Improve Assessment and Enhance Safety for the Evaluation of Whiplash Protection Systems Addressing Male and Female Occupants in Different Seat Configurations by Introducing Virtual Methods in Consumer Tests

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Abstract Low severity rear vehicle impacts can cause Whiplash Associated Disorders (WAD) which is one of the most common traumas leading to permanent medical impairment. Therefore, new vehicles are being equipped with anti-whiplash systems. Those systems are rated in consumer tests such as the Euro NCAP, evaluating loads on a dummy based on a 50th percentile male in one seat configuration. However, many vehicle occupants adjust their seats differently from this particular seat configuration. Studies show that females have a higher risk of sustaining these injuries, by up to 3.1 times. To address these issues, 54 simulations comprising one seat model, one male (BioRID II) and one female (EvaRID) occupant model, and several different seat configurations were evaluated. Results show, for example, that the backrest angle can influence loads on the neck (e.g. NIC) by up to 78% for the BioRID II occupant model. To address both males and females, and different seat configurations, it is proposed that the current consumer testing protocol be extended to include virtual testing. Experimental tests are suggested to be complemented by at least 12 virtual Finite Element Method simulations in order to address differing seat configurations and the population for which no physical dummy is available.

Keywords BioRID, consumer test, EvaRID, virtual testing, whiplash associated disorder

I. INTRODUCTION

Rear-end collisions are one of the most common accidents in today's traffic. For example, in Austria rear-end collisions make up one third of all accidents (Fig. 1). These crashes occur at relatively low velocity changes (typically <25 km/h).

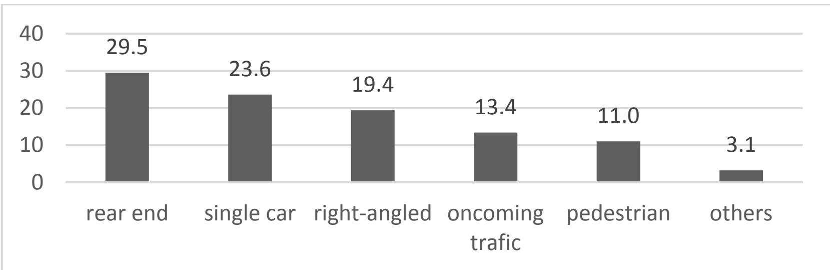

Fig. 1 Percentage of accidents in order of accident types in Austria 2011 [1].

The fatality rate in these kinds of accidents is low, however, rear-end collisions can result in Whiplash Associated Disorders (WAD), thus leading to an issue that still needs to be addressed. The majority of those experiencing initial neck symptoms as a result of a low severity impacts recover within a few weeks or months after the crash; however, 5–10% of individuals experience different levels of permanent disabilities. About 5% of all WAD victims sustain a permanent degree of disability of at least 10% while 1.7% are signed off work permanently due to WADs. Within the European Union (EU 27), according to [2], an estimate of more than 800 000 victims suffer WADs resulting in insurance and other social costs of approximately €10 billion annually (e.g. Italy € 2.4 billion, Germany € 0.5 billion, Sweden € 0.46 billion, UK € 3.5 billion, US $ 29 billion [3]). The

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associated socio-economic burden on society with regard to WADs needs to be addressed.

As a complement to European legislation and regulations with regard to collision safety, vehicle safety is assessed in the European New Car Assessment Programme (Euro NCAP). Euro NCAP conducts consumer tests, where the whiplash score is part of the overall rating. Currently whiplash tests are performed with the 50th percentile male occupant model Biofidelic Rear Impact Dummy V2 (BioRID II) [4]. At present, Euro NCAP rates the performance of car seats during rear-end collisions by conducting one static and three dynamic tests. In addition, car and car seat manufacturers today also develop and evaluate new designs of seats by performing Finite Element Method (FEM) simulations. For this purpose, the BioRID II dummy model and a virtual seat model are used.

It is firmly established by numerous studies dating back to the 1960s that females have a 1.5-3.1 times higher risk of sustaining WADs than males [5]-[6]. Despite this fact, a dummy representing the female part of the population is not yet available today.

Driver studies [7] show that many vehicle occupants do not adjust their car seats to the most appropriate setting for optimal protection. Furthermore, vehicle occupants position themselves differently in the seat which leads to a vast variety of seated positions. Additionally, vehicle occupants vary significantly from each other in terms of gender, age and anthropometry, and different driving situations (relaxed posture on a highway, tensed seated position in city traffic, muscle tension, etc.) lead to different pre-crash situations which significantly influence the outcome during rear impact crashes. However, none of these situations are represented by current testing protocols and safety development.

Therefore, the aim of the present study was to develop a method for evaluating the protective performance for more than one occupant model, initially the 50th percentile female and male, in a larger variety of seat adjustment situations than is currently addressed in the Euro NCAP tests.

The scope of this study was to propose additions to the current testing programme for whiplash protection systems, considering different occupants and car seat configurations occurring in vehicles today. Recent developments within the ADSEAT project (www.adseat.eu) facilitates FEM analysis in the field of car seat occupant safety with a virtual 50th percentile female rear impact occupant model called EvaRID (Eva – indicating female, RID – Rear Impact Dummy) which cover a large portion of female occupants at risk [7]-[10]. Additionally, the use of a variety of *Non* Euro NCAP seat configurations has the potential to significantly influence the testing system. *Non* Euro NCAP seat configurations are configurations where the adjustable seat components are set to other settings (e.g. head restraint positions, backrest angles, seat cushion angles, tilted head restraint, etc.) than described in the Euro NCAP protocol or where another occupant model is used (i.e. EvaRID).

II. METHODS

In this study, virtual and experimental methods, which are illustrated in Fig. 2, have been used. Firstly, a general comparison between a dynamic sled test with a BioRID II dummy and a corresponding virtual sled test was performed to show that real and virtual sled tests provide comparable results under the same conditions, and to prove that the occupant model and seat model were compatible.

Secondly, sled tests and virtual sled tests with the BioRID II dummy and the corresponding virtual dummy model were performed and analysed using seat configurations which do not comply with the Euro NCAP protocol [4]. This step was performed to show that the physical dummy and virtual dummy model show reasonable responses under loads they were not designed for.

Thirdly, the newly developed virtual EvaRID dummy model was used in virtual sled tests to show what influence diversity of occupants has on loads that occur during rear impact crashes. Unfortunately, a physical female rear impact dummy is not available yet; therefore real world sled tests could not be conducted for the female occupant model.

Finally, based on the results of the conducted tests, a proposal to extend future consumer testing has been developed. Some of the suggestions include tasks that can easily be achieved without much additional effort, while other tasks need some further development and approval. The additional suggested virtual investigations should be regarded as added gains for consumers to enhance, rather than to replace or change, the current Euro NCAP whiplash rating system.

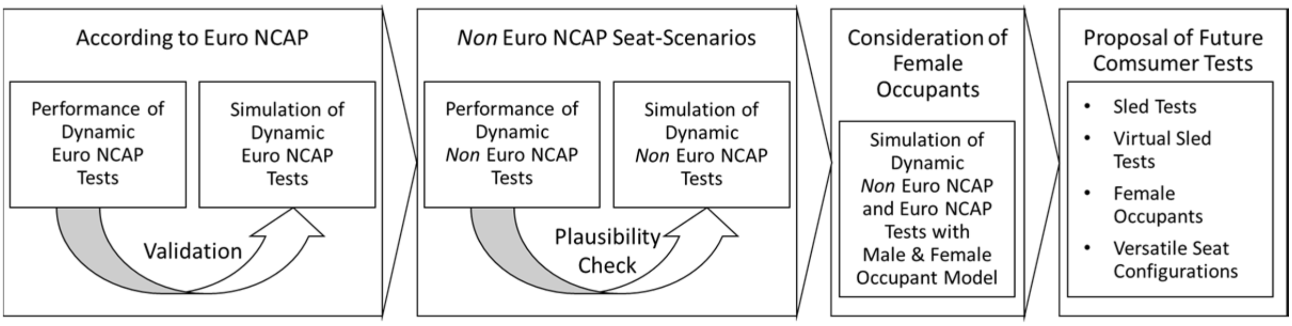

Fig. 2 Flowchart of the steps performed within this study

It should be pointed out that the purpose of this study was not to assess the seats or components used throughout the work conducted, but to highlight to what extent occupant loading results are influenced when using the same car seat in different configuration scenarios.

Virtual Sled Testing

FEMs, in this case LS-DYNA V971 R6.0.0, were used for all virtual sled tests. The main components in the finite element simulations were two dummy models; the commercially available BioRID II dummy model (78.7 kg, 177cm) and the development model EvaRID (62.3kg, 162cm), as well as one particular seat model provided by a car seat manufacturer (Faurecia, France) validated for Euro NCAP test scenarios. The three main components are displayed in Fig. 3, Fig. 4 and Fig. 5.

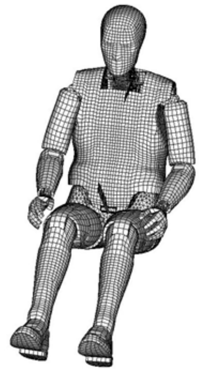

Fig. 3 BioRID II FEM model

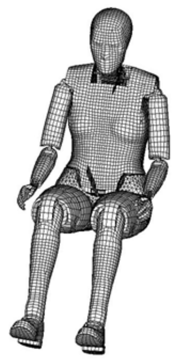

Fig. 4 EvaRID FEM model

Fig. 5 Validated car seat model

Fifty four simulations were selected for this study considering male and female anthropometry and different seat configurations as displayed in TABLE V. The adjustment options of the seat model were limited to backrest angle and head restraint height to reflect the actual options consumers can influence themselves. Both male and female anthropometry was taken into account due to the availability of the two occupant models, BioRID II and EvaRID. The different setting options of the seat are illustrated in Fig. 6 and Fig. 7. The *Centred* backrest position and *Middle* head restraint setting are the configurations used in accordance to Euro NCAP protocol. A *Forward* tilted backrest indicates it has been adjusted forward by 10° from the *Middle* position, and *Backward* in this context means adjusted 10° backward from the *Middle* position. The head restraint for these simulations was raised to its highest (*High*) and lowered to its lowest (*Low*) possible position, respectively.

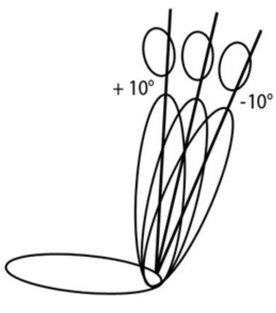

Fig. 6 Illustration of backrest position settings

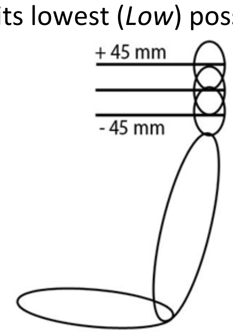

Fig. 7 Illustration of headrest position settings

Experimental Testing

Several real world whiplash sled tests were conducted. The different configurations can be seen in TABLE I. The tests complying with the Euro NCAP protocol were performed in a first series of whiplash tests at an independent test laboratory.

TABLE I Test Matrix of all relevant sled tests for comparison with virtual sled tests

TEST MATRIX

Euro NCAP Tests			
Occupant Model	Backrest Position	Head Restraint Position	Pulse
BioRID II	Centred	Middle	SRA 16 km/h
	Centred	Middle	SRA 24 km/h
	Centred	Middle	IIWPG 16 km/h
Non Euro NCAP Tests			
Occupant Model	Backrest Position	Head Restraint Position	Pulse
BioRID II	Forward	Middle	IIWPG 16 km/h
	Centred	Middle	IIWPG 16 km/h
	Backward	Middle	IIWPG 16 km/h

The tests for comparison between configurations complying with Euro NCAP standards [4] were carried out with the corresponding car seat as used during the virtual investigations. Three different pulses were applied: SRA 16 km/h (Swedish Road Administration), SRA 24 km/h and IIWGP 16 km/h (International Insurance Whiplash Prevention Group). Loads on the occupant models were recorded and neck injury criteria (i.e. NIC, Nkm, etc.) as well as the Euro NCAP scores were computed. Several high speed videos of the physical tests were captured for comparison purposes with the virtual simulations.

For the *Non* Euro NCAP Seat Scenario sled tests, a current state-of-the-art medium-class car seat was selected. The seat was selected for comparison with the model used in the virtual investigations; although the exact same seat was not available. All *Non* Euro NCAP tests were performed in a second series of whiplash sled tests. The loading device was represented by a BioRID II dummy and the IIWPG 16 km/h pulse was applied. During these tests, the backrest angle and the head restraint position were adjusted to different settings. In Fig. 8 three different settings for the backrest are displayed. Fig. 8a (left) shows the initial test configuration with the seat configured according to the Euro NCAP protocol. Fig. 8b (middle) illustrates the configuration with the backrest being adjusted backwards by 10°. Fig. 8c (right) shows the same seat with the backrest adjusted forward 10° in relation to the initial configuration.

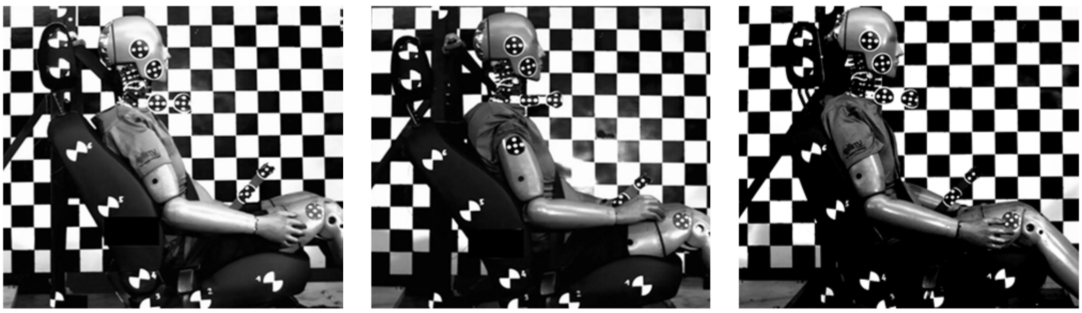

Fig. 8 Illustration of backrest position settings during sled tests: Left picture (a) according to Euro NCAP protocol, middle picture (b) 10° tilted backwards and in the right picture (c) 10° forward in relation to the Euro NCAP configuration [4].

Furthermore, records for these tests loads on the occupant models were recorded, neck injury criteria were computed and several high speed videos for comparison with virtual investigations were captured. The results of the sled tests are important in order to verify that virtual sled testing delivers comparable and reasonable results in load cases differing from Euro NCAP standards, such as different backrest angles, head restraint positions and occupant models.

Data Analysis and Comparison

The loads on the dummy models were analysed in all simulations. Based on the available data, several injury criteria, as listed in TABLE II, were computed and used for comparison. Since the goal of this study was to compare different configurations of *one* seat, not rate this seat according to the Euro NCAP protocol, all criteria mentioned in TABLE II have been summarised and normalised.

TABLE II List of Injury criteria and loads used in this study

INJURY CRITERIA

Abbreviation	Description	Criterion Number	Normalised Criterion.	Weighting	Unit
NIC	Neck Injury Criterion	C_1	c_1	w_1	(-)
Nkm	Neck criteria N_{fa}, N_{ea}, N_{fp}, N_{ep}	C_2	c_2	w_2	(-)
Fx upper neck	Tension Force upper neck	C_3	c_3	w_3	(N)
Fz upper neck	Shear Force upper neck	C_4	c_4	w_4	(N)
T1 acc	Acceleration of T1 vertebral body	C_5	c_5	w_5	(g)
T-HRC	Time until head to head restraint contact	C_6	c_6	w_6	(ms)
My OC Flex	Flexion bending moment at occiput	C_7	c_7	w_7	(Nm)
My OC Ext	Extension bending moment at occiput	C_8	c_8	w_8	(Nm)
Nij	Normalised neck injury criterion	C_9	c_9	w_9	(-)

N_{fa} flexion anterior, N_{ea} extension anterior
N_{fp} flexion posterior, N_{ep} extension posterior

The baseline for normalisation is the result gathered from the configuration according to the Euro NCAP Whiplash testing protocol [4] using the IIWPG 16km/h pulse. The normalised criterion was compared with the corresponding criterion of the simulation according to Euro NCAP (centred backrest, middle head restraint height) under the load of the IIWPG 16km/h pulse equipped with the male occupant model as in the following equation:

$$c_{i(p,s,b,h)} = \frac{C_{i(p,s,b,h)}}{C_{i(M,1,2,2)}} \tag{1}$$

TABLE III List of variables in formula (1)

FORMULA EXPLANATION

Variable	Explanation
$c_{i(p,s,b,h)}$	normalised neck injury criterion listed in TABLE II dependent on
p	pulse used which can be L (SRA 16km/h), M (IIWPG 16km/h) or H (SRA 24 km/h)
s	the gender of the occupant model which can be 1 (male) or 2 (female)
b	the setting of the backrest which can be 1 (forward),2 (centred) or 3 (backward)
h	the setting of the head restraint which can be 1 (High), 2 (Middle) or 3 (Low)
$C_{i(p,s,b,h)}$	the corresponding neck injury criterion dependent on the above parameters and
$C_{i(M,1,2,2)}$	the corresponding neck injury criterion from the simulation according to [4] with the IIWPG 16 km/h pulse and the male occupant model (BioRID)

For example, the normalised NIC of the load case low severity pulse (SRA16 km/h), the female occupant model, with the backrest in its backward position and the head restraint at the highest possible setting (L231) is $c_{1(L231)} = \frac{C_{1(L,2,3,1)}}{C_{1(M,1,2,2)}}$ (-).

The weighting and summarisation of the normalised neck injury criteria c_i leading to the normalised and weighted value (NV) were conducted in accordance with the following equation:

$$NV = \frac{\sum_{i=1}^{n} c_i \cdot w_i}{\sum_{i=1}^{n} w_i} \tag{2}$$

TABLE IV List of variables in formula (2)
FORMULA EXPLANATION

Variable	Explanation
NV	the normalised and weighted value (-)
c_i	each of the normalised neck injury criteria listed in TABLE II
w_i	the corresponding weighting factor (-) listed in TABLE II

The weighting factors w_1 through w_9 have been set to one (unity) for this first investigation.

In this rating a value of $NV = 1$ represents the corresponding seat configuration with its occupant model and pulse performing equally well compared to the configuration with the head restraint in its middle position, the backrest centred, the IIWPG 16 km/h pulse and the male occupant model (BioRID II). A value lower than one (unity) indicates that the occupant has to cope with lower loads, and a value higher than one that the occupant has to sustain higher loads than in the configuration according to [4] and the IIWPG 16km/h pulse.

Fig. 9 shows a graph in which all possible seat adjustment configurations are displayed. These notional results were chosen in order to explain the graph. For each pulse and occupant model, every configuration result can be displayed in this graph. Since the NV values are normalised the configurations according to the Euro NCAP protocol (centred, middle) show a value of one (unity). The three lines in Fig. 9 are examples of the possible outcome of such an investigation. One line represents one occupant model under the loading of one specific pulse. The solid line, for example, represents a car seat which for one occupant delivers the same loading level in all possible seat adjustment configurations when exposed the same pulse. The dashed line (not robust) shows that the performance is about 25% worse in all configurations than in the Euro NCAP configuration (centred, middle). The dotted line (good) shows the result for a seat performing 25% better in all configurations than the Euro NCAP configuration (centred, middle). The ultimate aim is to develop a seat for which all NV values are lower than one (unity) whereby the graph would be surrounded by the solid line (robust) in Fig. 9.

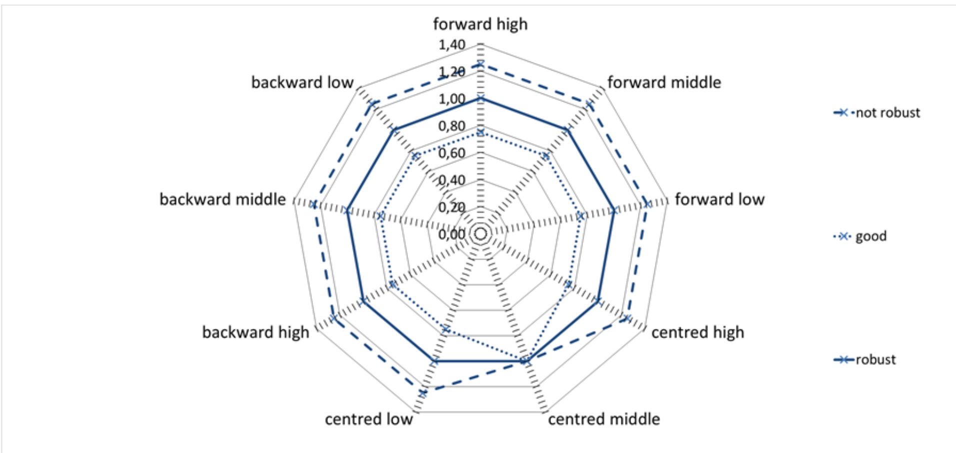

Fig. 9 Possible extension of the current Euro NCAP testing with virtual methods to gain additional scores

III. RESULTS

Comparison of Real and Virtual Sled Testing according to the Euro NCAP protocol

The comparison of real sled tests and virtual sled test simulations, which meet the Euro NCAP protocol [4] shows that a very good compliance was found. Comparing the x-acceleration signals of the head and the upper neck shear force Fx values for both, the test (solid line) and the simulations (dashed line) in Fig. 10 correlated well for trend, peak values and timing. Head x-acceleration and Fx for the IIWPG 16km/h pulse have been selected as examples, although further values have been compared of which additional graphs can be found in Appendix I and Appendix II. The values in Fig. 10 have been normalised by the maximum values (x-acceleration in the left graph, Fx in the right graph) of the real sled test results.

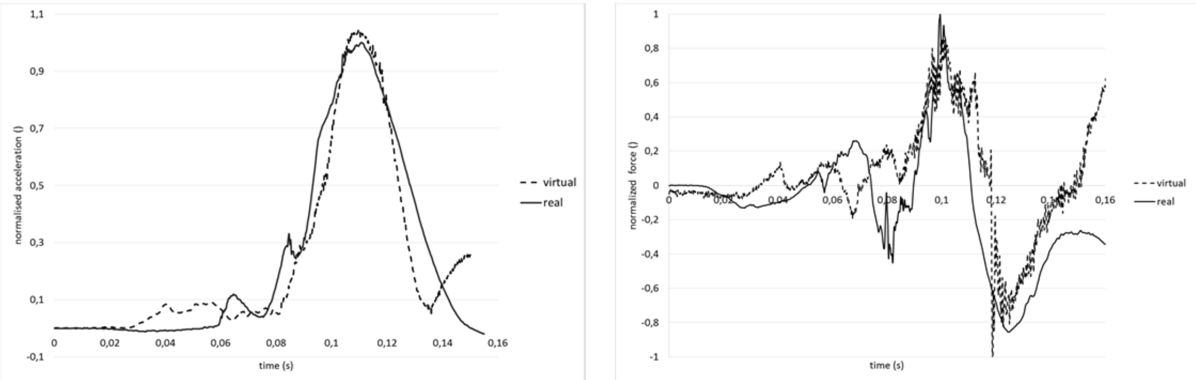

Fig. 10 Head x-acceleration (left), upper neck shear force Fx (right) comparison of a real sled test and the corresponding simulation for the IIWPG 16 km/h pulse and BioRID II according to the Euro NCAP protocol

Comparison of Real and Virtual Sled Testing under Non Euro NCAP configurations

Based on the results from tests and virtual simulations performed according to the Euro NCAP protocol, additional physical sled tests and virtual sled tests were conducted. Fig. 11 and Fig. 12 show three head x-acceleration graphs of the BioRID II dummy (sled test) and BioRID II FEM model (virtual sled test), respectively. In both graphs, the full line describes the results according to a sled test configured to a regular Euro NCAP test. The dotted curve represents the result for a sled test with *Non* Euro NCAP configuration of the backrest which had been tilted forward 10 in occupant's view. The dashed curve shows the result for a test with the backrest tilted backwards 10 .

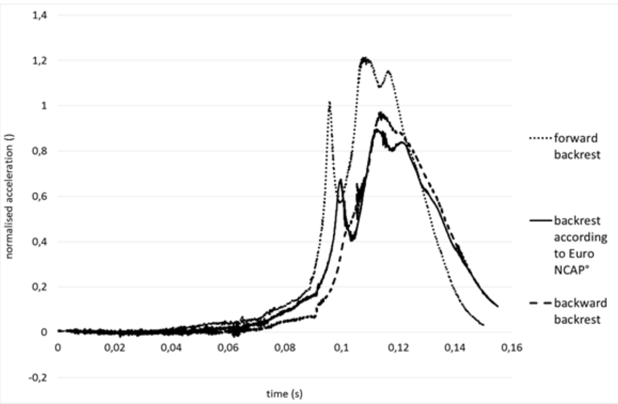

Fig. 11 Graph of the head x-acceleration during three whiplash sled tests

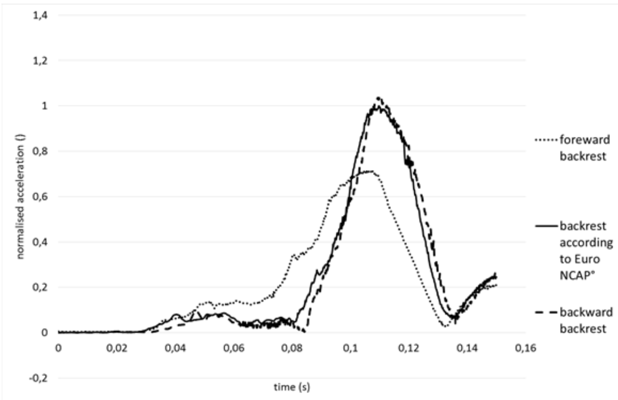

Fig. 12 Graph of the head x-acceleration during three virtual whiplash sled test simulations

The dashed lines in the two figures both lag behind whereas the dotted curves begin to rise ahead of the solid lines and the configuration with a backward tilted backrest (dashed line) peaks higher than the graph according to the Euro NCAP configuration (solid line). Please note that this comparison is only of qualitative character, since the virtual seat model and the real seat used in these *Non* Euro NCAP tests are similar but not equal. Furthermore, the sled tests were conducted without an available seating procedure or dummy positioning guideline, since for "out of position" this information is not available. These preconditions can be the explanation for why the dotted curves in Fig. 11 peaks at a higher value and oscillates more than the corresponding simulation and the associated sled tests.

Comparing the graphs, it can be seen that simulation and sled testing have a similar trend with regard to head acceleration. The timing is comparable and the peak values (except for the test with the backrest tilted forward) fit nicely. The values in Fig. 11 and Fig. 12 have been normalised by the maximum value of the virtual sled test results according to the Euro NCAP protocol [4].

Virtual sled testing with a female occupant model EvaRID

Currently there is no physical rear impact dummy available that represent the female part of the population. Similarly, no established thresholds can be found in current literature except for a suggestion by [11], and seating and positioning procedures are not available either. Hence, for the simulations carried out within this study, some assumptions have had to be made.

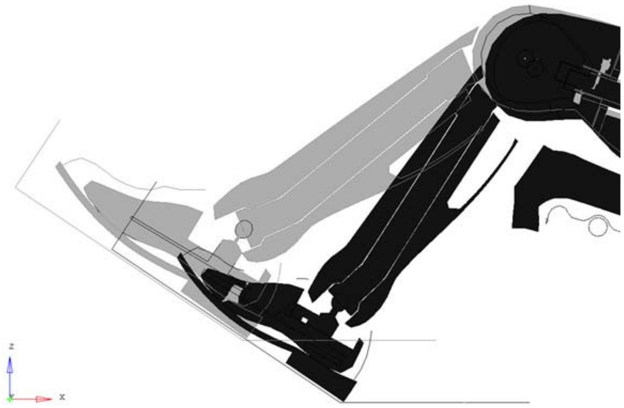

Fig. 13 Comparison of legs of male (grey) and female (black) occupant model

The seated position of an average female compared to the average male occupant (BioRID II) is very likely to be further forward, leading to a change in leg and foot angles (Fig. 13). Some studies [7] show that a change in backrest angle might be applicable, however, to simplify comparison between male and female occupants the backrest was adjusted to the same angle settings for both dummy models. As the head restraint setting options do not allow for adjusting it to suit the female occupant model in most cases, again, the same settings were used for both female and male simulations, for comparison reasons.

Furthermore the height of most backrests does not suit the smaller occupant model and it was not possible to modify or make adjustments to accommodate for this fact. Also for comparison reasons, the same thresholds as for male occupants have been applied for females.

Since seating procedures are not yet available for an average female dummy model (e.g. EvaRID), the positioning of the virtual dummy in the car seat was accomplished by positioning the dummy model as close above the seat cushion and as near to the backrest as possible, to ensure that initial penetrations were avoided. From this location, the dummy model was dropped into the seat by applying a down force of one g (9.81 m/s²). This pre-simulation was conducted for as long as necessary until the dummy found its final position in the seat. Following this procedure, the actual loading pulse was applied. This procedure proved to be stable for all seat configurations used during this study. A comparison of the head and neck kinematics of the male (upper row) and the female (lower row) occupant model can be seen in Fig. 14. It shows, that the kinematics are similar, although timing and deflection differ.

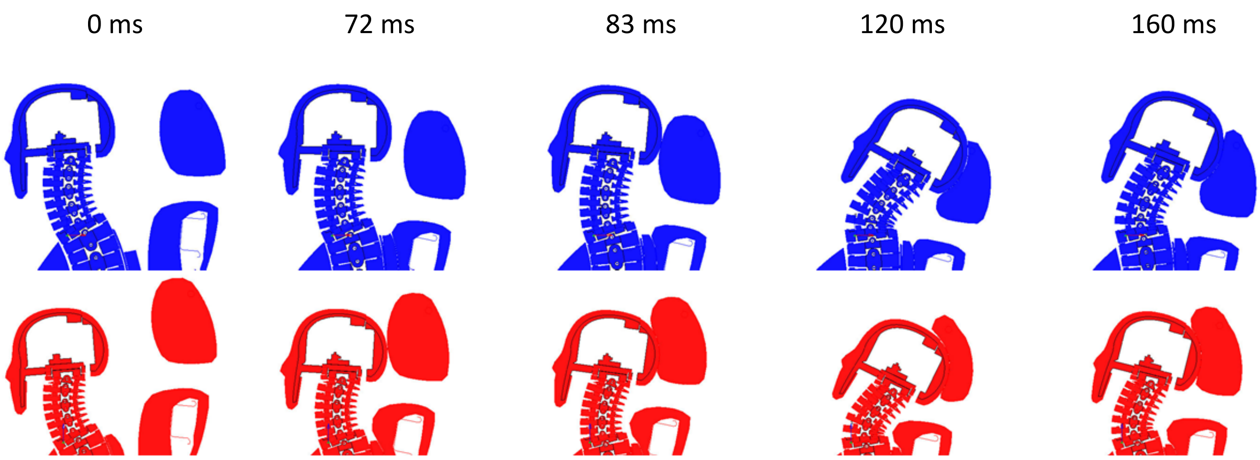

Fig. 14 Comparison of head and neck kinematics of the virtual BioRID II (upper row) and EvaRID (lower row) dummy models.

Analysis of Differing Load Cases

For comparison between the 54 different simulations as shown in TABLE V, only the NV was used. The different seat configurations at different backrest angles and headrest positions equipped with different occupant models and loaded with three acceleration pulses were analysed and all NV have been calculated and compared.

TABLE V Comparison of the virtual sled test results for male and female occupants in nine different seat configurations and with three different loading pulses.

SIMULATION MATRIX

Occupant Model	Backrest Position	Head Restraint Position	Pulse SRA 16 km/h	Pulse IIWPG 16 km/h	Pulse SRA 24km/h
			NV | Trend		
BioRID II	Forward	High	0.81 | ↗	0.96 | →	0.90 | →
		Middle	0.63 | ↗	0.65 | ↗	0.67 | ↗
		Low	0.56 | ↗	0.47 | ↗	0.64 | ↗
	Centred	High	1.11 | →	1.15 | ↘	1.29 | ↘
		Middle	0.84 | ↗	1.00 | →	1.20 | ↘
		Low	1.05 | →	1.20 | ↘	1.46 | ↘
	Backward	High	1.18 | ↘	1.43 | ↘	1.56 | ↘
		Middle	0.98 | →	1.16 | ↘	1.49 | ↘
		Low	1.10 | →	1.05 | →	1.78 | ↘
EvaRID	Forward	High	0.76 | ↗	1.05 | →	1.03 | →
		Middle	0.64 | ↗	0.89 | →	0.85 | ↗
		Low	0.36 | ↗	0.66 | ↗	0.59 | ↗
	Centred	High	1.48 | ↘	2.01 | ↘	2.09 | ↘
		Middle	1.10 | →	1.52 | ↘	1.62 | ↘
		Low	0.74 | ↗	1.14 | →	1.38 | ↘
	Backward	High	1.50 | ↘	1.62 | ↘	2.18 | ↘
		Middle	1.07 | →	1.37 | ↘	1.79 | ↘
		Low	0.72 | ↗	1.07 | →	1.65 | ↘

The virtual sled testing shows, that one car seat loaded with different occupant models can deliver very diverse results. Furthermore, different seat configurations loaded with the same occupant also delivers diverse results. The comparison in TABLE V gives an overview of all simulations. Aside from the normalised and weighted value NV, the trend of each configuration is indicated by an arrow. The trend is defined as steady (→) between 0.85 and 1.15. A NV equal or higher than 1.15 is considered disadvantageous (↘) and a NV equal and lower than 0.85, advantageous (↗).

The minimum NV for this particular seat with the male occupant model was found to be under the loading of the IIWPG 16km/h pulse (male, forward backrest downward head restraint), not as may have been expected at the lower SRA 16km/h pulse. The lowest loading for the female occupant model, however, could be determined under loading with what is referred to as the low severity pulse (SRA 16km/h) at the configuration of forward backrest, downward head restraint. This is also the overall minimum value causing a load of only 36% of the basis value from the male Euro NCAP configuration with the IIWPG 16 km/h pulse to the (female) occupant model. Nevertheless, the maximum value was also found to be applied to the female occupant model at the configuration high severity pulse (SRA 24 km/h), backward back rest and upward head restraint with a NV of 2.18.

Comparing the configuration female occupant, backward backrest and highest head restraint position under the load of the low severity pulse (SRA 16 km/h) rather than the high severity pulse (SRA 24 km/h), a NV of 1.50 was found. This shows that the injury risk results can be significantly different for the same occupant model by simply adjusting the seat components slightly differently (absolute difference of 116%). Moreover, the male occupant model was also exposed to load increases of up to 78% higher (configuration male occupant, backward backrest, low head restraint position) than in the configuration the seat has been developed for (male occupant, centred backrest, middle head restraint). Graphs of selected configurations and signals can be found in Appendix III to Appendix VII.

In the subsequent Fig. 15, the results for all 54 different virtual sled tests for this particular seat model with two differing occupant models are displayed. It can be seen that all configurations with a forward tilted backrest seem to perform better in rear end crash scenarios, where a backward tilted backrest seems to be disadvantageous.

Looking at the scenarios with the backrest tilted forward, it seems to be irrelevant if the occupant model is male or female, and also the position of the head restraint seems to only marginally influence the outcome. Perhaps it would be possible to reduce investigation on configuration scenarios like these to one with a male and one with a female occupant model.

The configurations *centred middle* (Fig. 15) represents the Euro NCAP configurations. The results for the male occupant, irrespective of the head restraint setting, appear to be very stable for all three pulses. However, protection of the female, for whom this seat was not developed was lacking in this scenario.

Almost all configurations with the backrest tilted backward seem to contribute to a loss of protection, for both occupant models.

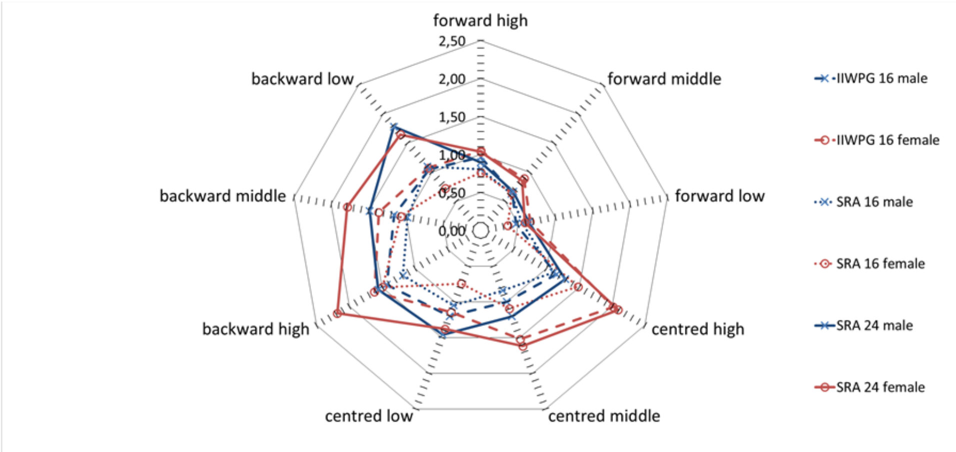

Fig. 15 Graph of NV results all scenarios investigated with virtual sled tests

A well designed, robust seat for rear impact crashes with an equal protection level for both occupant models (EvaRID and BioRID), for all seat adjustment scenarios (backrest, head restraint), under the loading of all three different acceleration pulses currently in use (SRA 16km/h SRA24 km/h and IIWG 16 km/h) would be shown in the diagram in Fig. 15 with all values equal or close to one (unity). It must be kept in mind, that this is only a relative comparison of the actual seat and its performance in different adjustment scenarios (robustness), not a qualitative rating. For this purpose, the standard Euro NCAP rating should be used.

Proposal to extend the current Euro NCAP whiplash tests by adding virtual methods

Fig. 16 illustrates the current Euro NCAP protocol situation and a possible scenario for future implementation of virtual methods. The top block “Euro NCAP” represents the current (dynamic) testing procedure which contributes to the overall Euro NCAP rating. The block “Future NCAP” describes how virtual investigations could be implemented without changing the current scenario but adding additional scores to the (whiplash) overall rating.

In the first two steps, the current dynamic testing procedure can remain as it is today. The real seat model would be tested with the BioRID II dummy with the seating posture and the pulses described in the current Euro NCAP protocol.

In a future scenario, these tests would serve as a base for the validation (Step 4) of a virtual simulation model with the validated virtual BioRID II dummy model and a validated virtual car seat model (Step 3). This simulation model is then configured with “new” seat adjustments (i.e. all possible adjustment options of the seat, such as backrest angle, head restraint height, backset, etc.), additional acceleration pulses and different occupant models (e.g. EvaRID, Total human model for safety - THUMS, etc.).

From the results of the virtual investigation, additional points for the Euro NCAP whiplash score could be gained and added to the score achieved in the current real world Euro NCAP whiplash test (Step 7).

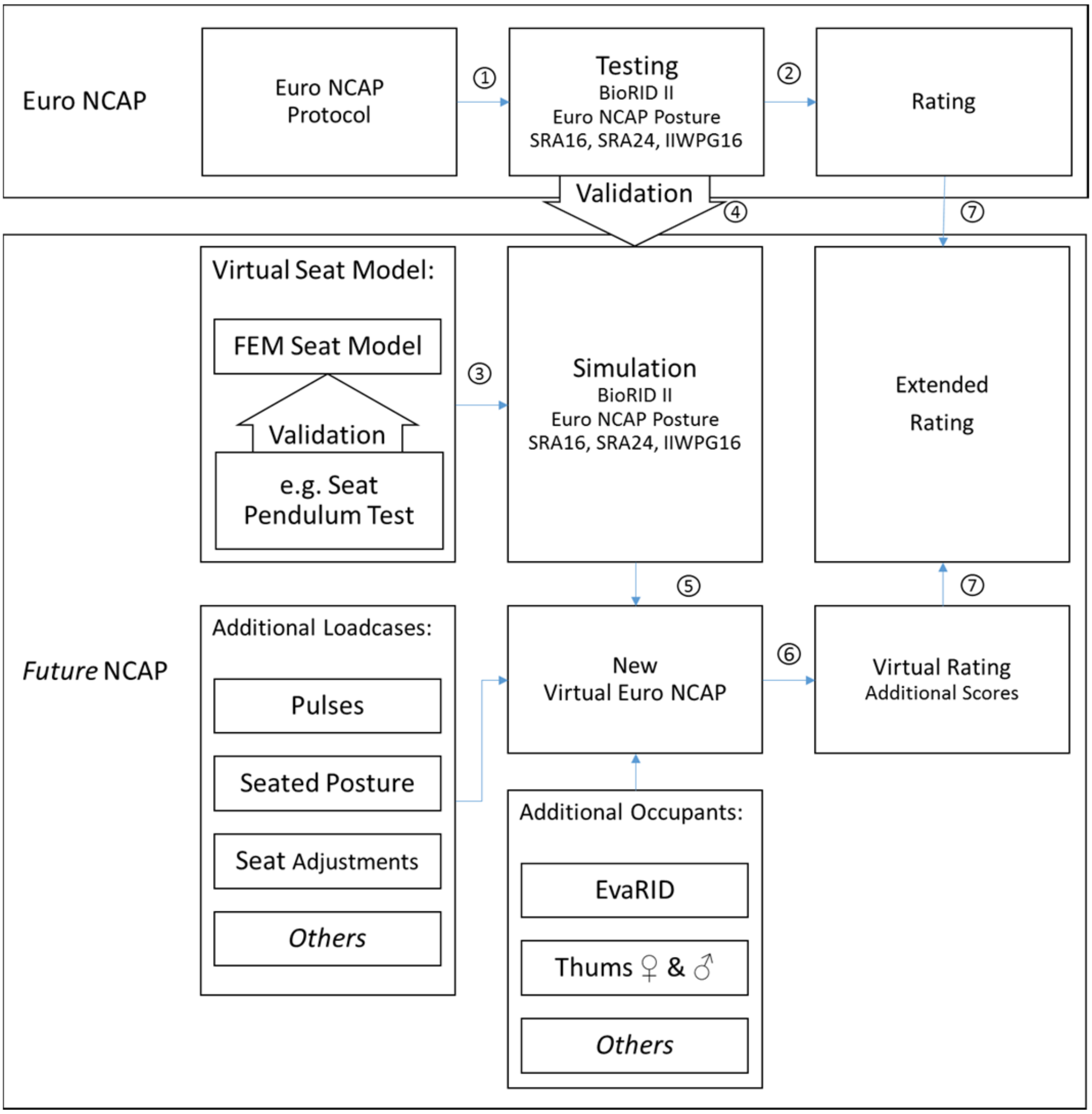

Fig. 16 Possible extension of the current Euro NCAP testing with virtual methods to gain additional scores

IV. DISCUSSION

Using both male and female dummy models as well as the possible configurations of the adjustable components of a seat (in this case head restraint and backrest) in the virtual tests had a vast influence on the outcome on the whiplash injury criteria in rear end impact scenarios.

Due to the fact that the finite element car seat model and the car seat used in physical sled tests were different only a qualitative, not a quantitative comparison was possible. The BioRID II dummy as well as the virtual BioRID II dummy model seem comparable and therefore qualify for investigations with *Non* Euro NCAP configurations. In order to validate and further develop the virtual EvaRID dummy model, a physical EvaRID dummy would be of high value. In addition, positioning of the dummy model and other preconditions, such as female threshold values, need to be established.

The simulations in this study were limited to one virtual seat model and the two occupant models BioRID II and EvaRID. To get a more detailed overview on this topic, more seat models and alternative occupant models (e.g. BioRID II, EvaRID, THUMS, etc.) should be applied. In addition further backrest and head restraint adjustment options should be made available, including more detailed and smaller increment adjustment possibilities for car seats (i.e. tilting of head restraint, lumbar support, etc.). As an alternative to virtual dummy models, virtual human body models would be of interest. However, the data acquisition to determine injury criteria as used to date would have to be implemented in such models.

V. CONCLUSIONS

Vehicle seat safety evaluations conducted by Euro NCAP are limited by the availability of only one occupant model, the average male, and one defined seating position. In order to address male and female occupant's anthropometries and seated positions, as well as a larger variety of car seat setting scenarios, this factum should be changed. Suggested methods to implement such a change include the use of virtual methods. For this purpose, the currently applicable sled tests within the Euro NCAP protocol [4] for whiplash testing should be performed. These results can be utilised as the source data for validation of virtual FEM sled tests. Virtual tests can then be conducted with both male and female occupant models, as well as different seat component adjustments. By taking further load cases into consideration in future car seat safety development a more robust seat design is feasible. Thus, reductions of Whiplash Associated Disorders and their severity would be achieved.

VI. ACKNOWLEDGEMENT

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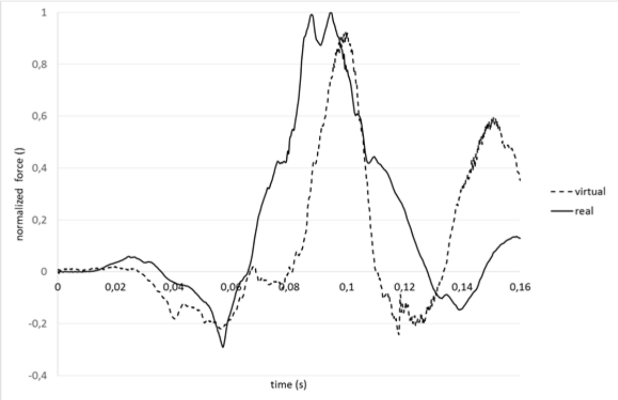
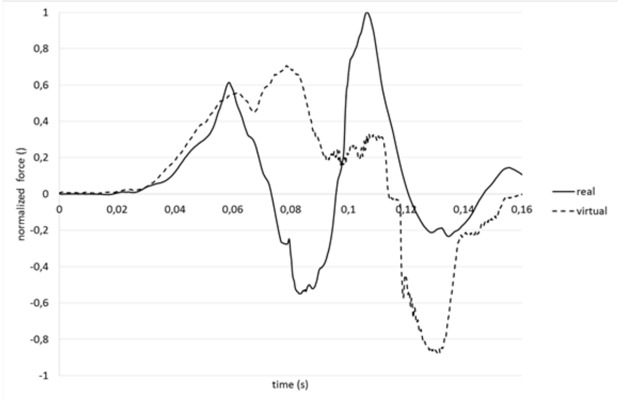
Appendix

Comparison of real and virtual Sled tests according to Euro NCAP*

*normalised by the maximum values of the real sled test



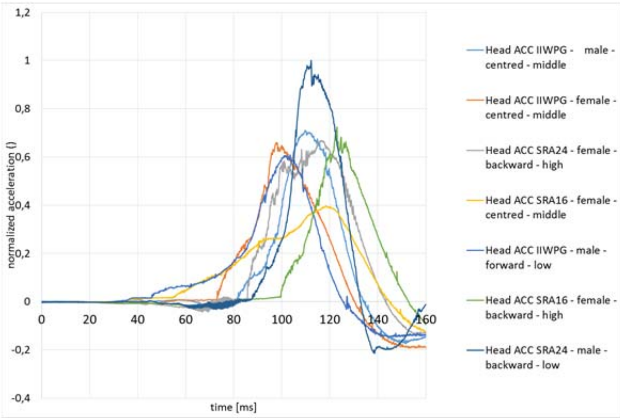
Appendix I Upper neck tension force Fz



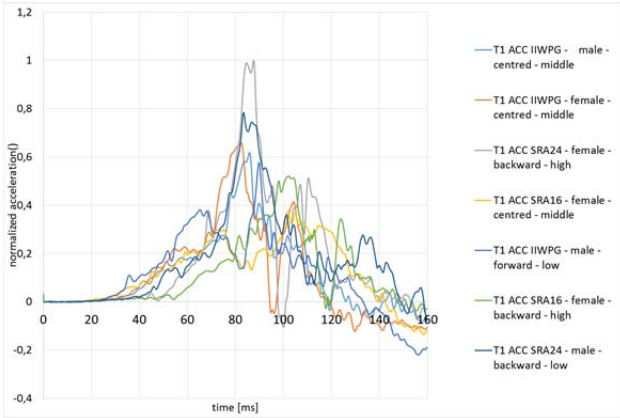
Appendix II Upper neck bending moment My

Comparison of seven virtual Sled tests**

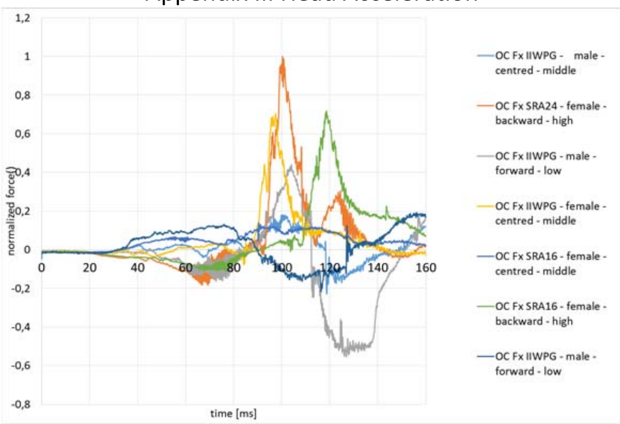
** normalised by the maximum value shown in each graph



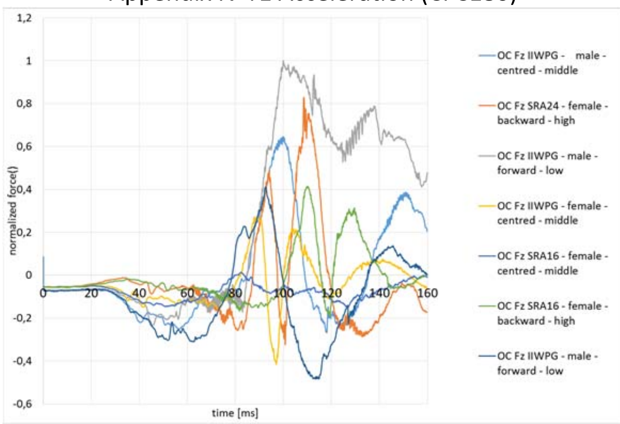
Appendix III Head Acceleration



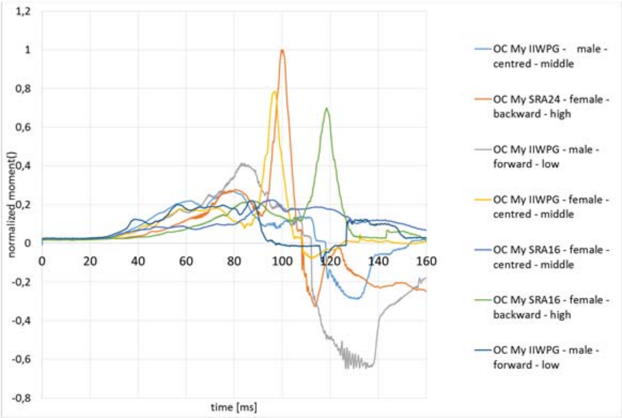
Appendix IV T1 Acceleration (CFC180)



Appendix V Upper neck shear force Fx



Appendix VI Upper neck tension force Fz



Appendix VII Upper neck bending moment My