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Can a multibody model accurately replicate real e-scooter crashes?

Marianne Guesneau*[a], Oscar Cherta-Ballester[b], Pierre-Jean Arnoux[c], Valentin Honoré[b], Nicolas Bailly[c]

a In&motion, LBA, UGE and AMU, Marseille, France
b In&motion, Annecy, France
c LBA, UGE and AMU, Marseille, France
* Corresponding author: marianne.guesneau@univ-eiffel.fr

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1. Introduction

Multibody models for road accident simulations are typically developed and validated based on laboratory impact tests with cadaveric or anthropomorphic test devices (ATD). Few studies, however, compare these models with real human crashes, particularly e-scooter crashes. This comparison is crucial as micromobility crash timings (approximately 1 second) might allow for protective reflexes, potentially altering the overall kinematics compared to those of a cadaver or ATD (Crandall *et al.*, 2011). This study aims to reconstruct real-world e-scooter crashes from video footage using an existing multibody model to assess its ability to accurately replicate these events, focusing on two scenarios: a single fall and a collision with a car.

2. Methods

2.1 Presentation of the crashes

Two e-scooter crashes found on YouTube were analysed and reconstructed. The first involved a car colliding with the e-scooter as it crossed the road, resulting in the rider being ejected to the ground. The second depicted a rider falling over the handlebars after hitting a curbstone.

2.2 Video Analysis

The videos were recorded by surveillance cameras, at 30 fps. Using the video analysis software Kinovea 0.9.5 the displacements and speeds of the e-scooter rider's head or back (depending on which was most visible) and of the car were measured according to the method described by Shishov *et al.* (2021). To calibrate the dimensions of the pictures, a 2D grid was placed in the plane of the fall (Shishov *et al.*, 2021). The first video was calibrated using the car's dimensions, and the second using the e-scooter's dimensions. Time T=0 marked the contact with the obstacle (car or curbstone), and position (0,0) was defined as the ground level beneath the e-scooter at T=0. To measure the uncertainty associated with the video measurements, the calibration process was repeated five times for each video. Two or three different frames were used as the initial (T=0) and final frames (impact with the ground) of the falls. This resulted in 45 different video analyses for the fall and 30 for the collision.

2.3 Multibody reconstruction

Fournier *et al.* (2023) used the human multibody model originally developed and validated with cadaveric data by van Hoof *et al.* (2003) to create an e-scooter crash model involving a collision with a curb. This combined model was employed to replicate the two scenarios investigated in this study. The car was derived from the model used in previous work (Cherta-Ballester *et al.*, 2019), which dimensions were adjusted to match those of the SUV in the video. The motion of the car (linear displacement including braking deceleration) was given by the displacements measured in the video. The e-scooter initial speed was also estimated from the video. The mean absolute error (MAE) was calculated

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between rider's displacements measured from each video analysis and the displacements of the multibody models during the falls. The duration and distance of the falls and the speed of impact with the ground were also compared.

3. Results and discussion

Table 1. Mean kinematic parameters measured on the videos (with min-max) and on the multibody models

Case		Video	Model
-1- Back	fall duration (s)	1.12 (1.07-1.17)	0.97
	fall distance (m)	6.30 (5.52-7.07)	5.30
	impact speed (km/h)	19.6 (14.6-27.4)	27.2
-2- Head	fall duration (s)	0.58 (0.53-0.63)	0.65
	fall distance (m)	2.15 (1.80-2.50)	2.65
	impact speed (km/h)	15.7 (14.3-18.0)	13.3

For the first case, the modeled car had a speed of 26.7km/h at the time of first impact, and the e-scooter of 7.2km/h. The average displacement MAE across all video analysis was 0.14m (ranging from 0.07 to 0.29m) on the horizontal axis (x) and 0.14m (0.10-0.20m) on the vertical axis (z) (Figure 1). While the model exhibited a shorter fall duration compared to the video analysis, the fall distance and impact speed fell within the range of the 30 measurements obtained from the video (Table 1). The global kinematics were very similar (Figure 1), with only minor discrepancies, such as the rider's back rising slightly higher above the car in the video compared to the reconstruction (see at 500ms, Figure 1). Consequently, the rider fell later and further to the ground in the video. The difference in rise is attributed to muscle tone (hollowed back in the model) and to the variation in bonnet angle during braking, which was not modelled in the reconstruction. For the single fall simulation, the speed of the e-scooter before colliding with the curbstone was 15.4km/h. In this case, the displacement MAE averaged 0.21m (0.10-0.43m) on the horizontal axis and 0.10m (0.05-0.14m) on the vertical axis. The model exhibited a longer fall duration and distance compared to the video, with a lower impact speed (Table 1). This discrepancy is attributed to the model's lack of muscle tone, which caused the abdomen and arms to contact the ground before the head, slowing its fall. Additionally, the wide range measured in the videos indicates that using a single video to reconstruct the crash presents challenges for accurate calibration by placing the 2D grid in the plane of the fall. This limitation is exacerbated by low video quality and frame rate. Moreover, in the selected videos, the riders seemed unaware of the obstacle until the last moment, resulting in minimal protective reflexes. Simulating crashes at lower speeds, where reflexes are more likely, could be challenging. The model may then simulate worst case scenarios where reflexes are still absent, for example due to alcohol or drug use. Although the use of a 2D video to reconstruct a crash has undeniable limitations, it does allow to verify the accuracy of the overall kinematics and the order of magnitude of displacements.

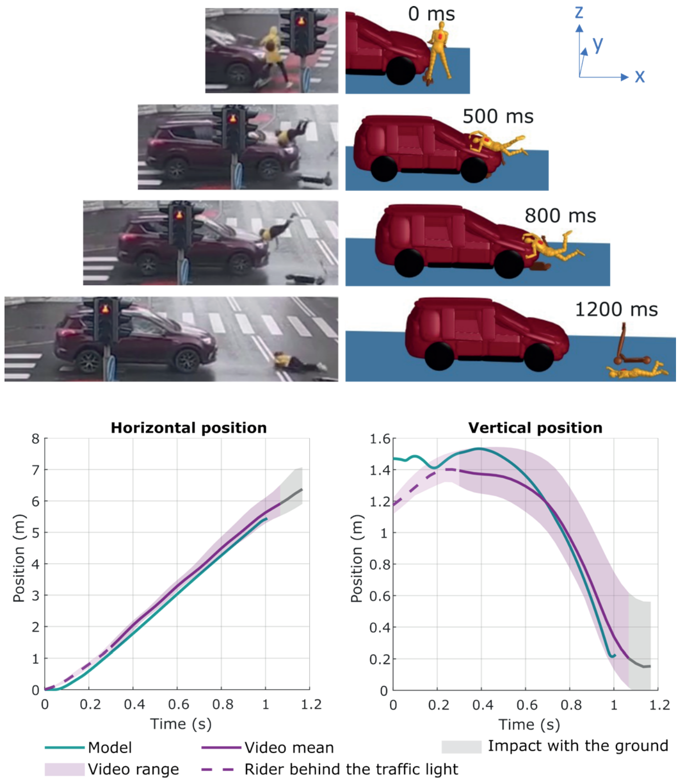

Figure 1. Collision between an e-scooter and a car: general kinematics and back displacement

4. Conclusions

The study used multibody simulation to reconstruct two e-scooter crashes captured by surveillance cameras. The model, previously used to reconstruct a crash with an ATD, accurately replicated these two real-world crashes with a good agreement of the global kinematics and the riders' displacements. We conclude that despite its limitations (no reflexes) this type of model can be valuable in the simulation of real e-scooter crashes. Future studies should be conducted to determine the sensitivity of the model to input variations and their effect on the model responses and on the human body impact conditions.

Conflict of interest statement

No potential conflict of interest is reported by the authors.

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