Numerical Analysis of Bicycle Helmet Impacts using Biomechanical Metrics

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1) ABSTRACT
This study evaluates various safety aspects of standardized impacts that cyclist may suffer while wearing a bicycle helmet, by combining a partially validated finite element model of the cranio-cervical region and a newly developed commercial bicycle helmet model.

2) OBJECTIVES OF RESEARCH
The objective of the research is to develop a Numerical Impact Model of bicycle helmets including a partially validated human FEA head in LS-DYNA to analyze the following parameters:

- Biomechanical Metrics
  - Peak Linear Acceleration (PLA)
  - Gadd Severity Index (GSI)
  - Head Injury Criterion (HIC15)
  - 3 Ms Criterion (A3MS)
  - 5 Ms Criterion (A5MS)
  - Skull Fracture Probability

- FE Analysis based on the head-helmet biomechanical system
  - Energy absorbed by the helmet
  - Importance of the EPS Foam density
  - Curves to assess the probability of injury based on impact speed

3) FEA DEVELOPMENT
All the elements involved in an experimental impact are included in the simulation; the mesh includes the padding, chin strap, rear strap, shell, and EPS foam of the bicycle helmet, which is based on a helmet available on market.

Partially validated finite element model of the cranio-cervical region[1] developed the Japan Automobile Research Institute which includes brain, skull, skin, grey matter, brainstem...

Hexahedral and quadrilateral elements in the helmet mesh for convergence purposes.

4) VALIDATION OF FEM MODEL
The results of this research and previous experimental studies were validated comparing the resultant acceleration of the Center of Gravity of the head with experimental studies:

5) IMPACT SEQUENCE OF RESULTS

6) RESULTS OF BIOMECHANICAL METRICS (EN 1078 STANDARD)

<table>
<thead>
<tr>
<th>Impact Energy</th>
<th>FLAT ANVIL</th>
<th>CURSTONE ANVIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 % Minor Injury</td>
<td>88 % Moderate Injury</td>
<td>100 % Minor Injury</td>
</tr>
<tr>
<td>49 % Serious Injury</td>
<td>35 % Severe Injury</td>
<td>20 % Minor Injury</td>
</tr>
<tr>
<td>3 % Serious Injury</td>
<td>0 % Severe Injury</td>
<td>7 % Moderate Injury</td>
</tr>
<tr>
<td>0 % Critical Injury</td>
<td>0 % Severe Injury</td>
<td>0 % Critical Injury</td>
</tr>
<tr>
<td>0 % Maximum Injury</td>
<td>0 % Maximum Injury</td>
<td></td>
</tr>
</tbody>
</table>

3 Ms Criterion (A3MS) Does NOT Meet Requirements
5 Ms Criterion (A5MS) Meets Requirements

| Skull Fracture Probability | 14.04 % | 0.13 % |

7) ENERGY ABSORBED BASED ON IMPACT SPEED

8) INFLUENCE OF EPS FOAM DENSITY

9) PROBABILITY OF INJURY BASED ON IMPACT SPEED

10) CONCLUSIONS

- Under European standard impact conditions (EN 1078) cyclists can suffer head injuries
- Under EN 1078 impact conditions the helmet can absorb 40 to 50 % of the total impact energy at speeds above 4 m/s
- A larger EPS foam density achieves a more distributed impact, with a lower HIC value and a lower maximum acceleration
- Minor injuries may occur at impact velocities of 10 km/h, serious injuries at 15 km/h, and severe injuries at 20 km/h. Fatal Injuries will very likely occur at impact speeds of 30 km/h and higher

11) ACKNOWLEDGEMENTS

REFERENCES

AKNOWLEDGEMENTS

The authors acknowledge the Ministry of Economics and Competences of Spain and FEDER program under the Project DPI2017-86588-I for the financial support of the work, and Dr. Pedro Rodriguez-Millan under the Spanish Ministry of Education, Culture and Sports for the professor’s mobility program Juan Carlos I. 2017 grant (E006/2017).