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VIRTUAL - a European approach to foster the uptake of virtual testing in vehicle safety assessment

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Abstract

In the assessment of road user and vehicle occupant safety, physical testing is limited to a few scenarios. To advance transport safety it is vital to include more relevant scenarios. Virtual Testing offers an opportunity to introduce additional test scenarios. The objectives of the VIRTUAL project, described in this paper, include: Identifying impact scenarios relevant for the future, providing tools such as models, guidelines, and a corresponding platform to foster the uptake of virtual testing.
The safety of standing passengers on public transport has been reviewed, scenarios for Vulnerable Road User testing have been identified and new seated positions for future vehicles have been described. In addition, a virtual testing platform has been established on which human body models are provided. The platform follows the open access approach, complements other approaches and does not just provide the models, but also guidelines on how to implement new scenarios in test procedures.

Keywords: Female and Male; Human Body Models; Open Source; Road Transport; Vehicle Safety; Virtual Testing; Vulnerable Road Users

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1. Introduction

In the assessment of road user and vehicle occupant safety, physical testing is limited to a few scenarios. To advance transport safety, more relevant scenarios must be addressed. Virtual Testing (VT) grants an opportunity to introduce additional test cases.

Future vehicles will face new challenges to keep up with the general demand for the best possible safety for all road users. For example, automated vehicles will alter passenger and driver behaviour, with respect to seating positions and seated postures. The driver of a vehicle in automated mode will be able to adopt a reclined restful posture or rotate the seat for easier interaction with fellow occupants. New postures pose a challenge for occupant safety and may indeed require development of new restraint systems, which will be difficult with prevailing directional-dependent crash test dummies. Furthermore, road vehicles coexisting with Vulnerable Road Users (VRUs) must also provide exterior protection in case of a collision. As mobility demands escalate, safety of passengers travelling on public transport also becomes increasingly relevant. Already today, to encourage sustainable urban mobility by means of public transportation, adequate safety and comfort must be provided to a variety of occupants in different postures in public transport vehicles (e.g., erect, different seat positions, children, the elderly and persons with reduced mobility). Virtual models and VT could provide new insights into how to improve safety and identify such achievements.

Current physical vehicle safety testing is limited to only a few scenarios, which do not meet future demands. In order to advance transport safety, a wider range of relevant scenarios must be addressed. The norm is currently represented by the average male (height: 175 cm; weight: 78 kg), and consequently safety testing does not incorporate safety assessment for all anthropometries. Current safety assessment aims for the future is to take into account population diversity and consider the entire population, including gender, size and age ranges. Comparing the risk of injury for males and females, reveals that females are exposed to a higher injury risk for a range of crash types (by Bose et al. 2011 and Forman et al. 2019). Bose et al. (2011) shows that the odds of a belt-restrained female driver sustaining a MAIS 3+ and MAIS 2+ injury were 47% and 71% higher, respectively, than for a belt-restrained male driver, when controlled for the effects of age, mass, Body Mass Index category, crash scenario, change of velocity, vehicle body type, number of events, and crash direction. Forman et al. (2019) shows that females are at greater risk of AIS 2+ and AIS 3+ injuries compared to males, with increased risk across most injury types. The odds ratio for females are 2.4 higher for (MAIS2+) and 1.7 (MAIS 3+) than for males. For the injuries studied to date, the largest difference between male and female injury risk is found for soft tissue neck injuries, injuries referred to as "whiplash injuries". In Sweden, such injuries account for ~70% of all injuries leading to disability due to vehicle crashes (Kullgren et al. 2007). The majority of those experiencing initial whiplash injury symptoms following a car crash recovered within a few weeks or months of the crash (The Whiplash Commission, 2005). However, 5 to 10% of these individuals also experience permanent disabilities of varying degrees (Nygren 1984; The Whiplash Commission, 2005). Injury statistics from the mid-1960s until today show that on average, females are exposed to double the risk of sustaining whiplash injuries than males, ranging from 1.5 to 3 times higher (among others: Kihlberg 1969; Morris & Thomas 1996; Temming & Zobel 1998; Richter et al. 2000; Chapline et al. 2000; Kullgren et al. 2003; Krafft et al. 2003; Jakobsson et al. 2004; Carstensen et al. 2012). In addition, regulations in force focus on reducing life threatening injuries.

Valuable improvements over the past few decades have significantly reduced life-threatening injuries. However, any effects on non-life-threatening injuries causing long-term disability, have been limited, and thus expensive for society due to their common occurrence. Future road safety strategies should therefore follow a broader, more holistic approach to address all casualties, which would require more comprehensive safety assessments than implemented today.

According to Parkin (2015), VT is likely the most feasible technique to assess safety performance in a multitude of crash configurations. VT incorporating evaluation through advanced Human Body Models (HBMs) has the potential to expand our safety concepts by introducing additional test cases/scenarios, including additional injury mechanisms. VT allows a far wider range of occupant specific characteristics than is, and would ever be, viable in physical testing; including factors related to population heterogeneity such as age or size.

Therefore, the aims of the VIRTUAL project, commenced on 1 June 2018 and ends on 31 May 2022, include identifying relevant future accident and impact scenarios, in order to provide tools and models suitable for VT, and to initiate an open platform that will foster the uptake of VT. The objective of this paper is to present the concept of this undertaking and present the first results of this work.

2. Method

The overall objective of the VIRTUAL project is to improve road safety by providing procedures and open access tools to assess the benefit of novel safety systems. The goal is to establish a European based global hub for Open Source Virtual Testing freely accessible on the internet and to demonstrate its success in traffic safety. Open Source Human Body Models (OS-HBMs) of both men and women will be developed in a format that is scalable to represent all different ages and sizes for car occupants, VRUs, and users of public transport.

2.1. The OpenVT platform: Open Source and Open Access

"Open Source" and "Open Access" are amongst the key design elements of VIRTUAL: all models and tools to be developed within VIRTUAL will be available Open Source, while maintaining a strict open access policy to any scientific output. Adopting an open science approach will not only ensure that project results will be freely available to the general public: it will also allow project members and external users access to the development platform to collaborate on tools and models, actively participating in the development process, even beyond the project duration. The OpenVT platform is intended as VIRTUAL's open science infrastructure, which will also serve as a dissemination platform, where users can access software results as well as experimental data.

2.1.1. OpenVT Gitlab server

The different aspects of the OpenVT platform concept and the variety of expected user groups (from project members to external users) give rise to a number of different and partly contradictory server requirements, such as "fast development and dissemination" vs. "quality control of published contents" and "efficient user self-administration" vs. "protection of confidential development contents."

2.2. Open Source VIRTUAL Models

Development of Open source HBMs, based on the previously developed average female VIVA HBM (Östh et al., 2017), representing vehicle occupants and different road users required to perform various VT has been initiated. The baseline models will represent average male and female occupants and VRUs. Initially, a workshop was organised to facilitate conversation among experts within industry, academia and other organisations, discussing the development and challenges of diverse future applications of HBMs.

2.3. Occupant protection: future seated postures and crash configurations

Focusing on occupant protection in future passenger vehicles based on literature and workshops, one part of VIRTUAL will address novel seat positions (i.e., how seats are positioned and adjusted in vehicles) as well as seated postures (i.e., how occupants are positioned when seated). In addition to novel seated postures, occupant crash protection will be affected by how future traffic systems influence the distribution of crashes, which may call for modification of the types of crashes used for predicting real-world safety performance of vehicles. Studies of existing real-world accident statistics combined with pre-crash simulations performed with crash avoidance technologies will be used to predict future crash configurations. Initially, the testing that VT will complement with regard to occupant protection is the Euro NCAP low severity rear impact tests, with the delta-v 16 km/h (2 pulses) and 24 km/h, with both an average female and average male model.

2.4. Integrated virtual assessment of pedestrian and cyclist protection

Two important aims of the VIRTUAL project involve establishing which parts of the population to focus on and which injuries to evaluate in VT. Preliminary analysis results of VRU properties as well as injury distributions among VRUs, in which long-term disability was taken into account, are presented in this paper. Several different data sources were used for the analysis of injury and accident parameters covering base-level databases (national statistics) as well as in-depth databases.

Parameters including initial vehicle speed and VRUs, weather and road conditions, etc., have been collected for each of the conflict scenarios, in order to compile a comprehensive catalogue of VT scenarios of the distributions derived from different data sources. VT scenarios based on the compiled scenarios will be used for pre-crash simulations with virtual autonomous emergency braking (AEB) systems. To evaluate the overall effectivity of different AEB systems, outcomes will be weighted according to the collected distribution of accident scenarios obtained from the accident databases. Accident scenarios that cannot be addressed with AEB will be simulated with male and female HBMs to assess the injury risks for specific vehicles. In these simulations, injuries will be assessed and an overall evaluation to establish the integrated VRU protection of a specific vehicle will be performed. The whole procedure will be summarised as the VIRTUAL Integrated Safety Assessment Framework. To derive the requirements for the HBMs suitable for in-crash-simulations, the most relevant part of the population and injuries were analysed in the accident databases, described below.

2.4.1. Relevant part of the population for pedestrian and cyclist accidents

To establish which VRU properties should be represented by the HBMs, analysis was made of real-world accidents held on the European base-level Community Road Accident Database (CARE) of road accidents resulting in death or injury within 31 European countries. The analysis comprised the gender and age of pedestrians and cyclists whose injuries were documented between 2000-2017.

Obtaining further comprehensive information concerning anthropometry (e.g., height, weight) is necessary for the development of different HBM models. Accordingly, the intermediate level database, Initiative for the Global Harmonization of Accident Data (IGLAD), was also analysed. Although IGLAD contains accident data from 11 different countries worldwide, only data from the seven European countries were included in the current analysis.

2.4.2. Relevant body regions for pedestrian and cyclist injuries

Non-life-threatening injuries, causing long-term disability are far more common than life-threatening injuries, and therefore more expensive for society. VIRTUAL aims to address both the most frequent severe, as well as the non-life-threatening, injuries. Most often, injury severity is expressed based on the Abbreviated Injury Scale (AIS) (AAAM, 2005), which generally reflects injury severity in terms of “threat to life”. In order to also include long-term consequences, the Risk of Permanent Medical Impairment (RPMI) method was used. The RPMI method was developed to estimate the risk of a patient suffering a certain level of Permanent Medical Impairment (PMI) based on the location of the injury and criteria of Swedish insurance companies (Malm et al., 2008; Insurance Sweden, 2004).

Analysis of crashes involving cyclists and pedestrians in collision with passenger cars between January 2013-December 2017, based on hospital reported data obtained from the Swedish Traffic Accident Data Acquisition (STRADA) database was undertaken. The STRADA database contains information relating to road traffic crashes collected from emergency hospital departments and police reports nationally. As the information on sustained injuries is only reported by emergency hospital departments, not by the police, only data from emergency hospital departments were included in the analysis. To keep in line with the focus of VIRTUAL, long-term disability, only non-fatal cases were included. Data were analysed using two different injury classification methods. Firstly, the Abbreviated Injury Scale (AIS) was considered and secondly, the Risk of Permanent Medical Impairment (RPMI) was calculated using the method described in Malm et al (2008). Injury distributions for men and women were computed.

2.5. Standing occupants on public transport: braking and take off during normal driving

The recently developed standing HBMs will be used to model falls, in non-collision events, on public transport vehicles. Specifically, the objective is three-fold, (i) identify the characteristics of passengers involved most frequently in non-collision injuries, (ii) identify factors where braking and acceleration manoeuvres lead *to* falls resulting in injuries of a standing passenger, and (iii) characterise acceleration and deceleration properties of public transport vehicles (e.g., magnitude, duration, shape).

This paper includes the results of a literature review, a data analysis of falling events on public transport buses due to driver manoeuvres (i.e., acceleration or braking), and the properties of acceleration and deceleration profiles. Relevant literature was searched for in the database TRID which is a merger of two well-known databases, the Transportation Research Information Services (TRIS) and the International Transport Research Documentation

(ITRD). The analysis of falling events due to driver manoeuvres was conducted through hospital reported data obtained from STRADA for the period January 2015 until August 2018 (i.e., three years and eight months), where bus passengers had sustained injuries.

The acceleration and deceleration properties were analysed using driving profiles of buses in the Stockholm area of Sweden and the city of Zurich in Switzerland. These acceleration time series were split into acceleration and deceleration events. After time normalisation, the events were analysed using Legendre polynomial representations, following the work by Kirchner et al. (2014). A new method for deriving "generic pulse" shapes was developed which comprises computing a weighted mean of the Legendre coefficients. It can be proven that this method yields the artificial pulse shape with the highest possible mean similarity with all acceleration or deceleration pulses under consideration.

3. Results

3.1. Open VT platform development

During the first planning phase, different software solutions were evaluated, leading to the conclusion that a self-hosted GitLab server, an open source repository management system based on the Git version control framework (see https://about.gitlab.com/), would be the best match to the formulated requirements. Hence, a web server running GitLab EE v. 11.6.3.-ee was set up at the project partner DYNAmore Nordic, which can be accessed through https://virtual.openvt.eu/. It contains file server functionalities as well as member administration and therefore constitutes a versatile development tool and project administration platform.

The OpenVT platform has been operational since December 2018. As of March 2019, there are 33 registered members, of which 11 are external users (i.e., not affiliated to a VIRTUAL project partner). With six internal and one public project, the platform is already actively used as a collaboration platform for VIRTUAL partners. Furthermore, the first HBM, the average female, has been available on the OpenVT platform since April 2019.

As a dissemination vessel and a container for the output of the project, a vital part of VIRTUAL's dissemination strategy includes keeping the OpenVT platform up and running beyond the active project duration. Similarly, the content of the platform is intended to be kept actively evolving as a community effort, although how the survival of the OpenVT platform will be organised in terms of funding and legal form, is yet to be decided. The VIRTUAL project incorporates an upcoming subtask dedicated to developing this particular concept.

3.2. Open Source VIRTUAL Models

The discussion among experts and users from industry, academia and other organisations brought forth many requisites for better utilisation and future applications of HBMs. Open source HBMs are uniquely placed to meet the expectations and challenges involved with these requisites, especially the use of HBMs in VT. Some of these include objective HBM evaluation/validation and load case-dependent modularity of HBMs. For example, the objective evaluation and comparison of HBMs will require that details of modelling and validation are made public, which however, may not be viable due to IP restrictions of many current models. This can be easily overcome by the use of open source HBMs, as both the models and validation load cases can be made publicly available for harmonisation of validation and VT activities.

The models being developed in the VIRTUAL project, having undergone extensive enhancement, will be known as VIVA+ models. The baseline models of VIVA+ family of models will include average female (VIVA+ 50F) and average male (VIVA+ 50M) vehicle occupants and road users (pedestrian and cyclist). An overview of the model development workflow is shown in Figure 1. The Open VT GitLab platform is used for collaborative development of the VIVA+ models. The baseline models will also be configured for use with currently available morphing tools to generate non-average HBMs. The VIVA+ models will contain scaling methodologies to facilitate morphing the models for stature and age.

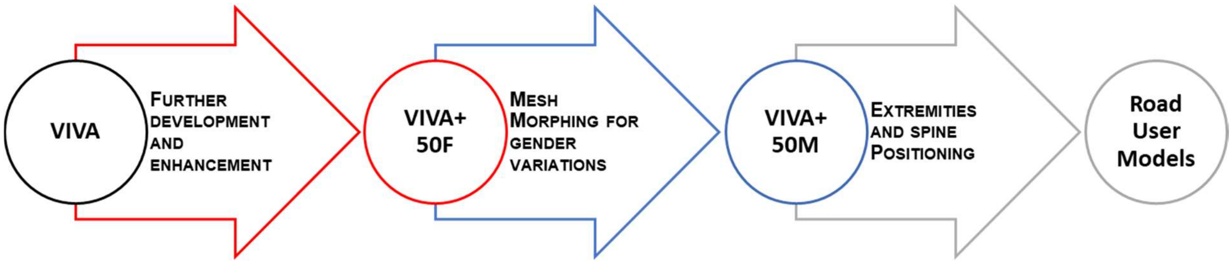


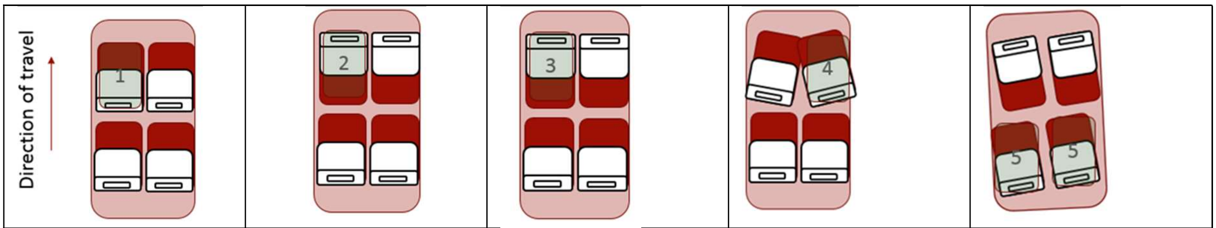
Figure 1: Workflow for the generation of VIRTUAL HBMs.

3.3. Occupant protection: future seated postures and crash configurations

Initial results from a workshop in January 2019 have shown that occupants of future vehicles may be provided with further seat adjusting options. Some of the relevant seated postures are based on the following seat positions:

- Swivel — Seat slightly rotated around vehicle vertical axis
- Transverse/lateral — Seat rotated 90° around vehicle vertical axis relative to direction of travel
- Reversed — Seat rotated 180° around vehicle vertical axis relative to direction of travel
- Reclined — Seatback rotated around seatback pivot axle(s)

Several other seat configurations were identified as well. For instance, it is foreseen that a combination of forward-facing as well as rearward-facing seats may be installed in the same vehicle as shown in Figure 2.



Forward facing, relaxed	Face-to-face, upright	Face-to-face, relaxed	Inboard swivelled front seats, upright	Parallel swivelled seats in face-to-face, upright

Figure 2: Combination of forward-facing as well as rearward-facing seats and upright and relaxed positions.

3.4. Pedestrians and Cyclists

3.4.1. Relevant population for pedestrian and cyclist accidents

The age and gender analyses of the CARE database are shown in Figures 3-5--: Regarding pedestrians, 45% of the injured and 34 % of the killed, were females. Of the cyclists, 33% of the injured and 20% of the killed were females. The injury severity was affected by the average age of the injured VRUs. The average age was 35.1 years for minorly injured pedestrians, 41.5 years for severely and 52.8 for fatally injured. A similar trend was observed for cyclists. The average age was 35 years for minorly, 42 years for severely and 54 years for fatally injured cyclists. Table 1 shows the average height and weight of injured adult (age 18+) pedestrians and cyclists analysed from IGLAD cases. Average values were derived for cases from the European IGLAD dataset. Cyclists tended to be taller than the pedestrians injured in the analysed traffic accidents.

Table 1: Height and weight of adult (age 18+) injured pedestrians and cyclists from the European IGLAD database.

	Female		Male	
	Pedestrian	Cyclist	Pedestrian	Cyclist
Number of adult victims	61	57	44	87
Mean height of adults [cm]	164.9	166.9	175.1	179.9
Mean weight of adults [kg]	66.8	66.6	79.9	80.3

3.4.2. Relevant body regions for pedestrian and cyclist injuries

The analysis of injury distribution showed that there are some differences when comparing AIS 2 and AIS 3+ with PMI 1+ (impairing injuries) and PMI 10+ injuries (severe impairing injuries). For example, Figure 3 shows that AIS 3+ pedestrian injuries to the thorax were common, however, these injuries were not common when looking at the long-term impact according to PMI 1+ and PMI 10+ injuries. Further, almost half of all severe impairing injuries (PMI 10+) were head injuries.

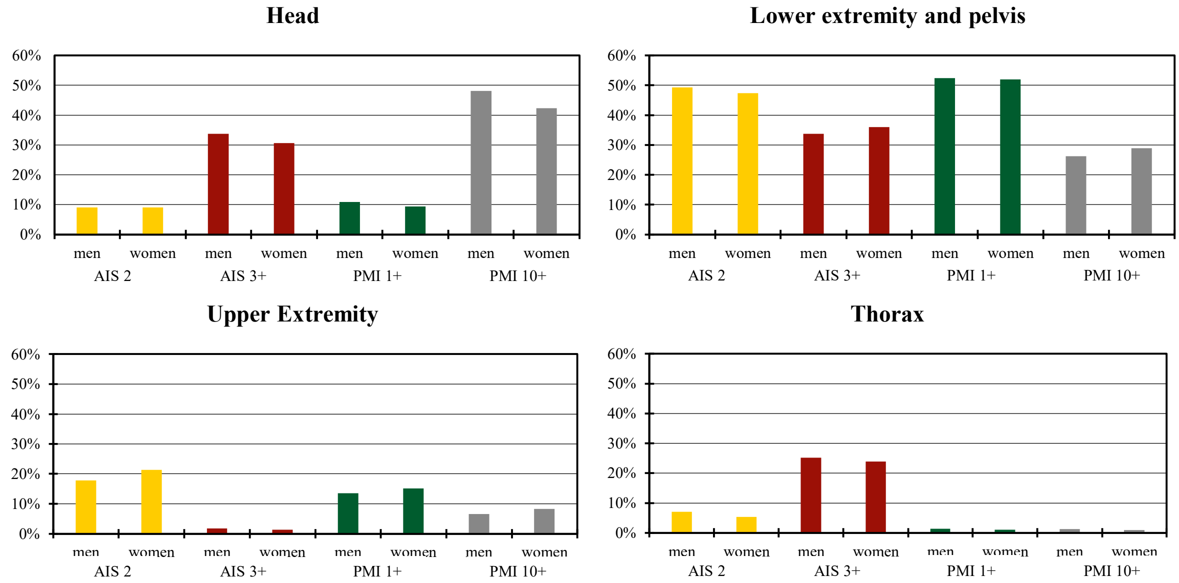


Figure 3. Percentage of pedestrian injuries to Upper Extremity, Head, Lower Extremity and Pelvis, and Thorax, of different injury classification (AIS 2, AIS 3+, PMI 1+ and PMI 10+) divided by sex.

For cyclists there were some dissimilarities between men and women. Figure 4 shows that lower extremity injuries (both AIS and PMI injuries) were common, however, the pattern shows that overall, women tend to have a higher share of lower extremity injuries. The pattern also applies to head injuries, where women present a higher share of severe (AIS 3+ and PMI 10+) head injuries. On the other hand, for thorax and cervical spine injuries the trend shows a higher share of injuries among men compared with women.

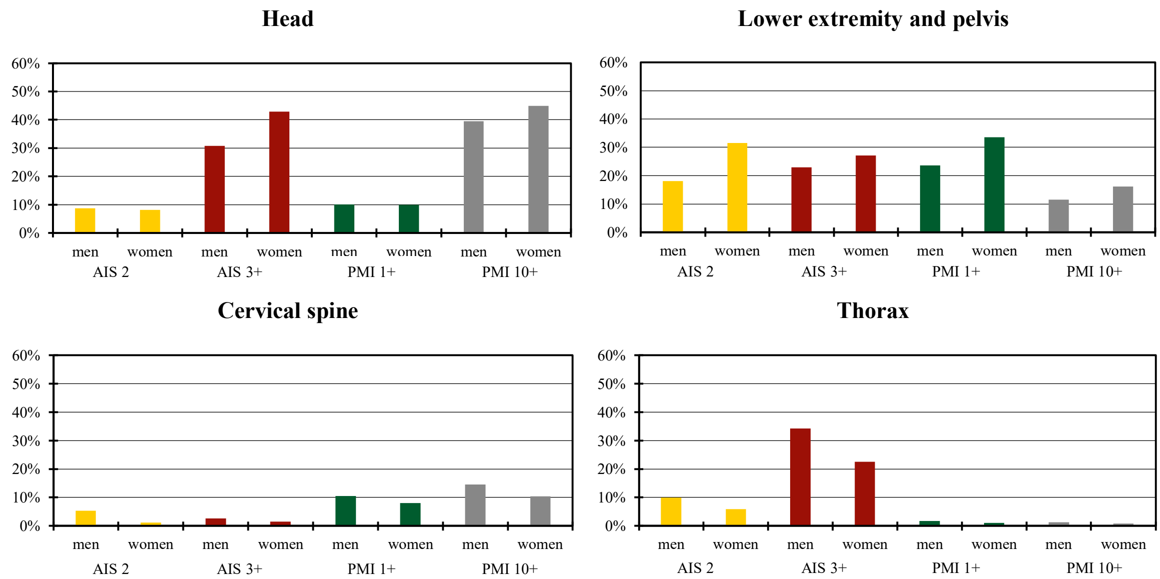


Figure 4. Percentage of cyclist injuries to Head, Lower Extremity and Pelvis, Cervical Spine and Thorax, of different injury classifications (AIS 2, AIS 3+, PMI 1+ and PMI 10+) divided by sex.

3.5. Standing occupants on public transport: hard braking and sudden acceleration during normal driving

According to the literature, fall incidents of standing passengers represent a significant source of injury, mostly affecting elderly passengers (>55%). Older females being the largest group affected (>70%) (Björnstig et al., 2005; Kirk et al., 2003; Halpern et al., 2005; Kendrick et al., 2015), due to older females travelling more frequently by public transport and living longer than their male counterparts (Björnstig et al., 2005). The literature highlights that elderly people have lower threshold values for sustaining balance compared to young people due to the deterioration of muscle and sensory functions (Graaf and van Weperen, 1997; Schubert et al., 2017). The most common sources of these types of incidents are hard breaking and sudden acceleration of a vehicle (Albertsson & Falkmer, 2005; Halpern et al., 2005; Kendrick et al., 2015; Elvik, 2019), a particularly concern involves the change of acceleration over unit of time (jerk, m/s^3) (Vallée & Robert et al., 2015). The results of the hospital data analyses show that driver manoeuvres (i.e., hard braking or sudden acceleration) and passenger conditions (i.e., standing after boarding, standing before alighting, and standing while travelling) are important characteristics differently impacting the mechanisms of falling (see Table 2). For a comprehensive discussion of the hospital data analysis, see Silvano & Ohlin (2019).

Table 2. Driver manoeuvre and passenger condition

	Passenger condition				Total
Driver manoeuvre	Alighting	Boarding	Travelling	Unknown	
Acceleration	9	99	6	6	120 (38%)
Braking	56	24	96	20	196 (62%)
Total	65	123	102	26	316

Due to urbanisation, demographic changes and promoting public transport, the development of an Open Access finite element HBM of a standing occupant is an important step in providing safer sustainable mobility for the future society. The standing occupant whole-body HBM is aimed at simulating human body active responses to posture perturbations that may emerge during bus manoeuvring, providing coherency with VIRTUAL developments and overcoming potential limitations in body positioning and injury assessment, inherent to the concept of the inverted pendulum model from Vallé et al., (2015) and Aftab et al., (2016).

The VT framework for standing occupants will include perturbations that resemble main characteristics of real-life acceleration profiles, while simultaneously being generic to provide well defined and comparable test conditions. Based on the data available from project partners and literature, the magnitude, duration and shape were identified as the key parameters for the perturbation profiles. Although the braking performance requirements for buses and coaches are set by regulations (ECE R13, FMVSS 135), characteristics relevant to the safety of standing occupants during bus travel have not been defined to date. Moreover, studies on active human body responses were typically performed with perturbations not representing real-life acceleration profiles (Carpenter et al., 2005; Tokuno et al., 2010; Verriest et al., 2010). As a result, the acceleration measurements on a bus of the Zurich local transport provider VBZ, a set of 39 longitudinal acceleration and 40 deceleration pulses was obtained during normal operation. Descriptive statistics of the pulse magnitudes and durations are displayed in Table 3.

Table 3: Statistics of acceleration and deceleration pulses.

	Acceleration pulses	Deceleration pulses
Number	39	40
Duration (mean±SD) [s]	13.3 ± 7.7	12.9 ± 9.3
Peak magnitude (mean±SD) [g]	0.12 ± 0.29	0.12 ± 0.36

The maximum jerks were estimated in the order of magnitude of 2 m/s^3. For both pulse types, generic average pulses, Figure 5, were generated using the newly developed weighted-mean method based on the study from Kirchner et al. (2014).

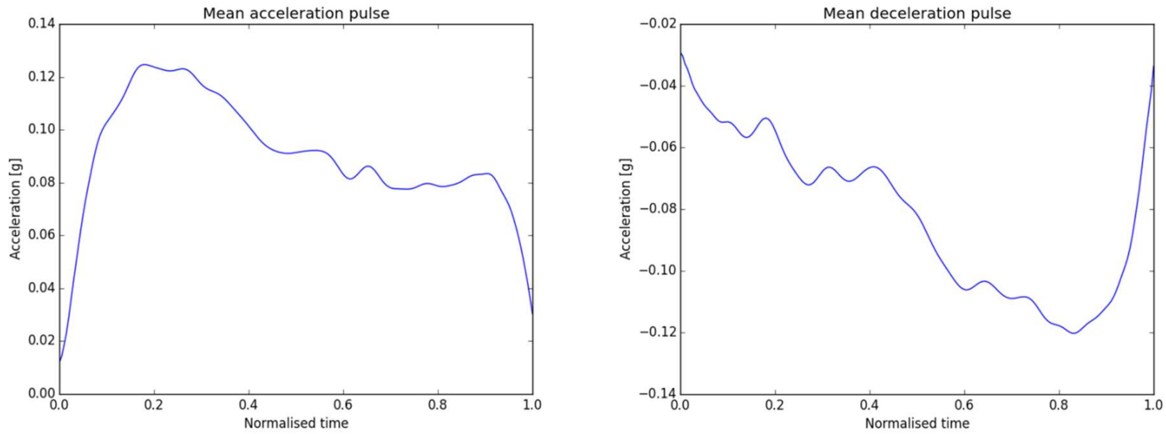


Figure 5: Mean acceleration and deceleration pulses resulting from the weighted-mean method, as a function of normalised time parameter.

On the deceleration pulse, the typical roughly linear increase in breaking force can be seen as predicted by the literature (see above). The generic acceleration pulse shows a strong jerk at the beginning, followed by a constant phase and a strong drop at the end. The pulse magnitudes are in accordance to the literature data for normal braking and accelerating (Palacio et al., 2009; English et al., 2012; Kirchner et al., 2014; Schubert et al., 2017). Although the recommended tolerable limits for free standing occupants are 0.6–2.0 m/s^2 acceleration and 0.9–1.0 m/s^3 jerk (Karekla & Tyler, 2018; De Graaf & Van Weperen, 1997), the occupants may experience significantly higher loads due to emergency manoeuvres or reckless driving, compromising the safety and comfort (Powell et al., 2015), up to 4.5 m/s2 in bus emergency stops (Kühn, 2013; Brooks et al., 1980) with a duration of ~4.0–5.5 s at 40 km/h. A severe jerk can occur at the take-up initiation or at the end of the braking, exceeding 10.0 m/s^3 in critical situations (Bagdadi & Várhelyi, 2013).

The acceleration profiles characterising bus manoeuvring will be included into the VT framework for injury risk assessment of public transport users. The profiles will be used in physical testing within the VIRTUAL project to obtain experimental data on standing occupants' reflex response to balance perturbation needed for calibration and validation of the HBM.

4. Discussion

This paper demonstrates the methods and initial results of the VIRTUAL project. Development of the VT platform as well as the open source HBMs have been initiated. Also ongoing is the data collection to derive current and future accident scenarios that will be included in VT.

The initial findings have shown that for pedestrians and cyclists, the use of HBMs representing the 50^{th} percentile male and female, seems to be a good starting point to cover the parts of the population that are injured in real-world cases. The analysis of injury distribution showed that injury assessment should focus on the head, extremities, torso and the cervical spine, to be able to cover both the most frequent injuries and those injuries most likely to lead to permanent medical impairment.

The review of the literature and databases addressing standing occupants on public transport indicates significant gaps in data on the acceleration profiles bus occupants are exposed to in emergency manoeuvres and normal driving. The key parameters identified characterising the acceleration profiles will be considered in physical testing within VIRTUAL to obtain the experimental data on standing occupants' reflex response to balance perturbations needed for calibration and validation of the HBMs. The accident data of falling passengers on public transport showed that females were more often injured than males. However, data on exposure is required in order to draw conclusions about the risk for different groups (male, female, elderly, etc.) of suffering injuries. This is also the case regarding the risk of injuries and fatalities for different groups of pedestrians and cyclists.

In the last few decades, finite element Human Body Models (HBMs) for the assessment of human responses in crashes have been developed with detailed representation of the geometries and mechanical properties of human body structures. These models typically started out as average sized male models, for example the Total HUman Model for Safety (THUMS) (Iwamoto et al. 2002; Iwamoto & Nakahira 2015) and the Global Human Model Consortium (GHBMC) (Gayzik et al. 2011; Vavalle 2012). These models have recently been further developed into a small female and a large male version to represent a more extensive occupant height and weight range. Although these additional sizes are important, they are not sufficient or comparable, in representing the female part of the population, similar to the average sized male manikin representing the male part of the population. Thus, developing an average sized female human model similar to the average male model, still remains. The first step has been taken by developing the open source HBM VIVA model (VIVA, 2016), representing an average female adapted for low severity rear impact testing (Östh et al., 2016). The VIVA+ HBMs will include an average female model, based on the VIVA model, and an average male model, available in different postures to enable gender equal safety assessment for multiple load cases.

5. Ackowledgements

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