts (X: Impact side; A: Separation of the right sacroiliac joint; B: Double vertical fracture of the pelvic girdle on the right - the so-called Malgaigne's fracture; C: Fracture of the left iliac ala; D: Vertical fracture of the left iliac bone and pubic symphysis separation) (Teresinski & Madro, 2001c, p. 69)

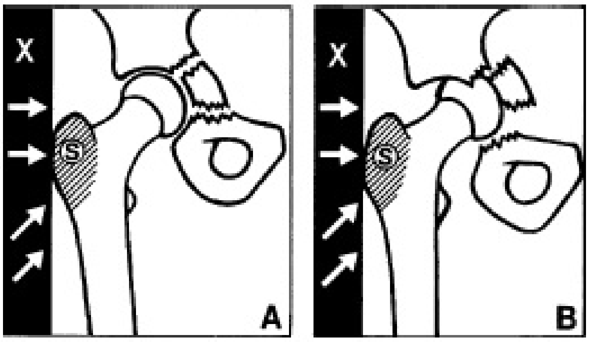


Figure 3.41.: Mechanism of central fracture (A) or dislocation (B) of the hip acetabulum (X: Impact side; S: Intraosseous suffusions within the greater trochanter) (Teresinski & Madro, 2001c, p. 69)

3.2.2.6. Head Injuries

Anatomy of the Head The human cranium (head) is a multi-layered structure, with the scalp, skull, meninges and central nervous system being the layers from the outside to the inside (see figure 3.42).

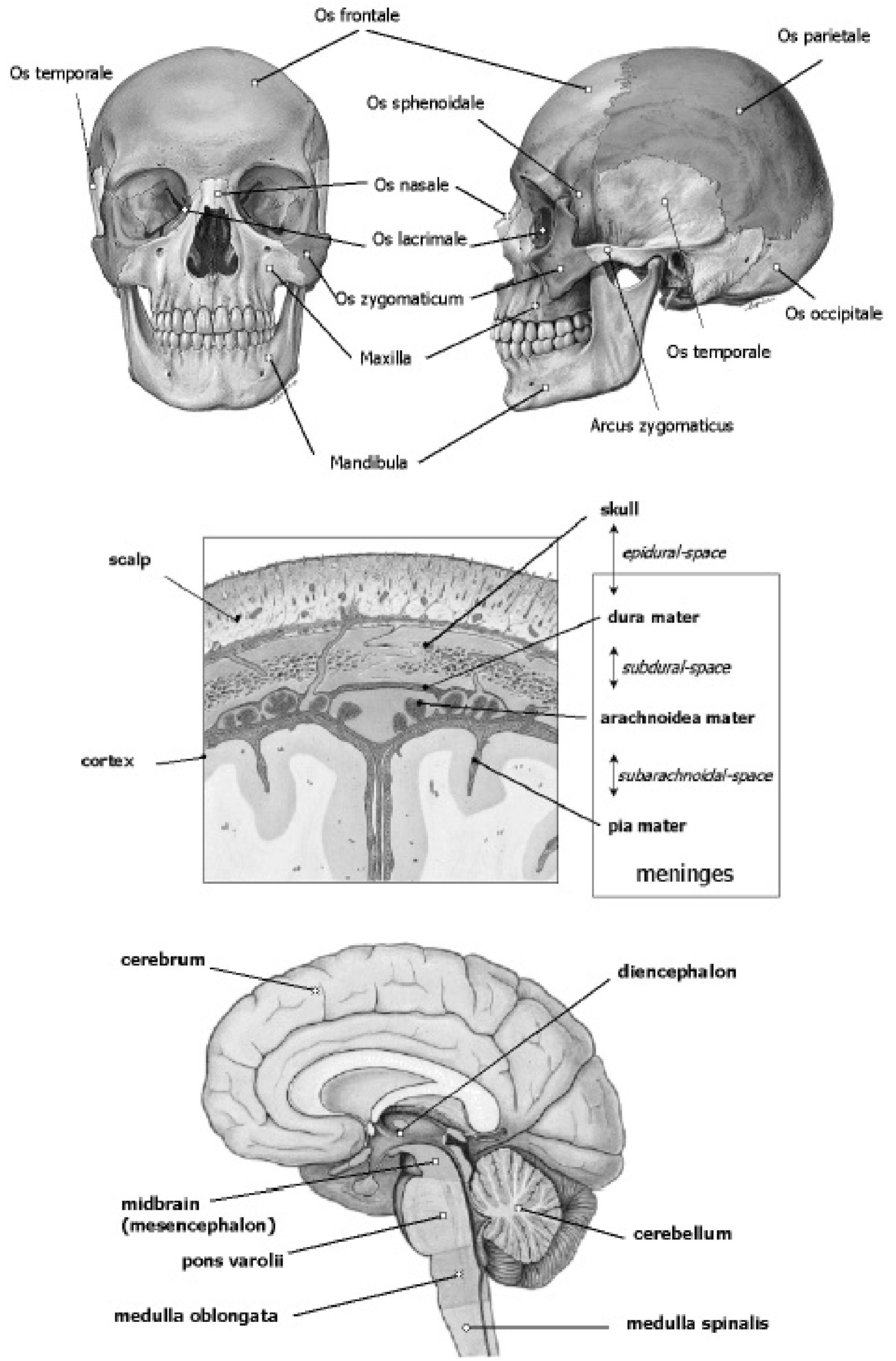


Figure 3.42.: Anatomy of the head: bony structures of the skull (top), the meninges (middle), and the brain (bottom) (Schmitt et al., 2010, p. 64)

Injury Mechanisms Skull and brain injuries are the two groups head injuries can be subdivided into.

Critical skull injuries are primarily fractures, which are distinguished between basilar and vault fractures.

Diffuse and focal injuries are the two categories brain injuries are subdivided into.

Static and dynamic loading are the two injury mechanisms leading to head injuries as shown in figure 3.43.

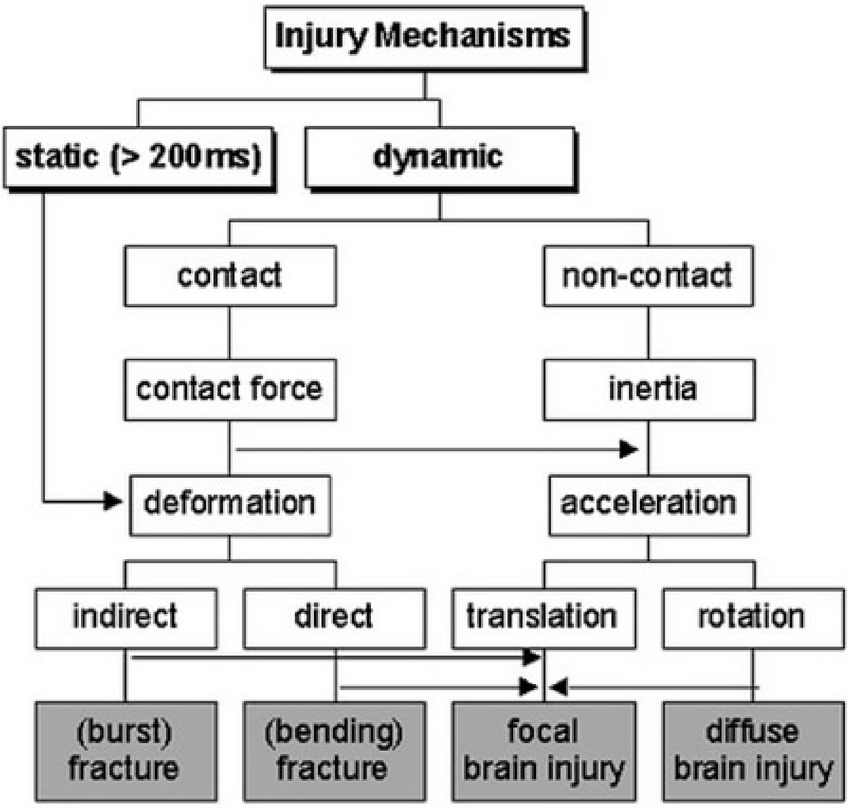


Figure 3.43.: Possible mechanisms for head injury (Schmitt et al., 2010, p. 68)

Static loading, however, is rare in pedestrian accidents and rather indicative of a pedestrian's head being run over by the vehicle's wheel. Dynamic loading, on the other hand, is the common mechanism in pedestrian accidents. Contact and non-contact scenarios are distinguished, which result in different responses (Schmitt et al., 2010). Under contact loading, stress waves are induced and propagate through the skull or brain (see figure 3.44). Under non-contact loading, the loading is solely due to inertial forces.

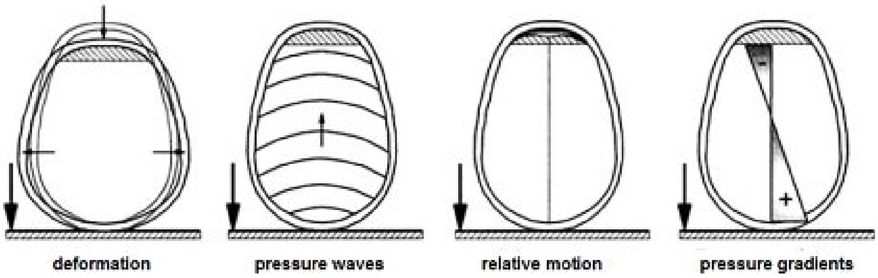


Figure 3.44.: Different injury mechanisms for contact impact; fractures do not necessarily occur (Schmitt et al., 2010, p. 69)

4. Analysis of Vehicle-Pedestrian Crash Tests

In the summer of 2018, DEKRA has conducted nine crash tests with the Biofidelic Dummy in conjunction with AXA Insurance in Wildhaus, Switzerland. Crash tests with the Žilina Dummy have been conducted earlier, of which four have been chosen for further evaluation.

The crash sequences of these crash tests can be found in appendix D.

The results of these thirteen crash tests will be compared with the in-depth analysis of the 21 real-world pedestrian accidents found in appendix A.

Table 4.1 provides an overview of the crash tests.

Table 4.1.: Overview of the crash tests

crash test	vehicle	collision speed	braking	dummy
wh18.22	BMW 1 Series 2004	75 km/h	pre-crash	biofidelic
wh18.23	BMW 1 Series 2004	99 km/h	in-crash	biofidelic
wh18.24	VW Touareg 2003	75 km/h	pre-crash	biofidelic
wh18.25	VW Touareg 2003	99 km/h	in-crash	biofidelic
wh18.26	VW Passat Variant 2006	75 km/h	pre-crash	biofidelic
wh18.27	VW Passat Variant 2006	99 km/h	in-crash	biofidelic
wh18.28	Mercedes A-Class 2005	72 km/h	pre-crash	biofidelic
wh18.29	Mercedes A-Class 2005	96 km/h	in-crash	biofidelic
wh18.34	VW Touareg 2003	27 km/h	in-crash	biofidelic
wh08.27	Ford Galaxy 1998	40 km/h	pre-crash	Žilina
wh08.28	BMW 523i 1998	40 km/h	pre-crash	Žilina
wh08.29	Toyota Avensis 1998	40 km/h	pre-crash	Žilina
wh10.12	Fiat Punto 1996	55 km/h	late or unbraked	Žilina

4.1. Dummy Trajectories

In order to obtain the trajectories of the different ATDs, the crash test videos were analysed by the programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998-2006$ FalCon GmbH).

The frame rate of the videos is 500 pictures/s. Time is set to zero at the point of first contact between the pedestrian and vehicle, which is visualised by means of a light signal mounted on top of the vehicle. The coordinate system, which is required for the programme to make its calculations, has its origin at the first target on the vehicle. The x-direction faces in the direction of travel, while the y-direction faces upwards. The dummy targets, used by the programme to track the dummy movements, had to be applied manually to the dummy. Targets were applied to the head, hip and foot. Every body region was analysed three-times and the average value was calculated, in order to reduce any errors stemming from manually placing the targets on the dummy. Every 10^{th} picture has been analysed, i.e. the time interval between the different measurements is $0.02\,s$. The value $s\,(x)$ has been calculated relative to the vehicle. “FalCon” provides txt-files as data output, which have been uploaded into Excel, with which the lines have been drawn. The final trajectory graphs have been created with CorelDraw.

The obtained measurements can be found in appendix E.

4.1.1. Biofidelic Dummy

4.1.1.1. BMW 1 Series (crash tests wh18.22 and wh18.23)

The results for the trajectories are seen in figure 4.1.

It can be clearly seen that the “suck below”-effect of the foot increases with increasing collision speed. Due to the friction force and the inertia of the foot, the latter has less time to react to the impact at greater collision speeds, and is therefore sucked below the bumper.

This can produce large bending and shear forces. While the legs are catapulted higher into the air at the lower collision speed, the lower extremities remain rather stuck to the vehicle's front due to the higher "suck below"-effect at the higher collision speed. In the meantime, however, the dummy's torso is accelerated and moves along the vehicle's contour, leading to extensive stretching of the dummy. Without the wet suit, the dummy would most probably have been torn apart. Kolla et al. (2017) report in their study a probability of dismemberment at a collision speed of $100\,km/h$ of 0.281947 as mean, 0.157408 as lower and 0.514652 as upper value. Hence, the extensive stretching of the dummy is not unrealistic. Due to a lack of cadaveric tests at such high collision speeds, it is, however, difficult to assess the exact biofidelity of the dummy's stretching behaviour.

In crash test wh18.22, the thigh is pushing backwards the headlight assembly, which creates a sharp edge at the front part of the left fender. As the dummy further slides onto the bonnet, this edge begins to pierce the dummy's leg. Such injuries are known from real-word accidents, and the dummy's behaviour and the vehicle's damage are realistic.

The head also moves further along the vehicle's contour with an increase in speed. As such, while the head still impacts the windscreen at $70\,km/h$, the head impacts the roof leading edge at $100\,km/h$.

The hip is also further elevated at the higher speed, partially due to the extensive stretching.

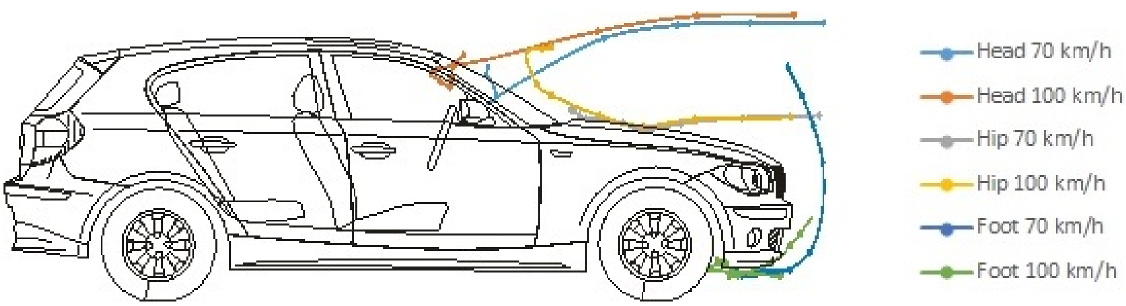


Figure 4.1.: Dummy trajectories of crash tests wh18.22 and wh18.23

4.1.1.2. VW Touareg (crash tests wh18.24, wh18.25 and wh18.34)

The dummy trajectories are shown in figure 4.2.

At $30\,km/h$, there is hardly any "suck below"-effect, and the hip impacts against the bonnet leading edge. The chest rolls onto the bonnet, before the tertiary impact occurs at roughly mid-bonnet. Thereafter, the lower extremities begin to swing upwards. The dummy dynamics and kinematics are in accordance with the theory.

At $70\,km/h$, the "suck below"-effect is again much more pronounced. The hip impacts the bonnet leading edge again, while the torso begins to roll onto the bonnet. Due to the greater collision speed and hence greater impact energy, the dummy starts to stretch again, with the head impacting the windscreen. After some while, the hip rolls over the bonnet leading edge and the whole dummy slides onto the bonnet.

At $100\,km/h$, the dummy movements are quite similar at the beginning, though the "suck below"-effect is even more pronounced. Ultimately, the dummy begins to slide off the fender sideways, before the heads contacts the A-pillar roughly halfway along it. The dummy does not only stretch at the waist, but also at the lower extremities, which is explained by the "suck below"-effect. Finally, the legs begin to swing upwards and the dummy looses contacts with the vehicle.

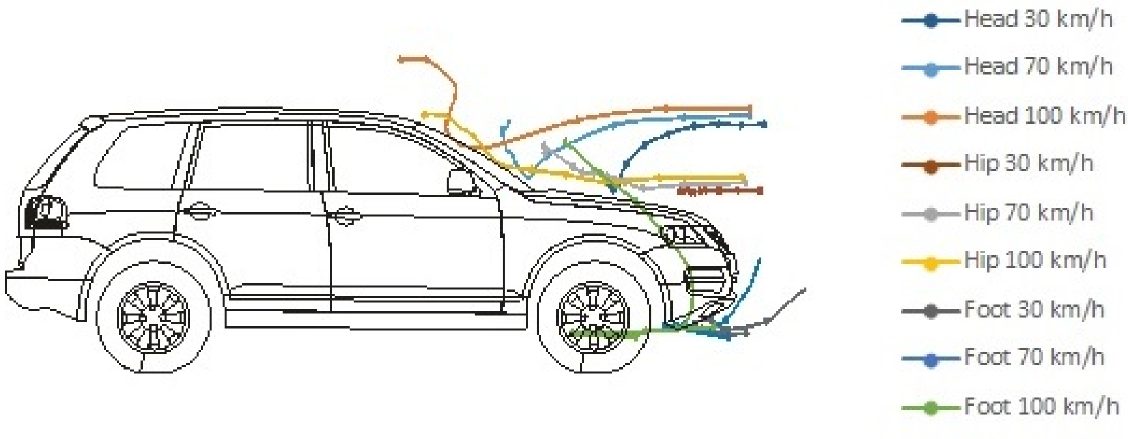


Figure 4.2.: Dummy trajectories of crash tests wh18.24, wh18.25 and wh18.34

4.1.1.3. VW Passat (crash tests wh18.26 and wh18.27)

The dummy trajectories are shown in figure 4.3.

As before, the "suck below"-effect increases with speed. At $100\,km/h$, the induced bending and shear forces cause the amputation of the right foot. This is in accordance with observations from real-world accidents.

At $70\,km/h$, the thigh impacts the bonnet leading edge and stretching of the lower extremities sets in as the torso rolls onto the bonnet. Stretching of the lower extremities is more pronounced than stretching at the waist. This is in contrast to crash test wh18.24. This deviating behaviour is explained by the different front-end geometries. While the hip can easily glide onto the Passat's bonnet, the hip is rather "held" back by the taller bonnet leading edge of the Touareg. As such, there is less stretching at the waist induced in the case of the Passat. Due to the impact, the headlight assembly is pushed backwards like in crash test wh18.22. This again creates a sharp edge which then pierces the dummy's leg. As the dummy easily glides onto the vehicle, the head finally impacts the roof leading edge.

At $100\,km/h$, the dummy's behaviour is quite similar, though stretching is more pronounced. While the head impacts the roof leading edge again, the shoulder and chest smash the windscreen, which causes the dummy to enter the passenger compartment. The dummy ultimately becomes stuck and travels with the vehicle. In a real-world accident, the intruding dummy/pedestrian would have posed a high risk for the driver.

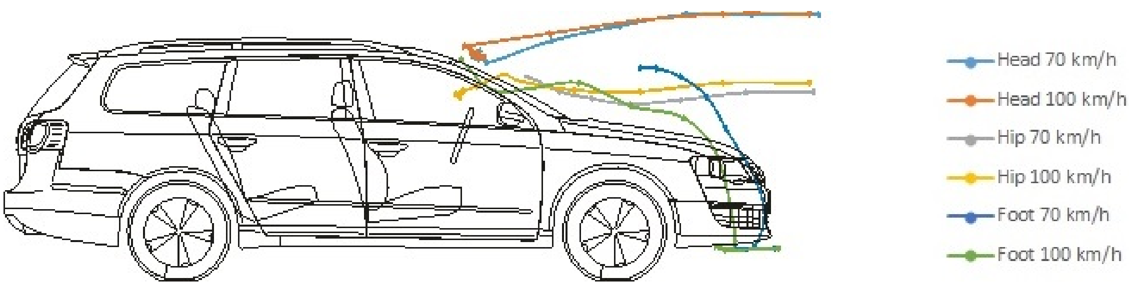


Figure 4.3.: Dummy trajectories of crash tests wh18.26 and wh18.27

4.1.1.4. Mercedes A-Class (crash tests wh18.28 and wh18.29)

The dummy trajectories are shown in figure 4.4.

Here, stretching seems to be less pronounced than in the other crash tests. This is explicable in the more van-like front-end geometry. As there is no “sharp” edge around which the dummy has to bend, the dummy easily glides onto the vehicle and the head directly impacts the roof leading edge. The legs swing upwards and lift the dummy, so that the latter is being catapulted over the vehicle.

At $100\,km/h$, however, the head smashed the windscreen and penetrates the passenger compartment. As the legs swing upwards, the dummy turns around the head. The head is pulled out of the windscreen as soon as the chest turned over the head, and the dummy is finally being catapulted over the vehicle.

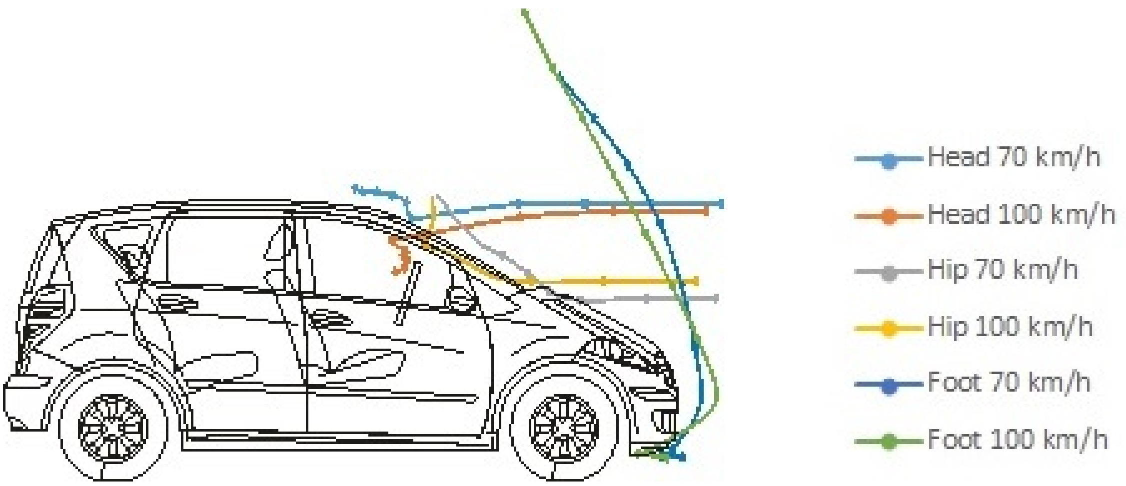


Figure 4.4.: Dummy trajectories of crash tests wh18.28 and wh18.29

Though there are certain similarities, it can be concluded that the front-end geometry has a major affect on the dynamics and kinematics of the dummy, as already known from the theory of the pedestrian accident.

4.1.2. Žilina Dummy

4.1.2.1. Ford Galaxy (crash test wh08.27)

The dummy trajectories are shown in figure 4.5.

The “suck below”-effect is much less pronounced, which has two reasons. First of all, the collision speed is much lower. Second, the dummy’s bones are made of steel. Thus, they bend less and the legs cannot huddle against the vehicle’s front-end geometry in the same way as the Biofidelic Dummy.

The legs are immediately catapulted away from the vehicle and the dummy rotates onto the bonnet around its CoM. The collision between the legs and the bumper is elastic.

The torso rolls onto the bonnet, while the dummy props itself on its arm, before the head impacts the windscreen. The rotation around the CoM continues.

Generally, the dummy remains stiff throughout the whole impact.

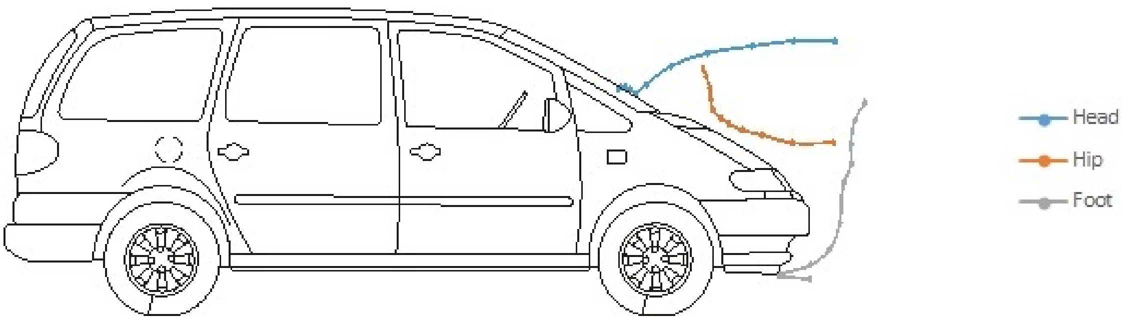


Figure 4.5.: Dummy trajectories of crash test wh08.27

4.1.2.2. BMW 5 Series (crash test wh08.28)

The dummy trajectories are shown in figure 4.6.

As before, the legs are immediately catapulted away and the dummy rotates around its CoM. The dummy further props itself on its arm again, while the torso glides onto the bonnet. This induces a rotation around sagittal plane. The head finally impacts the windscreen close to the cowl, while the legs still swing upwards. The dummy remains stiff throughout the whole impact again.

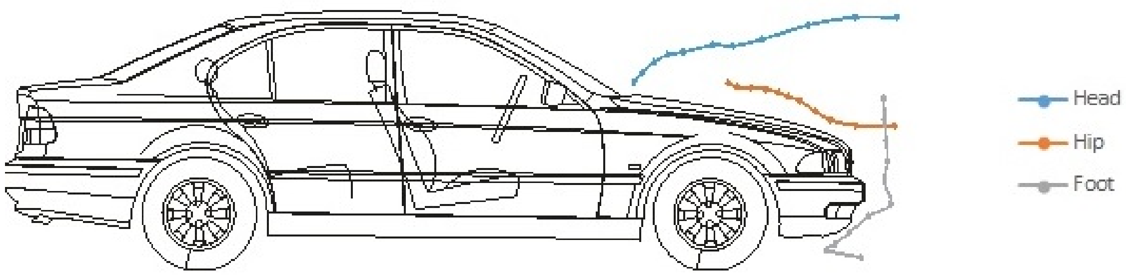


Figure 4.6.: Dummy trajectories of crash test wh08.28

4.1.2.3. Toyota Avensis (crash test wh08.29)

The dummy trajectories are shown in figure 4.7.

At the beginning, the dummy dynamics and kinematics are similar to the two previous crash tests. As soon as the dummy begins to props itself on its arm, however, the dynamics and kinematics start to differ a lot. The dummy propping itself on its arm lift the chest and hip, and causes the legs to swing upwards even more. The dummy remains on the bonnet propped on its arm, and then rotates around the arm like a seesaw, before the head seems to impact the bonnet rear edge just before the dummy disappears in the crash test video.

This behaviour is completely unrealistic, as a human being would not be able to prop themselves on their arm like the Žilina Dummy did. The weight of the chest would push it down onto the arm and "bury" the latter below it.

Again, the dummy remains stiff throughout the whole impact

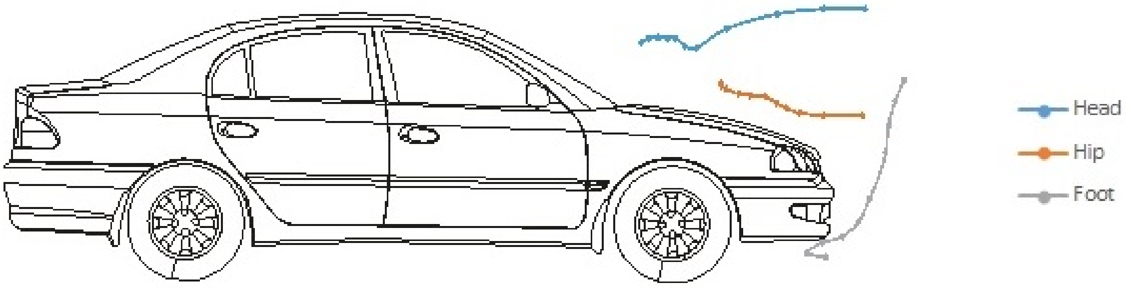


Figure 4.7.: Dummy trajectories of crash test wh08.29

4.1.2.4. Fiat Punto (crash test wh10.12)

The dummy trajectories are shown in figure 4.8.

As before, the legs remain stiff and there is hardly any “suck below”-effect. The dummy rotates around its CoM, while the legs swing upwards. The torso rolls onto the bonnet, though the dummy does not prop itself on its arm as much as it did in the previous crash tests. The head finally impacts the windscreen. The lower extremities still swing upwards and cause the dummy to rotate around the head.

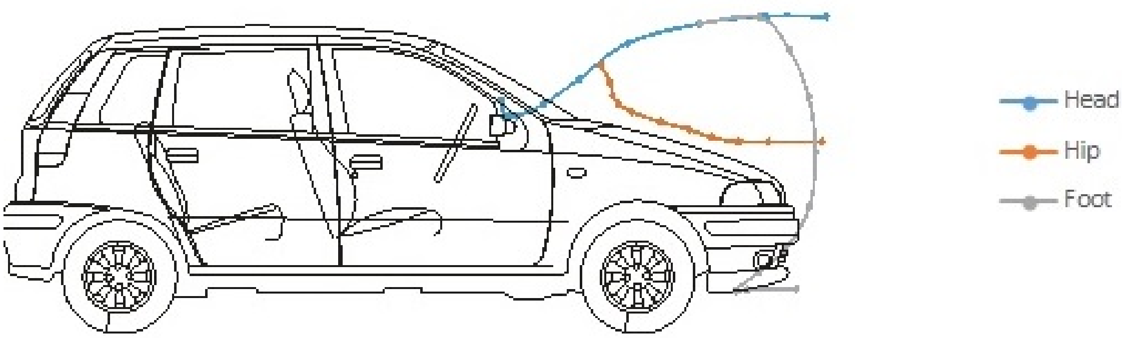


Figure 4.8.: Dummy trajectories of crash test wh10.12

4.1.3. Comparison between Biofidelic Dummy and Žilina Dummy

In contrast to the Biofidelic Dummy, which is a pseudoelastic body, the Žilina Dummy is an elastic body.

Considering crash test wh08.27, a speed for the leg of $44.87\,km/h$ was recorded $0.02\,s$ after impact. With a collision speed of $40\,km/h$, this would equal to a coefficient of restitution as shown in equation 4.1.

$$e = \frac{relative\,velocity\,after\,collision}{relative\,velocity\,before\,collision} = \frac{44.87}{40} = 1.12 \quad (4.1)$$

Normally, $e \leq 1$, but the determination of the dummy's velocity via the programme "FalCon" is afflicted with errors. Thus, it can be concluded that the collision is perfectly elastic. Human tissue, however, is pseudoelastic, which means that the tissue behaves plastically while a force is applied, and elastically when the force is removed. Hence, the dummy tissue, which has similar pseudoelastic characteristics as the human, is deformed by the impact force and causes the legs to huddle against the vehicle's front. Due to this plastic behaviour, impact energy is absorbed, which means that less energy is available for the legs to be catapulted away. In case of crash test wh18.22, for example, $e = \frac{47.06}{75} = 0.63$.

4.1.4. Comparison with PMHS-Tests

In order to validate the biofidelity of the trajectories of both the Biofidelic and Žilina Dummy, the findings are compared with PMHS-tests.

Subit et al. (2008) conducted altogether four PMHS-tests with a mid-sized sedan and a small city car with a collision speed of $40\,km/h$ at the Center for Applied Biomechanics of the University of Virginia. The four cadavers were male and exhibited no preexisting fractures, lesions or other bone pathology, though three of the subjects had poor bone mineral density.

The trajectories along the vehicle contour were obtained. Figure 4.9 displays the trajectories of the PMHS-tests with the mid-sized sedan, the Biofidelic Dummy tests with the VW Passat and the Žilina Dummy test with the Toyota Avensis. The VW Passat and Toyota Avensis were chosen for comparison as they should equal the mid-sized sedan in weight the most and also have a similar front-end geometry. However, the different collision speeds must be taken into account, making a direct comparison somewhat complicated.

As for the ATDs, the PMHSs exhibit the "suck below"-effect, before the lower extremities rebound and swing upwards. The trajectories of the PMHSs' lower extremities resemble a circle, while the Žilina Dummy's foot swings upwards much steeper. The trajectory of the Biofidelic Dummy's foot resembles rather the PMHS, though the lower extremities slide off the front-end in course of the impact, which makes a direct comparison somewhat difficult. Considering the head and hip, no big contrasts can be determined between the PMHSs and the ATDs. The only major difference is that the Žilina Dummy's head did not impact the bonnet/windscreen, as the dummy propped itself on its arm.

Subit et al. (2008) also determined the body part trajectories relative to the pelvis as shown in figure 4.10. The same computations were done for the Biofidelic and Žilina Dummy, and are depicted in figure 4.11. The measurements for the trajectories can be found in appendix F. As Subit et al. (2008) used the opposite orientation for the x-axis, i.e. facing opposite to the test vehicle's direction of travel, the $s(x)$-values were multiplied by -1 to obtain graphs with the same orientation. Graphs for each vehicle can be found in appendix G. While Subit et al. (2008) cut the trajectories off at the point of the head's impact, the present author computed the trajectories for $0.2\,s$ after the first collision between the vehicle and ATD regardless of the head's impact time.

The trajectories of the heads of both ATDs form a cloud and there are no major differences between the individual trajectories, even though the collision speed differs a lot between the Biofidelic and Žilina Dummy. Considering the feet of the ATDs, two clusters are formed, one for each the Biofidelic and Žilina Dummy. The feet of the Žilina Dummies swing upwards much faster, also inducing a faster hip rotation, while the feet of the biofidelic dummies swing upwards much slower. At the beginning, these trajectories are also pretty vertical, which is explained first by the “suck below”-effect, the huddling of the lower extremities against the front-end structure and finally by the stretching of the lower extremities.

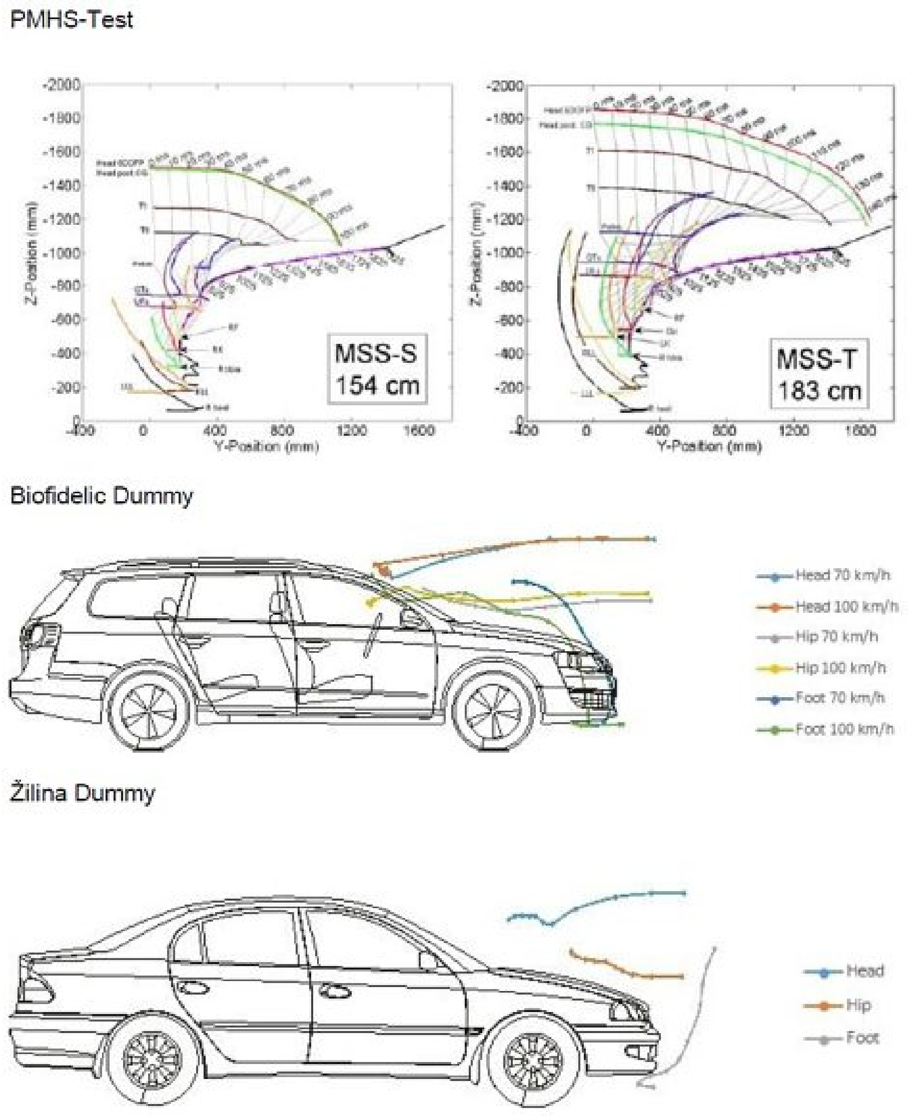


Figure 4.9.: Comparison between trajectories of PMHS, Biofidelic Dummy and Žilina Dummy. Top: MSS-S: mid-sized sedan small subject (body height); MSS-T: mid-sized sedan tall subject (body height); GT: greater trochanter; UF: upper femur; F: femur; K: knee; T: tibia; LL: lower leg; R: right; L: left (Subit et al., 2008, p. 280). Middle: crash tests wh18.26 and wh18.27. Bottom: crash test wh08.29

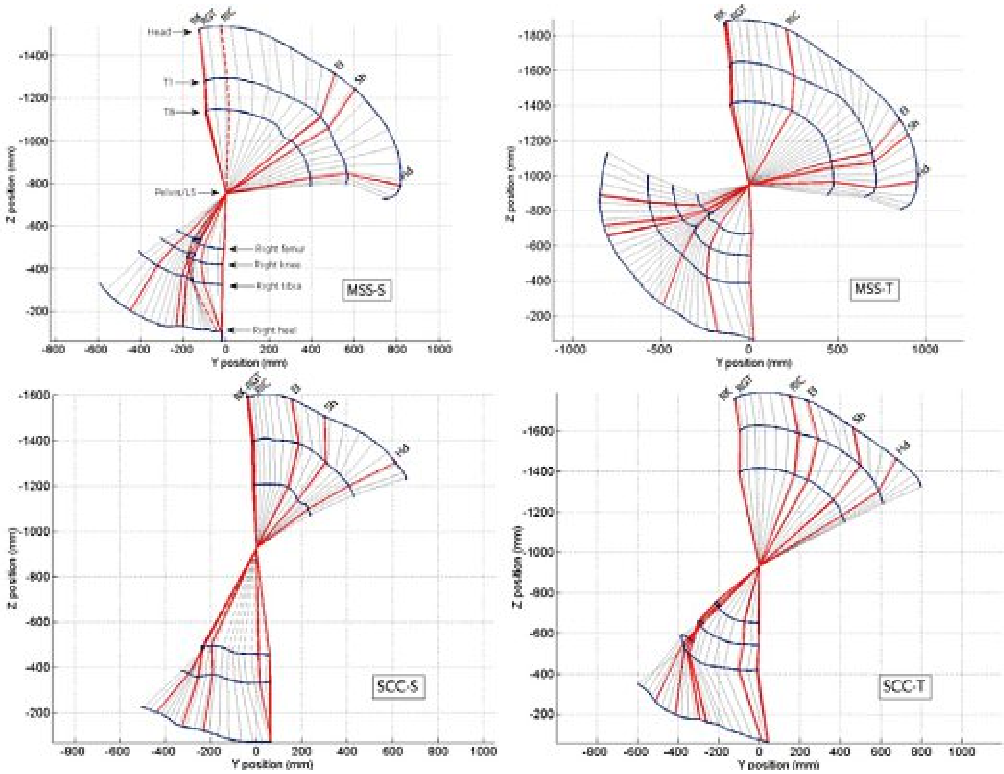


Figure 4.10.: PMHS trajectories relative to the pelvis. MSS-S: mid-sized sedan small subject; MSS-T: mid-sized sedan tall subject; SCC-S: small city car small subject; SCC-T: small city car tall subject (Subit et al., 2008, p. 281)

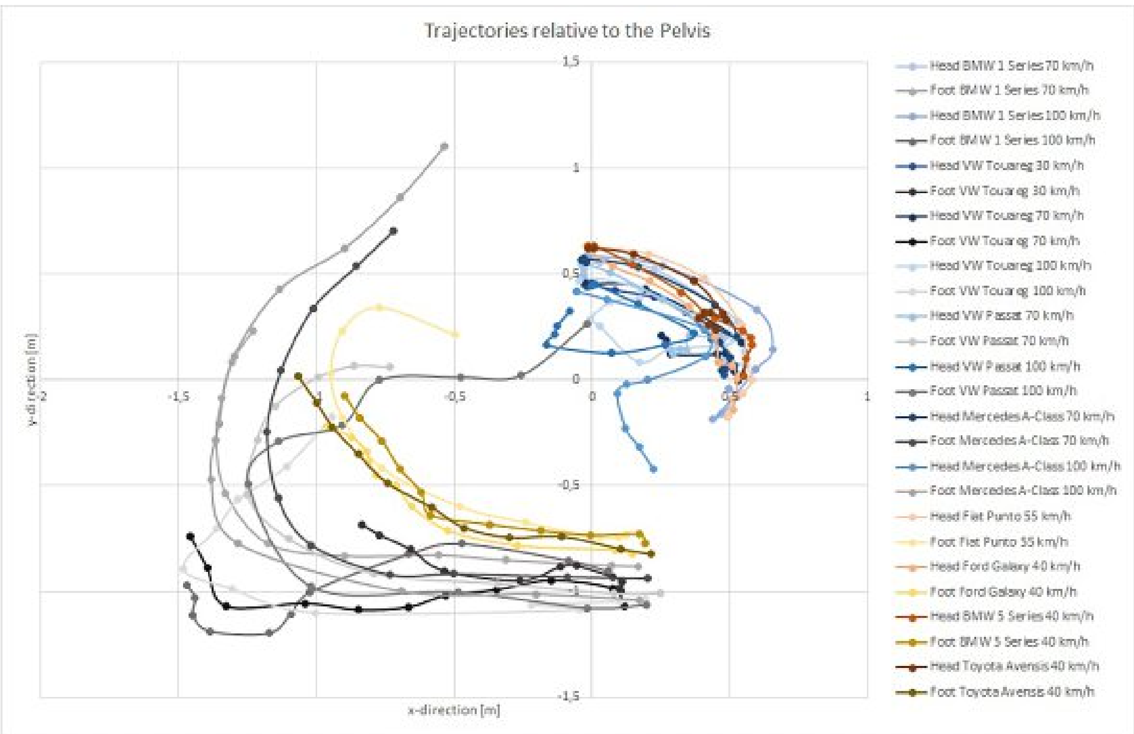


Figure 4.11.: ATD trajectories relative to the pelvis. Blue: Biofidelic Dummy's head; Grey: Biofidelic Dummy's foot; Orange: Žilina Dummy's head; Gold: Žilina Dummy's foot

Thus, there are no differences in the head trajectories relative to the pelvis between the Biofidelic and Žilina Dummy. However, the upper body kinematics are still different. Regarding the lower extremities, though, there are stark differences, primarily explained by the fact that the Biofidelic Dummy is a pseudoelastic body, while the Žilina Dummy is an elastic body.

Comparing the trajectories of the ATDs with the PMHSs, bearing in mind that the collision speeds are quite different, the trajectories of the Biofidelic Dummy match those of the PMHSs more than the Žilina Dummy does. The lower extremities of the PMHSs swing upwards in a slower manner just as the Biofidelic Dummy does, being explained by a prolonged contact phase between the PMHS's lower extremities and the vehicle's front-end compared to the Žilina Dummy, as the human body is a pseudoelastic body as well.

Kerrigan et al. (2005) conducted three PMHS-tests at $40\,km/h$ with a small sedan at the Center for Applied Biomechanics of the University of Virginia. Figure 4.12 shows the crash sequence of one of these tests compared with one Biofidelic Dummy test and Žilina Dummy test. These two crash tests have been chosen for comparison due to the same reasons as above. While the Toyota Avensis has the same collision speed of $40\,km/h$, it is stressed again that the collision speed of the VW Passat is much higher with $75\,km/h$.

The different kinematics of the Žilina Dummy can be easily noted, especially the fact that the chest props itself on the arm and thereby lifts the waist off the bonnet. The Biofidelic Dummy, on the other hand, huddles against the vehicle's contour.

Thus, it can be concluded that the trajectories of the Biofidelic Dummy are much more human-like than those of the Žilina Dummy. Particularly the "propping" effect of the latter is unnatural. These findings, however, come with the caveat that the collision speeds are quite different. Nonetheless, the tendency that the Biofidelic Dummy behaves more human-like cannot be dismissed.

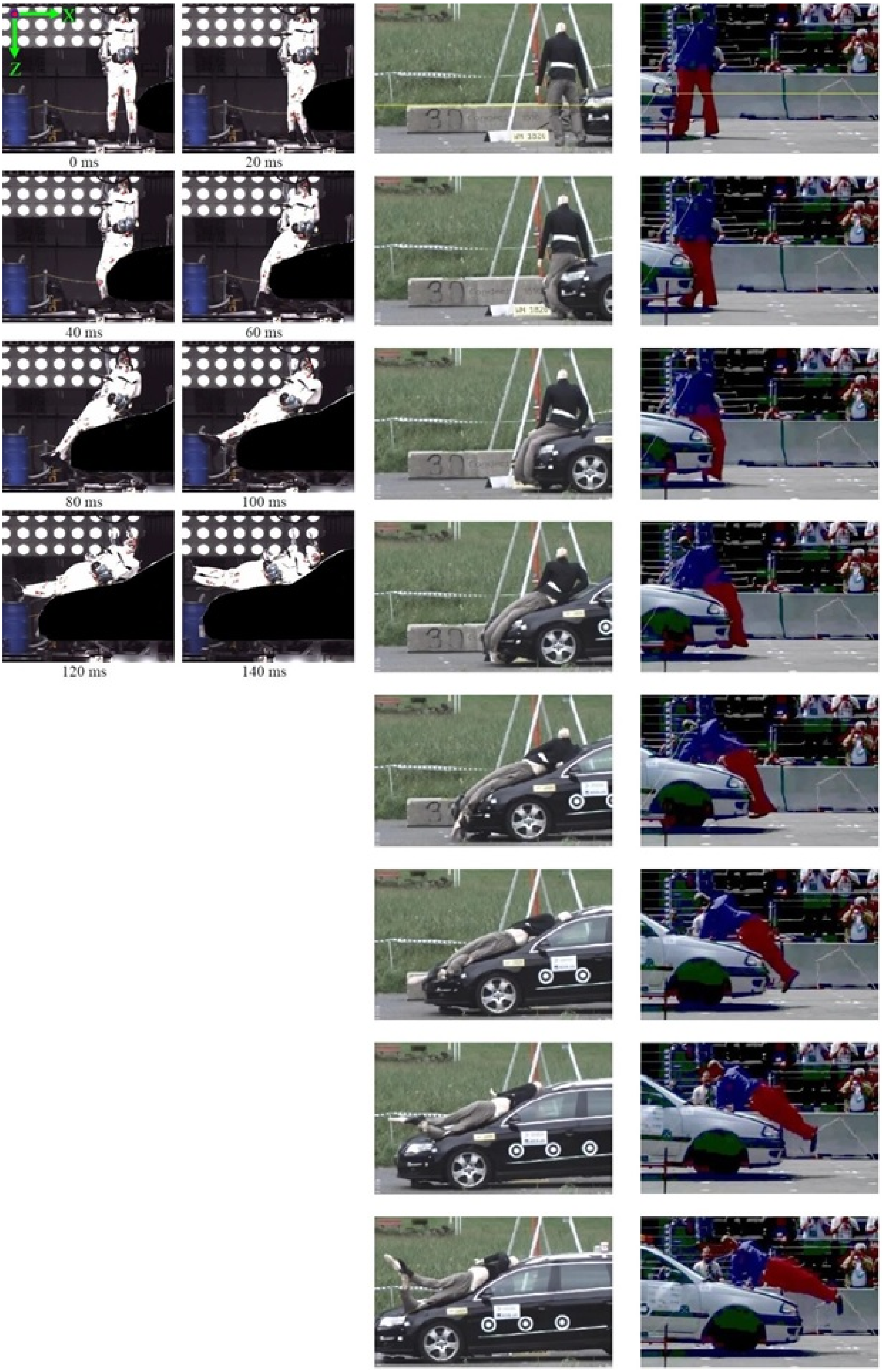


Figure 4.12.: Crash sequences of a PMHS (left) (Kerrigan et al., 2005, p. 7), Biofidelic Dummy (middle) and Žilina Dummy test (right) at $20\,ms$ intervals

4.2. Vehicle Damages

For reconstruction purposes, it is very important that the vehicle damages caused by the ATD are comparable to those caused by the pedestrian. Of the nine crash tests with the Biofidelic Dummy conducted by DEKRA in the summer of 2018, crash tests wh18.22 and wh18.26 are the only ones comparable to two of the analysed real-world accidents. The collision speed, dummy/pedestrian height and weight are still within an acceptable deviation.

Considering the Žilina Dummy, all four crash tests are considered, even though the collision speed is much lower.

Next to the slightly different collision speeds and differences in dummy and pedestrian anthropometry, differences in front-end geometry and local vehicle stiffness should also be kept in mind.

The pictures documenting these tests can be found in appendix H.

4.2.1. Biofidelic Dummy vs. Real Accident

The damages to the bonnet leading edge caused by both the Biofidelic Dummy and the two pedestrians are shown in figure 4.13.

In both real accidents, the damages to the bonnet leading edge were caused by the thigh and hip rolling over the edge and onto the bonnet. The bonnet is slightly indented and the headlight assembly of the BMW is pushed backwards.

Considering the two crash tests, the damages were also caused by the thigh and hip as the dummy rolled onto the vehicle. Again, the bonnet is slightly indented. The headlight assembly of the BMW is also pushed backwards and the glass is fractured.

Figure 4.13.: Vehicle damages Biofidelic Dummy vs. pedestrian. Top left: wh18.22; Bottom left: wh18.26; Top right: Accident 1; Bottom right: Accident 2

The damages produced by the Biofidelic Dummy match those seen in the real accidents pretty well.

4.2.2. Žilina Dummy vs. Real Accident

The damages to the bonnet leading edge caused by both the Žilina Dummy and the two pedestrians are shown in figure 4.14.

Even though the collision speed is much lower in the crash tests, the damages are much more intense. The thigh and hip of the Žilina Dummy indented the bonnet leading edge much further than the two pedestrians. Moreover, the bonnet is bulged by this impact, before the chest of the dummy indents it much deeper than the pedestrians. The pattern of the damages is completely different and cannot be compared with the two real-world accidents.

As the Žilina Dummy is a rigid body, it can also cause scratch marks on the bonnet or even lacerate metal parts of the vehicle (see figure 4.15). Such damages cannot be caused by a human being.

Figure 4.14.: Vehicle damages Žilina Dummy vs. pedestrian. Top left: wh08.27; Upper left: wh08.28; Lower left: wh08.29; Bottom left: wh10.12; Top right: Accident 1; Bottom right: Accident 2

Figure 4.15.: Scratch marks caused by the Žilina Dummy

The Žilina Dummy causes damages that are much more intense even at a lower collision speed. Hence, it can be concluded that the Žilina Dummy does not produce realistic damages and would suggest a lower collision speed when compared with a similar real-world accident.

4.2.3. Biofidelic Dummy vs. Žilina Dummy

The damages to the bonnet leading edge caused by both the Biofidelic Dummy and Žilina Dummy are shown in figure 4.16.

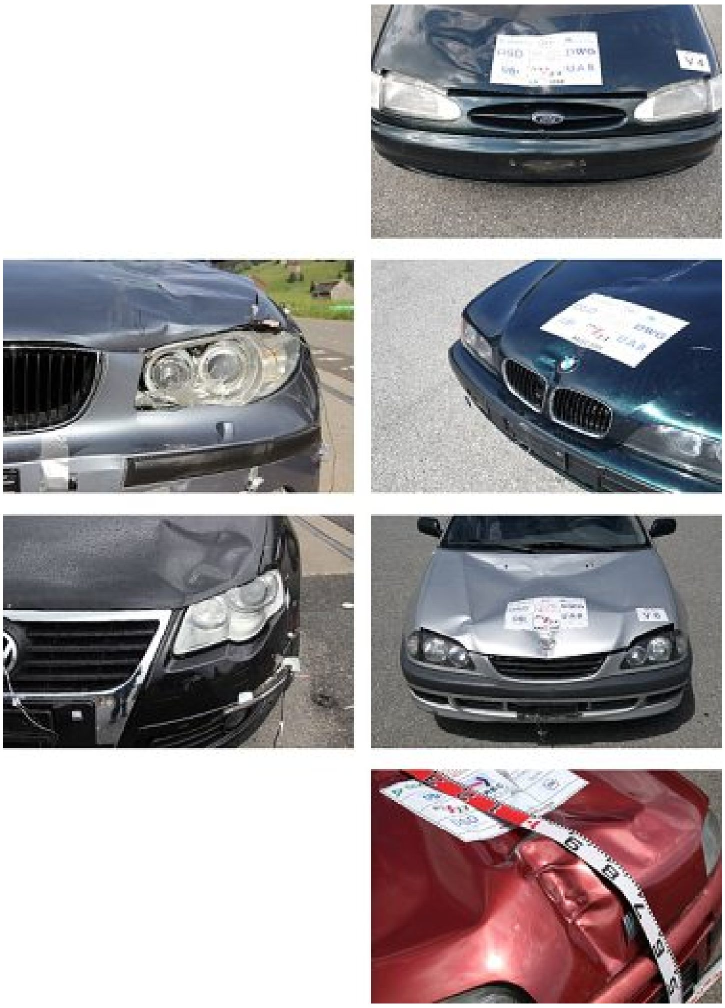


Figure 4.16.: Vehicle damages Biofidelic Dummy vs. Žilina Dummy. Top left: wh18.22; Bottom left: wh18.26; Top right: wh08.27; Upper right: wh08.28; Lower right: wh08.29; Bottom right: wh10.12

Consequently from the comparison above, it can be seen that the damages produced by the Žilina Dummy are much more intense. The bonnet is more bulged and indented much deeper than compared to the Biofidelic Dummy.

The conclusion that the Žilina Dummy produces damages that would suggest a lower collision speed is corroborated by a study done by Kortmann (2018).

4.3. C-Ratio

The C-ratio is defined as the closing speed over collision speed, and is an important parameter in accident reconstruction. Collision speed is the speed with which the striking vehicle hits the pedestrian, and is therefore a property of the vehicle. Closing speed is the speed with which the pedestrian's body part to be analysed impacts with the striking vehicle, and is therefore a property of the pedestrian.

In practice, the C-ratio is determined using the pedestrian's anthropometric data and the vehicle's geometry. This geometrical C-ratio is determined using an internal DEKRA algorithm.

Here, it shall be analysed in how far the ATD's C-ratio determined using the geometrical approach matches the one determined by using crash test video analysis.

As no specific body part shall be analysed in this instance, but rather the whole body, DEKRA uses the following convention in determining the closing speed of the whole body: The closing speed is determined by evaluating the CoM's speed at just that moment when the whole dummy detaches from the vehicle. Appendix I lists all the $v(res)$-measurements .

The C-ratio is then computed by dividing the closing speed with the collision speed. By DEKRA convention, the C-ratio is not stated as $C = 0.9$ for example, but the result is multiplied by 100 to yield a C-ratio of $C = 90$.

Table 4.2 lists the determined C-ratios of the thirteen crash tests.

C is the C-ratio determined via video analysis and is the reference value. It is also called the analytical C-ratio. Depending on the impact characteristics, a correction factor of between $5\,\%$ and $15\,\%$ is applied to the geometrical C-ratio C_g. This is marked as C_{g5}, for example. The difference between the two C-ratio values is marked with ΔC, and the percentage-wise difference with $\Delta C\%$. A "minus" indicates that the value is less than the reference value.

Table 4.2.: C-ratios (the smallest deviation is marked in red)

crashtest	C	C_g	C_{g5}	C_{g10}	C_{g15}	ΔC	ΔC_5	ΔC_{10}	ΔC_{15}	$\Delta C\%$	$\Delta C\%_5$	$\Delta C\%_{10}$	$\Delta C\%_{15}$
wh18.22	90	74	78	82	86	-16	-12	-8	-4	-17.78	-13.33	-8.89	-4.44
wh18.23	100	72	76	80	84	-28	-24	-20	-16	-28.00	-24.00	-20.00	-16.00
wh18.24	95	87	91	95	99	-8	-4	0	4	-8.42	-4.21	0.00	4.21
wh18.25	80	86	90	94	98	6	10	14	18	7.50	12.50	17.50	22.50
wh18.26	97	73	77	81	85	-24	-20	-16	-12	-24.74	-20.62	-16.49	-12.37
wh18.27	100	73	77	81	85	-27	-23	-19	-15	-27.00	-23.00	-19.00	-15.00
wh18.28	77	72	76	80	84	-5	-1	3	7	-6.49	-1.30	3.90	9.09
wh18.29	93	71	75	79	83	-22	-18	-14	-10	-23.65	-19.30	-15.05	-10.75
wh18.34	87	87	91	95	99	0	4	8	12	0.00	4.60	9.19	13.79
average										15.95	13.66	12.22	12.02
wh10.12	90	72	76	80	84	-18	-14	-10	-6	-20.00	-15.56	-11.11	-6.67
wh08.27	102	79	83	87	91	-23	-19	-15	-11	-22.55	-18.63	-14.71	-10.78
wh08.28	70	68	72	76	80	-2	2	6	10	-2.86	2.86	8.57	14.29
wh08.29	66	72	76	80	84	6	10	14	18	9.09	15.15	21.21	27.27
average										13.63	13.05	13.90	14.75

While the average deviation decreases with an increase in the correction factor for the Biofidelic Dummy, the deviations are more or less the same for the Žilina Dummy, though the correction factor of $5\,\%$ exhibits the smallest deviation. The respective deviation with no correction factor and a $5\,\%$ correction factor for the Biofidelic Dummy is higher compared to the Žilina Dummy, while with a correction factor of $10\,\%$ and $15\,\%$, respectively, the average deviation is lower for the Biofidelic Dummy compared to the Žilina Dummy.

Regarding the Biofidelic Dummy, positive deviations only occur in crash tests conducted with the VW Touareg and the Mercedes A-Class. Looking at the Žilina Dummy, positive deviations occur in the crash tests with the BMW 5 Series and Toyota Avensis.

Considering the Biofidelic Dummy, $\varDelta C\% \sim 25$ for all the cases where the dummy hit the roof leading edge and remained attached to it for at least a short time. In crash test wh18.28, the dummy impacted the roof leading edge, but detached immediately. As the different correction values are applied, the values for $\varDelta C\%$ all decrease in a similar pattern. How different front-end geometries and the fact that the roof leading edge has been impacted affect this behaviour merits further investigation, but this is, however, beyond the scope of this diploma thesis.

4.3.1. Dynamic, time-dependent C-Ratio

While the C-ratio is a single value determined at the point of dummy detachment, the dynamic, time-dependent C-ratio, $C(t)$, is the fraction between closing and collision speed at any point of time. It visualises how the pedestrian gains energy, and hence speed, during the primary impact, and how the impact energy is then slowly absorbed during the secondary and tertiary impacts.

In contrast to the C-ratio, the fraction is then not multiplied by 100. Hence, $C(0.1) = 0.4$ for example.

Figures 4.17, 4.18 and 4.19 show the dynamic, time-dependent C-ratio for the head, hip and foot, respectively. While these figures show the different body parts for all the tested vehicles in one graph each, graphs for each vehicle are found in appendix J.

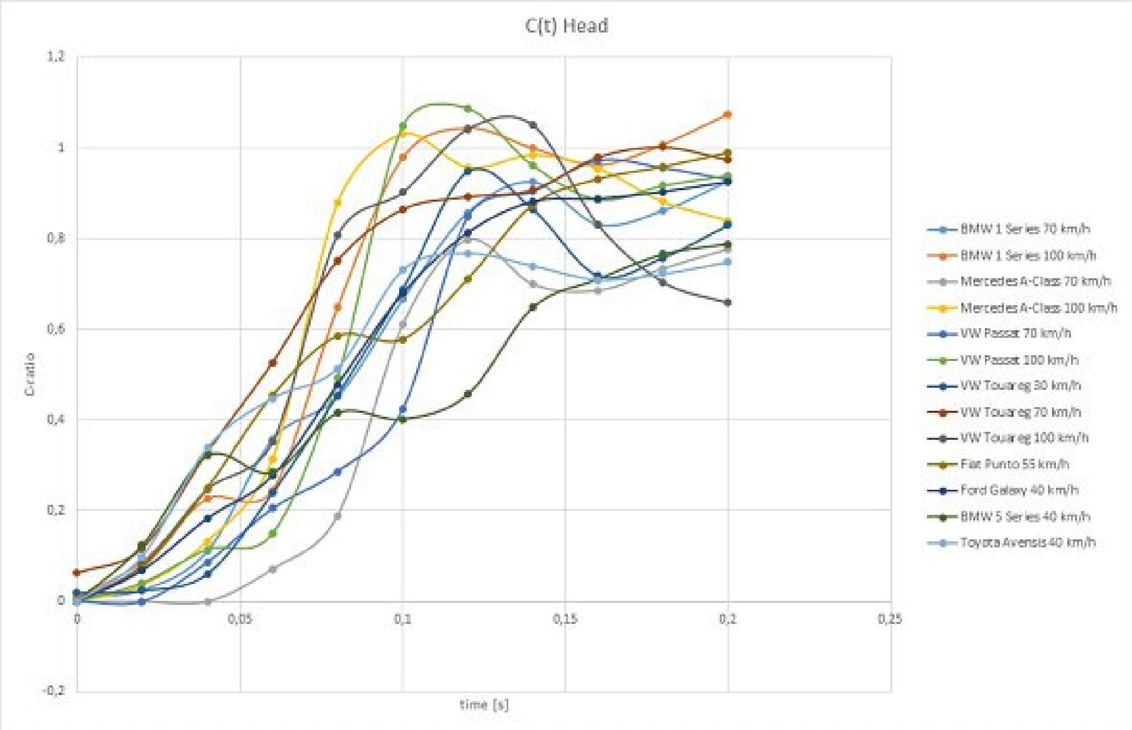


Figure 4.17.: $C(t)$ of the head

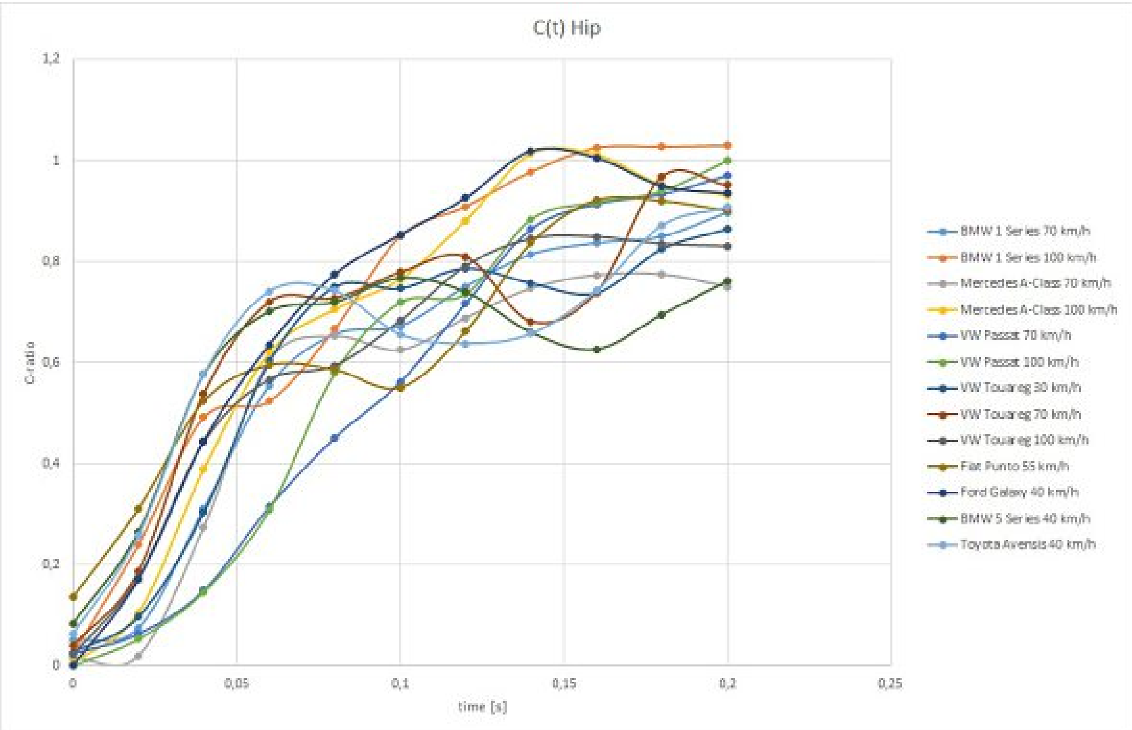


Figure 4.18.: $C(t)$ of the hip

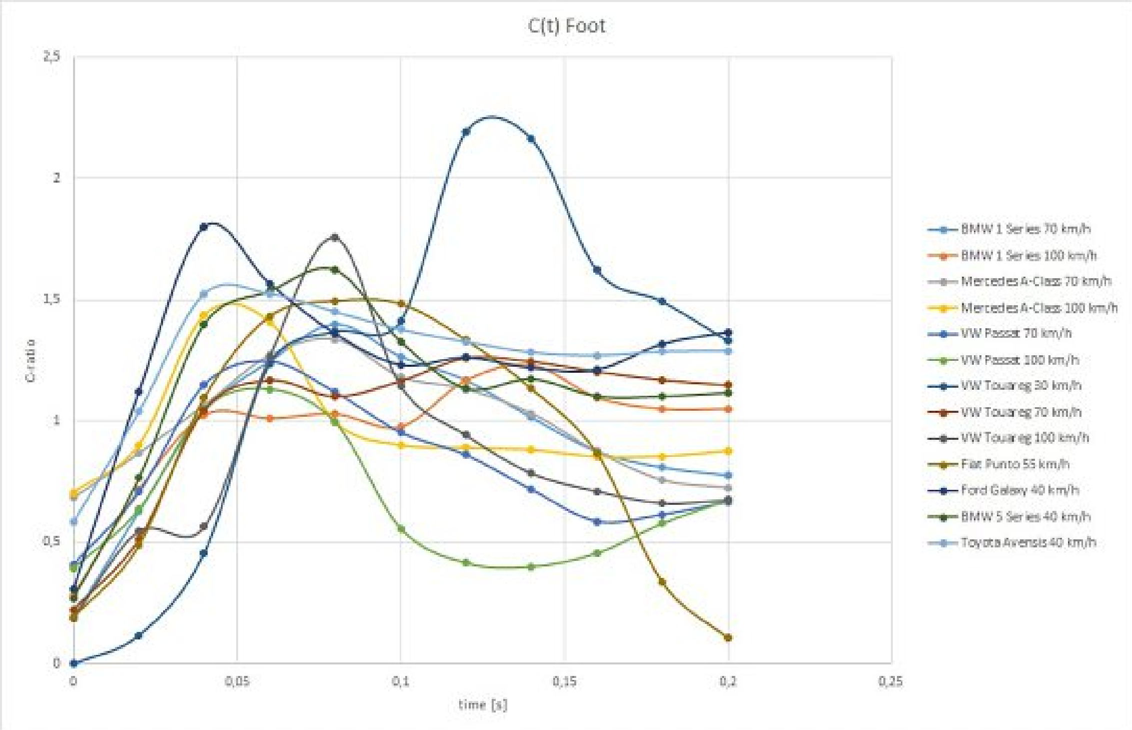


Figure 4.19.: $C(t)$ of the foot

4.3.1.1. Biofidelic Dummy

Considering the head and hip, certain patterns can be spotted, while the response of the foot seems to strongly depend on the front-end geometry and the subsequent dynamics and kinematics of the pedestrian. Especially the severity of the “suck below”-effect seems to influence the behaviour, as well as whether the leg is pierced by any sharp edges such as in crash tests wh18.22 and wh18.26.

The shapes of the $C(t)$-curves for the head and hip often are relatively similar for the different collision speeds when impacted by the same vehicle. With an increase in collision speed, they only shift more towards the left and upwards (see figure 4.20).

Considering the same body part, e.g. the head, at the same collision speed, the shapes of the curves are relatively similar, though the different front-end geometries do have an influence on $C(t)$ (see figure 4.21).

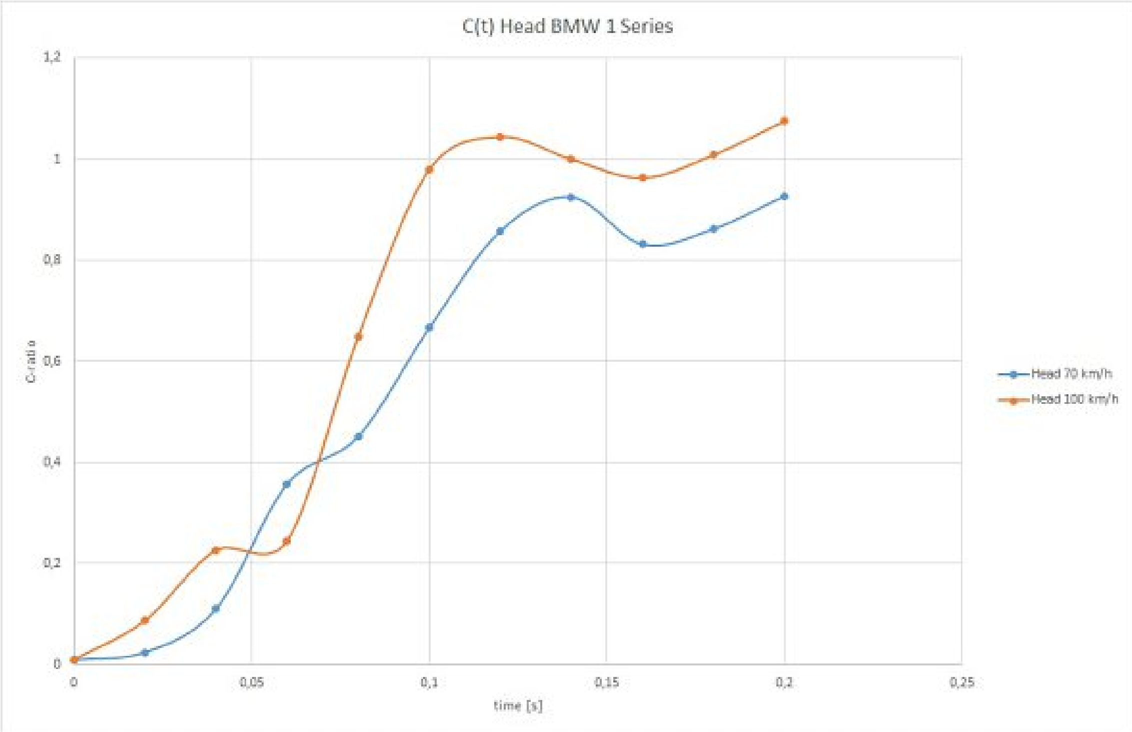


Figure 4.20.: $C(t)$ of the head when hit by the BMW 1 Series (Biofidelic Dummy)

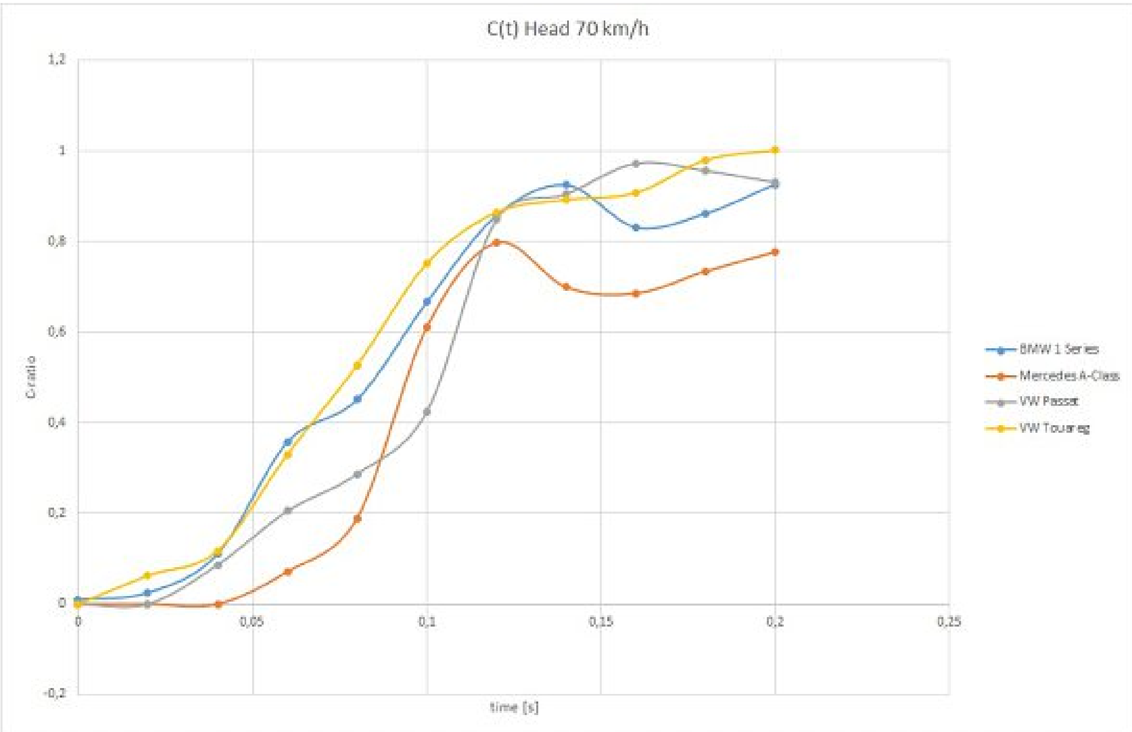


Figure 4.21.: $C(t)$ of the head at $70\,km/h$ (Biofidelic Dummy)

4.3.1.2. Žilina Dummy

In comparison to the Biofidelic Dummy, the different curves have a much steeper slope, which is not surprising. As the Žilina Dummy is an elastic body, less energy is absorbed by the impact itself, and hence the dummy gains more energy compared to the Biofidelic Dummy resulting in a steeper increase in speed, especially regarding the lower extremities.

Considering the lower extremities, as similar to the Biofidelic Dummy, there seems to be no recognisable pattern.

For the head and hip, the shape of the curves is relatively similar to each other at the same impact speed with some influence of the front-end geometry (see figure 4.22 and note that the Fiat Punto has a slightly higher collision speed).

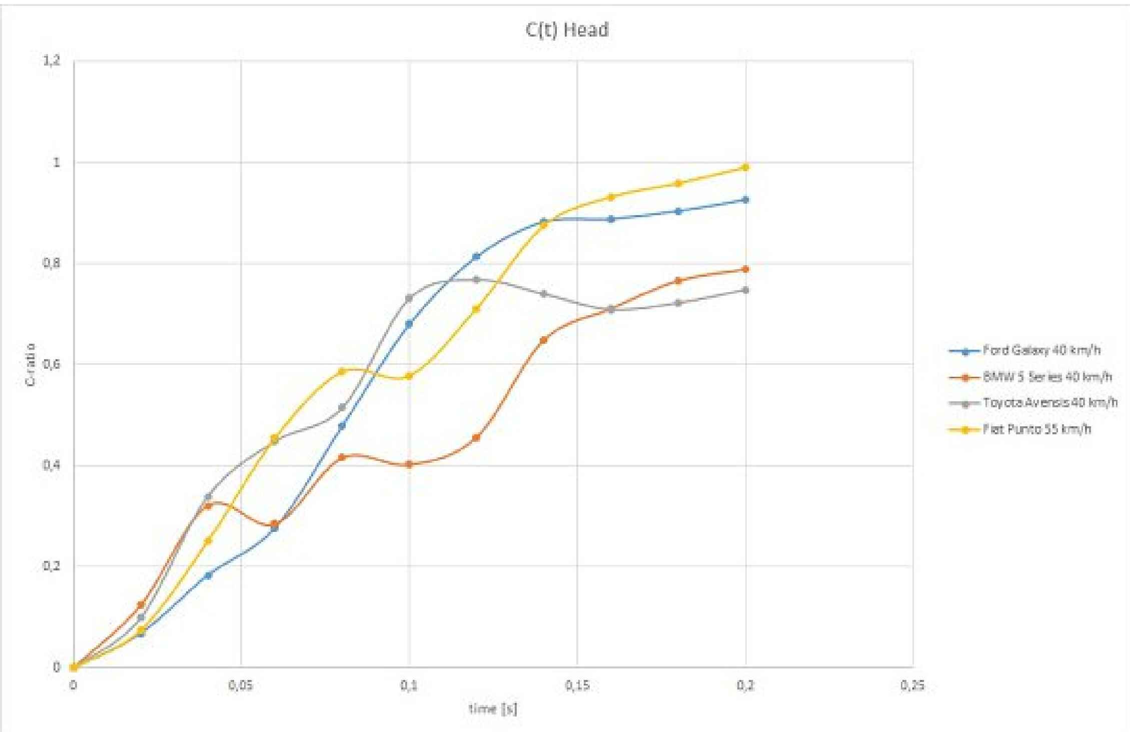


Figure 4.22.: $C(t)$ of the head (Žilina Dummy)

4.3.2. Dynamic, time-dependent C-Ratio relative to the Pelvis

As with the dummy trajectories relative to the pelvis (see subsection 4.1.4), the dynamic, time-dependent C-ratio $C(t)$ of the head and foot can also be analysed relative to the pelvis.

This means that the velocities of the foot and head required to compute the respective dynamic, time-dependent C-ratio $C(t)$ have been determined relative to the pelvis by means of the programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998 - 2006$ FalCon GmbH).

The measurements for $C(t;P)$ can be found in appendix K, while the graphs for the individual vehicles can be found in appendix L.

Plotting $C(t;P)$ over time, it can be seen that the heads of both the Biofidelic and Žilina Dummy behave in similar ways, while there is hardly any pattern discernable considering the feet (see figure 4.23). The shape of the head's $C(t;P)$-graph resembles more or less a sine curve with decreasing amplitude. The only exception constitutes crash test wh18.34, i.e. a Biofidelic Dummy being hit by a VW Touareg at $30\,km/h$.

Figure 4.24 depicts $C(t;P)$ plotted over distance, i.e. $C(t)$ of the head and foot relative to the pelvis measured along the x-axis. This also shows how far the head and foot move away from the pelvis in the x-direction. The distance $x = 0$ refers to the upright posture of the ATD just before impact, where the head, pelvis and foot are in one line and not offset in the x-direction. Here, a much more distinct pattern can be discerned considering the heads and feet measured relative to the pelvis.

First, this graph visualises the kinematics and dynamics of the ATDs, which the other one does not. This is because, as $C(t;P)$ is plotted over distance, the graph visualises the movements of the heads and feet relative to the pelvis along the x-axis as described above. It is shown that, relative to the pelvis, the head is accelerated towards the striking vehicle, while the lower extremities are accelerated away from the vehicle, which is not surprising. However, the behaviour of the different heads is very similar. The graphs resemble a neg-

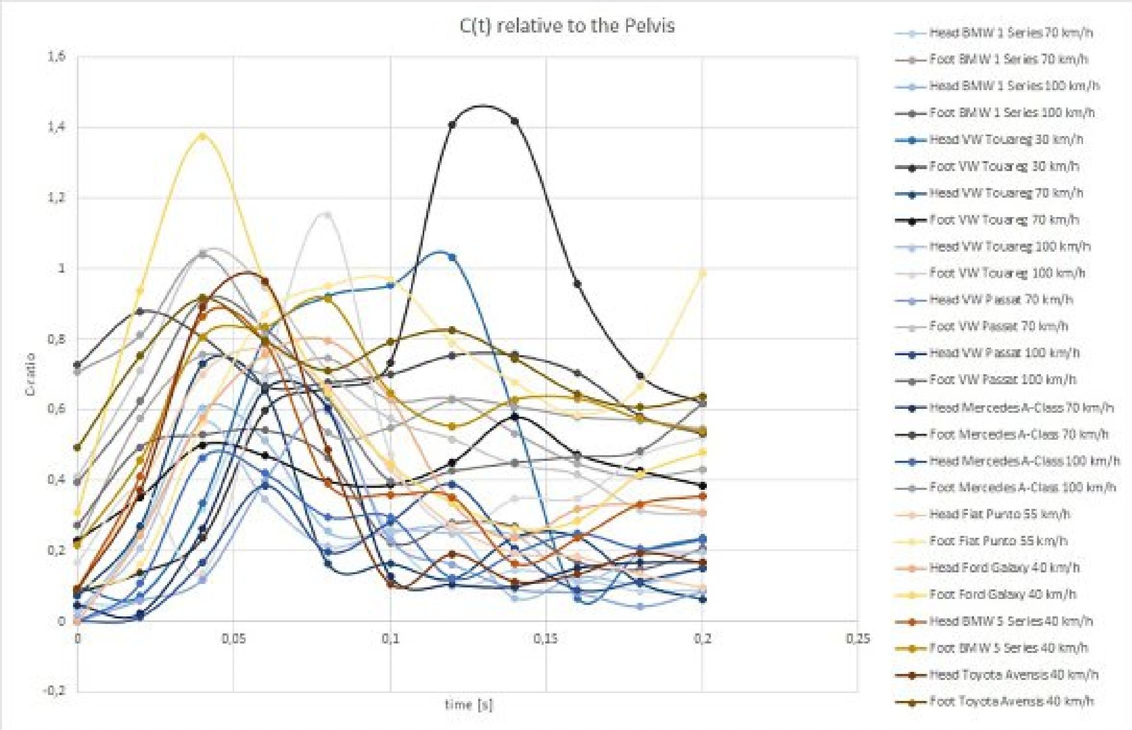


Figure 4.23.: $C(t)$ relative to the pelvis plotted over time. Blue: Biofidelic Dummy's head; Grey: Biofidelic Dummy's foot; Orange: Žilina Dummy's head; Gold: Žilina Dummy's foot

ative square parabola, i.e. the head first experiences a positive acceleration relative to the pelvis and then a negative one. As $C(t;P)$ is a ratio, one can argue that the heads experience a similar relative acceleration irrespective of collision speed and front-end geometry. On the other hand, the behaviour of the feet does not allow for any discernable patterns. Neither the Biofidelic nor the Žilina Dummy exhibit a distinct pattern, nor are there any particular characteristics concerning the collision speed or front-end geometry. The dynamic, time-dependent C-ratio of the feet relative to the pelvis seems to exhibit a completely random behaviour.

From this analysis it can be concluded that the first collision between the striking vehicle and the pelvis is the primary determining factor considering the dynamics and kinematics of the ATD, and hence most possibly for the pedestrian too. As the heads exhibited more or less the same relative accelerations, the impact of the pelvis may thus have a direct influence on the injury mechanism and severity of the injuries to the head/neck complex. As the graphs resemble a negative square parabola and thus first exhibit a positive slope followed by a negative slope, the head first experiences an acceleration relative to the pelvis which

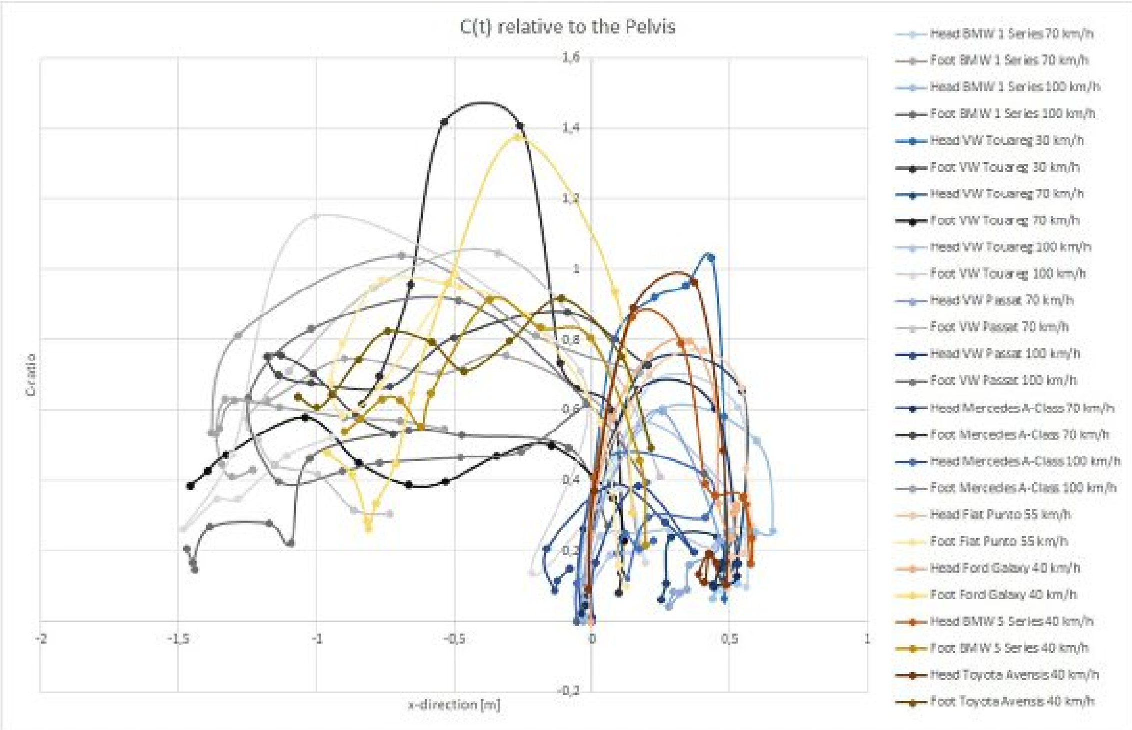


Figure 4.24.: $C(t)$ relative to the pelvis plotted over distance. Blue: Biofidelic Dummy's head; Grey: Biofidelic Dummy's foot; Orange: Žilina Dummy's head; Gold: Žilina Dummy's foot

is followed by a deceleration. As $C(t;P)_H$ is dependent on the pelvis, one can deduce that if $C(t)_P$ increases, $C(t;P)_H$ will increase too, i.e. the head will impact at a higher speed. Consequently, by reducing $C(t)_P$, the severity of head injuries may be reduced. As the head and pelvis are "connected" by the chest, the severity of chest injuries may possibly be lowered, too. $C(t)_P$, and thus $C(t;P)_H$, may be lowered by increasing the detaching time, i.e. allowing for greater deformation at the site of pelvis impact. Therefore, the local vehicle stiffness around the bonnet leading edge may be a decisive factor influencing both the kinematics and dynamics, as well as the injury mechanisms and injury likelihood of the upper body.

The influence of the pelvis on the head is much greater than on the lower extremities. Considering the latter, the extensiveness of the "suck-below"-effect and the height of the bonnet leading edge may have a decisive influence. While the front-end geometry seems to have a minor effect on the behaviour of the head relative to the pelvis, the influence on the lower extremities relative to the pelvis is much greater. The variability of $C(t;P)_F$ may also be explained by the anatomy of human beings. While the head and pelvis are "connected" to each other via the rather rigid spinal column, the feet and pelvis are “connected” to each other via the legs, which allow for greater relative movements.

Subit et al. (2008) already concluded by means of PMHS-tests that the motion of the pelvis has an effect on the kinematics of both the upper body and lower extremities.

These findings warrant further investigation, but, however, this is beyond the scope of this diploma thesis.

4.3.3. Conclusion

By analysing the C-ratio, it can be concluded that both the Biofidelic and the Žilina Dummy exhibit acceptable deviations comparing the geometrical C-ratio with the one obtained by video analysis. The deviations decrease in similar ways when using a higher correction factor, though the Žilina Dummy always exhibits a slightly lower deviation. However, the procedure of calculating the geometrical C-ratio was developed by using data stemming from crash tests with the Žilina Dummy. Thus, this procedure has an inherent bias towards the Žilina Dummy which must be taken into account. Therefore, the performance of the Biofidelic Dummy should be regarded in even more favourable terms.

It can be concluded that the current procedure of determining the geometrical C-ratio based on the Žilina Dummy is still valid and can be further used. The method should only be revised, in order to further refine the correctness of the results. This merits further investigation which is, however, beyond the scope of this diploma thesis.

4.4. Throw Distance

Given that both the final position of the pedestrian as well as the point of collision are known, the throw distance can be used to determine the collision speed.

Throw distance charts have been developed by DEKRA based on crash tests with the Žilina Dummy and results from well documented real-world pedestrian accidents. Different throw charts have been developed for complete, partial and streaking hits. Considering complete hits, one has to further distinguish between pre-crash and in-crash braking.

Regarding the four pre-crash braking crash tests with the Biofidelic Dummy, two of the throw distances lie within the boundaries, while one lies just above the upper boundary and the fourth throw distance lies outside of the empirically developed corridor. However, the deviation is still within an acceptable range. The three pre-crash braking crash tests with the Žilina Dummy are also marked in the chart. Two of the throw distances lie just below the lower boundary, while one lies outside the corridor. As the deviation is unacceptably high, data from the ADR have been analysed. The data highlight the fact that the brakes were not applied with full force, and hence the dummy was not catapulted away from the vehicle, but "travelled" with the vehicle for a prolonged time. This obviously falsified the throw distance, which is why the Ford Galaxy must be excluded. Figure 4.25 shows the throw distance chart for complete hits and pre-crash braking.

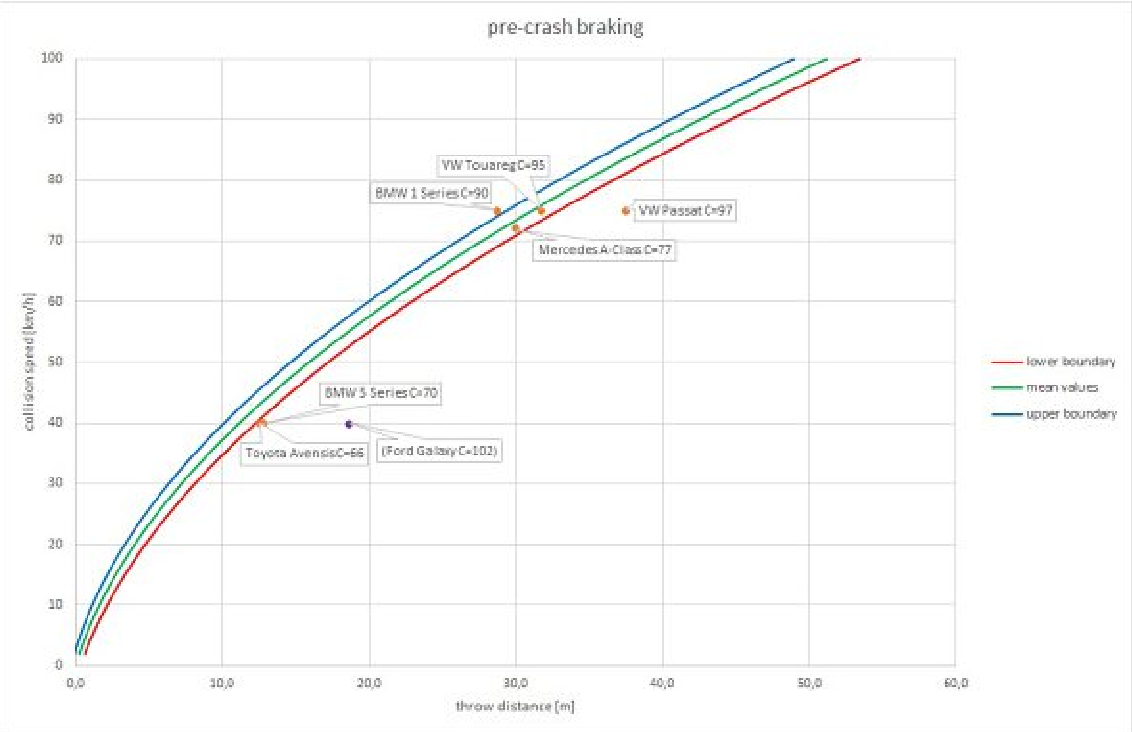


Figure 4.25.: Throw distance chart for complete hits and pre-crash braking

Considering in-crash braking, only three crash tests can be analysed, as the dummy penetrated the windscreen and got stuck in crash test wh18.27. While the throw distance for the Mercedes A-Class lies within the boundaries, the throw distance for the BMW 1 Series lies outside the boundaries, but still within an acceptable range. Regarding the VW Touareg, however, the deviation is by far too big. But, by further analysing the dynamics and kinematics of the dummy in this crash test, one realises that the dummy begins to slide off the fender quite immediately after impact and the complete hit hence becomes a partial hit. The throw distance lies well within the boundaries for partial hits. Thus, crash test wh18.25 is special case, as the impact constellation equals to a complete hit, but due to the dummy kinematics and dynamics turns into a partial hit. Figure 4.26 displays the throw distance chart for complete hits and in-crash braking, and figure 4.27 the throw distance chart for partial hits.

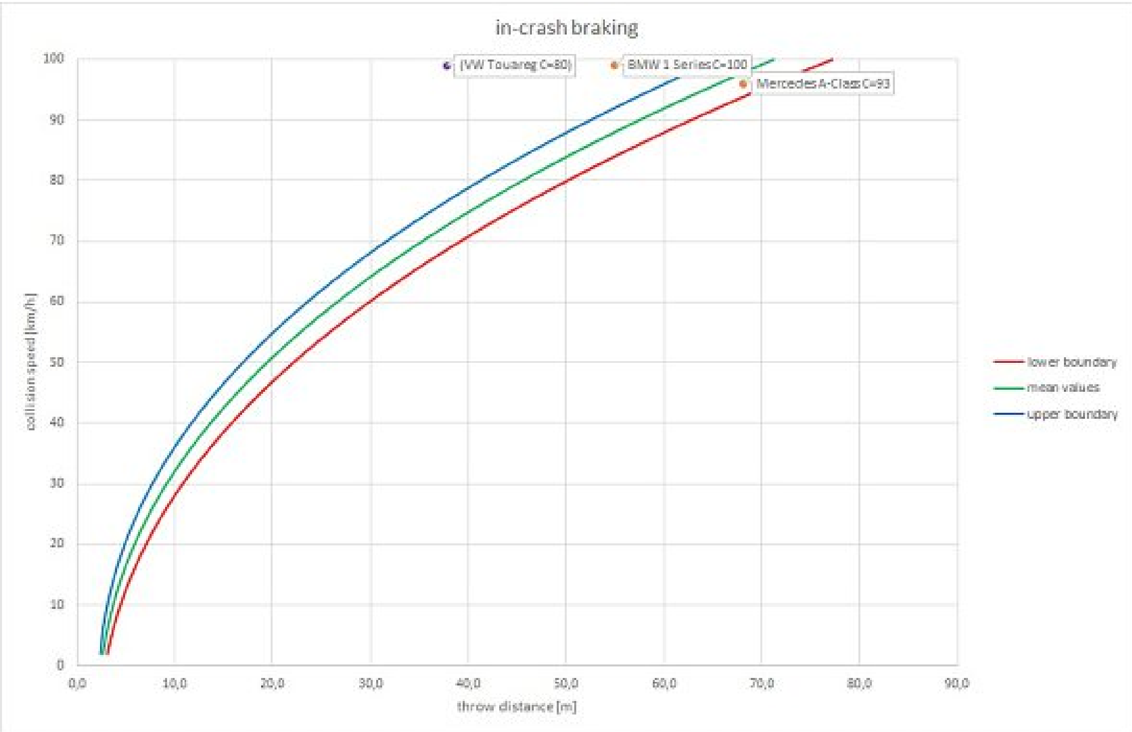


Figure 4.26.: Throw distance chart for complete hits and in-crash braking

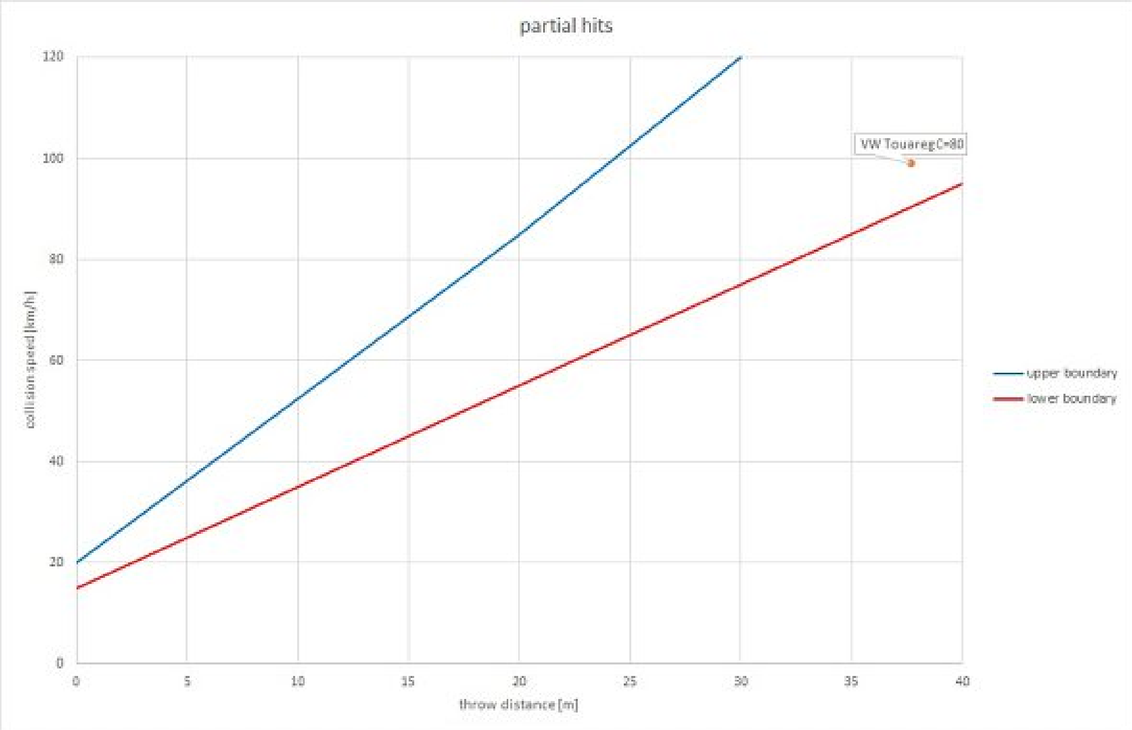


Figure 4.27.: Throw distance chart for partial hits

It can be concluded that both the Biofidelic and Žilina Dummy "produce" expected throw distances. However, as the throw distance charts have been developed partially based on crash tests with the Žilina Dummy, the charts are slightly biased towards the Žilina Dummy. Nonetheless, the results from the Biofidelic Dummy are very pleasing and further corroborate the validity of the throw distance charts.

4.5. "Injuries"

"Autopsies" of the eight biofidelic dummies have been conducted at the "Bureau for Accident Reconstruction Berlin" from $12 - 13$ July 2018 and $10 - 12$ October 2018.

The damages of the Biofidelic Dummies have been determined by dismembering the ATDs and these damages have then been translated into the respective injuries of a human being. By means of video analysis, it was possible to ascertain which vehicle structure most likely caused the damages/injuries. The findings are summarised in spec-sheets similar to those of the real-world pedestrian accidents, and can be found in appendix B. The spec-sheets, however, come with the caveat that they solely list the damages/injuries the ATDs sustained and not the injuries a pedestrian should have sustained in a real-world accident of a similar severity. Therefore, only bone fractures are listed, as the Biofidelic Dummy cannot mimic injuries to other tissues and organs.

During the second set of “autopsies”, small vests containing tiny metal balls and weighing more than $5\,kg$ each have been discovered in the ATDs used for the $70\,km/h$ crash tests. These alterations to the ATDs have been made without knowledge of DEKRA. In one case, the vest did influence the injury biomechanics of the ATD’s pelvis negatively. The right pubis of the Biofidelic Dummy used in crash test wh18.22 exhibited a crack close to the acetabulum. Due to the vest placed inside the pelvic cavity, however, the pubis was propped up and did therefore not break entirely, which it would have done with a very high likelihood if there had not been the vest. As such, the damages to the pelvis must be considered with caution as the vests may have tampered with the biofidelity of the pelvic region. The respective spec-sheets are therefore marked with an “attention sign”. Figure 4.28 displays the vest containing the metal balls and the crack in the pubis of the Biofidelic Dummy used in crash test wh18.22.

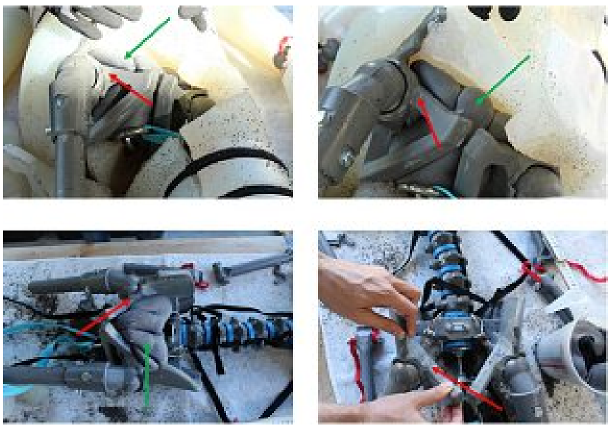


Figure 4.28.: Alteration to the Biofidelic Dummy used in crash test wh18.22 (Green arrow: Vest containing the metal balls; Red Arrow: Crack in the pubis, which did not entirely break as it was propped up by the vest)

The dummy “autopsies” were the last task performed during this research project. Prior to the finding of the vests, no “upnormal” behaviour of those dummies has been recognised. Thus, the vests thankfully do not seem to have had a major detrimental effect on the biofidelity of the ATDs, apart from the injury characteristics of the pelvic region which were veritably detrimentally effected in one instance . Thanks to the high collision speed of the vehicles, the inertia of the dummy has a negligible effect on the impact dynamics. Therefore, it can be assumed that the trajectories and C-ratios were not significantly altered given these specific crash tests. However, it is hard to say in how far the ATDs did cause different damages to the vehicles because of the vests. As the vehicle damages were compared to the damages caused by real-world accidents and did match those pretty well, it can be assumed, however, that the vests did not significantly affect the damages produced. Nonetheless, it cannot be excluded that the respective ATDs may have performed slightly differently if they had not been equipped with the vests.

In Schäuble (2018), the author analysed the correlations between collision parameters, vehicle damages and pedestrian injuries and concluded that the fracture patterns of long bone fractures in the lower limbs, knee joint injuries, injuries to the ankle, pelvic injuries and head injuries can be used for reconstruction purposes. As such, the following analysis of the Biofidelic Dummy's "injuries" will primarily focus on these injuries, because the main area of use of this ATD will be in accident reconstruction. Nonetheless, the overall behaviour related to trauma biomechanics will be analysed too.

Figure 4.29 shows an overview of the "autopsy" of the Biofidelic Dummy used in crash test wh18.25.

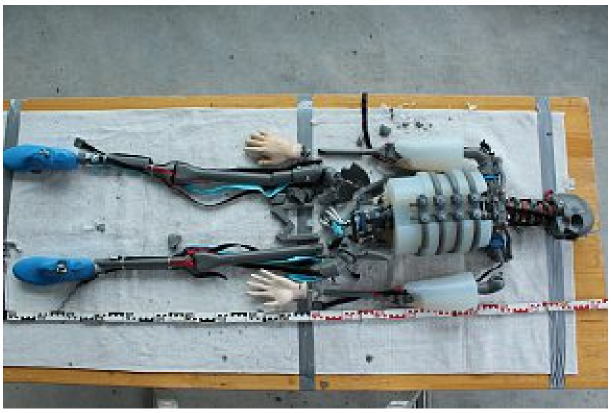


Figure 4.29.: Overview of the "autopsy" of the Biofidelic Dummy used in crash test wh18.25

4.5.1. Fracture Patterns of the Lower Leg's Long Bones

The characteristic wedge-shaped fracture pattern, know as the Messerer's wedge fracture, can be often found in pedestrians hit by a vehicle. The apex points in the direction of the vehicle's velocity vector and is thus indicative of the direction of impact. However, as already mentioned, the Messerer's wedge fracture must not be considered on its own, as such fractures also occur under indirect loading alone. Here, however, bending occurs as a secondary effect due to the direct loading of the long bone by the bumper. Hence, there will most likely be some soft tissue lesions at the direct site of impact. If the site of the soft tissue lesions and the direction of the Messerer's wedge are in concordance with each other, the validity of the latter has been corroborated by the former, and the wedge-shaped fracture can be used as a reconstruction parameter.

Figure 3.18 depicts the Messerer's wedge fracture in a human being.

When conducting a crash test, on the other hand, the impact direction of the vehicle and the exact position of the ATD are known. Thus, it would be beneficial if the Biofidelic Dummy did also exhibit this typical fracture pattern, in order to allow for direct comparisons between the pedestrian and the ATD, and to hence draw conclusions pertaining to the impact direction.

Figure 4.30 shows the wedge-shaped fracture in the Biofidelic Dummy used in crash test wh18.23.

While the fracture of the Biofidelic Dummy's lower leg does not exhibit the characteristic two faces of the Messerer's wedge fracture with the apex showing in the impact direction, a unique fracture pattern can be observed nonetheless. Initially, the fracture surface is flat and then ends with a protrusion on one of the two fracture surfaces. As with the apex of the Messerer's wedge fracture, this protrusion always indicates the impact direction.

Bone is a heterogeneous material, whereas the ATD's bones are made of a homogeneous material with similar strength. This difference explains the different fracture patterns ob-

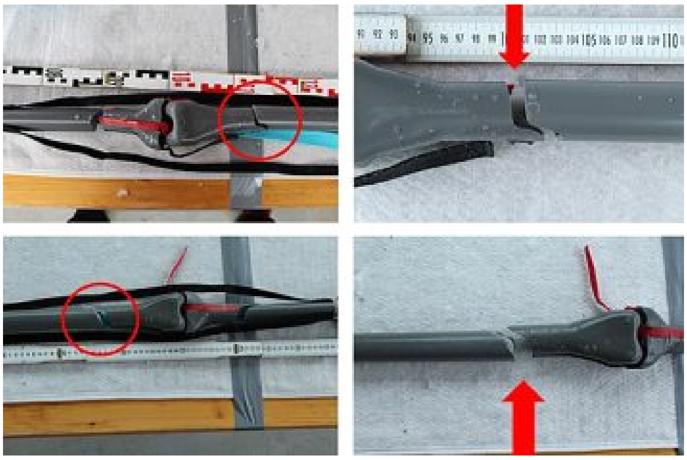


Figure 4.30.: Messerer's wedge fracture in the Biofidelic Dummy used for crash test wh18.23 (Top: Left side; Bottom: Right side; Red circle: Location of wedge-shaped fracture; Red arrow: Impact direction)

served in human beings and the Biofidelic Dummy. Notwithstanding, the Biofidelic Dummy exhibits a fracture pattern comparable to the Messerer's wedge fracture which can be used as a supporting factor in determining the impact direction.

4.5.2. Knee Joint Injuries

The knee injuries sustained by the pedestrian can be classified according to their mechanism, namely avulsive or compressive. The resulting injuries to the condyles, the collateral ligaments and the cruciate ligaments are indicative of the impact direction. While valgus flexion was primarily found in lateral hits, varus flexion was found in medial ones.

The Biofidelic Dummy's knees have a very human-like anatomy. The biofidelity of the dummy's knee joint injuries is analysed by means of the left knee joints of the ATDs used in crash tests wh18.23 and wh18.25, which are shown in figures 4.31 and 4.32. The underlying injury mechanism is varus flexion.

Considering crash test wh18.23 and figure 4.31, the black tape, representing the lateral collateral ligament, has been torn off the femur. The tapes are glued to the bones. Here, the attachment site was weaker than the tape itself, which is why the tape was torn off and did not rupture. In reality, however, the ligament would rupture. Nonetheless, this damage to the Biofidelic Dummy's knee can be interpreted as a ruptured lateral collateral ligament. Moreover, both the anterior and the posterior cruciate ligaments are frayed. These "injuries" coincide with those found by Teresinski & Madro (2001b) in humans.

Considering crash test wh18.25 and figure 4.32, the induced bending was even stronger resulting in the fracture of the medial tibial condyle. In addition, the lateral collateral ligament as well as both the anterior and posterior cruciate ligaments were ruptured. The medial collateral ligament was also frayed by the impact. Figures 3.24 and 3.23 display the varus flexion mechanism as described by Teresinski & Madro (2001b). Note, however, that Teresinski & Madro (2001b) refers to the right knee, while the left knee of the Biofidelic Dummy is analysed.

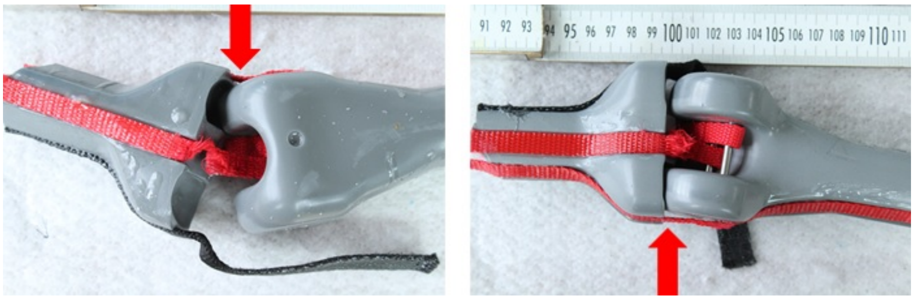


Figure 4.31.: Knee injury of the Biofidelic Dummy used in crash test wh18.23 (Left: Front view; Right: Rear view; Red arrow: Impact direction)

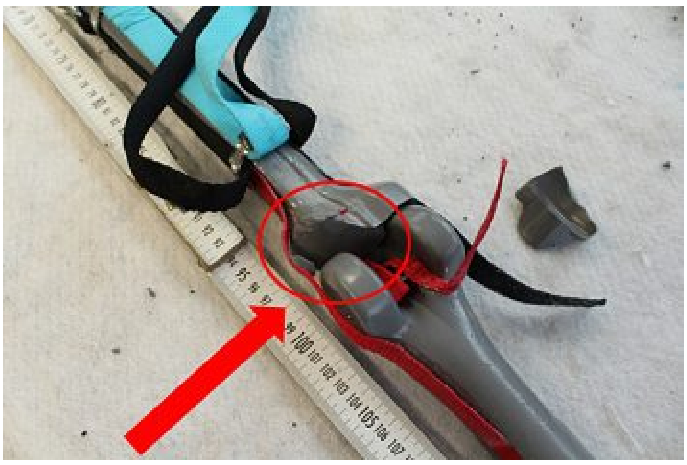


Figure 4.32.: Rear view of the knee injury of the Biofidelic Dummy used in crash test wh18.25 (Red circle: Location of medial tibial condyle fracture; Red arrow: Impact direction)

4.5.3. Injuries to the Ankle

The "injuries" to the Biofidelic Dummy's ankle cannot be analysed as of yet, as the ankle's anatomy is not humanoid at all. The foot, made of rubber, is simply screwed into the lower leg. Figure 4.33 displays the ankle joint of the Biofidelic Dummy used in crash test wh18.25.

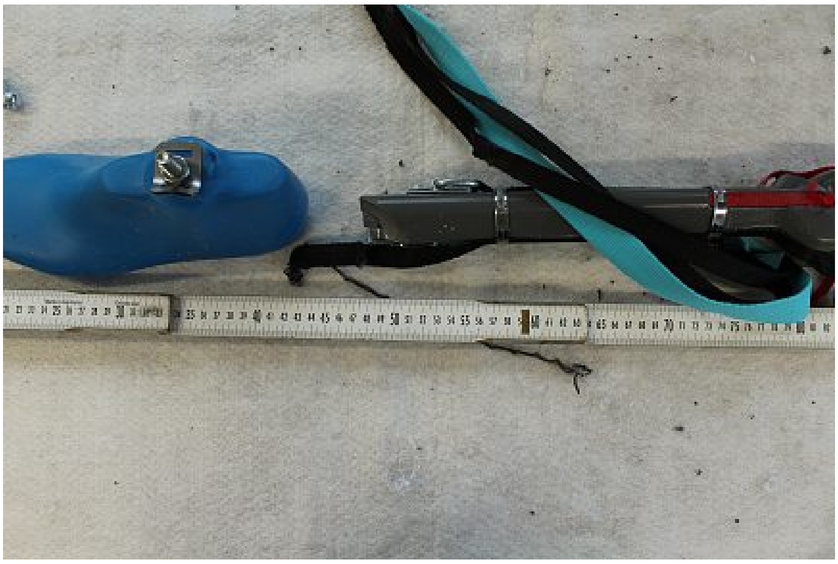


Figure 4.33.: Ankle joint of the Biofidelic Dummy used in crash test wh18.25

4.5.4. Pelvic Injuries

Pelvic fractures seem to be more common in pedestrians who have been run over than in those hit close to an upright posture.

Teresinski & Madro (2001c) determined that injuries to the sacroiliac joint were the best parameter to determine the side of impact in case of lateral hits, and were found to occur, with very few exceptions, on the direct side of impact. Figures 3.40 and 3.41 depict the pelvic injuries which can be found in lateral impacts, and the mechanisms of central fracture or dislocation of the hip acetabulum, respectively.

Of the eight Biofidelic Dummies tested, only those used in crash tests wh18.24 and wh18.26 exhibited fractures of the right sacroiliac joint, while those used in crash tests wh18.28 and wh18.29 exhibited fractures of the left sacroiliac joint. Interestingly, three of these dummies had the vests placed in their pelvic cavity. In how far the vests had an influence on this particular "injury" cannot be determined. Figure 4.34 displays the fractures of the right sacroiliac joint, whereas figure 4.35 displays the fractures of the left sacroiliac joint.

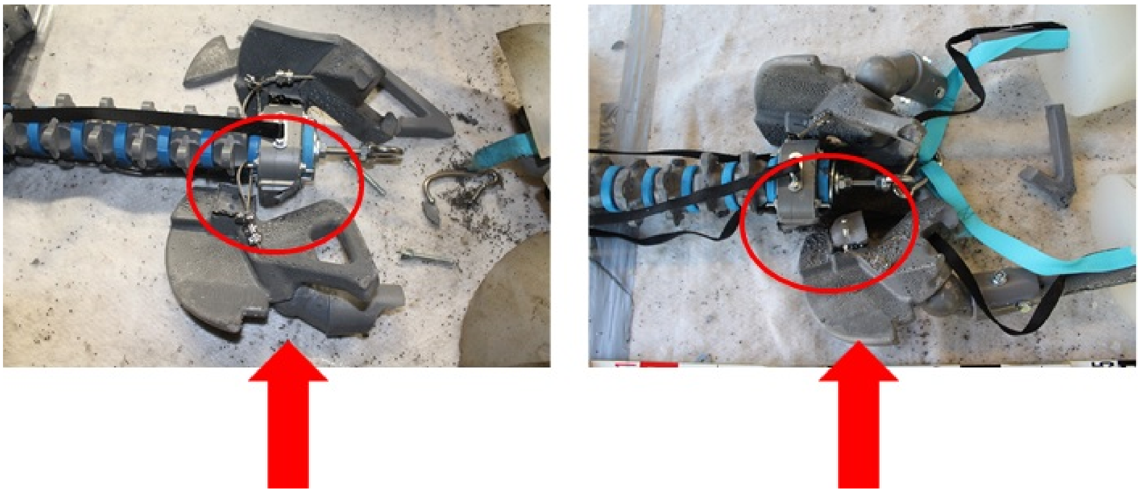


Figure 4.34.: Fracture of the right sacroiliac joint of the Biofidelic Dummy (Left: Crash test wh18.24; Right: Crash test wh18.26; Red circle: Location of fracture; Red arrow: Impact direction)

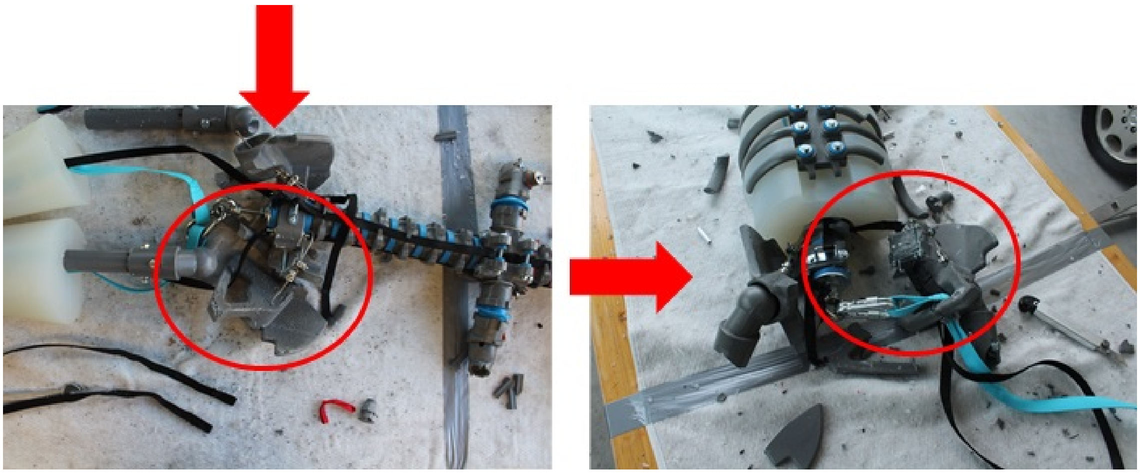


Figure 4.35.: Fracture of the left sacroiliac joint of the Biofidelic Dummy (Left: Crash test wh18.28; Right: Crash test wh18.29; Red circle: Location of fracture; Red arrow: Impact direction)

The "injuries" to the sacroiliac joint found are in concordance with those reported by Teresinski & Madro (2001c). However, only two "injuries" occurred at the direct side of impact, while the other two occurred at the opposite side of impact.

Further, the Biofidelic Dummies used in crash tests wh18.25 and wh18.27 sustained "injuries" to the ilium very close to the sacroiliac joint. Both Biofidelic Dummies sustained a fracture to the right ilium. As these "injuries" are so close to the sacroiliac joint, they could be considered as sacroiliac injuries for reconstruction purposes, but have been denoted as ilium fractures in the spec sheets. The fractures of the left and right ilium of the Biofidelic Dummy used in crash test wh18.23 are further away from the respective sacroiliac joints and can hence hardly be considered as "injuries" to the sacroiliac joint region. This classification, of course, is somewhat subjective. Obviously, the design of the Biofidelic Dummy and the way it is constructed influence the "injury" patterns. Figure 4.36 shows the fractures to the ilium within the sacroiliac joint region, while figure 4.37 shows the fracture to the ilium outside the sacroiliac joint region.

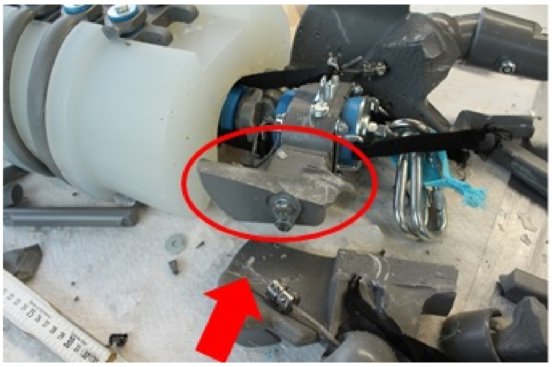
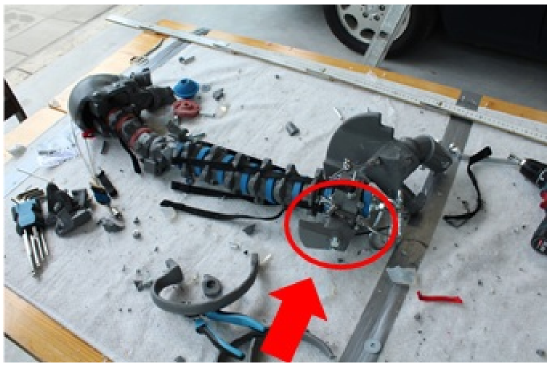



Figure 4.36.: Fracture of the ilium next to the sacroiliac joint of the Biofidelic Dummy (Left: Crash test wh18.25; Right: Crash test wh18.27; Red circle: Location of fracture; Red arrow: Impact direction)

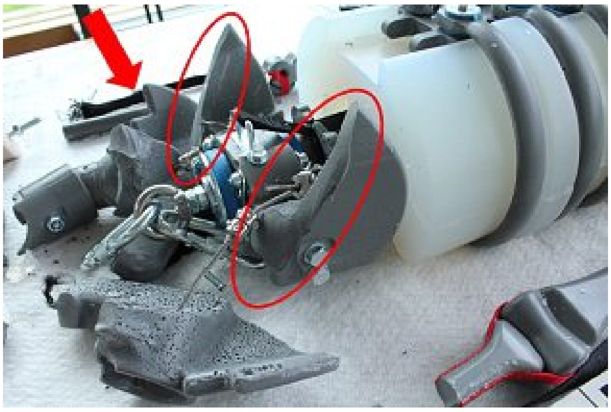


Figure 4.37.: Fracture of the left and right ilium of the Biofidelic Dummy used in crash test wh18.23 (Red circle: Location of fracture; Red arrow: Impact direction)

Thus, of the six "injuries" to the sacroiliac joint region, four occurred at the direct side of impact and two at the opposite side of impact. Though the sample size is too small to make a valid statement, these findings suggest that injuries to the pelvic region are less reliable for reconstruction purposes than those to the knee joint for example.

“Injuries” to the Biofidelic Dummy’s acetabulum were also frequently noted. According to Teresinski & Madro (2001c), these injuries, however, are less useful for reconstruction purposes. Nonetheless, the damages of the Biofidelic Dummies’s acetabulums are largely in concordance with the injury mechanism as described by Teresinski & Madro (2001c). However, bony split-offs have also been noted at the left acetabulum, i.e. the opposite side of impact. Figure 4.38 depicts the fracture of the right acetabulum of the Biofidelic Dummy used in crash test wh18.25.

Figure 4.38.: Fracture of the right acetabulum of the Biofidelic Dummy used in crash test wh18.25 (Red circle: Location of fracture; Red arrow: Impact direction)

All in all, the “injuries” to the pelvic region seem to be pretty realistic and are largely in concordance with those reported in literature. Still, many “injuries” were found on the left side of the Biofidelic Dummy. According to Teresinski & Madro (2001c), though, pelvic injuries rather occur on the direct side of impact, i.e. the right side of the Biofidelic Dummy. In how far the design and the construction of the Biofidelic Dummy’s pelvis influences the injury patterns requires further investigation. While the pelvic region is supported by many tendons and ligaments, the ATD’s pelvic region is not. Moreover, the collision speeds were very high, resulting in a high impact energy.

4.5.5. Head Injuries

As with injuries to the ankle, head injuries cannot be analysed as of yet. This is due to the rigid design of the head. The latest design consists of one cast component with a cavity at the base of the skull. Inside of this rectangular cavity the spinal column is mounted. As this mount is more or less a rigid rectangular block, it props up the skull. Thus, the overall design of the cranium is so rigid that it does not break.

One example is the Biofidelic Dummy used in crash test wh18.25. Here, the ATD was hit at $99\,km/h$ and the head impacted the A-pillar. The only “injuries” the ATD sustained to the head can be described as a laceration of the latex/wet suit with abrasions on the os parietale beneath. In reality, the skull would have fractured, resulting in severe injuries to the brain which would not have been survivable with an extreme likelihood. Figure 4.39 shows these “injuries”.

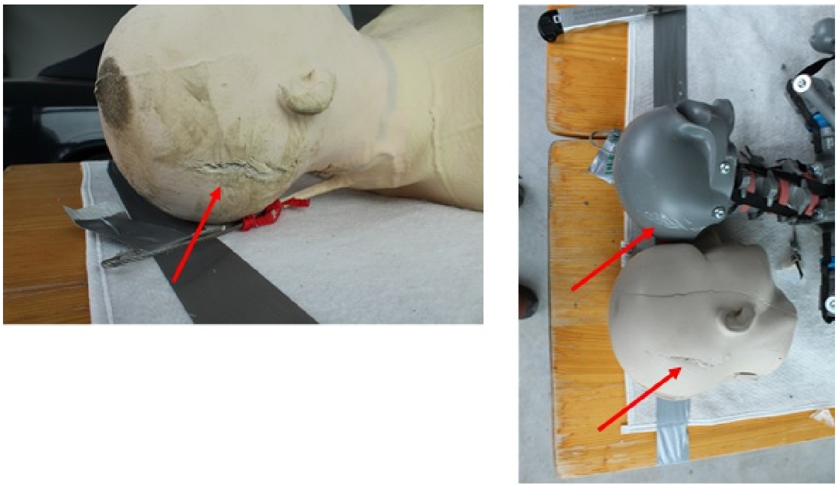


Figure 4.39.: Head injuries of the Biofidelic Dummy used in crash test wh18.25 (Left: Laceration of the latex/wet suit; Right: Abrasions on the os parietale)

4.5.6. Other Injuries

While the biofidelic dummies used for the $100\,km/h$ crash tests feature the current designs of the shoulder and elbow, the ATDs used for the $70\,km/h$ crash tests still feature the old design.

The old design of the shoulder joint created sort of a predetermined breaking point, so that the left and right humerus suffered fractures next to the shoulder joint in all four cases.With the new design, this was avoided. Figure 4.40 displays these two designs.

Figure 4.40.: Injuries to the shoulder joints of the biofidelic dummies used in crash tests wh18.22 and wh18.23 (Left: Old design creating sort of a predetermined breaking point; Right: New design)

This is a good example of how the biofidelity of the Biofidelic Dummy is constantly advanced thanks to improvements made to its design. However, this also highlights the importance of exactly knowing the design changes, in order to be able to scrutinise certain injury patterns and to subsequently draw the correct conclusions.

The design of the elbow was also changed, resulting in big differences. The old design is rather flimsy, easily leading to luxations of the elbow. Furthermore, the circular shoulder of the cylindrical part of the joint breaks easily. The new design, on the other hand, is sturdier and no damages to these elbows were noted. See figure 4.41 for a comparison of these two designs.

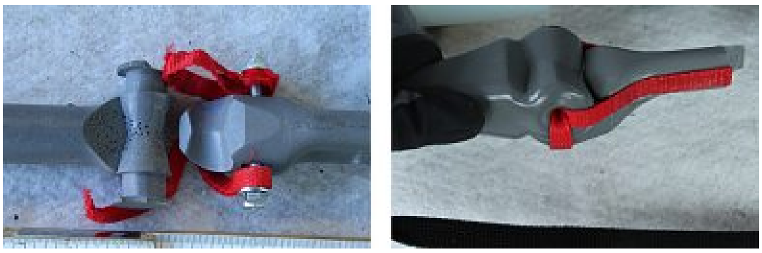


Figure 4.41.: Injuries to the elbows of the biofidelic dummies used in crash tests wh18.22 and wh18.23 (Left: Old design; Right: New design)

The rib cage of the Biofidelic Dummy only features four pairs of ribs, while the human rib cage features twelve pairs. Considering the usage of the ATD in pedestrian crash tests, this deviation in design does not matter, as injuries to the thorax are not suitable for reconstruction purposes. However, the injuries to the rib cage, clavicles and sternoclavicular joints seem to be in accordance with those observed in pedestrians.Figure 4.42 shows the injuries to the thorax of the Biofidelic Dummy used in crash test wh18.23.

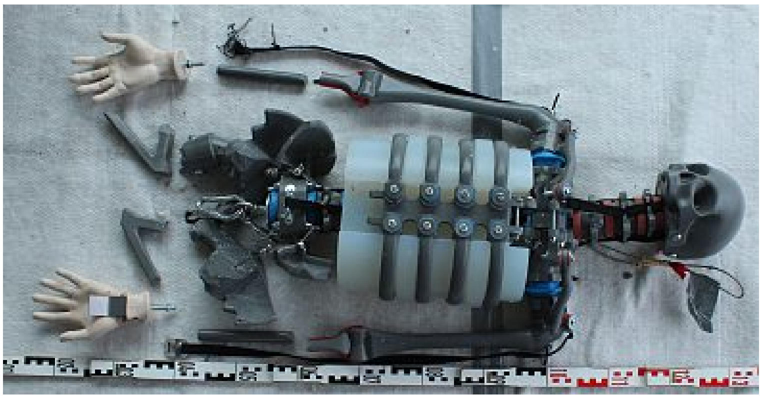


Figure 4.42.: Injuries to the thorax of the Biofidelic Dummy used in crash test wh18.23

Separations were also observed. Kolla et al. (2017) reported about the likelihood of separations at high collision speeds and the performance of the Biofidelic Dummy is in agreement with those observations. Figure 4.43 depicts the amputation of the right foot of the Biofidelic Dummy used in crash test wh18.27.

Figure 4.43.: Separation of the right foot of the Biofidelic Dummy used in crash test wh18.27

4.5.7. Comparison with real-world Pedestrian Accidents

As with the vehicle damages, crash tests wh18.22 and wh18.26 are compared with two of the real-world pedestrian accidents. The considered accidents are the same. Figure 4.44 displays the different injury diagrams.

Without comparing every single injury, it can be noted that overall the injuries of the Biofidelic Dummy match those of the pedestrians pretty well. Both the pedestrians as well as the biofidelic dummies suffered injuries to the thorax, shoulder region, pelvic region, and the lower extremities.

Obviously, one must consider that the pedestrians and ATDs each collided with different vehicles. Furthermore, the individual fitness of a human being also influences their biomechanical response, explaining variations in the injury patterns. The exact kinematics and dynamics throughout the collision further influence the biomechanics and a crash test will never be able to exactly imitate those.

Nonetheless, it can be concluded that the Biofidelic Dummy exhibits very similar injuries to pedestrians.

In appendix C, the injuries of the pedestrians and ATDs are compared in more detail.

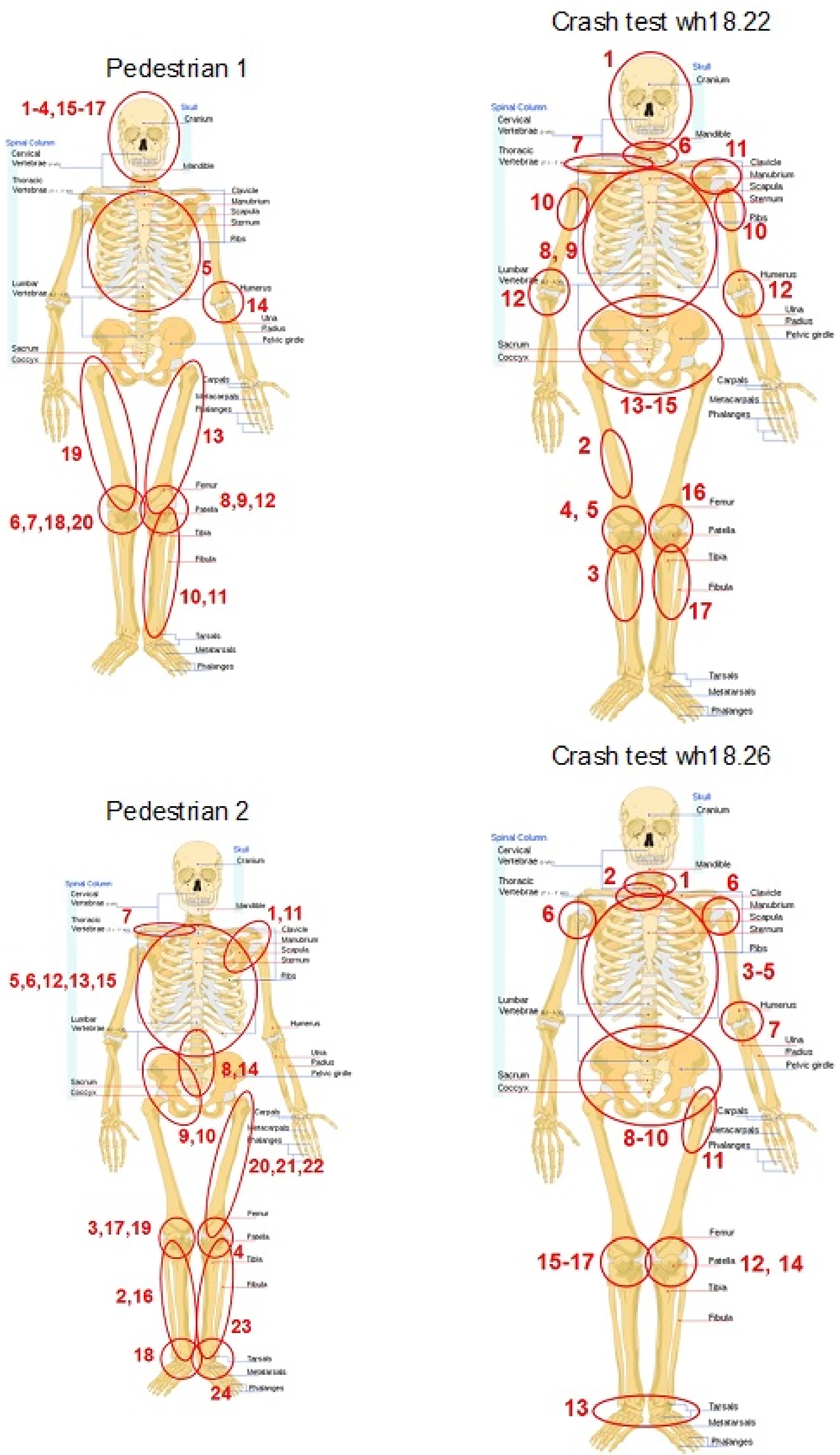


Figure 4.44.: Comparison of injuries between pedestrian and Biofidelic Dummy

5. Evaluation of suitable Dummies for specific Experiments

Depending on the specific issue to be investigated, a different ATD might be the best suited.

The evaluation of suitable dummies for specific experiments is entirely based on the demands of DEKRA and is hence subjective. Another organisation may have different demands and would thus come to different conclusions. This analysis primarily focuses on the Žilina Dummy and the Biofidelic Dummy, as those two ATDs are mostly used by DEKRA. Considering these two ATDs, the evaluation is solely based on the results from the crash tests performed by DEKRA and AXA. Hence, one must bear in mind that the evaluation is based on a rather small sample size.

The evaluation is based on an evaluation matrix, which is shown in table 5.1.

Table 5.1.: Evaluation matrix

	++	+	0	-	--
biofidelity					
realistic throw distances					
realistic vehicle damages					
usability in a collision speed interval of 40 km/h to 100 km/h					
cost					
durability					

5.1. Explanation of Evaluation Criteria

The classification of the individual criteria of the evaluation matrix is described below.

5.1.1. Biofidelity

The criterion "biofidelity" has the classification as shown in table 5.2. Here, "biofidelity" is regarded in terms of realistic kinematics and dynamics, as well as being able to mimic injuries a pedestrian would sustain in a pedestrian-vehicle accident of a similar severity.

Table 5.2.: Classification of the evaluation matrix's criterion "biofidelity"

biofidelity	
++	good
+	adequate
0	marginal
-	weak
--	poor

5.1.2. Realistic Throw Distances

The criterion "realistic throw distances" has the classification as shown in table 5.3.

Here, every single crash test has been considered and the average performance was then determined, as some ATDs of the same kind lie within the boundaries of the throw distance charts and others outside of the boundaries.

Table 5.3.: Classification of the evaluation matrix's criterion "realistic throw distances"

realistic throw distances	
++	within the boundaries
+	on the boundaries
0	just outside of the boundaries
-	outside of the boundaries
--	far away from the boundaries

5.1.3. Realistic Vehicle Damages

The criterion “realistic vehicle damages” has the classification as shown in table 5.4.

Table 5.4.: Classification of the evaluation matrix’s criterion “realistic vehicle damages”

realistic vehicle damages	
++	realistic damages
+	good concordance with real damages
0	acceptable concordance with real damages
-	poor concordance with real damages
--	completely unrealistic

5.1.4. Usability in a Collision Speed Interval of $40\,km/h$ to $100\,km/h$

The criterion “usability in a collision speed interval of $40\,km/h$ to $100\,km/h$” has the classification as shown in table 5.5

Table 5.5.: Classification of the evaluation matrix’s criterion “usability in a collision speed interval of $40\,km/h$ to $100\,km/h$”

usability in a collision speed interval of 40 km/h to 100 km/h	
++	good
+	adequate
0	marginal
-	weak
--	poor

5.1.5. Cost

The criterion “cost” has the classification as shown in table 5.6.

Table 5.6.: Classification of the evaluation matrix’s criterion “cost”

cost	
++	0 < x < 10.000 €
+	10.00 < x < 20.000 €
0	20.000 < x < 50.000 €
-	50.000 < x < 100.000 €
--	x < 100.000 €

5.1.6. Durability

The criterion "durability" has the classification as shown in table 5.7.

Table 5.7.: Classification of the evaluation matrix's criterion "durability"

durability	
++	can be used several times
+	requires only minimal repair after crash test
0	requires repair after crash test
-	requires extensive repair after crash test
--	cannot be used again

5.2. Žilina Dummy

The evaluation matrix of the Žilina Dummy is shown in table 5.8.

Table 5.8.: Evaluation matrix of the Žilina Dummy

Žilina dummy	++	+	0	-	--
biofidelity					X
realistic throw distances		X			
realistic vehicle damages					X
usability in a collision speed interval of 40 km/h to 100 km/h	X				
cost	X				
durability	X				

Considering "usability in a collision speed interval of $40\,km/h$ to $100\,km/h$", "cost" and "durability", the Žilina Dummy scores highly.

It scores poorly considering "biofidelity" and "realistic vehicle damages".

The ATD's performance concerning "realistic throw distances" is good.

5.3. Biofidelic Dummy

The evaluation matrix of the Biofidelic Dummy is shown in table 5.9.

Table 5.9.: Evaluation matrix of the Biofidelic Dummy

biofidelic dummy	++	+	0	-	--
biofidelity	X				
realistic throw distances		X			
realistic vehicle damages	X				
usability in a collision speed interval of 40 km/h to 100 km/h	X				
cost			X		
durability					X

Considering "biofidelity", "realistic vehicle damages" and "usability in a collision speed interval of $40\,km/h$ to $100\,km/h$", the Biofidelic Dummy scores highly.

It scores poorly considering "durability".

The ATD's performance concerning "realistic throw distances" is good.

The criterion "cost" is deemed as being acceptable.

5.4. Suitability for specific Experiments

Based on the evaluation matrices of the Žilina Dummy and the Biofidelic Dummy, recommendations can be made as regards the suitability of these ATDs for specific experiments.

If the expert witness only wants to obtain the throw distances, the Žilina Dummy is the better suited ATD due to its low price and good durability. If, however, vehicle damages are also of importance, the Žilina Dummy is not suited at all, as the caused damages are by far too severe and would lead to the assumption of a collision speed which is too slow. In this instance, the Biofidelic Dummy needs to be chosen. The damages caused by this

ATD are comparable with those caused by a pedestrian under similar conditions. As soon as the injuries of the pedestrian shall be considered as well, there is no way around the Biofidelic Dummy. The only “disadvantage” of the Biofidelic Dummy is the fact that the ATD can only be used once, unless the collision speed is very slow. However, as the purpose of this dummy is to mimic the injuries a pedestrian could sustain in a pedestrian-vehicle collision, this “disadvantage” is simply thanks to a feature which makes this ATD unique. But this also entails that the usage of the Biofidelic Dummy in comparison with the Žilina Dummy is far more cost intensive.

As soon as the mechanical loading parameters must be measured, however, the conventional ATDs such as the Hybrid-III dummy, THOR dummy, or POLAR dummy must be used, as these ATDs are certified.

6. Potential for Improvement of the Biofidelic Dummy

Considering any device, it should be as complex as necessary, but as simple as possible.

The presented potential for improvement of the Biofidelic Dummy is based on the demands of DEKRA, and would hence vary from organisation to organisation. The main usage of the Biofidelic Dummy will be in the area of reconstructing pedestrian-vehicle accidents.

As of yet, the Biofidelic Dummy cannot mimic two of the five injuries which can be used for reconstruction purposes as outlined in Schäuble (2018). These are injuries to the ankle and head injuries.

The current version of the Biofidelic Dummy does not possess a biofidelic ankle. The foot design simply consists of a rubber foot which is screwed into the lower leg. Here, the design needs to be refined to more properly mimic the anatomy of a human being. Such an improvement would also entail a design change of the lower leg. So far, the lower leg consists of only one bone. In order to properly design the ankle joint, however, the design of the lower leg has to feature the tibia and fibula.

The current head design is too rigid. The design should be revised as to be more flexible. The design should consist of a cranium which is filled by a material mimicking the brain. In such a way, the head could suffer fractures as seen in real life. Moreover, this could reduce the severity of the vehicle damages caused by the head, though this hypothesis would then need to be investigated comparing the old design with the new design.

The current design of the wrist can be obtained, as injuries to the wrist are not important for reconstruction purposes. The same is true for the thorax.

In general, the way of how the different dummy components are assembled should be revised. Any screw used can function as a stress riser. The old shoulder design is a good example of how the design influences the “injury” pattern of the Biofidelic Dummy.

Should the Biofidelic Dummy be used for other purposes, different improvements may be desirable.

Devising a concept design, however, is beyond the scope of this diploma thesis.

7. Conclusions

The analyses of the Žilina Dummy and the Biofidelic Dummy lead to the conclusion that each dummy is well suitable for specific applications.

The Žilina Dummy is a simple, robust and cheap ATD which can be well used to determine throw distances and the C-ratio. Considering trajectories and vehicle damages, this ATD exhibits large deficiencies. Owing to its design, the Žilina Dummy cannot mimic any injuries a pedestrian would suffer in a pedestrian-vehicle accident of similar severity.

On the other hand, the Biofidelic Dummy already exhibits a high degree of biofidelity. Its trajectories are comparable with those of PMHSs and this ATD also creates realistic vehicle damages. This allows to more correctly determine the collision speed. The obtained C-ratios are also good and the deviations to those obtained by the Žilina Dummy are minimal. Nonetheless, this warrants further investigations. The throw distances obtained with the Biofidelic Dummy are good. The unique feature of the Biofidelic Dummy is its ability to mimic the injuries a pedestrian would suffer in a pedestrian-vehicle accident of similar severity. The “injuries” of the ATD resemble those of a pedestrian pretty well, especially those of the knee joint. Thus, the Biofidelic Dummy enables expert witnesses to reconstruct a pedestrian-vehicle accident and to obtain realistic vehicle damages, throw distances and injuries. This opens up new possibilities in the field of accident reconstruction.

As long as the mechanical loading parameters need to be determined in a certified way, however, there is no way around the sophisticated ATDs of the like of Hybrid-III dummy, THOR dummy and POLAR dummy.

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A. Spec Sheets: Real-World Pedestrian Accidents

A total of 21 real-world pedestrian accidents has been analysed. The most important findings are summarised in the spec sheets below.

The orange table lists the basic vehicle and pedestrian data.

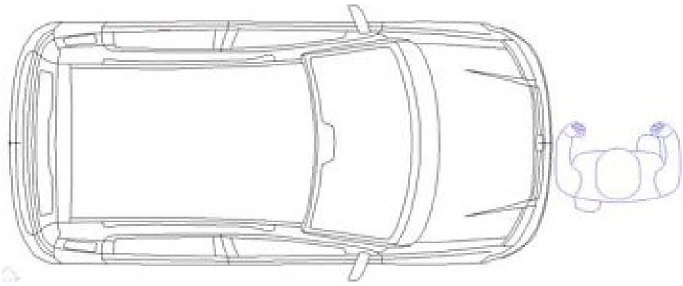
The blue table lists all the injuries for which it was possible to ascertain the exact vehicle structure that caused the injury, or the ground in case of an injury-causing secondary hit. The individual injuries are numbered and shown in the skeleton top right. The picture top left shows the damaged vehicle and the vehicle structures that have been responsible for the different injuries. The picture below displays the impact constellation.

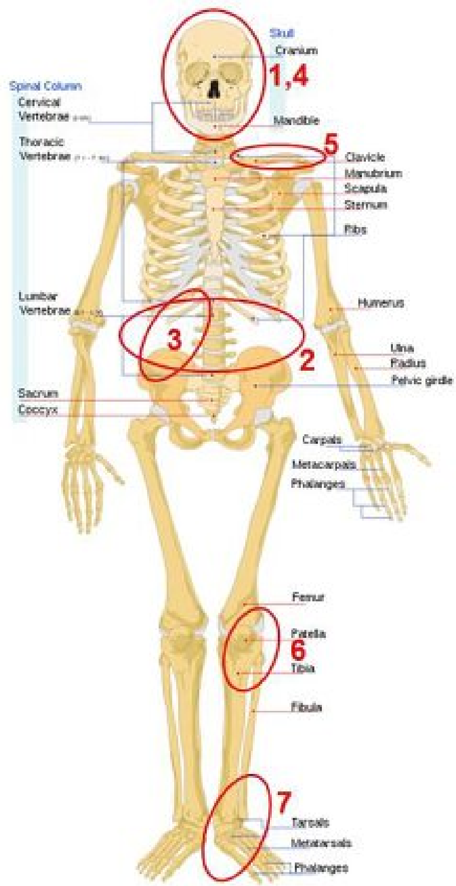
The green table, if present, lists all the injuries for which it was not possible to ascertain a specific injury-causing vehicle structure. If several vehicle structures have been responsible for a single injury, the different parts are separated by a ",", while a "/" signifies that either vehicle structure may have caused the injury.

Table A.1 shows an overview of the different pedestrian accidents.

Table A.1.: Overview of the pedestrian accidents

vehicle data		pedestrian data			page
Opel Astra Caravan F 1994	60 – 65 km/h	39 years	male	survived	125
Alfa Romeo 155 1995	50 – 55 km/h	67 years	female	survived	127
Seat Cordoba 1997	58 – 68 km/h	43 years	male	survived	128
VW Lupo 2001	36 – 48 km/h	42 years	male	survived	130
Opel Vectra A 1991	46 – 51 km/h	38 years	female	survived	132
VW Vento 1993	55 – 65 km/h	56 years	female	deceased	134
Opel Vectra A 1992	37 – 43 km/h	7 years	male	survived	137
Opel Vectra B 2001	44 – 50 km/h	15 years	male	survived	139
VW Golf 3 1996	37 – 40 km/h	26 years	female	survived	141
Opel Corsa B 2000	37 – 43 km/h	10 years	female	survived	143
Mercedes E 220T 2002	25 – 30 km/h	43 years	male	survived	145
VW Polo 1999	55 km/h	82 years	female	survived	147
VW Passat 1998	64 – 67 km/h	26 years	male	survived	149
Nissan Primera 1998	60 – 65 km/h	67 years	female	deceased	151
BMW 320i 1996	53 – 63 km/h	51 years	male	deceased	155
Honda Civic Coupé 1997	50 km/h	22 years	female	deceased	159
Opel Zafira 2001	34 – 38 km/h	13 years	male	survived	160
Opel Vectra A 1992	40 km/h	77 years	female	deceased	162
Opel Corsa B 1994	40 – 50 km/h	72 years	female	deceased	163
Fiat Bravo 1996	45 – 53 km/h	28 years	female	deceased	164
VW T3 1989	32 – 40 km/h	92 years	male	deceased	166

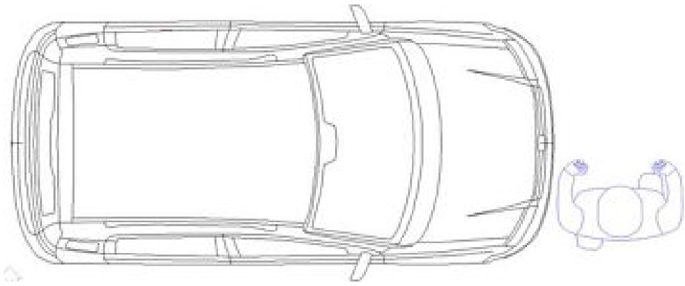


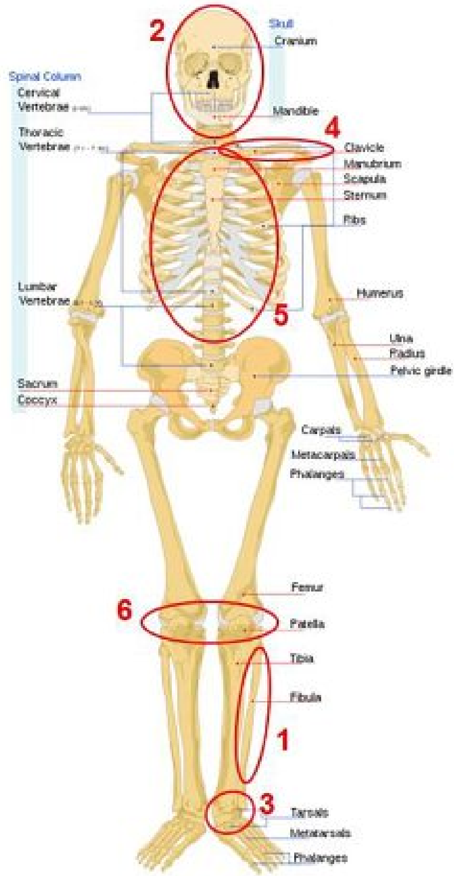


vehicle data	pedestrian data
Opel Astra Caravan F 1994	39 years
trapezium	male
1095 kg	182 cm
60 - 65 km/h	113 kg
pre-crash braking	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	1st degree craniocerebral injury with temporary unconsciousness	primary	roof leading edge
2	blunt abdominal trauma	primary	windscreen
3	liver haematoma	primary	windscreen
4	facial skin abrasion	primary	windscreen
5	fracture of left clavicle	primary	bonnet
6	maisonneuve fracture of left fibula with fracture of left lateral malleolus	primary	bumper
7	medial malleolus haematoma	primary	bumper

injury	injury caused by hit	injury caused by …
left parietal laceration	primary	windscreen, roof leading edge
laceration of right concha	primary	windscreen, roof leading edge
multiple lacerations on left upper arm; partial transection of extensor	primary	bonnet, windscreen, roof
multiple skin abrasions and lacerations of lower and upper limbs	primary	bumper, bonnet, windscreen, roof

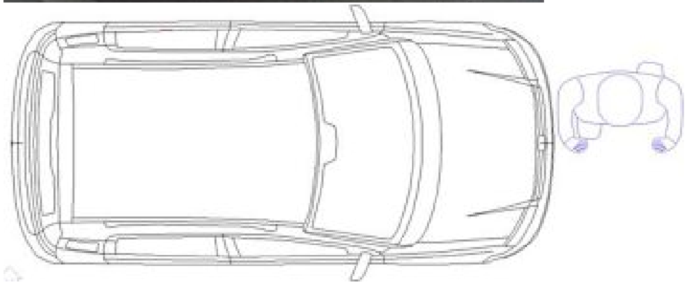


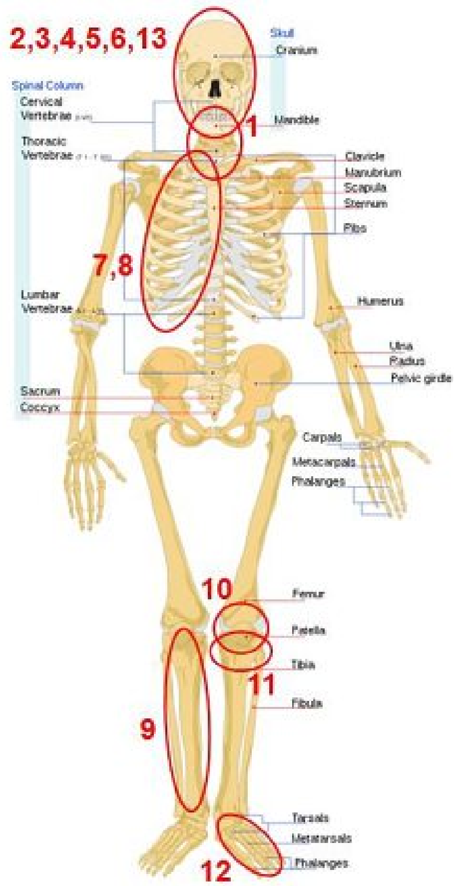


vehicle data	pedestrian data
Alfa Romeo 155 1995	67 years
trapezium	female
1215 kg	164 cm
50 - 55 km/h	78 kg
late or unbraked	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	fracture of left fibula	primary	bumper
2	large occipital laceration	primary	windscreen
3	bimalleolar fracture of upper ankle joint	primary	bumper
4	fracture of left clavicle	primary	bonnet
5	multiple fractures of 3rd to 5th rib in axillary line with pneumothorax	primary	bonnet
6	haematomas on both knees	secondary	ground

injury	injury caused by hit	injury caused by …
traumatic subarachnoid haemmorhage	primary/secondary	windscreen/ground



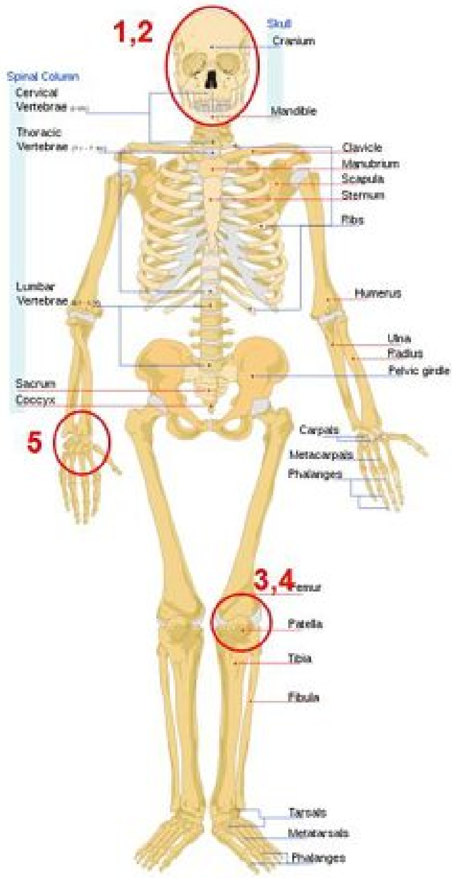


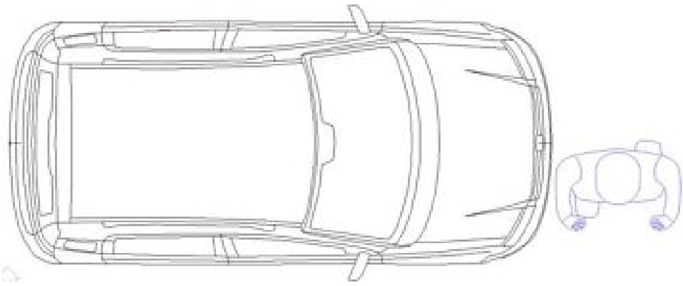
vehicle data	pedestrian data
Seat Cordoba 1997	43 years
trapezium	male
1080 kg	190 cm
58 - 68 km/h	90 kg
in-crash braking	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	luxation fracture of 6th and 7th cervical vertebrae	primary	roof leading edge
2	traumatic subarachnoid haemmorhage	primary	windscreen
3	3rd degree contre-coup craniocerebral injury	primary	windscreen
4	traumatic subdural haemmorhage right	primary	windscreen
5	parietal laceration left	secondary	ground
6	orbital floor fracture	secondary	ground
7	multiple fractures of 3rd to 7th rib right	primary	roof leading edge
8	lung contusion right	primary	roof leading edge

9	3rd degree open fracture of right lower leg	primary	bumper
10	left knee joint instability	primary	bumper
11	tibia plateau luxation fracture left	primary	bumper
12	metatarsal V-fracture left	primary	spoiler
13	fracture of nasal bone	secondary	ground

injury	injury caused by hit	injury caused by …
multiple skin abrasions	primary	bumper, bonnet, windscreen, roof

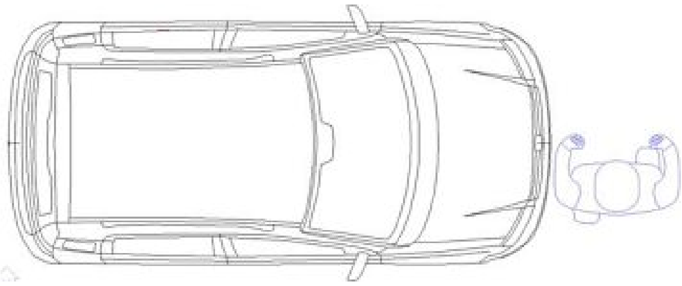


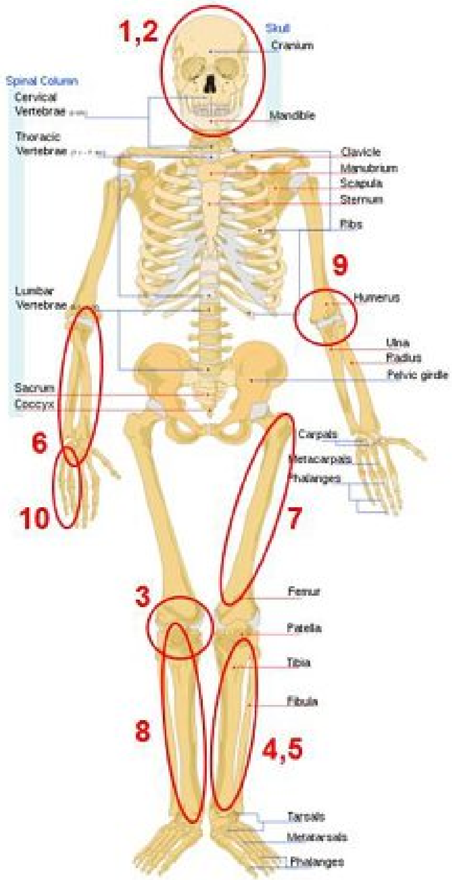


vehicle data	pedestrian data
VW Lupo 2001	42 years
trapezium	male
1043 kg	175 cm
36 - 48 km/h	70 kg
pre-crash braking	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	1st degree craniocerebral injury	primary	A-pillar
2	frontal head laceration left	secondary	kerbstone
3	contusion of left knee	primary	bumper
4	small contusion mark below knee joint, medial	primary	bumper
5	pressure on nerve in right wrist leading to sensory disturbance	secondary	ground
6	multiple skin abrasions	secondary	ground

injury	injury caused by hit	injury caused by …
cardiac contusion with 4mm pericardial effusion	primary/secondary	A-pillar/ground
closed dislocated proximal multi-fragment fracture of the humerus shaft right	primary/secondary	windscreen/ground
tumescence on right upper arm	primary/secondary	windscreen/ground

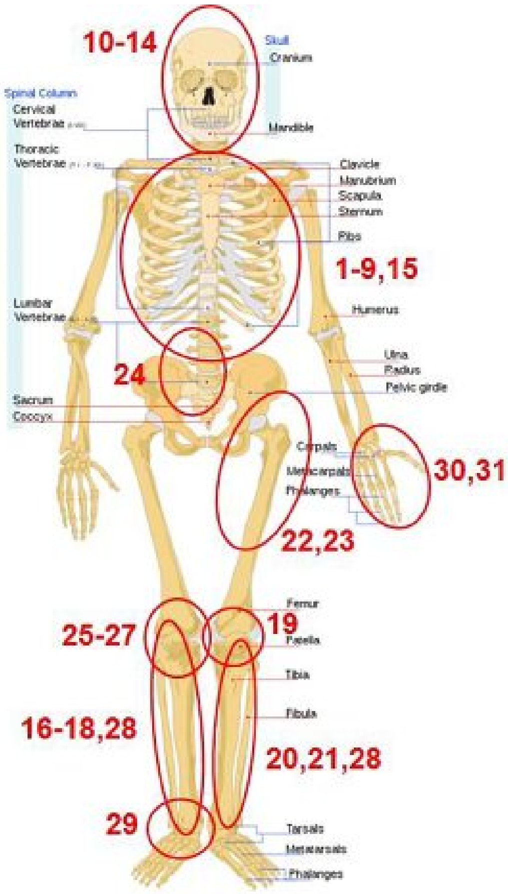


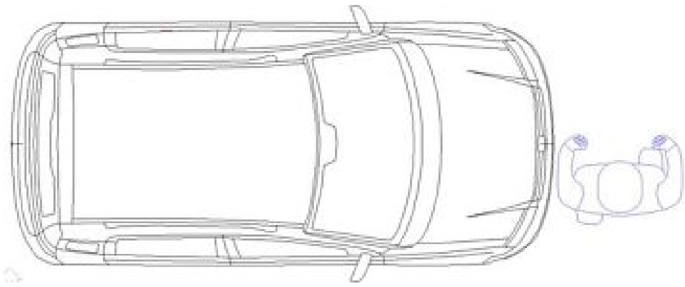


vehicle data	pedestrian data
Opel Vectra A 1991	38 years
trapezium	female
1043 kg	165 cm
46 - 51 km/h	90 kg
in-crash braking	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	1st degree craniocerebral injury	primary	windscreen
2	pariotooccipital head laceration right	primary	windscreen
3	skin abrasion and contusion on right knee joint	secondary	ground
4	open mehretagen fracture of left tibia	primary	bumper
5	multi-fragment fracture of left fibula	primary	bumper
6	skin abrasion on outer right lower arm	secondary	ground
7	haematoma on left thigh	primary	radiator grill

8	skin abrasion on right lower leg	secondary	ground
9	skin abrasion on left elbow	primary	bonnet
10	skin abrasion on right little finger Dig. V	secondary	ground



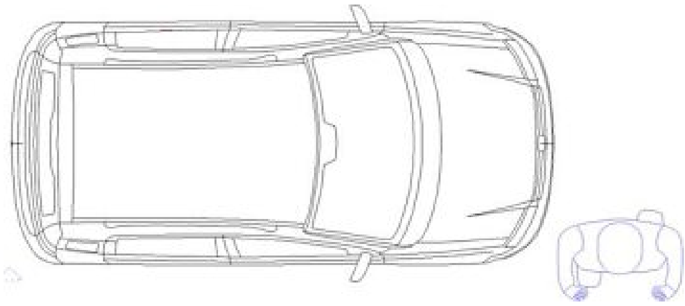


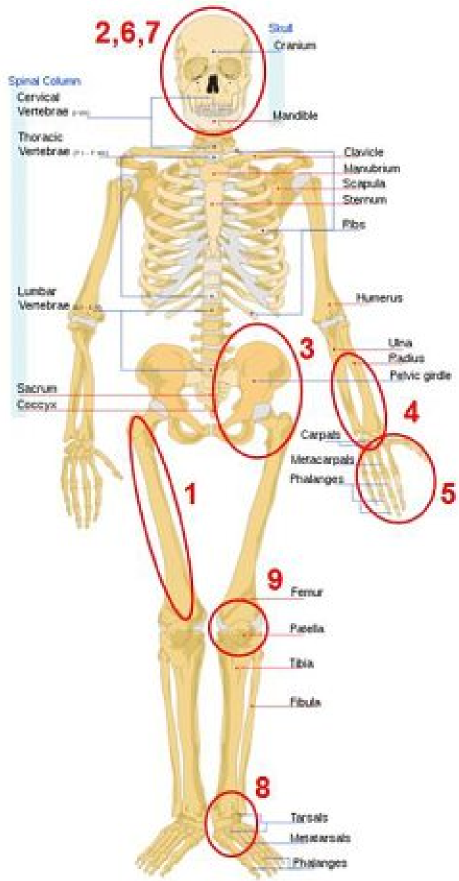
vehicle data	pedestrian data
VW Vento 1993	56 years
trapezium	female
1075 kg	156 cm
55 - 65 km/h	110 kg
late or unbraked	deceased
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	comminuted fracture of the 7th and 8th thoracic vertebra with spinal cord tear off and transection of the autochtonous dorsal musculature	primary	bonnet
2	dorsal opening of the chest	primary	bonnet
3	fracture of the processus spinalis vertebrae thoracica 9/10	primary	bonnet

4	rupture of the aorta thoracica below the aortic arch with bleedings in the mediastinum	primary	bonnet
5	blunt trauma of the chest with haemopneumothorax on both sides	primary	bonnet
6	perforation of the inferior right lobe of the lung	primary	bonnet
7	splenic rupture	primary	bonnet
8	diaphragmatic rupture in the left pars lumbalis	primary	bonnet
9	double hepatic rupture; right hepatic lobules facies diaphragmatica and between right and left lobules facies diaphragmatica	primary	bonnet
10	haematoma of the scalp; parietooccipital right	primary	bonnet
11	subarachnoid haemmorhage parietooccipital; minor extend on the right, increased extend on the left; expansion to the basal regions of the brain	primary	bonnet
12	minor cortex bleedings	primary	bonnet
13	bleedings in the hypophysis	primary	bonnet
14	minor subdural bleedings	primary	bonnet
15	multiple rib fractures; left 2nd to 4th rib ventral and 8th rib dorsal	primary	bonnet
16	tibia plateau fracture with split-off of the lateral tibia plateau part right	primary	bumper
17	fibula plateau fracture with split-off right	primary	bumper
18	non-dislocated distal tibia fracture right	primary	bumper

19	left knee joint space opened	primary	bumper
20	tibia plateau fracture with split-off of the ventral tibia plateau part left	primary	bumper
21	dislocated proximal fibula shaft fracture left	primary	bumper
22	split-off of the trochanter major left	primary	bonnet leading edge
23	extensive bleedings below the muscles in the hip joint and lateral ventral upper leg region left	primary	bonnet leading edge
24	osseous split-off at the right iliosacral joint; joint space opened and suffused with blood	primary	bonnet leading edge
25	complete tear-out of the knee joint ligaments right	primary	bumper
26	tear of the medial meniscus right	primary	bumper
27	right knee joint space opened	primary	bumper
28	haematomas on lower legs front side left and right	primary	spoiler
29	haematoma at the medial malleolus right	primary	spoiler
30	skin abrasions at the back of left hand	primary	windscreen
31	haematoma on left wrist on the ulnar side dorsal	primary	windscreen



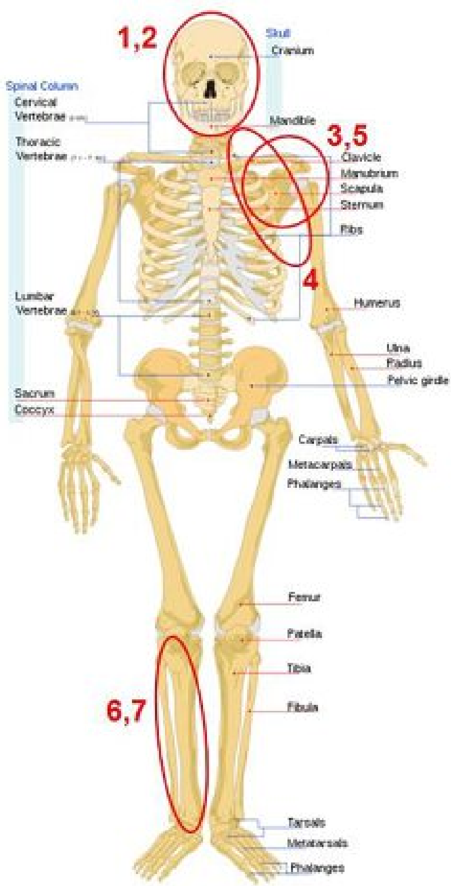


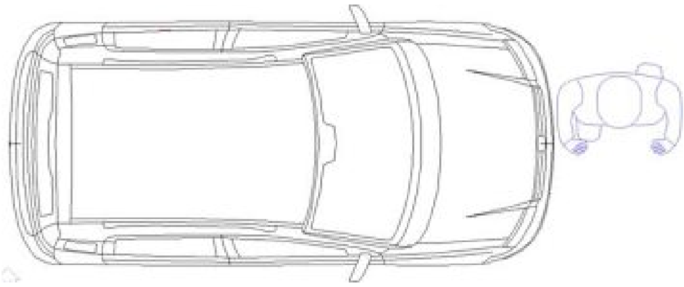
vehicle data	pedestrian data
Opel Vectra A 1992	7 years
trapezium	male
1140 kg	130 cm
37 - 43 km/h	23,5 kg
pre-crash braking	survived
frontal	
partial	

no.	injury	injury caused by hit	injury caused by …
1	closed fracture of right femur shaft	primary	bumper
2	head laceration on the right, parietooccipital	primary	edge between bonnet and fender
3	haematoma on left gluteal region, lateral	secondary	ground
4	haematoma on left arm proximal to wrist and skin abrasions on inner side	secondary	ground

5	skin abrasion on left hand dorsal lateral from metacarpophalangeal joint of the thumb and nearby the metacarpophalangeal joint of index	secondary	ground
6	transversal skin abrasions left frontoparietal at eyebrow and forehead	secondary	ground
7	skin abrasion beneath left eyelid running nasal to temporal	secondary	ground
8	haematoma on left heel dorsal medial	primary	bumper
9	haematoma in left patella region front side medial	primary	bumper

injury	injury caused by hit	injury caused by …
3rd degree craniocerebral injury	primary	bonnet, fender
traumatic cerebral oedema	primary	bonnet, fender
subarachnoid haemorrhage supratentorial	primary	bonnet, fender
haematoma on right flank	primary	headlight, bonnet leading edge
haematoma on right arm lateral below musculus deltoidus	primary	bonnet, fender
haematomas and skin abrasions on right upper arm dorsal lateral	primary	bonnet, fender
contusion of the cerebellum	primary	bonnet, fender
contusion in the splenium corpus callosi	primary	bonnet, fender

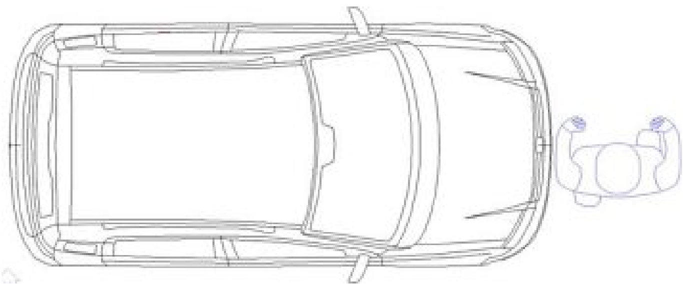


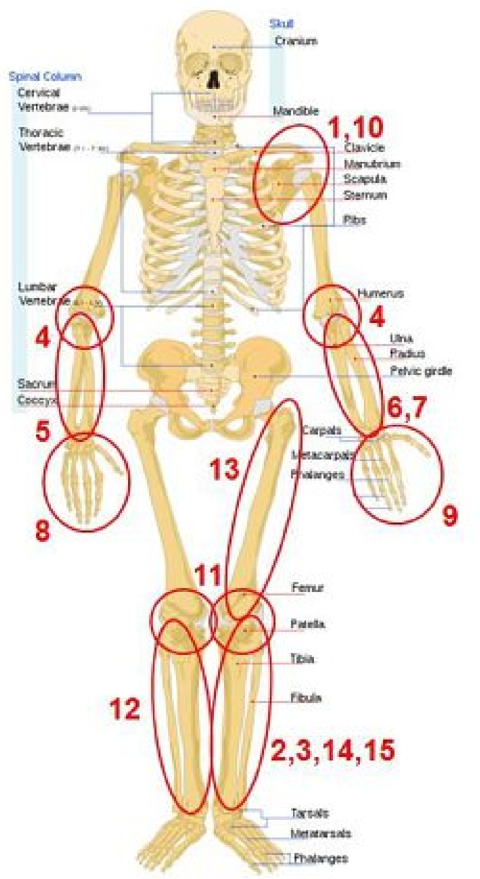


vehicle data	pedestrian data
Opel Vectra B 2001	15 years
trapezium	male
1280 kg	178 cm
44 - 50 km/h	72 kg
late or unbraked	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by ...
1	1st degree craniocerebral injury	secondary	ground
2	head laceration on the left, frontoparietal	secondary	ground
3	contusion of left shoulder with movement restriction in all planes	primary	windscreen
4	haematoma and tumescence on lateral part of musculus trapezius left	primary	windscreen
5	luxation of left shoulder	primary	windscreen
6	contusion of right calf	primary	bumper

7	subcapital fracture of right fibula without significant dislocation	primary	bumper



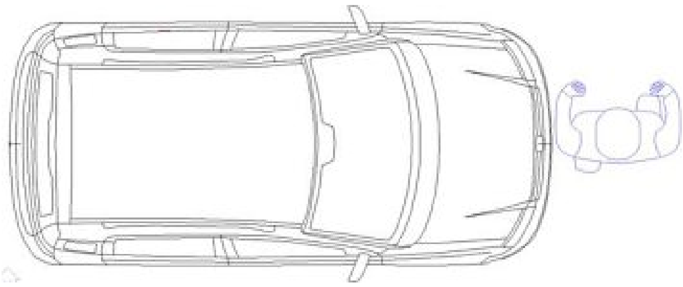


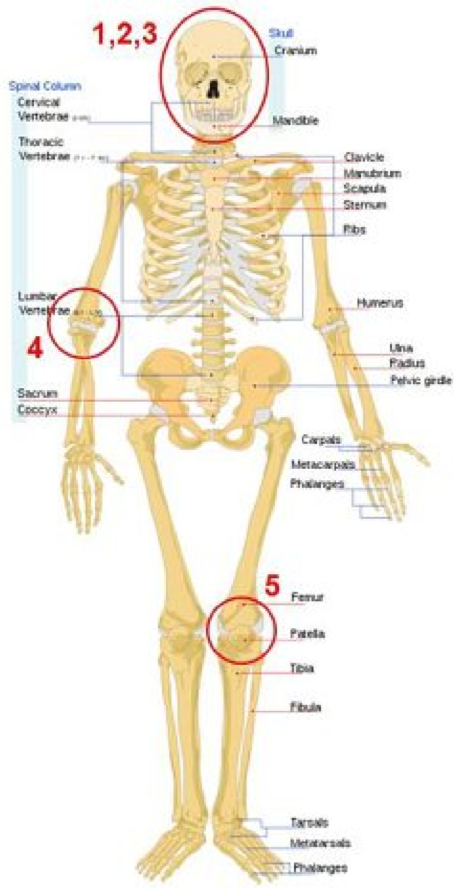
vehicle data	pedestrian data
VW Golf 3 1996	26 years
trapezium	female
1015 kg	173 cm
37 - 40 km/h	72 kg
late or unbraked	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	luxation of left shoulder	primary	windscreen
2	fracture of tibia shaft left	primary	bumper
3	suspicion of non-dislocated fracture of left fibula head	primary	bumper
4	contusion and skin abrasion on both elbows	secondary	ground
5	contusion mark on right forearm dorsal medial	secondary	ground
6	contusion and skin abrasion on left forearm dorsal lateral	secondary	ground
7	contusion mark on left forearm dorsal medial	secondary	ground

8	skin abrasions on all middle and end phalanxes of right hand, dorsal	secondary	ground
9	skin abrasions on all middle phalanxes of left hand, dorsal Dig. IV - V	secondary	ground
10	laceration and contusion of left shoulder	primary	windscreen wiper
11	skin abrasion on both knees ventral	secondary	ground
12	contusion mark on right lower leg ventral lateral	primary	bumper
13	contusion mark on left thigh ventral lateral	primary	bonnet leading edge
14	contusion mark on left lower leg ventral lateral	primary	bumper
15	haematoma on left lower leg ventral medial	primary	bumper

injury	injury caused by hit	injury caused by …
suspicion of non-dislocated fracture of nasal bone	primary/secondary	windscreen/ground
contusion of nasal bone	primary/secondary	windscreen/ground
superficial head laceration parietooccipital left	primary/secondary	windscreen/ground
contusion of right forehead	primary/secondary	windscreen/ground

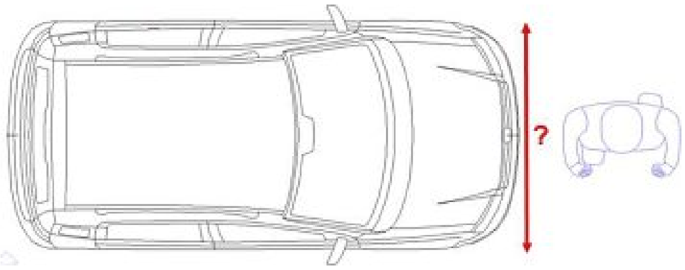


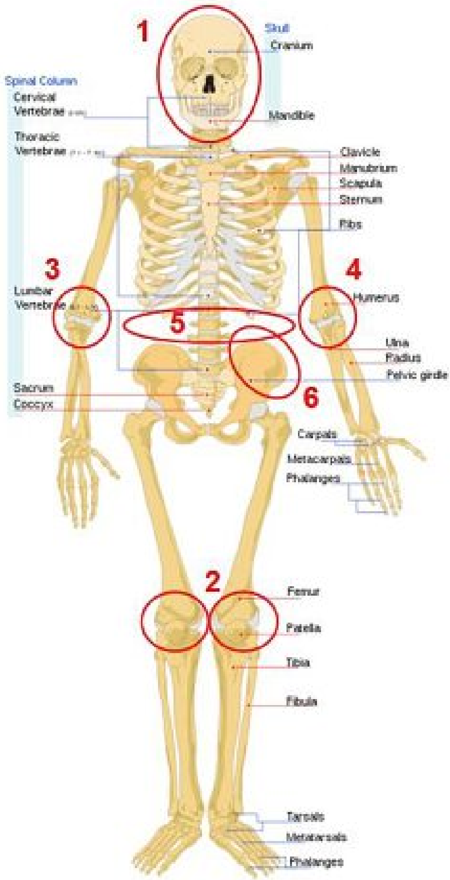


vehicle data	pedestrian data
Opel Corsa B 2000	10 years
trapezium	female
940 kg	130 cm
37 - 43 km/h	28 kg
pre-crash braking	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	cerebral contusion right frontal and left parietooccipital	primary	bonnet rear edge
2	monocular periorbital haematoma and contusion right	primary	bonnet rear edge
3	contusion and skin abrasion on forehead right lateral	primary	bonnet rear edge
4	contusion of elbow right backside medial and lateral	secondary	ground
5	contusion mark on left knee front lateral	primary	bumper

injury	injury caused by hit	injury caused by …
traumatic epidural haematoma right frontal	primary/secondary	bonnet rear edge/ground
traumatic cerebral oedema	primary/secondary	bonnet rear edge/ground
covered basal skull fracture right forehead	primary/secondary	bonnet rear edge/ground
fracture of the calvaria right frontal	primary/secondary	bonnet rear edge/ground
fracture of ethmoid bone right side	primary/secondary	bonnet rear edge/ground
closed fracture of right orbita	primary/secondary	bonnet rear edge/ground

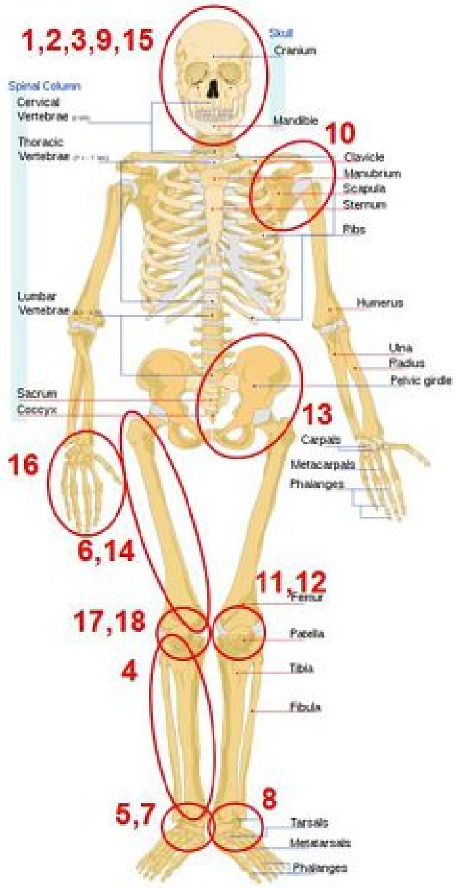


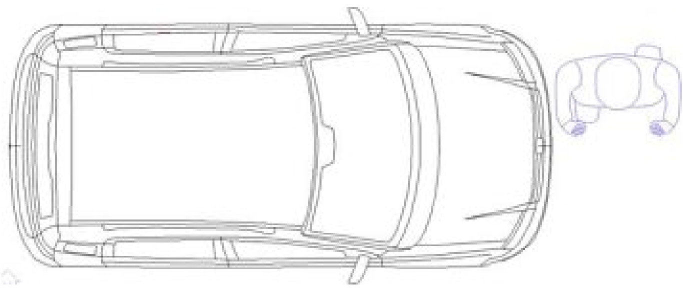


vehicle data	pedestrian data
Mercedes E 220T 2002	43 years
trapezium	male
1640 kg	175 cm
25 - 30 km/h	93 kg
pre-crash braking	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	1st degree craniocerebral injury with commotio cerebri and unconsciousness	secondary	ground
2	superficial skin abrasions on both knees infrapatellar ventral lateral	secondary	ground
3	skin abrasion on right elbow dorsal medial	secondary	ground
4	skin abrasion on left elbow dorsal lateral	secondary	ground

5	superficial skin abrasion and contusion of left upper abdomen and mesogastrium reaching to left flank with very slight haematoma colouring and abrasion marks	secondary	ground
6	skin abrasion above left iliac crest ventral lateral	secondary	ground

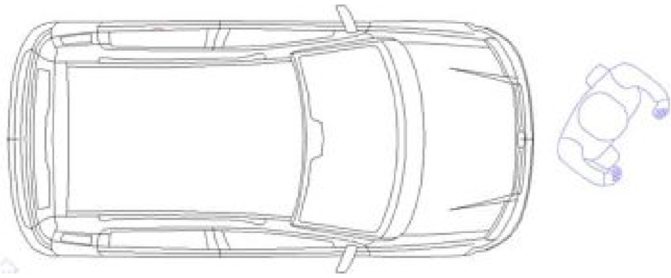


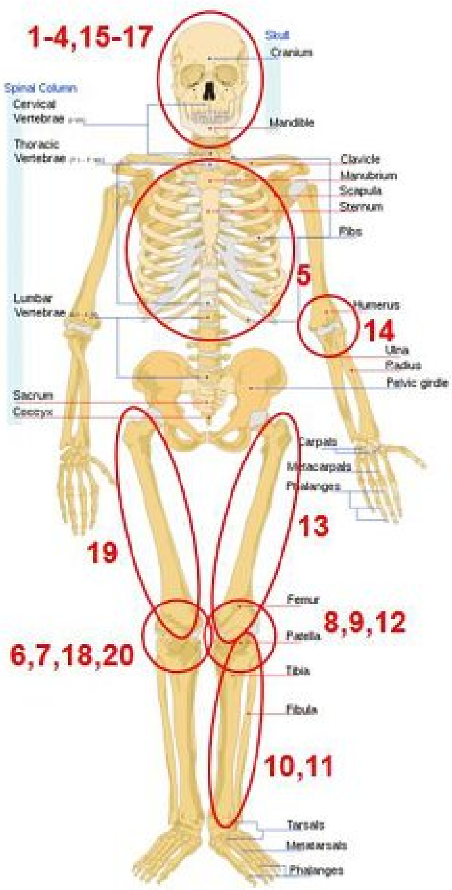


vehicle data	pedestrian data
VW Polo 1999	82 years
trapezium	female
972 kg	159 cm
55 km/h	50 kg
late or unbraked	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	2nd degree craniocerebral injury	primary	windscreen
2	traumatic subarachnoid haemorrhage	primary	windscreen
3	head laceration left parietooccipital	secondary	ground
4	fibula fracture right proximal	primary	bumper
5	trimalleolar fracture of right upper ankle joint	secondary	ground
6	contusion of right thigh	primary	bonnet leading edge

7	ankle joint fracture right and skin abrasion	secondary	ground
8	3 small irregular abrasions on outside of left ankle associated with a tumescence	secondary	ground
9	contusion of forehead between eyebrows	primary	windscreen
10	contusion mark on left shoulder dorsal	secondary	ground
11	skin abrasion on left knee ventral outside	secondary	ground
12	contusion mark below left knee joint ventral inside	primary	bumper
13	haematoma on left buttocks backside outside	secondary	ground
14	contusion of right thigh front with haematoma and tumescence	primary	bonnet leading edge
15	starting haematoma on right upper eyelid and orbita	primary	windscreen
16	skin abrasion on back of left hand	secondary	ground
17	contusion of right knee front inside	primary	bumper
18	skin abrasion on right knee	secondary	ground



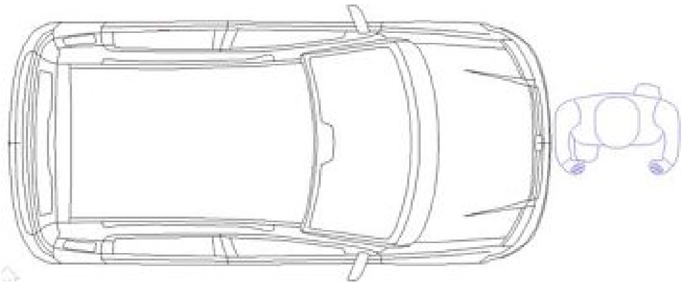


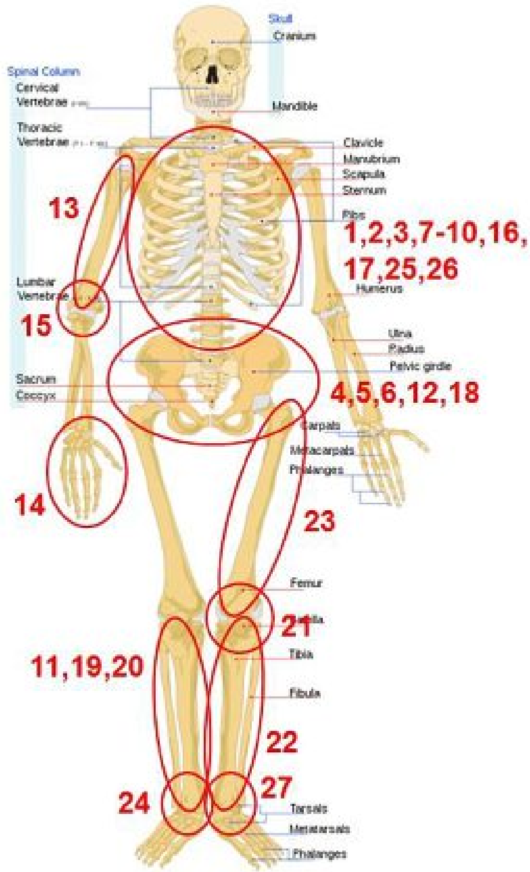
vehicle data	pedestrian data
VW Passat 1998	29 years
trapezium	male
1155 kg	178 cm
64 - 67 km/h	78 kg
late or unbraked	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	2nd degree craniocerebral injury	primary	windscreen
2	head laceration right temporal and above zygomatic bone with foreign bodies in wound	primary	windscreen
3	light cerebral swelling parietal left	primary	windscreen
4	galeahaematoma temporobasal right and temporoparietal left	primary	windscreen

5	ambilateral lung contusion; segments IV and VIII right and segment IV left	primary	bonnet
6	rupture of anterior cruciate ligament right	primary	bumper
7	rupture of medial collateral ligament right	primary	bumper
8	suspicion of strain of lateral collateral ligament left	primary	bumper
9	bony tear-out of intercondylar area left knee joint	primary	bumper
10	skin abrasion and haematoma on lower leg left lateral	primary	bumper
11	skin abrasion on lower leg left medial dorsal	primary	bumper
12	contusion mark left knee inside	primary	bumper
13	skin abrasion on left thigh dorsal lateral	primary	bonnet leading edge
14	skin abrasion on left elbow medial	secondary	ground
15	skin abrasion on chin	primary	windscreen
16	skin abrasion on nose running from left bride to ala	primary	windscreen
17	superficial skin abrasion on left forehead	primary	windscreen
18	skin abrasion on right knee front	primary	bumper
19	contusion mark on right thigh front lateral	primary	bonnet leading edge
20	skin abrasion in the hollow of the knee right	primary	bumper

injury	injury caused by hit	injury caused by …
skin abrasion on buttocks ambilateral	primary/secondary	bonnet/ground
contusion mark left upper arm	primary/secondary	bonnet, bonnet rear edge, roof/ground
contusion mark on left back of the hand	primary/secondary	roof leading edge/ground
skin abrasion on lift side of back	primary/secondary	bonnet/ground





vehicle data	pedestrian data
Nissan Primera 1998	67 years
trapezium	female
1335 kg	155 cm
60 - 65 km/h	80 kg
pre-crash braking	deceased
frontal	
complete	

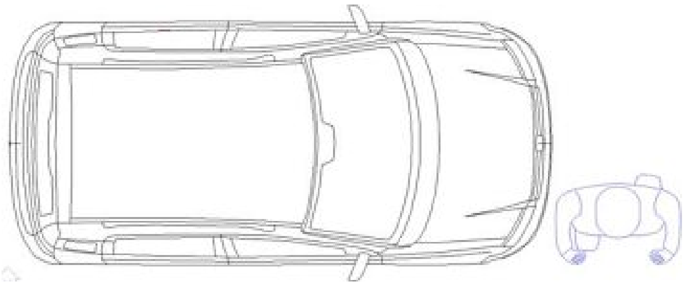
no.	injury	injury caused by hit	injury caused by …
1	haematothorax right	primary	bonnet
2	small effusion left thorax	primary	bonnet
3	multiple rib fractures; right 1st to 3rd rib next to bone-cartilage-transition with mediastinal bleeding, 6th rib at front linea axillaries, 3rd to 5th rib at medial linea axillaries, 6th to 9th rib paravertebral	primary	bonnet

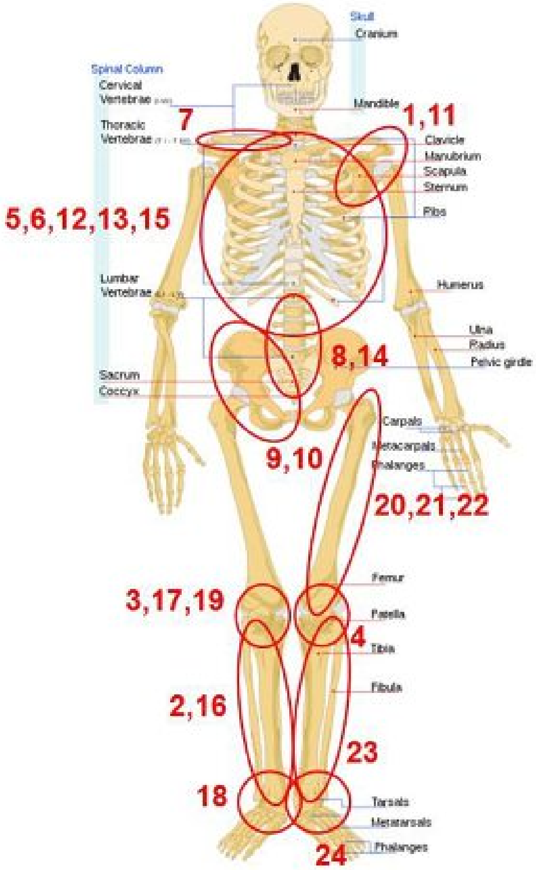
4	frontal fracture of pelvic ring ambilateral with double fracture of left upper pubis	primary	bonnet leading edge
5	non-dislocated transforaminal fracture on right side of sacrum	primary	bonnet leading edge
6	blasting of sacroiliac joint ambilateral	primary	bonnet leading edge
7	leading edge abruption at 6th thoracic segment with rupture of intervertebral ligaments at 5th and 6th thoracic segments	primary	bonnet
8	multiple ruptures of liver capsule	primary	bonnet
9	rupture of right renal artery and renal vein with large retroperitoneal haematoma	primary	bonnet
10	big dorsolateral fascicle abdominal wall hernia on right side with herniation of parts of preterminal ileum	primary	bonnet
11	1st degree open fracture of lower leg right with transfixion	primary	front spoiler
12	spacious “untertaschung” of the musculature in the area of the right buttocks	primary	bonnet leading edge
13	haematoma on right upper arm diagonal dorsal	primary	bonnet
14	haematoma on right back of the hand in the area of the metacarpophalangeal joint of the thumb	primary	bonnet
15	1st degree open fracture of right elbow with transfixion and skin abrasion	primary	bonnet

16	diagonally striped haematoma on the right side of back dorsal above iliac bone	primary	bonnet leading edge
17	tear of right atrium	primary	bonnet
18	subcutaneous haemorrhage at right hip	primary	bonnet leading edge
19	haematoma on right lower leg lateral above upper ankle joint	primary	front spoiler
20	haematoma on right lower leg medial	primary	front spoiler
21	haematoma in left hollow of the knee medial	primary	right leg
22	haematoma on left lower leg medial to dorsal up to thigh with untertaschung of medial musculature of lower leg	secondary	ground
23	haematoma on left thigh medial	secondary	ground
24	haematoma on outside of right ankle	primary	front spoiler
25	minor subcutaneous haemorrhage at left mammary gland	primary	bonnet
26	splenic rupture dorsal	primary	bonnet
27	contusion mark on left ankle lateral	secondary	ground

injury	injury caused by hit	injury caused by …
subarachnoid haemorrhage	primary	windscreen, left wiper arm
3rd degree craniocerebral injury	primary	windscreen, left wiper arm
skin abrasions complete outside of right leg and inner and outer side of left leg	primary/secondary	bumper, bonnet leading edge/ground
diagonal head laceration frontoparietal medial left	primary	windscreen, left wiper arm
forehead contusion right frontal diagonal	primary	windscreen, left wiper arm
point-shaped laceration on right forehead	primary	windscreen, left wiper arm

contusion mark on nose bridge	primary	windscreen, left wiper arm
tear of vena jugularis	primary	windscreen, left wiper arm
extensive subcutaneous haemorrhages reaching from right lower leg to right upper leg	primary	bumper, bonnet leading edge
several contusions and skin abrasions above subcutaneous haemorrhages on right thigh reaching to knee lateral	primary/secondary	bonnet leading edge/ground
red contusion marks on right lower leg medial	primary	front spoiler, bumper
haematoma on both sides of the gluteal region dorsal lateral with skin abrasions right	primary/secondary	bonnet leading edge/ground





vehicle data	pedestrian data
BMW 320i 1996	51 years
trapezium	male
1300 kg	173 cm
53 - 63 km/h	83 kg
late or unbraked	deceased
frontal	
complete	

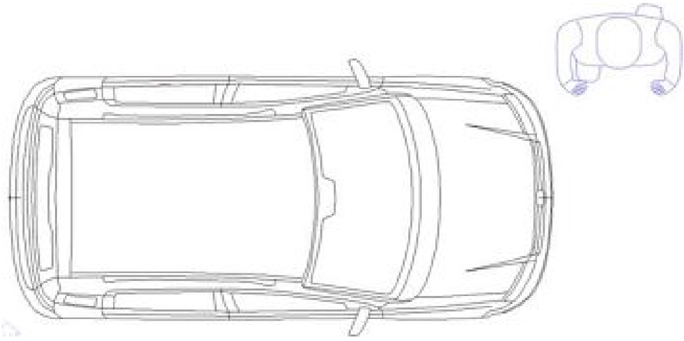
no.	injury	injury caused by hit	injury caused by …
1	fracture of left scapula	secondary	ground
2	fracture of right fibula	primary	bumper
3	fraying of fibres of right knee joint's medial collateral ligament	primary	bumper
4	rupture of left knee joint's lateral collateral ligament with opening of articular cavity and bony rupture of lateral collateral ligament	primary	right leg

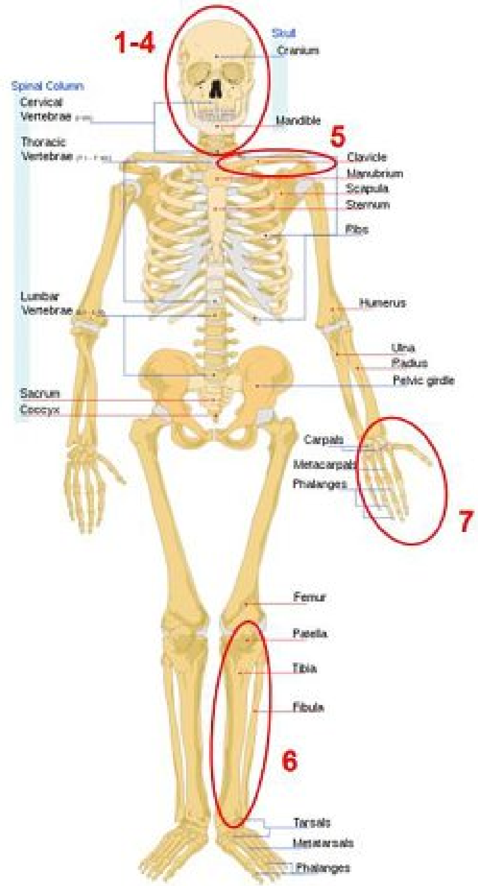
5	multiple rib fractures left; 1st to 6th rib at linea axillaries anterior and 3rd to 8th rib at medial linea scapula	secondary	ground
6	multiple rib fractures right; 1st to 8th rib paravertebral and 1st to 6th rib at linea axillaries anterior	primary	bonnet
7	fracture of left clavicle	secondary	ground
8	fracture of the 2nd lumbar vertebra	secondary	ground
9	fracture of front and rear pelvic ring right	primary	bonnet leading edge
10	fracture of iliac wing right	primary	bonnet leading edge
11	subcutaneous haemorrhage on left scapula in area of fracture	secondary	ground
12	haematoma and contusion mark on right side of upper sternum	primary	bonnet
13	haematoma in right regio axillaris	primary	bonnet
14	diagonally band-shaped subcutaneous haemorrhaging of musculature in area of lumbar spine left to right medial and of the subcutaneous fatty tissue with superficial skin abrasion	secondary	ground
15	orbital contusion mark on left side of sacrum at beginning of rima ani	secondary	ground
16	intensive subcutaneous haemorrhaging of right lower leg dorsal in area of soleus muscle reaching to area above the hollow of the knee	primary	bumper
17	contusion mark in the right hollow of the knee medial	primary	bumper

18	skin abrasion in region of right medial malleolus	primary	left leg
19	bleedings in the right knee joint with degloving of fascia	primary	bumper
20	skin abrasion in region of head of femoral bone left	secondary	ground
21	subcutaneous haemorrhaging in backside of left thigh medial	secondary	ground
22	subcutaneous haemorrhaging in inside of left thigh	primary	right leg
23	subcutaneous haemorrhaging in backside of left lower leg	primary	right leg
24	contusion in area of left Achilles tendon	primary	right leg

injury	injury caused by hit	injury caused by …
fracture and dislocation of processus spinalis of 4th and 5th lumbar vertebrae	primary/secondary	bonnet leading edge/ground
fracture of sternum left side	primary/secondary	bonnet/ground
fracture of 1st rib left and right with haemorrhaging of musculature and pleura rupture; corresponds to multiple rib fractures with haemopneumothorax	primary, secondary	bonnet, ground
ambilateral lung contusion	primary/secondary	bonnet/ground
mediastinal haemorrhage 50 ml	primary/secondary	bonnet/ground
head laceration right temporal	primary	windscreen, A-pillar, roof leading edge
2 head lacerations right diagonally parietal	primary	windscreen, A-pillar, roof leading edge
3rd degree craniocerebral injury	primary	windscreen, A-pillar, roof leading edge

rupture of scalp left parietooccipital; along outer edge of plastic implant from former accident	primary	windscreen, A-pillar, roof leading edge
fracture of right humerus shaft with dislocation	primary	bonnet, bonnet rear edge
fracture of 7th cervical vertebra	primary	bonnet, bonnet rear edge
rupture of liver capsule	primary/secondary	bonnet/ground
central rupture of right hepatic lobe	primary/secondary	bonnet/ground
liver contusion of left lobe	primary/secondary	bonnet/ground
bleedings in renal capsule right with haemorrhaging of adrenal gland	primary/secondary	bonnet/ground
rupture of spleen	primary/secondary	bonnet/ground
subarachnoid haemorrhage	primary	windscreen, A-pillar, roof leading edge
pons haemorrhage	primary	windscreen, A-pillar, roof leading edge
skin abrasions on back of right hand in area of all metacarpophalangeal joints and on backside of right wrist dorsal	primary/secondary	roof/ground
contusion and skin abrasion on left elbow	primary/secondary	roof/ground
skin abrasions on back of left hand in area of all metacarpophalangeal joints	primary/secondary	roof/ground

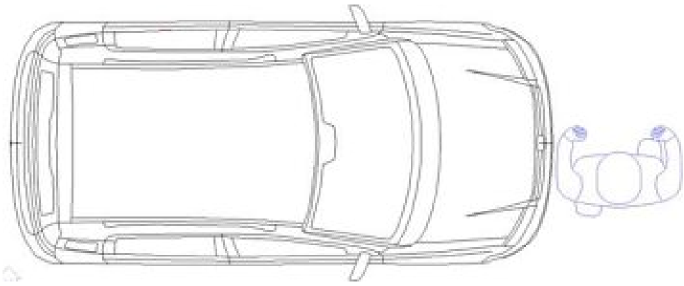


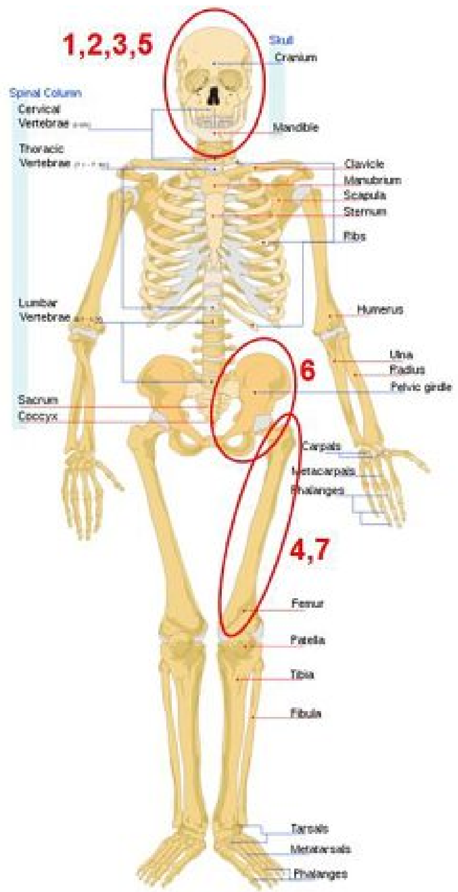


vehicle data	pedestrian data
Honda Civic Coupé 1997	22 years
trapezium	female
1110 kg	160 cm
50 km/h	55 kg
late or unbraked	deceased
frontal	
streaking	

no.	injury	injury caused by hit	injury caused by …
1	traumatic cerebral oedema	primary	A-pillar
2	subdural haematoma right	primary	A-pillar
3	fracture of base of skull	primary	A-pillar
4	cephalohaematoma	primary	A-pillar
5	fracture of left scapula	secondary	ground
6	fracture of left lower leg	primary	bumper
7	skin abrasion on left hand	secondary	ground

injury	injury caused by hit	injury caused by …
ambilateral lung contusion	primary/secondary	bonnet, fender/ground



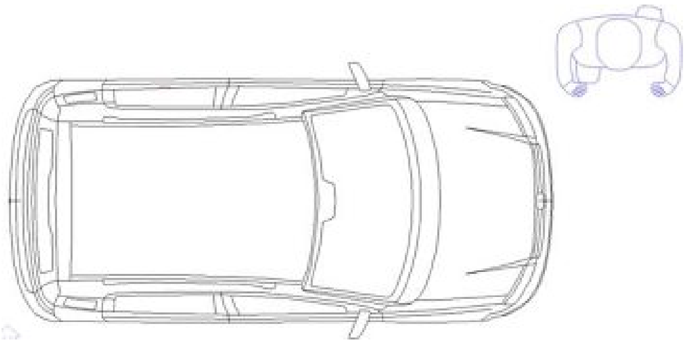


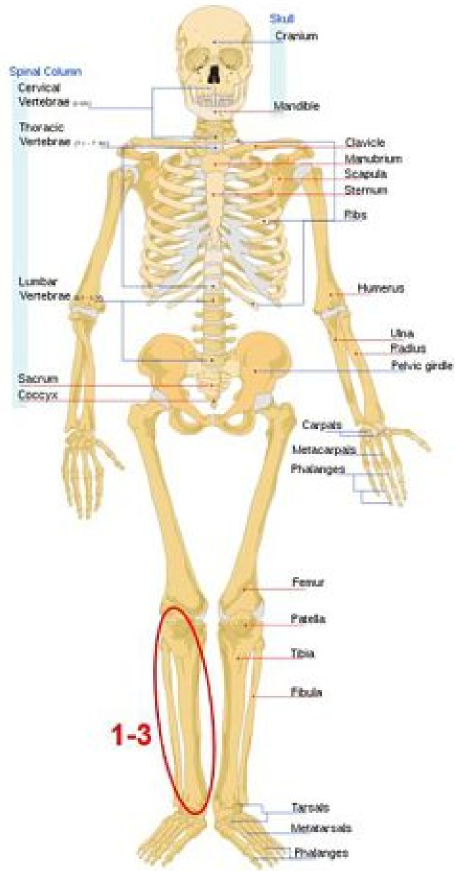
vehicle data	pedestrian data
Opel Zafira 2001	13 years
van	male
1395 kg	154 cm
34 - 38 km/h	48 kg
pre-crash braking	survived
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	1st degree craniocerebral injury with retrograde amnesia	primary	windscreen
2	half t-shaped laceration above and left of upper lip	primary	windscreen
3	luxation of left incisor	primary	windscreen
4	contusion of left thigh front	primary	bumper
5	superficial skin abrasions on left and right side of forehead	primary	windscreen
6	superficial skin abrasion on left iliac crest	primary	bonnet leading edge

7	contusion mark on left thigh medial lateral	primary	bumper

injury	injury caused by hit	injury caused by …
contusion of left wrist	primary/secondary	windscreen/ground
superficial skin abrasions on back of both hands	primary/secondary	windscreen/ground
punctiform skin abrasions above left and right acromions	primary/secondary	windscreen/ground

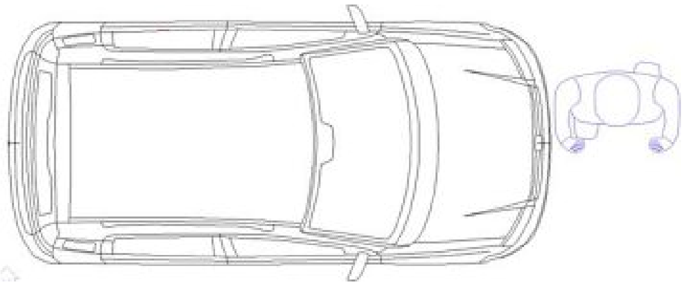


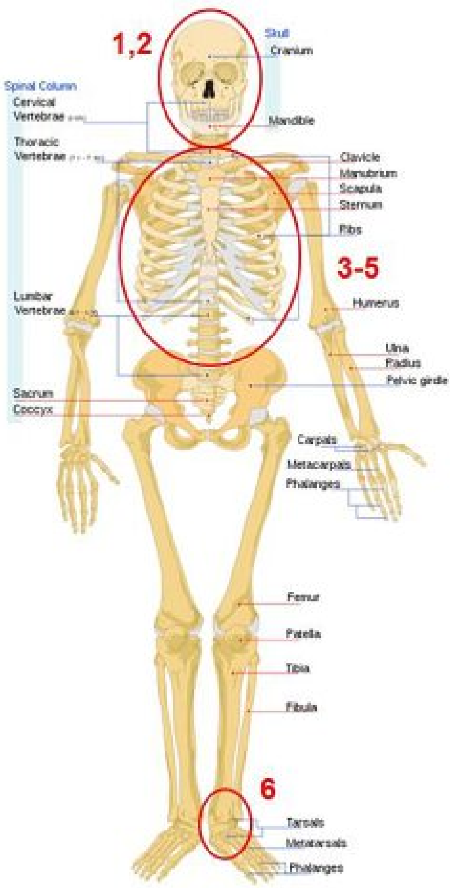


vehicle data	pedestrian data
Opel Vectra A 1992	77 years
trapezium	female
1020 kg	159 cm
40 km/h	74 kg
pre-crash braking	deceased
frontal	
partial	

no.	injury	injury caused by hit	injury caused by …
1	fracture of right fibula	primary	bumper
2	fracture of right tibia head	primary	bumper
3	subcutaneous haemorrhaging in right lower leg	primary	bumper

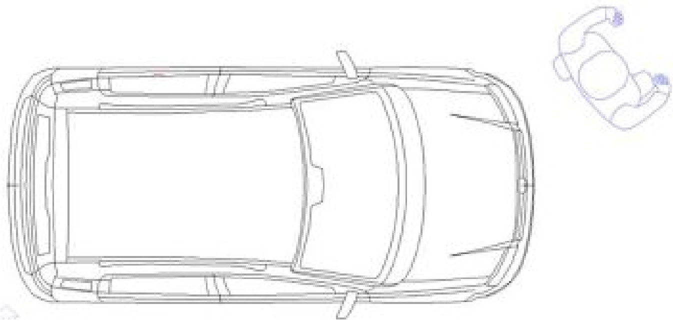
injury	injury caused by hit	injury caused by …
fracture of vault of skull right	primary	windscreen, A-pillar
fracture of base of skull right	primary	windscreen, A-pillar
cerebral haemorrhages	primary	windscreen, A-pillar
cerebral contusion	primary	windscreen, A-pillar

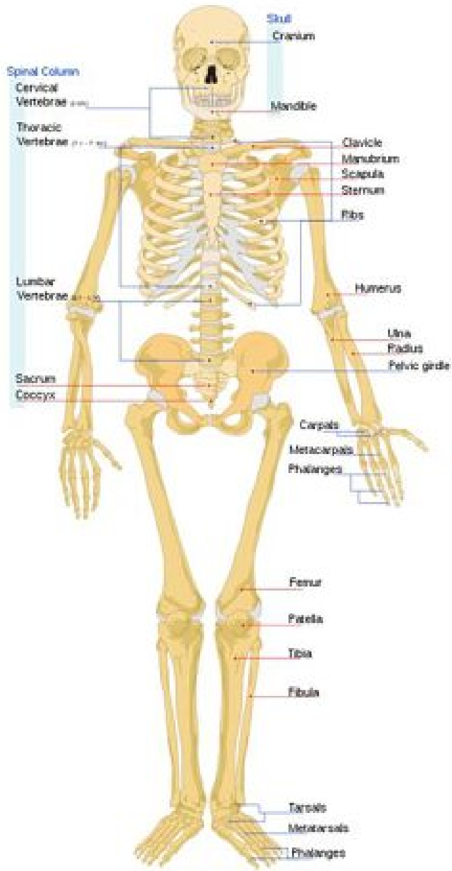




vehicle data	pedestrian data
Opel Corsa B 1994	72 years
trapezium	female
835 kg	149 cm
40 - 50 km/h	72,5 kg
late or unbraked	deceased
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	subdural haematoma left	primary	windscreen
2	fracture of vault of skull	primary	windscreen
3	haematothorax left	primary	bonnet
4	multiple rib fractures left; 2nd to 9th rib	primary	bonnet
5	multiple rib fractures right; 2nd to 3rd rib	primary	bonnet
6	fracture of left talocalcanean joint	primary	bumper

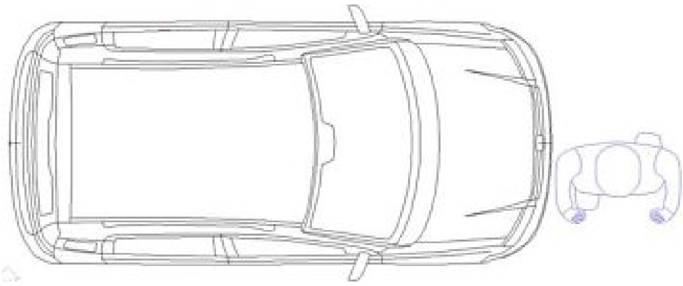


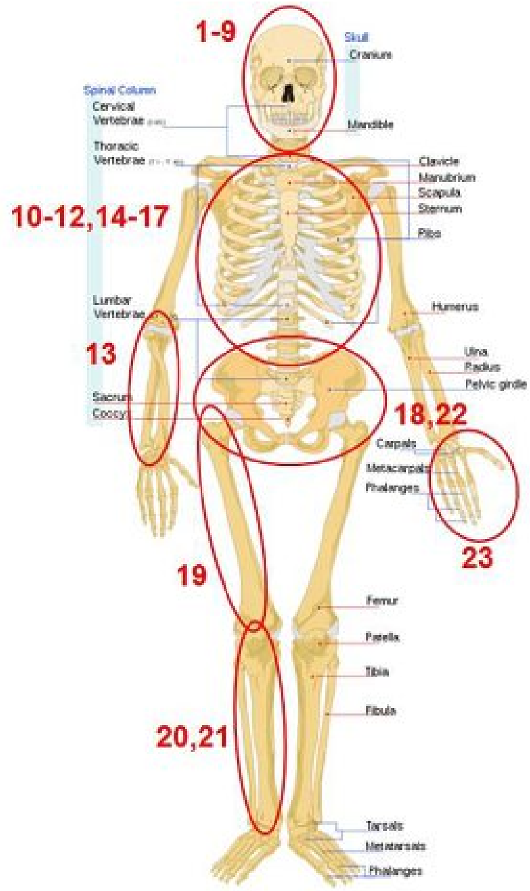


vehicle data	pedestrian data
Fiat Bravo 1996	28 years
trapezium	female
1010 kg	160 cm
45 - 53 km/h	61 kg
late or unbraked	deceased
frontal	
partial	

injury	injury caused by hit	injury caused by …
laceration on face reaching from root of the nose to forehead	primary	windscreen, A-pillar
massive tumescence on forehead with subcutaneous haemorrhaging	primary	windscreen, A-pillar
contusion and subcutaneous haemorrhaging on left lower leg	primary	bumper, fender
subcutaneous haemorrhaging below left buttocks	primary	fender, bonnet

epidural haematoma	primary	windscreen, A-pillar
subgaleal haematoma	primary	windscreen, A-pillar
fracture of base of skull	primary	windscreen, A-pillar
subarachnoid haemorrage	primary	windscreen, A-pillar
contusion of cerebrum	primary	windscreen, A-pillar
contusion of brainstem	primary	windscreen, A-pillar
contusion of cerebellum	primary	windscreen, A-pillar





vehicle data	pedestrian data
VW T3 1989	92 years
box type 1	male
1508 kg	172 cm
32 - 40 km/h	75 kg
pre-crash braking	deceased
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	contusion of skull right with subcutaneous haemorrhaging in scalp	primary	windscreen wiper
2	fracture of vault of skull right	primary	windscreen wiper
3	fracture of base of skull right	primary	windscreen wiper
4	massive contre-coup contusion haemorrhage in cerebrum left	primary	windscreen wiper
5	subdural haematoma	primary	windscreen wiper
6	subarachnoid haemorrhage	primary	windscreen wiper

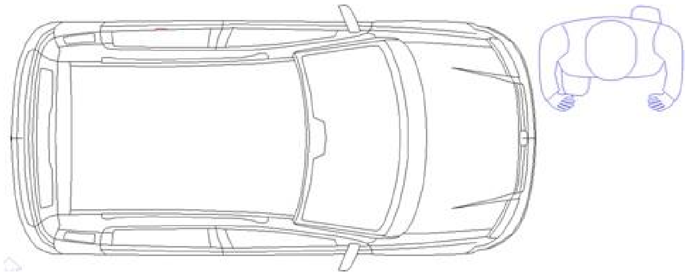
7	fracture of zygomatic bone right	primary	windscreen wiper
8	skin abrasions and laceration on left temple	secondary	ground
9	skin abrasion on nose bridge	secondary	ground
10	multiple rib fractures right; 1st to 12th rib next to spine and 2nd to 6th along frontal axillary line with tearing of pleura and haemothorax	primary	front panel
11	multiple rib fractures left; 1st to 2nd rib next to spine with haemorrhaging in intercostal space	primary	front panel
12	massive contusion of torso right with haemorrhaging in subcutaneous fat tissue in area of thorax and pelvis	primary	front panel
13	fracture of right lower arm with haematoma	primary	front panel
14	rupture of pericardium left	primary	front panel
15	rupture of liver right	primary	front panel
16	rupture of right kidney with massive haemorrhaging in kidney bed	primary	front panel
17	haemorrhaging in right adrenal gland	primary	front panel
18	symmetrical fractures of pubis and ischium	primary	front panel
19	fracture of right femur	primary	front panel
20	comminuted fracture of right tibia	primary	bumper
21	wedge fracture of right fibula	primary	bumper
22	massive haemorrhaging in connective tissue of pelvis minor and major	primary	bumper
23	skin abrasions on left knuckles	secondary	ground

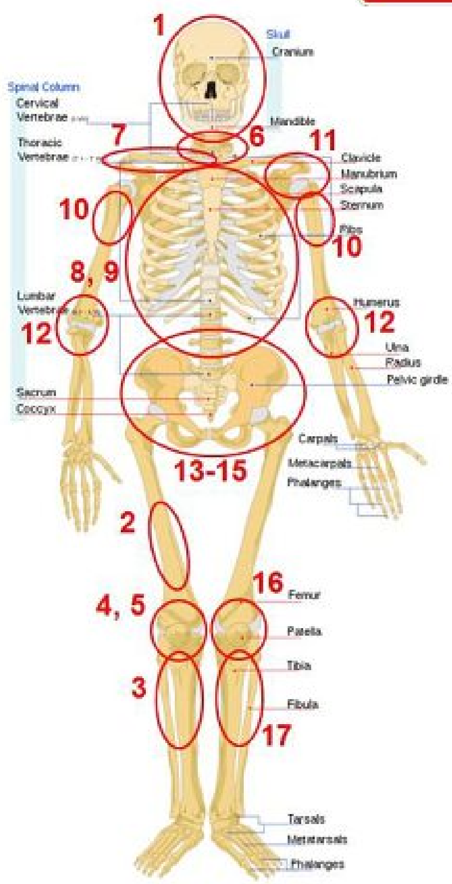
B. Spec-Sheets: "Injuries" of the Biofidelic Dummy

"Autopsies" of the eight biofidelic dummies have been conducted at the "Bureau for Accident Reconstruction Berlin" from $12 - 13$ July 2018 and $10 - 12$ October 2018.

The damages of the biofidelic dummies have been determined by dismembering the ATDs and these damages have then been translated into the respective injuries of a human being. By means of video analysis, it was possible to ascertain which vehicle structure most likely caused the damages/injuries. The findings are summarised in spec-sheets similar to those of the real-world pedestrian accidents. The spec-sheets, however, come with the caveat that they solely list the damages/injuries the ATDs sustained and not the injuries a pedestrian should have sustained in a real-world accident of a similar severity. Therefore, only bone fractures are listed, as the Biofidelic Dummy cannot mimic injuries to other tissues and organs.

During the second set of autopsies, small vests containing tiny metal balls and weighing more than $5\,kg$ each have been discovered in the ATDs used for the $70\,km/h$ crash tests. These alterations to the ATDs have been made without knowledge of DEKRA. In one case, the vest did influence the injury biomechanics of the ATD's pelvis negatively. As such, the damages to the pelvis must be considered with caution as the vests may have tampered with the biofidelity of the pelvic region. The respective spec-sheets are therefore marked with an "attention sign".

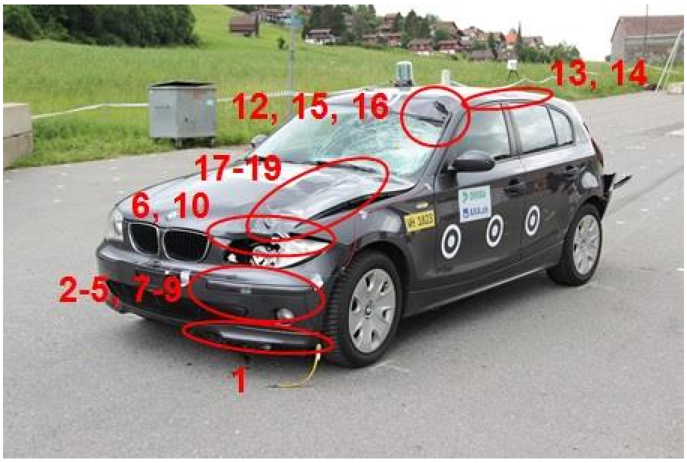


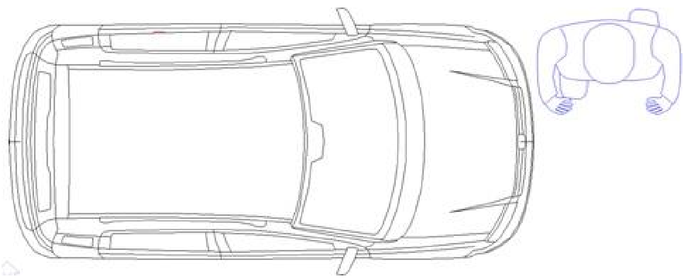


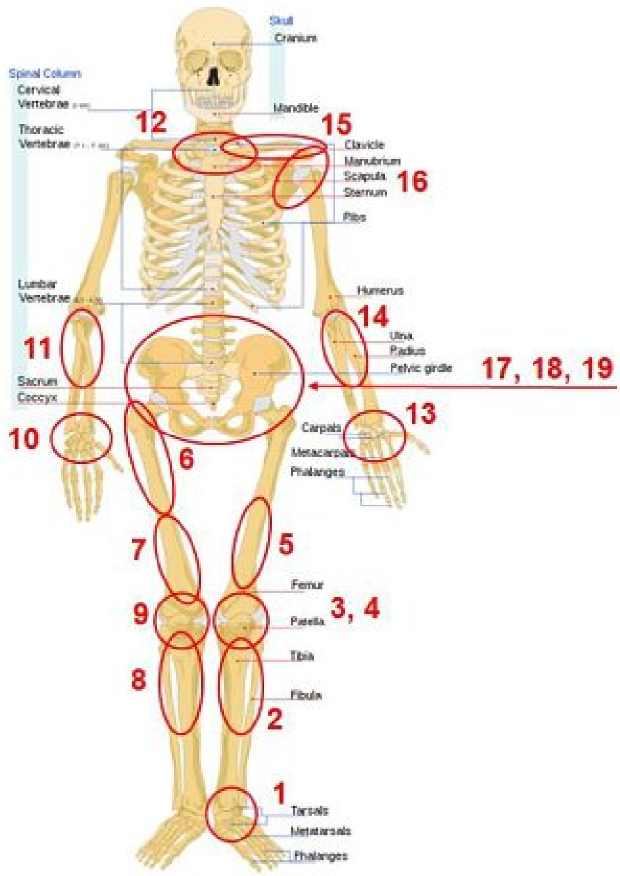
crash test wh18.22	
vehicle data	**dummy data**
BMW 1 Series 2004	D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	laceration on os parietale right	primary	A-pillar
2	fracture of lower femur right	primary	bumper
3	wedge-shaped fracture of right upper lower leg	primary	bumper
4	right knee torn out	primary	bumper
5	rupture of posterior cruciate ligament right	primary	bumper

6	fracture of spinal process of first cervical vertebra	primary	A-pillar
7	fracture of right clavicle	primary	windscreen
8	fracture of the two lower ribs right next to spinal column	primary	windscreen
9	fracture of lowest rib left laterally	primary	windscreen
10	fracture of left and right humerus next to shoulder joint	primary, secondary	windscreen, ground
11	bony split-offs at left shoulder joint	secondary	ground
12	luxation of left and right elbow with bony split-offs at humerus	primary, secondary	bonnet rear edge, windscreen, ground
13	crack in right pubis next to acetabulum	primary	bonnet
14	bony split-offs at acetabulum left and right	primary	bonnet
15	bony split-offs at left and right sacrum	primary	bonnet
16	rupture of lateral and medial collateral ligaments left	primary	bumper
17	wedge-shaped fracture of left lower leg	primary	bumper, spoiler



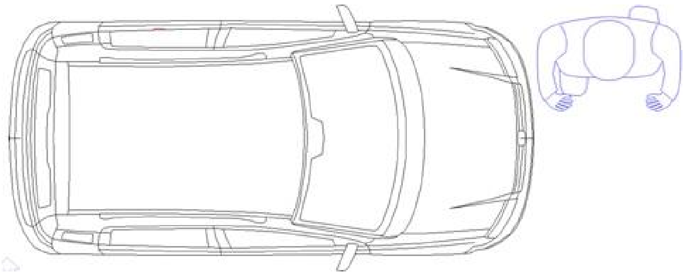


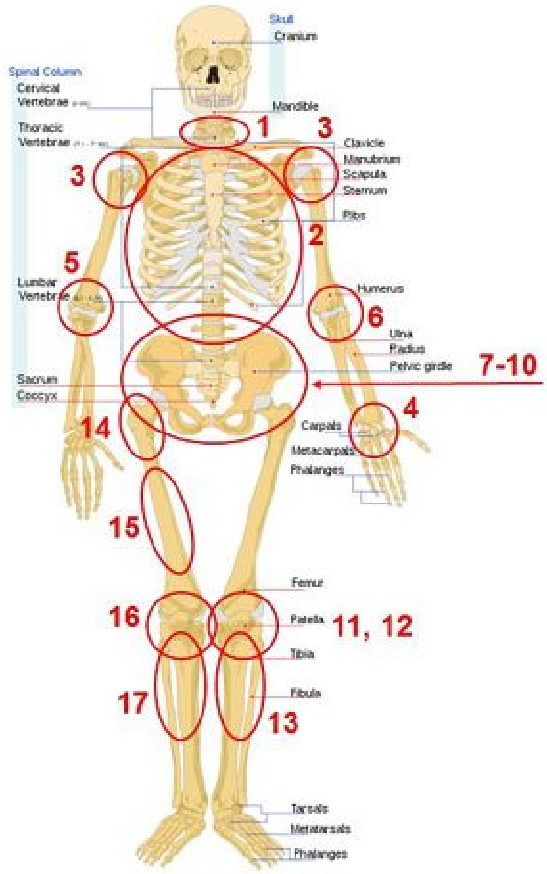


crash test wh18.23	
vehicle data	**dummy data**
BMW 1 Series 2004	D02
pontoon	171 cm
1315 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	fracture of left talocalcanean joint	primary	spoiler
2	lower leg plateau fracture left	primary	bumper
3	fraying of anterior and posterior cruciate ligaments left	primary	bumper
4	rupture of lateral collateral ligament left	primary	bumper
5	wedge-shaped fracture of lower femur left	primary	bumper

6	fracture of right femur head	primary	bonnet leading edge
7	wedge-shaped fracture of right lower femur	primary	bumper
8	wedge-shaped fracture of right upper lower leg	primary	bumper
9	rupture of medial collateral ligament right	primary	bumper
10	fracture of right wrist joint	primary	bonnet leading edge
11	wedge-shaped fracture of right upper forearm	primary	bonnet
12	fracture of right and left sternoclavicular joints	primary	roof leading edge
13	fracture of left wrist joint	primary	roof edge behind B-pillar
14	fracture of left upper forearm	primary	roof edge next to B-pillar
15	fracture of left clavicle	primary	roof leading edge
16	fracture of left shoulder joint	primary	roof leading edge
17	fracture of ilium right and left	primary	bonnet
18	fracture of pubis right and left	primary	bonnet
19	fracture of left acetabulum	primary	bonnet

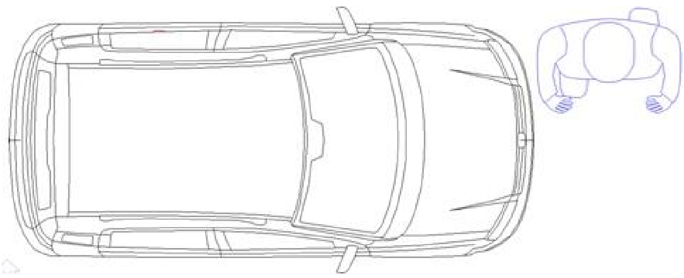


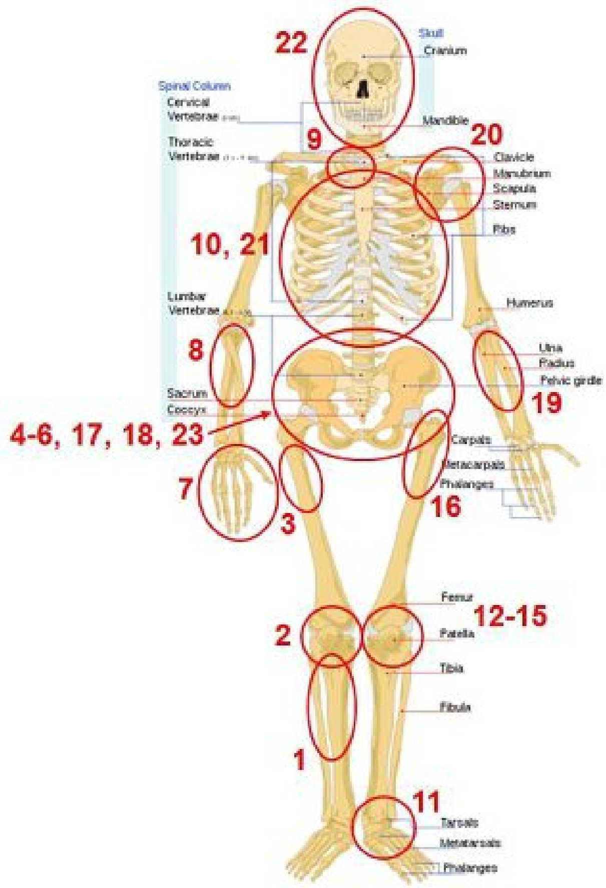


crash test wh18.24	
vehicle data	**dummy data**
VW Touareg 2003	D07
trapezium	170 cm
2542 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	fracture of spinal process of first cervical vertebra	primary	windscreen
2	fracture the two lower ribs left and right	primary, secondary	bonnet, ground
3	fracture of left and right humerus next to shoulder joint	primary, secondary	bonnet, ground
4	fracture of left wrist joint	primary	roof leading edge, A-pillar
5	fracture of right elbow	primary	bonnet
6	bony split-offs at left elbow	primary, secondary	A-pillar, ground

7	fracture of right sacroiliac joint	primary	bonnet leading edge
8	fracture of left pubis	primary	bonnet leading edge
9	fracture of left ilium	primary	bonnet leading edge
10	bony split-offs at right acetabulum	primary	bonnet leading edge
11	rupture of lateral and medial collateral ligaments left	primary	bumper
12	rupture of anterior and posterior cruciate ligaments left	primary	bumper
13	fracture of left lower leg next to knee joint	primary	bumper
14	fracture of right femur next to femur head	primary	bonnet leading edge
15	wedge-shaped fracture of right femur	primary	bumper
16	rupture of medial collateral ligament right	primary	bumper
17	fracture of right lower leg next to knee joint	primary	spoiler

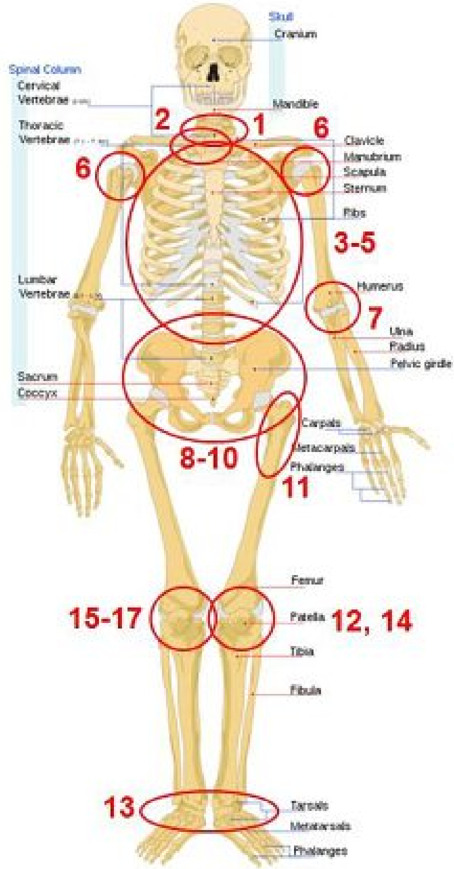


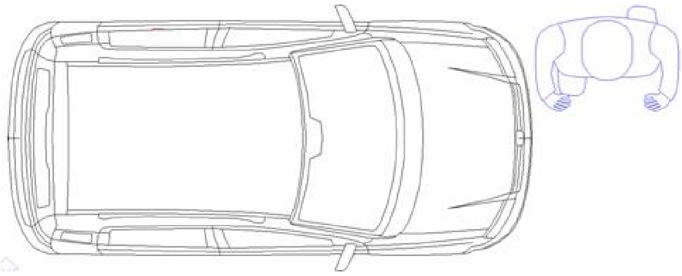


crash test wh18.25	
vehicle data	**dummy data**
VW Touareg 2003	D08
trapezium	173 cm
2494 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	wedge-shaped fracture of upper lower leg right	primary	bumper
2	rupture of medial collateral ligament right	primary	bumper
3	wedge-shaped fracture of upper femur right	primary	bumper
4	fracture acetabulum right	primary	bonnet leading edge
5	fracture ilium right	primary	bonnet leading edge
6	fracture pubis right	primary	bonnet leading edge
7	amputation of right hand	primary, secondary	bonnet leading edge, ground
8	wedge-shaped fracture of upper forearm right	primary	bonnet leading edge

9	fracture of right sternoclavicular joint	primary	bonnet rear edge
10	fracture of lowest rib right	primary	bonnet
11	fracture of left talocalcanean joint	primary	spoiler
12	rupture of anterior and posterior cruciate ligaments left	primary	bumper
13	split-off of medial condyle left	primary	bumper
14	rupture of lateral collateral ligament left	primary	bumper
15	fraying of medial collateral ligament left	primary	bumper
16	fracture of femur head left	primary	bonnet leading edge
17	fracture of pubis left	primary	bonnet leading edge
18	fracture of acetabulum left	primary	bonnet leading edge
19	fracture of upper forearm left	?	?
20	dislocation of left shoulder joint	primary	A-pillar
21	double fracture of lowest rib left	primary	A-pillar
22	laceration with abrasions on os parietale right	primary	A-pillar
23	both legs severed at hip	primary	bonnet leading edge

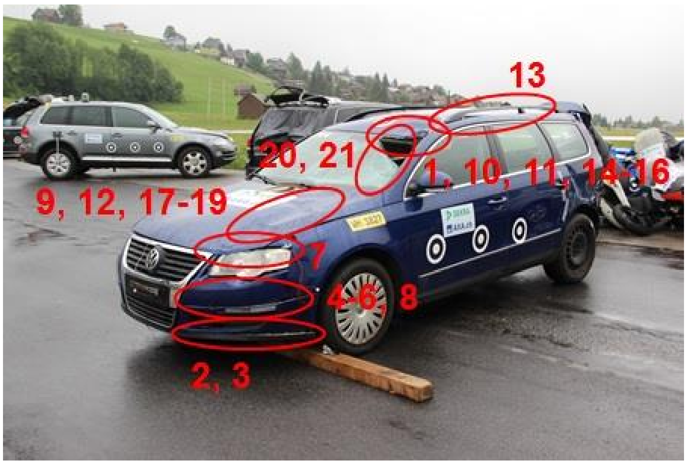


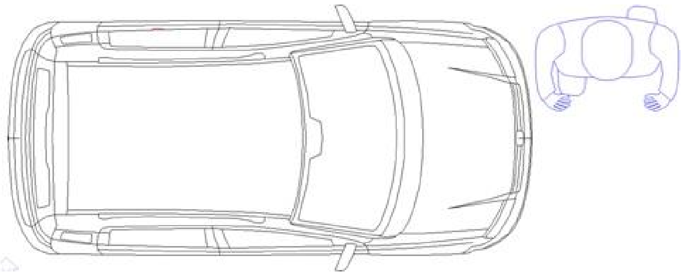


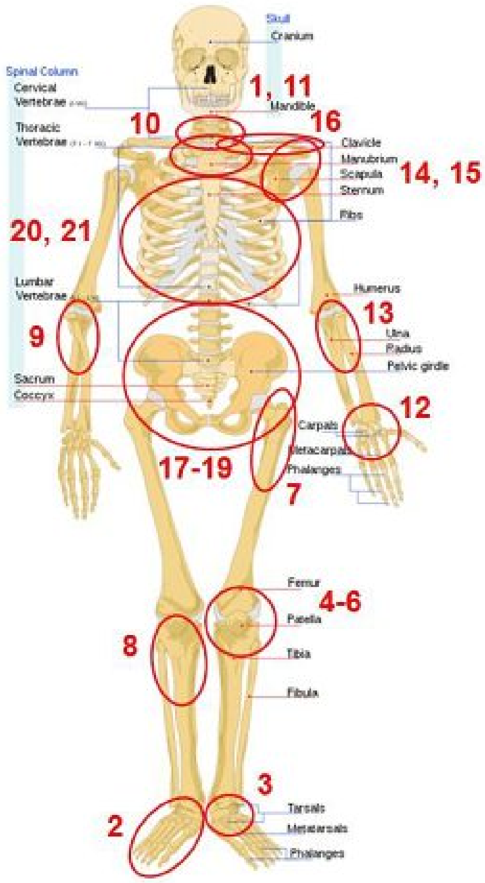
crash test wh18.26	
vehicle data	**dummy data**
VW Passat Variant 2006	D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	fracture of spinal process of first and second cervical vertebrae	primary	roof leading edge
2	fracture of right sternoclavicular joint	primary	windscreen
3	fracture of the three lower ribs right (the lowest twice)	primary	windscreen
4	fracture of second and fourth rib left	primary, secondary	windscreen, ground

5	fracture of sternum (manubrium)	primary, secondary	windscreen, ground
6	fracture of left and right humerus next to shoulder joint	primary, secondary	windscreen, ground
7	luxation of left elbow	primary, secondary	*(swinging motion)*, ground
8	fracture of right sacroiliac joint	primary	bonnet
9	fracture of right pubis	primary	bonnet
10	bony split-offs at acetabulum left and right	primary	bonnet
11	fracture of left femur next to femur head	primary	bonnet leading edge
12	fraying of medial collateral ligament left	primary	bumper
13	fracture of left and right talocalcanean joints	primary	spoiler
14	bony split-offs at medial tibial condyle left	primary	bumper
15	rupture of anterior and posterior cruciate ligaments right	primary	bumper
16	rupture of medial and lateral collateral ligaments right	primary	bumper
17	bony split-offs at lateral tibial condyle right	primary	bumper



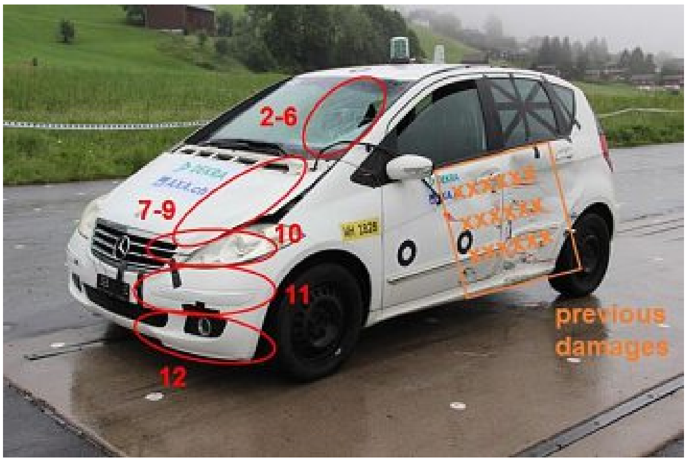


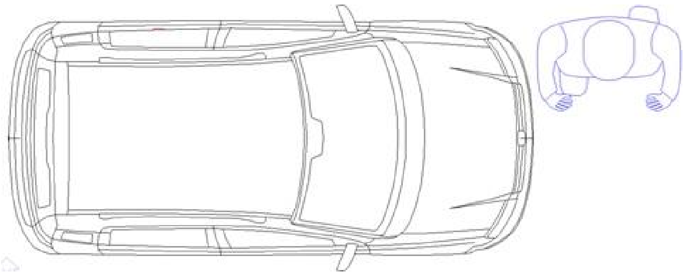


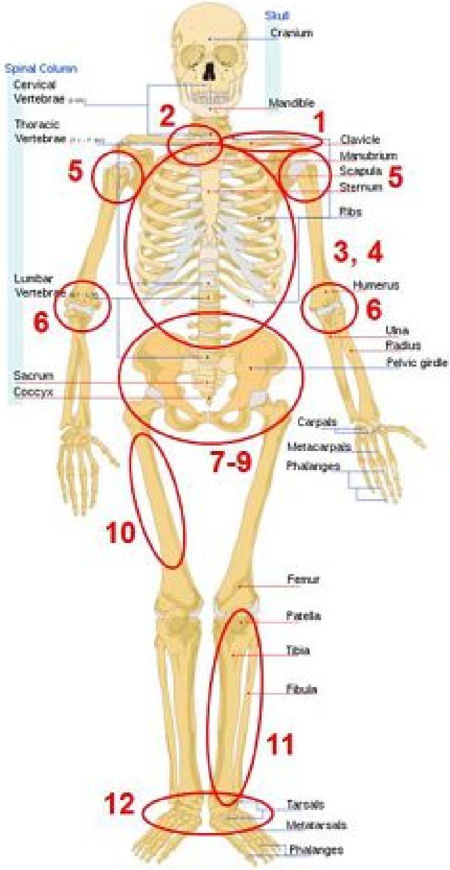
crash test wh18.27	
vehicle data	**dummy data**
VW Passat Variant 2006	D04
trapezium	172 cm
1514 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	fracture of neck	primary	roof leading edge
2	amputation of right foot	primary	spoiler
3	fracture of left talocalcanean joint	primary	spoiler
4	rupture of anterior and posterior cruciate ligaments left	primary	bumper
5	rupture of medial and lateral collateral ligaments left	primary	bumper
6	bony split-offs at medial condyle left	primary	bumper

7	fracture of femur head left	primary	bonnet leading edge
8	fracture of upper lower leg right	primary	bumper
9	fracture of upper forearm right	primary	bonnet
10	fracture of right and left sternoclavicular joints	primary	roof leading edge
11	fracture of several cervical vertebrae	primary	roof leading edge
12	fracture of wrist joint left	primary	bonnet
13	fracture of upper forearm left	primary	roof
14	dislocation of left shoulder joint	primary	roof leading edge
15	bony split-offs at shoulder joint left	primary	roof leading edge
16	fracture of left clavicle	primary	roof leading edge
17	fracture of ilium right	primary	bonnet
18	bony split-offs at acetabulum right	primary	bonnet
19	fracture of pubis left	primary	bonnet
20	fracture of the three lower ribs left	primary	windscreen, roof leading edge
21	fracture of the two lower ribs right	primary	windscreen, roof leading edge



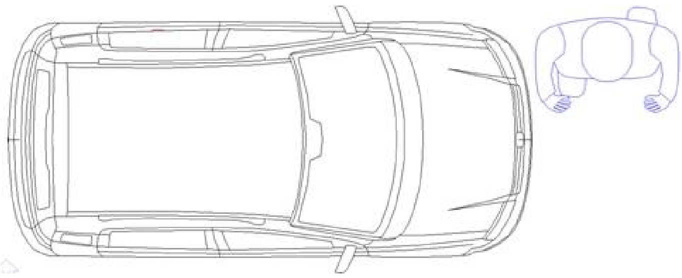


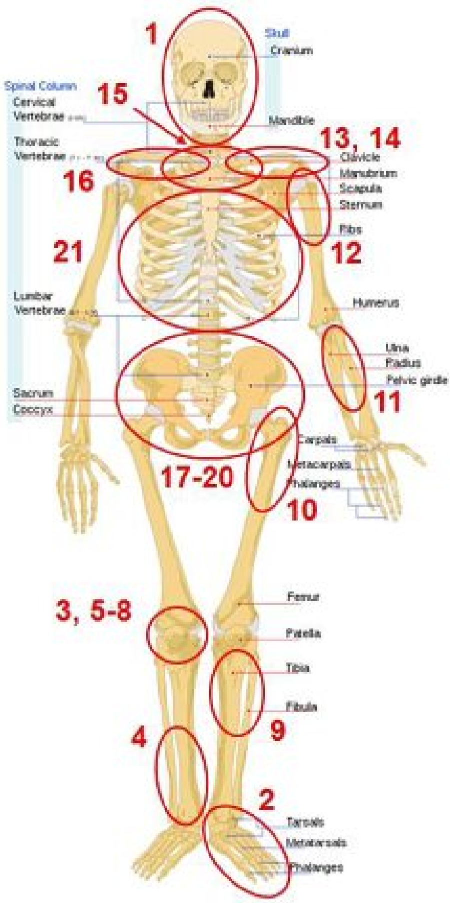


crash test wh18.28	
vehicle data	**dummy data**
Mercedes A-Class 2005	D05
van	169 cm
1257 kg	78 kg
72 km/h	
pre-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	fracture of left clavicle	secondary	ground
2	fracture of right sternoclavicular joint	primary	windscreen
3	fracture of sternum	primary, secondary	windscreen, ground
4	fracture of all eight ribs (the lowest right twice)	primary, secondary	windscreen, ground
5	fracture of left and right humerus next to shoulder joint	primary, secondary	windscreen, ground
6	fracture of left and right elbow	primary, secondary	windscreen, ground
7	fracture of right pubis	primary	bonnet

8	fracture of ilium and sacroiliac joint left	primary	bonnet
9	bony split-offs at acetabulum left	primary	bonnet
10	fracture of right femur	primary	bonnet leading edge
11	fracture of left lower leg	primary	bumper
12	fracture of left and right talocalcanean joints	primary	spoiler





crash test wh18.29	
vehicle data	**dummy data**
Mercedes A-Class 2007	D06
van	172 cm
1195 kg	78 kg
96 km/h	
in-crash braking	
frontal	
complete	

no.	injury	injury caused by hit	injury caused by …
1	laceration with abrasions on os parietale right	primary	roof leading edge
2	amputation of left foot	primary	spoiler
3	tearing of soft tissue lateral around right knee	primary	bumper
4	fracture of lower lower leg right	primary	spoiler
5	rupture of anterior and posterior cruciate ligaments right	primary	bumper

6	rupture of medial and lateral collateral ligaments right	primary	bumper
7	split-off of lateral condyle right	primary	bumper
8	bony tear-outs at attachment site of medial lateral ligament right	primary	bumper
9	fracture of upper lower leg left	primary	bumper
10	fracture of femur head left	primary	bonnet leading edge
11	fracture of upper forearm left	primary	roof
12	fracture of upper upper arm next to shoulder joint left	primary	roof leading edge
13	bony split-offs at shoulder joint left	primary	roof leading edge
14	fracture of left clavicle	primary	roof leading edge
15	fracture of right and left sternoclavicular joints	primary	roof leading edge
16	fracture of right clavicle	primary	roof leading edge
17	bony split-offs at acetabulum right and left	primary	bonnet
18	fracture of pubis right	primary	bonnet
19	fracture of ilium right	primary	bonnet
20	fracture of left sacroiliac joint	primary	bonnet
21	fracture of all eight ribs	primary	bonnet rear edge, windscreen

C. Comparison between Pedestrian Injuries and Biofidelic Dummy "Injuries"

As with the vehicle damages, crash tests wh18.22 and wh18.26 are compared with two of the real-world pedestrian accidents. The considered accidents are the same.

Here, one Biofidelic Dummy is compared with one pedestrian. The Biofidelic Dummy used in crash test wh18.22 is compared with a case where a 51 year old male was struck by a 1996 BMW 320i, while the Biofidelic Dummy used in crash test wh18.26 is compared with a case where a 29 year old male was struck by a 1998 VW Passat.

The injuries of the pedestrian and the Biofidelic Dummy which match each other are marked in red and italic. Obviously, the Biofidelic Dummy's "injuries" are never exactly the same as those of the pedestrian, which is why similar injuries have sometimes been considered as well.

Interestingly, pedestrian 2 and the Biofidelic Dummy used in crash test wh18.22 have more injuries in common than pedestrian 1 and the Biofidelic Dummy used in crash test wh18.26. This difference is explained by the fact that the biofidelic dummies are similar, while the two pedestrians are obviously different.

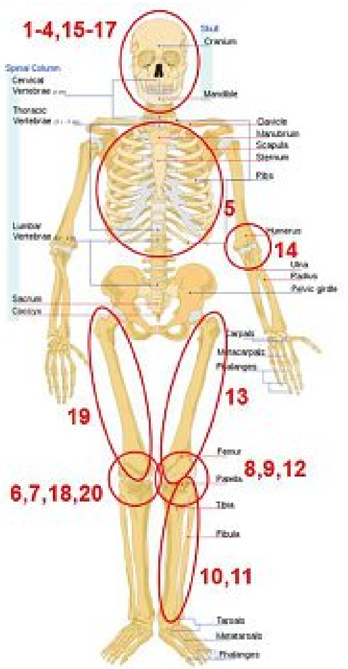
Here, the unique biomechanical response of every individual comes into play. Height, weight, age and fitness all play an important role and influence the kinematics and dynamics during the collision. Moreover, the exact impact constellation can never be replicated, meaning that a crash test always slightly deviates. Slight differences in impact angle can already alter the kinematics and dynamics significantly.

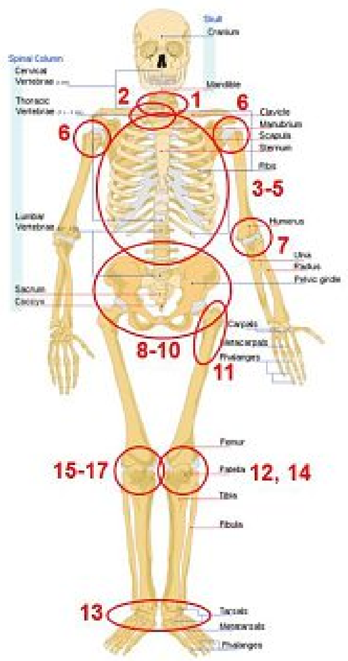
This must be born in mind when evaluating the “injuries” of the Biofidelic Dummy and comparing them with a pedestrian.

The “colour code” of the tables is the same as used in appendix A.

pedestrian 1	
vehicle data	**pedestrian data**
VW Passat 1998	29 years
trapezium	male
1155 kg	178 cm
64 - 67 km/h	78 kg
late or unbraked	survived
frontal	
complete	

crash test wh18.26	
vehicle data	**dummy data**
VW Passat Variant 2006	D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	





no.	injury
1	2nd degree craniocerebral injury
2	head laceration right temporal and above zygomatic bone with foreign bodies in wound
3	light cerebral swelling parietal left
4	galeahaematoma temporobasal right and temporoparietal left
5	ambilateral lung contusion; segments IV and VIII right and segment IV left
6	*rupture of anterior cruciate ligament right*

no.	injury
1	fracture of spinal process of first and second cervical vertebrae
2	fracture of right sternoclavicular joint
3	fracture of the three lower ribs right (the lowest twice)
4	fracture of second and fourth rib left
5	fracture of sternum (manubrium)
6	fracture of left and right humerus next to shoulder joint
7	luxation of left elbow

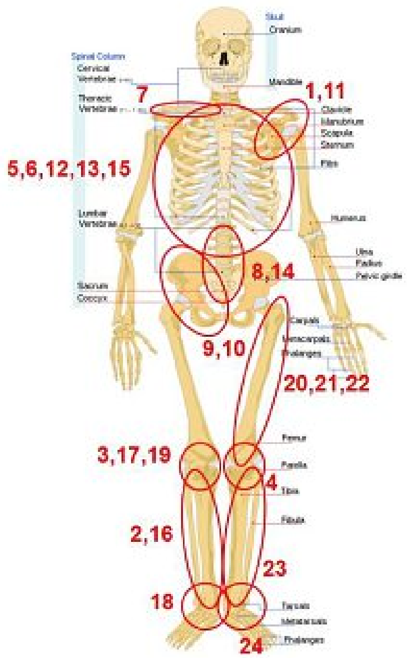
7	*rupture of medial collateral ligament right*
8	*suspicion of strain of lateral collateral ligament left*
9	*bony tear-out of intercondylar area left knee joint*
10	skin abrasion and haematoma on lower leg left lateral
11	skin abrasion on lower leg left medial dorsal
12	contusion mark left knee inside
13	skin abrasion on left thigh dorsal lateral
14	skin abrasion on left elbow medial
15	skin abrasion on chin
16	skin abrasion on nose running from left bride to ala
17	superficial skin abrasion on left forehead
18	skin abrasion on right knee front
19	contusion mark on right thigh front lateral
20	skin abrasion in the hollow of the knee right

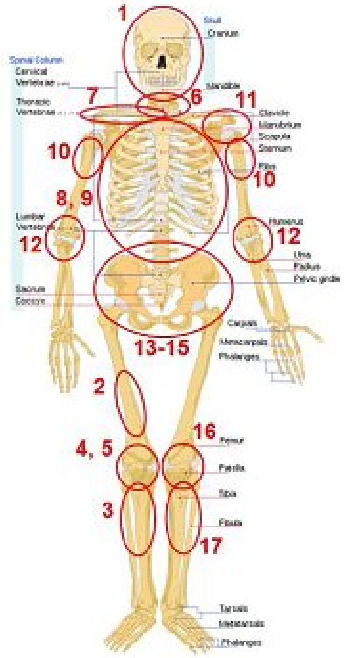
injury
skin abrasion on buttocks ambilateral
contusion mark left upper arm
contusion mark on left back of the hand
skin abrasion on lift side of back

8	fracture of right sacroiliac joint
9	fracture of right pubis
10	bony split-offs at acetabulum left and right
11	fracture of left femur next to femur head
12	*fraying of medial collateral ligament left*
13	fracture of left and right talocalcanean joints
14	*bony split-offs at medial tibial condyle left*
15	*rupture of anterior and posterior cruciate ligaments right*
16	*rupture of medial and lateral collateral ligaments right*
17	*bony split-offs at lateral tibial condyle right*

pedestrian 2	
vehicle data	**pedestrian data**
BMW 320i 1996	51 years
trapezium	male
1300 kg	173 cm
53 - 63 km/h	83 kg
late or unbraked	deceased
frontal	
complete	

crash test wh18.22	
vehicle data	**dummy data**
BMW 1 Series 2004	D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	





no.	injury
1	fracture of left scapula
2	*fracture of right fibula*
3	*fraying of fibres of right knee joint's medial collateral ligament*
4	*rupture of left knee joint's lateral collateral ligament with opening of articular cavity and bony rupture of lateral collateral ligament*
5	*multiple rib fractures left; 1st to 6th rib at linea axillaries anterior and 3rd to 8th rib at medial linea scapula*

no.	injury
1	*laceration on os parietale right*
2	fracture of lower femur right
3	*wedge-shaped fracture of right upper lower leg*
4	*right knee torn out*
5	*rupture of posterior cruciate ligament right*
6	*fracture of spinal process of first cervical vertebra*
7	fracture of right clavicle
8	*fracture of the two lower ribs right next to spinal column*
9	*fracture of lowest rib left laterally*

6	*multiple rib fractures right; 1st to 8th rib paravertebral and 1st to 6th rib at linea axillaries anterior*
7	*fracture of left clavicle*
8	fracture of the 2nd lumbar vertebra
9	*fracture of front and rear pelvic ring right*
10	*fracture of iliac wing right*
11	subcutaneous haemorrhage on left scapula in area of fracture
12	haematoma and contusion mark on right side of upper sternum
13	haematoma in right regio axillaris
14	diagonally band-shaped subcutaneous haemorrhaging of musculature in area of lumbar spine left to right medial and of the subcutaneous fatty tissue with superficial skin abrasion
15	orbital contusion mark on left side of sacrum at beginning of rima ani
16	intensive subcutaneous haemorrhaging of right lower leg dorsal in area of soleus muscle reaching to area above the hollow of the knee
17	contusion mark in the right hollow of the knee medial
18	skin abrasion in region of right medial malleolus
19	bleedings in the right knee joint with degloving of fascia

10	*fracture of left and right humerus next to shoulder joint*
11	*bony split-offs at left shoulder joint*
12	luxation of left and right elbow with bony split-offs at humerus
13	*crack in right pubis next to acetabulum*
14	*bony split-offs at acetabulum left and right*
15	*bony split-offs at left and right sacrum*
16	*rupture of lateral and medial collateral ligaments left*
17	wedge-shaped fracture of left lower leg

20	skin abrasion in region of head of femoral bone left
21	subcutaneous haemorrhaging in backside of left thigh medial
22	subcutaneous haemorrhaging in inside of left thigh
23	subcutaneous haemorrhaging in backside of left lower leg
24	contusion in area of left Achilles tendon

injury
fracture and dislocation of processus spinalis of 4th and 5th lumbar vertebrae
fracture of sternum left side
fracture of 1st rib left and right with haemorrhaging of musculature and pleura rupture; corresponds to multiple rib fractures with haemopneumothorax
ambilateral lung contusion
mediastinal haemorrhage 50 ml
head laceration right temporal
2 head lacerations right diagonally parietal
3rd degree craniocerebral injury
rupture of scalp left parietooccipital; along outer edge of plastic implant from former accident
fracture of right humerus shaft with dislocation

fracture of 7th cervical vertebra
rupture of liver capsule
central rupture of right hepatic lobe
liver contusion of left lobe
bleedings in renal capsule right with haemorrhaging of adrenal gland
rupture of spleen
subarachnoid haemorrhage
pons haemorrhage
skin abrasions on back of right hand in area of all metacarpophalangeal joints and on backside of right wrist dorsal
contusion and skin abrasion on left elbow
skin abrasions on back of left hand in area of all metacarpophalangeal joints

D. Crash Sequence

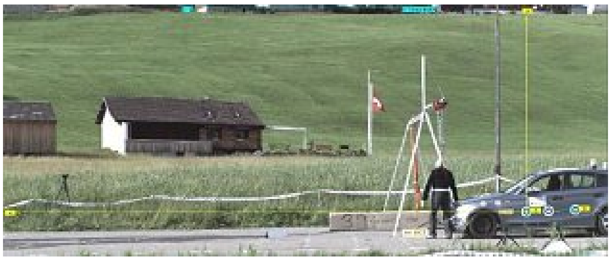
Nine crash tests with the Biofidelic Dummy were conducted in the summer of 2018 by DEKRA in conjunction with AXA Insurance in Wildhaus, Switzerland. The four crash tests with the Žilina Dummy have been conducted by DEKRA and AXA in 2008 and 2010, respectively.

The frame rate of the crash test videos is $500\, frames/s$. In the video analysis, however, only every 10^{th} picture has been analysed. The analysed pictures are shown below and represent the crash sequence. Thus, the individual pictures are only $0.02\, s$ apart.

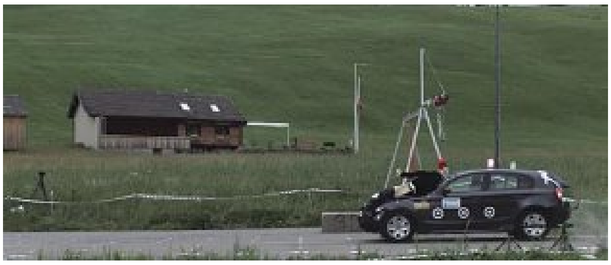
The sequence begins in the top right corner and goes from left to right ending in the bottom right corner.

The orange table lists the most important vehicle and dummy data.

crash test wh18.22	
vehicle data	**dummy data**
BMW 1 Series 2004	biofidelic D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	
frame rate: 0.02 s	



crash test wh18.23	
vehicle data	**dummy data**
BMW 1 Series 2004	biofidelic D02
pontoon	171 cm
1315 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	
frame rate: 0.02 s	

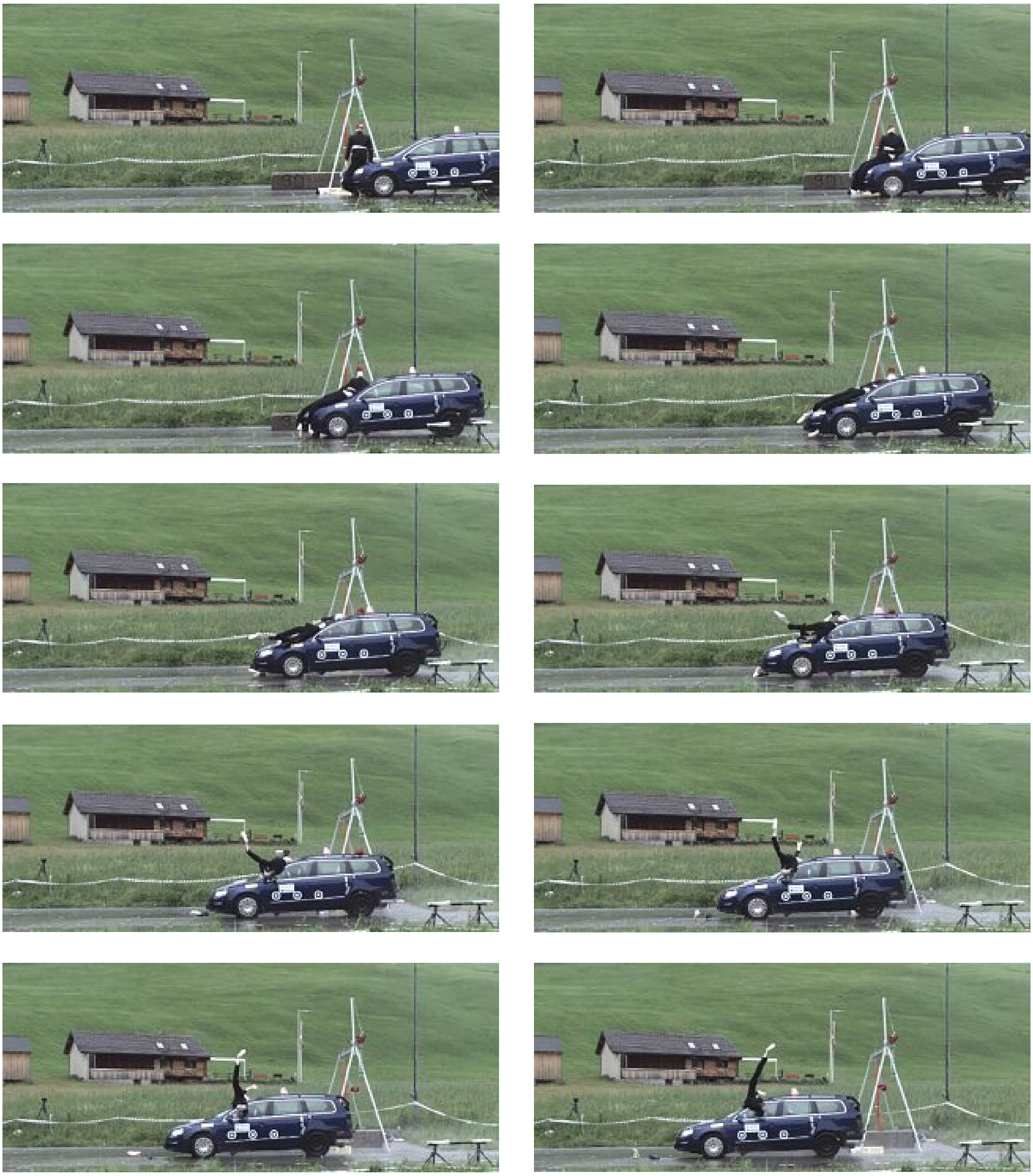


crash test wh18.24	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D07
trapezium	170 cm
2542 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	
frame rate: 0.02 s	

crash test wh18.25	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D08
trapezium	173 cm
2494 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	
frame rate: 0.02 s	

crash test wh18.26	
vehicle data	**dummy data**
VW Passat Variant 2006	biofidelic D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	
frame rate: 0.02 s	

crash test wh18.27	
vehicle data	**dummy data**
VW Passat Variant 2006	biofidelic D04
trapezium	172 cm
1514 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	
frame rate: 0.02 s	



crash test wh18.28	
vehicle data	dummy data
Mercedes A-Class 2005	biofidelic D05
van	169 cm
1257 kg	78 kg
72 km/h	
pre-crash braking	
frontal	
complete	
frame rate: 0.02 s	



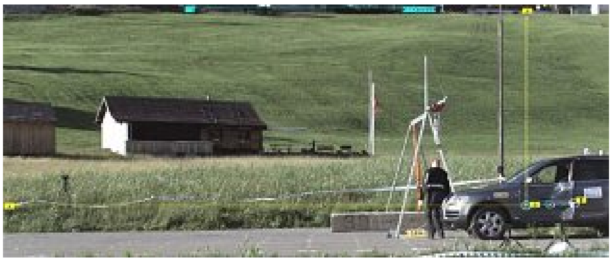







crash test wh18.29	
vehicle data	**dummy data**
Mercedes A-Class 2007	biofidelic D06
van	172 cm
1195 kg	78 kg
96 km/h	
in-crash braking	
frontal	
complete	
frame rate: 0.02 s	

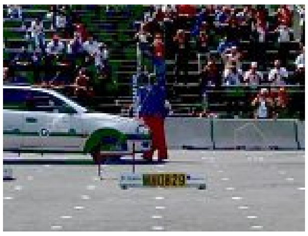
crash test wh18.34	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D07
trapezium	169 cm
2542 kg	78 kg
27 km/h	
in-crash braking	
frontal	
complete	
frame rate: 0.02 s	

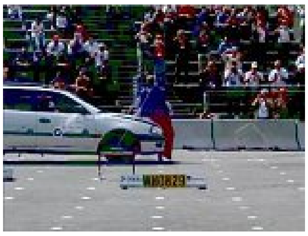


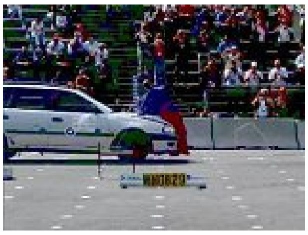
crash test wh08.27	
vehicle data	**dummy data**
Ford Galaxy 1998	Žilina
van	168 cm
1705 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	
frame rate: 0.02 s	

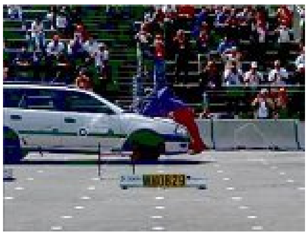
crash test wh08.28	
vehicle data	**dummy data**
BMW 523i 1998	Žilina
trapezium	168 cm
1550 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	
frame rate: 0.02 s	

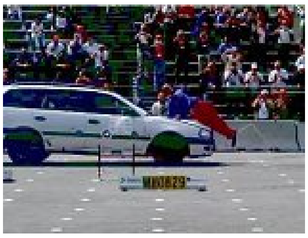
crash test wh08.29	
vehicle data	**dummy data**
Toyota Avensis 1998	Žilina
trapezium	168 cm
1329 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	
frame rate: 0.02 s	

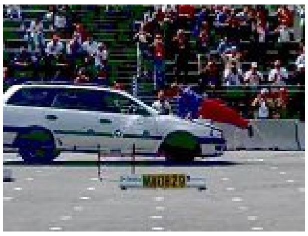












crash test wh10.12	
vehicle data	**dummy data**
Fiat Punto 1996	Žilina
trapezium	168 cm
1012 kg	75 kg
55 km/h	
late or unbraked	
frontal	
complete	
frame rate: 0.02 s	

E. Measurements for Dummy Trajectories

In order to obtain the trajectories of the different ATDs, the crash test videos were analysed by the programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998-2006$ FalCon GmbH).

The frame rate of the videos is $500\,pictures/s$. Time is set to zero at the point of first contact between the pedestrian and vehicle. The coordinate system has its origin at the first target on the vehicle. The x-direction faces in the direction of travel, while the y-direction faces upwards. The dummy targets had to be applied manually to the dummy. Targets were applied to the head, hip and foot. Every body region was analysed three-times and the average value was calculated , in order to reduce any errors stemming from manually placing the targets on the dummy. Every 10^{th} picture has been analysed, i.e. the time interval between the different measurements is $0.02\,s$. The value $s(x)$ has been calculated relative to the vehicle.

The three measurements are marked with “head $1\,s(x)$”, “head $2\,s(x)$” and “head $3\,s(x)$”, for example, and the resulting average value with “average head $s(x)$”.

The orange table lists the most important vehicle and dummy data, while the blue table lists the measurements.

crash test wh18.22	
vehicle data	dummy data
BMW 1 Series 2004	biofidelic D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,740284	1,740284	1,740284	1,740284	0,98897	0,971837	0,971837	0,977548
0,02	1,316986	1,325553	1,325553	1,322697333	0,980404	0,971837	0,971837	0,974692667
0,04	0,902944	0,91151	0,91151	0,908654667	0,963271	0,963271	0,954705	0,960415667
0,06	0,495713	0,487147	0,495713	0,492857667	0,894741	0,886175	0,877609	0,886175
0,08	0,061878	0,07901	0,07901	0,073299333	0,672019	0,672019	0,654886	0,666308
0,1	-0,084853	-0,06772	-0,06772	-0,073431	0,586356	0,569224	0,569224	0,574934667
0,12	-0,157026	-0,157026	-0,165592	-0,159881333	0,50926	0,50926	0,526393	0,514971
0,14	-0,112629	-0,112629	-0,121195	-0,115484333	0,526393	0,57779	0,560658	0,554947
0,16	-0,157523	-0,140391	-0,140391	-0,146101667	0,629188	0,654886	0,654886	0,64632
0,18	-0,191197	-0,156932	-0,165498	-0,171209	0,672019	0,680585	0,663453	0,672019
0,2	-0,176966	-0,151268	-0,159834	-0,162689333	0,71485	0,731982	0,731982	0,726271333

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,714586	1,706019	1,706019	1,708874667	0,449296	0,449296	0,44073	0,446440667
0,02	1,282721	1,265589	1,282721	1,277010333	0,432164	0,432164	0,44073	0,435019333
0,04	0,937209	0,928643	0,928643	0,931498333	0,406465	0,397899	0,397899	0,400754333
0,06	0,718436	0,718436	0,727002	0,721291333	0,363634	0,355068	0,363634	0,360778667
0,08	0,601551	0,601551	0,610118	0,604406667	0,389333	0,397899	0,423598	0,40361
0,1	0,480519	0,489086	0,489086	0,486230333	0,44073	0,415031	0,432164	0,429308333
0,12	0,39978	0,391214	0,39978	0,396924667	0,44073	0,397899	0,44073	0,426453
0,14	0,367081	0,349949	0,349949	0,355659667	0,457863	0,44073	0,449296	0,449296333
0,16	0,330753	0,330753	0,322186	0,327897333	0,483561	0,474995	0,457863	0,472139667
0,18	0,305646	0,331344	0,305646	0,314212	0,474995	0,483561	0,483561	0,480705667
0,2	0,302744	0,302744	0,31131	0,305599333	0,492128	0,483561	0,457863	0,477850667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,551827	1,551827	1,543261	1,548971667	-0,433027	-0,424461	-0,433027	-0,430171667
0,02	1,197059	1,231324	1,205625	1,211336	-0,458726	-0,441593	-0,433027	-0,444448667
0,04	1,211329	1,271293	1,271293	1,251305	-0,458726	-0,424461	-0,45016	-0,444449
0,06	1,266675	1,283808	1,275242	1,275241667	-0,467292	-0,467292	-0,458726	-0,464436667
0,08	1,492441	1,501007	1,509573	1,501007	-0,475858	-0,424461	-0,424461	-0,441593333
0,1	1,654095	1,654095	1,662661	1,656950333	-0,338798	-0,330232	-0,330232	-0,333087333
0,12	1,736114	1,727548	1,727548	1,730403333	-0,090377	-0,090377	-0,098943	-0,093232333
0,14	1,746247	1,729115	1,720548	1,73197	0,192309	0,175176	0,158044	0,175176333
0,16	1,68422	1,667087	1,675653	1,675653333	0,406465	0,389333	0,389333	0,395043667
0,18	1,607715	1,616281	1,616281	1,613425667	0,569224	0,560658	0,552091	0,560657667
0,2	1,536283	1,536283	1,527717	1,533427667	0,731982	0,723416	0,723416	0,726271333

crash test wh18.23	
vehicle data	**dummy data**
BMW 1 Series 2004	biofidelic D02
pontoon	171 cm
1315 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,571963	1,571963	1,571963	1,571963	1,022883	1,022883	1,014617	1,020127667
0,02	1,021363	1,021363	1,021363	1,021363	1,014617	1,014617	1,014617	1,014617
0,04	0,46204	0,445508	0,46204	0,456529333	0,931957	0,923691	0,923691	0,926446333
0,06	-0,133503	-0,125237	-0,125237	-0,127992333	0,774902	0,783168	0,766636	0,774902
0,08	-0,460057	-0,460057	-0,435259	-0,451791	0,700508	0,71704	0,71704	0,711529333
0,1	-0,492344	-0,484078	-0,467546	-0,481322667	0,667444	0,692242	0,692242	0,683976
0,12	-0,419755	-0,436287	-0,428021	-0,428021	0,609582	0,650912	0,659178	0,639890667
0,14	-0,386521	-0,378255	-0,369989	-0,378255	0,59305	0,626114	0,617848	0,612337333
0,16	-0,384152	-0,351088	-0,36762	-0,36762	0,659178	0,683976	0,659178	0,667444
0,18	-0,380716	-0,37245	-0,33112	-0,361428667	0,725306	0,733572	0,725306	0,728061333
0,2	-0,307353	-0,299087	-0,282555	-0,296331667	0,791434	0,807966	0,774902	0,791434

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,547165	1,555431	1,555431	1,552675667	0,435995	0,435995	0,435995	0,435995
0,02	1,004831	1,004831	1,013097	1,007586333	0,427729	0,419463	0,427729	0,424973667
0,04	0,710021	0,718287	0,726553	0,718287	0,386399	0,386399	0,386399	0,386399
0,06	0,469917	0,469917	0,461651	0,467161667	0,444261	0,452527	0,444261	0,447016333
0,08	0,201224	0,192958	0,192958	0,195713333	0,568252	0,559986	0,559986	0,562741333
0,1	0,111076	0,119342	0,119342	0,116586667	0,63438	0,626114	0,617848	0,626114
0,12	0,076206	0,051408	0,059674	0,062429333	0,733572	0,750104	0,741838	0,741838
0,14	0,059844	0,059844	0,051578	0,057088667	0,7997	0,7997	0,807966	0,802455333
0,16	0,103543	0,095277	0,087011	0,095277	0,824499	0,824499	0,841031	0,830009667
0,18	0,164841	0,131777	0,148309	0,148309	0,807966	0,832765	0,841031	0,827254
0,2	0,196875	0,196875	0,188609	0,194119667	0,832765	0,841031	0,832765	0,835520333

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,481037	1,497569	1,497569	1,492058333	-0,489799	-0,456735	-0,456735	-0,467756333
0,02	1,079225	1,112289	1,079225	1,090246333	-0,423671	-0,423671	-0,431937	-0,426426333
0,04	1,18945	1,181184	1,181184	1,183939333	-0,390607	-0,382341	-0,390607	-0,387851667
0,06	1,147731	1,139465	1,122933	1,136709667	-0,374075	-0,382341	-0,382341	-0,379585667
0,08	1,217945	1,226211	1,234477	1,226211	-0,440203	-0,423671	-0,440203	-0,434692333
0,1	1,185659	1,202191	1,226989	1,204946333	-0,489799	-0,465001	-0,456735	-0,470511667
0,12	1,200385	1,241715	1,307843	1,249981	-0,481533	-0,473267	-0,431937	-0,462245667
0,14	1,324546	1,423738	1,589059	1,445781	-0,407139	-0,423671	-0,332745	-0,387851667
0,16	1,401309	1,649289	1,607959	1,552852333	-0,423671	-0,225286	-0,21702	-0,288659
0,18	1,528735	1,652725	1,636193	1,605884333	-0,299681	-0,17569	-0,192222	-0,222531
0,2	1,626897	1,676493	1,701291	1,668227	-0,225286	-0,09303	-0,09303	-0,137115333

crash test wh18.24	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D07
trapezium	170 cm
2542 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,763484	1,771902	1,763484	1,76629	0,916488	0,916488	0,916488	0,916488
0,02	1,316935	1,316935	1,316935	1,316935	0,90807	0,891233	0,899651	0,899651333
0,04	0,852097	0,843679	0,83526	0,843678667	0,857558	0,865977	0,823884	0,849139667
0,06	0,382446	0,382446	0,399283	0,388058333	0,647094	0,638676	0,630257	0,638675667
0,08	0,260988	0,260988	0,269406	0,263794	0,470305	0,503979	0,503979	0,492754333
0,1	0,169649	0,194905	0,186487	0,183680333	0,571327	0,579746	0,562909	0,571327333
0,12	0,141845	0,141845	0,158682	0,147457333	0,663931	0,655513	0,647094	0,655512667
0,14	0,108574	0,108574	0,108574	0,108574	0,680769	0,689187	0,680769	0,683575
0,16	0,078089	0,078089	0,086508	0,080895333	0,815466	0,823884	0,823884	0,821078
0,18	0,111422	0,111422	0,11984	0,114228	0,823884	0,840721	0,840721	0,835108667
0,2	0,120603	0,120603	0,129022	0,123409333	0,865977	0,865977	0,882814	0,871589333

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,738228	1,738228	1,738228	1,738228	0,453467	0,453467	0,453467	0,453467
0,02	1,316935	1,316935	1,316935	1,316935	0,445049	0,43663	0,43663	0,439436333
0,04	1,037306	1,037306	1,037306	1,037306	0,419793	0,419793	0,411375	0,416987
0,06	0,929653	0,921234	0,921234	0,924040333	0,461886	0,453467	0,461886	0,459079667
0,08	0,791357	0,791357	0,808194	0,796969333	0,49556	0,49556	0,503979	0,498366333
0,1	0,700019	0,700019	0,700019	0,700019	0,529234	0,520816	0,512397	0,520815667
0,12	0,630122	0,630122	0,621703	0,627315667	0,529234	0,520816	0,529234	0,526428
0,14	0,563177	0,563177	0,563177	0,563177	0,562909	0,562909	0,562909	0,562909
0,16	0,364321	0,364321	0,355902	0,361514667	0,697606	0,714443	0,706024	0,706024333
0,18	0,380816	0,372397	0,372397	0,375203333	0,647094	0,647094	0,680769	0,658319
0,2	0,37316	0,37316	0,381579	0,375966333	0,663931	0,663931	0,655513	0,661125

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,620368	1,620368	1,620368	1,620368	-0,61569	-0,61569	-0,61569	-0,61569
0,02	1,241168	1,232749	1,258005	1,243974	-0,531505	-0,539923	-0,548342	-0,539923333
0,04	1,163584	1,205677	1,18884	1,186033667	-0,531505	-0,523086	-0,523086	-0,525892333
0,06	1,24114	1,316907	1,266395	1,274814	-0,523086	-0,531505	-0,531505	-0,528698667
0,08	1,372238	1,296471	1,30489	1,324533	-0,506249	-0,531505	-0,531505	-0,523086333
0,1	1,348248	1,373504	1,373504	1,365085333	-0,582016	-0,523086	-0,523086	-0,542729333
0,12	1,471978	1,480397	1,480397	1,477590667	-0,565179	-0,55676	-0,548342	-0,556760333
0,14	1,59866	1,59866	1,615497	1,604272333	-0,523086	-0,480993	-0,472575	-0,492218
0,16	1,694454	1,694454	1,694454	1,694454	-0,354715	-0,379971	-0,379971	-0,371552333
0,18	1,76146	1,786716	1,786716	1,778297333	-0,220018	-0,245273	-0,253692	-0,239661
0,2	1,812735	1,829572	1,854827	1,832378	-0,060065	-0,093739	-0,068484	-0,074096

crash test wh18.25	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D08
trapezium	173 cm
2494 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,764681	1,764681	1,764681	1,764681	0,962654	0,962654	0,962654	0,962654
0,02	1,199612	1,199612	1,199612	1,199612	0,962654	0,962654	0,962654	0,962654
0,04	0,59425	0,59425	0,59425	0,59425	0,887456	0,887456	0,8791	0,884670667
0,06	-0,007466	0,009244	0,000889	0,000889	0,703638	0,703638	0,695282	0,700852667
0,08	-0,187159	-0,170448	-0,178803	-0,178803333	0,703638	0,711993	0,703638	0,706423
0,1	-0,223706	-0,215351	-0,223706	-0,220921	0,720348	0,720348	0,737059	0,725918333
0,12	-0,300743	-0,300743	-0,309098	-0,303528	0,854034	0,828968	0,828968	0,837323333
0,14	-0,27251	-0,197311	-0,230733	-0,233518	1,087984	1,071274	1,087984	1,082414
0,16	-0,292162	-0,292162	-0,300517	-0,294947	1,179893	1,179893	1,188249	1,182678333
0,18	-0,432567	-0,424211	-0,440922	-0,432566667	1,296868	1,296868	1,296868	1,296868
0,2	-0,603152	-0,603152	-0,619863	-0,608722333	1,305224	1,296868	1,296868	1,299653333

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,714549	1,714549	1,714549	1,714549	0,494754	0,494754	0,494754	0,494754
0,02	1,157835	1,14948	1,14948	1,152265	0,478043	0,494754	0,478043	0,483613333
0,04	0,769713	0,778068	0,778068	0,775283	0,452977	0,469687	0,461332	0,461332
0,06	0,510566	0,518921	0,518921	0,516136	0,503109	0,511464	0,511464	0,508679
0,08	0,264031	0,289097	0,280742	0,277956667	0,544886	0,544886	0,53653	0,542100667
0,1	0,060376	0,052021	0,052021	0,054806	0,578307	0,595018	0,595018	0,589447667
0,12	-0,133636	-0,116925	-0,100214	-0,116925	0,75377	0,787191	0,795547	0,778836
0,14	-0,205667	-0,214022	-0,214022	-0,211237	0,828968	0,837323	0,837323	0,834538
0,16	-0,300517	-0,283806	-0,283806	-0,289376333	0,895811	0,912522	0,904166	0,904166333
0,18	-0,365724	-0,374079	-0,365724	-0,368509	0,929232	0,920877	0,920877	0,923662
0,2	-0,436045	-0,461111	-0,452755	-0,449970333	0,912522	0,929232	0,929232	0,923662

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,522376	1,522376	1,522376	1,522376	-0,541311	-0,541311	-0,541311	-0,541311
0,02	1,04086	1,082637	1,049216	1,057571	-0,574733	-0,558022	-0,574733	-0,569162667
0,04	0,953531	1,020374	1,003663	0,992522667	-0,61651	-0,599799	-0,608154	-0,608154333
0,06	0,577409	0,527277	0,560698	0,555128	-0,591444	-0,574733	-0,583088	-0,583088333
0,08	1,266674	1,27503	1,266674	1,269459333	-0,566377	-0,549667	-0,549667	-0,555237
0,1	1,380523	1,363813	1,363813	1,369383	-0,424336	-0,39927	-0,39927	-0,407625333
0,12	1,353619	1,353619	1,345263	1,350833667	-0,140254	-0,131899	-0,140254	-0,137469
0,14	1,156257	1,156257	1,156257	1,156257	0,127118	0,127118	0,127118	0,127118
0,16	0,986209	0,977853	0,986209	0,983423667	0,327646	0,336002	0,327646	0,330431333
0,18	0,737184	0,745539	0,753895	0,745539333	0,503109	0,51982	0,53653	0,519819667
0,2	0,516467	0,499756	0,508111	0,508111333	0,737059	0,728704	0,745414	0,737059

crash test wh18.26	
vehicle data	**dummy data**
VW Passat Variant 2006	biofidelic D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,863708	1,863708	1,863708	1,863708	1,050889	1,050889	1,050889	1,050889
0,02	1,437837	1,437837	1,437837	1,437837	1,050889	1,050889	1,050889	1,050889
0,04	1,017929	1,017929	1,017929	1,017929	1,050889	1,050889	1,050889	1,050889
0,06	0,592624	0,592624	0,592624	0,592624	0,976444	0,976444	0,984716	0,979201333
0,08	0,164766	0,156494	0,156494	0,159251333	0,885457	0,877185	0,885457	0,882699667
0,1	-0,258211	-0,24994	-0,258211	-0,255454	0,744839	0,736568	0,744839	0,742082
0,12	-0,302797	-0,294526	-0,302797	-0,30004	0,811012	0,819284	0,819284	0,816526667
0,14	-0,342075	-0,342075	-0,350347	-0,344832333	0,786197	0,786197	0,786197	0,786197
0,16	-0,326088	-0,33436	-0,33436	-0,331602667	0,777926	0,777926	0,786197	0,780683
0,18	-0,299401	-0,315944	-0,315944	-0,310429667	0,777926	0,794469	0,786197	0,786197333
0,2	-0,301633	-0,309904	-0,301633	-0,30439	0,761382	0,769654	0,769654	0,766896667

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,830621	1,830621	1,830621	1,830621	0,554592	0,554592	0,554592	0,554592
0,02	1,404751	1,388207	1,396479	1,396479	0,554592	0,54632	0,54632	0,549077333
0,04	0,984843	0,984843	0,976571	0,982085667	0,504962	0,504962	0,496691	0,502205
0,06	0,658797	0,658797	0,658797	0,658797	0,471876	0,471876	0,480148	0,474633333
0,08	0,412914	0,412914	0,421186	0,415671333	0,504962	0,513234	0,513234	0,510476667
0,1	0,204999	0,204999	0,213271	0,207756333	0,538049	0,554592	0,579407	0,557349333
0,12	0,052882	0,061154	0,069425	0,061153667	0,604222	0,64558	0,637308	0,629036667
0,14	-0,002939	0,005333	0,005333	0,002575667	0,64558	0,637308	0,662123	0,648337
0,16	-0,011767	-0,003495	0,004776	-0,003495333	0,637308	0,653851	0,662123	0,651094
0,18	-0,034709	-0,001623	-0,001623	-0,012651667	0,637308	0,653851	0,670395	0,653851333
0,2	-0,012126	0,012689	0,012689	0,004417333	0,64558	0,637308	0,670395	0,651094333

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,582473	1,582473	1,582473	1,582473	-0,454545	-0,454545	-0,454545	-0,454545
0,02	1,330306	1,313763	1,338578	1,327549	-0,462816	-0,446273	-0,454545	-0,454544667
0,04	1,323979	1,323979	1,332251	1,326736333	-0,454545	-0,462816	-0,454545	-0,457302
0,06	1,436328	1,452871	1,461143	1,450114	-0,462816	-0,438001	-0,42973	-0,443515667
0,08	1,52131	1,513039	1,513039	1,515796	-0,247754	-0,247754	-0,239483	-0,244997
0,1	1,478827	1,445741	1,445741	1,456769667	-0,016149	0,000394	0,000394	-0,005120333
0,12	1,268809	1,268809	1,268809	1,268809	0,322987	0,33953	0,298172	0,320229667
0,14	1,146815	1,146815	1,155087	1,149572333	0,496691	0,529777	0,538049	0,521505667
0,16	0,989098	0,972555	0,989098	0,983583667	0,64558	0,678666	0,629037	0,651094333
0,18	0,842082	0,83381	0,808995	0,828295667	0,703481	0,703481	0,703481	0,703481
0,2	0,732319	0,724047	0,715776	0,724047333	0,711753	0,703481	0,703481	0,706238333

crash test wh18.27	
vehicle data	dummy data
VW Passat Variant 2006	biofidelic D04
trapezium	172 cm
1514 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,803331	1,803331	1,803331	1,803331	1,056076	1,056076	1,056076	1,056076
0,02	1,25018	1,25018	1,25018	1,25018	1,056076	1,056076	1,056076	1,056076
0,04	0,701878	0,701878	0,718354	0,70737	1,014886	1,006648	1,014886	1,01214
0,06	0,144848	0,144848	0,144848	0,144848	0,932506	0,932506	0,924268	0,92976
0,08	-0,407324	-0,399086	-0,38261	-0,39634	0,850126	0,850126	0,841888	0,84738
0,1	-0,417898	-0,393184	-0,393184	-0,401422	0,841888	0,841888	0,850126	0,844634
0,12	-0,317297	-0,325535	-0,300821	-0,314551	0,808936	0,79246	0,808936	0,803444
0,14	-0,279522	-0,263046	-0,271284	-0,271284	0,784222	0,775984	0,767746	0,775984
0,16	-0,321934	-0,305458	-0,321934	-0,316442	0,775984	0,775984	0,775984	0,775984
0,18	-0,353977	-0,353977	-0,345739	-0,351231	0,800698	0,800698	0,800698	0,800698
0,2	-0,356909	-0,356909	-0,356909	-0,356909	0,817174	0,817174	0,83365	0,822666

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,803331	1,803331	1,803331	1,803331	0,611224	0,611224	0,611224	0,611224
0,02	1,25018	1,25018	1,25018	1,25018	0,611224	0,611224	0,611224	0,611224
0,04	0,718354	0,726592	0,718354	0,7211	0,561796	0,553558	0,553558	0,556304
0,06	0,309608	0,317846	0,293132	0,306862	0,570034	0,561796	0,561796	0,564542
0,08	-0,028376	-0,044852	-0,044852	-0,03936	0,6277	0,619462	0,619462	0,622208
0,1	-0,137806	-0,137806	-0,16252	-0,146044	0,677128	0,660652	0,652414	0,663398
0,12	-0,243155	-0,383201	-0,342011	-0,322789	0,677128	0,54532	0,54532	0,589256
0,14	-0,436044	-0,394854	-0,394854	-0,408584	0,611224	0,520606	0,54532	0,55905
0,16	-0,453741	-0,396075	-0,387837	-0,412551	0,561796	0,553558	0,54532	0,553558
0,18	-0,477547	-0,452833	-0,436357	-0,455579	0,54532	0,553558	0,520606	0,539828
0,2	-0,439289	-0,447527	-0,398099	-0,428305	0,495892	0,54532	0,520606	0,520606

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,605619	1,605619	1,605619	1,605619	-0,451477	-0,451477	-0,451477	-0,451477
0,02	1,266656	1,258418	1,283132	1,269402	-0,459715	-0,467953	-0,467953	-0,465207
0,04	1,196157	1,196157	1,220871	1,204395	-0,443239	-0,435001	-0,443239	-0,440493
0,06	1,33112	1,339358	1,314644	1,328374	-0,393811	-0,402049	-0,426763	-0,407541
0,08	1,240275	1,215561	1,199085	1,218307	0,108706	0,141658	0,149896	0,13342
0,1	1,031989	1,015513	0,957847	1,001783	0,397036	0,388798	0,372322	0,386052
0,12	0,687738	0,654786	0,654786	0,66577	0,446464	0,479416	0,46294	0,46294
0,14	0,346566	0,346566	0,313614	0,335582	0,635938	0,602986	0,594748	0,611224
0,16	0,07349	0,015824	-0,017128	0,024062	0,693604	0,50413	0,528844	0,575526
0,18	-0,222169	-0,213931	-0,222169	-0,219423	0,561796	0,570034	0,570034	0,567288
0,2	-0,439289	-0,422813	-0,398099	-0,420067	0,743032	0,767746	0,767746	0,759508

crash test wh18.28	
vehicle data	dummy data
Mercedes A-Class 2005	biofidelic D05
van	169 cm
1257 kg	78 kg
72 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,48468	1,48468	1,48468	1,48468	1,048602	1,048602	1,048602	1,048602
0,02	1,081692	1,081692	1,081692	1,081692	1,048602	1,048602	1,048602	1,048602
0,04	0,686726	0,686726	0,686726	0,686726	1,048602	1,048602	1,048602	1,048602
0,06	0,298925	0,298925	0,298925	0,298925	1,048602	1,048602	1,048602	1,048602
0,08	-0,096906	-0,105212	-0,105212	-0,102443333	0,998768	0,990463	0,998768	0,995999667
0,1	-0,338199	-0,321588	-0,329893	-0,329893333	0,95724	0,965545	0,965545	0,962776667
0,12	-0,358851	-0,358851	-0,367157	-0,361619667	1,056908	1,056908	1,065214	1,059676667
0,14	-0,434174	-0,442479	-0,450785	-0,442479333	1,106742	1,098436	1,098436	1,101204667
0,16	-0,530735	-0,53904	-0,530735	-0,533503333	1,131659	1,106742	1,115048	1,117816333
0,18	-0,622803	-0,614498	-0,606192	-0,614497667	1,115048	1,131659	1,115048	1,120585
0,2	-0,66113	-0,652824	-0,66113	-0,658361333	1,139965	1,14827	1,139965	1,142733333

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,459763	1,451458	1,451458	1,454226333	0,492122	0,492122	0,492122	0,492122
0,02	1,040163	1,048469	1,048469	1,045700333	0,483816	0,492122	0,492122	0,489353333
0,04	0,653504	0,661809	0,661809	0,659040667	0,475511	0,483816	0,475511	0,478279333
0,06	0,465039	0,489956	0,48165	0,478881667	0,517039	0,541956	0,53365	0,530881667
0,08	0,343295	0,3516	0,3516	0,348831667	0,641624	0,641624	0,633319	0,638855667
0,1	0,193364	0,20167	0,209975	0,201669667	0,757904	0,732987	0,741292	0,744061
0,12	0,073044	0,081349	0,073044	0,075812333	0,807738	0,816043	0,799432	0,807737667
0,14	-0,002278	-0,002278	-0,002278	-0,002278	0,890794	0,8991	0,874183	0,888025667
0,16	-0,073923	-0,073923	-0,073923	-0,073923	0,940628	0,965545	0,965545	0,957239333
0,18	-0,116157	-0,124463	-0,116157	-0,118925667	1,01538	1,023685	1,031991	1,023685333
0,2	-0,187706	-0,187706	-0,171095	-0,182169	1,098436	1,098436	1,098436	1,098436

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,260427	1,260427	1,260427	1,260427	-0,446419	-0,446419	-0,446419	-0,446419
0,02	1,12322	1,148137	1,12322	1,131525667	-0,454725	-0,438113	-0,446419	-0,446419
0,04	1,16015	1,168455	1,143538	1,157381	-0,438113	-0,438113	-0,446419	-0,440881667
0,06	1,204244	1,212549	1,187632	1,201475	-0,404891	-0,388279	-0,413196	-0,402122
0,08	1,348281	1,381504	1,356587	1,362124	-0,089275	-0,15572	-0,172332	-0,139109
0,1	1,306324	1,347853	1,347853	1,33401	0,226341	0,193118	0,176506	0,198655
0,12	1,244144	1,260755	1,252449	1,252449333	0,550262	0,575179	0,566873	0,564104667
0,14	1,135599	1,118987	1,127293	1,127293	0,95724	0,924017	0,924017	0,935091333
0,16	0,93937	0,93937	0,93937	0,93937	1,272855	1,289467	1,272855	1,278392333
0,18	0,747633	0,731021	0,739327	0,739327	1,555248	1,555248	1,546943	1,552479667
0,2	0,534887	0,543193	0,526582	0,534887333	1,804419	1,804419	1,796113	1,801650333

crash test wh18.29	
vehicle data	**dummy data**
Mercedes A-Class 2007	biofidelic D06
van	172 cm
1195 kg	78 kg
96 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,395828	1,395828	1,395828	1,395828	1,004759	1,004759	1,004759	1,004759
0,02	0,852523	0,852523	0,852523	0,852523	1,004759	1,004759	1,004759	1,004759
0,04	0,3017	0,3017	0,318061	0,307153667	0,963855	0,980216	0,963855	0,969308667
0,06	-0,23677	-0,253132	-0,261312	-0,250404667	0,865686	0,865686	0,873867	0,868413
0,08	-0,44993	-0,44175	-0,433569	-0,441749667	0,824782	0,841144	0,824782	0,830236
0,1	-0,445473	-0,298219	-0,339123	-0,360938333	0,816602	0,734794	0,751156	0,767517333
0,12	-0,405135	-0,339689	-0,396955	-0,380593	0,751156	0,751156	0,734794	0,745702
0,14	-0,360976	-0,369157	-0,377338	-0,369157	0,726614	0,742975	0,710252	0,726613667
0,16	-0,347611	-0,355792	-0,355792	-0,353065	0,718433	0,718433	0,702071	0,712979
0,18	-0,306293	-0,429004	-0,371738	-0,369011667	0,693891	0,669348	0,652987	0,672075333
0,2	-0,41623	-0,440772	-0,41623	-0,424410667	0,669348	0,644806	0,628445	0,647533

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,338563	1,338563	1,338563	1,338563	0,587541	0,595722	0,595722	0,592995
0,02	0,795257	0,795257	0,795257	0,795257	0,587541	0,595722	0,587541	0,590268
0,04	0,358965	0,383507	0,375326	0,372599333	0,587541	0,587541	0,57936	0,584814
0,06	0,155905	0,147725	0,131363	0,144997667	0,628445	0,620264	0,612083	0,620264
0,08	-0,032713	-0,032713	-0,032713	-0,032713	0,718433	0,702071	0,718433	0,712979
0,1	-0,159147	-0,167327	-0,159147	-0,161873667	0,767517	0,775698	0,783879	0,775698
0,12	-0,257882	-0,257882	-0,257882	-0,257882	0,767517	0,832963	0,808421	0,802967
0,14	-0,279169	-0,254626	-0,221903	-0,251899333	0,792059	0,849325	0,857505	0,832963
0,16	-0,233081	-0,200358	-0,192177	-0,208538667	0,939313	0,922951	0,955674	0,939312667
0,18	-0,199943	-0,199943	-0,208124	-0,20267	0,988397	0,996578	1,004759	0,996578
0,2	-0,203531	-0,211711	-0,219892	-0,211711333	1,070205	1,070205	1,078385	1,072931667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,166767	1,166767	1,166767	1,166767	-0,451413	-0,451413	-0,451413	-0,451413
0,02	0,958872	0,983414	1,057041	0,999775667	-0,443232	-0,410509	-0,41869	-0,424143667
0,04	1,062508	1,021605	1,070689	1,051600667	-0,385967	-0,426871	-0,41869	-0,410509333
0,06	1,432101	1,448462	1,448462	1,443008333	-0,140545	-0,132364	-0,156907	-0,143272
0,08	1,32529	1,349833	1,374375	1,349832667	0,24395	0,24395	0,252131	0,246677
0,1	1,174314	1,215218	1,198856	1,196129333	0,562999	0,571179	0,554818	0,562998667
0,12	1,026494	1,051037	1,051037	1,042856	0,873867	0,873867	0,882048	0,876594
0,14	0,849774	0,857954	0,857954	0,855227333	1,217458	1,225639	1,217458	1,220185
0,16	0,65862	0,683162	0,65862	0,666800667	1,561049	1,577411	1,544688	1,561049333
0,18	0,487239	0,49542	0,503601	0,49542	1,863737	1,847375	1,847375	1,852829
0,2	0,328218	0,328218	0,336398	0,330944667	2,182785	2,174605	2,174605	2,177331667

crash test wh18.34	
vehicle data	dummy data
VW Touareg 2003	biofidelic D07
trapezium	169 cm
2542 kg	78 kg
27 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,86308	1,86308	1,86308	1,86308	0,85395	0,85395	0,85395	0,85395
0,02	1,707476	1,707476	1,707476	1,707476	0,85395	0,845223	0,85395	0,851041
0,04	1,553773	1,545047	1,553773	1,550864333	0,862676	0,845223	0,85395	0,853949667
0,06	1,381925	1,381925	1,399378	1,387742667	0,845223	0,845223	0,836497	0,842314333
0,08	1,213874	1,213874	1,213874	1,213874	0,792867	0,78414	0,792867	0,789958
0,1	1,057331	1,048605	1,048605	1,051513667	0,714331	0,705605	0,714331	0,711422333
0,12	0,931935	0,923208	0,923208	0,926117	0,583439	0,583439	0,583439	0,583439
0,14	0,861597	0,861597	0,870324	0,864506	0,435094	0,44382	0,452546	0,44382
0,16	0,837626	0,837626	0,837626	0,837626	0,400189	0,408915	0,408915	0,406006333
0,18	0,808578	0,808578	0,808578	0,808578	0,452546	0,44382	0,452546	0,449637333
0,2	0,78959	0,780864	0,798316	0,78959	0,469999	0,469999	0,469999	0,469999

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,836902	1,836902	1,836902	1,836902	0,0004	0,0004	0,0004	0,4
0,02	1,690024	1,681298	1,681298	1,684206667	0,000409	0,0004	0,0004	0,403
0,04	1,545047	1,562499	1,562499	1,556681667	0,0004	0,0004	0,0004	0,4
0,06	1,469187	1,477913	1,451735	1,466278333	0,000418	0,0004	0,000383	0,400333333
0,08	1,440754	1,432028	1,423302	1,432028	0,0004	0,000391	0,000391	0,394
0,1	1,388925	1,388925	1,397651	1,391833667	0,000391	0,000383	0,0004	0,391333333
0,12	1,359516	1,368243	1,368243	1,365334	0,000391	0,000383	0,000391	0,388333333
0,14	1,341536	1,341536	1,350262	1,344444667	0,0004	0,0004	0,000409	0,403
0,16	1,317565	1,317565	1,308838	1,314656	0,000383	0,0004	0,0004	0,394333333
0,18	1,297243	1,288517	1,297243	1,294334333	0,000391	0,0004	0,000391	0,394
0,2	1,304434	1,295707	1,286981	1,295707333	0,0004	0,000391	0,0004	0,397

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,740914	1,740914	1,740914	1,740914	-0,585867	-0,585867	-0,585867	-0,585867
0,02	1,58531	1,58531	1,58531	1,58531	-0,585867	-0,585867	-0,585867	-0,585867
0,04	1,431607	1,440333	1,440333	1,437424333	-0,585867	-0,53351	-0,53351	-0,550962333
0,06	1,381925	1,390652	1,408104	1,393560333	-0,524784	-0,507331	-0,507331	-0,513148667
0,08	1,493111	1,493111	1,501838	1,49602	-0,481153	-0,481153	-0,472427	-0,478244333
0,1	1,502365	1,502365	1,511092	1,505274	-0,516057	-0,489879	-0,4637	-0,489878667
0,12	1,551492	1,568944	1,743467	1,621301	-0,568414	-0,559688	-0,542236	-0,556779333
0,14	1,865106	1,891284	1,882558	1,879649333	-0,507331	-0,498605	-0,498605	-0,501513667
0,16	1,972027	1,989479	1,972027	1,977844333	-0,411343	-0,411343	-0,428796	-0,417160667
0,18	2,065145	2,065145	2,073872	2,068054	-0,35026	-0,341534	-0,332808	-0,341534
0,2	2,142145	2,142145	2,133419	2,139236333	-0,280451	-0,280451	-0,289177	-0,283359667

crash test wh08.27	
vehicle data	**dummy data**
Ford Galaxy 1998	Žilina
van	168 cm
1705 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,715892	1,715892	1,715892	1,715892	0,933307	0,933307	0,933307	0,933307
0,02	1,470378	1,470378	1,470378	1,470378	0,933307	0,933307	0,933307	0,933307
0,04	1,222057	1,228979	1,222057	1,224364333	0,912541	0,905619	0,891776	0,903312
0,06	0,955956	0,955956	0,955956	0,955956	0,857166	0,864088	0,857166	0,859473333
0,08	0,74277	0,735848	0,735848	0,738155333	0,781024	0,781024	0,781024	0,781024
0,1	0,587372	0,594294	0,594294	0,591986667	0,677194	0,684116	0,656428	0,672579333
0,12	0,537585	0,523741	0,530663	0,530663	0,621818	0,614896	0,614896	0,617203333
0,14	0,512034	0,484346	0,491268	0,495882667	0,635662	0,642584	0,649506	0,642584
0,16	0,493129	0,444675	0,465441	0,467748333	0,649506	0,670272	0,649506	0,656428
0,18	0,455649	0,434883	0,427961	0,439497667	0,649506	0,66335	0,649506	0,654120667
0,2	0,420843	0,427765	0,420843	0,423150333	0,642584	0,642584	0,642584	0,642584

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,70897	1,70897	1,70897	1,70897	0,324172	0,31725	0,31725	0,319557333
0,02	1,463456	1,463456	1,463456	1,463456	0,324172	0,31725	0,31725	0,319557333
0,04	1,298199	1,270511	1,270511	1,279740333	0,365704	0,372626	0,365704	0,368011333
0,06	1,163615	1,156693	1,177459	1,165922333	0,393392	0,407236	0,38647	0,395699333
0,08	1,08887	1,081948	1,075026	1,081948	0,434924	0,441846	0,428002	0,434924
0,1	1,037301	1,044223	1,030379	1,037301	0,469534	0,469534	0,462612	0,467226667
0,12	0,987514	0,994436	0,987514	0,989821333	0,531832	0,517988	0,511066	0,520295333
0,14	1,003495	0,961963	0,961963	0,975807	0,573364	0,601052	0,573364	0,582593333
0,16	0,991512	0,970746	0,94998	0,970746	0,649506	0,649506	0,649506	0,649506
0,18	0,960954	0,94711	0,940188	0,949417333	0,725648	0,69796	0,73257	0,718726
0,2	0,93307	0,926148	0,926148	0,928455333	0,781024	0,760258	0,774102	0,771794667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,563608	1,563608	1,563608	1,563608	-0,499544	-0,499544	-0,499544	-0,499544
0,02	1,380392	1,380392	1,387314	1,382699333	-0,464935	-0,4857	-0,4857	-0,478778333
0,04	1,568156	1,568156	1,568156	1,568156	-0,409559	-0,409559	-0,430325	-0,416481
0,06	1,682765	1,689687	1,689687	1,687379667	-0,312651	-0,312651	-0,326495	-0,317265667
0,08	1,767225	1,739537	1,725693	1,744151667	-0,160367	-0,160367	-0,167289	-0,162674333
0,1	1,76411	1,750266	1,743344	1,752573333	-0,008083	-0,035771	-0,035771	-0,026541667
0,12	1,769699	1,769699	1,776621	1,772006333	0,088825	0,081903	0,081903	0,084210333
0,14	1,806446	1,813368	1,82029	1,813368	0,199577	0,192655	0,185733	0,192655
0,16	1,822151	1,794463	1,815229	1,810614333	0,296484	0,331094	0,310328	0,312635333
0,18	1,826203	1,826203	1,846969	1,833125	0,469534	0,462612	0,434924	0,45569
0,2	1,915993	1,888305	1,881383	1,895227	0,552598	0,573364	0,55952	0,561827333

crash test wh08.28	
vehicle data	dummy data
BMW 523i 1998	Žilina
trapezium	168 cm
1550 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,952593	1,952593	1,952593	1,952593	0,908594	0,908594	0,908594	0,908594
0,02	1,708972	1,708972	1,708972	1,708972	0,908594	0,908594	0,908594	0,908594
0,04	1,449671	1,435893	1,435893	1,440485667	0,86037	0,867259	0,86037	0,862666333
0,06	1,171423	1,171423	1,171423	1,171423	0,784589	0,77081	0,784589	0,779996
0,08	0,992038	1,005817	1,005817	1,001224	0,736364	0,743254	0,743254	0,740957333
0,1	0,890187	0,876409	0,890187	0,885594333	0,750143	0,743254	0,743254	0,745550333
0,12	0,722631	0,708853	0,708853	0,713445667	0,708808	0,708808	0,695029	0,704215
0,14	0,627411	0,627411	0,620522	0,625114667	0,68814	0,695029	0,68814	0,690436333
0,16	0,549069	0,549069	0,54218	0,546772667	0,646805	0,653694	0,639916	0,646805
0,18	0,486122	0,472343	0,479233	0,479232667	0,577913	0,591691	0,591691	0,587098333
0,2	0,420123	0,427012	0,433902	0,427012333	0,51591	0,529688	0,543467	0,529688333

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,938815	1,938815	1,938815	1,938815	0,274788	0,274788	0,274788	0,274788
0,02	1,715862	1,722751	1,702083	1,713565333	0,274788	0,281677	0,274788	0,277084333
0,04	1,587455	1,566788	1,553009	1,569084	0,316123	0,309234	0,302345	0,309234
0,06	1,495216	1,467659	1,481437	1,481437333	0,364347	0,357458	0,350569	0,357458
0,08	1,412279	1,370944	1,384723	1,389315333	0,42635	0,412572	0,419461	0,419461
0,1	1,331096	1,317318	1,317318	1,321910667	0,453907	0,433239	0,447018	0,444721333
0,12	1,259989	1,266878	1,266878	1,264581667	0,474575	0,453907	0,474575	0,467685667
0,14	1,199215	1,199215	1,178547	1,192325667	0,488353	0,481464	0,495242	0,488353
0,16	1,127762	1,113983	1,079537	1,107094	0,481464	0,495242	0,509021	0,495242333
0,18	1,037258	1,023479	1,01659	1,025775667	0,488353	0,495242	0,522799	0,502131333
0,2	0,978148	0,957481	0,991927	0,975852	0,509021	0,522799	0,543467	0,525095667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,745917	1,745917	1,745917	1,745917	-0,496803	-0,496803	-0,496803	-0,496803
0,02	1,55741	1,536742	1,536742	1,543631333	-0,441689	-0,462357	-0,455467	-0,453171
0,04	1,587455	1,594345	1,601234	1,594344667	-0,421021	-0,414132	-0,414132	-0,416428333
0,06	1,653667	1,681224	1,708781	1,681224	-0,359019	-0,331462	-0,352129	-0,347536667
0,08	1,784296	1,798075	1,777407	1,786592667	-0,241902	-0,255681	-0,269459	-0,255680667
0,1	1,937346	1,909789	1,9029	1,916678333	-0,200567	-0,166121	-0,186789	-0,184492333
0,12	1,880017	1,880017	1,880017	1,880017	-0,049005	-0,055894	-0,062783	-0,055894
0,14	1,895024	1,901914	1,895024	1,897320667	0,075001	0,068112	0,061223	0,068112
0,16	1,885574	1,892463	1,892463	1,890166667	0,212785	0,185228	0,178339	0,192117333
0,18	1,88463	1,870851	1,88463	1,880037	0,323012	0,302345	0,302345	0,309234
0,2	1,894412	1,859966	1,873745	1,876041	0,440129	0,433239	0,433239	0,435535667

crash test wh08.29	
vehicle data	dummy data
Toyota Avensis 1998	Žilina
trapezium	168 cm
1329 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,705512	1,705512	1,705512	1,705512	0,957925	0,957925	0,957925	0,957925
0,02	1,465458	1,465458	1,465458	1,465458	0,957925	0,957925	0,957925	0,957925
0,04	1,194989	1,201838	1,194989	1,197272	0,937376	0,923677	0,923677	0,928243333
0,06	0,910938	0,904088	0,897239	0,904088333	0,841485	0,841485	0,841485	0,841485
0,08	0,746713	0,733015	0,719316	0,733014667	0,718195	0,738743	0,731894	0,729610667
0,1	0,670149	0,6633	0,65645	0,663299667	0,738743	0,745593	0,738743	0,741026333
0,12	0,628064	0,607516	0,600666	0,612082	0,786689	0,786689	0,786689	0,786689
0,14	0,570916	0,557217	0,570916	0,566349667	0,786689	0,793539	0,786689	0,788972333
0,16	0,514378	0,514378	0,507528	0,512094667	0,786689	0,800388	0,793539	0,793538667
0,18	0,475029	0,447631	0,447631	0,456763667	0,793539	0,77984	0,786689	0,786689333
0,2	0,411829	0,425528	0,404979	0,414112	0,759292	0,759292	0,77299	0,763858

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,691813	1,691813	1,691813	1,691813	0,334628	0,334628	0,334628	0,334628
0,02	1,472308	1,472308	1,451759	1,465458333	0,334628	0,341477	0,334628	0,336911
0,04	1,345676	1,318278	1,318278	1,327410667	0,334628	0,348327	0,375724	0,352893
0,06	1,273957	1,23971	1,246559	1,253408667	0,375724	0,375724	0,382574	0,378007333
0,08	1,205624	1,205624	1,178226	1,196491333	0,416821	0,403122	0,403122	0,407688333
0,1	1,149608	1,12221	1,115361	1,129059667	0,457917	0,451068	0,437369	0,448784667
0,12	1,039029	1,045878	1,045878	1,043595	0,464767	0,444219	0,457917	0,455634333
0,14	0,975031	0,981881	0,975031	0,977314333	0,471616	0,451068	0,464767	0,462483667
0,16	0,897945	0,911644	0,904794	0,904794333	0,499014	0,492164	0,478466	0,489881333
0,18	0,879144	0,865445	0,892843	0,879144	0,526412	0,492164	0,512713	0,510429667
0,2	0,86389	0,86389	0,891288	0,873022667	0,526412	0,519562	0,526412	0,524128667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,479481	1,479481	1,479481	1,479481	-0,487302	-0,487302	-0,487302	-0,487302
0,02	1,362717	1,369566	1,369566	1,367283	-0,466753	-0,459904	-0,466753	-0,46447
0,04	1,434718	1,455266	1,482664	1,457549333	-0,39141	-0,405109	-0,418808	-0,405109
0,06	1,575331	1,568481	1,575331	1,573047667	-0,370862	-0,364012	-0,370862	-0,368578667
0,08	1,678234	1,650836	1,678234	1,669101333	-0,281819	-0,281819	-0,281819	-0,281819
0,1	1,731808	1,731808	1,731808	1,731808	-0,15168	-0,131132	-0,15168	-0,144830667
0,12	1,785615	1,785615	1,778766	1,783332	-0,021542	-0,014692	-0,028391	-0,021541667
0,14	1,831208	1,817509	1,824358	1,824358333	0,135995	0,122296	0,101748	0,120013
0,16	1,850013	1,822616	1,850013	1,840880667	0,279833	0,272983	0,279833	0,277549667
0,18	1,872309	1,879158	1,886008	1,879158333	0,409971	0,416821	0,43052	0,419104
0,2	1,898152	1,959796	1,932399	1,930115667	0,54696	0,526412	0,553809	0,542393667

crash test wh10.12	
vehicle data	**dummy data**
Fiat Punto 1996	Žilina
trapezium	168 cm
1012 kg	75 kg
55 km/h	
late or unbraked	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	1,694281	1,694281	1,694281	1,694281	0,965185	0,965185	0,965185	0,965185
0,02	1,388755	1,388755	1,388755	1,388755	0,965185	0,965185	0,965185	0,965185
0,04	1,069341	1,069341	1,055454	1,064712	0,930466	0,923522	0,930466	0,928151333
0,06	0,708265	0,715209	0,708265	0,710579667	0,833253	0,826309	0,833253	0,830938333
0,08	0,465233	0,472177	0,465233	0,467547667	0,652715	0,652715	0,645771	0,650400333
0,1	0,291639	0,298582	0,277751	0,289324	0,513839	0,520783	0,534671	0,523097667
0,12	0,159707	0,159707	0,152763	0,157392333	0,47912	0,465233	0,451345	0,465232667
0,14	0,097213	0,1111	0,138875	0,115729333	0,465233	0,472177	0,451345	0,462918333
0,16	0,1111	0,069438	0,104157	0,094898333	0,472177	0,465233	0,465233	0,467547667
0,18	0,104157	0,05555	0,124988	0,094898333	0,465233	0,458289	0,444402	0,455974667
0,2	0,069438	0,083325	0,083325	0,078696	0,555502	0,541614	0,534671	0,543929

time	hip 1 s(x)	hip 2 s(x)	hip 3 s(x)	average hip s(x)	hip 1 s(y)	hip 2 s(y)	hip 3 s(y)	average hip s(y)
0	1,67345	1,67345	1,67345	1,67345	0,333301	0,333301	0,333301	0,333301
0,02	1,395699	1,437361	1,395699	1,409586333	0,333301	0,333301	0,333301	0,333301
0,04	1,270711	1,256823	1,249879	1,259137667	0,333301	0,333301	0,340245	0,335615667
0,06	1,117948	1,117948	1,138779	1,124891667	0,354133	0,354133	0,361076	0,356447333
0,08	1,006847	1,034622	0,999904	1,013791	0,388851	0,402739	0,395795	0,395795
0,1	0,847141	0,895747	0,867972	0,870286667	0,42357	0,444402	0,437458	0,435143333
0,12	0,73604	0,722153	0,722153	0,726782	0,465233	0,499952	0,493008	0,486064333
0,14	0,659659	0,659659	0,659659	0,659659	0,527727	0,527727	0,527727	0,527727
0,16	0,604108	0,652715	0,645771	0,634198	0,562446	0,562446	0,576333	0,567075
0,18	0,590221	0,631884	0,645771	0,622625333	0,617996	0,617996	0,659659	0,631883667
0,2	0,56939	0,576333	0,590221	0,578648	0,715209	0,701321	0,73604	0,717523333

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	1,548462	1,548462	1,548462	1,548462	-0,402739	-0,402739	-0,402739	-0,402739
0,02	1,30543	1,30543	1,291542	1,300800667	-0,409683	-0,416626	-0,402739	-0,409682667
0,04	1,222104	1,249879	1,256823	1,242935333	-0,416626	-0,409683	-0,409683	-0,411997333
0,06	1,374867	1,36098	1,347092	1,360979667	-0,319414	-0,319414	-0,319414	-0,319414
0,08	1,485968	1,492912	1,492912	1,490597333	-0,201369	-0,215257	-0,208313	-0,208313
0,1	1,597068	1,6179	1,6179	1,610956	0,006944	0,013888	0	0,006944
0,12	1,631787	1,645675	1,645675	1,641045667	0,291639	0,284695	0,277751	0,284695
0,14	1,604012	1,610956	1,610956	1,608641333	0,555502	0,555502	0,562446	0,557816667
0,16	1,513743	1,506799	1,513743	1,511428333	0,79159	0,79159	0,805478	0,796219333
0,18	1,36098	1,367924	1,36098	1,363294667	0,972128	0,958241	0,951297	0,960555333
0,2	1,069341	1,069341	1,069341	1,069341	0,93741	0,930466	0,923522	0,930466

F. Measurements for Dummy Trajectories relative to the Pelvis

In order to obtain the trajectories relative to the pelvis of the different ATDs, the crash test videos were analysed by the programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998 - 2006$ FalCon GmbH).

The frame rate of the videos is $500\,pictures/s$. Time is set to zero at the point of first contact between the pedestrian and vehicle. The coordinate system has its origin at the first target on the vehicle. The x-direction faces in the direction of travel, while the y-direction faces upwards. The dummy targets had to be applied manually to the dummy. Targets were applied to the head and foot. Every body region was analysed three-times and the average value was calculated , in order to reduce any errors stemming from manually placing the targets on the dummy. Every 10^{th} picture has been analysed, i.e. the time interval between the different measurements is $0.02\,s$. The values $s(x)$ and $s(y)$ have been calculated relative to the pelvis.

The three measurements are marked with “head $1\,s(x)$”, “head $2\,s(x)$” and “head $3\,s(x)$”, for example, and the resulting average value with “average head $s(x)$”.

The orange table lists the most important vehicle and dummy data, while the blue table lists the measurements.

crash test wh18.22	
vehicle data	dummy data
BMW 1 Series 2004	biofidelic D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,025699	0,025699	0,025699	0,025699	0,539674	0,522541	0,522541	0,528252
0,02	0,034265	0,042831	0,042831	0,039975667	0,54824	0,539674	0,539674	0,542529333
0,04	-0,034265	-0,025699	-0,025699	-0,028554333	0,556806	0,556806	0,54824	0,553950667
0,06	-0,222722	-0,231289	-0,222722	-0,225577667	0,531107	0,522541	0,513975	0,522541
0,08	-0,539674	-0,522541	-0,522541	-0,528252	0,282686	0,282686	0,265554	0,276975333
0,1	-0,565372	-0,54824	-0,54824	-0,553950667	0,145626	0,128494	0,128494	0,134204667
0,12	-0,556806	-0,556806	-0,565372	-0,559661333	0,06853	0,06853	0,085662	0,074240667
0,14	-0,47971	-0,47971	-0,488276	-0,482565333	0,06853	0,119927	0,102795	0,097084
0,16	-0,488276	-0,471144	-0,471144	-0,476854667	0,145626	0,171325	0,171325	0,162758667
0,18	-0,496842	-0,462577	-0,471144	-0,476854333	0,197024	0,20559	0,188457	0,197023667
0,2	-0,47971	-0,454011	-0,462577	-0,465432667	0,222722	0,239855	0,239855	0,234144

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,162759	-0,162759	-0,171325	-0,165614333	-0,882323	-0,873757	-0,882323	-0,879467667
0,02	-0,085662	-0,051397	-0,077096	-0,071385	-0,89089	-0,873757	-0,865191	-0,876612667
0,04	0,27412	0,334084	0,334084	0,314096	-0,865191	-0,830926	-0,856625	-0,850914
0,06	0,54824	0,565372	0,556806	0,556806	-0,830926	-0,830926	-0,82236	-0,828070667
0,08	0,89089	0,899456	0,908022	0,899456	-0,865191	-0,813793	-0,813793	-0,830925667
0,1	1,173576	1,173576	1,182142	1,176431333	-0,779528	-0,770962	-0,770962	-0,773817333
0,12	1,336335	1,327768	1,327768	1,330623667	-0,531107	-0,531107	-0,539674	-0,533962667
0,14	1,379166	1,362033	1,353467	1,364888667	-0,265554	-0,282686	-0,299819	-0,282686333
0,16	1,353467	1,336335	1,344901	1,344901	-0,077096	-0,094229	-0,094229	-0,088518
0,18	1,30207	1,310636	1,310636	1,307780667	0,094229	0,085662	0,077096	0,085662333
0,2	1,23354	1,23354	1,224973	1,230684333	0,239855	0,231289	0,231289	0,234144333

crash test wh18.23	
vehicle data	dummy data
BMW 1 Series 2004	biofidelic D02
pontoon	171 cm
1315 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,024798	0,024798	0,024798	0,024798	0,586888	0,586888	0,578622	0,584132667
0,02	0,016532	0,016532	0,016532	0,016532	0,586888	0,586888	0,586888	0,586888
0,04	-0,247981	-0,264513	-0,247981	-0,253491667	0,545558	0,537291	0,537291	0,540046667
0,06	-0,60342	-0,595154	-0,595154	-0,597909333	0,330641	0,338907	0,322375	0,330641
0,08	-0,661282	-0,661282	-0,636484	-0,653016	0,132256	0,148788	0,148788	0,143277333
0,1	-0,60342	-0,595154	-0,578622	-0,592398667	0,033064	0,057862	0,057862	0,049596
0,12	-0,495961	-0,512493	-0,504227	-0,504227	-0,12399	-0,08266	-0,074394	-0,093681333
0,14	-0,446365	-0,438099	-0,429833	-0,438099	-0,206651	-0,173586	-0,181853	-0,187363333
0,16	-0,487695	-0,454631	-0,471163	-0,471163	-0,16532	-0,140522	-0,16532	-0,157054
0,18	-0,545558	-0,537291	-0,495961	-0,52627	-0,08266	-0,074394	-0,08266	-0,079904667
0,2	-0,504227	-0,495961	-0,479429	-0,493205667	-0,04133	-0,024798	-0,057862	-0,04133

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,066128	-0,049596	-0,049596	-0,055106667	-0,925795	-0,89273	-0,89273	-0,903751667
0,02	0,074394	0,107458	0,074394	0,085415333	-0,8514	-0,8514	-0,859666	-0,854155333
0,04	0,479429	0,471163	0,471163	0,473918333	-0,777006	-0,76874	-0,777006	-0,774250667
0,06	0,677814	0,669548	0,653016	0,666792667	-0,818336	-0,826602	-0,826602	-0,823846667
0,08	1,016721	1,024987	1,033253	1,024987	-1,008455	-0,991923	-1,008455	-1,002944333
0,1	1,074583	1,091115	1,115913	1,093870333	-1,124179	-1,099381	-1,091115	-1,104891667
0,12	1,124179	1,165509	1,231637	1,173775	-1,215105	-1,206839	-1,165509	-1,195817667
0,14	1,264702	1,363894	1,529214	1,385936667	-1,206839	-1,223371	-1,132445	-1,187551667
0,16	1,297766	1,545746	1,504416	1,449309333	-1,248169	-1,049785	-1,041519	-1,113157667
0,18	1,363894	1,487884	1,471352	1,441043333	-1,107647	-0,983657	-1,000189	-1,030497667
0,2	1,430022	1,479618	1,504416	1,471352	-1,058051	-0,925795	-0,925795	-0,969880333

crash test wh18.24	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D07
trapezium	170 cm
2542 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,025256	0,033674	0,025256	0,028062	0,463021	0,463021	0,463021	0,463021
0,02	0	0	0	0	0,463021	0,446184	0,454602	0,454602333
0,04	-0,185208	-0,193627	-0,202046	-0,193627	0,437765	0,446184	0,404091	0,429346667
0,06	-0,547207	-0,547207	-0,53037	-0,541594667	0,185208	0,17679	0,168371	0,176789667
0,08	-0,53037	-0,53037	-0,521951	-0,527563667	-0,025256	0,008419	0,008419	-0,002806
0,1	-0,53037	-0,505114	-0,513532	-0,516338667	0,042093	0,050511	0,033674	0,042092667
0,12	-0,488277	-0,488277	-0,47144	-0,482664667	0,134697	0,126278	0,11786	0,126278333
0,14	-0,454602	-0,454602	-0,454602	-0,454602	0,11786	0,126278	0,11786	0,120666
0,16	-0,286231	-0,286231	-0,277813	-0,283425	0,11786	0,126278	0,126278	0,123472
0,18	-0,269394	-0,269394	-0,260976	-0,266588	0,17679	0,193627	0,193627	0,188014667
0,2	-0,252557	-0,252557	-0,244138	-0,249750667	0,202046	0,202046	0,218883	0,207658333

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,11786	-0,11786	-0,11786	-0,11786	-1,069158	-1,069158	-1,069158	-1,069158
0,02	-0,075767	-0,084186	-0,05893	-0,072961	-0,976554	-0,984972	-0,993391	-0,984972333
0,04	0,126278	0,168371	0,151534	0,148727667	-0,951298	-0,942879	-0,942879	-0,945685333
0,06	0,311487	0,387254	0,336743	0,345161333	-0,984972	-0,993391	-0,993391	-0,990584667
0,08	0,580881	0,505114	0,513532	0,533175667	-1,001809	-1,027065	-1,027065	-1,018646333
0,1	0,648229	0,673485	0,673485	0,665066333	-1,111251	-1,052321	-1,052321	-1,071964333
0,12	0,841856	0,850275	0,850275	0,847468667	-1,094413	-1,085995	-1,077576	-1,085994667
0,14	1,035483	1,035483	1,052321	1,041095667	-1,085995	-1,043902	-1,035483	-1,055126667
0,16	1,330133	1,330133	1,330133	1,330133	-1,052321	-1,077576	-1,077576	-1,069157667
0,18	1,380645	1,4059	1,4059	1,397481667	-0,867112	-0,892368	-0,900786	-0,886755333
0,2	1,439575	1,456412	1,481667	1,459218	-0,723997	-0,757671	-0,732415	-0,738027667

crash test wh18.25	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D08
trapezium	173 cm
2494 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,050132	0,050132	0,050132	0,050132	0,4679	0,4679	0,4679	0,4679
0,02	0,041777	0,041777	0,041777	0,041777	0,484611	0,484611	0,484611	0,484611
0,04	-0,175463	-0,175463	-0,175463	-0,175463	0,434479	0,434479	0,426123	0,431693667
0,06	-0,518032	-0,501322	-0,509677	-0,509677	0,200529	0,200529	0,192173	0,197743667
0,08	-0,45119	-0,434479	-0,442834	-0,442834333	0,158752	0,167107	0,158752	0,161537
0,1	-0,284082	-0,275727	-0,284082	-0,281297	0,142041	0,142041	0,158752	0,147611333
0,12	-0,167107	-0,167107	-0,175463	-0,169892333	0,100264	0,075198	0,075198	0,083553333
0,14	-0,066843	0,008355	-0,025066	-0,027851333	0,259016	0,242305	0,259016	0,253445667
0,16	0,008355	0,008355	0	0,00557	0,284082	0,284082	0,292438	0,286867333
0,18	-0,066843	-0,058488	-0,075198	-0,066843	0,367636	0,367636	0,367636	0,367636
0,2	-0,167107	-0,167107	-0,183818	-0,172677333	0,392702	0,384347	0,384347	0,387132

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,192173	-0,192173	-0,192173	-0,192173	-1,036065	-1,036065	-1,036065	-1,036065
0,02	-0,116975	-0,075198	-0,10862	-0,100264333	-1,052776	-1,036065	-1,052776	-1,047205667
0,04	0,183818	0,250661	0,23395	0,222809667	-1,069486	-1,052776	-1,061131	-1,061131
0,06	0,066843	0,016711	0,050132	0,044562	-1,094552	-1,077842	-1,086197	-1,086197
0,08	1,002643	1,010999	1,002643	1,005428333	-1,111263	-1,094552	-1,094552	-1,100122333
0,1	1,320147	1,303436	1,303436	1,309006333	-1,002643	-0,977577	-0,977577	-0,985932333
0,12	1,487254	1,487254	1,478899	1,484469	-0,894024	-0,885668	-0,894024	-0,891238667
0,14	1,361924	1,361924	1,361924	1,361924	-0,70185	-0,70185	-0,70185	-0,70185
0,16	1,286726	1,27837	1,286726	1,283940667	-0,568165	-0,559809	-0,568165	-0,565379667
0,18	1,102908	1,111263	1,119619	1,111263333	-0,426123	-0,409413	-0,392702	-0,409412667
0,2	0,952511	0,935801	0,944156	0,944156	-0,175463	-0,183818	-0,167107	-0,175462667

crash test wh18.26	
vehicle data	**dummy data**
VW Passat Variant 2006	biofidelic D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,033086	0,033086	0,033086	0,033086	0,496297	0,496297	0,496297	0,496297
0,02	0,033086	0,033086	0,033086	0,033086	0,496297	0,496297	0,496297	0,496297
0,04	0,033086	0,033086	0,033086	0,033086	0,545926	0,545926	0,545926	0,545926
0,06	-0,066173	-0,066173	-0,066173	-0,066173	0,504568	0,504568	0,51284	0,507325333
0,08	-0,248148	-0,25642	-0,25642	-0,253662667	0,380494	0,372223	0,380494	0,377737
0,1	-0,46321	-0,454939	-0,46321	-0,460453	0,20679	0,198519	0,20679	0,204033
0,12	-0,355679	-0,347408	-0,355679	-0,352922	0,20679	0,215062	0,215062	0,212304667
0,14	-0,339136	-0,339136	-0,347408	-0,341893333	0,140617	0,140617	0,140617	0,140617
0,16	-0,314321	-0,322593	-0,322593	-0,319835667	0,140617	0,140617	0,148889	0,143374333
0,18	-0,264692	-0,281235	-0,281235	-0,275720667	0,140617	0,157161	0,148889	0,148889
0,2	-0,289506	-0,297778	-0,289506	-0,292263333	0,115803	0,124074	0,124074	0,121317

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,248148	-0,248148	-0,248148	-0,248148	-1,009137	-1,009137	-1,009137	-1,009137
0,02	-0,074445	-0,090988	-0,066173	-0,077202	-1,017408	-1,000865	-1,009137	-1,009136667
0,04	0,339136	0,339136	0,347408	0,341893333	-0,959507	-0,967779	-0,959507	-0,962264333
0,06	0,777532	0,794075	0,802346	0,791317667	-0,934692	-0,909877	-0,901606	-0,915391667
0,08	1,108396	1,100125	1,100125	1,102882	-0,752717	-0,752717	-0,744445	-0,749959667
0,1	1,273828	1,240742	1,240742	1,251770667	-0,554198	-0,537655	-0,537655	-0,543169333
0,12	1,215927	1,215927	1,215927	1,215927	-0,281235	-0,264692	-0,30605	-0,283992333
0,14	1,149754	1,149754	1,158026	1,152511333	-0,148889	-0,115803	-0,107531	-0,124074333
0,16	1,000865	0,984322	1,000865	0,995350667	0,008272	0,041358	-0,008272	0,013786
0,18	0,876791	0,868519	0,843705	0,863005	0,066173	0,066173	0,066173	0,066173
0,2	0,744445	0,736174	0,727902	0,736173667	0,066173	0,057901	0,057901	0,060658333

crash test wh18.27	
vehicle data	**dummy data**
VW Passat Variant 2006	biofidelic D04
trapezium	172 cm
1514 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0	0	0	0	0,444852	0,444852	0,444852	0,444852
0,02	0	0	0	0	0,444852	0,444852	0,444852	0,444852
0,04	-0,016476	-0,016476	0	-0,010984	0,45309	0,444852	0,45309	0,450344
0,06	-0,16476	-0,16476	-0,16476	-0,16476	0,362472	0,362472	0,354234	0,359726
0,08	-0,378948	-0,37071	-0,354234	-0,367964	0,222426	0,222426	0,214188	0,21968
0,1	-0,280092	-0,255378	-0,255378	-0,263616	0,16476	0,16476	0,172998	0,167506
0,12	-0,074142	-0,08238	-0,057666	-0,071396	0,131808	0,115332	0,131808	0,126316
0,14	0,156522	0,172998	0,16476	0,16476	0,172998	0,16476	0,156522	0,16476
0,16	0,131808	0,148284	0,131808	0,1373	0,214188	0,214188	0,214188	0,214188
0,18	0,12357	0,12357	0,131808	0,126316	0,255378	0,255378	0,255378	0,255378
0,2	0,08238	0,08238	0,08238	0,08238	0,321282	0,321282	0,337758	0,326774

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,197712	-0,197712	-0,197712	-0,197712	-1,062701	-1,062701	-1,062701	-1,062701
0,02	0,016476	0,008238	0,032952	0,019222	-1,070939	-1,079177	-1,079177	-1,076431
0,04	0,477804	0,477804	0,502518	0,486042	-1,005035	-0,996797	-1,005035	-1,002289
0,06	1,021511	1,029749	1,005035	1,018765	-0,963845	-0,972083	-0,996797	-0,977575
0,08	1,268651	1,243937	1,227461	1,246683	-0,518994	-0,486042	-0,477804	-0,49428
0,1	1,169795	1,153319	1,095653	1,139589	-0,280092	-0,28833	-0,304806	-0,291076
0,12	0,930893	0,897941	0,897941	0,908925	-0,230664	-0,197712	-0,214188	-0,214188
0,14	0,78261	0,78261	0,749658	0,771626	0,024714	-0,008238	-0,016476	-1,16E-18
0,16	0,527232	0,469566	0,436614	0,477804	0,131808	-0,057666	-0,032952	0,01373
0,18	0,255378	0,263616	0,255378	0,258124	0,016476	0,024714	0,024714	0,021968
0,2	0	0,016476	0,04119	0,019222	0,24714	0,271854	0,271854	0,263616

crash test wh18.28	
vehicle data	**dummy data**
Mercedes A-Class 2005	biofidelic D05
van	169 cm
1257 kg	78 kg
72 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,024917	0,024917	0,024917	0,024917	0,55648	0,55648	0,55648	0,55648
0,02	0,041528	0,041528	0,041528	0,041528	0,564786	0,564786	0,564786	0,564786
0,04	0,033223	0,033223	0,033223	0,033223	0,573092	0,573092	0,573092	0,573092
0,06	-0,166113	-0,166113	-0,166113	-0,166113	0,531563	0,531563	0,531563	0,531563
0,08	-0,440201	-0,448506	-0,448506	-0,445737667	0,357144	0,348838	0,357144	0,354375333
0,1	-0,531563	-0,514952	-0,523257	-0,523257333	0,199336	0,207642	0,207642	0,204873333
0,12	-0,431895	-0,431895	-0,440201	-0,434663667	0,24917	0,24917	0,257476	0,251938667
0,14	-0,431895	-0,440201	-0,448506	-0,440200667	0,215948	0,207642	0,207642	0,210410667
0,16	-0,456812	-0,465118	-0,456812	-0,459580667	0,191031	0,166113	0,174419	0,177187667
0,18	-0,506646	-0,49834	-0,490035	-0,498340333	0,099668	0,116279	0,099668	0,105205
0,2	-0,473423	-0,465118	-0,473423	-0,470654667	0,041528	0,049834	0,041528	0,044296667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,199336	-0,199336	-0,199336	-0,199336	-0,938541	-0,938541	-0,938541	-0,938541
0,02	0,083057	0,107974	0,083057	0,091362667	-0,938541	-0,92193	-0,930235	-0,930235333
0,04	0,506646	0,514952	0,490035	0,503877667	-0,913624	-0,913624	-0,92193	-0,916392667
0,06	0,739205	0,747511	0,722594	0,736436667	-0,92193	-0,905318	-0,930235	-0,919161
0,08	1,004987	1,038209	1,013292	1,018829333	-0,730899	-0,797345	-0,813956	-0,780733333
0,1	1,11296	1,154489	1,154489	1,140646	-0,531563	-0,564786	-0,581397	-0,559248667
0,12	1,1711	1,187711	1,179406	1,179405667	-0,257476	-0,232559	-0,240865	-0,243633333
0,14	1,137877	1,121266	1,129572	1,129571667	0,066445	0,033223	0,033223	4,43E-02
0,16	1,013292	1,013292	1,013292	1,013292	0,332227	0,348838	0,332227	0,337764
0,18	0,86379	0,847179	0,855484	0,855484333	0,539869	0,539869	0,531563	0,537100333
0,2	0,722594	0,730899	0,714288	0,722593667	0,705982	0,705982	0,697677	0,703213667

crash test wh18.29	
vehicle data	**dummy data**
Mercedes A-Class 2007	biofidelic D06
van	172 cm
1195 kg	78 kg
96 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,057265	0,057265	0,057265	0,057265	0,417218	0,417218	0,417218	0,417218
0,02	0,057265	0,057265	0,057265	0,057265	0,417218	0,417218	0,417218	0,417218
0,04	-0,057265	-0,057265	-0,040904	-0,051811333	0,376314	0,392676	0,376314	0,381768
0,06	-0,392676	-0,409037	-0,417218	-0,406310333	0,237241	0,237241	0,245422	0,239968
0,08	-0,417218	-0,409037	-0,400856	-0,409037	0,10635	0,122711	0,10635	0,111803667
0,1	-0,286326	-0,139073	-0,179976	-0,201791667	0,049084	-0,032723	-0,016361	0
0,12	-0,147253	-0,081807	-0,139073	-0,122711	-0,016361	-0,016361	-0,032723	-0,021815
0,14	-0,081807	-0,089988	-0,098169	-0,089988	-0,065446	-0,049084	-0,081807	-0,065445667
0,16	-0,11453	-0,122711	-0,122711	-0,119984	-0,22088	-0,22088	-0,237241	-0,226333667
0,18	-0,10635	-0,229061	-0,171796	-0,169069	-0,294507	-0,319049	-0,33541	-0,316322
0,2	-0,212699	-0,237241	-0,212699	-0,220879667	-0,400856	-0,425399	-0,44176	-0,422671667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,171796	-0,171796	-0,171796	-0,171796	-1,038954	-1,038954	-1,038954	-1,038954
0,02	0,163615	0,188157	0,261784	0,204518667	-1,030773	-0,99805	-1,006231	-1,011684667
0,04	0,703544	0,66264	0,711724	0,692636	-0,973508	-1,014412	-1,006231	-0,998050333
0,06	1,276196	1,292557	1,292557	1,287103333	-0,76899	-0,760809	-0,785351	-0,771716667
0,08	1,358003	1,382545	1,407087	1,382545	-0,474483	-0,474483	-0,466302	-0,471756
0,1	1,333461	1,374365	1,358003	1,355276333	-0,204519	-0,196338	-0,212699	-0,204518667
0,12	1,284376	1,308919	1,308919	1,300738	0,10635	0,10635	0,11453	0,109076667
0,14	1,128942	1,137123	1,137123	1,134396	0,425399	0,433579	0,425399	4,28E-01
0,16	0,891701	0,916243	0,891701	0,899881667	0,621736	0,638098	0,605375	0,621736333
0,18	0,687182	0,695363	0,703544	0,695363	0,875339	0,858978	0,858978	0,864431667
0,2	0,531748	0,531748	0,539929	0,534475	1,112581	1,1044	1,1044	1,107127

crash test wh18.34	
vehicle data	dummy data
VW Touareg 2003	biofidelic D07
trapezium	169 cm
2542 kg	78 kg
27 km/h	
in-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,026178	0,026178	0,026178	0,026178	0,45376	0,45376	0,45376	0,45376
0,02	0,017452	0,017452	0,017452	0,017452	0,445034	0,436308	0,445034	0,442125333
0,04	0,008726	0	0,008726	0,005817333	0,462486	0,445034	0,45376	0,45376
0,06	-0,087262	-0,087262	-0,069809	-0,081444333	0,427582	0,427582	0,418856	0,424673333
0,08	-0,22688	-0,22688	-0,22688	-0,22688	0,392677	0,383951	0,392677	0,389768333
0,1	-0,331594	-0,34032	-0,34032	-0,337411333	0,322868	0,314142	0,322868	0,319959333
0,12	-0,427582	-0,436308	-0,436308	-0,433399333	0,191976	0,191976	0,191976	0,191976
0,14	-0,479939	-0,479939	-0,471213	-0,477030333	0,034905	0,043631	0,052357	0,043631
0,16	-0,479939	-0,479939	-0,479939	-0,479939	0,017452	0,026178	0,026178	0,023269333
0,18	-0,488665	-0,488665	-0,488665	-0,488665	0,061083	0,052357	0,061083	0,058174333
0,2	-0,514843	-0,52357	-0,506117	-0,514843333	0,069809	0,069809	0,069809	0,069809

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,095988	-0,095988	-0,095988	-0,095988	-0,986056	-0,986056	-0,986056	-0,986056
0,02	-0,104714	-0,104714	-0,104714	-0,104714	-0,994782	-0,994782	-0,994782	-0,994782
0,04	-0,11344	-0,104714	-0,104714	-0,107622667	-0,986056	-0,933699	-0,933699	-0,951151333
0,06	-0,087262	-0,078535	-0,061083	-0,075626667	-0,942425	-0,924973	-0,924973	-0,930790333
0,08	0,052357	0,052357	0,061083	0,055265667	-0,881342	-0,881342	-0,872616	-0,878433333
0,1	0,11344	0,11344	0,122166	0,116348667	-0,907521	-0,881342	-0,855164	-0,881342333
0,12	0,191976	0,209428	0,383951	0,261785	-0,959878	-0,951151	-0,933699	-0,948242667
0,14	0,52357	0,549748	0,541022	0,538113333	-0,907521	-0,898794	-0,898794	-9,02E-01
0,16	0,654462	0,671914	0,654462	0,660279333	-0,794081	-0,794081	-0,811533	-0,799898333
0,18	0,767902	0,767902	0,776628	0,770810667	-0,741724	-0,732997	-0,724271	-0,732997333
0,2	0,837711	0,837711	0,828985	0,834802333	-0,68064	-0,68064	-0,689367	-0,683549

crash test wh08.27	
vehicle data	dummy data
Ford Galaxy 1998	Žilina
van	168 cm
1705 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,006922	0,006922	0,006922	0,006922	0,609135	0,609135	0,609135	0,609135
0,02	0,006922	0,006922	0,006922	0,006922	0,609135	0,609135	0,609135	0,609135
0,04	-0,076142	-0,06922	-0,076142	-0,073834667	0,546837	0,539915	0,526071	0,537607667
0,06	-0,20766	-0,20766	-0,20766	-0,20766	0,463773	0,470695	0,463773	0,466080333
0,08	-0,346099	-0,353021	-0,353021	-0,350713667	0,346099	0,346099	0,346099	0,346099
0,1	-0,449929	-0,443007	-0,443007	-0,445314333	0,20766	0,214582	0,186894	0,203045333
0,12	-0,449929	-0,463773	-0,456851	-0,456851	0,089986	0,083064	0,083064	0,085371333
0,14	-0,491461	-0,519149	-0,512227	-0,507612333	0,062298	0,06922	0,076142	0,06922
0,16	-0,498383	-0,546837	-0,526071	-0,523763667	0	0,020766	0	0,006922
0,18	-0,505305	-0,526071	-0,532993	-0,521456333	-0,076142	-0,062298	-0,076142	-0,071527333
0,2	-0,512227	-0,505305	-0,512227	-0,509919667	-0,13844	-0,13844	-0,13844	-0,13844

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,145362	-0,145362	-0,145362	-0,145362	-0,823717	-0,823717	-0,823717	-0,823717
0,02	-0,083064	-0,083064	-0,076142	-0,080756667	-0,789107	-0,809873	-0,809873	-0,802951
0,04	0,269958	0,269958	0,269958	0,269958	-0,775263	-0,775263	-0,796029	-0,782185
0,06	0,519149	0,526071	0,526071	0,523763667	-0,706043	-0,706043	-0,719887	-0,710657667
0,08	0,678355	0,650667	0,636823	0,655281667	-0,595291	-0,595291	-0,602213	-0,597598333
0,1	0,726809	0,712965	0,706043	0,715272333	-0,477617	-0,505305	-0,505305	-0,496075667
0,12	0,782185	0,782185	0,789107	0,784492333	-0,443007	-0,449929	-0,449929	-0,447621667
0,14	0,802951	0,809873	0,816795	0,809873	-0,373787	-0,380709	-0,387631	-3,81E-01
0,16	0,830639	0,802951	0,823717	0,819102333	-0,353021	-0,318412	-0,339178	-0,336870333
0,18	0,865249	0,865249	0,886015	0,872171	-0,256114	-0,263036	-0,290724	-0,269958
0,2	0,982923	0,955235	0,948313	0,962157	-0,228426	-0,20766	-0,221504	-0,219196667

crash test wh08.28	
vehicle data	**dummy data**
BMW 523i 1998	Žilina
trapezium	168 cm
1550 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,013778	0,013778	0,013778	0,013778	0,633807	0,633807	0,633807	0,633807
0,02	-0,006889	-0,006889	-0,006889	-0,006889	0,633807	0,633807	0,633807	0,633807
0,04	-0,137784	-0,151562	-0,151562	-0,146969333	0,544247	0,551136	0,544247	0,546543333
0,06	-0,323792	-0,323792	-0,323792	-0,323792	0,420241	0,406463	0,420241	0,415648333
0,08	-0,420241	-0,406463	-0,406463	-0,411055667	0,310014	0,316903	0,316903	0,314606667
0,1	-0,440909	-0,454687	-0,440909	-0,445501667	0,296236	0,289346	0,289346	0,291642667
0,12	-0,537358	-0,551136	-0,551136	-0,546543333	0,234233	0,234233	0,220454	0,22964
0,14	-0,571804	-0,571804	-0,578693	-0,574100333	0,199787	0,206676	0,199787	0,202083333
0,16	-0,578693	-0,578693	-0,585582	-0,580989333	0,165341	0,17223	0,158452	0,165341
0,18	-0,551136	-0,564914	-0,558025	-0,558025	0,08956	0,103338	0,103338	0,098745333
0,2	-0,558025	-0,551136	-0,544247	-0,551136	0,006889	0,020668	0,034446	0,020667667

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,192898	-0,192898	-0,192898	-0,192898	-0,771591	-0,771591	-0,771591	-0,771591
0,02	-0,158452	-0,179119	-0,179119	-0,17223	-0,716477	-0,737145	-0,730255	-0,727959
0,04	0	0,006889	0,013778	0,006889	-0,737145	-0,730255	-0,730255	-0,732551667
0,06	0,158452	0,186008	0,213565	0,186008333	-0,723366	-0,695809	-0,716477	-0,711884
0,08	0,372017	0,385795	0,365128	0,374313333	-0,668253	-0,682031	-0,695809	-0,682031
0,1	0,60625	0,578693	0,571804	0,585582333	-0,654474	-0,620028	-0,640696	-0,638399333
0,12	0,620028	0,620028	0,620028	0,620028	-0,523579	-0,530468	-0,537358	-0,530468333
0,14	0,695809	0,702699	0,695809	0,698105667	-0,413352	-0,420241	-0,42713	-4,20E-01
0,16	0,757812	0,764701	0,764701	0,762404667	-0,268679	-0,296236	-0,303125	-0,289346667
0,18	0,847372	0,833593	0,847372	0,842779	-0,165341	-0,186008	-0,186008	-0,179119
0,2	0,916264	0,881818	0,895596	0,897892667	-0,068892	-0,075781	-0,075781	-0,073484667

crash test wh08.29	
vehicle data	**dummy data**
Toyota Avensis 1998	Žilina
trapezium	168 cm
1329 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,013699	0,013699	0,013699	0,013699	0,623297	0,623297	0,623297	0,623297
0,02	-0,006849	-0,006849	-0,006849	-0,006849	0,623297	0,623297	0,623297	0,623297
0,04	-0,150687	-0,143838	-0,150687	-0,148404	0,602748	0,58905	0,58905	0,593616
0,06	-0,363019	-0,369868	-0,376718	-0,369868333	0,46576	0,46576	0,46576	0,46576
0,08	-0,458911	-0,47261	-0,486308	-0,472609667	0,301374	0,321922	0,315073	0,312789667
0,1	-0,479459	-0,486308	-0,493158	-0,486308333	0,280826	0,287675	0,280826	0,283109
0,12	-0,410965	-0,431513	-0,438362	-0,426946667	0,321922	0,321922	0,321922	0,321922
0,14	-0,404115	-0,417814	-0,404115	-0,408681333	0,315073	0,321922	0,315073	0,317356
0,16	-0,383567	-0,383567	-0,390417	-0,385850333	0,287675	0,301374	0,294525	0,294524667
0,18	-0,404115	-0,431513	-0,431513	-0,422380333	0,267127	0,253428	0,260278	0,260277667
0,2	-0,452061	-0,438362	-0,458911	-0,449778	0,23288	0,23288	0,246579	0,237446333

time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,212332	-0,212332	-0,212332	-0,212332	-0,82193	-0,82193	-0,82193	-0,82193
0,02	-0,109591	-0,102741	-0,102741	-0,105024333	-0,801381	-0,794532	-0,801381	-0,799098
0,04	0,089042	0,109591	0,136988	0,111873667	-0,726038	-0,739737	-0,753435	-0,739736667
0,06	0,301374	0,294525	0,301374	0,299091	-0,746586	-0,739737	-0,746586	-0,744303
0,08	0,47261	0,445212	0,47261	0,463477333	-0,69864	-0,69864	-0,69864	-0,69864
0,1	0,5822	0,5822	0,5822	0,5822	-0,609598	-0,58905	-0,609598	-0,602748667
0,12	0,746586	0,746586	0,739737	0,744303	-0,486308	-0,479459	-0,493158	-0,486308333
0,14	0,856177	0,842478	0,849327	0,849327333	-0,335621	-0,34932	-0,369868	-3,52E-01
0,16	0,952068	0,924671	0,952068	0,942935667	-0,219181	-0,226031	-0,219181	-0,221464333
0,18	0,993165	1,000014	1,006864	1,000014333	-0,11644	-0,109591	-0,095892	-0,107307667
0,2	1,034261	1,095906	1,068508	1,066225	0,020548	0	0,027398	0,015982

crash test wh10.12	
vehicle data	**dummy data**
Fiat Punto 1996	Žilina
trapezium	168 cm
1012 kg	75 kg
55 km/h	
late or unbraked	
frontal	
complete	

time	head 1 s(x)	head 2 s(x)	head 3 s(x)	average head s(x)	head 1 s(y)	head 2 s(y)	head 3 s(y)	average head s(y)
0	0,020831	0,020831	0,020831	0,020831	0,631884	0,631884	0,631884	0,631884
0,02	-0,006944	-0,006944	-0,006944	-0,006944	0,631884	0,631884	0,631884	0,631884
0,04	-0,201369	-0,201369	-0,215257	-0,205998333	0,597165	0,590221	0,597165	0,594850333
0,06	-0,409683	-0,402739	-0,409683	-0,407368333	0,47912	0,472177	0,47912	0,476805667
0,08	-0,541614	-0,534671	-0,541614	-0,539299667	0,263863	0,263863	0,25692	0,261548667
0,1	-0,555502	-0,548558	-0,56939	-0,557816667	0,090269	0,097213	0,1111	0,099527333
0,12	-0,576333	-0,576333	-0,583277	-0,578647667	0,013888	0	-0,013888	0
0,14	-0,562446	-0,548558	-0,520783	-0,543929	-0,062494	-0,05555	-0,076382	-0,064808667
0,16	-0,493008	-0,534671	-0,499952	-0,509210333	-0,090269	-0,097213	-0,097213	-0,094898333
0,18	-0,486064	-0,534671	-0,465233	-0,495322667	-0,152763	-0,159707	-0,173594	-0,162021333
0,2	-0,499952	-0,486064	-0,486064	-0,490693333	-0,159707	-0,173594	-0,180538	-0,171279667

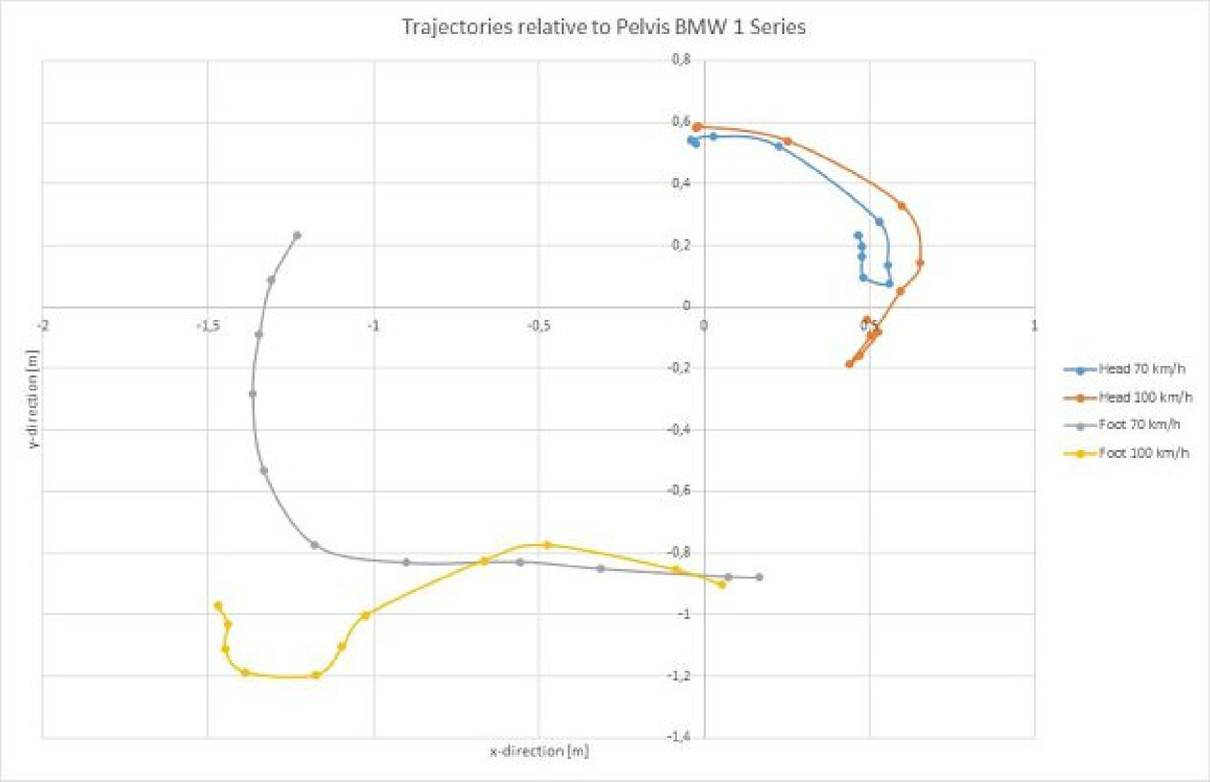
time	foot 1 s(x)	foot 2 s(x)	foot 3 s(x)	average foot s(x)	foot 1 s(y)	foot 2 s(y)	foot 3 s(y)	average foot s(y)
0	-0,124988	-0,124988	-0,124988	-0,124988	-0,73604	-0,73604	-0,73604	-0,73604
0,02	-0,090269	-0,090269	-0,104157	-0,094898333	-0,742984	-0,749928	-0,73604	-0,742984
0,04	-0,048606	-0,020831	-0,013888	-0,027775	-0,749928	-0,742984	-0,742984	-0,745298667
0,06	0,25692	0,243032	0,229145	0,243032333	-0,673546	-0,673546	-0,673546	-0,673546
0,08	0,47912	0,486064	0,486064	0,483749333	-0,590221	-0,604108	-0,597165	-0,597164667
0,1	0,749928	0,770759	0,770759	0,763815333	-0,416626	-0,409683	-0,42357	-0,416626333
0,12	0,895747	0,909634	0,909634	0,905005	-0,173594	-0,180538	-0,187482	-0,180538
0,14	0,944353	0,951297	0,951297	0,948982333	0,027775	0,027775	0,034719	3,01E-02
0,16	0,909634	0,902691	0,909634	0,907319667	0,229145	0,229145	0,243032	0,233774
0,18	0,770759	0,777703	0,770759	0,773073667	0,354133	0,340245	0,333301	0,342559667
0,2	0,499952	0,499952	0,499952	0,499952	0,222201	0,215257	0,208313	0,215257

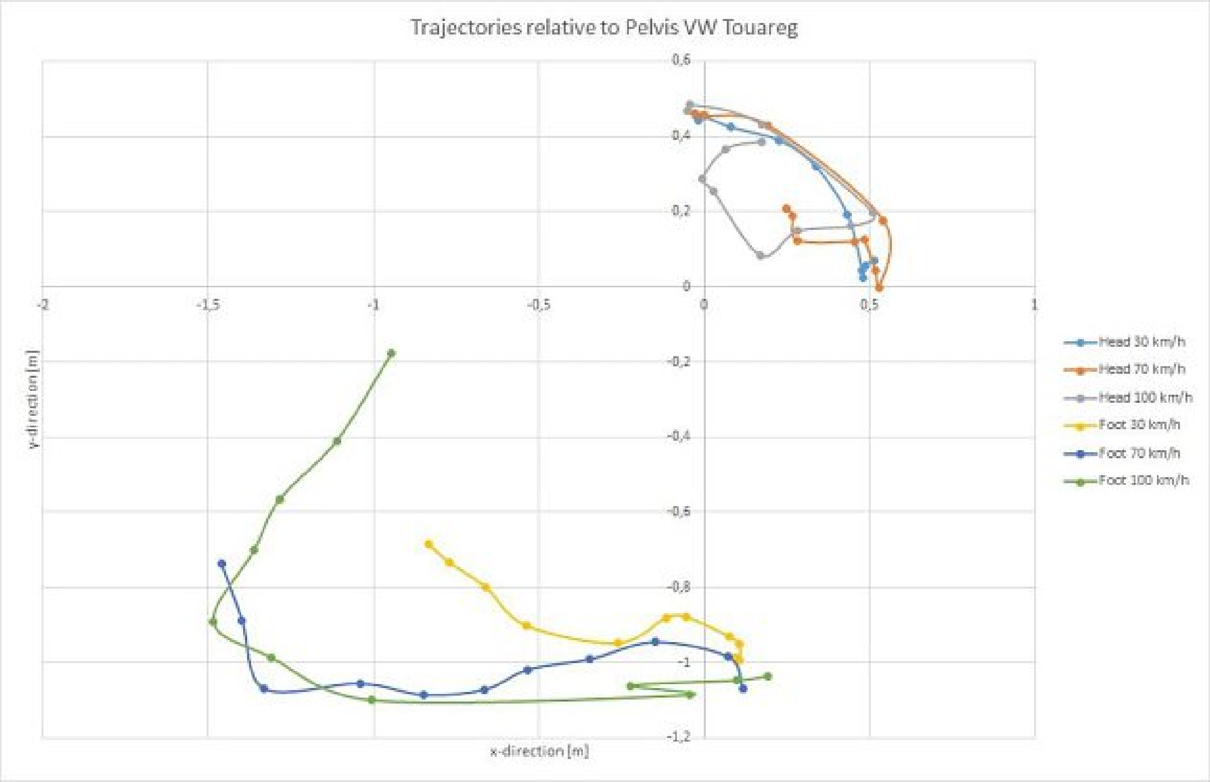
G. Dummy Trajectories relative to the Pelvis

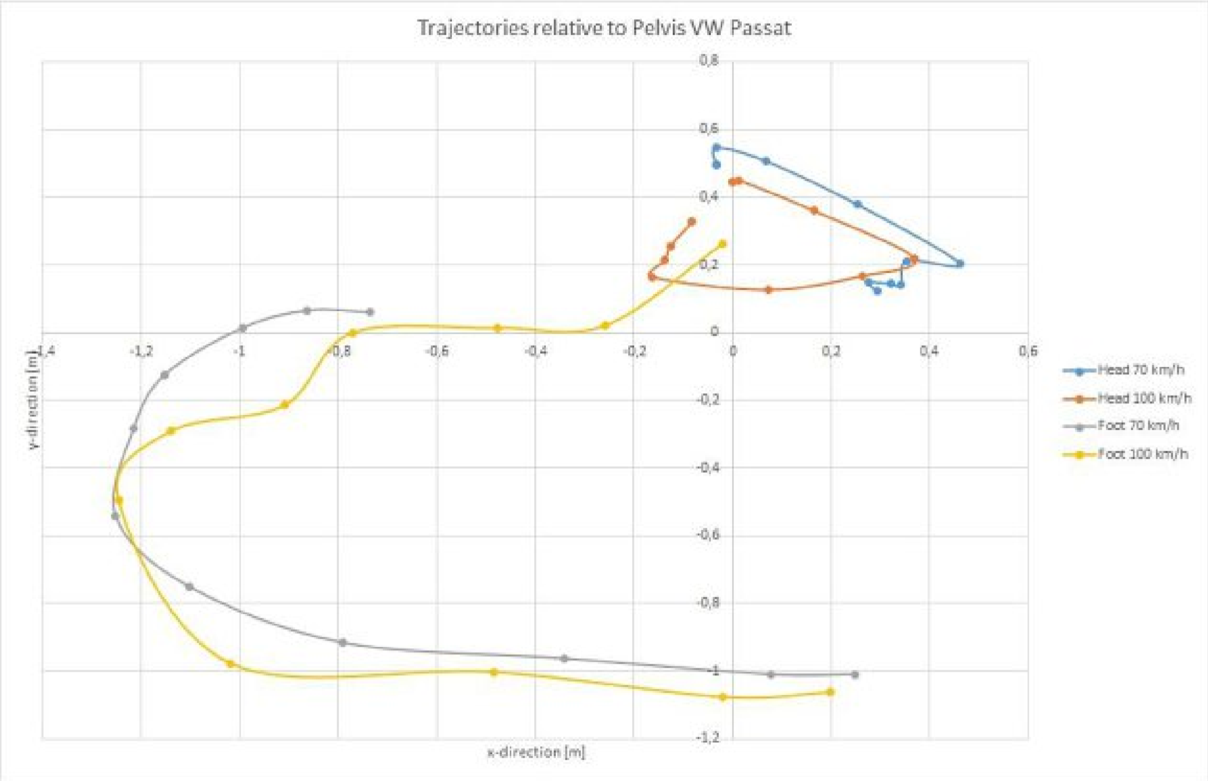
The dummy trajectories relative to the pelvis were obtained by using the measurements listed in appendix F.

The programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998 - 2006$ FalCon GmbH) provides txt-files as data output, which have been uploaded into Excel, with which the graphs have then been created.

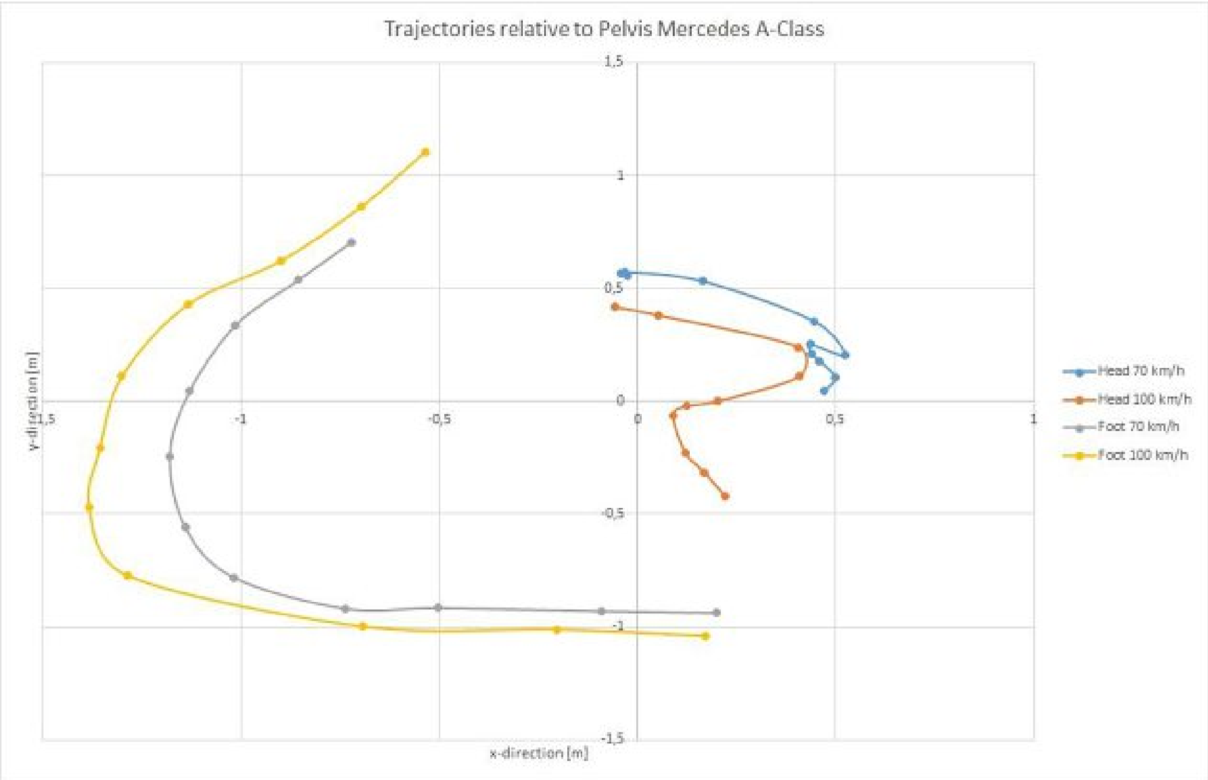
As the x-direction faces in the direction of travel and the present author wants to obtain graphs similar to Subit et al. (2008) for comparison purposes, the $s(x)$-values have to be multiplied by -1, as the x-direction in Subit et al. (2008) faces in the opposite direction.


Trajectories relative to Pelvis BMW 1 Series
y-direction [m]
x-direction [m]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h

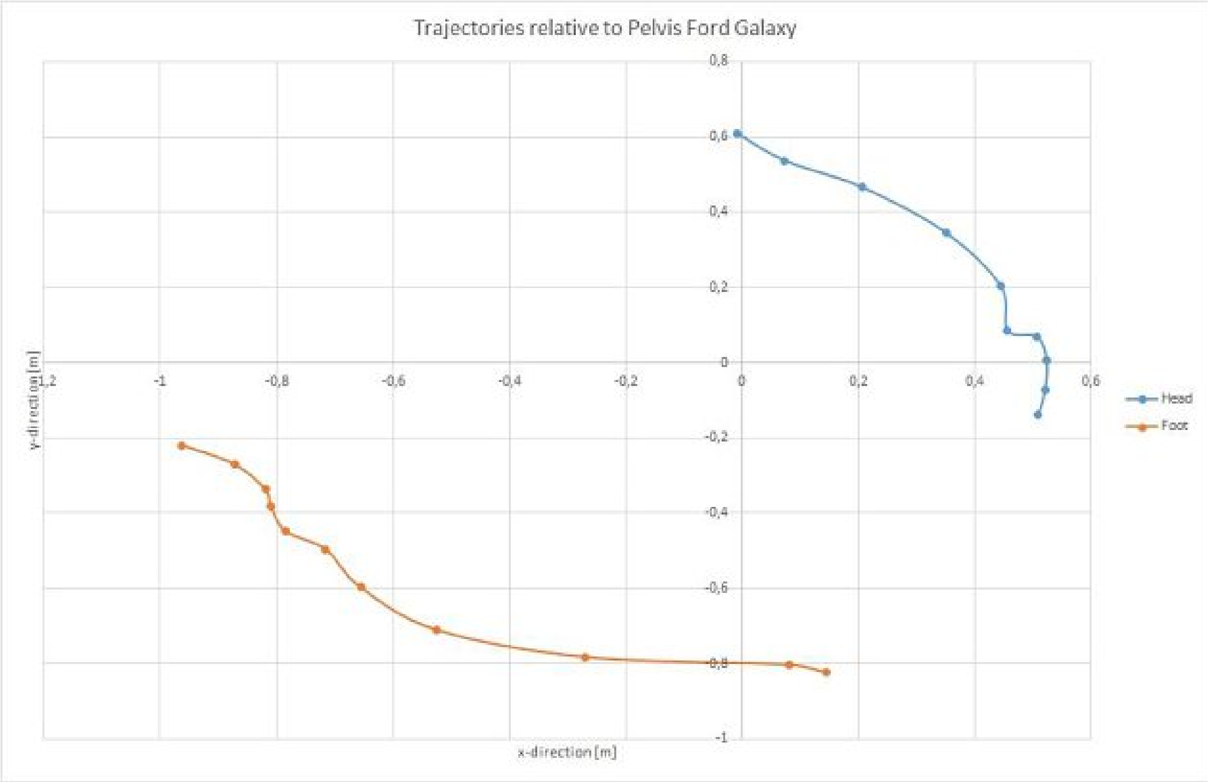

Trajectories relative to Pelvis VW Touareg
y-direction [m]
x-direction [m]
Head 30 km/h
Head 70 km/h
Head 100 km/h
Foot 30 km/h
Foot 70 km/h
Foot 100 km/h

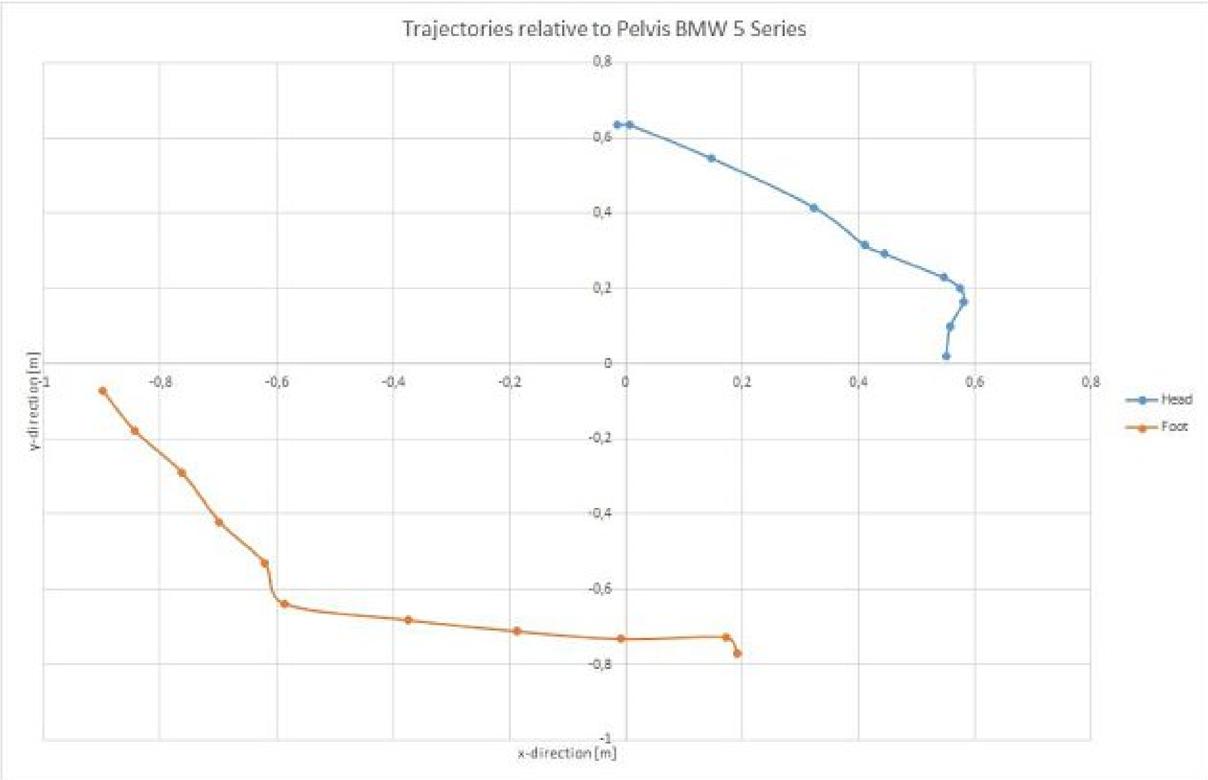


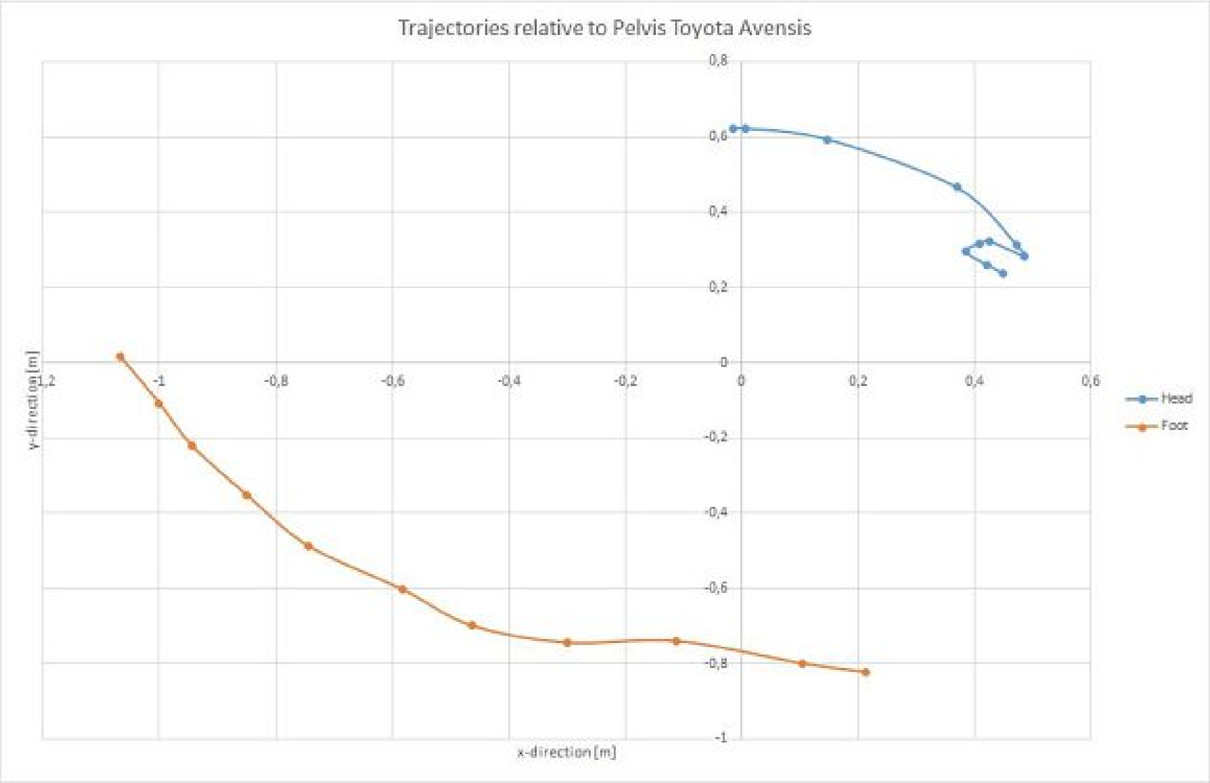
Trajectories relative to Pelvis VW Passat
y-direction [m]
x-direction [m]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h

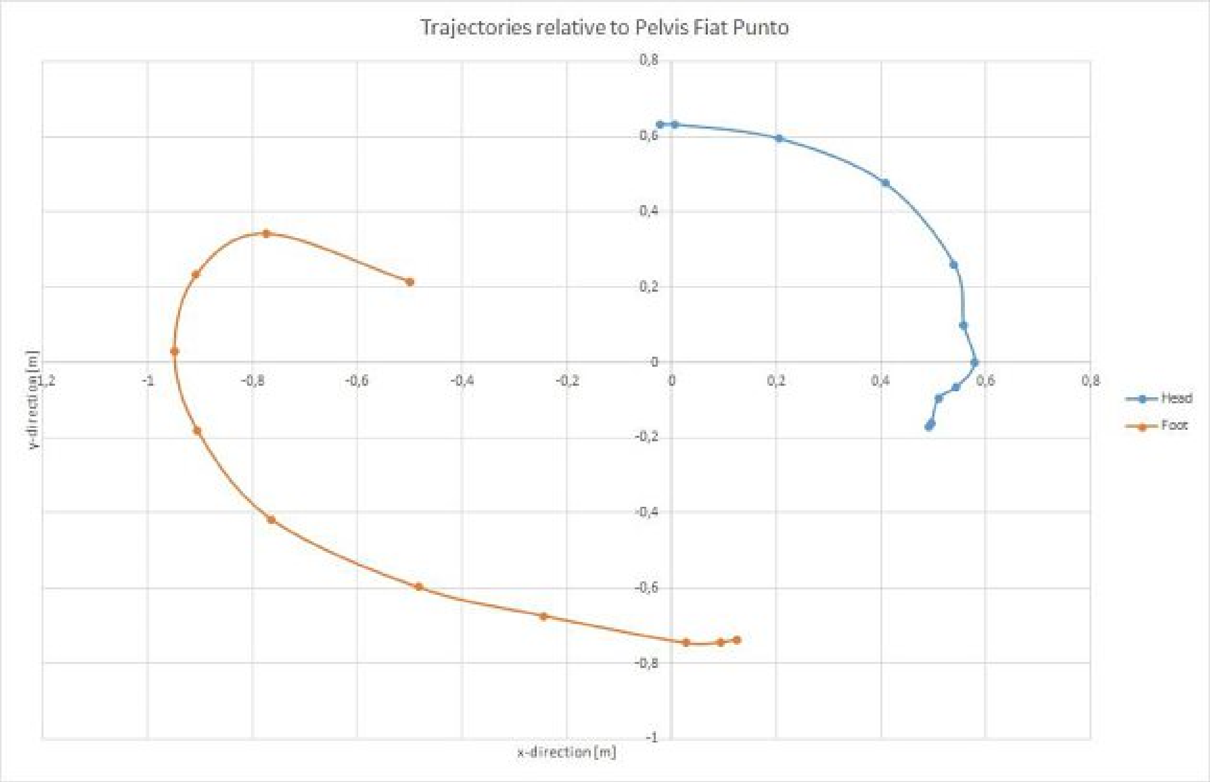


Trajectories relative to Pelvis Mercedes A-Class
y-direction [m]
x-direction [m]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h


Trajectories relative to Pelvis Ford Galaxy
y-direction [m]
x-direction [m]
Head
Foot


Trajectories relative to Pelvis BMW 5 Series
y-direction [m]
x-direction [m]
Head
Foot


Trajectories relative to Pelvis Toyota Avensis
y-direction [m]
x-direction [m]
Head
Foot


Trajectories relative to Pelvis Fiat Punto
y-direction [m]
x-direction [m]
Head
Foot

H. Vehicle Damages

Vehicle damages are important evidences for reconstruction purposes. In order to evaluate in how far the damages produced by the ATDs used by DEKRA are biofidelic, crash tests are compared with similar real-world accidents.

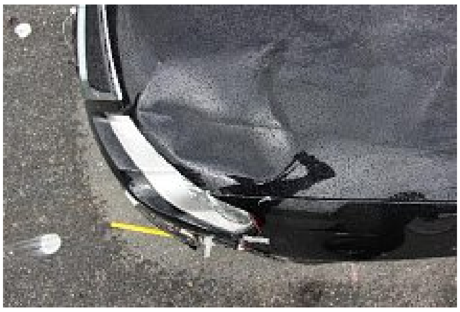
As such, the crash tests wh18.22 and wh18.26 were chosen for the Biofidelic Dummy, as they are the most similar to two of the analysed real-world accidents. The collision speed, dummy/pedestrian height and weight are still within an acceptable deviation.

Considering the Žilina Dummy, all four crash tests are considered, even though the collision speed is much lower.

Pictures of the vehicle damages are given below.

crash test wh18.22	
vehicle data	**dummy data**
BMW 1 Series 2004	biofidelic D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

crash test wh18.26	
vehicle data	**dummy data**
VW Passat Variant 2006	biofidelic D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	



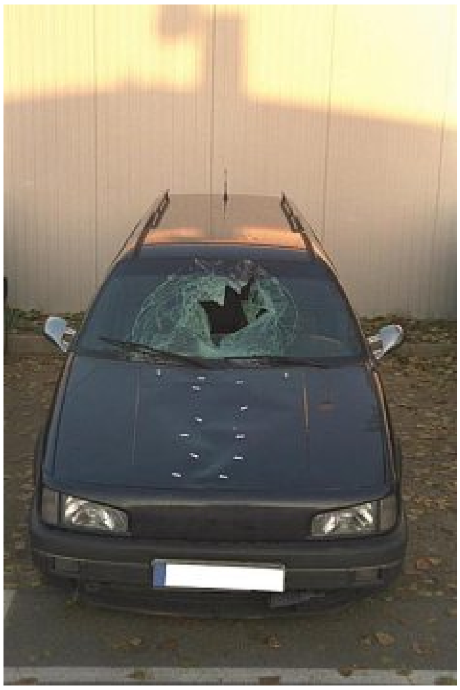
crash test wh08.27	
vehicle data	**dummy data**
Ford Galaxy 1998	Žilina
van	168 cm
1705 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

crash test wh08.28	
vehicle data	**dummy data**
BMW 523i 1998	Žilina
trapezium	168 cm
1550 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

crash test wh08.29	
vehicle data	**dummy data**
Toyota Avensis 1998	Žilina
trapezium	168 cm
1329 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

crash test wh10.12	
vehicle data	dummy data
Fiat Punto 1996	Žilina
trapezium	168 cm
1012 kg	75 kg
55 km/h	
late or unbraked	
frontal	
complete	

accident 1	
vehicle data	pedestrian data
VW Passat 1998	29 years
trapezium	male
1155 kg	178 cm
64 - 67 km/h	78 kg
late or unbraked	survived
frontal	
complete	



accident 2	
vehicle data	pedestrian data
BMW 320i 1996	51 years
trapezium	male
1300 kg	173 cm
53 - 63 km/h	83 kg
late or unbraked	deceased
frontal	
complete	

I. Measurements for C-Ratio

In order to obtain the C-ratio of the different ATDs, the crash test videos were analysed by the programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998 - 2006$ FalCon GmbH).

The frame rate of the videos is $500\, pictures/s$. Time is set to zero at the point of first contact between the pedestrian and vehicle. The coordinate system has its origin at the first target on the vehicle. The x-direction faces in the direction of travel, while the y-direction faces upwards. The dummy targets had to be applied manually to the dummy. Targets were applied to the head, hip and foot. Every body region was analysed three-times and the average value was calculated , in order to reduce any errors stemming from manually placing the targets on the dummy. Every 10^{th} picture has been analysed, i.e. the time interval between the different measurements is $0.02\, s$.

The three measurements are marked with “head $1\, v(res)$”, “head $2\, v(res)$” and “head $3\, v(res)$”, for example, and the resulting average value with “average head $v(res)$”.

The orange table lists the most important vehicle and dummy data, while the blue table lists the measurements.

crash test wh18.22	
vehicle data	dummy data
BMW 1 Series 2004	biofidelic D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	2,18061	0	0	0,72687
0,02	2,779744	1,090305	1,723924	1,864657667
0,04	7,862303	8,303517	8,790322	8,318714
0,06	26,617743	26,494642	27,257631	26,79000533
0,08	32,935521	34,864204	33,790669	33,86346467
0,1	51,47003	49,993795	48,429685	49,96450333
0,12	65,753633	63,994509	63,223604	64,32391533
0,14	67,936604	69,856155	70,343702	69,37882033
0,16	60,793684	63,129521	63,129521	62,35090867
0,18	64,452627	65,131481	64,364958	64,64968867
0,2	70,668267	68,198571	69,732671	69,53316967

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	4,361221	5,559488	1,541924	3,820877667
0,02	5,451526	6,021408	5,451526	5,641486667
0,04	22,450759	24,147246	23,409846	23,33595033
0,06	40,890081	41,63196	42,465955	41,66266533
0,08	49,063736	49,635839	48,960654	49,22007633
0,1	51,093337	50,112545	50,136261	50,447381
0,12	57,842723	55,557445	55,530692	56,31028667
0,14	61,027882	62,066051	60,154819	61,08291733
0,16	60,925531	64,875452	62,524039	62,77500733
0,18	63,223604	63,223604	64,760827	63,73601167
0,2	68,61997	66,320679	67,073714	67,338121

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	11,742947	17,23924	13,87732	14,28650233
0,02	43,235793	48,57062	49,365669	47,05736067
0,04	78,641927	77,130908	78,672153	78,14832933
0,06	96,382613	91,744505	92,544374	93,557164
0,08	105,48668	104,042774	105,48668	105,005378
0,1	97,364319	94,350785	93,375589	95,030231
0,12	90,057497	87,530531	85,41343	87,66715267
0,14	76,806568	75,286347	76,360296	76,15107033
0,16	63,743239	66,114226	67,175546	65,67767033
0,18	60,055929	61,778084	60,435768	60,75659367
0,2	58,638761	57,960774	58,333878	58,31113767

crash test wh18.23	
vehicle data	dummy data
BMW 1 Series 2004	biofidelic D02
pontoon	171 cm
1315 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	1,487884	1,487884	0	0,991922667
0,02	8,317525	9,410206	8,317525	8,681752
0,04	22,589394	21,66392	23,098174	22,450496
0,06	24,763328	23,817768	24,289452	24,29018267
0,08	63,970368	63,76239	65,068357	64,26703833
0,1	98,540738	96,895421	95,366875	96,93434467
0,12	103,624482	103,579074	102,882106	103,3618873
0,14	96,815423	101,219874	98,944296	98,99319767
0,16	94,48943	94,234294	97,194829	95,30618433
0,18	100,396355	98,093213	100,970783	99,820117
0,2	108,997035	106,581225	103,736581	106,4382803

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	2,104186	2,975768	2,104186	2,394713333
0,02	23,490199	23,490199	24,220999	23,733799
0,04	49,122716	49,190269	47,635535	48,64950667
0,06	53,169744	51,52571	50,817289	51,837581
0,08	65,509159	65,858835	66,581777	65,983257
0,1	84,639556	83,603335	84,183875	84,14225533
0,12	90,50446	89,89702	89,437186	89,946222
0,14	96,316799	97,686139	96,382857	96,795265
0,16	102,666702	99,732643	101,963497	101,4542807
0,18	101,178857	101,930924	101,92278	101,6775203
0,2	100,434936	103,43203	101,92278	101,9299153

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	29,307919	30,347001	24,220999	27,95863967
0,02	72,712489	70,250352	70,183355	71,048732
0,04	103,504242	99,757612	101,274537	101,5121303
0,06	99,044929	100,50104	101,274537	100,273502
0,08	99,490954	101,449262	105,109301	102,0165057
0,1	93,067124	96,072278	101,178857	96,772753
0,12	106,643519	113,883901	126,961513	115,8296443
0,14	111,712756	132,089005	122,060923	121,954228
0,16	112,009615	115,990566	98,273594	108,757925
0,18	114,480093	95,965644	101,789655	104,078464
0,2	107,871601	99,815848	104,496722	104,0613903

crash test wh18.24	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D07
trapezium	170 cm
2542 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	3,388407	6,42905	4,286033	4,701163333
0,02	7,500558	8,195463	10,768526	8,821515667
0,04	24,922649	24,209924	25,186145	24,772906
0,06	41,200855	39,725368	37,640306	39,52217633
0,08	55,728736	57,826716	55,641108	56,39885333
0,1	65,25653	64,348515	64,934644	64,846563
0,12	68,148268	65,899942	66,765375	66,93786167
0,14	68,055544	68,375332	67,81048	68,080452
0,16	73,122104	73,259364	74,147294	73,50958733
0,18	75,147043	75,105016	75,196682	75,14958033
0,2	73,129954	72,878324	73,129954	73,04607733

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	2,143017	3,388407	3,388407	2,973277
0,02	13,97076	13,97076	14,154459	14,031993
0,04	40,942277	40,185135	40,220833	40,449415
0,06	53,473527	53,473527	55,185281	54,04411167
0,08	54,135037	54,888009	54,741389	54,588145
0,1	59,175983	59,14202	56,870754	58,39625233
0,12	60,689386	60,731936	60,783903	60,735075
0,14	50,803509	51,527187	51,034628	51,12177467
0,16	55,826511	55,075946	55,574006	55,49215433
0,18	72,042504	72,122144	73,634534	72,59972733
0,2	69,771569	71,285511	72,878324	71,31180133

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	17,671768	15,601397	17,144134	16,80576633
0,02	36,40764	40,270757	38,78949	38,48929567
0,04	75,77087	83,347234	76,539755	78,55261967
0,06	93,978674	83,347234	85,620155	87,64868767
0,08	84,268529	79,559044	84,104874	82,644149
0,1	82,756247	90,191475	89,417998	87,45524
0,12	95,613735	93,270478	94,817895	94,56736933
0,14	94,356639	93,04864	92,922079	93,44245267
0,16	90,578905	91,150666	89,331286	90,353619
0,18	86,018165	87,234206	90,089578	87,78064967
0,2	85,317906	83,385108	89,764009	86,15567433

crash test wh18.25	
vehicle data	dummy data
VW Touareg 2003	biofidelic D08
trapezium	173 cm
2494 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	7,742135	7,742135	8,407421	7,963897
0,04	24,494325	24,075189	24,997059	24,522191
0,06	34,328643	35,311167	34,640206	34,76000533
0,08	80,47619	79,72434	79,798781	79,99977033
0,1	90,503845	88,609589	88,702075	89,27183633
0,12	100,360802	105,599348	103,448863	103,1363377
0,14	103,503512	104,165196	104,395659	104,0214557
0,16	85,560947	80,071139	81,165364	82,26581667
0,18	70,09591	69,978838	69,125158	69,733302
0,2	66,191555	64,670502	64,670502	65,17751967

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	3,362968	0	3,00793	2,123632667
0,02	16,9655	17,442106	17,55521	17,32093867
0,04	42,922333	44,392456	44,468819	43,92786933
0,06	55,514449	56,803313	56,056758	56,12484
0,08	59,790891	58,388917	58,388917	58,85624167
0,1	66,625826	66,824982	69,451606	67,634138
0,12	78,509286	78,296519	78,296519	78,36744133
0,14	84,443324	84,228763	82,547002	83,73969633
0,16	83,956422	83,808113	84,557089	84,107208
0,18	84,98734	81,228043	81,99714	82,73750767
0,2	84,275745	81,228043	81,228043	82,24394367

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	16,1982	22,759123	17,603461	18,85359467
0,02	50,835357	56,643808	55,223381	54,234182
0,04	59,425658	51,156928	57,155623	55,91273633
0,06	128,668153	123,40765	124,188733	125,421512
0,08	172,859516	175,922142	172,996857	173,9261717
0,1	114,167698	113,207724	112,960199	113,445207
0,12	93,261	93,373105	93,373105	93,33573667
0,14	77,803855	77,172613	78,437226	77,80456467
0,16	69,022826	70,421874	71,833035	70,42591167
0,18	66,114623	64,657385	65,917611	65,56320633
0,2	70,989705	64,687987	64,687987	66,78855967

crash test wh18.26	
vehicle data	dummy data
VW Passat Variant 2006	biofidelic D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	0	0	0	0
0,04	6,741238	6,741238	6,001909	6,494795
0,06	15,055472	15,91442	15,183762	15,38455133
0,08	21,05609	21,70412	21,793307	21,517839
0,1	31,248968	32,43253	31,828841	31,83677967
0,12	64,130399	63,435292	63,387224	63,65097167
0,14	68,553661	67,103382	67,809926	67,822323
0,16	73,703833	72,21502	72,955628	72,95816033
0,18	71,482246	71,470615	72,226531	71,726464
0,2	67,760872	70,120256	71,528748	69,803292

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	0	3,32926	2,105609	1,811623
0,02	4,466671	4,466671	5,264022	4,732454667
0,04	11,066973	11,770712	10,736541	11,19140867
0,06	23,077801	23,089805	24,611768	23,59312467
0,08	33,292601	33,590898	34,670691	33,85139667
0,1	41,180673	42,641831	42,439905	42,08746967
0,12	53,734299	54,11456	53,377291	53,74205
0,14	64,83515	64,77101	64,805226	64,80379533
0,16	67,004203	69,24941	69,237405	68,497006
0,18	69,237405	70,737964	69,981807	69,98572533
0,2	75,281042	71,528748	71,466738	72,75884267

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	31,302128	28,328071	32,755588	30,79526233
0,02	52,855608	52,860851	53,600054	53,10550433
0,04	84,866751	87,847687	86,384516	86,366318
0,06	94,168638	93,590114	92,861891	93,54021433
0,08	87,236779	82,941351	81,932949	84,03702633
0,1	71,598446	73,186951	70,029306	71,604901
0,12	62,195711	65,30783	66,360096	64,62121233
0,14	53,899065	53,486198	54,303692	53,89631833
0,16	46,335359	44,523797	41,475687	44,11161433
0,18	46,538245	46,953191	45,166417	46,21928433
0,2	49,155936	49,133382	52,111163	50,13349367

crash test wh18.27	
vehicle data	dummy data
VW Passat Variant 2006	biofidelic D04
trapezium	172 cm
1514 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	3,707098	4,448517	3,992666	4,049427
0,04	11,14598	11,14598	11,88586	11,39260667
0,06	14,902349	14,106469	15,587453	14,86542367
0,08	47,416085	49,60867	49,386557	48,80377067
0,1	104,605865	103,187917	103,841096	103,8782927
0,12	108,3716	107,669335	107,021544	107,687493
0,14	94,94803	97,13728	93,465926	95,18374533
0,16	88,241387	86,774599	88,278756	87,764914
0,18	91,269922	89,788326	91,342167	90,80013833
0,2	93,465926	93,465926	92,12716	93,01967067

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	0	0	0	0
0,02	4,689149	5,646483	5,397616	5,244416
0,04	14,566583	15,481295	13,366131	14,47133633
0,06	31,69948	29,517439	30,244102	30,487007
0,08	57,897225	57,04596	56,935036	57,29274033
0,1	77,23585	66,32287	70,012151	71,19029033
0,12	69,20666	73,744229	75,501124	72,81733767
0,14	77,068414	94,163202	91,194605	87,475407
0,16	91,387291	89,760772	91,221726	90,78992967
0,18	95,826864	89,71483	93,445339	92,99567767
0,2	101,224815	94,913287	100,833059	98,990387

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	38,582322	37,189416	41,625277	39,13233833
0,02	62,283656	62,296893	64,507762	63,029437
0,04	104,708287	106,188779	101,642104	104,1797233
0,06	113,73724	112,746977	110,180035	112,2214173
0,08	100,135566	98,583712	97,10332	98,60753267
0,1	55,7299	55,10997	55,18473	55,34153333
0,12	40,317138	40,473631	42,78447	41,19174633
0,14	45,800289	37,87776	35,347911	39,67532
0,16	44,249768	44,58392	46,76236	45,19868267
0,18	48,397152	59,775155	63,78794	57,32008233
0,2	63,831014	64,978984	71,730187	66,84672833

crash test wh18.28	
vehicle data	dummy data
Mercedes A-Class 2005	biofidelic D05
van	169 cm
1257 kg	78 kg
72 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	0	0	0	0
0,04	0	0	0	0
0,06	4,727672	5,692872	5,014454	5,144999333
0,08	13,309049	14,104003	13,47594	13,629664
0,1	43,670235	44,506712	43,766094	43,98101367
0,12	59,110087	56,594011	56,594011	57,432703
0,14	50,533047	49,53915	51,028211	50,36680267
0,16	47,846521	49,426227	50,852705	49,375151
0,18	52,331085	53,950387	52,373778	52,88508333
0,2	56,987577	56,889441	54,007321	55,96144633

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	3,342969	0	0	1,114323
0,02	1,671485	1,05714	1,671485	1,466703333
0,04	18,925458	20,675123	19,791395	19,79732533
0,06	43,746939	43,497156	43,497156	43,580417
0,08	48,473054	45,253729	47,211675	46,979486
0,1	45,154841	45,407811	44,450179	45,004277
0,12	50,038566	50,122248	48,588192	49,583002
0,14	53,675221	53,304376	54,419597	53,79973133
0,16	55,708354	54,976347	56,38629	55,69033033
0,18	55,663199	55,133662	56,594011	55,79695733
0,2	52,98369	54,02801	55,133662	54,048454

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	47,864036	52,347099	47,840682	49,35060567
0,02	62,795344	63,542803	61,295874	62,54467367
0,04	77,870377	76,377886	76,304692	76,850985
0,06	91,517409	91,794795	91,590647	91,63428367
0,08	95,684284	95,57911	97,866817	96,376737
0,1	81,399757	86,430465	87,971556	85,26725933
0,12	83,131789	80,039509	81,694399	81,621899
0,14	75,383772	73,988452	73,716073	74,36276567
0,16	61,568746	64,198938	63,538406	63,10203
0,18	55,260202	54,357955	54,239612	54,61925633
0,2	51,551144	53,90376	51,551144	52,33534933

crash test wh18.29	
vehicle data	dummy data
Mercedes A-Class 2007	biofidelic D06
van	172 cm
1195 kg	78 kg
96 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	3,964918	2,654647	3,681334	3,433633
0,04	12,709934	13,046679	12,581331	12,77931467
0,06	29,97971	30,65028	29,97971	30,20323333
0,08	75,229021	90,593721	87,578607	84,46711633
0,1	97,412843	102,661033	96,790372	98,95474933
0,12	100,459268	86,146351	89,164299	91,923306
0,14	97,231817	90,608679	95,759969	94,53348833
0,16	96,49589	86,39769	92,177533	91,690371
0,18	84,785834	83,461603	85,66361	84,63701567
0,2	70,819519	88,462375	82,580114	80,62066933

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	0	0	1,472533	0,490844333
0,02	8,8352	11,068516	10,412384	10,10536667
0,04	38,462449	37,61451	36,144622	37,40719367
0,06	60,789953	58,346523	59,496546	59,54434067
0,08	66,712427	67,004315	69,47877	67,73183733
0,1	73,024148	73,836208	73,338964	73,39977333
0,12	81,755447	84,929569	87,131806	84,60560733
0,14	95,502051	97,524076	98,816208	97,28077833
0,16	100,229671	97,357178	93,711452	97,09943367
0,18	94,245014	90,79694	89,039579	91,360511
0,2	89,694692	89,340435	89,340435	89,45852067

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	60,391825	65,208461	78,266224	67,95550333
0,02	87,813502	83,963462	88,401075	86,726013
0,04	141,073388	139,939104	133,156434	138,0563087
0,06	131,39834	138,302561	136,318741	135,3398807
0,08	94,89561	96,552051	95,935297	95,79431933
0,1	87,206432	87,206432	85,540123	86,65099567
0,12	86,479218	84,346734	85,916362	85,58077133
0,14	85,406937	86,479218	82,284186	84,723447
0,16	82,780086	81,243286	82,284186	82,10251933
0,18	82,858632	79,738058	83,898875	82,16518833
0,2	84,398134	84,346734	84,346734	84,36386733

crash test wh18.34	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D07
trapezium	169 cm
2542 kg	78 kg
27 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	1,570709	0	0,523569667
0,02	0,785354	1,110659	0	0,632004333
0,04	1,756106	1,570709	1,570709	1,632508
0,06	7,024423	5,981081	6,331729	6,445744333
0,08	12,013611	12,952396	11,962161	12,30938933
0,1	18,864859	18,06315	18,848504	18,592171
0,12	26,329876	25,094499	25,375576	25,59998367
0,14	23,323834	23,350263	23,350263	23,34145333
0,16	19,696587	19,633859	18,848504	19,39298333
0,18	20,614617	19,633859	21,146313	20,46492967
0,2	21,905615	22,666693	22,666693	22,41300033

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	2,221318	0	0	0,740439333
0,02	1,570709	3,141417	3,141417	2,617847667
0,04	7,892714	9,424252	7,240609	8,185858333
0,06	18,06315	15,726709	14,942386	16,24408167
0,08	19,774717	18,913837	22,045947	20,24483367
0,1	18,864859	20,43431	21,204567	20,167912
0,12	21,219106	21,262662	21,219106	21,23362467
0,14	21,219106	20,479536	19,64956	20,44940067
0,16	20,43431	19,633859	19,696587	19,92158533
0,18	22,829374	22,003941	21,989922	22,27441233
0,2	22,788813	23,612929	23,612929	23,33822367

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	0	0	0	0
0,02	0	4,777124	4,777124	3,184749333
0,04	10,910491	12,417543	13,73809	12,35537467
0,06	34,304796	32,542492	33,439868	33,429052
0,08	37,705189	36,945059	36,339085	36,99644433
0,1	32,380989	33,733689	48,316848	38,143842
0,12	58,121528	60,477384	58,985288	59,19473333
0,14	64,399057	64,231232	46,680712	58,43700033
0,16	44,703153	42,474531	44,217612	43,798432
0,18	40,996701	39,494814	40,481951	40,32448867
0,2	35,297288	36,50842	36,032277	35,945995

crash test wh08.27	
vehicle data	dummy data
Ford Galaxy 1998	Žilina
van	168 cm
1705 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	1,970033	2,491916	3,789434	2,750461
0,04	7,527485	6,965118	7,527485	7,340029333
0,06	11,852986	11,368302	10,045236	11,08884133
0,08	18,396352	18,699753	20,340053	19,145386
0,1	27,140733	26,954197	27,47472	27,18988333
0,12	34,467131	31,372426	31,778041	32,53919933
0,14	36,840142	34,00804	35,025611	35,29126433
0,16	35,531661	36,18109	34,886829	35,53319333
0,18	33,646639	38,705005	36,138158	36,16326733
0,2	33,663937	38,805147	38,644795	37,03795967

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	0	0	0	0
0,02	7,805906	6,622359	6,167178	6,865147667
0,04	17,35419	17,554309	18,5225	17,810333
0,06	24,479195	26,290899	25,542143	25,43741233
0,08	31,28571	32,26286	29,465001	31,00452367
0,1	33,548451	34,331744	34,461501	34,11389867
0,12	39,1338	35,662493	36,28285	37,026381
0,14	42,458665	40,397685	39,400658	40,752336
0,16	39,227901	40,205084	41,196774	40,20991967
0,18	36,840142	37,482432	39,621667	37,98141367
0,2	36,28285	37,832839	38,118991	37,41156

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	12,827925	11,487167	12,70633	12,340474
0,02	44,966837	44,966837	44,668079	44,867251
0,04	71,718397	72,707292	71,840052	72,08858033
0,06	64,456514	62,126354	61,435342	62,67273667
0,08	56,333985	53,503714	53,550843	54,46284733
0,1	47,383284	49,313823	51,266297	49,32113467
0,12	48,59237	51,046285	51,946895	50,52851667
0,14	49,168011	48,484426	48,775723	48,80938667
0,16	48,835363	48,29595	48,484426	48,53857967
0,18	53,782259	53,260159	51,266297	52,76957167
0,2	58,027418	54,836317	51,266297	54,71001067

crash test wh08.28	
vehicle data	dummy data
BMW 523i 1998	Žilina
trapezium	168 cm
1550 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	4,721993	4,842574	5,333683	4,966083333
0,04	12,477825	13,598278	12,477825	12,85130933
0,06	11,229187	11,764206	11,177716	11,39036967
0,08	17,025389	15,697858	17,14913	16,62412567
0,1	17,537043	15,200176	15,500703	16,07930733
0,12	18,235574	19,100489	17,46015	18,26540433
0,14	25,421152	26,509374	25,900556	25,943694
0,16	29,028972	27,652141	28,628921	28,436678
0,18	30,286326	30,627129	31,001405	30,63828667
0,2	29,4758	32,949113	32,193732	31,53954833

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	3,720169	5,112883	1,240056	3,357702667
0,02	12,353973	10,393565	9,027746	10,59176133
0,04	24,315855	20,980417	23,933406	23,07655933
0,06	28,447063	26,487612	29,246667	28,06044733
0,08	28,447063	29,325429	28,628921	28,800471
0,1	28,236818	32,455377	31,395716	30,69597033
0,12	29,305758	30,689826	28,849635	29,615073
0,14	28,528032	26,919504	23,764149	26,403895
0,16	25,421152	24,212872	25,541847	25,05862367
0,18	26,159015	25,541847	31,773038	27,82463333
0,2	28,762889	27,7285	34,9203	30,470563

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	14,029635	8,768522	9,685149	10,82776867
0,02	29,928802	30,677297	31,279174	30,62842433
0,04	51,997407	57,032476	59,020032	56,01663833
0,06	62,265765	62,413768	59,719362	61,46629833
0,08	69,071242	64,366563	61,354593	64,93079933
0,1	53,138254	52,17823	54,138076	53,15152
0,12	44,710863	45,482348	46,070216	45,42114233
0,14	47,219934	46,868548	46,868548	46,98567667
0,16	44,989438	42,759469	44,68506	44,14465567
0,18	45,198305	42,853766	44,235432	44,09583433
0,2	46,032651	44,035093	44,035093	44,70094567

crash test wh08.29	
vehicle data	**dummy data**
Toyota Avensis 1998	Žilina
trapezium	168 cm
1329 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	3,594474	3,947188	4,35894	3,966867333
0,04	13,192546	13,575841	13,975824	13,58140367
0,06	19,73594	16,689674	17,35931	17,928308
0,08	20,676267	20,408033	20,676267	20,58685567
0,1	29,621554	28,683017	29,38973	29,23143367
0,12	30,512579	29,902455	31,733561	30,71619833
0,14	28,356571	30,231063	30,212202	29,59994533
0,16	29,595886	28,38336	27,123676	28,36764067
0,18	28,463577	29,819737	28,416811	28,90004167
0,2	26,614532	33,493	29,692029	29,933187

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	3,698683	3,898754	0	2,532479
0,02	11,712497	9,328539	9,959009	10,33334833
0,04	24,324291	21,184627	23,819124	23,10934733
0,06	29,305565	31,214393	28,463577	29,66117833
0,08	29,902455	30,356504	28,782209	29,68038933
0,1	25,032614	25,543536	28,175076	26,25040867
0,12	23,457415	26,507229	26,62167	25,52877133
0,14	26,073603	26,856164	25,956746	26,29550433
0,16	29,997615	27,985616	31,122953	29,70206133
0,18	34,608994	33,379349	36,625472	34,87127167
0,2	34,521043	37,314155	37,068933	36,301377

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	22,498211	23,938479	23,715197	23,38396233
0,02	39,783536	41,352535	43,589399	41,57515667
0,04	61,635472	60,41497	61,025158	61,0252
0,06	63,646493	59,604419	59,846197	61,03236967
0,08	57,722635	58,730953	57,722635	58,058741
0,1	54,596483	57,090465	53,775964	55,154304
0,12	54,610402	52,107111	52,662056	53,126523
0,14	52,015871	49,26952	52,863716	51,38303567
0,16	48,632956	51,16883	52,831358	50,87771467
0,18	48,323326	54,89496	51,313443	51,51057633
0,2	48,632956	55,411711	50,728772	51,59114633

crash test wh10.12	
vehicle data	dummy data
Fiat Punto 1996	Žilina
trapezium	168 cm
1012 kg	75 kg
55 km/h	
late or unbraked	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	3,643993	4,192223	4,418991	4,085069
0,04	13,720238	13,974077	13,720238	13,804851
0,06	24,997589	24,38066	25,652996	25,010415
0,08	33,333374	32,261662	31,084077	32,226371
0,1	31,625902	31,730695	32,067386	31,80799433
0,12	37,130046	37,750705	42,537238	39,13932967
0,14	49,374194	45,6206	49,386057	48,12695033
0,16	53,744817	48,136588	51,873762	51,25172233
0,18	50,554495	55,422677	52,245111	52,740761
0,2	51,382056	61,84062	50,197873	54,47351633

time	hip 1 v(res)	hip 2 v(res)	hip 3 v(res)	average hip v(res)
0	4,999518	12,498795	4,999518	7,499277
0,02	18,123252	16,873373	16,260447	17,08569067
0,04	29,431941	25,691028	31,346817	28,823262
0,06	31,027486	34,935193	32,261662	32,741447
0,08	30,641171	35,318772	30,774713	32,24488533
0,1	31,384172	28,260822	31,246986	30,29732667
0,12	38,650388	33,96017	36,536266	36,38227467
0,14	42,775287	47,827287	47,46663	46,023068
0,16	47,569368	51,267916	53,2117	50,68299467
0,18	52,454002	48,508367	50,82032	50,59422967
0,2	54,150225	47,429591	47,049288	49,54303467

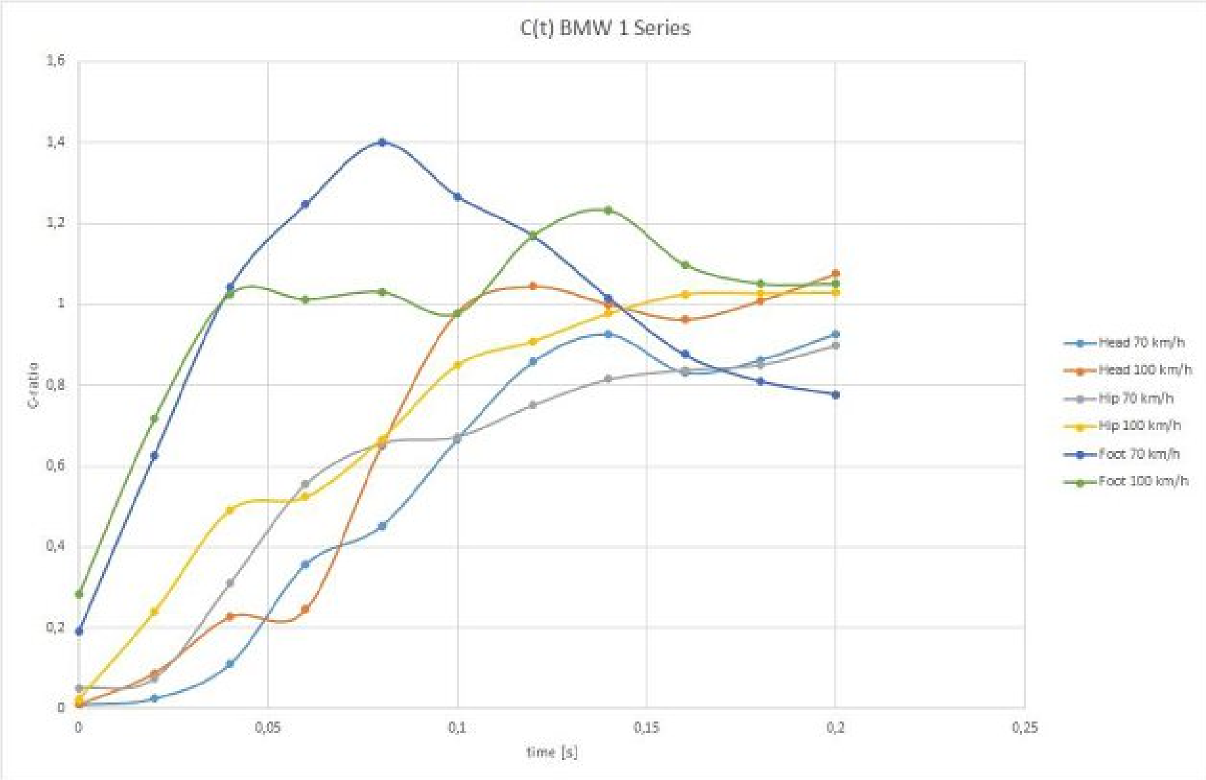
time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	11,31814	11,523319	8,749156	10,530205
0,02	25,028817	27,504449	28,129231	26,887499
0,04	61,161137	60,010486	59,841038	60,33755367
0,06	80,483891	78,224882	77,759179	78,82265067
0,08	79,958101	83,095836	83,825829	82,29325533
0,1	81,295027	82,159968	81,482171	81,645722
0,12	73,904242	72,557628	73,830222	73,43069733
0,14	62,321877	61,501817	63,316604	62,38009933
0,16	48,809353	47,855859	46,502403	47,72253833
0,18	19,0068	19,047851	17,375123	18,47659133
0,2	6,730807	5,153385	5,589631	5,824607667

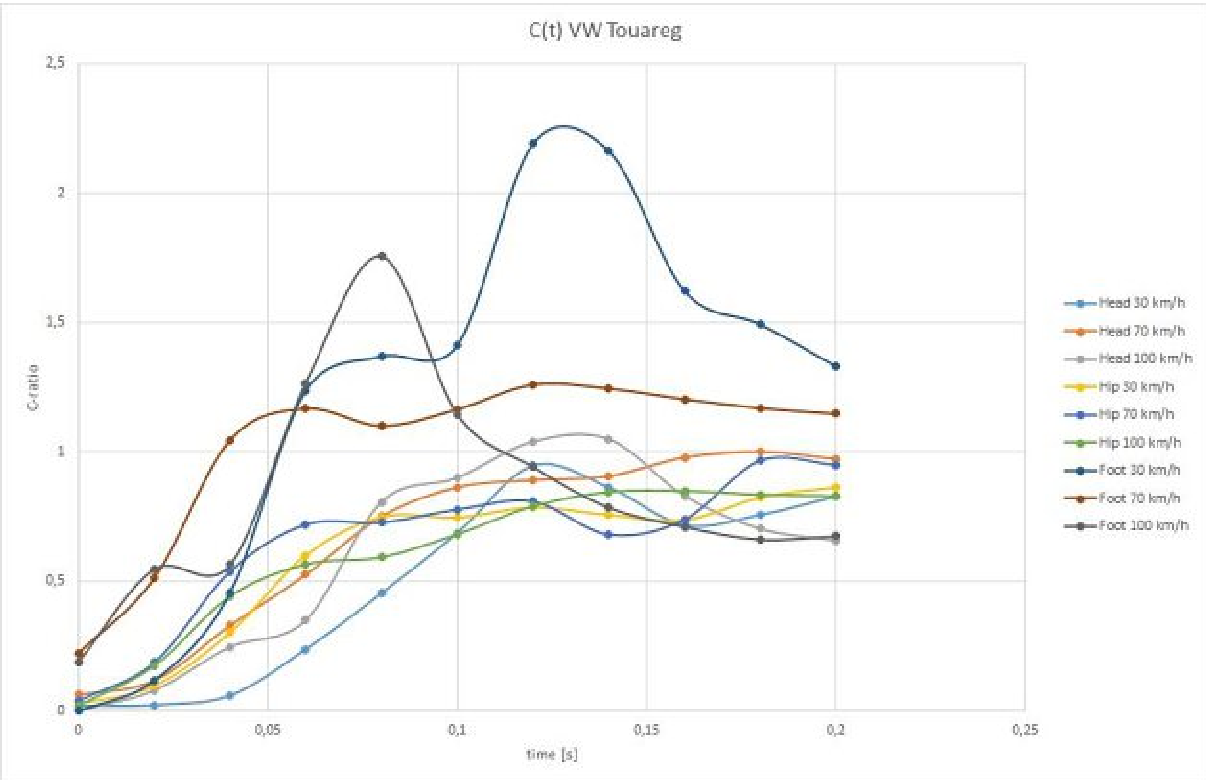
J. C(t)-Diagrams

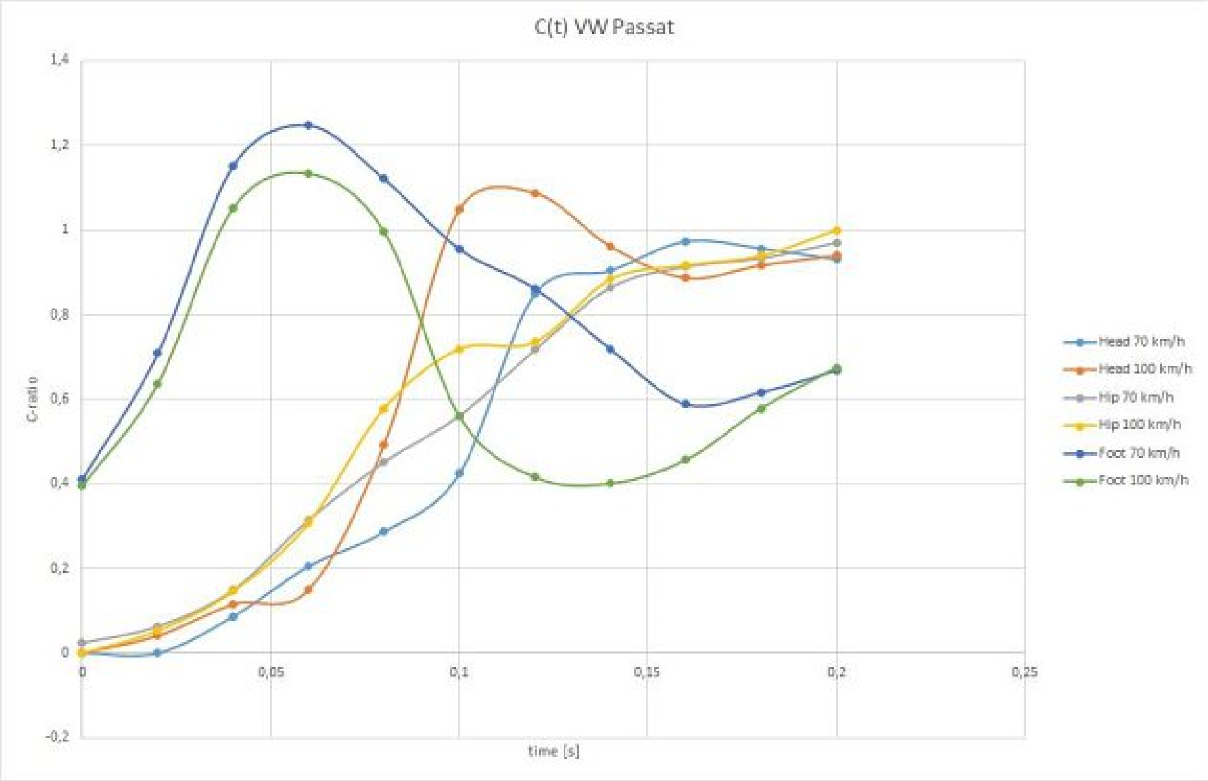
The $C(t)$-diagrams were obtained by using the measurements listed in appendix I.

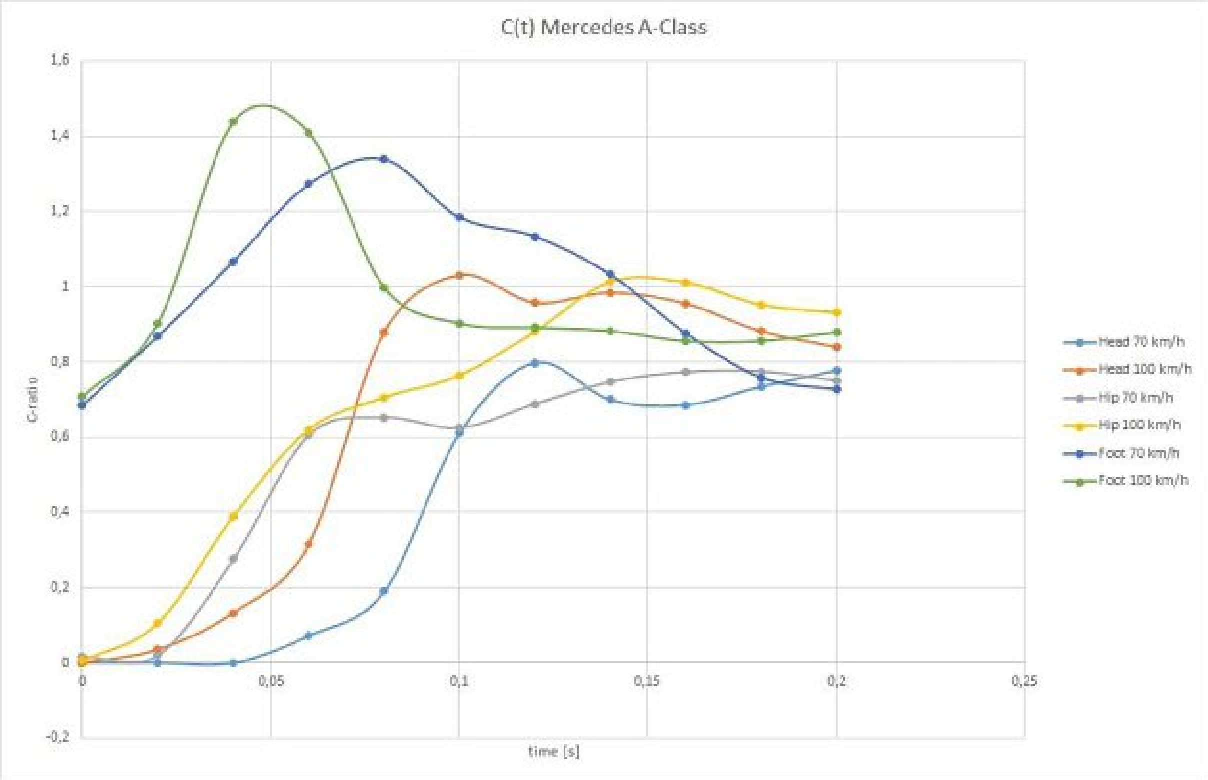
The programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998 - 2006$ FalCon GmbH) provides txt-files as data output, which have been uploaded into Excel, with which the graphs have then been created.

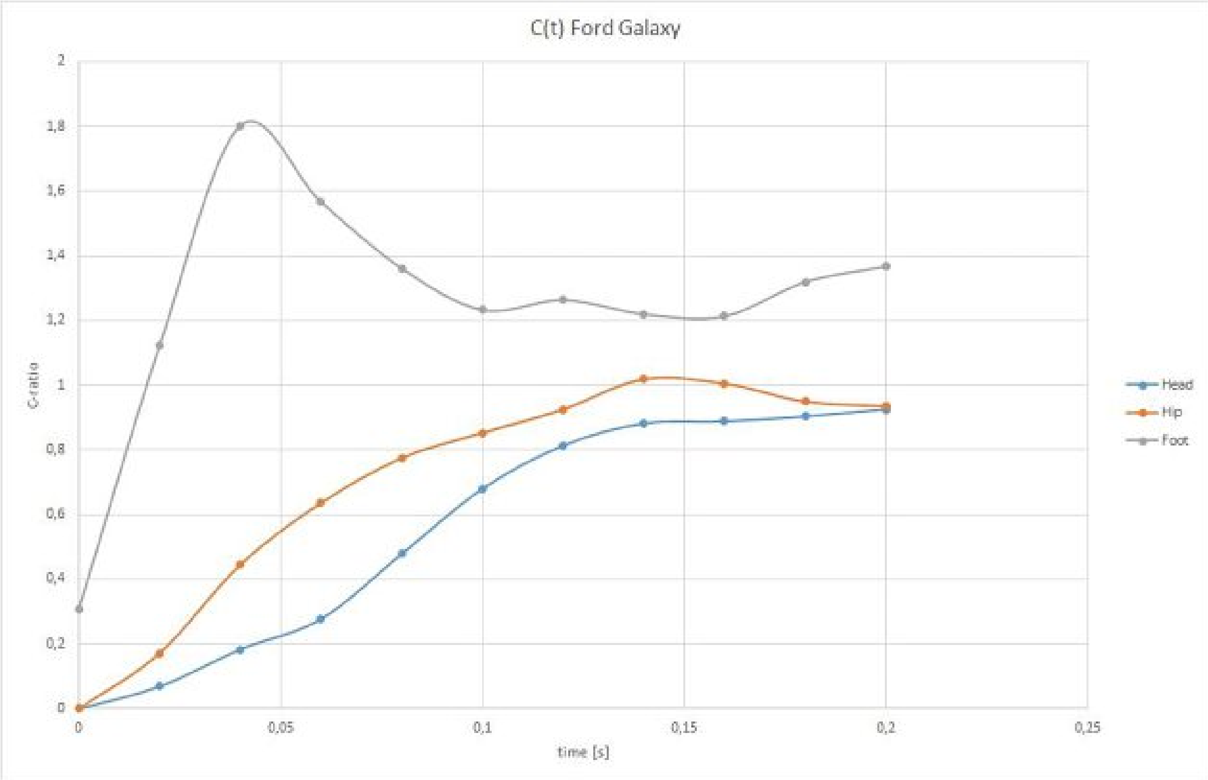
The individual $v(res)$-values have to be divided by the collision speed, in order to obtain the C-ratio.

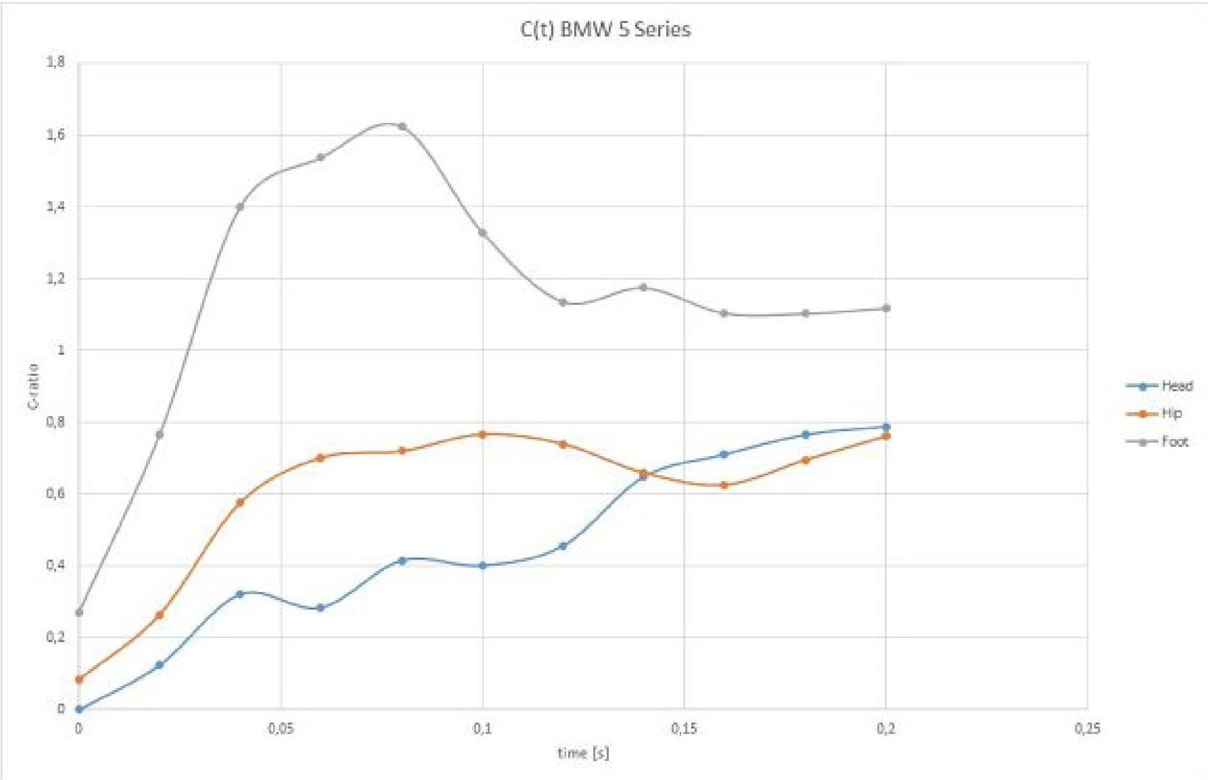

C(t) BMW 1 Series
C-ratio
time [s]
Head 70 km/h
Head 100 km/h
Hip 70 km/h
Hip 100 km/h
Foot 70 km/h
Foot 100 km/h

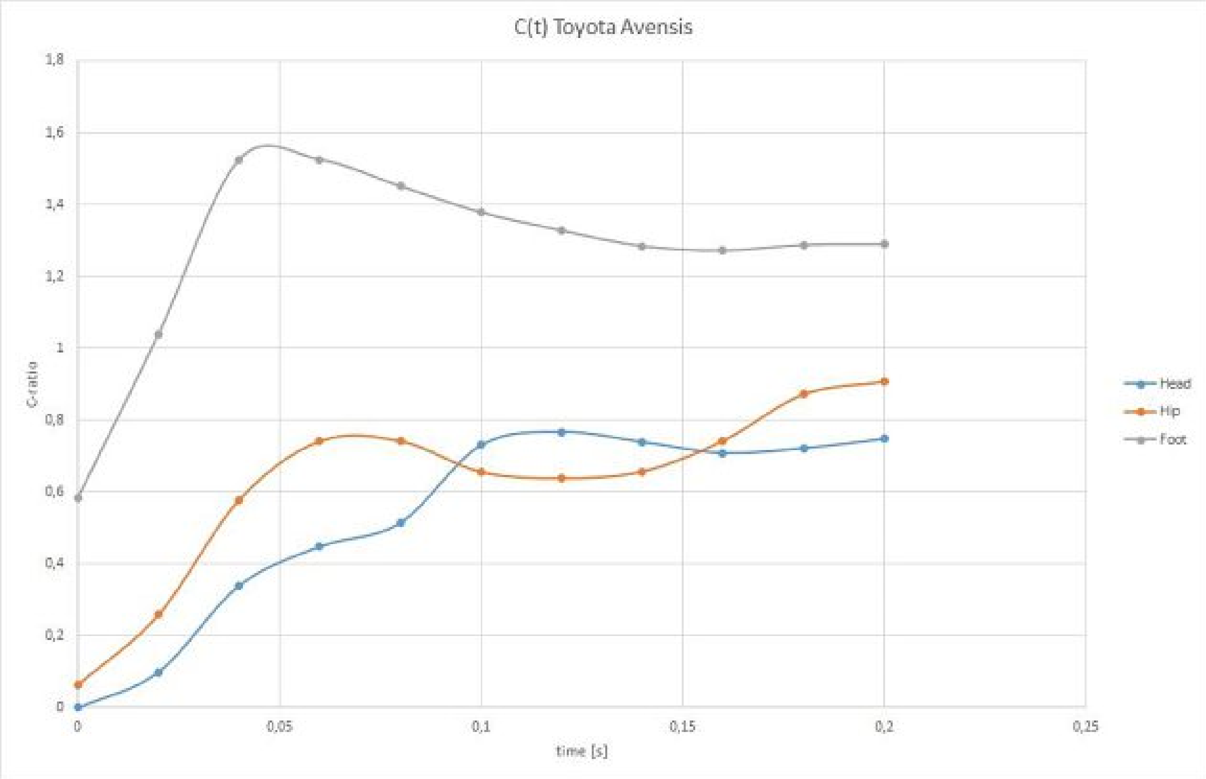

C(t) VW Touareg
C-ratio
time [s]
Head 30 km/h
Head 70 km/h
Head 100 km/h
Hip 30 km/h
Hip 70 km/h
Hip 100 km/h
Foot 30 km/h
Foot 70 km/h
Foot 100 km/h

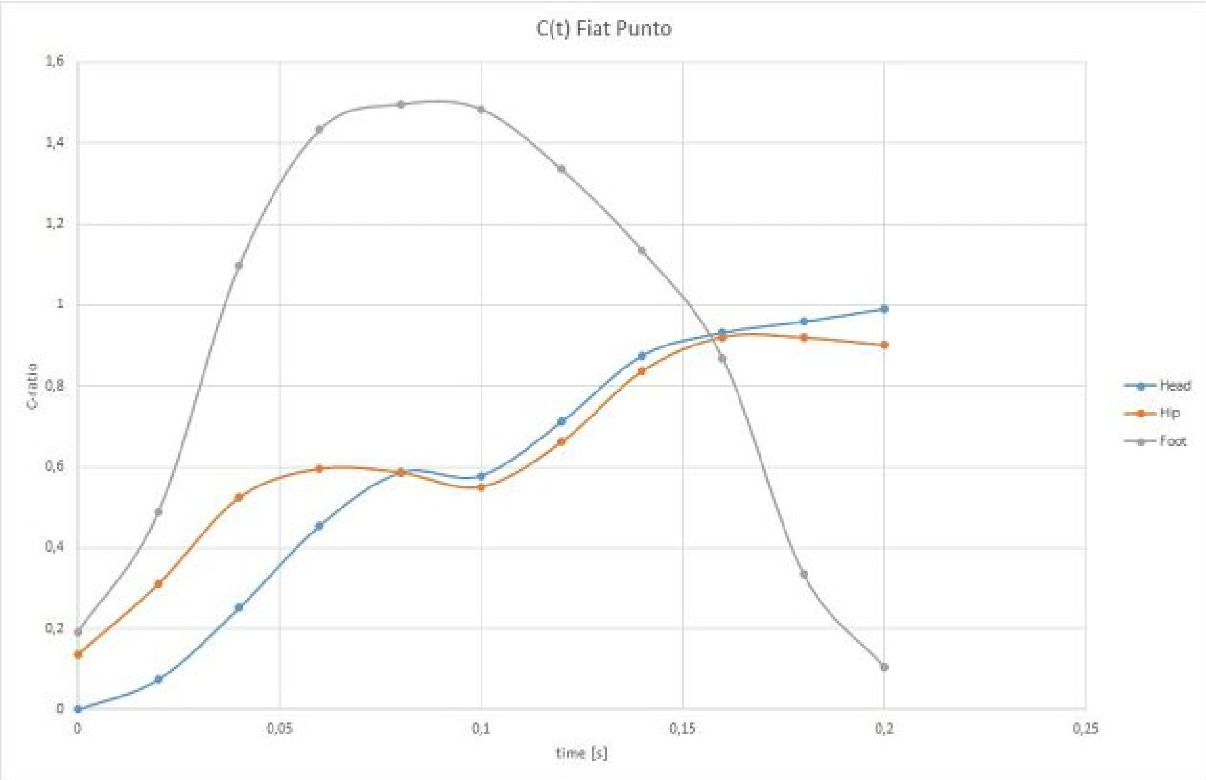

C(t) VW Passat
1,4
1,2
1
0,8
0,6
0,4
0,2
0
-0,2
C-ratio
0
0,05
0,1
0,15
0,2
0,25
time [s]
Head 70 km/h
Head 100 km/h
Hip 70 km/h
Hip 100 km/h
Foot 70 km/h
Foot 100 km/h


C(t) Mercedes A-Class
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
-0,2
C-ratio
0
0,05
0,1
0,15
0,2
0,25
time [s]
Head 70 km/h
Head 100 km/h
Hip 70 km/h
Hip 100 km/h
Foot 70 km/h
Foot 100 km/h


C(t) Ford Galaxy
C-ratio
time [s]
Head
Hip
Foot


C(t) BMW 5 Series
C-ratio
time [s]
Head
Hip
Foot


C(t) Toyota Avensis
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
C-ratio
0
0,05
0,1
0,15
0,2
0,25
time [s]
Head
Hip
Foot


C(t) Fiat Punto
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
C-ratio
0
0,05
0,1
0,15
0,2
0,25
time [s]
Head
Hip
Foot

K. Measurements for C(t) relative to the Pelvis

In order to obtain $C(t)$ relative to the pelvis of the different ATDs, the crash test videos were analysed by the programme "FalCon" (FalCon eXtra, Version $5.05.0003$, $1998 - 2006$ FalCon GmbH).

The frame rate of the videos is $500\,pictures/s$. Time is set to zero at the point of first contact between the pedestrian and vehicle. The coordinate system has its origin at the first target on the vehicle. The x-direction faces in the direction of travel, while the y-direction faces upwards. The dummy targets had to be applied manually to the dummy. Targets were applied to the head and foot. Every body region was analysed three-times and the average value was calculated , in order to reduce any errors stemming from manually placing the targets on the dummy. Every 10^{th} picture has been analysed, i.e. the time interval between the different measurements is $0.02\,s$. The value $v(res)$ has been calculated relative to the pelvis.

The three measurements are marked with "head $1\,v(res)$", "head $2\,v(res)$" and "head $3\,v(res)$", for example, and the resulting average value with "average head $v(res)$".

The orange table lists the most important vehicle and dummy data, while the blue table lists the measurements.

crash test wh18.22	
vehicle data	dummy data
BMW 1 Series 2004	biofidelic D01
pontoon	166 cm
1282 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	2,18061	4,361221	4,361221	3,634350667
0,02	5,61269	5,559488	5,171772	5,447983333
0,04	23,180207	24,71893	24,011482	23,97020633
0,06	51,746443	51,070065	51,446928	51,42114533
0,08	46,418073	45,512898	45,408301	45,77975733
0,1	19,335634	19,519205	16,642787	18,49920867
0,12	10,372236	6,215696	5,871473	7,486468333
0,14	9,283615	12,042815	11,461178	10,92920267
0,16	11,666776	7,862303	7,862303	9,130460667
0,18	6,98136	6,357517	6,215696	6,518191
0,2	7,862303	6,215696	6,215696	6,764565

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	13,96272	20,045018	17,23924	17,082326
0,02	39,349296	44,881657	45,545536	43,25882967
0,04	57,305888	55,642967	57,181287	56,71004733
0,06	55,509281	50,906864	51,798106	52,73808367
0,08	56,470023	55,003711	56,470023	55,98125233
0,1	50,112545	46,187008	45,119408	47,13965367
0,12	49,821104	47,104467	45,119408	47,34832633
0,14	40,890081	39,326631	40,119677	40,11212967
0,16	33,115498	33,472548	34,140659	33,576235
0,18	30,499328	30,722627	31,221591	30,81451533
0,2	31,87162	32,288502	32,935521	32,36521433

crash test wh18.23	
vehicle data	dummy data
BMW 1 Series 2004	biofidelic D02
pontoon	171 cm
1315 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	1,487884	1,487884	2,104186	1,693318
0,02	24,830286	26,417801	24,830286	25,35945767
0,04	60,374005	59,40367	59,978528	59,91873433
0,06	52,604649	49,977185	49,44837	50,67673467
0,08	26,781915	25,294031	23,852598	25,30951467
0,1	27,445313	24,763328	23,348406	25,18568233
0,12	25,792376	25,173399	25,392303	25,45269267
0,14	3,793375	7,364651	8,707619	6,621881667
0,16	14,290661	12,625116	10,729285	12,548354
0,18	11,257886	11,059494	9,699818	10,67239933
0,2	16,635051	14,367908	14,310012	15,10432367

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	28,620023	29,232285	23,098174	26,983494
0,02	50,893468	48,178507	48,011649	49,02787467
0,04	54,389238	50,637269	52,160898	52,39580167
0,06	52,651972	53,739195	54,708835	53,70000067
0,08	45,086818	45,191037	47,982822	46,08689233
0,1	20,962804	23,110151	22,772406	22,281787
0,12	18,657972	26,967259	37,382627	27,669286
0,14	15,903665	37,025602	26,967259	26,63217533
0,16	12,625116	24,289452	12,99239	16,63565267
0,18	20,843659	12,647015	10,415189	14,63528767
0,2	18,116173	21,041859	22,367803	20,50861167

crash test wh18.24	
vehicle data	dummy data
VW Touareg 2003	biofidelic D07
trapezium	170 cm
2542 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	4,546025	6,776814	4,791931	5,37159
0,02	19,077664	20,513159	21,133448	20,24142367
0,04	55,232072	54,893238	54,240976	54,788762
0,06	51,976439	49,706902	45,793665	49,159002
0,08	12,969235	11,979828	12,217075	12,38871267
0,1	14,88587	11,263587	10,848195	12,33255067
0,12	9,643575	8,195463	9,248551	9,029196333
0,14	18,24713	18,1841	17,442892	17,95804067
0,16	17,492189	17,736619	18,713089	17,98063233
0,18	8,160364	7,462192	8,86831	8,163622
0,2	5,463642	3,388407	5,463642	4,771897

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	18,309943	16,320729	17,277553	17,30274167
0,02	24,398883	28,156418	26,776992	26,44409767
0,04	34,861092	42,43633	35,610529	37,63598367
0,06	41,166007	31,239568	33,449258	35,28494433
0,08	32,367712	26,301111	30,767407	29,81207667
0,1	24,922649	31,514006	30,645888	29,02751433
0,12	34,926899	32,588654	34,128845	33,881466
0,14	44,107897	43,193883	43,187237	43,496339
0,16	36,784119	36,01926	34,053068	35,61881567
0,18	31,147552	30,953426	33,926398	32,00912533
0,2	27,859217	25,894169	33,234037	28,99580767

crash test wh18.25	
vehicle data	dummy data
VW Touareg 2003	biofidelic D08
trapezium	173 cm
2494 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	3,362968	3,362968	3,362968	3,362968
0,02	20,52513	20,52513	20,648735	20,56633167
0,04	56,498869	55,161907	56,177679	55,94615167
0,06	35,094311	33,503335	34,030847	34,20949767
0,08	21,703525	20,974788	20,52513	21,06781433
0,1	26,103654	25,445473	25,21105	25,58672567
0,12	22,205779	27,113117	24,997059	24,771985
0,14	22,870657	24,551972	25,132423	24,18501733
0,16	9,775774	12,783704	10,766752	11,10874333
0,18	18,5726	18,188032	18,496326	18,418986
0,2	18,603022	19,781573	19,781573	19,38872267

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	13,865874	21,055512	15,337495	16,75296033
0,02	33,972639	39,883443	38,417406	37,424496
0,04	16,9655	9,08624	14,600861	13,550867
0,06	73,790147	68,533631	69,247756	70,52384467
0,08	113,10028	116,156361	113,220211	114,1589507
0,1	47,79676	46,804498	46,507554	47,03627067
0,12	27,331231	25,367573	25,367573	26,02212567
0,14	34,435548	34,835547	34,047459	34,439518
0,16	34,047459	34,664684	35,35118	34,68777433
0,18	46,410181	45,778387	47,470296	46,55295467
0,2	52,617291	51,443523	51,443523	51,834779

crash test wh18.26	
vehicle data	**dummy data**
VW Passat Variant 2006	biofidelic D03
trapezium	171 cm
1687 kg	78 kg
75 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	4,466671	4,466671	4,466671	4,466671
0,04	8,964307	8,964307	9,056567	8,995060333
0,06	29,365508	30,385769	30,009545	29,920274
0,08	44,666711	44,53002	45,117309	44,77134667
0,1	18,38644	16,343921	17,363296	17,36455233
0,12	12,655568	11,65241	12,003818	12,103932
0,14	7,023082	7,062427	6,65852	6,914676333
0,16	6,700007	5,419643	6,001909	6,040519667
0,18	3,158413	2,684135	3,722226	3,188258
0,2	7,772236	6,65852	4,708285	6,379680333

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	31,302128	28,328071	32,755588	30,79526233
0,02	53,044005	52,986511	53,785843	53,27211967
0,04	77,038388	80,075453	78,763567	78,62580267
0,06	71,69127	71,171452	70,455356	71,106026
0,08	56,283207	52,328725	51,280333	53,29742167
0,1	43,522993	45,14187	40,808907	43,15792333
0,12	38,14873	38,839782	39,420464	38,802992
0,14	32,458152	34,542578	33,058731	33,35315367
0,16	31,275559	30,147732	32,321269	31,24818667
0,18	23,658838	22,38293	25,278272	23,77334667
0,2	23,822246	23,868728	20,897572	22,86284867

crash test wh18.27	
vehicle data	dummy data
VW Passat Variant 2006	biofidelic D04
trapezium	172 cm
1514 kg	78 kg
99 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	1,657865	1,482839	0,74142	1,294041333
0,04	16,578645	16,578645	16,923216	16,693502
0,06	38,667713	37,644843	38,453881	38,255479
0,08	20,600259	19,574038	18,23651	19,470269
0,1	28,619179	27,68187	27,701721	28,00092333
0,12	39,30223	38,553817	37,841461	38,565836
0,14	19,963332	22,585932	18,594708	20,381324
0,16	7,985333	9,28996	9,378298	8,884530333
0,18	10,615513	11,317278	11,977999	11,30359667
0,2	13,989076	13,989076	17,292727	15,090293

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	38,582322	37,189416	41,625277	39,13233833
0,02	61,017523	61,085053	63,234004	61,77886
0,04	90,96526	92,439886	87,801106	90,402084
0,06	83,543871	82,870013	80,67517	82,363018
0,08	62,968305	62,534685	62,810971	62,77132033
0,1	39,967947	40,534703	37,979212	39,493954
0,12	44,349038	41,816326	40,534703	42,23335567
0,14	48,826854	40,561816	44,608572	44,66574733
0,16	47,456643	46,803486	44,639368	46,29983233
0,18	48,572884	50,421981	44,93394	47,97626833
0,2	61,94293	62,911535	58,867032	61,240499

crash test wh18.28	
vehicle data	dummy data
Mercedes A-Class 2005	biofidelic D05
van	169 cm
1257 kg	78 kg
72 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	3,342969	3,342969	3,342969	3,342969
0,02	1,671485	1,671485	1,671485	1,671485
0,04	18,925458	18,925458	18,925458	18,925458
0,06	46,831408	47,823159	47,51252	47,389029
0,08	44,450179	42,843513	43,394265	43,56265233
0,1	9,746347	9,09386	9,00122	9,280475667
0,12	9,09386	6,727596	6,727596	7,516350667
0,14	5,692872	8,050936	7,623143	7,122317
0,16	12,441057	9,746347	10,411619	10,866341
0,18	13,537994	10,465149	12,053247	12,01879667
0,2	12,053247	13,371877	10,883919	12,10301433

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	50,830724	55,396541	50,852705	52,35999
0,02	63,577967	64,325018	62,061394	63,32145967
0,04	59,072263	57,577733	57,55832	58,06943867
0,06	47,770551	48,241954	48,085333	48,03261267
0,08	48,639916	47,758853	49,965929	48,78823267
0,1	45,154841	52,581411	53,70124	50,479164
0,12	53,867466	53,90376	55,361226	54,377484
0,14	54,940762	54,629682	53,70124	54,42389467
0,16	49,233664	51,842976	51,186744	50,75446133
0,18	42,614664	40,97695	42,49649	42,029368
0,2	39,242529	36,498121	39,242529	38,32772633

crash test wh18.29	
vehicle data	**dummy data**
Mercedes A-Class 2007	biofidelic D06
van	172 cm
1195 kg	78 kg
96 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	10,945391	10,541735	9,571467	10,35286433
0,04	43,614093	44,98463	45,416377	44,6717
0,06	40,494669	39,9081	40,494669	40,299146
0,08	19,451938	34,360866	31,796153	28,536319
0,1	26,689033	32,000086	26,678876	28,45599833
0,12	21,096322	4,656559	9,428814	11,72723167
0,14	18,640784	18,771191	18,465475	18,62581667
0,16	20,733459	27,331267	23,766707	23,943811
0,18	18,450791	21,096322	20,109653	19,88558867
0,2	27,072197	19,199487	20,510017	22,260567

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	60,391825	65,208461	78,266224	67,95550333
0,02	79,000422	75,131679	79,571323	77,90114133
0,04	102,866761	101,663476	94,875614	99,80195033
0,06	74,070772	80,989337	79,233381	78,09783
0,08	51,063161	51,333157	51,874156	51,42349133
0,1	52,693245	52,693245	53,016315	52,800935
0,12	59,60578	60,580031	60,772115	60,31930867
0,14	58,313996	59,49199	57,978373	58,59478633
0,16	56,749879	55,195455	55,185633	55,71032233
0,18	54,781409	54,394116	54,949375	54,7083
0,2	51,052544	53,092947	53,092947	52,41281267

crash test wh18.34	
vehicle data	**dummy data**
VW Touareg 2003	biofidelic D07
trapezium	169 cm
2542 kg	78 kg
27 km/h	
in-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	2,221318	3,512211	2,221318	2,651615667
0,02	1,756106	2,483509	1,570709	1,936774667
0,04	9,554248	9,456919	8,19934	9,070169
0,06	22,115779	21,146313	21,905615	21,722569
0,08	23,924322	24,958952	25,833264	24,90551267
0,1	25,545152	25,569285	26,106388	25,740275
0,12	29,15347	27,3975	27,046308	27,86575933
0,14	16,39868	15,429765	15,429765	15,75273667
0,16	2,483509	1,110659	1,756106	1,783424667
0,18	5,663271	5,553294	4,579363	5,265309333
0,2	6,476198	6,331729	6,331729	6,379885333

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	2,221318	2,221318	2,221318	2,221318
0,02	1,570709	4,777124	4,777124	3,708319
0,04	4,967017	6,71007	7,409018	6,362035
0,06	17,648644	14,901051	15,902214	16,15063633
0,08	18,334282	17,718402	17,648644	17,90044267
0,1	14,417189	15,469687	29,573571	19,820149
0,12	36,911654	39,299119	37,900976	38,03724967
0,14	44,217612	43,958802	26,713595	38,29666967
0,16	26,574702	24,660627	26,388374	25,87456767
0,18	19,396822	18,080215	19,172943	18,88332667
0,2	16,807317	17,224166	16,114124	16,71520233

crash test wh08.27	
vehicle data	dummy data
Ford Galaxy 1998	Žilina
van	168 cm
1705 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	0	0	0	0
0,02	9,344686	9,26125	10,572306	9,726080667
0,04	23,326387	22,982779	23,326387	23,211851
0,06	30,277041	30,930144	29,720739	30,309308
0,08	31,729152	31,304312	32,704919	31,91279433
0,1	24,872397	25,686086	25,450812	25,33643167
0,12	13,606069	14,768678	11,754346	13,37636433
0,14	9,198176	9,344686	9,731245	9,424702333
0,16	12,521725	11,852986	13,832381	12,73569733
0,18	12,521725	14,808044	12,521725	13,28383133
0,2	11,282631	14,206109	11,820197	12,43631233

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	12,827925	11,487167	12,70633	12,340474
0,02	37,632269	37,632269	37,461718	37,57541867
0,04	54,712321	55,61288	54,800919	55,04204
0,06	40,166454	37,89946	37,342388	38,469434
0,08	27,78375	24,684441	25,205645	25,89127867
0,1	16,588098	17,642522	19,382561	17,87106033
0,12	11,588081	14,206109	14,543593	13,44592767
0,14	9,198176	11,983242	10,443033	10,54148367
0,16	11,983242	11,704715	10,718138	11,46869833
0,18	17,708393	16,946864	15,424238	16,693165
0,2	21,759724	19,018726	16,762653	19,18036767

crash test wh08.28	
vehicle data	dummy data
BMW 523i 1998	Žilina
trapezium	168 cm
1550 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	3,720169	3,720169	3,720169	3,720169
0,02	15,844114	16,6371	16,923474	16,46822933
0,04	34,393401	35,101477	34,393401	34,62942633
0,06	33,024865	31,156027	30,739891	31,640261
0,08	15,351175	15,807677	15,807677	15,65550967
0,1	12,554612	14,996479	15,648802	14,39996433
0,12	14,633189	12,901949	14,789977	14,10837167
0,14	7,230708	6,106569	6,38358	6,573619
0,16	10,093326	9,321066	8,877451	9,430614333
0,18	14,381445	13,86425	11,764206	13,33663367
0,2	14,932254	15,085935	12,646142	14,22144367

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	11,698667	6,677907	7,842804	8,739792667
0,02	17,635413	18,361628	18,969213	18,32208467
0,04	28,528032	33,071395	35,363351	32,320926
0,06	34,050779	34,376631	31,773038	33,40014933
0,08	40,775982	35,993686	32,954946	36,57487133
0,1	25,841117	25,109225	27,01217	25,987504
0,12	23,149561	21,162859	22,226083	22,179501
0,14	26,078061	24,777862	24,777862	25,21126167
0,16	26,159015	24,149279	25,631995	25,31342967
0,18	22,949417	22,46693	23,609967	23,00877133
0,2	21,334734	21,656651	21,656651	21,54934533

crash test wh08.29	
vehicle data	dummy data
Toyota Avensis 1998	Žilina
trapezium	168 cm
1329 kg	82 kg
40 km/h	
pre-crash braking	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	3,698683	3,698683	3,698683	3,698683
0,02	14,909868	14,509444	15,112389	14,84390033
0,04	35,050864	35,6155	36,181827	35,61606367
0,06	38,797014	38,125153	38,992417	38,63819467
0,08	19,668433	19,149592	19,668433	19,495486
0,1	4,694722	3,698683	4,35894	4,250781667
0,12	7,44856	6,892089	8,586116	7,642255
0,14	3,947188	4,694722	4,969956	4,537288667
0,16	4,31513	6,286553	5,513671	5,371784667
0,18	7,894376	7,894376	7,524697	7,771149667
0,2	10,605758	3,898754	5,513671	6,672727667

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	18,859658	20,333415	20,070066	19,75437967
0,02	28,463577	29,902455	32,037467	30,13449967
0,04	37,314155	36,092443	36,703206	36,703268
0,06	34,608994	30,43152	30,605843	31,882119
0,08	28,121075	29,227659	28,121075	28,48993633
0,1	31,196126	33,538353	30,331457	31,68864533
0,12	34,871519	31,84712	32,303244	33,00729433
0,14	30,331457	27,876775	31,196126	29,80145267
0,16	23,262205	25,817291	28,443544	25,84101333
0,18	22,808546	25,521211	24,542032	24,29059633
0,2	25,74359	26,211694	24,811521	25,588935

crash test wh10.12	
vehicle data	dummy data
Fiat Punto 1996	Žilina
trapezium	168 cm
1012 kg	75 kg
55 km/h	
late or unbraked	
frontal	
complete	

time	head 1 v(res)	head 2 v(res)	head 3 v(res)	average head v(res)
0	4,999518	4,999518	4,999518	4,999518
0,02	20,240716	20,346563	21,476479	20,68791933
0,04	38,766417	38,412194	38,766417	38,64834267
0,06	42,866492	41,982742	42,431521	42,42691833
0,08	37,376412	36,208773	36,10616	36,56378167
0,1	22,713787	24,041911	24,659396	23,80503133
0,12	13,76287	13,748674	17,431226	14,98092333
0,14	12,0047	9,518798	10,605579	10,70969233
0,16	10,64234	9,457054	10,07685	10,058748
0,18	6,280567	8,148217	7,60272	7,343834667
0,2	2,794815	9,09926	3,952466	5,282180333

time	foot 1 v(res)	foot 2 v(res)	foot 3 v(res)	average foot v(res)
0	6,37316	6,730807	3,749638	5,617868333
0,02	6,987039	9,394904	10,018546	8,800163
0,04	31,865799	30,774713	30,519845	31,05345233
0,06	49,622733	47,301787	46,87048	47,93166667
0,08	50,034222	53,101493	53,686651	52,274122
0,1	53,027894	53,911693	53,035259	53,32494867
0,12	43,656413	42,59229	44,331094	43,526599
0,14	36,268047	36,87674	38,746263	37,29701667
0,16	33,26887	32,170741	31,402833	32,28081467
0,18	36,87674	36,268047	37,00361	36,71613233
0,2	54,2223	54,823993	53,686651	54,24431467

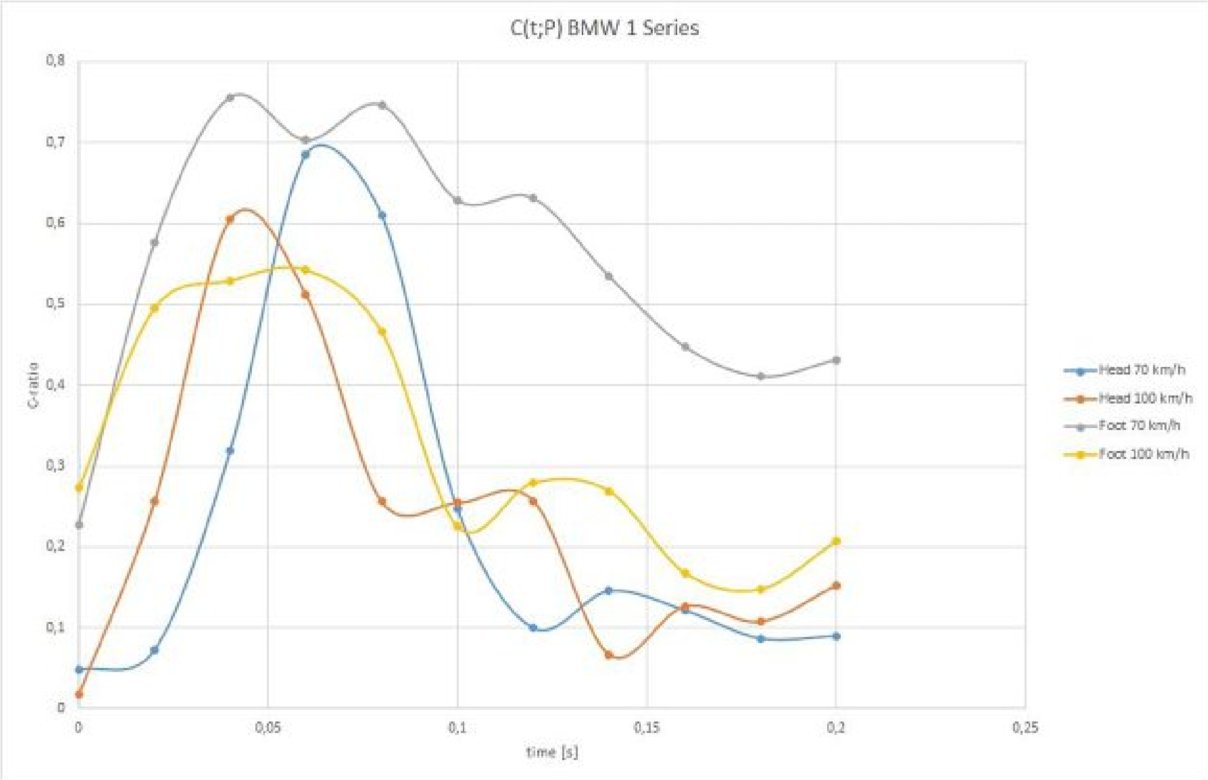
L. C(t)-Diagrams relative to the Pelvis

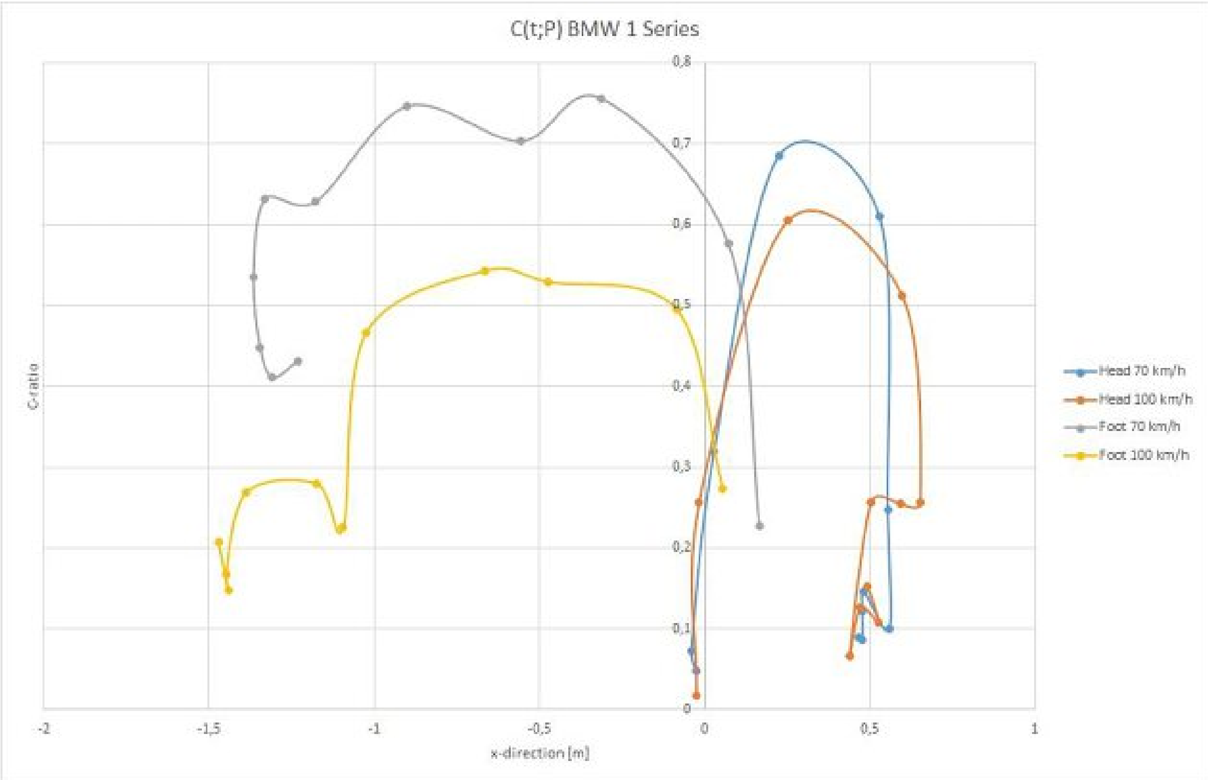
The $C(t)$-diagrams relative to the pelvis were obtained by using the measurements listed in appendix K.

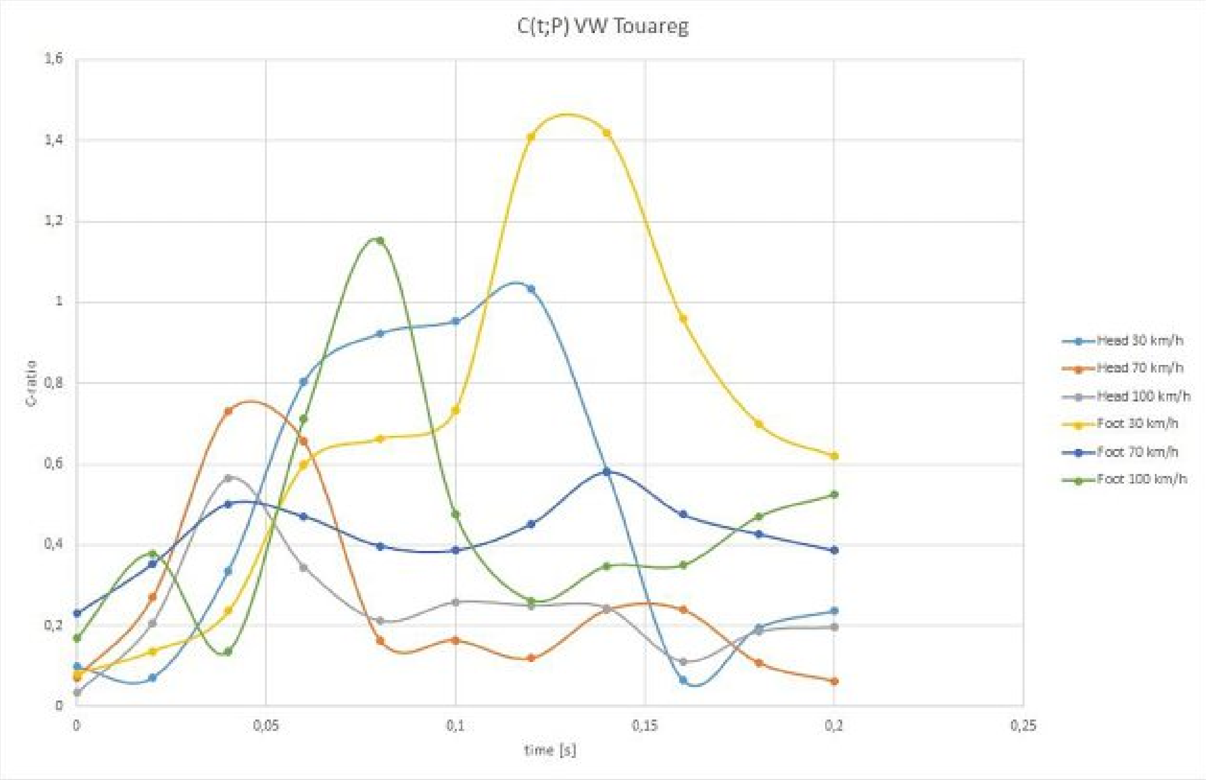
The programme “FalCon” (FalCon eXtra, Version $5.05.0003$, $1998 - 2006$ FalCon GmbH) provides txt-files as data output, which have been uploaded into Excel, with which the graphs have then been created.

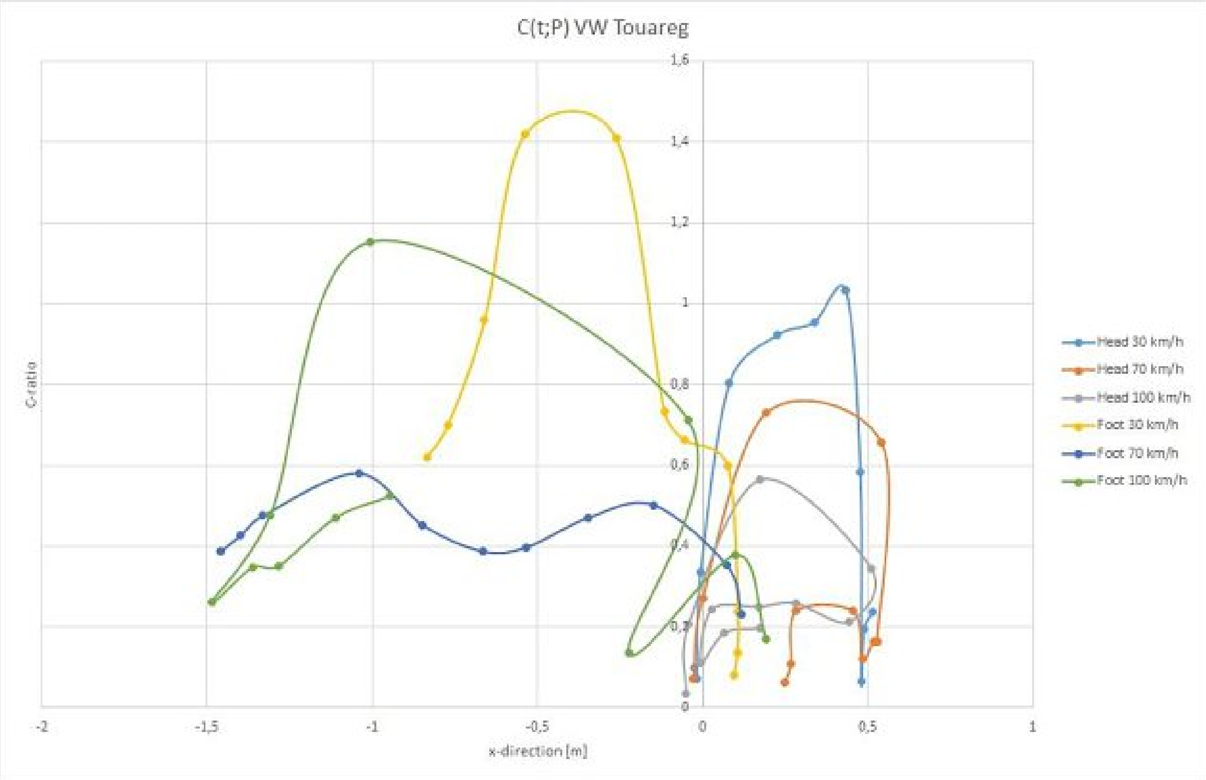
The individual $v(res)$-values have to be divided by the collision speed, in order to obtain the C-ratio. Similarly to the dummy trajectories relative to the pelvis, the $s(x)$-values have to be multiplied by -1.

The top graph on each page shows $C(t;P)$ plotted over time, while the bottom graph shows $C(t;P)$ plotted over distance.

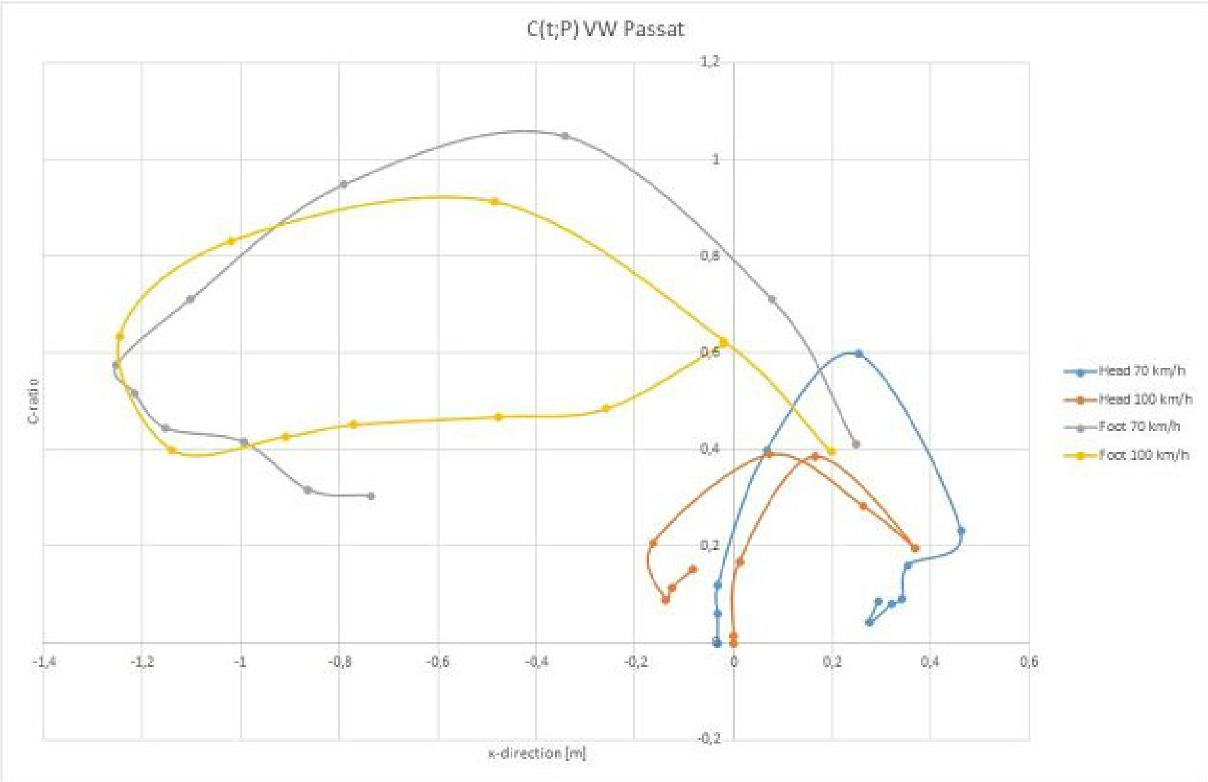

C(t;P) BMW 1 Series
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
C-ratio
0
0,05
0,1
0,15
0,2
0,25
time [s]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h

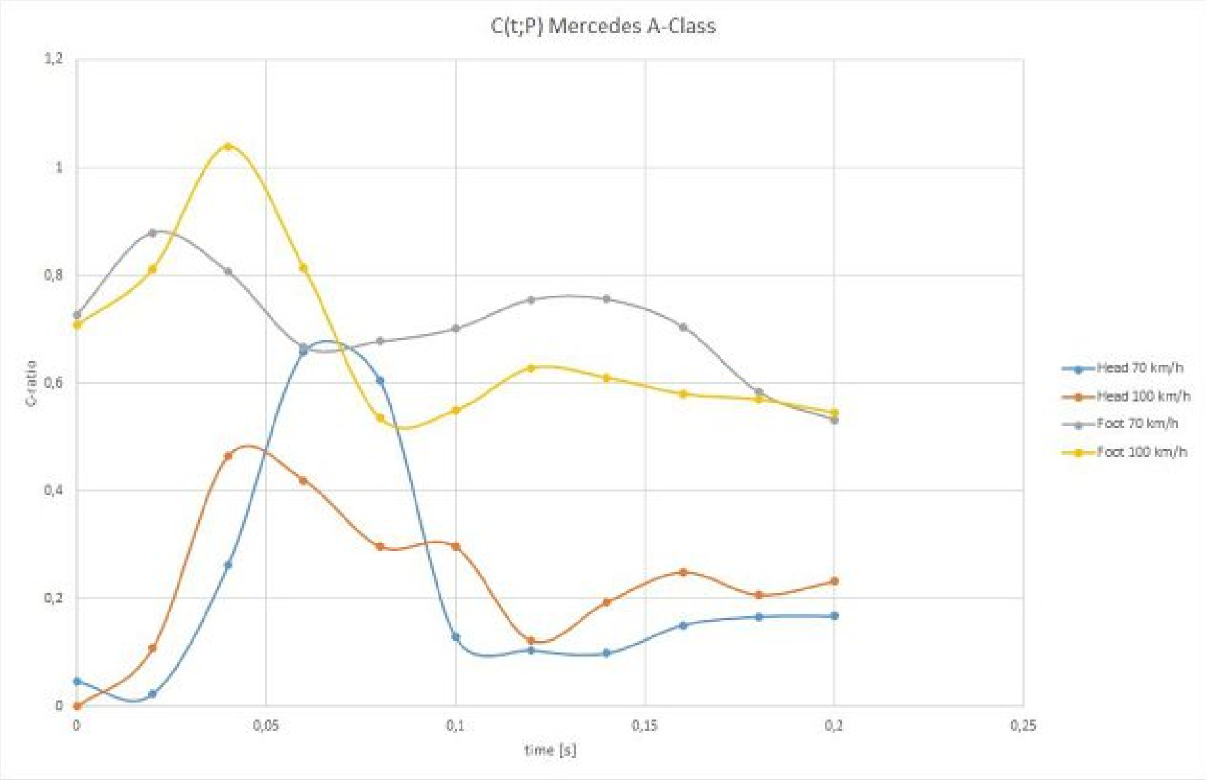

C(t;P) BMW 1 Series
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
C-ratio
-2
-1,5
-1
-0,5
0
0,5
1
x-direction [m]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h


C(t;P) VW Touareg
C-ratio
time [s]
0
0,05
0,1
0,15
0,2
0,25
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
Head 30 km/h
Head 70 km/h
Head 100 km/h
Foot 30 km/h
Foot 70 km/h
Foot 100 km/h

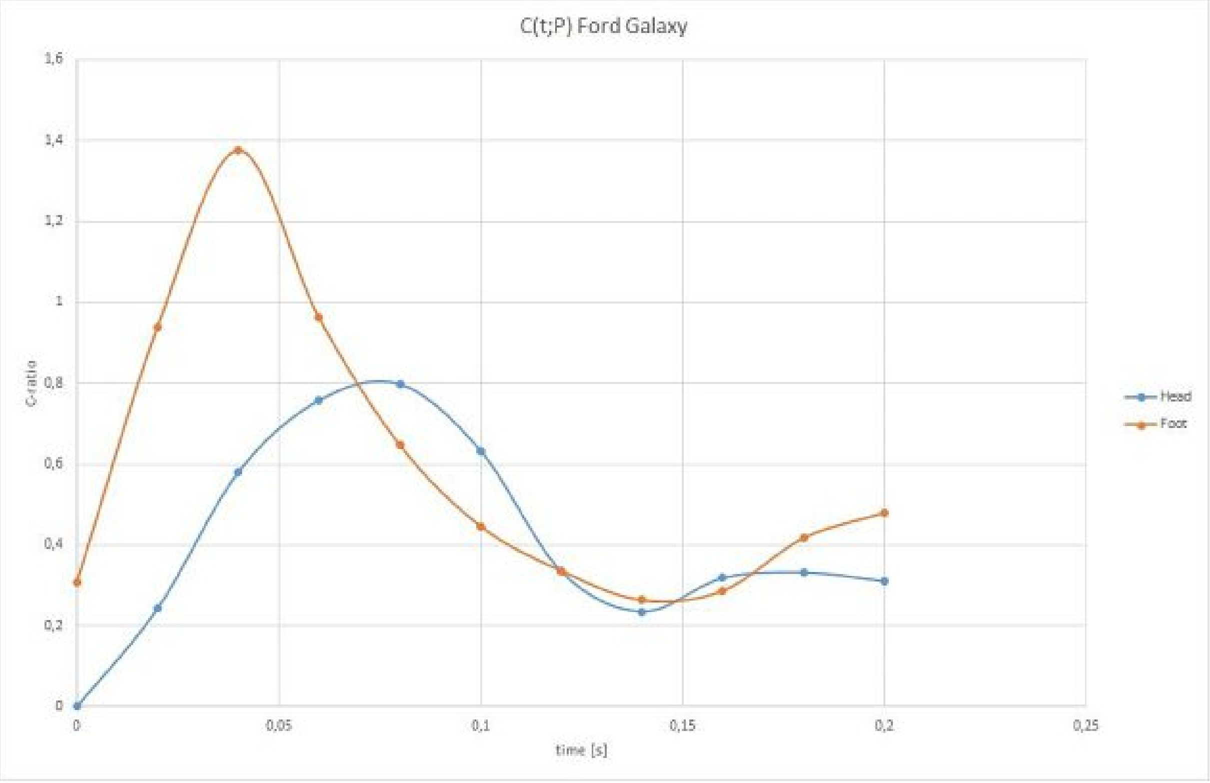

C(t;P) VW Touareg
C-ratio
x-direction [m]
-2
-1,5
-1
-0,5
0
0,5
1
Head 30 km/h
Head 70 km/h
Head 100 km/h
Foot 30 km/h
Foot 70 km/h
Foot 100 km/h

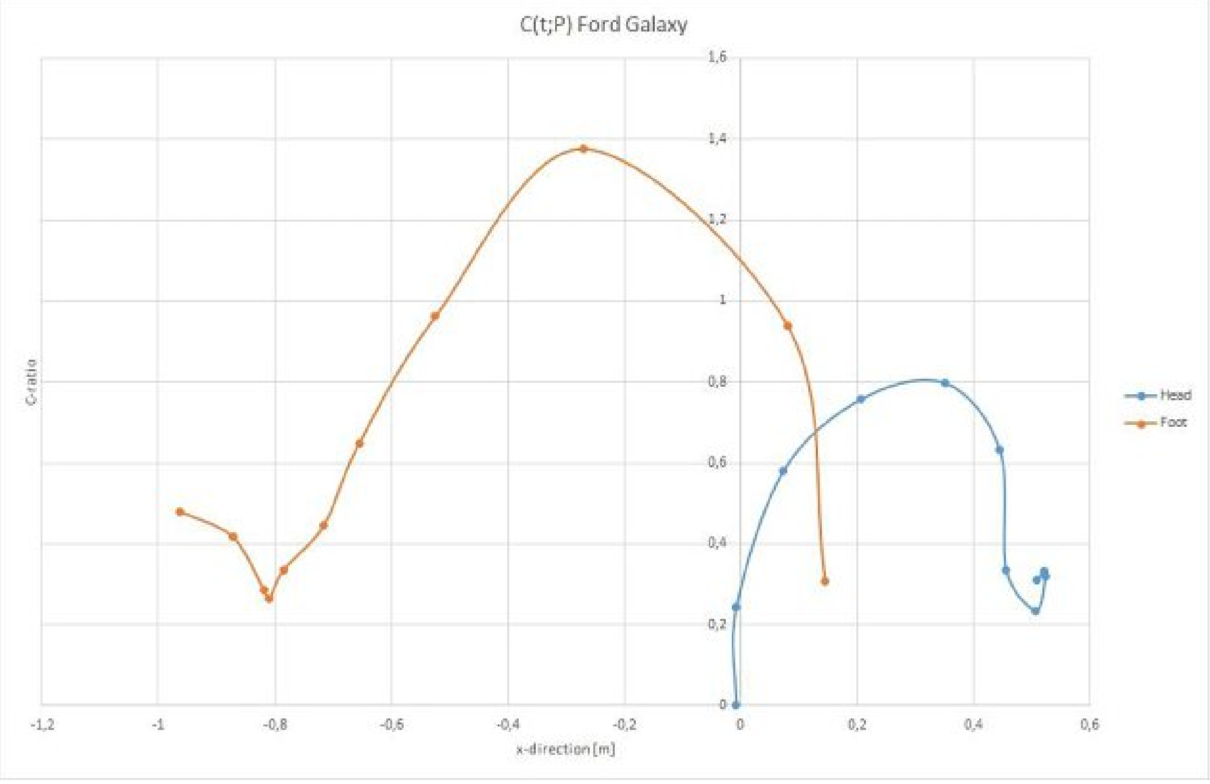

C(t;P) VW Passat
1,2
1
0,8
0,6
0,4
0,2
0
-0,2
C-ratio
0
0,05
0,1
0,15
0,2
0,25
time [s]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h

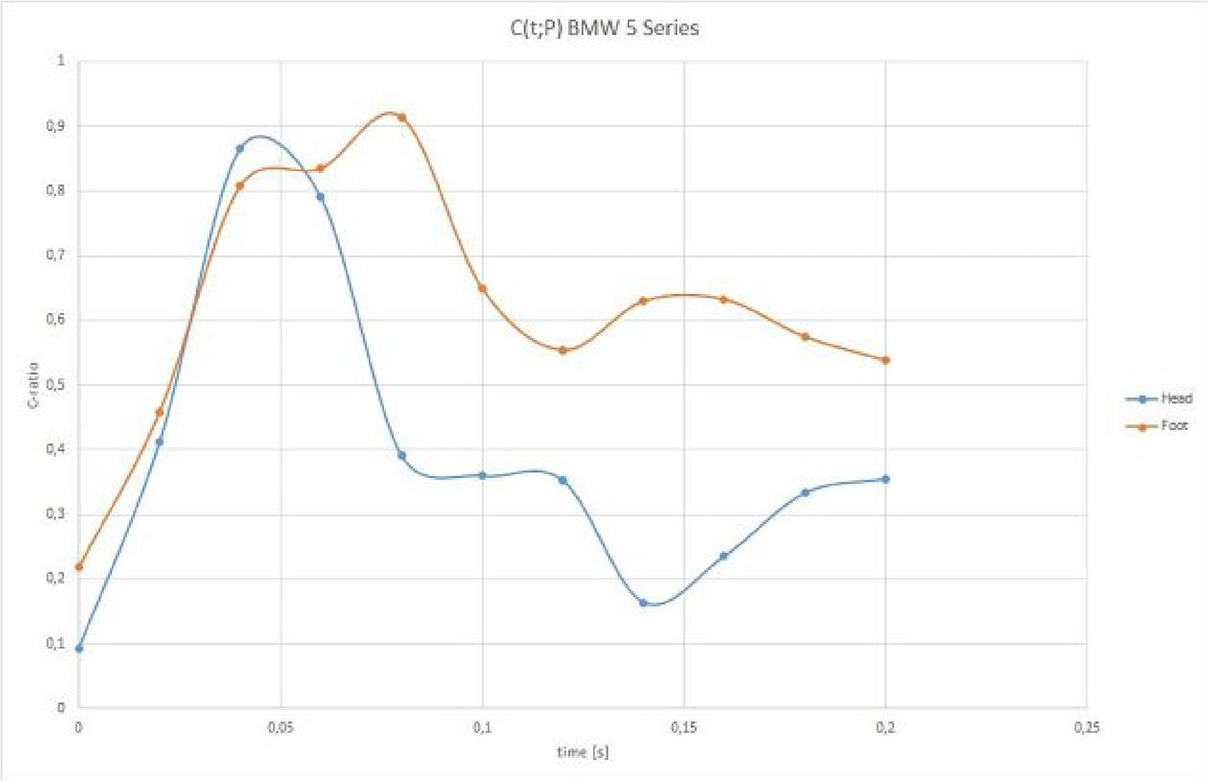

C(t;P) VW Passat
1,2
1
0,8
0,6
0,4
0,2
0
-0,2
C-ratio
-1,4
-1,2
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
0,4
0,6
x-direction [m]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h


C(t;P) Mercedes A-Class
C-ratio
time [s]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h

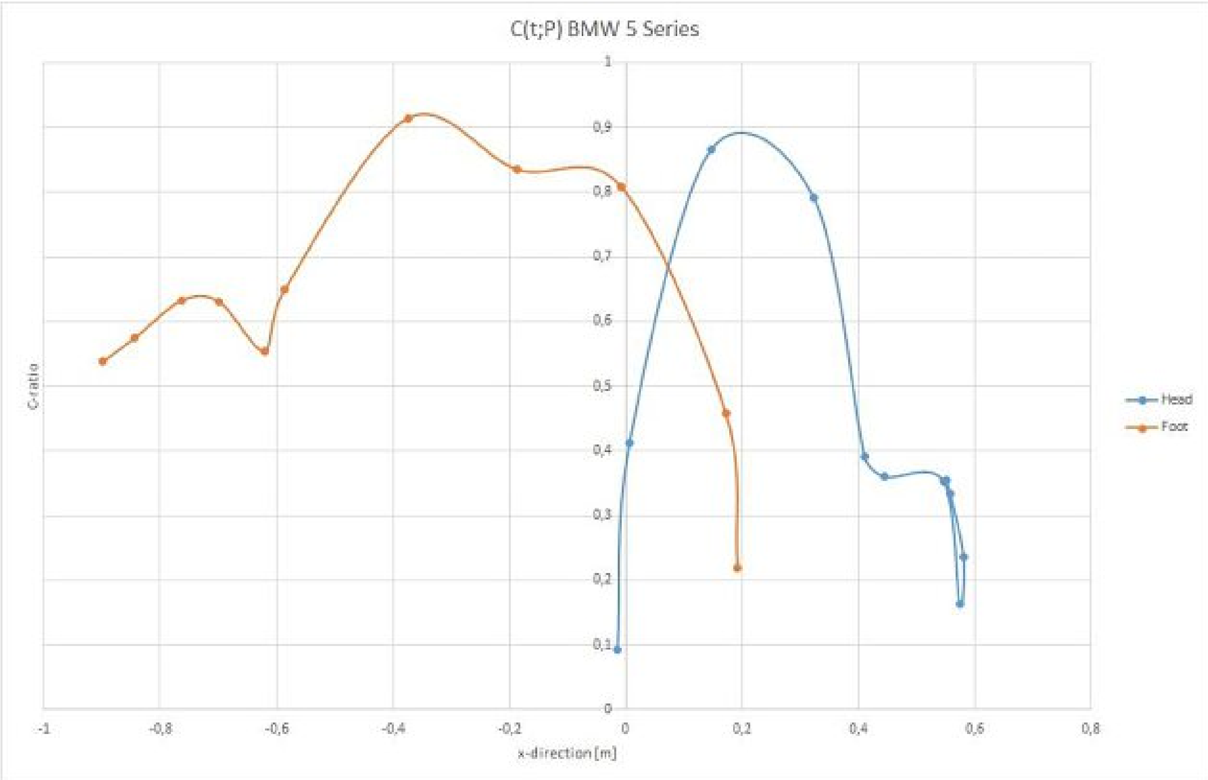

C(t;P) Mercedes A-Class
C-ratio
x-direction [m]
Head 70 km/h
Head 100 km/h
Foot 70 km/h
Foot 100 km/h


C(t;P) Ford Galaxy
C-ratio
time [s]
Head
Foot
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
0,05
0,1
0,15
0,2
0,25

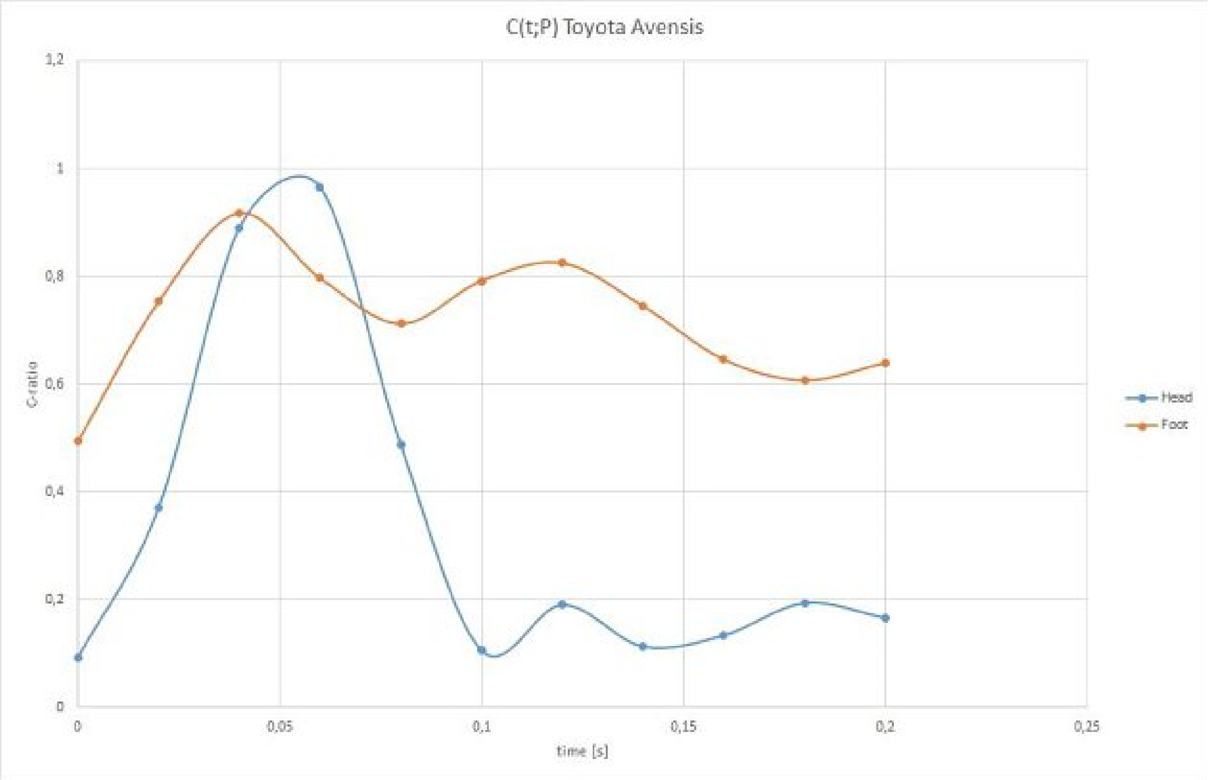

C(t;P) Ford Galaxy
C-ratio
x-direction [m]
Head
Foot
-1,2
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6

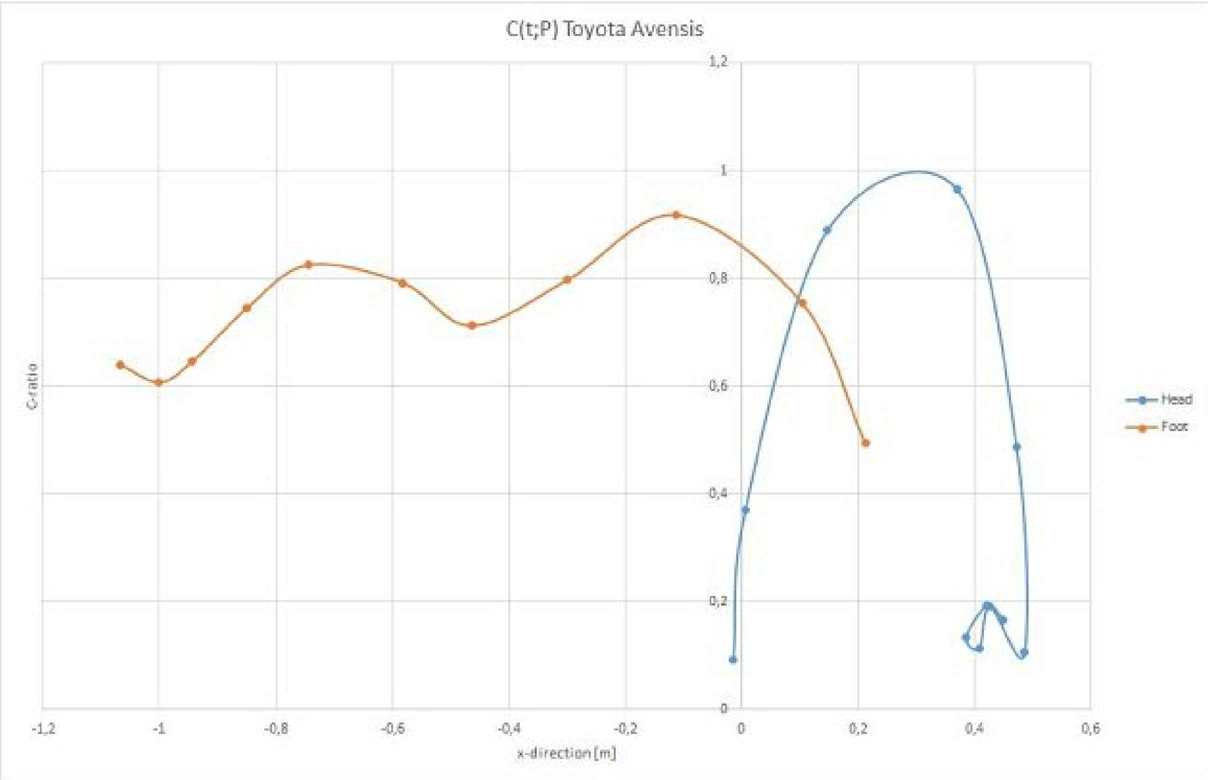


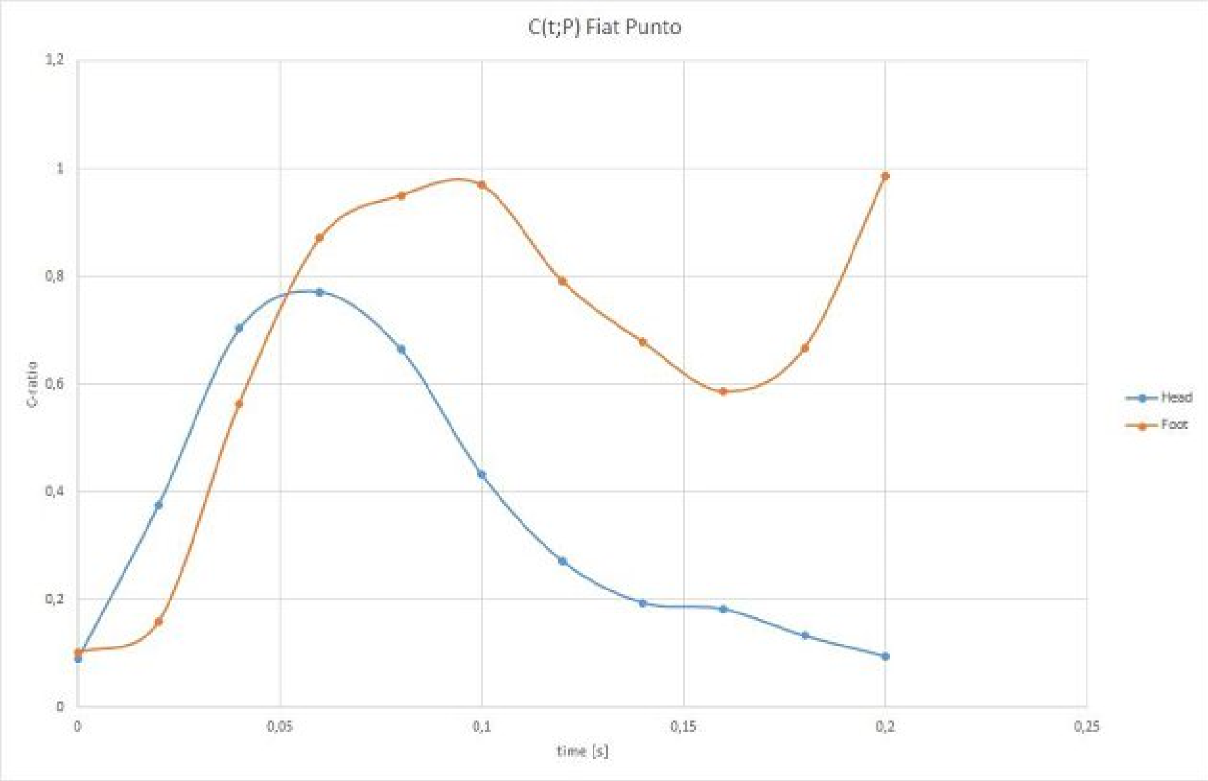
C(t;P) BMW 5 Series
C-ratio
time [s]
Head
Foot

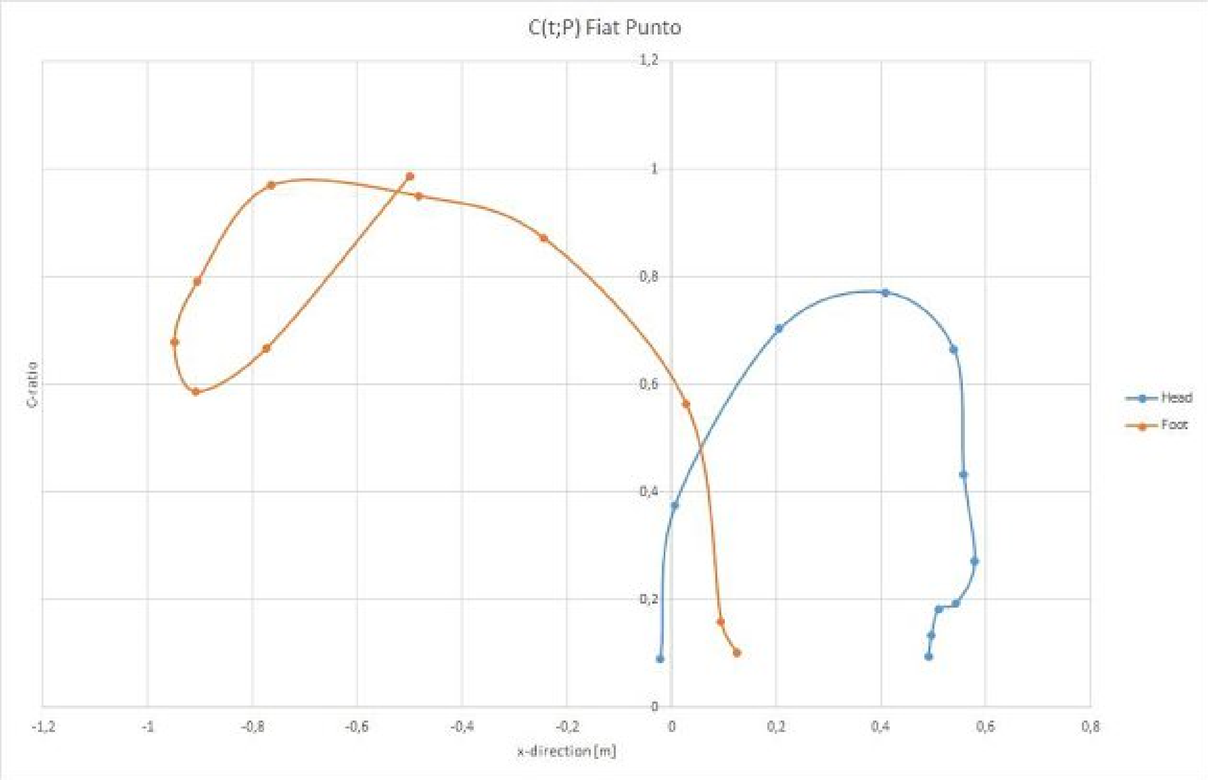


C(t;P) BMW 5 Series
C-ratio
x-direction [m]
Head
Foot


C(t;P) Toyota Avensis
C-ratio
time [s]
Head
Foot
0
0,2
0,4
0,6
0,8
1
1,2
0,05
0,1
0,15
0,2
0,25


C(t;P) Toyota Avensis
C-ratio
x-direction [m]
Head
Foot
-1,2
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
0,4
0,6
0,8
1
1,2


C(t;P) Fiat Punto
1,2
1
0,8
0,6
0,4
0,2
0
C-ratio
0
0,05
0,1
0,15
0,2
0,25
time [s]
Head
Foot


C(t;P) Fiat Punto
1,2
1
0,8
0,6
0,4
0,2
0
C-ratio
-1,2
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
0,4
0,6
0,8
x-direction [m]
Head
Foot

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