A Numerical Investigation of Rider Injury Risks From Falling off an E-scooter
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Table of Contents

1. Introduction
2. Methods
3. Impact simulations
4. Results & Discussion
5. Conclusion
1. Introduction

- Head and limbs most frequently injured regions [1]
- Fractures/dislocations and contusions are the most common types of injuries [1]
- Most e-scooter crashes are caused by falls

Data taken from Aizpuru et al. [1]
2. Methods: FE setup of Scooter Accident Simulation

• Dummy model used was of a standing 50% male Hybrid III dummy (78.1 kg, 1700 mm height). The FE model contained 4,301 elements and 7,355 nodes (LSTC/Ansys model).

• Flat ground created
  • Deformable top layer
    • Concrete material
  • Rigid bottom layer created to keep top layer stationary

• A stopper placed in path of scooter
2. Methods: Geometry Reconstruction & Meshing

Ninebot KickScooter
MAX electric scooter
(Spin, San Francisco, CA, USA)

FARO laser scanner system (Point clouds) → Rhino 3D (NURBS surfaces) → HyperMesh (model mesh)
2. Methods: Calibration of HIII FE Model

• Several tests were simulated and used to calibrate the HIII model

- Head drop test
  - HIII head model
  - 2.716 m/s
  - Fixed rigid

- Thorax Impact Test
  - 6.7 m/s

- Knee Impact Test
  - 2.1 m/s
  - 24°

- Neck Pendulum extension/flexion Tests
3. H III Calibration Example: Head and Thorax Calibration

**Head Calibration**

![Head Calibration Graph](image1)

- Original Head
- Calibrated Head

**Thorax Calibration**

![Thorax Calibration Graph](image2)

- Chest Calibrated
- Chest Original

![Force vs Time Graph for Thorax Calibration](image3)
3. Impact Simulations: Impact variables tested

- Stopper height
  - 52 mm
  - 101 mm
  - 152 mm

- Approach angle
  - 30°
  - 45°
  - 60°

- Impact speed
  - 3.2 m/s
  - 4.48 m/s
  - 11.16 m/s
3. Impact Simulations: Arm activation

- Arm activation added to all head-on collisions
- Accomplished by loading the shoulder and elbow joints
- Ran a total of 45 e-scooter crash simulations

a) No arm activation

a) Arm activation included
3. Impact Simulations: Injury Risks Calculation

- Injury metrics extracted from simulations
  - Head injury criteria (HIC)
  - Neck injury criteria \( N_{ij} \)
  - Chest Deflection
  - Maximum femur force

- Used to calculate Rider Injury Measure (RIM)

\[
RIM_{AIS3+} = 1 - (1 - P_{HIC}) \times \left(1 - P_{N_{ij}}\right) \times (1 - P_{\text{chest}}) \times (1 - P_{\text{femur}})
\]
3. Impact Simulations: Statistical Analysis

- Correlation coefficients measured the relationship between pre-impact variables and injury risks

- Sobol’s global sensitivities compared the effect of each pre-impact variable

- Student t-tests determined if arm activation caused any significant changes to injury risks
4. Results & Discussion: Injury Metrics

- About half of all neck and head injury risks were higher than 25%.

- 4 of the 5 lowest RIM scores occurred in simulations using smaller approach angles.

- Nearly all simulations with RIM scores of 1 occurred during head-on collisions.
4. Results & Discussion: Approach Angle

- The approach angle had strong positive correlations with head, neck, chest, and overall injury risks
- E-scooter impacting a 52 mm stopper at 11.16 m/s
  - Head-on collision
  - 30° approach angle
4. Results & Discussion: Impact Speed

- The impact speed had small negative correlations with RIM and chest injury and small positive correlations with head, neck, and chest injury risks.
- E-scooter impacting a 52 mm stopper with a 90° approach angle:
  - 3.2 m/s impact speed
  - 11.16 m/s impact speed
4. Results & Discussion: Stopper Height

- Stopper height had the lowest contribution to injury risk
- E-scooter impacting a stopper with a 90° approach angle at 3.2 m/s
  - 52 mm stopper
  - 152 mm stopper
4. Results & Discussion: Correlation Coefficients and Global Sensitivities

**Correlation Coefficients**

- **Impact angle**
- **Impact speed**
- **Stopper height**

**Global Sensitivities**

- **Impact angle**
- **Impact speed**
- **Stopper height**
4. Results & Discussion: Arm Activation

- Reduced RIM scores were reduced in two-thirds of the head-on crash simulations.
- Arm activation had a statistically significant effect on neck injury risk ($p=0.042$).
- E-scooter impacting a 52 mm stopper at a speed of 3.2 m/s.
4. Results & Discussion: Key points

• Key conclusions
  • The approach angle had the greatest impact on injury risk
  • The impact speed had a negative correlation with injury risks for small angles of approach
  • Overall arm activation did reduce RIM scores

• Limitations
  • Limited selection of injury measures
  • Coarse HIII dummy model
5. Conclusions

• Risks of serious injury were greatest for the head and neck regions
  • Corroborated by experimental data [2]

• A future study will look at impacts involving a collisions with vehicles

• This study showed a higher risk of serious injury than observed in hospitals
6. Acknowledgements

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7. References
