Rear-End Impact – Crash Prevention and Occupant Protection

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Abstract This study presents the enhancements of knowledge as well as countermeasures addressing crash prevention and occupant protection in rear-end impact situations. It includes the second-generation Whiplash Protection System (WHIPS) together with occupant pre-positioning by tightening the electrical reversible safety belts, acceleration reduction by applying the brakes when the car is at a standstill and rearward flashing lights triggered by sensors identifying a potential rear-end impact.

Significant steps towards whiplash injury reduction through rear-end impact crash prevention and occupant protection are taken by integrating pre-crash sensing and crash performance to address real-world safety needs. The pre-crash sensing information, with safety belt tightening, addresses some of the main high-risk situations in rear-end impacts, such as extensive head to head-restraint distance. By adjusting the occupants to sit closer to the seat at time of impact, the full benefit of the seat protection can be achieved. The WHIPS has been further improved by focusing energy absorption together with even and close support, and by addressing small and large occupants, both male and female, thus adding to overall occupant protection potential. Through the use of pre-crash sensing, opponent warning system and a braking functionality, additional injury reductions can be achieved and some crashes avoided altogether. Further studies are needed to quantify these effects.

Keywords pre-crash, prevention, occupant protection, whiplash injuries, WHIPS.

I. INTRODUCTION

Whiplash injuries (soft tissue neck injuries) are one of the most frequent types of injury in car crashes. A majority of the injuries heal within a short while, but some of the initial injured occupants develop long-term problems, making it a significant injury both with respect to frequency and long-term health issues [1]. Whiplash injuries can occur in all types of crash situations, but the highest risk occurs when the vehicle is impacted from behind [2]. These injuries also account for the main part of all injuries in rear-end impacts. Rear-end impact is defined as the event for a single vehicle (in which the occupant is sitting, even called host vehicle) that is impacted from the rear. Usually this occurs as a part of a rear-end crash, an event including an additional vehicle (called opponent or approaching) that is exposed to a frontal-impact. In the present paper, the focus is on the rear-end-impacted vehicle.

The first steps in addressing whiplash injuries were taken in the 1970s with the introduction of head restraints in order to support the head and avoid hyperextension of the neck in rear-end impacts. Real-world data follow-up studies confirm the effectiveness of head restraints [3-4]. In the late 1990s further steps were taken when Saab Automobile and Volvo Cars introduced whiplash protection seats: SAHR and WHIPS, respectively. Early on, real-world data confirmed the efficiency of these seats as compared to their predecessors [5-6]. This data was used as a benchmark in the development of the standardised test developments, starting in 2003 with testing by Folksam and Swedish Road Administration as well as German ADAC, followed by International Insurance Whiplash Prevention Group (IIWPG) in 2004 and Euro NCAP in 2009. Thanks to this consumer information testing, most vehicle seats were improved with respect to whiplash injury occupant protection in rear-end impacts. Using sled testing, seats are evaluated in three pre-defined crash test pulses using a mid-size male crash test dummy (BioRID) in one seating posture [7]. Although not providing a full picture of the real-world situation, which naturally comprise variations in occupant sizes and sitting postures and influence of vehicle structure, Kullgren et al. [8] did find a correlation between the consumer whiplash crash

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tests and real-life outcomes. It was concluded that seats aimed at preventing whiplash injuries in general also lower the risk in real-world rear-end impacts.

Several existing seat design concepts address whiplash injury occupant protection. Comparing some main designs using real-world data, Kullgren et al. [9] showed that seats with energy absorption in the seat backrest scored highest both for symptoms lasting longer than one month and permanent medical impairment, and for men as well as for women. Specifically, the WHIPS provided the highest injury-reducing effects. The WHIPS was introduced in 1998 and has been standard in all Volvo cars since model year 1999. The WHIPS was developed based on three guidelines: (a) reduce occupant acceleration; (b) minimise relative spine movements; and (c) minimise the forward rebound into the seatbelt. It was believed that if these guidelines were adhered to in the seat design, the risk of whiplash injuries could be reduced [2]. Compared to the prior seat, the WHIPS consisted of a new recliner mechanism, together with somewhat modified backrest characteristics and head-restraint geometry. Real-world data provided evidence that the WHIPS, compared to the prior seat, offers a significant whiplash-reducing effect, both for initial neck symptoms (33%) and long-term (53%) symptoms [6]. The injury-reducing effect was found to be higher for women than for men. These effects were confirmed by Folksam [8-9], who also provided relative measures to other cars than Volvo only.

Some first steps towards crash avoidance of rear-end impacts were taken with flashing brake-lights at heavy braking, to warn the car approaching from behind. Different countermeasures include activating hazard-warning lights, enlarging the lighted area and/or increased intensity of illumination of flashing brake-lights [10]. In addition to providing warning to the vehicle behind, initial steps for occupant protection measures include activating the reversible safety belts and braking the vehicle immediately before the impact. Beside these recent activities, most efforts in the area of whiplash injuries in rear-end impacts concern improvements in the seat designs, evaluated in standardised seat tests using mid-size male dummies in upright sitting posture [7]. However, seat design addresses only a limited part of the real-world context.

The present study explores the rear-end impact context within a wider scope and presents and evaluates countermeasures that take a holistic view of crash prevention as well as occupant protection in case of a crash. The objective is to present the enhancements of knowledge as well as countermeasures addressing crash prevention and occupant protection in rear-end impacts. The developments are based on the needs identified in real-world data, and countermeasures include pre-crash sensing and triggering of opponent driver crash warning system, together with host occupant positioning and acceleration reduction functionalities. In addition, further refinements of a state-of-the art whiplash protection seat are presented.

II. REAL-WORLD DATA

Factors influencing risk of whiplash injuries in rear-end impacts in cars with the state-of-the art seat WHIPS were identified from real-world data and served as the foundation for the next-generation seat design and the additional crash prevention and occupant protective countermeasures introduced in this study.

The real-world data comprised rear-end-impacted Volvo cars in Sweden from 1999 [11]. Detailed information about the crash and the occupants were collected, including occupant characteristics, seating position and occupant's best recollection of sitting posture during impact, including distance to head-restraint, head rotation and sideways lean as well as general injury data. One year after the accident, a follow-up questionnaire was sent to the occupants asking for details of neck symptoms, if any.

As presented in [11], a subset of 1,858 front-seat occupants seated in the WHIPS was used to identify needs for further reduction of whiplash injuries in rear-end impacts. In total, 494 of the 1,858 occupants reported initial neck symptoms and/or signs, whereof 114 had symptoms at least once a month one year after the impact occurred and describe them as seriously interfering with activities, or occurring weekly and described as hampering activities. Among the major factors identified as influencing injury outcome was sitting posture at time of impact, which was identified as an important area of improvement. Turned head and increased head to head-restraint distance, respectively, were shown to increase injury risk, separately as well in combination. A significantly lower risk (20 +/- 3%) was seen for occupants facing straight-forward with the head in close proximity to the head-restraint, as compared to the risk (42 +/- 7%) for occupants with rotated head and larger back [11]. Even though the highest risk of injury was found in higher impact severity, the large amount of whiplash injuries sustained at low impact severity emphasised the need to focus measures on crash avoidance

[11].

Hence, by addressing crash avoidance, impact speed reduction and improved occupant protection by occupant pre-positioning, important steps towards further whiplash injury reductions can be taken and will be in line with a holistic approach, based on real-world situations and diversity of occupants.

III. SYSTEM DESIGN

The rear-end impact crash prevention and occupant protection technologies as designed in this study include: rearward flashing lights triggered by sensors identifying a potential rear-end impact (from behind); acceleration reduction by applying the brakes when the car is at a standstill; an occupant pre-positioning functionality by tightening the electrical reversible safety belts triggered by the sensors, the second-generation WHIPS, and eCall (Fig. 1).

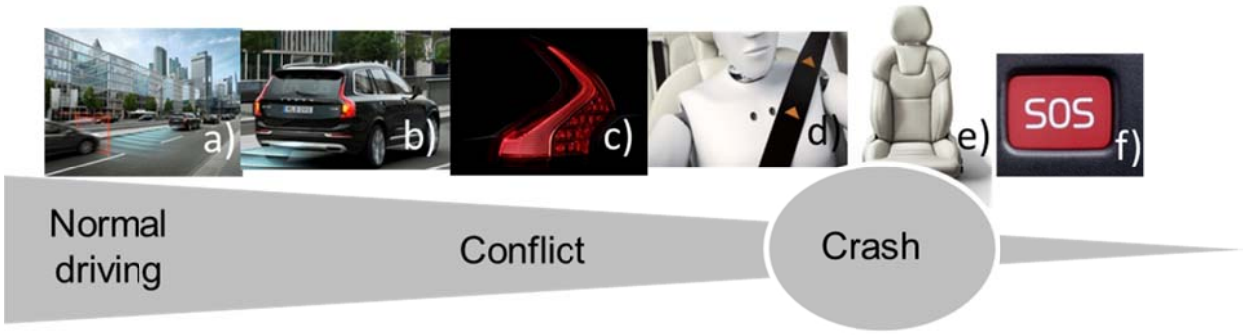

Fig. 1. Rear-end impact sequences: a) detection + activation; b) warning; c) braking; d) occupant pre-positioning; e)WHIPS generation 2; f) eCall.

Detection and Activation

Radar sensors detect vehicles that approach from behind, using radar sensors in the rear bumper (Fig. 1a). The sensors are placed one at each side of the rear bumper and they detect vehicles like cars, buses and motorbikes travelling in the path of the car from behind. The function generally works in all weather conditions, as long as the sensors are not blocked by, for example, snow or dirt.

The detection of an approaching vehicle from behind activates warning, braking and occupant pre-positioning. Detection is active at all speeds. Input to system activations is provided when the relative speed between the vehicles is greater than 25 km/h, when the overlap is more than 50%, and the approach angle is less than 10 degrees. Braking will only be applied if the car is at a standstill. The driver can always override the function. If the driver takes any measure to move the vehicle, the activation of the systems will be cancelled.

Warning

If the function determines that there is a risk of a rear-end impact, all six amber (yellow) lights flash at a higher frequency (approximately 5Hz) to alert the driver in the opponent vehicle approaching from behind (Fig. 1b). The flash starts prior to a potential upcoming collision (1.4 s time-to-collision).

Braking

If the car is stationary at time of impact, the brake pressure will be applied prior to the impact and held during the collision, helping to reduce the impact severity, as well as reducing likelihood of secondary frontal impacts (Fig. 1c). The reduction of impact severity for the host car is achieved by engaging the friction between the tyres and the ground.

Occupant pre-positioning

If a rear-end impact is unavoidable, an electrical reversible safety-belt pretensioner is activated for the front-seat occupants, provided they are belted. The safety belts are electrically tightened to retract and keep the occupants in position (Fig. 1d). Full retraction is achieved within 250 ms, belts load are up to 300 N and the belts

are kept firmly tightened as long as the car is in motion, whereafter the belt tension is released. The electrical reversible pretensioner forces are strong enough to also retract forward-leaning occupants [12-13].

WHIPS generation 2

A new seat was developed based on the guidelines as defined by Jakobsson et al. [2] and put into production 2015 (Fig. 1e). The most important parts of the seat with respect to rear-end impact occupant protection are the design of the backrest and head-restraint together with energy-absorbing functionality of the seat cushion/frame. The prerequisite of **even support** was facilitated by the seat frame and head-restraint design. The geometry of the seat backrest's frame is designed to allow the occupants to sink into the frame in case of a rear-end impact (Fig. 2). The non-adjustable head-restraint position and design is comfortable for a large range of occupants and provide short head to head-restraint distance. The head-restraint and seat-frame designs enable early support of the occupant's head in a rear-end impact. The seat is strong and the head-restraint is rigidly attached, with low flexibility even when loaded. The seat backrest and head-restraint provide an even support, with distributed load and contact points over the whole back of the occupant. The design is robust and forgiving for different occupant sizes and sitting postures

The energy-absorbing functionality is designed to give a controlled motion of the backrest relative to the seat rails. In a rear-end impact of sufficient severity, three deformation elements will deform and **absorb energy**. The deformation elements are triggered by force and torque, respectively, during the rear-end impact event. The loads are dependent on occupant weight in combination with acceleration amplitude and direction. The deformation elements will deform by buckling the elements, which are designed to give a certain force-displacement characteristic while providing a controlled rotation and translation of the seat backrest (Fig. 2). Two of the deformation elements are placed between the recliner plate (one on each side) and the seat chassis, allowing rotation of the seat-back. The third deformation element is built into the inner rear part of the seat chassis connection to the seat rails (Fig. 2). The torque occurring when the occupant sinks into the seat backrest activates this deformation element. This deformation element also plays a part in other crash situations, such as run off road situations [14] and frontal impacts with high degree of vertical loads. The deformation element allows for a controlled vertical deformation up to 25 mm. The space under the seat is cleared to allow for total occupant movement up to 150 mm. The torque from the occupant sinking into the seat backrest during a rear-end impact will make the seat slide vertically in the slot while deforming the deformation element, thus absorbing energy.

Fig. 2. Seat design of the WHIPS generation 2: overall seat design (*left*), seat-back structure (*middle left*), deformation elements (*middle right* and *right*).

IV. BENEFIT EVALUATION

Detection and Activation

The distribution of occurrences of different rear-end crash situations are essential for relevant detection and activation of pre-crash functionalities. Real-world data provide input to this knowledge. Previous studies have addressed the topic of rear-end impact occurrence, providing insight into distribution of situations. Using the UK road accident database 'On the Spot' OTS and German In-depth Accident Study (GIDAS) data, the European ASSESS project [15-16] defined the real-world traffic safety problem and provided detailed information on the crash conditions. Combining the variables "impact point of cars" and "accident type", rear crashes in longitudinal traffic were scored first and second, respectively, for the two data sets [15] when ranking the most

common traffic accident scenarios. When dividing conflicts between four-wheeled vehicles, bicyclists and powered two-wheelers (PTW) as initial collision partners in sub-levels (slower lead vehicle, decelerating lead vehicle and stopped lead vehicle); the stopped lead vehicle scenario has the largest share of causalities [16]. In the same study, relative speed values could be estimated for the two scenarios stopped lead vehicle and slower lead vehicle since the lead vehicle was going with a lower, constant driving speed or was standing still. In the scenario slower lead vehicle, the mean relative speed was approximately 50 km/h in the analysis of the GIDAS database. In the stopped lead vehicle scenario, where relative speed corresponds to the driving speed of the subject vehicle, the 50th percentile relative speed was approximately 50 km/h in both the GIDAS and the OTS data. For the decelerating lead vehicle scenario it was not possible to estimate the relative (closing) speed since it was not possible to identify the time at which the driving speeds were identified. The degree of overlap, defined as the percentage of impact structure overlap by the collision opponent, was also studied in [16]. In rear-end scenarios the overlap was larger than 50% (original vehicle width equals 100% overlap) for more than 70% of the analysed cars.

In the USA, a number of lead-vehicle pre-crash scenarios correspond to the rear-end crash type used in National Automotive Sampling System-General Estimates System (NASS-GES) crash database [17]. Three pre-crash scenarios constitute almost 90% , of the crashes that occurred in the USA in 2003. These individual pre-crash scenarios are 'lead vehicle stopped' 50.4%, 'lead vehicle decelerating' 23.4%, and 'lead vehicle moving at lower constant speed' 13.5% according to [17].

In relation to the USA as well as European data, the setting of the detection and activation in the present study covers an important part of the rear-end impact situations. First, it addresses a significant portion of the real-world traffic crash occurrences. Secondly, by targeting both approaching two-wheelers and four-wheelers in slower lead vehicle as well as stopped lead vehicle situations, the largest shares of situations/causalities are addressed. A structural overlap of more than 50% will cover the majority of the cases. Additionally, quantifications on relative speed or specifications in angles are not to be found in real-world data at this stage, and the restrictions in the setting will limit the activation rate.

Warning

Rear-end impacts often result from a failure to respond (or a delay in responding) to a stopped or decelerating lead vehicle. "Inattention to forward roadway", including secondary task engagement, driving-related inattention to the forward roadway, non-specific eye glances, and fatigue, were identified as the primary contributing factor to 93% of rear-end crashes [18]. The first three categories involve looking away from the forward roadway, and the last category involves loss of forward roadway vision from eyelid closure. Recent naturalistic crash data analysis [19] revealed a distinct mechanism in rear-end crashes whereby most rear-end crashes could be understood in terms of a "perfect mismatch" between the last off-road glance duration before a crash and the lead vehicle closure rate. Rear-end crashes occur with short glances and high closure rates, just as crashes occur with long glances and slow closure rates. This mechanism can be understood as a joint probability distribution of glance durations and lead vehicle closure rates. Thus, in rear-end crashes, drivers are predominantly looking away from the road ahead at a critical time when closing in on the lead-vehicle.

The issue then becomes one of effectively redirecting the eyes of a rearward approaching driver back to the forward roadway at an appropriate time. Using naturalistic driving data as well as test track data, it was concluded that a signal that more effectively draws the driver's eyes to the forward view and that provides more information to the driver regarding lead vehicle braking would be beneficial. Successful rear-signalling systems should work to redirect opponent driver visual attention to the forward roadway, particularly under cases of prolonged driver visual distraction. Advanced brake-lights fill the purpose of alerting the driver behind as well providing information on level of braking activity by the car in front. NHTSA performed test track tests involving 80 volunteers and different types of light [20]. Among the tested systems, flashing of all rear lighting combined with increased brightness was found to be most effective in redirecting the driver's eyes to the lead vehicle when the driver is looking away with tasks that involve visual load. Comparing conventional, additional hazard-lights and brake-lights flashing at different frequencies, [10] performed test track test with 39 subjects following a lead vehicle at 80 km/h. They found that flashing brake-lights provided the greatest benefit, significantly reducing the brake reaction times as compared to conventional brake-lights.

The results from the more recent naturalistic driving study 'SHRP2' give support to the approach chosen in

the present study, that is, to activate a threat-relevant flashing lights warning in addition to the conventional brake pedal-activated brake-lights [19]. The addition of a threat-relevant, time-to-collision based warning rearwards to the vehicle approaching from behind makes the brake-light activation threat-relevant (as opposed to only turning on when the brake pedal is pressed). Therefore, it is expected that the "cry-wolf" effect found with current brake-lights [19] would be avoided, and that the flashing lights would instead be threat-relevant and therefore more effective.

Activating flashing lights prior to a potential rear-end impact is believed to provide an effective threat-relevant warning to the driver of the approaching car and therefore reduce the severity of the impact, and even in some cases avoid the impact.

Braking

By applying the brakes at standstill, the acceleration of the car can be reduced as well as the risk of a secondary impact. By reducing the likelihood of hitting an object in front of the car, after the rear-end impact, the overall impact severity and complexity of kinematics for the impacted vehicle is reduced. Reducing the overall acceleration amplitude is one of the primary ambitions when designing a whiplash protection system [2]. Injury risk curves derived by crash recorder data [21] show an increasing higher risk for increased maximum acceleration up to a certain level. Comparing the crash energy levels with and without applied brakes provides reduction of maximum acceleration by up to 5%. The amount depends on impact speed as well as friction between tyres and ground. The higher the friction and the lower the impact speed, the higher the effect of braked tyres. As an example, at impact speed of 16 km/h and with a friction of 0.8, velocity will change from 2.4 m/s to 2.2 m/s, thanks to applying the brakes.

Occupant pre-positioning

The activation of the electrical reversible safety-belt pretensioner will pre-position the forward-leaning occupants closer to the seat backrest and head-restraint. The activation is made before impact and the electrical reversible pretensioner forces are strong enough to retract forward-leaning occupants [12-13]. Lorenz et al. [12] tested 24 volunteers in 64 tests with activation of electrical pretensioner in a stationary vehicle, whereof 25 tests were in forward-leaning positions. The belt forces were between 160 N and 290 N. The largest volunteer was 120 kg and 183 cm. Develet et al. [13] performed similar tests using seven volunteers of 50th - percentile male size, and compared to BioRID and THOR crash test dummies, in three different forward-leaning postures. In all of the 17 tests, the volunteers' chest and head were moved towards the seat. In more than half of the cases, the head was in contact with the head-restraint. Neither of the two dummies showed sufficiently large rearward motions nor head rotations to fit the corridors of the volunteers.

As a relative comparison, tests were run using the BioRID dummy to evaluate the crash performance effect of occupant pre-pretensioning. Rear-end impact tests, conducted according to Euro NCAP mid-severity test method, were performed with forward-leaning crash test dummies, comparing with and without activation of electrical reversible pretensioner. In the test with pre-positioning, the Neck Injury Criterion (NIC) value was in the range of tests performed in normal initial sitting posture. In the forward leaning test without pre-positioning, NIC was about three times higher. Figure 3a shows the initial forward-leaning position for both tests, which is also the initial position at time of crash pulse start for the test without activation of the electrical reversible pretensioner. Figure 3b shows the position after retraction by the electrical reversible pretensioner, and hence the dummy position at time of crash pulse start for that test. The head to head-restraint distance in the two cases are 275 mm and 170 mm, respectively, which are the two dummy positions at time of crash pulse start, respectively. The head to-head distances should be regarded relative to each other and not in relation to distances valid for humans exposed to the same pre-tensioning. As shown by [13], volunteers would move closer to the head restraint.

Fig. 3a. Initial occupant position at start of test.

Fig. 3b. Occupant position after activation of electrical reversible pretension.

According to real world-data [11], 43% of all occupants were sitting in a forward-leaning position more than (estimated) 5 cm from the head-restraint. In the same study, the average injury risk for the forward-leaning occupants was approximately 42%, as compared to the average injury risk of 20% for those sitting close to the head-restraint. By adjusting them into a sitting posture where they can provide full benefit of the seat protection, overall injury risks are likely to be reduced accordingly.

WHIPS generation 2

In a rear-end impact the occupant will sink into the seat frame and early contact to the head-restraint will help provide an even and distributed support over the whole back of the occupant. This, together with the energy-absorbing functionality in the seat, provide the occupant protection. Figure 4 illustrates occupant kinematics using a Finite Element (FE) model of BioRID (50%-ile male) and EvaRID (50%-ile female [22]), respectively, in a delta-v 16 km/h event. Early contacts are achieved for both occupants due to possibilities to sink into the seat frame and the close position of the head-restraint. The support provides a good balance and even support for the whole body. The resulting energy is substantially reduced thanks to the energy absorption of the deformation elements, resulting in a low rebound velocity and small movement forward at the end of the event.

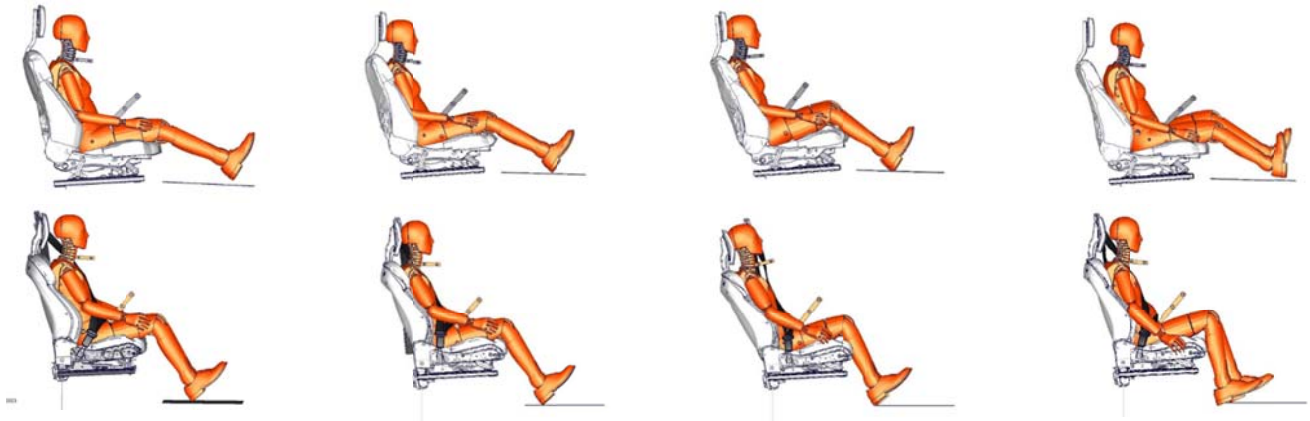

Fig. 4. Occupant kinematics illustrated by FE-simulations using EvaRID (*top*) and BioRID (*bottom*); initial position (*left*), initial head to head-restraint contact (*middle left*), at maximum relative most rearward position (*middle right*) and forward rebound (*right*).

The seat encompasses the state-of-the-art protection as for the first-generation WHIPS, by addressing robust design, even support and energy absorption in different crash severities. Compared to the prior seat generation, the robustness for occupant positions has been improved, as well as accommodating an earlier head to head-restraint contact overall. This provides a basis for real-world protection that addresses the numerous combinations of situations in reality of occupant sizes, sitting postures and severities, beyond what is possible

to test in laboratories today.

For comparison to the WHIPS generation 1, results from two sled test methods from Euro NCAP protocol (high- and mid-severity [7]) are presented. NIC is reduced in mid- as well as high-pulse severities, with 46% and 30%, respectively. This is due to an earlier head to head-restraint contact time, thanks to the design of the seat backrest's frame (allowing the occupant to sink into the seat). Figure 5 illustrates the occupant to seat interaction in the mid-pulse severity test for BioRID and the WHIPS generation 2. Due to the distributed occupant interaction and the improved energy absorption, the rebound velocity is reduced by 9% and 30% for mid- and high-pulse, respectively. As can be seen in Fig. 6 (a) and (b), the T1 acceleration is of similar magnitude between the seats, although earlier in engagement because of the early and effective occupant interaction. Upper neck shear forces (Fx) are low in both the WHIPS generations 1 and 2 for both severities (Fig. 6 (a) and (b)). The upper neck tension (Fz) is substantially reduced in the WHIPS generation 2 as compared to generation 1 (Fig. 6 (a) and (b)).

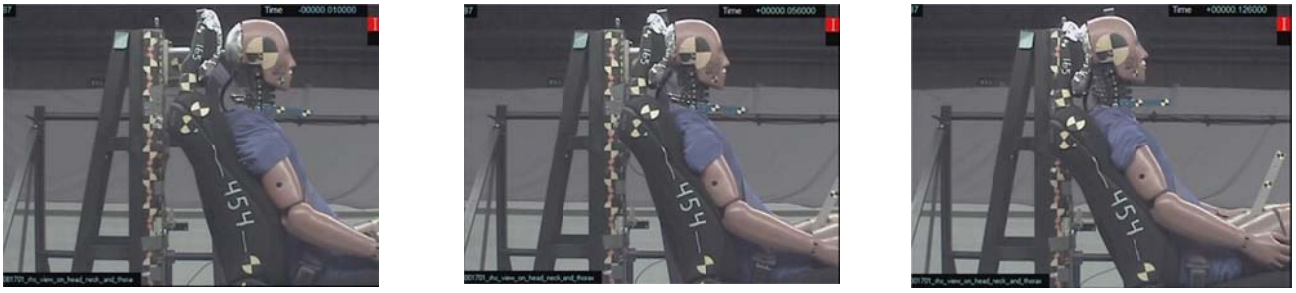

Fig. 5. BioRID in WHIPS generation 2, mid-severity Euro NCAP test method; initial position (*left*), initial head contact at t=56 ms (*middle*) and maximum relative rearward position at t=126 ms (*right*).

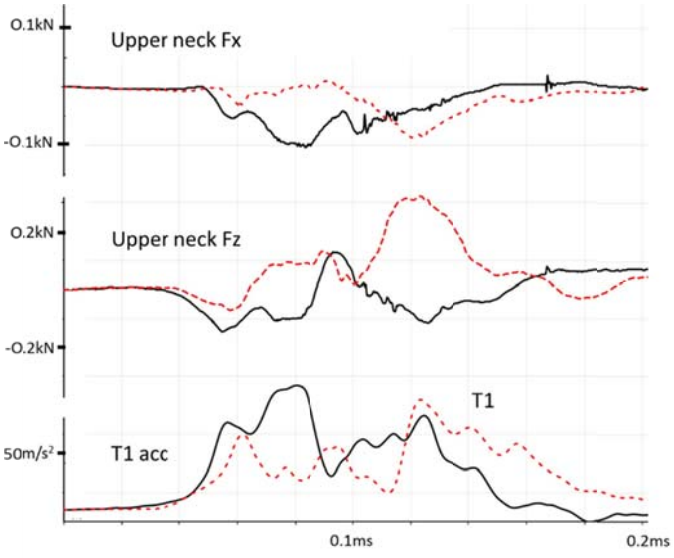

Fig. 6. (a) Upper neck Fx and Fz and T1 acceleration, comparing WHIPS generation 1 (red dotted line) and WHIPS generation 2 (black) in Euro NCAP's mid-pulse test method.

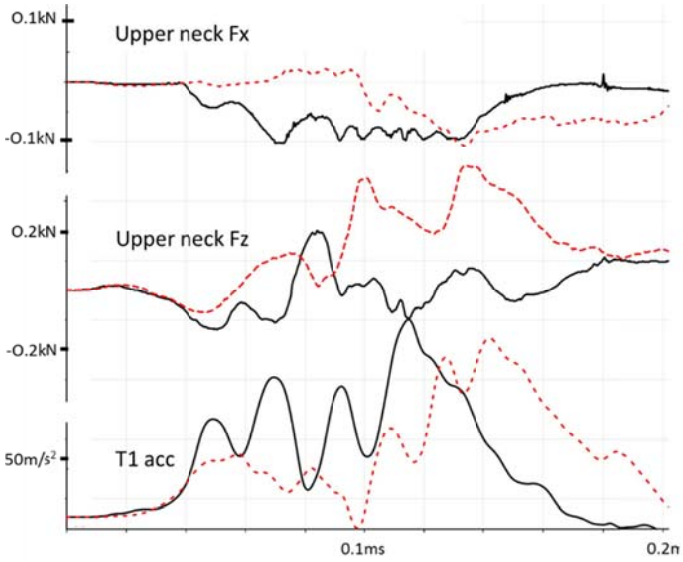

Fig. 6. (b) Upper neck Fx and Fz and T1 acceleration, comparing WHIPS generation 1 (red dotted line) and WHIPS generation 2 (black) in Euro NCAP's high-pulse test method.

The WHIPS generation 2 encompasses the benefits of the WHIPS generation 1 and adds on more robustness and improved protection, exemplified by the early engagement of T1 acceleration, reduced neck forces and reduced NIC in the two presented test set-ups. In addition to this, the design of the seat, with its robust and forgiving design for different occupant sizes and sitting postures, engenders a firm belief that the occupant protection in real-world situations would be as good, or even superior to, the WHIPS generation 1.

Overall benefit evaluation

The pre-sensing information with safety-belt tightening addresses some of the main high-risk situations in rear-end impacts, such as extensive head to head-restraint distance. The majority of occupants injured in a rear-end impact have a head to head-restraint distance greater than 5 cm. The injury risk within this group is, on average, more than double as compared to those sitting close to the head-restraint at time of impact. By pre-positioning those occupants who have an initial gap (the larger the gap, the higher the risk), a substantial injury risk reduction can be achieved. The WHIPS has been further improved by focusing on energy absorption together with even and close support, addressing both small and large occupants, male and female, adding to overall occupant protection potential. The flashing lights warning is expected to directly address the eyes-off-forward-roadway crash mechanism by redirecting the approaching driver's eyes back to the lead vehicle, and therefore is expected to significantly help avoid or mitigate rear-end impacts. Using pre-crash sensing, warning and a braking functionality, the vehicle is designed to lower the risk of consequences of a rear-end impact by helping to avoid or by mitigating the impact itself as well as consequent injury occurrence.

V. DISCUSSION

The aim of this study is to present the enhancements of knowledge as well as examples of countermeasures addressing the whole sequence of rear-end impacts, including crash prevention and occupant protection. At this stage it is not possible to quantify the enhancements of the new technologies in exact numbers; too many uncertainties are involved in order to achieve this. In analogy with the introduction of first-generation WHIPS, an overall injury reduction prediction was difficult to make [2]. The lack of tools and test methods reflecting the variety of occupant sizes and sitting postures as well as the lack of unified and agreed injury mechanisms, including injury criteria reflecting these injury mechanisms in a holistic way, exposed this injury type to special challenges [2]. Instead, the strategy of that study was to take steps in the right direction, which, after some years, was proven by real-world follow-up studies to be a substantial contribution [6][9]. Similarly, the present study aims at taking steps in the right direction, technically covering a wider scope of this traffic safety area by addressing the whole sequence of rear-end impact crash prevention and occupant protection. Although difficult to quantify at this stage, it is a firm belief that all the efforts will contribute in a positive way, driving the overall estimated injury reduction towards reduced numbers.

Real-world data emphasises the need to address varieties in situations, occupant sizes, behaviour and sitting postures. The holistic approach of this study has challenged the diversity of situations and occupants, introducing countermeasures that were developed with this in mind. In particular, the seat is developed to be robust and forgiving for different types of situation and occupant. Taking steps in crash avoidance and impact severity mitigation will provide benefits independent of occupant size, behaviour and sitting posture. Additionally, helping to pre-position occupants in a more favorable protection position will contribute towards real-world safety needs as well.

The approach in this study goes beyond standardised testing of today. Whiplash injury occupant protection is today tested in sled tests that evaluate the seat using standardised crash test pulses. Those types of methods do not take into account countermeasures beyond what is possible to integrate into the seat, not even the influence of the true crash pulse for that specific vehicle. This means that there is, from a standardised test procedure perspective, only limited incentives to introduce protective measures for whiplash injuries. Additionally, in standardised testing only one occupant size and posture is evaluated at this stage. Real-world data highlights the importance of occupant characteristics and sitting postures at time of impact. The EU project ADSEAT developed an alternative-size rear-end impact crash test dummy, EvaRID, representing a mid-size female [22]. This dummy was used in the development in this study, and provided an important complement to the mid-size male dummy. Just as important as an alternative-size dummy, however, is to base the seat development on the guidelines as identified for the development of the first-generation WHIPS [2]; using subsystem testing and design guidelines addressing the needs of real-world safety, beyond the standardised testing.

Improving rear-end impact occupant protection is of high importance since whiplash injury remains the most common and costly traffic injury type. This study presents rear-end impact crash prevention and occupant protection that offers functionality across the entire crash sequence, packaged into technology that is possible

to put into production, as shown by the introduction in 2015 of the Volvo XC90. Put into production, this approach will further reduce injury risks substantially, in addition to the number of potentially avoided and mitigated impacts due to pre-crash warning and braking.

VI. CONCLUSIONS

By integrating pre-crash sensing and crash performance, and by addressing real-world safety needs, important steps towards whiplash injury reduction by rear-end impact crash prevention and occupant protection are likely to be taken. Shown by test results and compared to prior generation real world performance, the second generation WHIPS is likely to further enhance occupant protection. This is achieved by addressing robust design, even support and energy absorption in different crash severities. As seen in real-world data, injury risks are higher for occupants with a wide distance from head to head-restraint. By adjusting the occupants to sit closer to the seat at time of impact, the full benefit of the seat protection can be achieved. This can be achieved by pre-tensing electrical reversible safety belts prior to impact. The flashing lights warning is expected to directly address the eyes-off-forward-roadway crash mechanism by redirecting the approaching driver's eyes back to the lead vehicle. Through the use of pre-crash sensing, warning and a braking functionality, additional host occupant injury reductions can be achieved as well as some crashes avoided altogether. Further studies are needed to quantify these effects.

VII. REFERENCES

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