THE SCATTER OF PEDESTRIAN UPPER-LEG IMPACTOR

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ABSTRACT

The pedestrian protection given by a vehicle is assessed according to four independent impact test procedures, related to different body segments. Four impactors were developed specifically: leg, femur (or upper-leg), child head and adult head. These impactors, which are thrown against specific zones of the front face of the vehicle, allow the measurements of biomechanical criteria simulating the injury risk during the impact. Such test procedures are used by Euro NCAP and by the European regulation on pedestrian protection.

Concerning the upper-leg impactor, two biomechanical criteria are analysed: the sum of force and the three femur bending moments. A specific study has been carried out on the scatter of upper-leg tests by PSA Peugeot Citroën in cooperation with UTAC in order to assess the scatter of this set of biomechanical criteria in different laboratories.

In order to reduce the number of parameters of scatter and to isolate those linked to the upper-leg impactor, these tests have not been made on a full vehicle but on a simplified sub-system which permits to obtain biomechanical criteria very close to those obtained with a complete vehicle.

Tests conditions of the upper-leg impactor (weight and speed) vary in protocols (Euro NCAP as well as regulation) according to the vehicle style. About forty tests have been carried out in each laboratory according to two different impact energies and with two different upper-leg impactors.

Results of those tests have enabled us to better understand and to quantify the scatter of the upper-leg impactor and to improve the design of our vehicles for the pedestrian protection.

INTRODUCTION - AIM OF THE STUDY

Every year, approximately 8,000 pedestrians and cyclists are killed and 300,000 others injured in road accidents in Europe. The accidents are particularly frequent in urban zones. Even when cars are driving at relatively reduced speeds, very severe injuries can occur.

Below a speed of approximately 40 km/h, it is nevertheless possible to considerably reduce the gravity of injury with modifications of the frontal parts of vehicles.

So, since 2005, a new European Directive [1] (called “phase 1”) requires the car manufacturers to treat their new vehicles for pedestrian protection.

Moreover, the consumerist organization Euro NCAP assesses the pedestrian protection offered by a new car through component tests [2], [3]. The level of pedestrian protection is then ranked by attributing the vehicle a given number of stars.

The assessment of pedestrian protection offered by a vehicle is made through three different and independent component test procedures corresponding to different body segments:

- the first one is related to the assessment of the protection of the leg. The test is called “legform to bumper test”
- the second one is related to the upper leg. The test is called “upper legform to bonnet leading edge”
- the last one is related to the head, adult head impact and child head impact. The tests are called “Adult and Child headforms to bonnet and windscreen test”
Four specific body form impactors are used in these tests. They are propelled against the front part of the vehicle (from the bumper up to the windscreen depending on the type of test) and they are equipped with several sensors in order to measure biomechanical criteria that are used to assess the risk of injuries (see Figure 1).

The leg and head impactors have already been discussed in a previous paper [4].

The upper leg impactor requirements are only present in the Euro NCAP assessment (a maximum of 6 points is given to the upper leg test performance). Whereas, the European Directive only asks the upper leg tests to be carried out for monitoring purpose. The reason is that this test has not been proved to be relevant to real world pedestrian accident and because the results of this test are highly scattered.

Because of the increasing requirements on the pedestrian protection performance in the Euro NCAP new rating (overall rating), predicting the performance of upper leg tests becomes more and more sensible.

This paper aims to assess the scattering measured on the upper leg impactor tests.

THE UPPER LEG IMPACTOR TEST PROTOCOL

Euro NCAP Test Protocol [2]

The upper leg impactor aims to represent the adult femur. It is made of a rigid frame on which a metallic tube (the femur) is fixed. This tube is surrounded by a specific foam which behaviour represents the muscles and the skin. The link between the rigid frame and the femur is made of two load cells. Three extensometric gages are present in the central part

The upper leg impactor tests consist in propelling the femur impactor against the front part of the car (hood). The impact test parameters (angle, velocity and mass) depend on the geometry of the car front (see Figure 2).

Definitions

In order to define the impact test conditions, we first need to know the following definitions.

- **The Bonnet Leading Edge Reference Line:** The Bonnet Leading Edge Reference Line is defined as the geometric trace of the points of contact between a straight edge 1000mm long and the front surface of the bonnet, when the straight edge, held parallel to the vertical longitudinal plane of the car and inclined rearwards by 50° and with the lower end 600mm above the ground, is traversed across and in contact with the bonnet leading edge (see Figure 3).
Figure 3. Definition of the Bonnet Leading Edge Reference Line.

- The Upper Bumper Reference Line:
The Upper Bumper Reference Line is defined as the geometric trace of the upper most points of contact between a straight edge and the bumper, when the straight edge, held parallel to the vertical longitudinal plane of the car and inclined rewards by 20°, is traversed across the front of the car whilst maintaining contact with the upper edge of the bumper (see Figure 4).

Figure 4. Upper Bumper Reference Line.

- The Bumper Lead:
This is defined as the horizontal distance between the Bonnet Leading Edge Reference Line and the Upper Bumper Reference Line. Please note that the vehicle has to be in its Normal Ride Attitude.

- The Bonnet Leading Edge Height:
This is defined simply as the vertical height above the ground of the Bonnet Leading Edge Reference Line.

Impact Test Conditions

At the time of first contact the impactor centre line shall be midway along the Bonnet Leading Edge.

The shape of the front of the car determines the velocity, angle of incidence and kinetic energy of the impactor. Indeed, these three parameters will be calculated from the Bonnet Leading Edge Height and Bumper Lead.

Therefore, three simple test parameters (velocity, angle of incidence and impactor mass) will vary from:

- mass: from 9.5 to 17.7 kg
- velocity: from 20 to 40 km/h
- angle: from 10° to 47°

Figure 5 presents the total kinetic energy with respect to Bumper Lead and the Bonnet Leading Edge Height.

Figure 5. Upper Leg kinetic energy variation depending on the car shape.

Impact Test Measurements

Two type of biomechanical criteria are measured during the Upper Leg impactor tests:
- Force: measured from the two load cells that fix the femur to the rigid frame
- Bending Moment: measured from the three extensometric gages

Table 1 presents the measurements performed of the Upper Leg impactor.

<table>
<thead>
<tr>
<th>Location</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper femur</td>
<td>Force</td>
</tr>
<tr>
<td>Lower femur</td>
<td>Force</td>
</tr>
<tr>
<td>Centre of femur</td>
<td>Bending moment</td>
</tr>
<tr>
<td>50mm above centre of femur</td>
<td>Bending moment</td>
</tr>
<tr>
<td>50mm below centre of femur</td>
<td>Bending moment</td>
</tr>
</tbody>
</table>

The requirements to get the upper leg full score in Euro NCAP [3] are:
- total force < 5kN
- each of the 3 bending moments < 300 N.m
PRESENTATION OF THE STUDY

Presentation Of The Test Rig

To get a relative high number of tests, we decided to carry out simplified test instead of test on a full car. The simplified test is made of a test rig (a rigid frame) that supports two absorbers. These absorbers are made of blocks of polypropylene foam and will be impacted by the upper leg impactor. Figures 6 and 7 present the test rig.

![Figure 6](image1.png)

**Figure 6.** Drawing of the test rig used for characterization of the upper leg impactor scattering.

![Figure 7](image2.png)

**Figure 7.** Picture of the test rig used for characterization of the upper leg impactor scattering.

The two blocks of polypropylene foam present a 20 mm of difference in height to reproduce a non symmetrical contact with the upper leg impactor. They have a 90 mm square surface and a 45 g/l density.

For each test, the upper leg impactor is centered midway between the two blocks of foam. (see Figure 7).

![Figure 7](image3.png)

**Figure 7.** Drawing of the test between the upper leg impactor and the two absorbers.

Presentation Of The Two Test Series

In order to reproduce Euro NCAP test conditions, two test series were carried out. They are described in Table 2.

<table>
<thead>
<tr>
<th>Test parameters used in the two test series</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test parameters</strong></td>
</tr>
<tr>
<td>Mass of the Upper Leg impactor (kg)</td>
</tr>
<tr>
<td>Velocity of the Upper Leg impactor (km/h)</td>
</tr>
</tbody>
</table>

For each test series, two laboratories performed the test: Lab 1 and Lab 2.

In each laboratory, up to three different Upper Leg Impactors were used:
- the one of the Lab,
- the one of the other Lab
- and sometimes a third one that belongs to another lab.

These Upper Leg Impactors will be named UL1, UL2 and UL3.

Each impactor was systematically calibrated before the lab test series according to the Euro NCAP test protocol [1].
RESULTS

For each test series, two sets of results will be presented: the one measured in Lab 1 and the one measured in Lab 2.

Results Of Test Series 1 (Mass = 12.8 kg and Velocity = 31.0 km/h)

Results from Lab 1 are presented in Table 3, whereas results from Lab 2 are in Table 4. The analysis of the results will be presented in the next Section: “Analysis Of Test Results”.

Table 3.
Results from Lab 1 for Test Series 1

<table>
<thead>
<tr>
<th>Upper Leg Impacteur</th>
<th>Total femur force (kN)</th>
<th>Maximum bending moment (N.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL1</td>
<td>8.77</td>
<td>393</td>
</tr>
<tr>
<td></td>
<td>8.53</td>
<td>383</td>
</tr>
<tr>
<td></td>
<td>8.44</td>
<td>369</td>
</tr>
<tr>
<td></td>
<td>8.45</td>
<td>372</td>
</tr>
<tr>
<td></td>
<td>8.32</td>
<td>370</td>
</tr>
<tr>
<td>UL2</td>
<td>9.31</td>
<td>399</td>
</tr>
<tr>
<td></td>
<td>9.49</td>
<td>413</td>
</tr>
<tr>
<td></td>
<td>9.59</td>
<td>409</td>
</tr>
<tr>
<td></td>
<td>9.56</td>
<td>404</td>
</tr>
<tr>
<td>UL3</td>
<td>9.41</td>
<td>402</td>
</tr>
<tr>
<td></td>
<td>9.26</td>
<td>416</td>
</tr>
<tr>
<td></td>
<td>9.36</td>
<td>413</td>
</tr>
<tr>
<td></td>
<td>9.08</td>
<td>401</td>
</tr>
</tbody>
</table>

Table 4.
Results from Lab 2 for Test Series 1

<table>
<thead>
<tr>
<th>Upper Leg Impacteur</th>
<th>Total femur force (kN)</th>
<th>Maximum bending moment (N.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL1</td>
<td>9.57</td>
<td>414</td>
</tr>
<tr>
<td></td>
<td>9.66</td>
<td>415</td>
</tr>
<tr>
<td></td>
<td>9.75</td>
<td>417</td>
</tr>
<tr>
<td></td>
<td>9.62</td>
<td>415</td>
</tr>
<tr>
<td></td>
<td>9.52</td>
<td>424</td>
</tr>
<tr>
<td>UL2</td>
<td>9.60</td>
<td>426</td>
</tr>
<tr>
<td></td>
<td>10.10</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>9.41</td>
<td>422</td>
</tr>
<tr>
<td></td>
<td>9.56</td>
<td>423</td>
</tr>
<tr>
<td></td>
<td>9.79</td>
<td>431</td>
</tr>
</tbody>
</table>

Results Of Test Series 2 (Mass = 10.9 kg and Velocity = 24.2 km/h)

Results from Lab 1 are presented in Table 5, whereas results from Lab 2 are in Table 6. The analysis of the results will be presented in the next Section: “Analysis Of Test Results”.

Table 5.
Results from Lab 1 for Test Series 2

<table>
<thead>
<tr>
<th>Upper Leg Impacteur</th>
<th>Total femur force (kN)</th>
<th>Maximum bending moment (N.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL1</td>
<td>5.87</td>
<td>316</td>
</tr>
<tr>
<td></td>
<td>5.90</td>
<td>279</td>
</tr>
<tr>
<td></td>
<td>6.02</td>
<td>289</td>
</tr>
<tr>
<td></td>
<td>5.85</td>
<td>286</td>
</tr>
<tr>
<td></td>
<td>5.86</td>
<td>283</td>
</tr>
<tr>
<td>UL2</td>
<td>5.80</td>
<td>272</td>
</tr>
<tr>
<td></td>
<td>6.15</td>
<td>293</td>
</tr>
<tr>
<td></td>
<td>5.68</td>
<td>271</td>
</tr>
<tr>
<td></td>
<td>6.00</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>6.20</td>
<td>295</td>
</tr>
</tbody>
</table>

Table 6.
Results from Lab 2 for Test Series 2

<table>
<thead>
<tr>
<th>Upper Leg Impacteur</th>
<th>Total femur force (kN)</th>
<th>Maximum bending moment (N.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL1</td>
<td>5.31</td>
<td>274</td>
</tr>
<tr>
<td></td>
<td>5.22</td>
<td>268</td>
</tr>
<tr>
<td></td>
<td>5.25</td>
<td>269</td>
</tr>
<tr>
<td></td>
<td>5.41</td>
<td>276</td>
</tr>
<tr>
<td></td>
<td>5.63</td>
<td>287</td>
</tr>
<tr>
<td>UL2</td>
<td>5.24</td>
<td>278</td>
</tr>
<tr>
<td></td>
<td>5.24</td>
<td>280</td>
</tr>
<tr>
<td></td>
<td>5.22</td>
<td>283</td>
</tr>
<tr>
<td></td>
<td>5.37</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>5.36</td>
<td>286</td>
</tr>
</tbody>
</table>

ANALYSIS OF TEST RESULTS

Concerning the total femur force, we can notice that:
- The average femur force obtained during the first trial series is 9.27 kN.
- The average femur force obtained during the second trial series is 5.63 kN.
Concerning the total maximum bending moment, we can notice that:
- the average maximum bending moment obtained during the first trial series is 407 N.m.
- the average maximum bending moment obtained during the second trial series is 262 N.m.

**Analysis Of The Total Femur Force With Regards To The Recorded Trial Speeds**

Forces obtained during the first series according to the recorded trials speeds are shown in Figure 8. Whereas Figure 9 presents the total femur force obtained during the second test series according to the recorded trials speeds.

Therefore, we can conclude that for the two test series where impact parameters are close to Euro NCAP requirements, the maximum scatter can go up to 20% of the average femur force value.

**Analysis Of The Average Femur Force Values Obtained With The Same Upper-Leg Impactor And At The Same Laboratory**

Average femur forces obtained with the same upper-leg impactor and same laboratory for the first test series are presented in Figure 10.

Average femur forces obtained with the same upper-leg impactor and same laboratory for the second test series are presented in Figure 11.

The Euro NCAP protocol imposes to comply with the impact speed with a tolerance of 2%, this means 0.62 km/h in the first test series and 0.48 km/h in the second test series.

In the first test series, a maximum scattering of 1.82 kN was measured. This means a scattering of almost 20% of the 9.27 kN global average value for this test series.

In the second test series, a maximum scatter of 0.92 kN was measured. This means a scatter of almost 18% of the 5.63 kN global average value for this test series.

The maximum scattering measured for a same lab and a same upper leg impactor (what can be called repeatability scattering) is 0.69 kN for the first test series and 0.52 kN for the second one.

If we take into account all the different combinations of lab and upper leg (what can be called reproducibility scattering), we can derive an average scattering.
This average scattering, for the first test series is equal to:

\[
(0.23 + 0.69 + 0.33 + 0.38 + 0.28) / 5 = 0.38 \text{ kN}.
\]

And for the second test series the average scattering is equal to:

\[
(0.40 + 0.17 + 0.15 + 0.52) / 4 = 0.31 \text{ kN}.
\]

First of all, this means that there is no significant decrease of the femur force scattering with the impact energy.

Then, if we look at the average values obtained for the different lab and different upper-leg impactor combination, we get a scattering of 1.12 kN (which is 12% of the average value, 9.27 kN) for the first test series and 0.68 kN (which is 12% of the average value, 5.63 kN) for the second test series.

In conclusion, we can say that the reproducibility scattering (scattering between average values of different test configurations) is two times or three times higher that the average repeatability scattering (scattering measured inside a same test configuration: same lab and same impactor).

**Analysis Of The Average Values Of Bending Moment, Obtained With The Same Upper-Leg Impactor And At The Same Laboratory**

Average bending moments obtained with the same upper-leg impactor and same laboratory for the first test series are presented in Figure 12.

![Figure 12. Comparison of femur forces (average and scatter) measured in the same lab and with the same upper leg impactor for the first test series](image)

Average bending moments obtained with the same upper-leg impactor and same laboratory for the second test series are presented in Figure 13.

![Figure 13. Comparison of bending moments (average and scatter) measured in the same lab and with the same upper leg impactor for the first test series](image)

The maximum scattering measured for a same lab and a same upper leg impactor (what can be called repeatability scattering) is 28 N.m for the first test series and 23 N.m for the second one.

If we take into account all the different combinations of lab and upper leg (what can be called reproducibility scattering), we can derive an average scattering. This average scattering, for the first test series is equal to:

\[
(24 + 14 + 15 + 9 + 28) / 5 = 18 \text{ N.m}
\]

And for the second test series the average scattering is equal to:

\[
(20 + 23 + 20 + 7) / 4 = 17.5 \text{ N.m}
\]

First of all, this means that there is no significant decrease of the bending moment scattering with the impact energy.

Then, if we look at the average values obtained for the different lab and different upper-leg impactor combination, we get a scattering of 53 N.m (which is 13% of the average value, 407 N.m) for the first test series and 33 N.m (which is 12% of the average value, 262 N.m) for the second test series.

In conclusion, we can say that the reproducibility scattering (scattering between average values of different test configurations) is 1.5 to 2 times higher that the average repeatability scattering (scattering measured inside a same test configuration: same lab and same impactor).

**CONCLUSIONS**

We assessed the scattering of the upper-leg impactor through tests carried out in two laboratories with up to three different impactors. The tests we made were close to the Euro NCAP impact energies applied to current cars. Therefore
we can assess the scattering of the Euro NCAP upper leg impactor tests. We measured we can be called repeatability scattering and reproducibility scattering. As expected, the repeatability scattering is always smaller than the reproducibility scattering.

These strong scatterings can be bound to the choice of the impactor, to the choice of the laboratory, the temperature, the impacted element, or the hygrometry.

By taking as an hypothesis that by increasing the number of tests, the Gaussian centre would be close to the calculated average values, we found that the maximum scattering between 2 pairs (laboratory / impactor) is 12 % of each of the two biomechanical criteria average.

Then, we can apply this scattering value in the Euro NCAP pedestrian rating. We recall that the maximum of points in the pedestrian upper-leg Euro NCAP protocol is given when the total femur force is lower than 5 kN, and the maximum bending moment lower than 300 N.m. We also recall that the femur zone is divided into 3 parts, each of them receive a maximum of 2 points in the Euro NCAP rating. Therefore, a 12% scattering of the biomechanical criteria level, will give a difference of 1.2*3=3.6 points for the total femur force and 0.9*3=2.7 points for the maximum bending moment, out of 6 in the pedestrian upper-leg Euro NCAP rating. So, we can lose a maximum of 3.6 points out of 6, for a target from 5kN and 300 N.m. As a final conclusion it should be stressed that this assessment of the upper-leg scattering will be added to other scatterings such as the difference in car behaviour or the scatter in the impact points.

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REFERENCES


