Injury Severity and Body Region Distribution in French Tramway-Pedestrian Accidents: A Basis for Finite Element Human Body Model Simulations

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I. INTRODUCTION

The expansion of tramway networks in recent years has raised the question of safety for the vulnerable road users (VRUs) sharing the same public space. While relatively safer than other means of transport [1], at the same speed, tramways pose a significantly higher fatality risk than cars [2]. Pedestrians have been documented to be particularly vulnerable in cases involving tramways [3-5]. To mitigate such risk, European authorities have issued technical guidelines such as [6] and CEN/TR 17420:2020 outlining tramway front-end design strategies aimed at reducing the consequences of collisions with pedestrians. Although the frequency of tramway-related accidents has steadily declined since the publication of those documents, fatalities have increased in recent years [7].

This study aims to investigate injury patterns in tramway pedestrian collisions by analyzing the French national road-traffic database, the Rhône trauma registry, and initiating the development of a finite-element human-body-model (FEHBM) for future numerical studies.

II. METHODS

Effects of Age and Sex on Injury Severity

Effect of age and sex on injury severity is highlighted using logistic regression methods. The study was conducted on 941 records of tramway accidents involving a single injured pedestrian. Data were extracted from the French national road traffic database for the period 2005–2022. Analyses were conducted separately for all injured pedestrian, as well as for male and female subgroups.

Injury by Body Regions

The distribution of 327 injury records among tramway-pedestrian victims in the Rhône registry for the period 2001–2020 was analyzed to investigate injury prone body regions. These records contain the injuries sustained by victims in tramway accidents per body region and were classified using the Maximum Abbreviated Injury Score (MAIS).

FEHBM Selection and Instrumentation

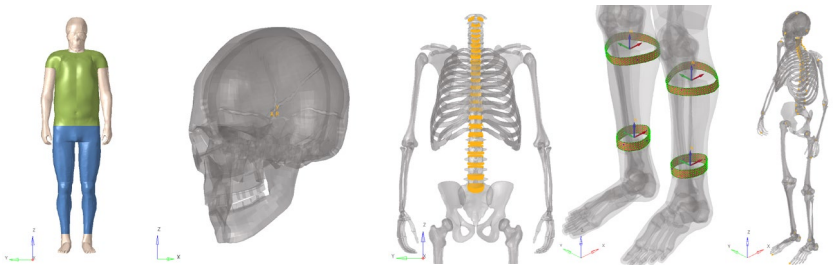

Figure 1: Instrumentation of THUMS AM50 for tram-pedestrian impact analysis.

Findings from analyses of injury severity by age, sex and body region distribution informed the selection, validation, and instrumentation of the FEHBM for future numerical studies. THUMS 50th percentile adult male (AM50) was selected to represent the demographic group with the highest exposure to incidents. The model, initially converted from LS-Dyna input, was developed in Radioss finite-element solver and was validated at the component level for the injury prone body regions (head, thorax, upper- and lower- extremities). Instrumentation included: accelerometers positioned at the anatomical landmarks, center of gravity of the head, each vertebra and pelvis; cross-sectional loadcells at the tibia and each vertebra (see Figure 1). The model was also configured to facilitate the extraction of global and local injury metrics such as Head Injury Criterion (HIC), Neck injury Criterion (Nij), Thoracic Trauma Index (TTI), Combined Thoracic Index (CTI), and Revised Tibia Index (RTI).

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III. INITIAL FINDINGS

Most victims are adults over 20 years old (72.7%). Among the victims, 57.6% are males. Most frequent age groups are elderly (35.8%) followed by adolescents (22.1%) and young adults (20.8%). Elderly female adults (50+ years old) are more likely to get killed in an accident (60.6% of elderly adult group).

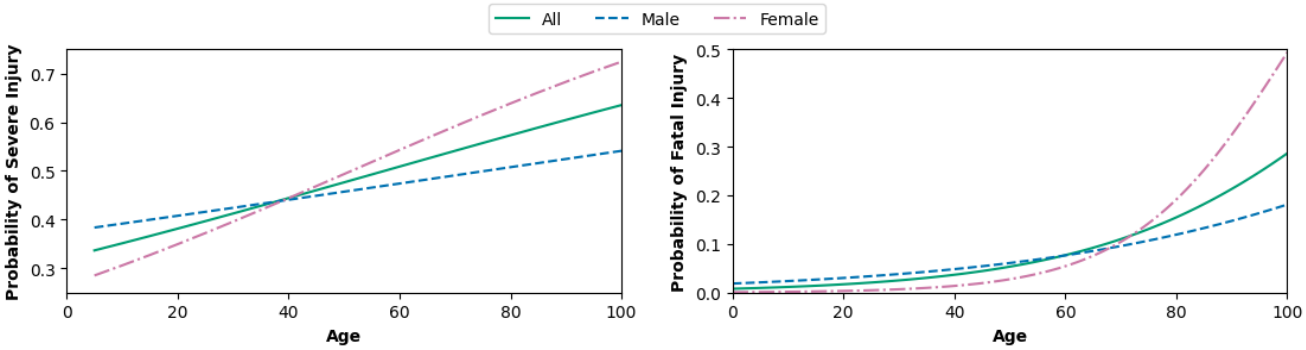

Figure 2: Predicted probability of injury severity by age and sex.

Figure 2 presents the predicted probabilities from the logistic regression analyses investigating the relationship between age and injury severity. The probability of sustaining a severe injury increases in almost a linear manner with age. In contrast, the probability of fatal injury rises more sharply, particularly for the elderly population of the sample (50+ years old). Across both analyses females exhibit a more pronounced increase in risk compared to males.

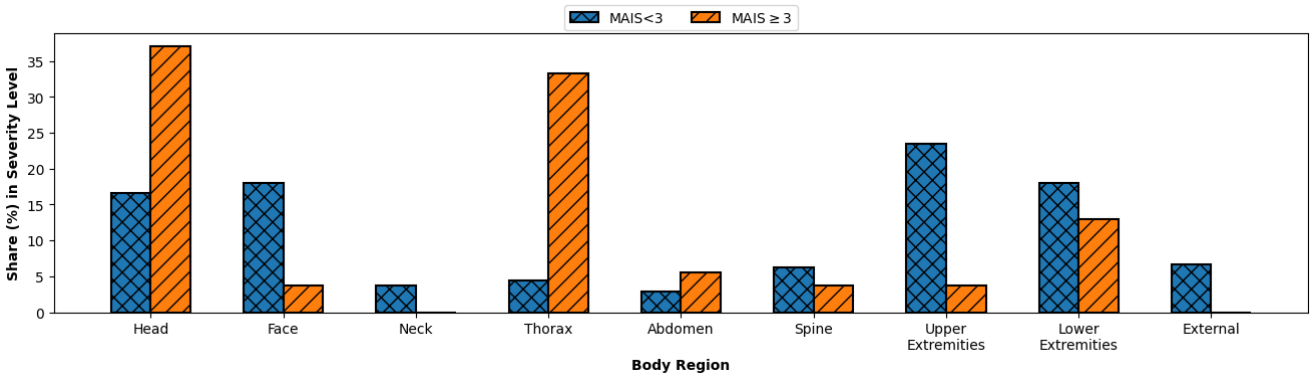

Figure 3: Share of injury by body region across different severity levels.

Figure 3 shows the share of injuries by severity level across different body regions. The only fatality (MAIS6) in the dataset was associated with an injury to the thorax. The head was the most frequently affected region in serious cases (MAIS≥3) followed by the thorax and lower extremities. In contrast, the upper extremities sustained the highest proportion of minor injuries (MAIS<3) followed by the lower extremities, face, and head.

These findings provided the basis for FEHBM selection and instrumentation, as described in the Methods section.

IV. DISCUSSION

Current evaluation in CEN/TR 17420:2020 relies on AM50 and 6YO HBMs. While AM50 aligns with the most frequently exposed demographic, this study highlights the need to account for age and sex in passive safety assessment. Additionally, current injury metrics, i.e., HIC may underrepresent thoracic and lower extremity risks, despite their prevalence in serious cases. In the present work, although the model includes instrumentation for key injury regions, the suitability of the selected metrics for capturing injury mechanisms specific to tramway-related impacts remains to be validated. Initial findings support the integration of targeted instrumentation and injury criteria in future tramway-front evaluation.

V. REFERENCES

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