QUANTIFICATION OF THE SCATTERRING DUE TO THE DUMMY SET-UP IN SIDE POLE IMPACT

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ABSTRACT

Up to 2008, in the Euro NCAP rating, the assessment of the adult protection in pole test was only made through the head criteria. From 2009, the pole test in the new "overall rating" Euro NCAP protocol will take into accounts all body regions (head, chest, abdomen and pelvis).
The aim of this study is to analyse the scatter of biomechanical criteria linked to these different body regions. Three phases were defined:

- Phase 1: analysis of a large number of pole tests in order to identify what body region was the most scattered.

- Phase 2: quantification of the scatter linked to the car, seat and dummy set-up. Ten trials of dummy set-up in three laboratories and on three types of vehicles were analysed. The first one of these trials was for reference, since it followed rigorously the vehicle and dummy set-up protocols proposed by Euro NCAP. The other trials were made to assess the scattering by varying several parameters such as vehicle mass, type of dummy, operator. These trials gave us the maximum scattering that could exist and that can be reproduced in dynamic tests.

- Phase 3: quantification of the consequences of the dummy positioning on the pole test's dummy readings. Indeed, several pole tests will be carried out on identical vehicles with different dummy positioning.

The results of this study will have to be linked to their consequences on the biomechanical criteria, in particular on the chest and abdomen.
Recommendations are given to improve the dummy set-up procedure by taking into account these possible scattering of the dummy positioning and by proposing counter measure to avoid them in a future protocol.

INTRODUCTION - AIM OF THE STUDY

A new balance appears with the brand new Euro NCAP overall rating, since new criteria or new tests come into force. One of the important changes is the pole test assessment which has been widely extended [1], [2]. Indeed, now all the body regions are rated (head, chest, abdomen and pelvis). By studying into details this new protocol and the results measured on the different body regions, it can be noticed a large scattering that needs to be quantified and controlled. This study takes place in this context.

In order to determine the reliability of the current Euro NCAP pole test assessment (4 body regions: head, chest, abdomen and pelvis), a test programme had been defined. The purpose is :

- to assess the scattering on dummy set-up

- to find the key test parameters/ conditions which influence repeatability and reproducibility of the contemplated test procedure.

- to assess the impact of the scattering on dummy set-up on the biomechanical criteria

- to prepare recommendations for the dummy pole test procedure.

Before going further into the details of this study, it should be wise to recall the main requirements of the Euro NCAP pole test impact protocol.

MAIN REQUIREMENTS OF THE POLE TEST IMPACT PROTOCOL

Car Preparation

The first part of the protocol is the preparation of the car. A reference weight is defined through the vehicle kerb weight. And after preparation, dummy and data acquisition system installations, the test mass is measured. It is important to notice that some tolerances are allowed between the reference weight and the test mass. For instance, 50 kg of difference on the front and rear axles can be OK.

Initial Seat Position

The impact line between the pole and the car is directly derived from the ES2 dummy's head position (Head Center of Gravity, named Head CG for the rest of the study).
For this purpose, it is needed first to define the initial position of the driver seat.

The driver seat is put in its mid rails / fully down position. The torso angle is measured on the H-Point Machine (named Oscar for the rest of the study). It has to be set to the manufacturer design position generally around to 22-25°.
Then, the H-point is measured on the Oscar, in order to position the ES2 in its initial position.
As a reminder, it may be interesting to recall that the initial ES2 H-point coordinates should be inside a 10 mm circle from the Oscar H-point ones.
We called this initial seat position: **"Step 1"**

Final Seat Position

When the ES2 is installed in its initial position, a specific distance has to be measured: the "daylight opening distance". This distance is measured between a reference point on the car and the rearmost point of the dummy head. Both of them have to be taken at the same height as the Head CG.
Note: At this stage, it is easy to notice that if between two cars, the dummy Head CG is not at the same height, then, two different reference points will be taken on the two cars (the front door daylight opening). Indeed, most of the time, the front door daylight opening is not vertical, therefore, these two points will probably not be at the same position in X.

If the daylight opening distance is 50 mm or more, the dummy will stay in its initial position and the impact point will be the initial Head CG position in X.

But if the daylight opening distance is less than 50 mm, it is required to change the seat set-up. There is a definite order to follow:

- first, the seat back has to be put upright, but it cannot be more than 5° change from the initial position. We call this action: **"Step 2"**
- if the daylight opening distance is still less than 50 mm, the seat is moved forward until the 50 mm is achieved or until the knees of the dummy contact the dashboard. We call this action: **"Step 3"**
- if the daylight opening distance is still less than 50 mm, the seat back have to be put upright again. On the vast majority of our cars, we do not need to go into this step.

At the end of this part, we can measure the Final ES2 H-point.

Impact Line Definition

The car has to impact the pole along the vertical line that passes through the ES2 dummy's head position (the Final Head CG).

Partial Conclusion

Since the main parameter is the daylight opening distance, one can easily imagine that if a dummy has a different initial head position, or if the seat back initial angle is set in a different way, the impact line can differ as well as the biomechanical results. This is what we will show in the next chapter.

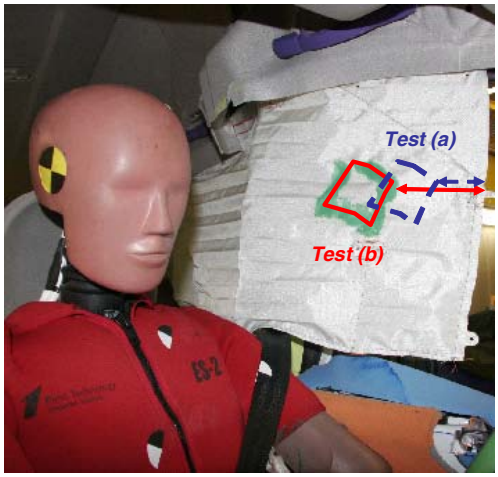
PHASE 1: ANALYSIS OF A LARGE NUMBER OF POLE TESTS

The first need to carry out such a study came from the comparison of two tests made on a PSA car in two different laboratories. These laboratories strictly followed the Euro NCAP protocol, and one of them is even Euro NCAP accredited.
The difference in the dummy test position and therefore in the pole impact line between the two tests are shown in Figure 1 (a) and (b).

Because of this difference in the dummy positioning, the head impacted a different zone on the curtain airbag. The head impact in the first test was twice forward from the extreme front of the curtain airbag as shown in Figure 1 (c).

(a)

(b)



(c)

Figure 1. Dummy test position for a same car in two different test laboratories (a) and (b), and its consequences on the impact against the curtain airbag (c).

This paragraph presents analyses on pole test realised with several PSA Peugeot Citroën's vehicle models. The results taken into account come from at least 4 pole tests carried out in different test laboratories. This means with different operators, different ES2 dummies and different cars of the same model.

The main outcomes are presented by taking an example on three vehicles that belongs to three different marketing segments:

- Car A: a small family car
- Car B: a family car – SUV type
- Car C: an executive car

Table 1 presents the overall scattering results from these 3 cars on the main test parameters. The scattering is reckoned as the difference between the maximum value measured on the different tests and the minimum value.

Table 1.
Overall scattering results from these 3 cars on the main test parameters.

Scattering	Car A	Car B	Car C
Final Head CG (mm)	8	33	-
Final H-point X (mm)	27	32	25
Final H-point Z (mm)	6	20	3
Test Mass (kg)	18	7	-
Pole test score (pts) Max. score = 16 points	2.98	2.9	1.2
% from max score	19 %	18 %	8 %

We can notice that for a car model, the overall scattering of the pole test can give a variation of 20% on the total score that can be obtained (16 points). This is really important and needs to be decreased. If we go a little bit further into the analysis, we can see the scattering in the biomechanical max values used in the Euro NCAP pole test rating.

But we also need to identify if there is a specific body region that sustained the most scattering.

For instance, it is clear from our analysis that the scattering on the head results (HIC or head resultant acceleration) has no effect on the Pole Test Rating.

On the other hand the three other body regions can be considered as sensitive to the scattering as it can be shown in Table 2.

Table 2 presents the biomechanical scattering results for these 3 cars. Here again, the scattering is reckon as the difference between the maximum value measured on the different tests and the minimum value.

Table 2.
Biomechanical scattering results from these 3 cars on the main test parameters.

Scattering	Car A	Car B	Car C
Pole test score (pts) Max. score = 16 points	2.98	2.9	1.2
Chest Compression (mm)	13.6	8.8	11.8
Back Plate force (kN)	0.2	0.14	0.25
T12 Force (kN)	0.61	1.07	0.34
T12 Moment (kN)	31	36	35
Abdomen Peak force (kN)	0.36	0.79	0.16
Pubic Symphysis force (kN)	0.51	0.91	0.35

As an example, it is interesting to stress that a difference of 13.6 mm in maximum chest compression can give a score from 2.72 points to 0 point, out of a maximum of 4 points.
In the same way, a difference of 0.8 kN in the Abdomen Peak force can lead to a score that goes from 2.13 points to 0 point, out of a maximum of 4 points.
Finally, a difference of 0.9 kN in the Pubic Symphysis force can lead to a score that goes from 1.2 points to 0 point, out of a maximum of 4 points.

Partial Conclusion

This first phase of the analysis clearly show that there is a significant scattering of the pole test results that can gives a high difference of Euro NCAP rating score.

Therefore, there is a need to better control the test parameters and to know which parameters are

linked to this scattering. This is the purpose of the next chapter that presents the 2nd phase of our analysis.

PHASE 2: QUANTIFICATION OF THE SCATTER

Presentation Of The Study

The study was performed on three different car models:

- Car 1: a small family car
- Car 2: a family car
- Car 3: an executive car

For each vehicle model, the same car was circulated to three different test laboratories (Lab 1, Lab 2 and Lab 3). So, we already removed the scattering due to the difference in car production. These three test laboratories are Euro NCAP crash test accredited.

For each car, we asked the labs to perform 10 different trials. Some of the trials were purely identical, in order to assess full **repeatability**.

Whereas some others were voluntarily modified, in order to take into account a difference of mass, a different operator, a different Oscar or a different ES2 dummy while still following the official pole impact test protocol.

These trials will give an assessment of the **reproducibility** within each lab.

Finally the comparison of the three labs will give the full assessment of reproducibility; what we can call the **overall reproducibility** (or overall scattering).

For each trial, we asked the lab to completely start as if it was a new car. Therefore, even the initial seat set-up was carried out again (e.g. setting the seat rail in mid position, finding the initial seat torso angle).

The only parameters we imposed were the car XYZ reference and axes and three points of measurement on the seat and on the seat back. The three seat reference points were used to quantify the change between step 1, step 2 and step 3 (see definition in Chapter "Main requirements of the pole test impact protocol").

Note: all the car models selected needed to go up to step 3 to get the proper daylight opening distance.

The complete test matrix, for each lab and each car is given in Table 3.
For each trial, we defined the parameters to measure and we used a common and unique datasheet to gather all the parameters.

Table 3.
The complete test matrix carried out for each lab and each car.

Test reference number and description		Operator n°1	Oscar n°1	ES2 n°1	Mass n°1	+50 kg front axle	+50 kg rear axle	Operator n°2	ES2 n°2	Oscar n°2
RA	Reference	X	X	X	X					
RB	Reference (repetition test)	X	X	X	X					
RC1 - 3	Partial repetition test	X	X	X	X					
OP1	Operator change		X	X	X			X		
OP2	Operator change (repetition test)		X	X	X			X		
E1	ES2 dummy change	X	X		X				X	
E2	ES2 dummy change (repetition test)	X	X		X				X	
OS1	Oscar change	X		X	X					X
MA1	Front axle tolerance	X	X	X		X				
MA2	Rear axle tolerance	X	X	X			X			

For each main change, we asked for a repetition test. This is the reason why there is an OP1 and an OP2, as well as an E1 and E2, and an MA1 and an MA2.

For test RC1-3, the idea was to keep the seat position as initially defined by the first dummy set-up (in RC1).

Then, after the full RC1 test was carried out, RC2 and RC3 started with the positioning of the ES2 in the final seat position defined in RC1 to measure the final H-Point, the final Head CG and the final daylight opening distance.

The main parameters that were gathered are:

- H-Point X and Z initial as well as for each step (including the final H-Point)
- Head CG X and Z initial as well as for each step (including the final Head CG)
- Seat back Angle initial as well as for each step
- Number of seat back notches for Step 2
- Number of seat rail notches for Step 3
- Daylight opening distance initial as well as for each step
- Seat reference point 1, 2 and 3 initial as well as for each step

Overall Results Of The Study

A quick analysis showed that counting the notches (for the seat back angle as well as for the seat rails) is not reliable and can lead to errors. Indeed, when one tries to put the seat back upright with the ES2 dummy in the seat, it is quite easy to miss one notch. Therefore it is far much more reliable to measure an angle in degrees or a forward movement in millimetres than to count notches. This is the reason why we will not show in this study any value linked to the number of notches.

The first drawings we created were to compare the four main parameters for each car:

- the initial Oscar H-Point
- the final ES2 H-Point
- the initial Head CG
- the final Head CG

In these drawings, we do not try to distinguish the lab or the other changes in the test parameters.

This gives the results shown in Figure 2 to 4.

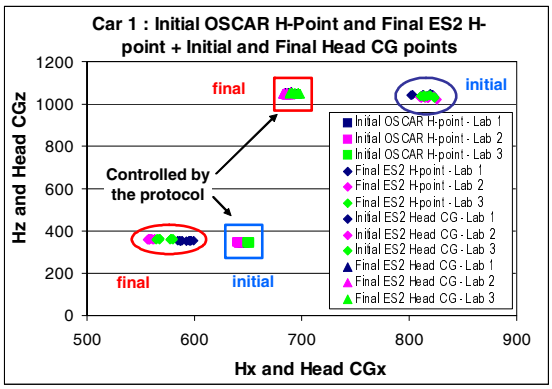


Figure 2. Overall scattering of the 4 main parameters for Car 1.

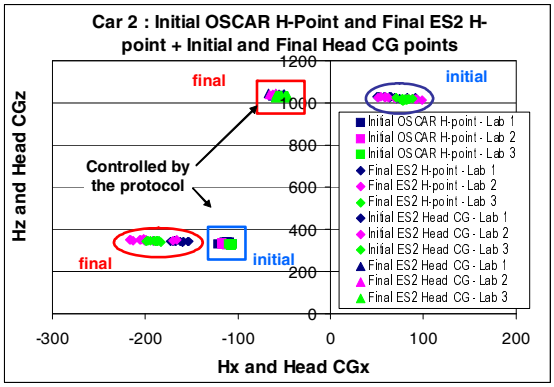


Figure 3. Overall scattering of the 4 main parameters for Car 2.

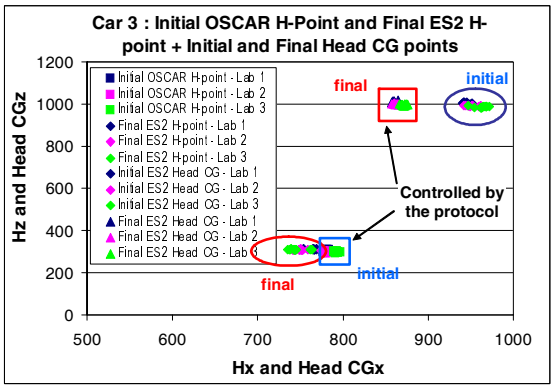


Figure 4. Overall scattering of the 4 main parameters for Car 3.

By looking at these drawings, one can notice that the initial Oscar H-Point and the final Head CG are less scattered than the initial Head CG and the final ES2 H-Point. This is completely linked to the test protocol that controls the initial H-Point and the Final Head CG through the daylight opening distance.

But if the two other parameters are scattered, this means that the dummy is not in the same final position. This is shown by one example presented in Figure 5.

(a)

(b)

Figure 1. Dummy test position for a same car in the same test laboratory but with two different test configurations (a) and (b) both fulfilling the Euro NCAP test protocol.

So, we need to know what the differences are in the dummy position, which extent and if it is due to the bad repeatability of the test procedure or to the bad reproducibility.

Figure 6 to 9 give some examples of the extent of the overall reproducibility for the 4 parameters without distinguishing the labs.

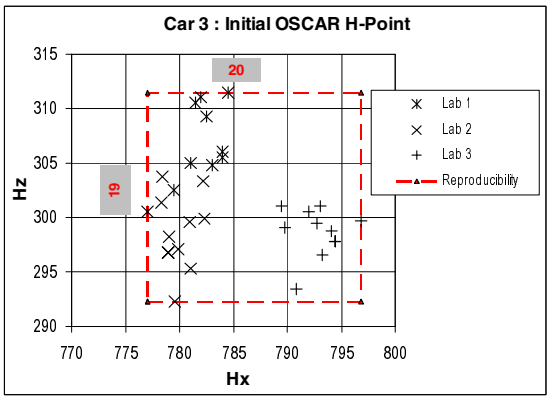


Figure 6. Overall scattering of the Initial Oscar H-Point for Car 3.

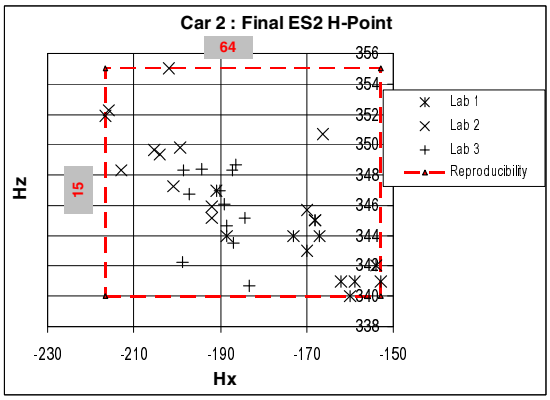


Figure 7. Overall scattering of the Final ES2 H-Point for Car 2.

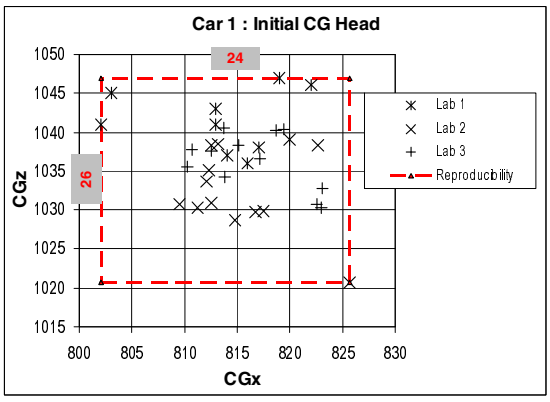


Figure 8. Overall scattering of the Initial Head CG for Car 1.

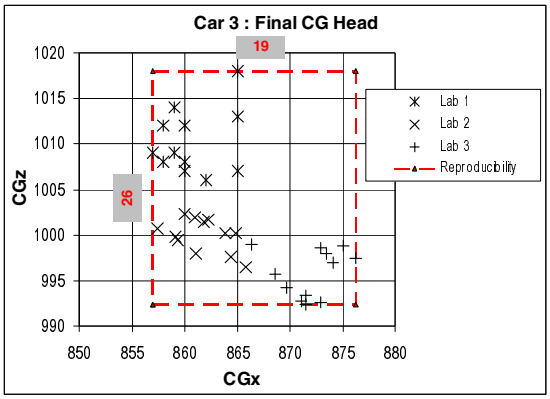


Figure 9. Overall scattering of the Final Head CG for Car 1.

Table 4 gives the complete results of the overall reproducibility scattering for the 4 main parameters.

Table 4.
Overall scattering results (reproducibility) for the 3 cars on the 4 main parameters.

Scattering (mm)	Car 1	Car 2	Car 3
Initial Oscar H-Point X	13	15	20
Initial Oscar H-Point Z	7	15	19
Final ES2 H-Point X	43	64	39
Final ES2 H-Point Z	13	15	11
Initial Head CG X	24	49	31
Initial Head CG Z	26	21	28
Final Head CG X	16	21	19
Final Head CG Z	13	20	26

From Table 4, we can notice that there is no car more scattered than the two others.

Overall Reproducibility And Best Repeatability Analysis

Before going into details to identify if there is one test parameter more sensitive than another, we decided to define what could be the minimum repeatability scattering. For this purpose, we looked at the results lab by lab and we found that Lab 3 gave less scattering than the others for the reference tests. Therefore, we decided to say that the repeatability cannot be lessened more than the scattering measured in lab 3 on the reference tests (RA, RB, RC1-3). We called the Lab 3 repeatability, the "best repeatability".

Combining this definition of repeatability with the distinction between the different test parameters, we got graphs that show that the overall reproducibility (by taking all the labs) is from 1.3 to 4.8 times larger than the best repeatability (Lab 3 repeatability). Examples are shown in Figure 10 to 13.

The other points shown on the graphs present the extreme values of each repeated test parameter (change of operator, change of Oscar, change of ES2, change of Mass) taking the three labs into account.

Figure 10 shows the case of a reproducibility scattering 4.8 times larger than repeatability (initial Oscar H-point X). And Figure 11 shows the case of a reproducibility scattering 1.3 times larger than repeatability (Final ES2 H-point Z). These are the extreme values we got in our study.

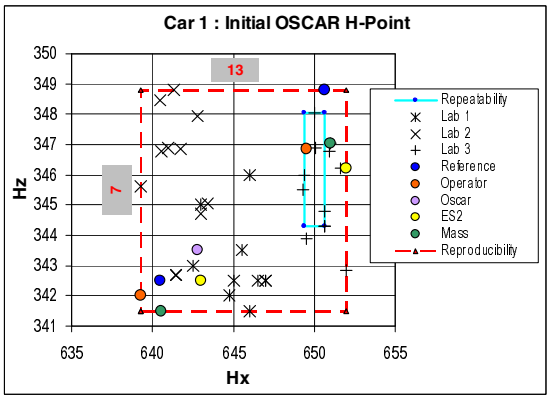


Figure 10. Overall scattering of the Initial Oscar H-Point for Car 1.

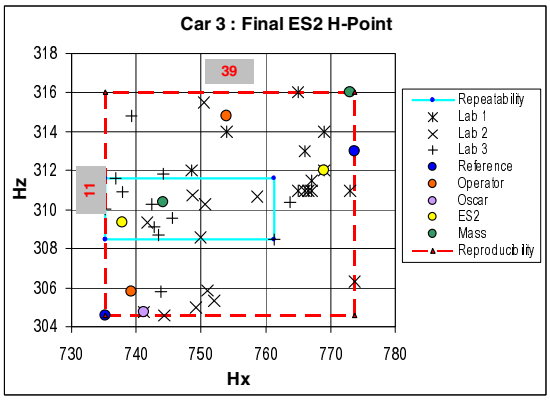


Figure 11. Overall scattering of the Final ES2 H-Point for Car 3.

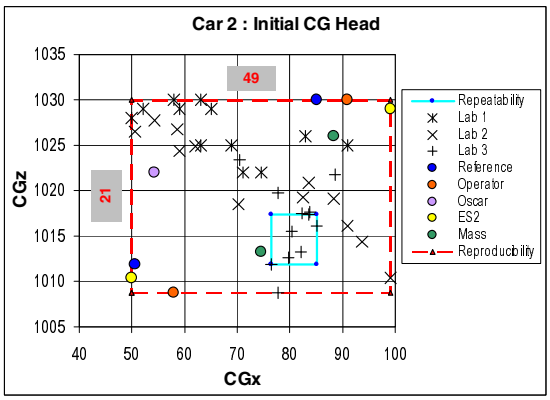


Figure 12. Overall scattering of the Initial Head CG for Car 2.

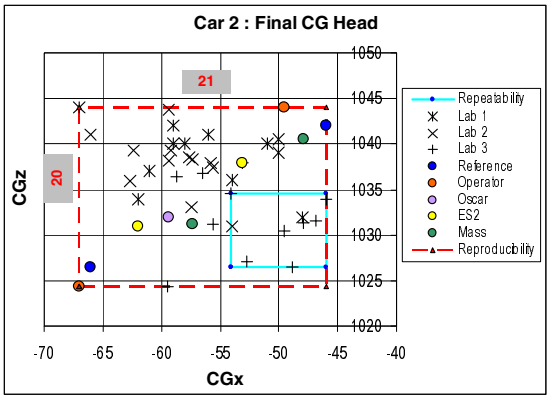


Figure 13. Overall scattering of the Final Head CG for Car 2.

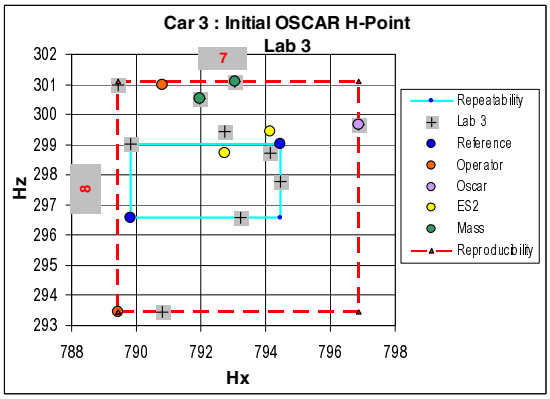


Figure 14. Scattering of the Initial Oscar H-Point for Car 3 in Lab 3 (Best Repeatability).

The distinction between the different test parameters does not give clear trends.

If we look at the reference scattering (blue circles) we can find that it highly contributes to the overall reproducibility. This conclusion is logical since the reference scattering is made of the reference tests carried out in the three labs. So, it already includes a different Operator, a different Oscar and a different ES2 dummy between the three laboratories. So, we logically find the contribution of three test parameters in the scattering named reference scattering.

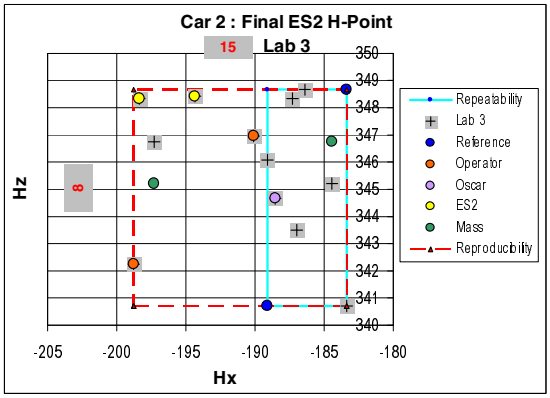


Figure 15. Scattering of the Final ES2 H-Point for Car 2 in Lab 3 (Best Repeatability).

Analysis Of The Best Repeatability And Its Reproducibility

To get a trend of the influence of each test parameters, we studied the results of Lab 3 only. Some of the results are presented in Figures 14 to 18.

For some exceptional cases, Lab 3 repeatability and Lab 3 reproducibility are identical. This is the case for Car 1 Initial CG Head (Figure 16). In this case, changing the dummy didn't give an extra scattering to add to the scattering measured by repeating the reference test.

On the other hand, for the same parameter, but for Car 2, changing the ES2 doubles or triples the scattering (Figure 17).

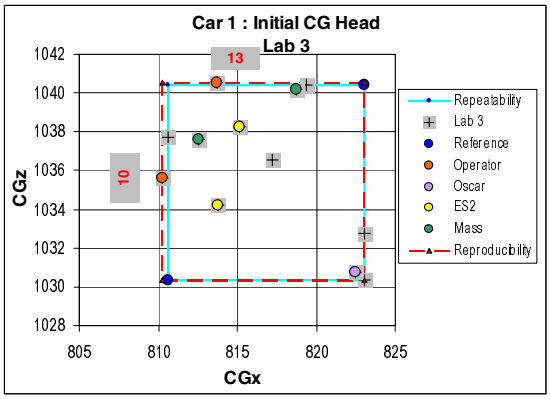


Figure 16. Scattering of the Initial Head CG for Car 1 in Lab 3 (Best Repeatability).

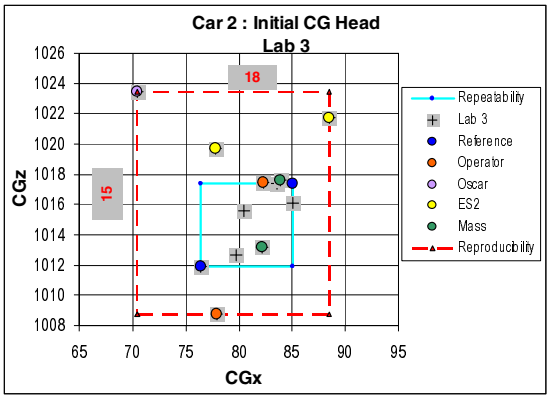


Figure 17. Scattering of the Initial Head CG for Car 2 in Lab 3 (Best Repeatability).

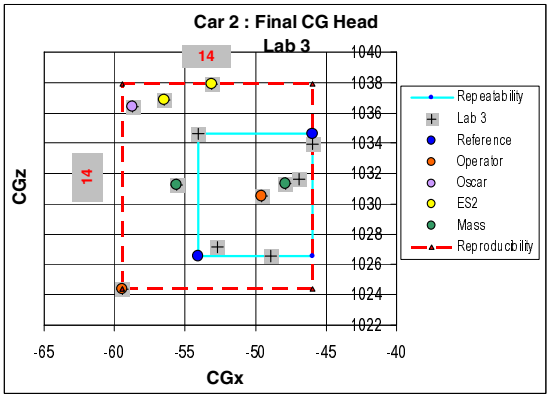


Figure 18. Scattering of the Final Head CG for Car 3 in Lab 3 (Best Repeatability).

DISCUSSION

Assessment Of The Scattering

First of all, from all our analysis, we couldn't highlight a car that gives more scatter than the two others.

We measured the scattering of repeating a same test, with the same tools in the three laboratories and we found that there is one lab that gives better results than the two others. From this remark we can assume that repeatability cannot be lessened more than what we got in Lab 3, without changing the test protocol.
So we know that the **best repeatability** scattering can be:

- a Final H-Point within 26 mm in X and 8 mm in Z
- a Final Head CG within 8 mm in X and 8 mm in Z

But we also measured, within the same lab; a higher scattering as soon as one parameter is changed (whether it is the Oscar, the ES2, the mass or the Operator).
Therefore, the assessment of the best reproducibility (within one lab) is:

- a Final H-Point within 28 mm in X and 9 mm in Z
- a Final Head CG within 14 mm in X and 14 mm in Z

So, even by looking only at the results obtained in Lab 3, we can have up to 28 mm of scattering on the Final ES2 H-Point in X.
For information, this value comes from a change in the mass with respect to a reference test.

In addition, the 14 mm of scattering found on the Final Head CG in X does not come from a change in the ES2 dummy but from a change of Operator! This will change by 14 mm the pole impact line against the car whereas the set-up was carried out in the same laboratory.

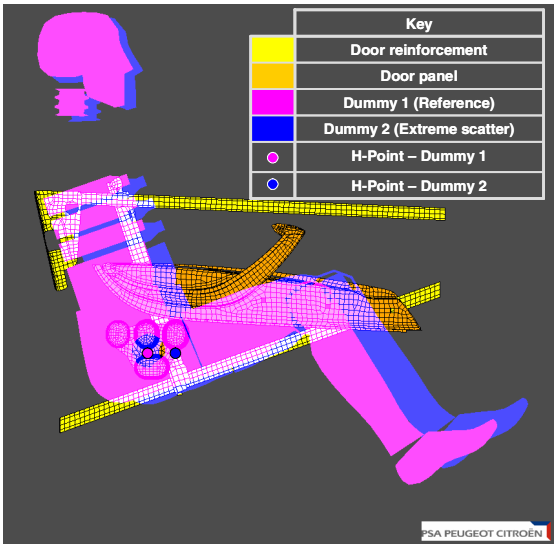
Now, if we look at the **overall reproducibility** - a case we can easily encounter when we develop a car in one lab and we assess its performance in the Euro NCAP rating in another lab - we find:

- a Final H-Point within 64 mm in X and 15 mm in Z
- a Final Head CG within 21 mm in X and 26 mm in Z

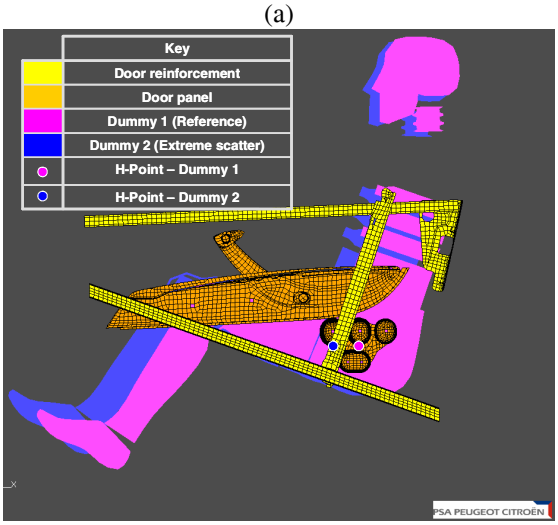
So, between two laboratories, the pole impact line may change by up to 21 mm while fulfilling all the Euro NCAP requirements. And at the same time, we can also have a final H-Point X scatters at 64 mm!

To try to represent the consequences of these two extreme positions a dummy can have in one car, we can get what is shown in Figure 19:

- Dummy 1 is the reference dummy
- Dummy 2 shows the dummy position with the extreme scatters
- Figure 19 shows the superposition of the dummies with the door reinforcements and door panel



(a)



(b)

Figure 19. Drawing of the two extreme positions a dummy can have in one car following the results of our study – (a) view from the car inside and (b) view from the car outside.

Now, we need to quantify exactly the consequences on the dummy readings. We will take the extreme positions defined in the study. But we already know that these dynamic tests will also give some extra scatterings since two different dummies will not have the same dynamic behaviour.
This will be made in a future phase, not yet realised.

Parameters To Measure Or Control During The Test Preparation

By following the tests in the different laboratories, it has been highlighted that some extra parameters have to be measured and controlled.

We need to avoid checking the changes between step 1, step 2 and step 3 by counting the number of notches in the seat back angle or in the seat rails.

Clearly, if we have something to check, we need to ask for the seat back angle change in degrees and the seat forward motion in millimetres. In addition, for the seat back angle change, we also need to clearly define how to measure it (on the head restraint stem angle, for instance, with an inclinometer or directly through some CMM measurements).

Moreover, the test protocol could also be better defined. Some pictures could be added to the different steps; to be sure operators will follow the same set-up. This is especially true for the definition of the daylight opening distance (we saw some hesitation between the way to take the reference point: door open or door closed?).

In the same way, some tolerances need to be added. For instance, the protocol states that for step 2 the angle could not be changed by more than 5°. But in some cars we have seat back articulation that moves 1.8° by 1.8° (one more notch gives a 1.8° change in seat back angle). Therefore, being less than 5° means two notches = 3.6°. On the other hand, going to the third notch will give 5.4° total change which is quite closer to 5° than the initial 3.6° change. Do we allow some tolerance to the maximum change of 5°? Or do we need to be strict even if only 3.6° are taken out of 5°?

Finally, the dummy intrinsic head position is of extreme importance. We already showed that in the phase 1 of our study. A specific zoom is given in Figure 20.

Figure 20. Two extreme final positions of the ES2 dummy head in real Euro NCAP-like pole impact tests.

This head position is not controlled by the dummy calibration and no specific device can be used to adjust it. The only explanation of the difference in the angle is the fact that there is the possibility of using three types of nodding blocks (rubber elements) of different stiffness. But the stiffness of these nodding blocks has to be chosen to fulfil the neck corridor. Normally, when using a brand new neck, the softer nodding blocks are used. Then, after several tests, there is a need to come to the mid-softness nodding blocks. And finally after some more tests, it is required to use the harder

nodding blocks to be sure the neck corridor is still fulfilled.
So, changing the nodding blocks or imposing one specific type of nodding blocks will not be possible unless multiplying by three the number of neck to buy and replace.

CONCLUSIONS

In order to assess the scattering of the pole test, we conducted a study on the dummy set-up and impact line set-up of three different car models in three different laboratories. Each laboratory used a same reference set-up (same Operator, same Oscar, same ES2 dummy and same mass repartition) and repeated it three to five times. Each lab also followed our demand to change one parameter after the other while still fulfilling the Euro NCAP pole test impact requirements. Every time, the measurements were repeated once.
With the whole database, we derived an assessment of the scattering and we shown that the final position of the dummy can be scattered from 64 mm in the ES2 final H-Point X coordinate and 21 mm in the ES2 Head CG X coordinate. This will change the position of the whole dummy with respect to the car inside (door panel, side airbag, curtain airbag) as well as a change in the pole impact line on the car.
We were able to assess the overall reproducibility but also what we can call the best repeatability. Indeed, we found one lab which gives less scatters than the others when repeating the test measurements with the same tools. But on the other hand, even in this lab, changing only one parameter gave an extra scatters.

This analytical study will also be analysed with a specific statistical tool which will be presented in the oral document. This will help to highlight if one test parameter, or tool, is more sensitive than the others.

Finally, the full study will be finished when we reproduce the extreme dummy positions in dynamic tests and we quantify the changes in the dummy measurements. This is planned to be carried out later this year.

But even without performing these extreme test positions, we already have an assessment of the scattering in the dummy readings, through dynamic tests carried out at different test labs, as presented in the phase 1 of our study. The maximum scattering we had, without trying to assess an extreme scattering, was 2.98 points out of 16. This is already of enough importance to pay attention and try to reduce the scatter.

We hope other studies will be carried out on the same topic, so that more expertise will be added, and probably the test protocol will be improved to control and restraint the overall scattering of the pole test impact.

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