DETAILED ANALYSIS OF BIORID-II RESPONSE VARIATIONS IN HARDWARE AND SIMULATION

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ABSTRACT

The BioRID-II rear impact dummy is used for assessing the level of protection of car seats against whiplash associated disorders (WAD) for many years. This level of protection is evaluated in consumer tests. For these tests comparatively low thresholds were introduced. Many questions which are related to injury criteria and their respective biomechanical tolerance levels remain unresolved. These low load ranges hold a claim against a high robustness of measuring devices used with respect to repeatability and reproducibility. However, especially the low load range and the low signals from the sensors show a certain variation. Therefore, a reliable assessment of the level of protection of car seats is difficult.

The presented study is focused on the assessment of repeatability and reproducibility of the BioRID-II. A series of sled tests with eight individual BioRID-IIg dummies were conducted under well defined and controlled boundary conditions. The dummies were placed in four hard bucket seats to ensure stable test conditions and to avoid any variation generated by regular car seats. Variations caused by the seats and the seating procedures were minimized by testing every dummy in each seat. Particular attention was paid to very accurate test reruns to keep the test variations as small as possible.

Dummy certification tests prior and after the test series were conducted to determine possible changes of the dummy performance induced by the test program.

Finally, the study was completed by running simulations and parametric studies with the FAT BioRID-II FE-model. The objective of this computational investigation was the identification of potential causations for the variances particularly seen in the upper and lower neck responses.

INTRODUCTION

Whiplash associated disorders (WAD) are characterized by a collection of symptoms that usually occur due to sudden extension and flexion of the neck. Typically, WAD are mainly sustained in rear-end collisions of car accidents. The severity of the WAD experienced by the passengers may not be related to the speed of the cars involved in the accidents or the amount of physical damages to the car. Therefore, it is possible that already low impact speeds can produce enough energy to cause WAD in occupants, whether or not they wear seat belts.

WAD sustained in rear-end accidents are still a major concern in road traffic safety. In recent years, many research activities were undertaken to investigate the injury mechanism and injury criteria related to whiplash associated disorders. Although, the underlying injury mechanism of WAD is still not fully understood, several injury predictors are proposed. Some of these injury predictors show good correlation with real world accident studies and seem suited to assess the risk of WAD. However, due to the complex nature of the injury even for those criteria uncertainties remain with respect to the threshold values suggested. Despite these uncertainties, there are indications that an improved seat design reduces WAD. Most of the car manufacturers have begun to improve the seat design or implement various whiplash protection devices in their products in order to reduce the risk of WAD. The introduction of consumer rating programs for rear impact loading conditions attempt to give an assessment for the potential risk of WAD.

The BioRID-II dummy is widely introduced as a measurement tool to assess the potential risk of WAD of car seats under dynamic test conditions. The development of the BioRID was started in 1995 with the aim to get a dummy with humanlike kinematics primarily in a rear-end impact and secondarily in frontal impacts. In 2002 the production version BioRID-IIa with a fully articulated humanlike spine was released from Denton Inc. In terms of improvements to be addressed on the dummy, many updates took place which leads to the current build level version G released in 2003, the BioRID-IIg. It is out of questions that the BioRID-IIg dummy shows good biofidelic kinematics based on the detailed designed spine with large degree of freedom. However, the combination of variations of the dummies, car seats and test conditions with a very low load level can possibly lead to considerable variations of the dummy responses which have often been reported. For the development of head restraint systems, it is essential to have also a reliable development tool available with a minimum of measurement variances under identical test conditions.

This study deals with the investigation of the repeatability and reproducibility capabilities of eight different BioRID-IIg dummies under well defined boundary conditions in sled tests. In addition the dummy responses were applied to different rating schemes to demonstrate the variations of rating results, even under well defined boundary conditions. Certification data prior and after the test series were also analyzed to keep records on possible changes of the dummy performance due to the test program. The data obtained in the test series were used to investigate differences in testing and numerical simulation.

APPROACH

The scatter of the BioRID responses in whiplash test scenarios is often discussed and analyzed [1, 2, 3]. However, influence of test sub-systems like dummy, seat or test facility on the global variances remains open. This study is purely focused on the dummy.
The main influence parameters in a whiplash test are positioning of the dummy, variances of the crash pulse and last but not least probably variances of the seat. These factors were eliminated by testing each dummy on every seat, by running three repetitions of each test set-up and finally, by the use of race car seats. These hard bucket seats withstand dozens of tests without any damage. So there was no need to replace the seats after each test.
In total eight BioRID-IIg were analyzed in this study. So the total number of tests per dummy is 12. At the end there is a very unique sample of 96 dummy data sets with comparable boundary conditions. This is sufficient information to analyze the repeatability as well as the reproducibility of the BioRID.

METHODS

Many of the studies on repeatability and reproducibility suffer on the unknown variations of vehicle seats. Therefore, it was decided to use hard bucket seats coming from racing cars. As these seats withstand whiplash tests without any damage, it was possible to use them during the whole test program.
Furthermore, the seats fitted almost perfectly to the BioRID. Its posture was very stable and it was easy to place the dummy into the seats. The backrest supported the whole back of the dummy.
Every dummy was checked and certified by the dummy manufacturer prior to the test program. After completion of the test program the dummies were checked and certified by the manufacturer again by conducting an initial and outgoing certification tests, to detect possible changes in the dummy performance respectively hardware.

Geometric Measurements

The seats were measured with the SAE-J826 H-Point Manikin with Head Restraint Measuring Device (HRMD) in order to determine the H-Point and the backset of each individual seat. The backset is defined as the horizontal distance between the rearmost located point of the head cap and the related contact point at the head rest.

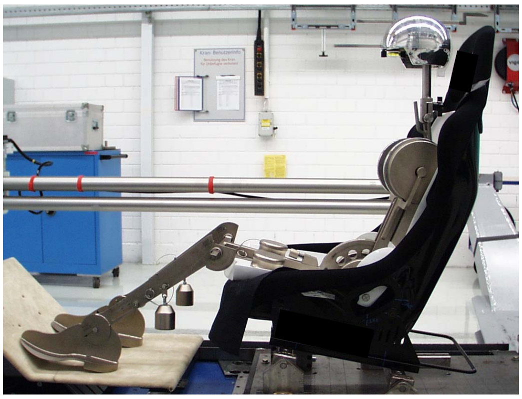

Figure 1. Hard bucket seat with H-Point Manikin and HRMD.

Figure 1 shows the H-Point Manikin with HRMD seated in the hard bucket seat exemplarily.

The seats and dummies were equipped with markers fixed to the surfaces to pick up geometric dimensions by a 3D measurement system. This geometric data was used for the numerical simulation to place the dummy FE model at exactly the same position as the BioRID-II in the sled tests. Figure 2 shows the markers on the seat and the dummies.
After completing half of the tests, a static check of the seats by using the H-Point Manikin with HRMD and the 3D measurement system were conducted to ensure consistent test conditions and reveal possible damages on the seats.

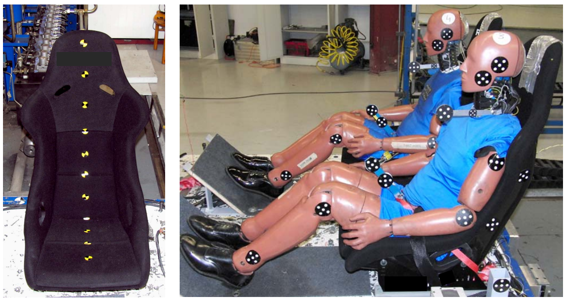

Figure 2. Markers for 3D geometric measurements.

Sled Tests

The dynamic testing was performed by using a HyperG220 acceleration sled on which the four hard bucket seats were rigidly mounted. A trapezoid sled pulse SRA16 (5 g, Δv=16 km/h) according to the draft Euro NCAP testing protocol v2.8 Draft [4] was used for all dynamic test runs. This pulse was chosen because of the low severity loading condition to avoid possible damages to the seats. The pulse characteristic is demonstrated in Figure 3.

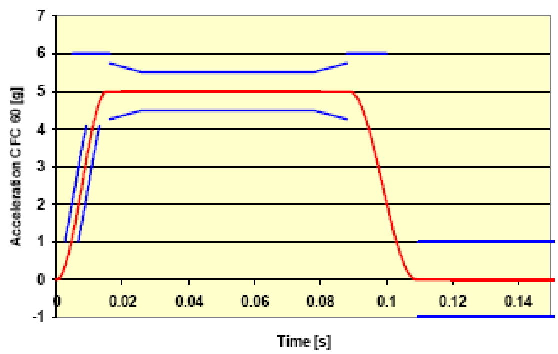

Figure 3. Sled Pulse (SRA16).

Particular attention was paid to very accurate test repeats to ensure good repeatability of the sled pulse over the complete test series.

Each dummy was positioned according to the data obtained from the SAE H-Point Manikin related to the individual seat. Pelvis belts were used to keep the dummies seated during the deceleration phase of the sled. These belts were laxly tightened to avoid any influence on the dummy response. Figure 4 shows test set-up.

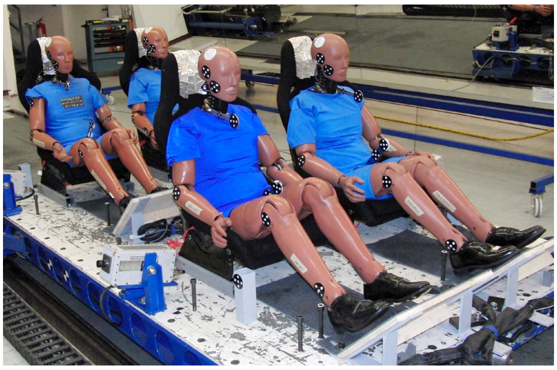

Figure 4. Test set-up.

In total 24 sled tests were conducted. Four dummies were tested simultaneously on the sled. Each dummy was tested three times on each seat. The complete test matrix is shown in Table 1. After each test the dummies were removed from the seats, checked and adjusted to the basic settings. After three test repetitions the dummies were moved to the next hard bucket seat and positioned according to the static measurement values obtained for the particular seat.

Table 1.
Test matrix

	Dy 1	Dy 2	Dy 3	Dy 4	Dy 5	Dy 6	Dy 7	Dy 8
Test 1	Seat 1	Seat 2	Seat 3	Seat 4	--	--	--	--
Test 2	Seat 1	Seat 2	Seat 3	Seat 4	--	--	--	--
Test 3	Seat 1	Seat 2	Seat 3	Seat 4	--	--	--	--
Test 4	Seat 2	Seat 3	Seat 4	Seat 1	--	--	--	--
Test 5	Seat 2	Seat 3	Seat 4	Seat 1	--	--	--	--
Test 6	Seat 2	Seat 3	Seat 4	Seat 1	--	--	--	--
Test 7	Seat 3	Seat 4	Seat 1	Seat 2	--	--	--	--
Test 8	Seat 3	Seat 4	Seat 1	Seat 2	--	--	--	--
Test 9	Seat 3	Seat 4	Seat 1	Seat 2	--	--	--	--
Test 10	Seat 4	Seat 1	Seat 2	Seat 3	--	--	--	--
Test 11	Seat 4	Seat 1	Seat 2	Seat 3	--	--	--	--
Test 12	Seat 4	Seat 1	Seat 2	Seat 3	--	--	--	--
Test 13	--	--	--	--	Seat 1	Seat 2	Seat 3	Seat 4
Test 14	--	--	--	--	Seat 1	Seat 2	Seat 3	Seat 4
Test 15	--	--	--	--	Seat 1	Seat 2	Seat 3	Seat 4
Test 16	--	--	--	--	Seat 2	Seat 3	Seat 4	Seat 1
Test 17	--	--	--	--	Seat 2	Seat 3	Seat 4	Seat 1
Test 18	--	--	--	--	Seat 2	Seat 3	Seat 4	Seat 1
Test 19	--	--	--	--	Seat 3	Seat 4	Seat 1	Seat 2
Test 20	--	--	--	--	Seat 3	Seat 4	Seat 1	Seat 2
Test 21	--	--	--	--	Seat 3	Seat 4	Seat 1	Seat 2
Test 22	--	--	--	--	Seat 4	Seat 1	Seat 2	Seat 3
Test 23	--	--	--	--	Seat 4	Seat 1	Seat 2	Seat 3
Test 24	--	--	--	--	Seat 4	Seat 1	Seat 2	Seat 3

All eight BioRID-IIg dummies were equipped with the instrumentation as shown in Table 2.

Table 2.
BioRID-II instrumentation

Location	Measurement	Dimension
HEAD	ax Head	acceleration [g]
	ay Head	acceleration [g]
	az Head	acceleration [g]
UPPER NECK	Fx Upper Neck	force [kN]
	Fz Upper Neck	force [kN]
	My Upper Neck	moment [Nm]
C4	ax C4 Cervical Spine	acceleration [g]
	az C4 Cervical Spine	acceleration [g]
LOWER NECK	Fx Lower Neck	force [kN]
	Fz Lower Neck	force [kN]
	My Lower Neck	moment [Nm]
T1	ax T1 Thoracic Spine le	acceleration [g]
	az T1 Thoracic Spine le	acceleration [g]
	ax T1 Thoracic Spine ri	acceleration [g]
	az T1 Thoracic Spine ri	acceleration [g]
T8	ax T8 Thoracic Spine	acceleration [g]
	az T8 Thoracic Spine	acceleration [g]
L1	ax L1 Lumbar Spine	acceleration [g]
	az L1 Lumbar Spine	acceleration [g]
PELVIS	ax Pelvis	acceleration [g]
	ay Pelvis	acceleration [g]
	az Pelvis	acceleration [g]

The sled was equipped with two triaxial accelerators mounted on the front and rear side of the sled frame. All seats were instrumented with two triaxial accelerometers located on the middle and upper part of the backrest as well as with an uniaxial accelerometer on the rear left seat rail.

The time of the head-contact events was obtained by using thin metal foils which were fixed on the head rests and the dummy head caps.

Four on-board high speed (HS) video cameras were mounted on the sled to record videos from each seat position. In addition one HS video was positioned on 45 degrees on the front side to get an overview of the complete test scene. All videos were recorded with 1000 frames per second.

Simulation

Numerical simulations were used to analyze the causes of variations and to identify possible problems and dummy artifacts.
All simulation runs were conducted with the release 2.5 of the FAT LS-DYNA BioRID-II dummy model. It was positioned in pre-simulations by using the seating protocols obtained in the sled tests. Therefore, all pre-stresses of dummy and seat were considered in the simulations runs. The computational model of the sled test set-up is shown in Figure 5.
The geometry of the computational model of the hard bucket seat is based on 3D scans of the hardware. The seat was already validated in a previous study but its performance was verified with the signals of the accelerometers mounted at the backrest.

The average crash pulse of the 24 sled tests was used as baseline pulse for all simulation runs.

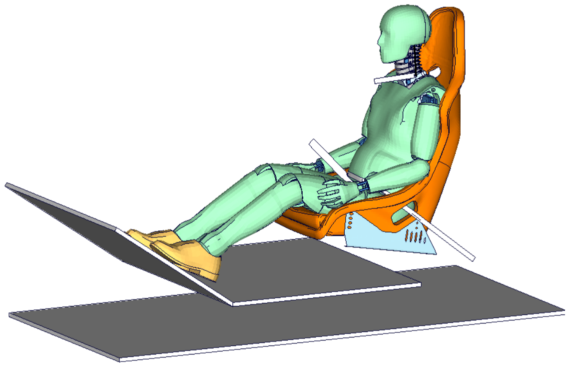

Figure 5. Computational test set-up.

Methods of Evaluation

As the total number of data sets is very extensive, the right methods of analysis and evaluation of the data has to be chosen. At first, the curves and their maximum and minimum peaks were analyzed globally to get a first impression on the total scatter of the data. Furthermore, the absolute scatter of the signals (e.g. peak force) is important because consumer tests are more focused on these values. Additionally, the injury criteria NIC and Nkm were calculated with respect to consumer tests. NIC considers the relative acceleration between head and torso. The equation of NIC is shown in (1)

$$NIC(t) = 0.2m \cdot a_{rel}(t) + (v_{rel}(t))^2 \qquad (1)$$

Whereas NIC is focused on the measured accelerations, Nkm evaluates the upper neck shear force and the neck extension/flexion moment (2).

$$N_{km}(t) = \frac{F_x(t)}{F_{\text{int}}} + \frac{M_y(t)}{M_{\text{int}}} \qquad (2)$$

The coefficient of variation (CV) was the second method of evaluation. CV is the quotient of root mean square deviation and sample mean. It is proportional to the scatter of the data. Table 4 [7] shows the classification of CV used in repeatability analysis. CV is calculated for the maximum and minimum peak of a signal. Depending on the meaning of the signal either the CV at the maximum or minimum peak is used for the subsequent analyzes. In case of using the coefficient of variation of the minimum peak, the absolute value is used.

Table 4.
Rating scale to assess repeatability

CV = 3%	3% < CV = 7%	7% < CV = 10%	CV > 10
good	acceptable	marginal	not acceptable

Finally, a new approach was used to evaluate the global variations of response signals objectively. The so-called CORA software [5] provides an objective evaluation of whole response curves coming from any source. The method combines two independent sub-methods, a corridor rating and a cross-correlation rating. The corridor rating evaluates the fitting of a response curve into user-defined or automatically calculated corridors. The cross-correlation method evaluates phase shift, shape and size. These two sub-methods are essential because the disadvantages of each sub-method are compensated by the other method. The rating results ranges from “0” (no correlation) to “1” (perfect match).
CORA was developed to evaluate the level of correlation between two curves and not to evaluate variances of a set of curves. To enable the usage of CORA anyway, the dummy responses could be compared with the responses of an ideal BioRID. Since no ideal BioRID responses were available, this limitation has to be bypassed by grouping the test results. At first, the mean responses of the twelve tests of every BioRID were calculated. Afterwards CORA evaluated the level of correlation of one dummy specimen to the group of the remaining seven dummies. This grouping was done for every dummy.
At the end there are eight CORA results per channel. The variances of a signal can be assumed as small if the eight ratings are close together. In this context the CORA rating is only an indirect measure of the scatter of the BioRID responses. The introduced method only analyzed the reproducibly of the BioRID.
To get a better understanding of the BioRID, the signals were spilt into sub-sections. The correlation was calculated before the head contact (0-70 ms), during the head contact (70-130 ms) and for the rebound (130-250 ms). Additionally, the analysis was done for the whole test (0-250 ms). This split-up helps to detect the crucial phases of the tests for variations of the dummy responses.

RESULTS

The dummy responses in the incoming inspection after completion of the test series are almost identical to those of the certification prior the tests. It can be assumed that the performance of each BioRID was constant during the whole test series.

In spite of the detailed check of all dummies by the manufacturer, there are differences in the hardware. The pelvis foam of three dummies was clearly stiffer than that of the others. Especially the pelvis acceleration is influenced by this stiffness. However, the influence on the dummy responses decreases from pelvis to head.
The check of the stiffness of the pelvis foam is obviously not covered by the dummy certification procedures.

The stability of the hard bucket seats did not change during the all test runs. No permanent deformations were observed. This was demonstrated by comparing the 3D measurement results of the static check after half of the tests with the initial measurements. In addition, the comparison of the backrest accelerations did not reveal any significant performance changes.

The 2D measurement values obtained from the seating position of the individual BioRID show good repeatability which is evident for the high accuracy of the test set-up. Figures 6 and 7 give an impression on the scatter of the backset and the H-Point of the dummies.

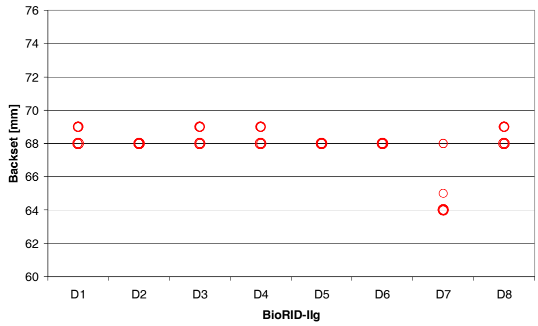

Figure 6. Backset distribution.

The backset of most of the dummies were achieved with almost the same value. Only dummy 7 shows a slightly larger range of scatter. However, the total value of variation is within 4 mm which is still a good repeatability.

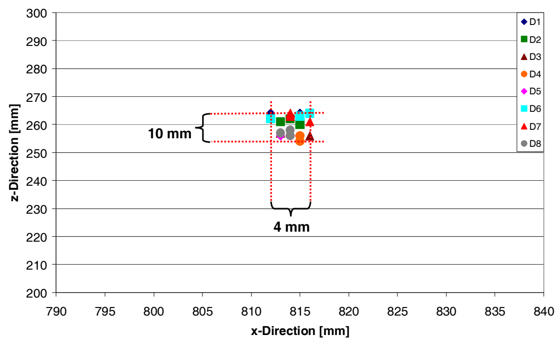

Figure 7. H-Point distribution.

Figure 7 shows the H-Point location for all dummies in one out of the four seats exemplarily. However, identical positioning accuracy was achieved on all seats. The small distribution range illustrates the good repeatability and reproducibility of the H-Point positioning achieved in this test series.

The basic condition to evaluate the repeatability and reproducibility capability of the tested BioRID-IIg is to ensure identical test runs. Figure 8 shows all sled pulses plotted in one chart.

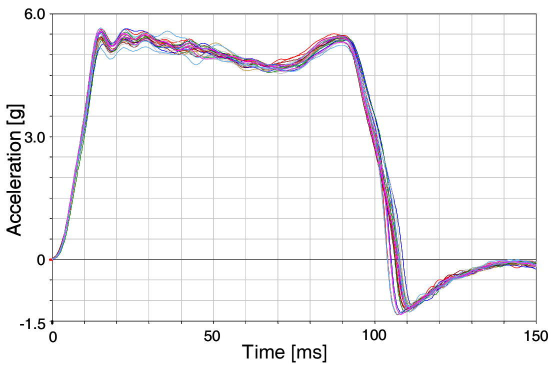

Figure 8. Repeatability of all sled pulses.

The graph shows good repeatability of the sled pulses. This is also confirmed by the coefficient of variation (CV) evaluation. The CV=1.83% emphasize good repeatability according to the rating scheme (Table 4).

For the repeatability and reproducibility analysis of the BioRID-IIg responses, a limited number of sensors were chosen which are also being used to determine the protection potential of car seats against WAD. The dummy responses are shown in Table 5.

Table 5.
BioRID-II responses used for evaluation

Location	Measurement	Dimension
HEAD	ax Head	acceleration [g]
UPPER NECK	Fx Upper Neck	force [kN]
	Fz Upper Neck	force [kN]
	My Upper Neck	moment [Nm]
LOWER NECK	Fx Lower Neck	force [kN]
	Fz Lower Neck	force [kN]
	My Lower Neck	moment [Nm]
T1	ax T1 Thoracic Spine le	acceleration [g]
	ax T1 Thoracic Spine ri	acceleration [g]
T8	ax T8 Thoracic Spine	acceleration [g]
PELVIS	ax Pelvis	acceleration [g]

Two methods were applied to evaluate the repeatability and reproducibility of the BioRID-IIg, the coefficient of variation (CV) method [6] and CORA. Figure 8 to 10 show exemplary the scatter of the upper neck shear force (Fx), the flexion/extension moment (My) and the lower neck tension force (Fz). Every color of the shown figures represents a specific dummy.

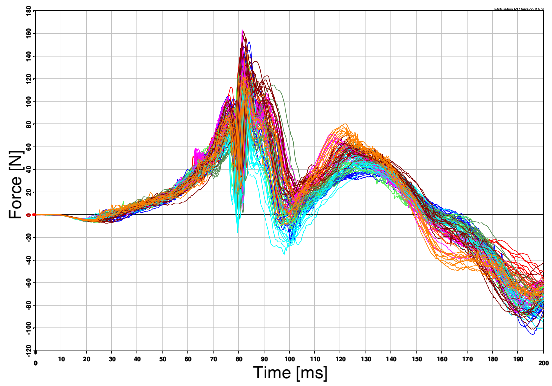

Figure 8. Repeatability of upper neck Fx.

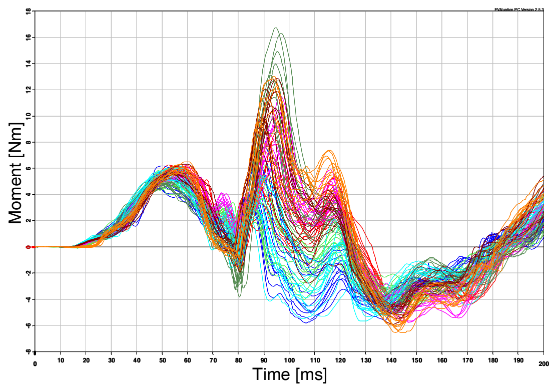

Figure 9. Repeatability of upper neck My.

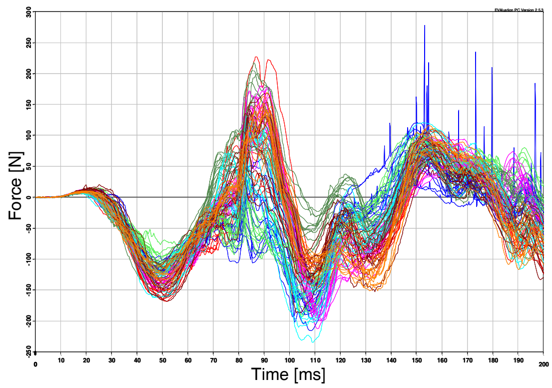

Figure 10. Repeatability of lower neck Fz.

At first, the CV method was applied. Figure 11 shows the repeatability results of the BioRID-IIg on all four seat positions. The accelerations head-ax, T1-ax and T8-ax show low variances on average. The rating according Table 4 can be qualified as good to acceptable. The NIC which is derived from these accelerations (head-ax, T1-ax) show a slightly decreased repeatability result and can be rated acceptable to marginal. The repeatability variances of the pelvis-ax acceleration are slightly higher and show a ranking range from acceptable to marginal. This slightly higher scatter is caused from differences in the pelvis flesh stiffness. The load cell responses of the upper and lower neck show clearly higher variances. In particular the variances of the upper neck shear force (Fx) as well as flexion/extension moment (My) and the lower neck tension force (Fz) exceed the not acceptable threshold considerably. The repeatability of the criterion Nkm depends on these signals. Hence, there is a wide dummy-specific range of the CV rating which moves within acceptable to considerable not acceptable.

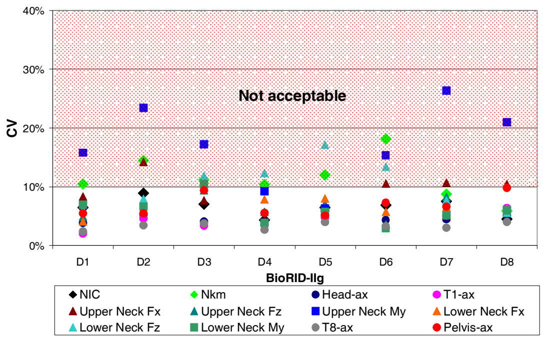

Figure 11. CV repeatability evaluation.

In Table 6 the reproducibility evaluation is presented based on the coefficient of variation method (CV). The results are similar to the repeatability evaluation described before. Again, the forces and moments exhibit the highest variances.

Table 6.
CV evaluation of the used BioRID-IIg on all seats

	D1 thru D8
NIC	8,06%
Nkm	15,26%
Head-ax	4,95%
T1-ax	8,92%
Upper Neck Fx	13,86%
Upper Neck Fz	9,11%
Upper Neck My	36,85%
Lower Neck Fx	10,93%
Lower Neck Fz	17,39%
Lower Neck My	11,11%
T8-ax	5,67%
Pelvis-ax	10,85%

Figure 12 illustrates the CV reproducibility results of Table 6 again.

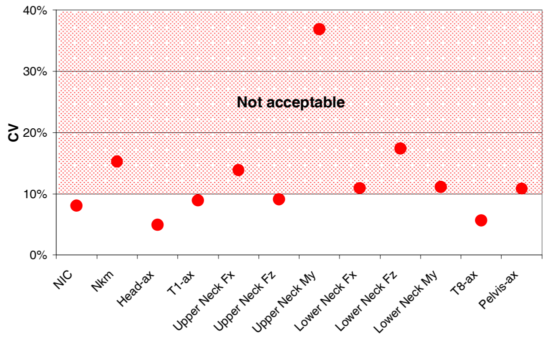

Figure 12. CV reproducibility evaluation.

It can be clearly seen, that almost all forces and moments exceed the threshold of CV=10% which is rated as not acceptable (Table 4). In particular the upper neck flexion/extension moment (My) shows the highest variances. This high scatter decreases the Nkm reproducibility automatically to not acceptable as well. The acceleration values change within the range 0% to 10% of CV (good to marginal).

The second part of the dummy response evaluation was conducted by using the objective rating tool CORA. As already mentioned, the level of correlation of every individual dummy specimen to the group of the remaining seven dummies was evaluated which resulted in eight CORA results of each channel considered. Hence, this evaluation method is focused on the reproducibility characteristic of the dummies used. It can be assumed that the variance of a signal is small if the eight ratings are close together.

Table 7 shows the subsections of the signals being evaluated.

Table 7.
CORA - Interval of evaluation

#	Description	Time [ms]
1	T0 to Time before Head Contact	0 - 70
2	Time of Head Contact to Time before Head Rebound	70 - 130
3	Time of Head Rebound to End of Test Interval	130 - 250
4	Complete Test Duration	0 - 250

Each of the time intervals were evaluated with CORA independently.

The evaluation of the acceleration responses of the BioRID-IIg are demonstrated in Figure 13 to 16. In general, the time intervals before the head contact (0-70 ms) as well as head contact (70-130 ms) demonstrate a good correlation for all dummy acceleration responses considered in x-direction. In the rebound phase (130-250 ms) a decrease of the correlation can be clearly seen. However, considering the time interval of the whole test duration (0-250 ms), the correlation show almost a perfect match and do not exactly reflect the findings in the time subsections described before.

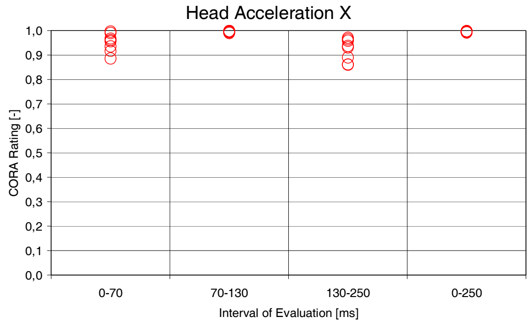

Figure 13. CORA evaluation of head-ax.

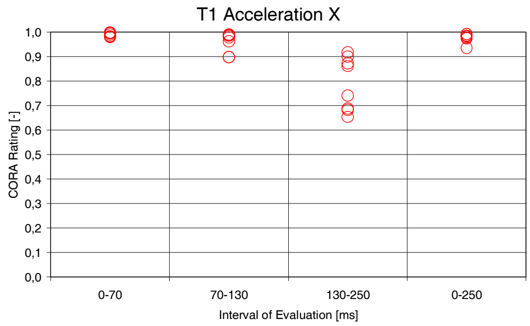

Figure 14. CORA evaluation of T1-ax.

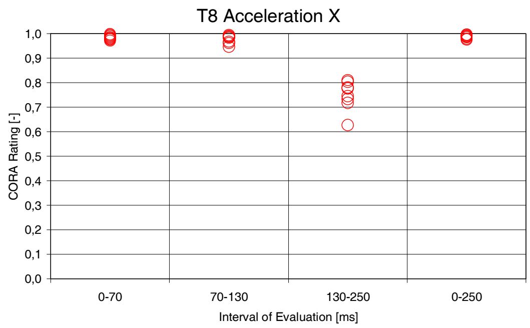

Figure 15. CORA evaluation of T8-ax.

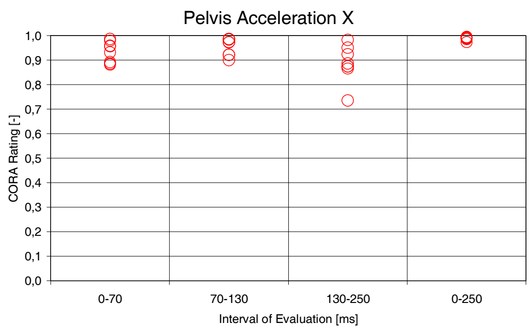

Figure 16. CORA evaluation of pelvis-ax.

Figure 17 to 22 show the evaluation of the upper and lower neck load cells. The upper neck load cell exhibits a lower correlation in the time interval of the head contact (70-130 ms). In particularly the upper neck moment My exhibits poor correlation (Figure 19) with large variances of the signals.

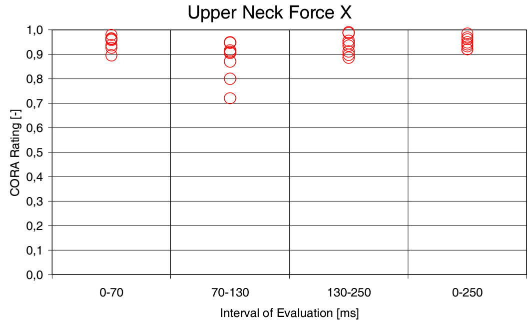

Figure 17. CORA evaluation of upper neck Fx.

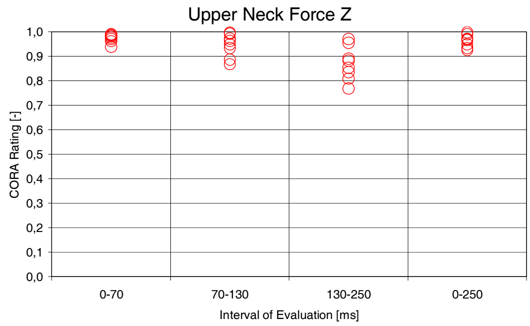

Figure 18. CORA evaluation of upper neck Fz.

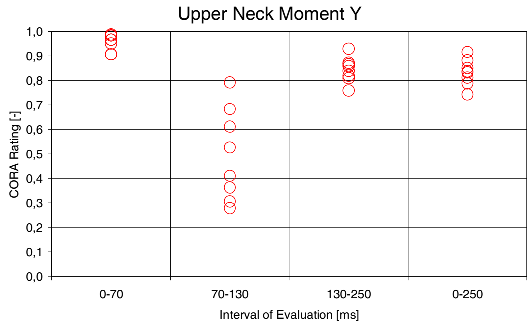

Figure 19. CORA evaluation of upper neck My.

The signals within the time interval before the head contact (0-70 ms) show good correlation.

The lower neck load cell responses exhibit a similar correlation like the upper neck load cell which is shown in Figure 20 to 22. In contrast to the upper neck load cell, the lower neck tension force (Fz) shows a lower correlation in the head contact time interval along with a clear increase of the scatter (Figure 21). However, the lower neck moment (My) demonstrates a much better correlation than of the upper neck load cell in this particular time interval.

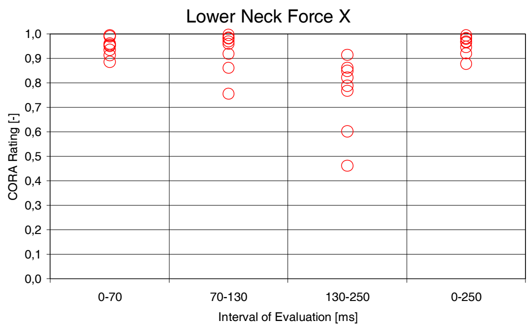

Figure 20. CORA evaluation of lower neck Fx.

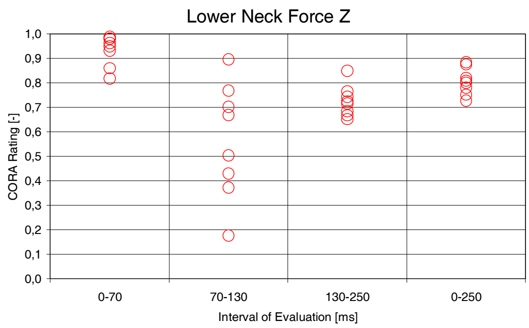

Figure 21. CORA evaluation of lower neck Fz.

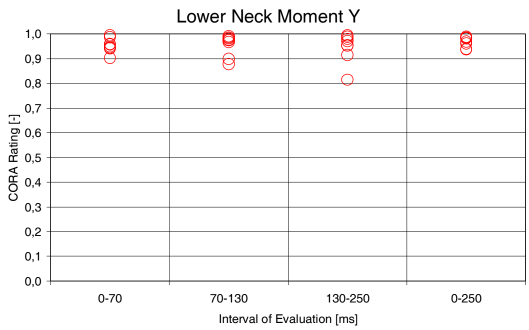

Figure 22. CORA evaluation of lower neck My.

The correlation shown in the rebound phase (130-250 ms) exhibits a decreased correlation in particular Fx.

In contrast to the consideration of the measurement responses in the respective subsections of evaluation, the overall ranking over the complete test duration (0-250 ms) shows an almost good correlation and comparable low deviations for all measurement responses.

The evaluation of the injury criteria NIC and Nkm according to CORA is shown in Figure 23.

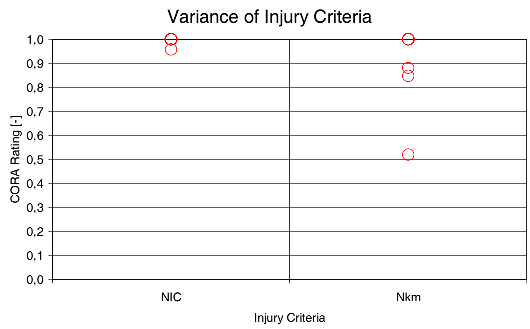

Figure 23. CORA evaluation of injury criteria.

It can be seen that the NIC achieves a good correlation with very minor variances. In addition, the spreading of the correlation dots indicate small variances respectively a good reproducibility. On the contrary Nkm demonstrates a low correlation with high variances of the reproducibility. These results correspond with the findings obtained by the CV evaluation method.

Simulation

The computational model of the test set-up was used to investigate the causes of the scatter of the upper and lower neck responses. Figure 24 give an impression on these variances. Dummy 4 and 8 (blue and black curves) seem to be the most extreme specimen of the eight BioRID. Especially the variances of the curves of the lower neck tension force (Fz) and the upper neck flexion/extension moment (My) are remarkable. They are purely related to the specific dummies because of the chosen test methods.

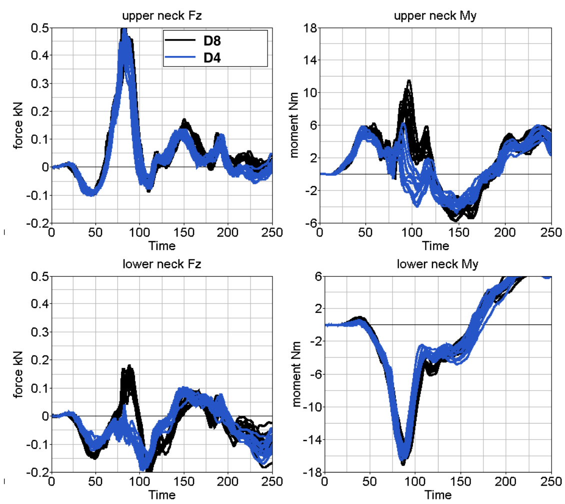

Figure 24. Neck responses of all 12 tests with dummy 4 and 8.

Various parts of the computational BioRID were analyzed to find the cause of those variations. At

first, attention was paid to potential secondary load paths around the load cells. It is possible to generate the scatter with the model in principle by modifying some parameters. However, as the values of those parameters exceed any plausible dimension to get these effects, secondary load paths could be excluded as cause of the variations.
So the focus was on parts which were not exactly represented in the computational model of the BioRID. The probably most important differences between hardware and model were found in the muscle substitute unit. As showed in Figure 25, the modelling technique of this component does not exactly match the physical properties.

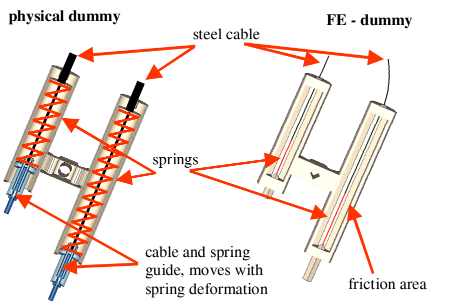

Figure 25. Muscle substitute of physical dummy and simulation model.

The end of the cable is attached to a slider that moves inside a bush. The pretension of the cable is adjusted by a spring that is compressed between slider and top of the bush. If the cable moves, the slider moves inside the bush. The spring is either loaded or unloaded.
The simulation model works in a simplified way. The system of slider, bush and spring is replaced by a system made of springs only.
However, the simplified muscle substitute unit of the model works well globally but some local effects are missing. So the friction between slider and bush is not realized in the model. Thus, the effects of friction were introduced to the muscle substitute unit. In a first attempt the friction force was set constant to investigate its general influence on the neck responses.
As the charts of Figure 26 indicates, friction effects of the muscle substitute unit (red curves) could be a cause of the scatter seen in physical tests. The green curves show the responses of the standard BioRID model without additional friction effects.

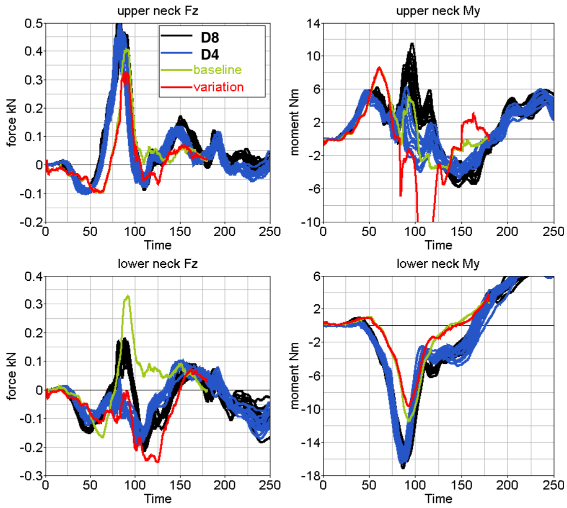

Figure 26. Results of BioRID simulation by using different friction values.

Friction between slider and bush reduces the peak of the lower neck force Fz. The upper neck moment My is influenced by this effect too. Its secondary peak drops from a positive value to a negative one. Compared to that, the friction has a very limited influence on the other dummy responses.
The definition of friction in the modified model is initially done in a simple way to investigate its influence on the dummy responses. This can be the causes for the strong negative peak of My value at 110 ms. However, the timing of the observed changes of the signals are identical to that in the tests.

DISCUSSION

This study clearly shows significant influences of the dummy on the test results. Especially the neck responses can be linked to a specific dummy. As these variations are not seen in the certification tests, it is questionable if the current test procedure for BioRID certification is sufficient to check the dummy performance. Furthermore, this procedure checks the kinematics of the spine without any limitation of the head’s motion. In vehicle test applications, the BioRID is used in a totally different environment. The neck extension is limited by a head rest. Therefore, the range of motion of neck as well as the characteristics of the measured signals differs significantly to those in the certification test. So it is not ensured that all BioRID have got a similar performance in the actual whiplash tests.

Although all dummies were certified by the dummy manufacturer itself, different pelvis flesh stiffness was observed. This stiffness influences the pelvis accelerations and decreases from pelvis to the head.

In general it is essential that the certification procedure ensures consistent build levels.

The choice for the hard bucket seats was based on the fact to gain as less as possible variances from the seat itself. On the other hand, this seat does not falsify the variances of the dummy as it usually happens with standard vehicle seats. In contrary to that, the hard bucket seats are very stable and may amplify dummy artifacts. However, it is clear that the kinematics of the head is somehow different to that in standard vehicle seats. The head tends to roll forwards around the OC joint when contacting the almost rigid head rest of the hard bucket seat and the flexion increases. Therefore, the absolute variances of the dummy responses are probably not representative to standard vehicle seats.

The accelerations of the dummies indicate the global kinematics as reproducible. However, not all signals especially neck forces and moments do reflect this finding.

The study examine significant differences in variances during the three phases of a test – before head contact, during head contact and during rebound. Whereas the reproducibility in the first and last phase is quite good, the dummy responses scatter significantly during the head contact phase. However, the global correlation of the dummy responses is good, because the relevant test phase (70-130 ms) is quite short compared to the duration of the whole test (250 ms). This result does not exactly reflect the findings during the head contact phase which allows the conclusion that the global correlation makes no sense in this context.
Obviously, some external boundary conditions which can not be directly influenced induce high variances of dummy responses. For example very minor changes of the head impact conditions such as head angle or impact location can cause these differences.

In this study the injury criteria are not criticized as well as their relevance to WAD is not discussed at all. However, the measurement signals to be used to calculate these criteria are subjected to high variances. Hence the criteria scatter, too. These variances can also be seen in tests with vehicle seats. [2, 3].

For a reliable assessment of the protection potential of car seats against WAD, it is essential that the criteria used are obtained from test data of high reproducibility. Any rating procedure has to identify good as well as poor protection potential of car seats reliably. Otherwise, the meaning of such a rating procedure is very limited.

The focus of the numerical simulation was on the investigation of the scatter of the neck responses. Previous studies [3] checked the influence of tighten or loose spring-damper systems on the dummy responses. The effects on the neck responses could not be reproduced by varying initial conditions of the springs and dampers. Also the assumption of the existence of secondary load paths around the neck load cells could not be verified by parametric studies with the BioRID model.
Finally, in-depth analyses indicate that variations of the friction inside the muscle substitute unit might be the cause of the neck response variations. The friction force could be influenced by the smoothness of the surfaces of slider and bush as well as by tolerances of the size of both parts, resulting in jamming between slider and bush. As this friction effect seems to be essential, these parts should be checked dynamically in one of the dummy certification procedures. However, these first findings have to be verified in further investigations.

CONCLUSIONS

This study comprises the evaluation of eight individual BioRID-IIg dummies under well defined testing conditions. Despite minimizing the variances from the test environment, large scatter of dummy responses were found. It could be examined that the distribution of the scatter is dependent on the different kinematics phases (before head contact, head contact, rebound phase) during the test event.
The highest variances of the dummy responses were detected during the time interval where the head is in contact with the head rest. Especially the forces and moments of the upper and lower neck load cells showed the highest variances, whereas the accelerations are almost good repeatable and reproducible.

The BioRID certification procedure only assesses the head/neck kinematics without head contact. The certification data do not show high variances of the signals. The analysis of the test data confirms that the variances of the dummy responses are very low before the head contacts the head rest. This particular time interval is comparable to the certification tests where no head contact occurs. However, the highest variances happen at the time interval of the head contact. It is questionable if the current certification procedure is sufficient to check the dummy performance for the current whiplash test procedures.

The numerical simulation could clearly show a similar effect on the variances of the neck load cells by varying the friction force of the muscle substitute units. This can be a potential cause for the significant variances seen in the tests. However, further investigations are needed to confirm this finding.

Most of the injury criteria are derived from peak values, when the signals show the highest values. Unfortunately, this happens usually during the head contact time interval, when the BioRID exhibits the highest variances of the responses. Therefore, it is all the more important that a whiplash assessment procedure should not be based on such high variable parameters in order to get repeatable seat assessments.

OUTLOOK

As mentioned above, some items need to be investigated in the future. At first, the assumption that changing friction inside the muscle substitute unit causes the variation of some neck responses. This has to be done with the BioRID model as well as with the dummy parts. These parts could be checked separately in a simple component tests.
Secondly, the current certification procedures should be discussed with the dummy manufacturer and users to include some additional checks of the consistence of the build level. Furthermore, any update should replace or supplement the current dynamical certification test by a test with more application-oriented loading conditions. Such an improved test would probably cover the mentioned friction-related problems too.

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