EVALUATING RECENT SEAT MODELS IN REAR-END IMPACTS ACCORDING TO CURRENTLY DISCUSSED CONSUMER TEST PROPOSALS

Kai-Uwe Schmitt
AGU Zürich, Switzerland, and
Institute for Biomedical Engineering,
University and ETH Zürich, Switzerland
Markus Muser
AGU Zürich, Switzerland
Paper Number 09-0116

ABSTRACT

To ensure a high safety standard of vehicle seats in rear-end collisions, consumer tests will include specific test standards. The prevention of soft tissue neck injuries is meant to be addressed by the introduction of such standards. To date particularly EuroNCAP has developed a detailed proposal how such seat tests should be conducted to assess the risk of whiplash associated disorders.
In this study the relevance of the different parameters included in the consumer test proposal for assessing seat performance under rear-end impact conditions was analysed. A series of sled tests according to the latest proposal were performed with different seats. The performance of the seats was assessed as suggested by the proposal. In a next step a sensitivity analysis was conducted to investigate the influence of the different parameters on the final score.

Based on our findings it is suggested to modify the test procedure such that criteria which are redundant or have a weak biomechanical foundation are omitted. The sensitivity analysis revealed that the final score and thus the discriminatory power of the evaluation scheme will persist such that the assessment procedure will still be able to rate the performance of the seats.

INTRODUCTION

To encourage car manufacturers to improve seat design such that it effectively reduces whiplash associated disorders (WAD), the inclusion of seat tests in consumer test procedures like EuroNCAP is discussed and corresponding proposals for test procedures were presented. Obviously, the crucial point in developing such test procedures is the choice of appropriate measures to assess seat performance. Also the final rating scheme that is used to combine different measures into a final score that is then used to classify the seats is of particular importance and therefore subject of several publications [e.g. 1, 2, 3].
The problem associated with the definition of a test procedure is two-fold. One the one hand it must be acknowledged that from a biomechanical point of view the WAD injury criteria and their respective biomechanical tolerance levels are associated with several uncertainties. For most criteria no widely accepted tolerance levels, let alone accurate injury risk curves, are available today. One of the often disregarded points in the tolerance limit discussions is the fact that most injury criteria values have a non-linear relation to injury risk. Many tolerance levels for criteria related to injuries other than WAD (such as HIC, Nij, TTI, Gambit, TI etc.) were derived using highly non-linear logistic regression curves. The biomechanical loads discussed in conjunction with WAD, e.g. accelerations, forces, moments of torque, are generally very low in comparison to loads acting in other crash situations. Therefore, even minor changes in a test set-up may result in significant changes in the loads measured.
In addition any test procedure must satisfy certain technical requirements that are essential to provide a powerful standard including e.g. repeatability and reproducibility. Generally, it was shown by several studies that sled tests seem a suitable method to investigate the behaviour of a seat in rear-impact [e.g. 2, 3]. However, with respect to the final rating of the results discussions are ongoing.
This study investigates a recent consumer test proposal by performing sled tests using different seats. Biomechanical aspects of the proposal are reviewed and the discriminatory power of the rating system is analysed.

MATERIALS & METHODS

A series of tests consisting of static as well as sled tests was performed. Table 1 summarizes the test series. Unless otherwise stated, the head restraint was positioned identically for all tests (head restraint was locked in the second-lowest position) and the seat back angle was always adjusted to a 25°± 0.2° torso line.

Table 1. Summary of the test series. A total of 21 sled tests were performed. 7 different seat models were used (A-G). In some tests more than one seat of the same model were used (e.g. A1, A2 and A3 are three seats of the same model). In some tests one specific seat was tested twice (marked with *).

Test no.	Seat	Re-active system	Pulse severity
MUS07001	A1	yes	medium
MUS07002	A2	yes	
MUS07014	B1	yes	
MUS07006	C1	yes	
MUS07007	C1*	yes	
AGU08001	D1	yes	
AGU08002	D1*	yes	
MUS07004	E1	no	
MUS07005	E1*	no	
MUS07012	E2	no	
AGU08004	E3	no	
AGU08005	E3*	no	
MUS07008	F1	no	
MUS07009	F2	no	
MUS07003	G1	no	
MUS07013	A3	yes	high
MUS07015	B2	yes	
MUS07011	C3	yes	
AGU08003	D2	yes	
MUS07010	E4	no	
AGU08006	E5	no	

Static tests

The head restraint height and the back set (i.e. the horizontal head to head restraint distance) was determined prior to each sled test. The data was acquired and recorded as described in the IIWPG geometry measurement technique [5] using a SAE H-point machine according to SAE J826 and the Head Restraint Measuring Device (HRMD).

Sled tests

Dynamic testing was performed using a HyperG220 sled to which the seats were rigidly mounted. All seats were adjusted in the same way. A BioRID-IIig dummy of the latest build level was used throughout this study. The dummy was seated and instrumented according to IIWPG/EuroNCAP procedures [1].

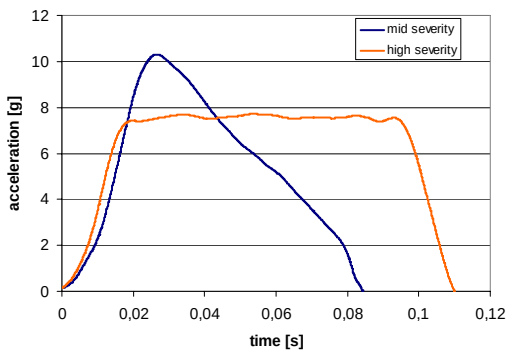

Figure 1. Crash pulses used in the sled tests.

Two different crash pulses were used in this study: a so-called medium severity pulse which represents a delta-v of 16 km/h and a high severity pulse that results in a delta-v of 24 km/h (Fig. 1).

For each test the following measures and neck injury predictors, respectively, were evaluated: NIC, Nkm, time until dummy head first contacts head restraint, T1-acceleration in x-direction, rebound velocity, neck shear force, and neck axial force.
For NIC the first 180ms were considered, i.e. NIC180. With respect to Nkm only the maximum Nkm is reported.

The results of the static and dynamic tests were scored in a system similar to the schemes currently discussed e.g. by EuroNCAP. The rating system considers both the static and the dynamic tests.
For the static tests, the backset and head restraint height were rated according to the limits given in Table 2. Scores range from -1 to +1; a sliding scale was used.
As for the results of the sled tests, Table 2 illustrates the higher and lower performance limits used for the rating. For results in between the higher and lower limits, a sliding scale was used to obtain the score. Each parameter in the dynamic tests can reach a maximum score of 0.5 points, i.e. for one pulse a maximum of 3 points is possible. Furthermore the capping limits as described in [1] were followed.

For the final rating, the worst score of the two static measurements is added to the score received for the corresponding sled test.

Table 2. Threshold values used for evaluating the static tests.

	Lower performance limit	Higher performance limit
Backset [mm]	40	100
Height [mm]	0	80

Table 3. Threshold values used for evaluating the dynamic tests.

	Lower performance limit	Higher performance limit
Medium severity pulse		
NIC [m2/s2]	11	24
Nkm [-]	0,15	0,55
Rebound velocity [m/s]	3,20	4,80
Fx (upper neck shear) [N]	30	190
Fz (neck axial) [N]	360	750
T1 x-acceleration [g]	9,3	13,1
Time to head restraint contact [ms]	51	76
High severity pulse		
NIC [m2/s2]	13	23
Nkm [-]	0,22	0,47
Rebound velocity [m/s]	4,10	5,50
Fx (upper neck shear) [N]	30	210
Fz (neck axial) [N]	470	770
T1 x-acceleration [g]	12,5	15,9
Time to head restraint contact THRC [ms]	48	75

To further investigate the sensitivity of the scoring scheme the dynamic results were scored according the current procedure, i.e. a maximum of 3 points was possible. The ranking of seats was determined and additionally the percentage of the maximum score was calculated (i.e. a seat that reaches 3 points has earned 100%). Afterwards, the number of parameters used to calculate the dynamic score was reduced. First the T1 acceleration and THRC were omitted, next the force measurements left out. To ensure that the test procedure accounts for criteria that are relevant in rearward as well as in the forward motion phase during a rear-end collision the final step included NIC and Nkm as well as the rebound velocity. Since the sliding scales and score system were not changed, the maximum score that could be reached changed accordingly. The changes in ranking were analysed.

RESULTS

Tables 4 and 5 (in the APPENDIX) present the results of the static and dynamic tests and also include the rating of the results according to the score scheme as described above.

The results of the sensitivity analysis of the rating system are shown in Tables 6 and 7 (both in the APPENDIX).

Table 4. Results for all static measures.

Test No.	Height [mm]	Score	Back set [mm]	Score	Total Score Static
MUS07001	30	0.25	30	1	0.25
MUS07002	33	0.18	26	1	0.18
MUS07014	49	-0.23	75	-0.17	-0.23
MUS07006	56	-0.4	40	1	-0.4
MUS07007	54	-0.35	45	0.83	-0.35
AGU08001	40	0	42	0.93	0
AGU08002	40	0	39	1	0
MUS07004	53	-0.33	79	-0.3	-0.33
MUS07005	51	-0.28	63	0.23	-0.28
MUS07012	29	0.28	61	0.3	0.28
AGU08004	32	0.20	60	0.33	0.20
AGU08005	30	0.25	65	0.17	0.17
MUS07008	88	-1.2	80	-0.33	-1.2
MUS07009	55	-0.38	74	-0.13	-0.38
MUS07003	56	-0.4	48	0.73	-0.4
MUS07013	34	0.15	26	1	0.15
MUS07015	53	-0.33	72	-0.07	-0.33
MUS07011	54	-0.35	49	0.7	-0.35
AGU08003	43	-0.08	41	0.97	-0.08
MUS07010	53	-0.33	70	0	-0.33
AGU08006	31	0.23	64	0.20	0.20

DISCUSSION

The results obtained in this test series are in the range of other similar test series as published in the literature. Generally the data shows a wide spread resulting in a corresponding final scores indicating that it included seats of different quality. It was observed that seats with re-active systems performed better than standard vehicle seats without such systems.

Reproducibility

As can be seen from the tests where the same seat was tested twice, the reproducibility of the results was acceptable and within limits described in the literature [e.g. 2]. However, in a more general view, reproducibility can be a problem in consumer tests where several test houses are involved. It should be kept in mind that reproducibility depends on different factors like the laboratory, the dummy, but also the seat and the procedure using the H-point machine. In our series we found that the latter aspect can especially be of importance for seats without lordosis restraint. Due to the straight back of the H-point manekin, a given curvature of the seat back can result in a higher variation when measuring the backset for example (see Fig. 2).

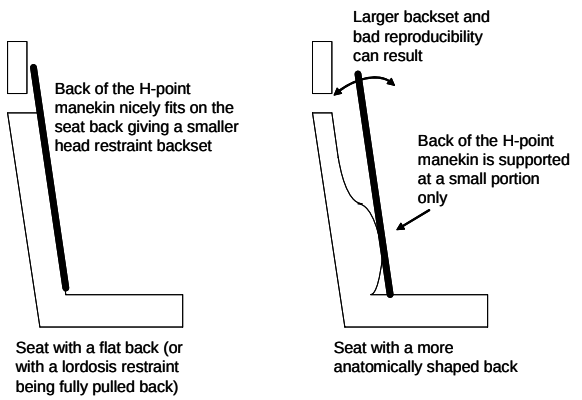

Figure 2. Illustrating the influence of a lordosis restraint on the measurement of the initial backset.

Sensitivity of the rating scheme

With respect to the score from the dynamic tests, it was found for the medium severity pulse the ranking is very robust. Even if some of the measures are omitted, the tendency of the ranking will not change significantly.

Looking at the percentage of the maximum scores, it can be seen that irrespectively of the actual maximum, the range is always between approx. 97% and 3%. Hence even when reducing the number of measures a wide spread of final scores can be expected, i.e the ability of the scoring system to differentiate the various seats is maintained. This can be relevant when designing a consumer test procedure. However, when reducing the number of criteria, the weighting of the different scores can be discussed. When solely regarding NIC, Nkm and the rebound velocity as relevant parameters to define the final score, it can be argued that criteria like NIC and Nkm that do show a link to the biomechanical background of neck injuries [6] should have a higher weight than the rebound velocity. For a future assessment procedure we therefore suggest to reduce the number of parameters but adjust the weight that a parameter has with respect to its biomechanical significance.

For the high severity pulse basically the same conclusions apply as for the medium severity pulse. However, it must be noted that the number of tests used for analysing the sensitivity of the high severity pulse is small. To assess whether the findings also hold true in a more general context, a larger number of test data is needed.

Threshold values and sliding scales

Questions arise concerning the biomechanical validity of a scoring system based on sliding scales. From a biomechanical point of view it seem fundamentally wrong to use a linear scale since it is to be expected that injury criteria values have a non-linear relation to injury risk.

Furthermore the use of performance limits and sliding scales that are different for the 16 km/h and the 24 km/h pulse is hard to understand biomechanically. One seat (model C, tests MUS07006, MUS07011), for instance, has reached exactly the same NIC value for both pulses, but obtains different scores. That the same NIC value was reached can be explained by the fact that the point in time when a maximum relative motion between head and torso occurs is more or less the same for both pulses. However, adjusting the limits that are used to score (i.e. the limit for NIC in the 16 and 24 km/h pulse, respectively) to different crash pulses by means of scaling seems wrong. From a biomechanical perspective, changing the limits means shifting the threshold on the underlying injury risk curve. In other words, a rating system with different injury threshold values accepts that the occupant is subjected to a different injury risk at a different pulse. Due to the lack of accurate injury risk curves today, the effect of such a shift can not be assessed. Facing a consumer test it might, however, become difficult to explain why an identical result as measured by a dummy is regarded less injurious at a high delta-v, i.e. a more severe accident.

T1 and THRC measurements

According to the proposal used here, the scores for T1 acceleration and THRC are linked. Only the worst of both scores is used to determine the final score. From a biomechanical standpoint, there seems no reason to link the criteria in the scoring system. Almost all research in the field of whiplash injuries is focused on the basic assumption that relative motion between head and thorax is responsible for whiplash injuries; this is taken into account explicitly by the NIC criterion, and implicitly also by all criteria using forces and moments. Neither a high T1 acceleration nor a high THRC must necessarily lead to excessive relative motion, as illustrated by the fact that low NIC values and high THRC and/or T1 measurements are observed in the tests (Tables X and X). Consequently also the correlation between e.g. NIC and THRC or T1 is bad. Hence, the inclusion of T1 and THRC appears to be questionable. As the sensitivity analysis indicated that the final score is not much influence by these two parameters we suggest omitting them.

Upper neck Fx

It has been hypothesised by various researchers that inter-vertebral shear forces are responsible for whiplash injuries [7]. Therefore, considering the upper neck Fx makes sense biomechanically. However, according the current proposal only the positive maximum of Fx is considered although volunteer tests have shown that the tolerance limits are almost identical in the positive and negative

direction [8]. For example, seat B in test MUS070014 showed only negative Fx values and thus obtained the maximum score of 0.5 for this criterion; if negative values would have been considered, the peak value of –173 N observed in this test would have led to a score of only 0.05 (!).
From a biomechanical consideration the inclusion of negative values for this criterion makes sense. If this is done, however, Fx is included already in the Nkm criterion and may, therefore, be left out altogether.

Upper neck Fz
The biomechanical significance of Fz with respect to whiplash injuries is not as clear as with Fx. Again, only the positive maximum (i.e. tension of the neck) is considered. Some researchers argue that a negative, i.e. compressive, loading of the spine is much more dangerous than a slight tensile loading, because by compressing the spine, the ligaments stabilising the vertebrae are relaxed and, thus, un-physiological inter-vertebral motion is made possible [7]. In contrast, a slight tensile loading might even be beneficial because the neck is stabilised. Thus, the relation between upper neck Fz and injury risk is not monotonous and does not cross the zero-point (Fig. 3).

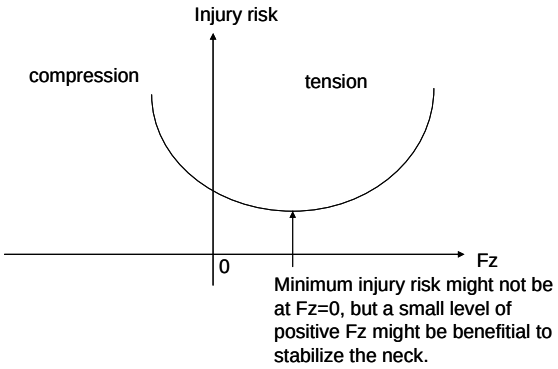

Figure 3. Schematic drawing of the relation between upper neck Fz and neck injury risk.

Furthermore, the BioRID dummy does not have compressible inter-vertebral discs that would allow for a certain damping of peak forces; the biofidelity of the Fz measurement is therefore unclear.

Static head restraint assessment
Comparing the outcome of the static and the dynamic parts of the test procedure, it is found that they conclude with a different ranking. Some seats even receive negative scores in the static tests. Generally, one must be aware that in the static measurement of the backset, i.e. the distance between head and head restraint, the actual contact point during impact is not necessarily the one which is used to measure the distance in the static case (see Fig. 4). In case of a rear-end collision the head of the person sitting on the seat will slightly rise relative to the head restraint due to a straightening of the spine and the rotation of the seat back. Hence the effective backset is to be expected higher than the one used in the static measurements. Consequently it depends very much on the design of the head restraint curvature whether this distance will increase in the dynamic case or not (Fig. 4). Additionally a re-active head restraint system will be able to bridge that gap such that a somewhat larger distance might be acceptable in the static case.
Therefore it is suggested using the static measurements as a pre-selection for the dynamic tests only. A seat that has a large backset in the static measurements and no re-active system intended to prevent whiplash injury, will most probably perform very bad in the dynamic tests. Hence there is no need to perform the dynamic part for seats with very poor static measurements. However, if a dynamic test is conducted, then the static measurements should be disregarded, i.e. if a seat manages to perform well in the dynamic tests, for instance, because of a well designed re-active system, the static measurement should not be part of the final scoring.

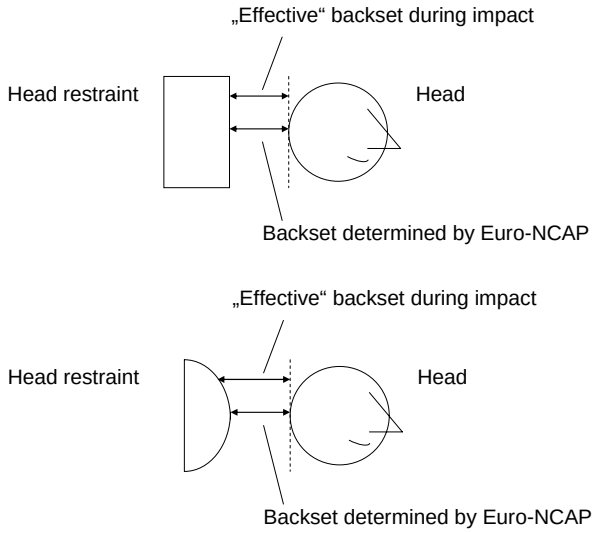

Figure 4. Backset situation for a’ theoretical’ block-shaped head restraint (top) and for a a more realistic head restraint showing a curved cross-section.

High severity pulse
Although WAD is primarily associated with low-speed impacts, it must be noted that a car manufacturer has additional seat design requirements to consider one of which is the seat performance in high speed impacts. Thus it can be argued that the 24 km/h pulse is of interest, for example, to ensure that the seat does not collapse in a high speed rear-end impact. But it has to be considered that in such crashes WAD is most

probably not the primary injury. Therefore it seems not reasonable to perform a 24 km/h sled test using the BioRID which was not designed for such high impacts and to determine criteria like NIC or Nkm that are not validated for such impacts. In order to assess whether a seat can withstand high loadings in rear-end impacts one can also perform a 24 km/h sled tests using a Hybrid III 95%ile dummy instead. In fact such a set-up seems suited to investigate the deformation characteristics of a seat. The Hybrid III 95%ile dummy is capable of performing such tests and by its anthropometry it represents a kind of worst case scenario. In such a dynamic test it can determined whether the seat collapses in case of a high speed rear-end impact. The determination of any neck injury criteria seems not necessary since the focus of such a test is the seat deformation rather than the neck injury risk. Although the seat stiffness could also be evaluated by other, probably much cheaper test set-ups, a sled test utilizing a crash test dummy seems the most illustrative way and thus particularly suited for consumer testing.

Rebound velocity

Generally it seems desirable that both the first phase of a rear-end impact as characterised by the backward motion of the occupant as well as the rebound phase are assessed in the test procedure.

The rebound velocity, although it has no direct correlation to biomechanics, seems a stable and reliable criterion for quantification of the rebound phase. All other criteria determined by dummy measurements might be dominated by the belt restraint phase. This can be problematic, because the belt system used for the sled tests does normally not correspond to the system used in the target vehicle, neither with respect to stiffness nor with respect to geometry. Thus it seems more appropriate to measure rebound velocity at a point in time before the belt restraint phase.

CONCLUSIONS

The test procedure that was used here intends to assess the performance of a seat with respect to its WAD injury risk. However, the proposal contains several factors that seem questionable from a biomechanics point of view. While the performance of sled tests with the set-up as proposed seem well suited, the evaluation scheme could be changed as follows:

- The number of criteria to be included in the rating system may significantly be reduced. By purely mathematical considerations, it was found that a reduced number of criteria does not sacrifice the accuracy of the assessment procedure. Some of the criteria are redundant, others not correlated to biomechanics (e.g. T1/THRC).
- It is proposed to reduce the parameters that determine the final score to be NIC, Nkm and the rebound velocity. If appropriate sliding scales are found, the moment My of the lower neck may be considered as well. There are few studies correlating this criterion to real-world accident data [6].
- The scoring system should be adjusted such that the kinematically more relevant phase of the occupant movement during rear-end impact is emphasized and a higher weight shall be put on the dynamic instead of the static parts of the test procedure.
- If more than one crash test pulse is used for the rating procedure, the same sliding scales should be used for all test pulses.
- A high speed pulse may be useful to ascertain seat back stability. In this case, however, a quasi-static test or a dynamic test where the seat back rearward deflection angle is measured as the only criterion would be sufficient.
- A harmonisation of the procedure how to position the head restraint is desired. The positioning of the head restraint prior to dynamic testing differs for tests that are conducted according to IIHS and EuroNCAP, respectively. Consequently also the results of the dynamic test are generally different. This can lead to quite different final scores
- An improvement of the currently straight back of the H-Point machine into a more anatomically shaped back should be envisaged.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support by Toyota Motor Company. All tests were conducted at the facilities of DSD Linz (Austria).

REFERENCES

[1] EuroNCAP (2007) The dynamic assessment of car seats for neck injury protection, Version 2.6, Final Draft, Status 05/03/07

[2] Bortenschlager K et al. (2007) Review of existing injury criteria and their tolerance limits for whiplash injuries with respect to testing experience and rating systems, Proc. ESV Conf., Paper-No. 07-0486

[3] Adalin C, Sferco R, Ray P (2005) The repeatibility and reproducibility of proposed test procedures and injury criteria for assessing neck injuries in rear impact, Proc. ESV Conf., Paper No. 05-0340

[4] Bortenschlager K et al (2003) Comparison tests of BioRID II and RID 2 with regard to repeatability, reproducibility and sensitivity for assessment of car seat protection potential in rear-end impacts, Stapp Car Crash Journal, 47:473-488

[5] International Insurance Whiplash Prevention Group IIWPG (2006) Seat/head restraint evaluation protocol, version 2.5.
[6] Kullgren A, Krafft M, Lie A, Tingvall C (2007) The effect of whiplash protection systems in real-life crashes and their correlation to consumer crash test programmes, Proc. ESV Conf., paper no. 07-0468
[7] Yang, K., P. Begeman, et al. (1997) On the role of cervical facet joints in rear end impact neck injury mechanisms. SP-1226; SAE 970497.
[8] Goldsmith, W. and A. Ommaya (1984) Head and neck injury criteria and tolerance levels. The biomechanics of impact trauma (Eds. B. Aldman and A. Chapon). Amsterdam, Elsevier Science Publishers: 149-187..

APPENDIX

Table 5. Results for the dynamic tests.

Test No.	NIC		Nkm		Fx upper		Fz upper		T1 acceleration		THRC		Rebound velocity		Total Score Dynamic
	[m2/s2]	Score	[-]	Score	[N]	Score	[N]	Score	[m/s2]	Score	[ms]	Score	[m/s]	Score	
MUS07001	11	0.47	0.15	0.5	36.1	0.48	464	0.37	7.8	0.5	94	0	2.5	0.5	2.82
MUS07002	12.6	0.44	0.15	0.5	37.9	0.48	389.1	0.46	7.1	0.5	88	0	2.67	0.5	2.88
MUS07014	13.9	0.39	0.46	0.11	0	0.5	340.4	0.5	11.3	0.24	79	0	3	0.5	2.24
MUS07006	14.6	0.36	0.41	0.18	93.1	0.3	747.7	0	15.1	0	69	0.14	5.05	0	0.98
MUS07007	12.4	0.45	0.4	0.18	90.8	0.31	745.3	0.01	15	0	75	0.02	5.01	0	0.97
AGU08001	13.8	0.39	0.59	0	163.0	0.08	741.5	0.01	15.6	0	70	0.12	5.37	0	0.60
AGU08002	13.6	0.40	0.54	0.01	132.0	0.18	724.8	0.03	15.1	0	69	0.14	5.50	0	0.76
MUS07004	23.3	0.03	0.56	0	200.5	0	1057.8	0	12.1	0.13	98	0	4.34	0.14	0.3
MUS07005	21.3	0.1	0.57	0	231.2	0	1077.2	0	12.4	0.09	92	0	4.34	0.14	0.33
MUS07012	17.3	0.26	0.52	0.04	185.2	0.02	887.1	0	11	0.28	88	0	4.42	0.12	0.72
AGU08004	18.7	0.20	0.76	0	247.0	0	956.5	0	13.3	0	84	0	5.47	0.07	0.27
AGU08005	22.4	0.06	0.79	0	250.0	0	970.9	0	11.9	0.15	86	0	4.80	0	0.21
MUS07004	25.7	0	0.51	0.05	238.7	0	1332.8	0	15.5	0	93	0	4.63	0.05	0.1
MUS07009	21	0.12	0.51	0.05	179.3	0.03	899.9	0	10.6	0.33	89	0	4.6	0.06	0.59
MUS07003	19	0.19	0.36	0.24	121.9	0.21	1043	0	14.1	0	82	0	4.25	0.17	0.81
MUS07013	13.8	0.46	0.33	0.29	48.6	0.45	779.3	0	15.6	0.04	113	0	5.01	0.18	1.42
MUS07015	17.6	0.27	0.41	0.13	53.7	0.43	646.1	0.21	12	0.5	82	0	3.33	0.5	2.04
MUS07011	14.6	0.42	0.27	0.41	0	0.5	691	0.13	16.8	0	72	0.06	5.92	0	1.52
AGU08003	14.7	0.42	0.53	0	0	0.5	659.6	0.18	18.5	0	69	0.10	5.71	0	1.20
MUS07010	25.3	0	0.38	0.18	176.1	0.09	777.6	0	14.4	0.22	87	0	4.56	0.34	0.83
AGU08006	23.1	0	0.90	0	367	0	864.2	0	12.7	0.47	89	0	5.51	0	0.47

Table 6. Analysing the sensitivity of the dynamic score for the medium severity pulse.

Test no.	NIC Score	Nkm Score	Fx upper Score	Fz upper Score	T1 Score	THRC Score	Rebound velocity Score	Total Score	**rank**	**% of max. score**
MUS07001	0,44	0,5	0,48	0,46	0,5	0	0,5	2,88	**1**	**96,0**
MUS07002	0,47	0,5	0,48	0,37	0,5	0	0,5	2,82	**2**	**94,0**
MUS07014	0,39	0,11	0,5	0,5	0,24	0	0,5	2,24	**3**	**74,7**
MUS07006	0,36	0,18	0,3	0	0	0,14	0	0,98	**4**	**32,7**
MUS07007	0,45	0,18	0,31	0,01	0	0,02	0	0,97	**5**	**32,3**
MUS07003	0,19	0,24	0,21	0	0	0	0,17	0,81	**6**	**27,0**
AGU08002	0,4	0,01	0,18	0,03	0	0,14	0	0,76	**7**	**25,3**
MUS07012	0,26	0,04	0,02	0	0,28	0	0,12	0,72	**8**	**24,0**
AGU08001	0,39	0	0,08	0,01	0	0,12	0	0,6	**9**	**20,0**
MUS07009	0,12	0,05	0,03	0	0,33	0	0,06	0,59	**10**	**19,7**
MUS07005	0,1	0	0	0	0,09	0	0,14	0,33	**11**	**11,0**
MUS07004	0,03	0	0	0	0,13	0	0,14	0,3	**12**	**10,0**
AGU08004	0,2	0	0	0	0	0	0,07	0,27	**13**	**9,0**
AGU08005	0,06	0	0	0	0,15	0	0	0,21	**14**	**7,0**
MUS07004	0	0,05	0	0	0	0	0,05	0,1	**15**	**3,3**
MUS07001	0,44	0,5	0,48	0,46			0,5	2,38	**1**	**95,2**
MUS07002	0,47	0,5	0,48	0,37			0,5	2,32	**2**	**92,8**
MUS07014	0,39	0,11	0,5	0,5			0,5	2	**3**	**80,0**
MUS07007	0,45	0,18	0,31	0,01			0	0,95	**5**	**38,0**
MUS07006	0,36	0,18	0,3	0			0	0,84	**4**	**33,6**
MUS07003	0,19	0,24	0,21	0			0,17	0,81	**6**	**32,4**
AGU08002	0,4	0,01	0,18	0,03			0	0,62	**7**	**24,8**
AGU08001	0,39	0	0,08	0,01			0	0,48	**9**	**19,2**
MUS07012	0,26	0,04	0,02	0			0,12	0,44	**8**	**17,6**
AGU08004	0,2	0	0	0			0,07	0,27	**13**	**10,8**
MUS07009	0,12	0,05	0,03	0			0,06	0,26	**10**	**10,4**
MUS07005	0,1	0	0	0			0,14	0,24	**11**	**9,6**
MUS07004	0,03	0	0	0			0,14	0,17	**12**	**6,8**
MUS07004	0	0,05	0	0			0,05	0,1	**15**	**4,0**
AGU08005	0,06	0	0	0			0	0,06	**14**	**2,4**
MUS07002	0,47	0,5	0,48				0,5	1,95	**2**	**97,5**
MUS07001	0,44	0,5	0,48				0,5	1,92	**1**	**96,0**
MUS07014	0,39	0,11	0,5				0,5	1,5	**3**	**75,0**
MUS07007	0,45	0,18	0,31				0	0,94	**5**	**47,0**
MUS07006	0,36	0,18	0,3				0	0,84	**4**	**42,0**
MUS07003	0,19	0,24	0,21				0,17	0,81	**6**	**40,5**
AGU08002	0,4	0,01	0,18				0	0,59	**7**	**29,5**
AGU08001	0,39	0	0,08				0	0,47	**9**	**23,5**
MUS07012	0,26	0,04	0,02				0,12	0,44	**8**	**22,0**
AGU08004	0,2	0	0				0,07	0,27	**13**	**13,5**
MUS07009	0,12	0,05	0,03				0,06	0,26	**10**	**13,0**
MUS07005	0,1	0	0				0,14	0,24	**11**	**12,0**
MUS07004	0,03	0	0				0,14	0,17	**12**	**8,5**
MUS07004	0	0,05	0				0,05	0,1	**15**	**5,0**
AGU08005	0,06	0	0				0	0,06	**14**	**3,0**
MUS07002	0,47	0,5					0,5	1,47	**2**	**98,0**
MUS07001	0,44	0,5					0,5	1,44	**1**	**96,0**
MUS07014	0,39	0,11					0,5	1	**3**	**66,7**
MUS07007	0,45	0,18					0	0,63	**5**	**42,0**
MUS07003	0,19	0,24					0,17	0,6	**6**	**40,0**
MUS07006	0,36	0,18					0	0,54	**4**	**36,0**
MUS07012	0,26	0,04					0,12	0,42	**8**	**28,0**
AGU08002	0,4	0,01					0	0,41	**7**	**27,3**
AGU08001	0,39	0					0	0,39	**9**	**26,0**
AGU08004	0,2	0					0,07	0,27	**13**	**18,0**
MUS07005	0,1	0					0,14	0,24	**11**	**16,0**
MUS07009	0,12	0,05					0,06	0,23	**10**	**15,3**
MUS07004	0,03	0					0,14	0,17	**12**	**11,3**
MUS07004	0	0,05					0,05	0,1	**15**	**6,7**
AGU08005	0,06	0					0	0,06	**14**	**4,0**

Table 6. Analysing the sensitivity of the dynamic score for the high severity pulse.

Test no.	NIC Score	Nkm Score	Fx upper Score	Fz upper Score	T1 Score	THRC Score	Rebound velocity Score	Total Score	**rank**	**% of max. score**
MUS07015	0,27	0,13	0,43	0,21	0,5	0	0,5	2,04	**1**	**68,0**
MUS07011	0,42	0,41	0,5	0,13	0	0,06	0	1,52	**2**	**50,7**
MUS07013	0,46	0,29	0,45	0	0,04	0	0,18	1,42	**3**	**47,3**
AGU08003	0,42	0	0,13	0,5	0	0,1	0	1,15	**4**	**38,3**
MUS07010	0	0,18	0,09	0	0,22	0	0,34	0,83	**5**	**27,7**
AGU08006	0	0	0	0	0,47	0	0	0,47	**6**	**15,7**
MUS07015	0,27	0,13	0,43	0,21			0,5	1,54	**1**	**61,6**
MUS07011	0,42	0,41	0,5	0,13			0	1,46	**2**	**58,4**
MUS07013	0,46	0,29	0,45	0			0,18	1,38	**3**	**55,2**
AGU08003	0,42	0	0,13	0,5			0	1,05	**4**	**42,0**
MUS07010	0	0,18	0,09	0			0,34	0,61	**5**	**24,4**
AGU08006	0	0	0	0			0	0	**6**	**0,0**
MUS07013	0,46	0,29	0,45				0,18	1,38	**3**	**69,0**
MUS07015	0,27	0,13	0,43				0,5	1,33	**1**	**66,5**
MUS07011	0,42	0,41	0,5				0	1,33	**2**	**66,5**
MUS07010	0	0,18	0,09				0,34	0,61	**5**	**30,5**
AGU08003	0,42	0	0,13				0	0,55	**4**	**27,5**
AGU08006	0	0	0				0	0	**6**	**0,0**
MUS07013	0,46	0,29					0,18	0,93	**3**	**62,0**
MUS07015	0,27	0,13					0,5	0,9	**1**	**60,0**
MUS07011	0,42	0,41					0	0,83	**2**	**55,3**
MUS07010	0	0,18					0,34	0,52	**5**	**34,7**
AGU08003	0,42	0					0	0,42	**4**	**28,0**
AGU08006	0	0					0	0	**6**	**0,0**