INVESTIGATION OF PRE-BRAKING ON UNBELTED OCCUPANT POSITION AND INJURIES USING AN ACTIVE HUMAN BODY MODEL (AHBM)

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ABSTRACT

Following intensive field research based on over 5000 vehicles [1], it was shown that 5% of the drivers still do not wear any seatbelts. New vehicles are now being fitted with active safety features which will influence the kinematics of these un-restrained drivers [2] and may have important safety implications.

The proposed study assesses the safety benefit of a pre-braking event on the occupant position, stance and injury and will review the contribution of active muscle behaviour of a 50th percentile human model [3] in comparison with a passive human model [4] and discusses the potential using active human simulation for testing driver assistance safety technologies.

INTRODUCTION

Original investigations undertaken [5] [6] backed up by physical tests, concluded that anthropometric test dummies (ATD) injuries in static FMVSS208 Out-Of-Position (OoP) load cases occurred mainly in the punch-out and membrane loading phases. Further airbag computer model improvements were developed to simulate scenarios involving occupants of different statures [7]. An initial method of assessing the effects of active safety involved the improved airbag model [7] and a constant 1.0'g' pre-braking scenario on an occupant [8]. This study showed that the Passive Human Body Model's (PHBM) spine was more flexible than the one of an ATD and that the kinematics were very different, leading to different injury levels between the two occupant models [8].

Some modelling improvements were suggested [8], especially the 1.0'g' braking pulse which did not consider the braking duration, the original stance of the occupant during the pre-braking phase, the effect of the occupant's muscle tensioning [9], as well as the airbag triggering time.

DRIVERS' KINEMATIC STUDY

Drivers' Positioning

The PRISM European project, which was completed in 2003, studied the occupant's behaviour whilst driving a vehicle. This study was conducted on 6 sites, 2 in the UK, 2 in Spain and 2 in Austria, recording information over 5000 vehicles [1]. Volunteers were tasked to follow an itinerary, in which they were filmed and photographed at set positions. The visuals were then inputted into a database for analysis. From this database, it was reported that 5% of all drivers did not wear a seatbelt (6% of all male drivers) [10], as shown in Figure 2.

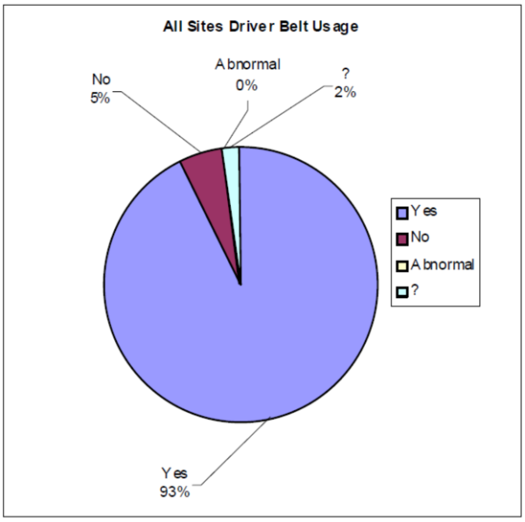


Figure 1: PRISM project. Percentage of drivers not using the seatbelt

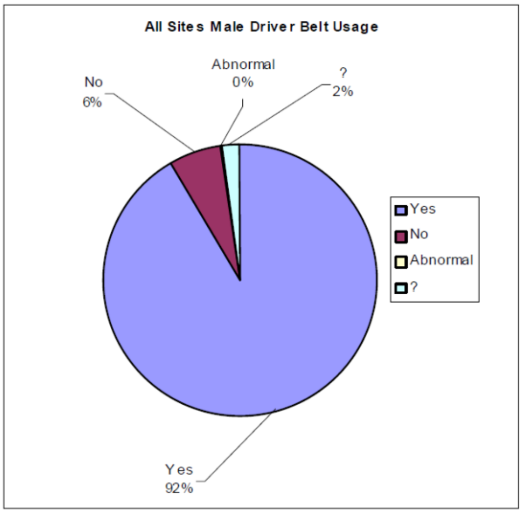


Figure 2: PRISM project. Percentage of male drivers not using the seatbelt

Most drivers were observed with both hands on the steering wheel in the FMVSS208 standard position (Figure 3) [11]. It was also observed that a large percentage of the participants adjusted the radio, as per Figure 4.

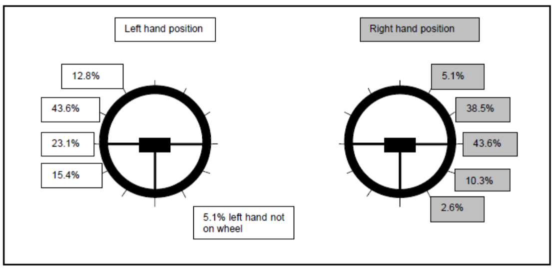


Figure 3: Volunteers preferred hand locations

Activity	Often %	Sometimes %	Seldom %	Never %
Adjust the radio	41.0	43.6	12.8	2.6
Change CDs	15.4	38.5	25.6	20.5
Arm on the waist rail	5.1	23.1	33.3	38.5
Arm on the arm rest	5.1	25.6	28.2	41.0
Hand on the grab Handle	0.0	0.0	23.1	76.9
Arm out of window	2.6	30.8	25.6	41.0
Using mobile phone	2.6	23.1	38.5	35.9
Hand on sun visor	0.0	2.6	23.1	74.4
Hand on head restraint	0.0	0.0	10.3	89.7
Fiddle with seat belt	0.0	25.6	30.8	43.6
Reach into passenger footwell	7.7	28.2	35.9	28.2
Eat/ Drink	7.7	25.6	48.7	17.9
Talk to rear passengers	2.6	12.8	33.3	51.3

Figure 4: Activities performed while driving

The stances which were chosen for the occupant kinematic study were:

1. FMVSS208: standard test position.
2. Adjusting the radio (left hand): most frequent activity.
3. Mobile phone in left hand: as it is usually illegal to use a hand-held phone.
4. Arm on armrest: activity leaving right hand free.

All other positions occurred less frequently, hence have not been included..

These positions were then modelled using the Madymo Active Human Body Model (AHBM) and positioned within a Madymo vehicle dynamic model [11] [12], able to simulate breaking scenarios as well as a brake dive.

FMVSS208's hand positioning follows the legislative requirement, which has been also verified by the PRISM project finding that 87.5% of the volunteers had a 3 and 10 o'clock right and left hand positioning (Figure 5).

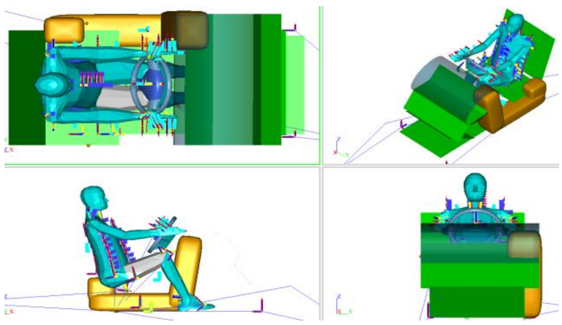


Figure 5: FMVSS208 computer model setup

Adjusting the radio's right hand positioning follows the PRISM's project finding [11] (see Figure 6). The height of the left hand had been estimated in the computer model (Figure 7).

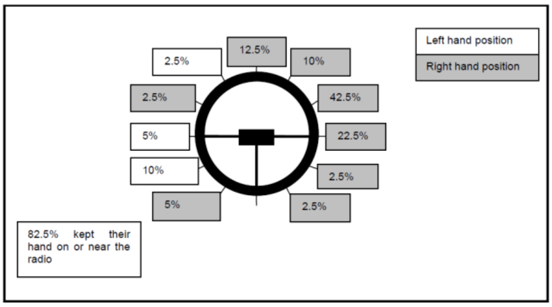


Figure 6: Right Hand position while adjusting radio

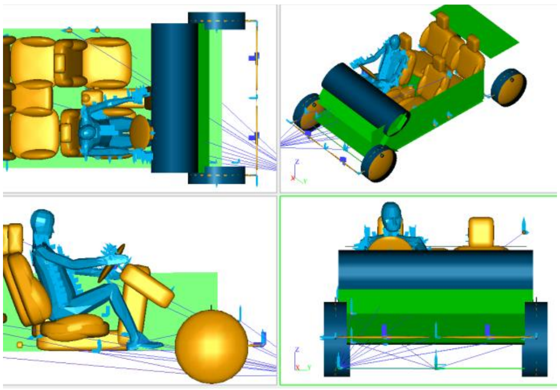


Figure 7: Radio adjustment computer model setup

The mobile phone in the left hand scenario (Figure 8) has shown that 67.5% of the volunteers who had reached their ear with the phone continued to hold it to their ear (Figure 9).

If no participant removed their right hand from the steering wheel during the event, some drivers with their right hand on the left of the steering wheel were turning it in an attempt to swerve around vehicles [11].

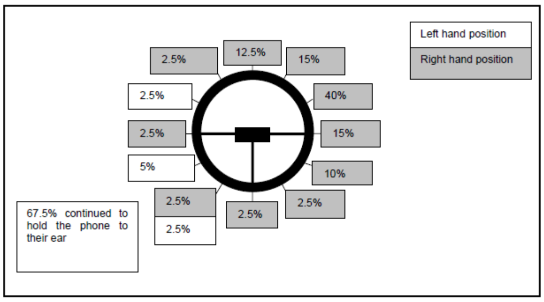


Figure 8: Right Hand position while holding a mobile phone

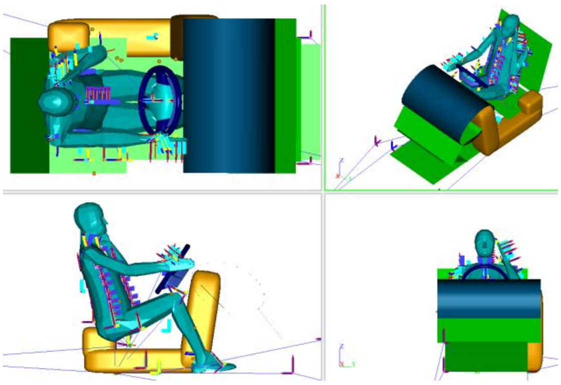


Figure 9: Mobile phone computer model setup

The right arm on the armrest scenario was chosen as a scenario considering the right hand not in contact with the steering wheel (Figure 10). It was noted that "82.5% kept their right arm on the rest and hand off the wheel" [11], as is modelled in Figure 11.

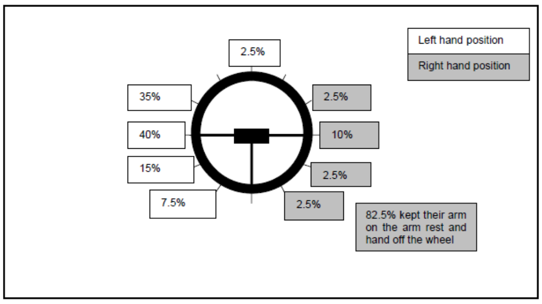


Figure 10: Left Hand position while resting on armrest

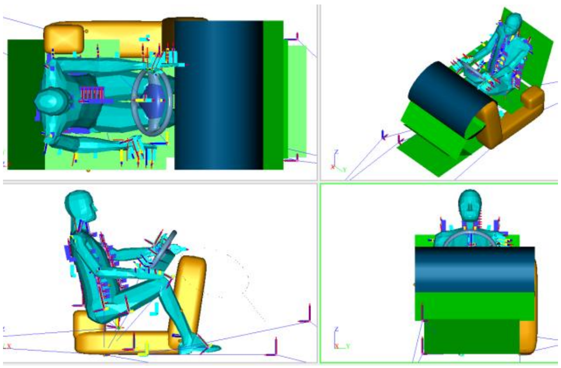


Figure 11: Armrest computer model setup

Vehicle braking extreme braking pattern

Vehicle braking deceleration cannot exceed the road coefficient of friction and is accepted to be in the interval of 1.0'g' to 1.3'g' in very rare instances [8]. Original work conducted on active safety assumed a constant 'g' pulse ignoring the duration of braking [8].

Some occupant behaviour under extreme braking was conducted to understand their reaction [13]. These occupants were belted and, without knowing, driven by a professional driver performing extreme braking scenarios. Accelerometers at the centre of gravity of the vehicle outputted the vehicle linear deceleration, without taking the brake dive into account (Figure 12).

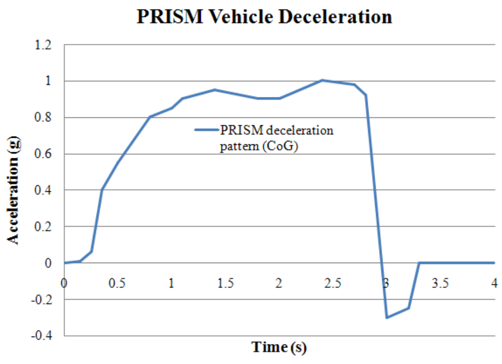


Figure 12: Straight line braking. Vehicle deceleration

From this deceleration pattern, it can be seen that the deceleration initially ramps up slowly during the first 0.3s and then abruptly to reach 0.9'g' after 1.0s (near plateau). This pulse is less severe than a constant step-function of 1.0'g' and shows that the longer the braking, the steeper the deceleration. This pre-braking pulse suggests a more gradual deceleration for the 1st second of deceleration compared to a step-function constant pre-braking value.

Modelling the occupant grip on the steering wheel

The 50th AHBM (Active Human Body Model) model designed by TNO, as seen in Figure 13, now includes a stabilized spine compared to the PHBM (Passive Human Body Model).

This 50th AHBM stabilizing spine contains 25 joint torque actuators, sensors and controllers for each of the two bending directions (25 in flexion-extension and 25 in lateral bending). The actuators are positioned between the pelvis and the L5 vertebra, between each set of vertebrae (L5-C1) and between C1 and the head. Each actuator applies a torque to the child body of the vertebra above (or of the head) calculated by the controller. The controller receives input from the sensors, which measure the angle of each vertebra with respect to the inertial coordinate system, hence maintaining the AHBM's posture [9].

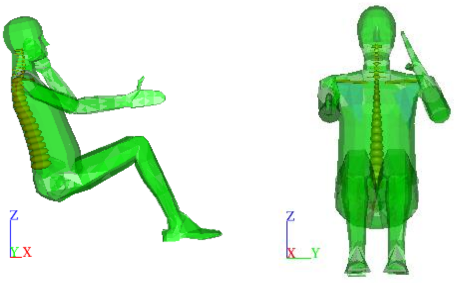


Figure 13: TNO AHBM [3]

To evaluate the gripping force, Bao [14] has performed experiments involving hand power and pinch grips among 14 subjects, using electromyograms (EMG). He has concluded that the power grip strength is approximately 300 N for women and 470 N for men. These values differ vastly from Bose [15] who has extrapolated the hand forces from the steering column loads to a maximum of 151N. Boa's tests being more applicable in the scenario of this study, an average resultant force value of 400N was chosen.

The grip was modeled using a RESTRAINT_POINT between the AHBM's hands and the steering wheel body. This feature is a spring-damper element for which stiffness has been determined to simulate the hand releasing force as well as keeping a reasonable computational timestep [9].

Table 1: RESTRAINT_POINT characteristic function

Displacement (m)	Force (N)
0	0
0.005	10000
0.010	20000
0.100	100000

The force level is monitored using a SWITCH_SENSOR command. Should the resulting force between the hand and the steering wheel body exceed 400N, the STATE RESTRAINT_REMOVE flag is activated, representing the effect of removing the hand from the steering wheel.

Comparison of AHMB and PHBM under 1.0'g' constant deceleration

Looking at this worst pre-braking scenario, an AHBM and PHBM are both compared under 1.0 'g' using the 400N hand grip threshold. The two occupants start at the same position and the simulation is stopped when the thorax impacts the steering wheel (Figure 14).

It can be noted that:

- The contact time between the thorax/ steering wheel is comparable between the two occupants.
- The kinematics between the 2 occupants is different. The PHBM tends to slouch because it does not have a stabilised spine, nor grip stiffness in its arms and hands. This can have an effect as the AHBM will stand straighter and will be more likely to impact the windscreen than the PHBM.

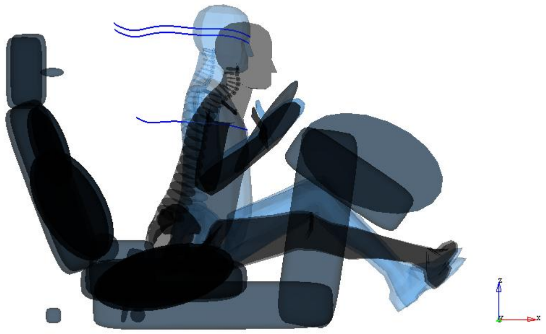


Figure 14: Comparison of AHBM (light) and PHBM (dark) kinematics under 1.0 'g' constant deceleration

Outputting the restraint force levels for both hands, it can be noted that in a FMVSS208 steering wheel grip, the 2 hands are subjected to a force of 90N.

The force level measured might be under-estimated due to the fact that there is no arm muscle activation included in this model yet.

Comparison of AHMB under 1.0'g' constant 'x' deceleration and PRISM deceleration pulse

Four occupant stances were considered and subjected to the PRISM deceleration and constant 1.0'g' deceleration. The results are summarised in Table 2.

Table 2: Comparison of occupant time to contact to hard points vs. Stance and deceleration pulse

Deceleration braking pulse	Driver's stance	Time thorax to steering wheel or any hard contact (ms)	Time hand not gripping the wheel anymore (ms)
PRISM	FMVSS208	720	Still gripping
PRISM	Mobile phone	750	Still gripping
PRISM	Arm on armrest	1000	Still gripping
PRISM	Left arm on radio	760	Still gripping
Constant 1'g'	FMVSS208	260	Still gripping
Constant 1'g'	Mobile phone	260	Still gripping
Constant 1'g'	Arm on armrest	260	Still gripping
Constant 1'g'	Left arm on radio	250	Still gripping

From the results obtained, it can be seen that the times for the occupant to impact the steering wheel, using the pre-braking pulse obtained in the PRISM project, are constantly longer (for every occupant's stance) than the ones obtained using a constant 1'g' pulse. The times to impact using the constant 1.0' g' pulse are almost 3 times faster.

Because the PRISM pulse is obtained from tests, it means that the assumption taken in previous studies [8] is much too severe.

Comparison of AHMB under 1.0'g' constant deceleration and vehicle braking dynamics

Original research was considering a 1.0'g' constant deceleration for a pre-braking scenario by using the MOTION_ACC command in Madymo [8] [16].

This can be observed in Figure 15, as the velocity slope of run 8 is constant.

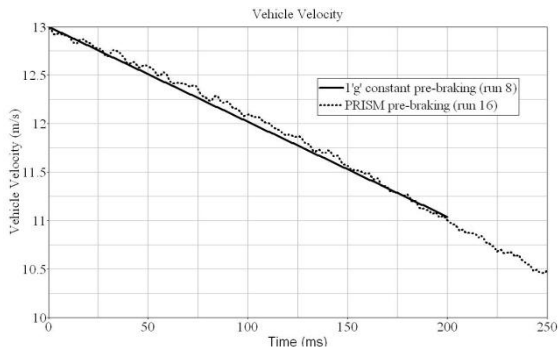


Figure 15: Vehicle velocity change under 1.0'g' constant braking

By measuring the vehicle mass (1140 kg) and applying a constant 1.0'g' deceleration would generate a braking force for the vehicle of 20307N. By splitting the braking forces at the front and the rear with a ratio of 60/40, would give a retarding force per wheel at the front of 6092N and of 4061N at the rear.

The occupant kinematics is then extracted (no dive – top, brake dive – bottom) (Figure 16, Figure 17 and Figure 18):

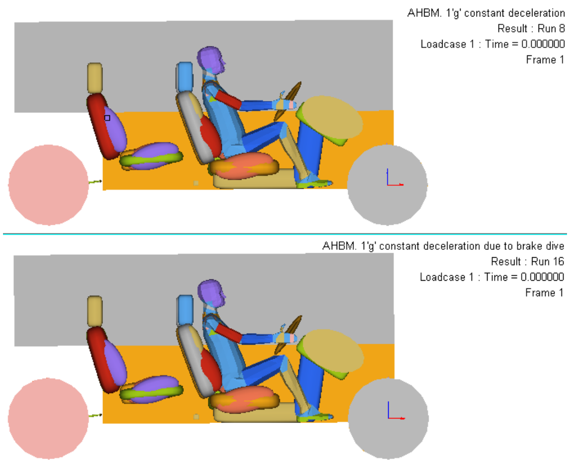


Figure 16: Brake dive estimation (time = 0ms)

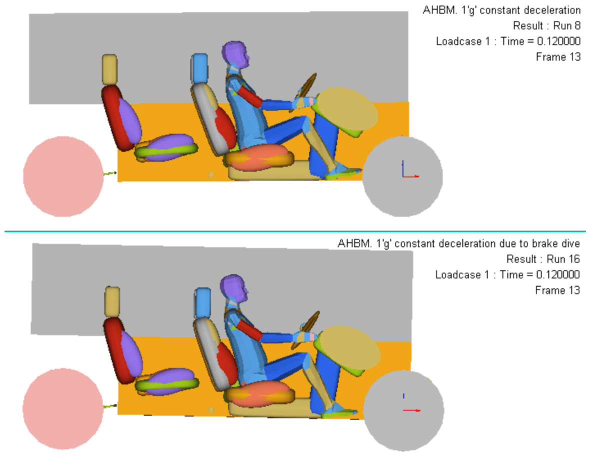


Figure 17: Time 120ms: drivers' stance and position in the cockpit is comparable.

In Figure 18 the drivers' stance and position in the cockpit is very different. The brake dive scenario delays the impact on the steering wheel compared to the 1.0'g' constant acceleration. The occupant submarines in his seat and the angle between the airbag and the occupant is wider.

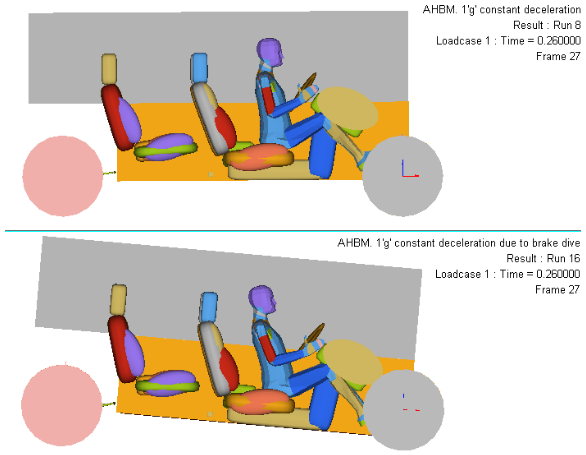


Figure 18: Time 260ms

Preliminary conclusions

The kinematics of an AHBM is different from a PHBM and tends to stay straighter because of its stabilising spine. These new AHBM kinematics suggests an increased likelihood of head contact with the windscreen as opposed to using the PHBM model, which has a more slouching behaviour.

The pre-braking kinematics modelling has been improved from previous studies, thanks to the addition of a more realistic pre-braking pulse obtained from the PRISM project as well as the grip feature from the new AHBM.

The first 120ms of an unbelted occupant kinematics subjected to a 1.0'g' constant pre-braking deceleration is not influenced by the vehicle brake dive. Looking at the PRISM test braking curve, which is much less severe than a constant 1.0'g' and knowing that all the occupants would impact the wheel around 0.7s, it would be surprising if the brake dive had any influence on an unbelted occupant's kinematics before a 1s braking duration (1.0'g' is only met around 1s braking duration). A side study could aid to find the braking/dive function which would match the PRISM deceleration pulse and demonstrate the above categorically.

For the continuation of this paper, the PRISM 'x direction' deceleration function will be used and will ignore vehicle brake dive.

ACTIVE SAFETY INJURY COMPUTATION

Active Safety Accident Scenario Proposal

A new methodology is now proposed [8] varying by the following (see Figure 19):

- The pre-braking will be provided by the PRISM braking pulse and not a constant 1.0'g' deceleration, as the former is more realistic.
- The vehicle crash pulse will be based on an FMVSS208 25mph full frontal barrier test and not a 35mph barrier test. The reason for this change is because unbelted occupant tests are performed at 25mph. This will then be useful for future injury comparisons.
- The occupant model used will be the AHBM with steering wheel grip feature

The starting point of the scenario is a vehicle driving at a constant velocity.

The vehicle is then subjected to a pre-braking pulse (from the PRISM project) with varying braking durations. When the pre-braking phase is finished, the vehicle occupant will be accelerated by a crash pulse based on a 25mph (11m/s) rigid wall impact. This acceleration will be followed shortly after by an airbag deployment (delay varying from 10ms to 20ms). The active safety scenario timeline is explained in Figure 19.

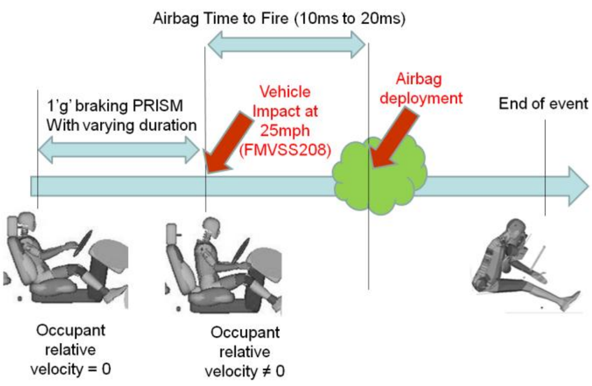


Figure 19: Updated Active safety scenario to investigate injury levels

Determination of the vehicle crash pulse and restraint systems assumptions

The airbag system provided has been validated in static positions OoP1 and OoP2 [6] [7] [8].

A simplified sled model was generated and tuned in order to meet a dynamic FMVSS208 test. This model has not been validated, but it does however allow investigation of relative analyses based upon a model meeting the legal requirements.

An LS-Dyna computer model of a Toyota Rav4 has been used [17] to simulate a 25mph rigid wall impact (Figure 20) and extract a generic low speed crash pulse.

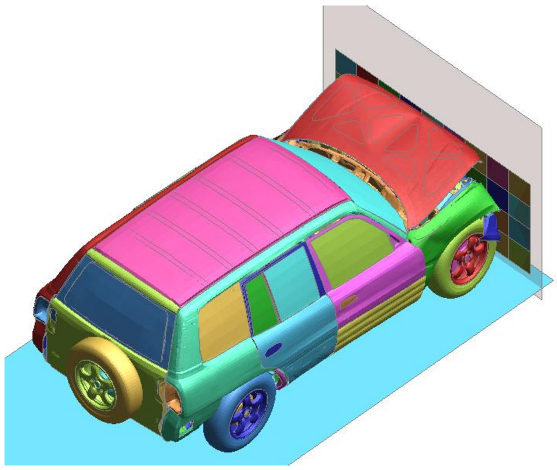


Figure 20: Toyota Rav4 impacting a rigid wall at 25mph

The pulse has been approximated to a triangular one (Figure 21). The maximum deceleration level is around 30'g'. In order for the system to meet FMVSS208, the starting value of 6'g' is chosen, whilst keeping the same pulse shape.

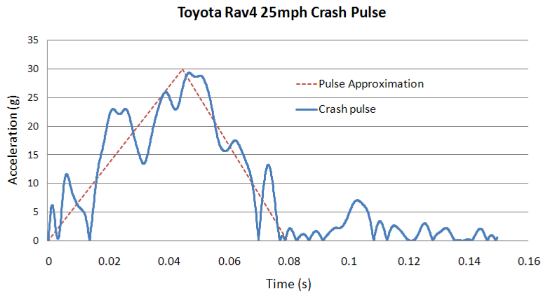


Figure 21: Approximation of Toyota Rav4 crash pulse

Determination of study parameters and permutations

The study will investigate the effect of the pre-braking duration, as well as the occupant starting stance and the airbag firing time.

Looking at the PRISM pre-braking pulse, the braking duration should be chosen before any hard contact between the occupant and the steering wheel take place.

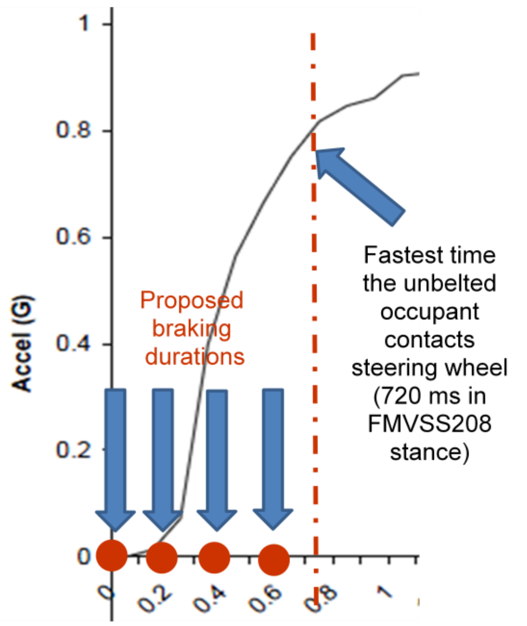


Figure 22: Proposed braking duration and occupant contact time with steering wheel

Furthermore a suitable accident time needs to be chosen for the injury investigation. Should the pre-braking phase be too small then no collision avoidance will be available. Should the pre-braking phase last too long, then the occupant will find himself in a forward position relative to the steering wheel with an initial velocity before the airbag is fired.

From the previous kinematics study, it was estimated that the contact occupant (FMVSS208) to steering wheel occurs after 720ms of pre-braking. Hence the pre-braking phase must be less than 720ms.

It is therefore proposed to split the pre-braking duration into 4 interval durations: 0ms, 200ms, 400ms and 500ms, staying within the 720ms window (Figure 22). 500ms is chosen because it is immediately before the legs start contacting the knee bolster.

The following parameters are taken into account in the study (Table 3):

Table 3
Study parameters

Occupant stance	Duration of pre-braking (ms)	Airbag TTF (ms)
FMVSS208	0	10
Left hand with mobile phone	200	20
Right arm on armrest	400	
Adjusting radio	500	

Computation of occupant initial velocities

The human_joint will be extracted for each driving stance position.

Table 4: Occupant initial velocities vs. pre-braking duration

Occupant stance	Duration of pre-braking (ms)	Velocity (m/s)
ALL STANCES	0	0
	200	0
	400	0.44
	500	0.90

Looking at Table 4, it can be seen that the first 200ms of the pre-braking have almost no effect on the occupant position and initial velocity. The ‘g’ level is very low (around 0.02’g’), which must be counter-acted by the seat friction and the occupant’s inertia.

At time 400ms, the occupant is moving forward with a linear velocity of 0.44m/s.

At time 500ms, the knees start to touch the knee bolster before the torso rotates to then touch the steering wheel.

It can be seen that all the velocities are identical in all stance cases under 500ms and will vary greatly thereafter (Figure 23).

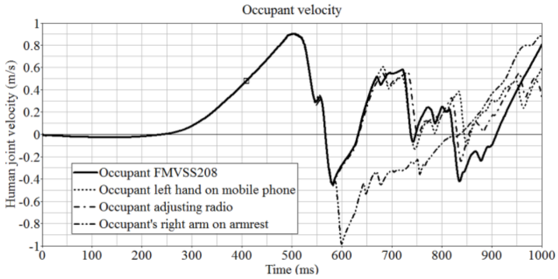


Figure 23: Occupant’s velocity during pre-braking

Also, from previous research, where a constant 1’g’ deceleration was used, the initial velocity of the occupant 250mm from the steering wheel was found to be 1.76m/s [8], which is more than twice the velocity extracted from models in which the PRISM pre-braking pulse is used.

Injury comparisons and analyses

To create a baseline for the study, the relationship between the windscreen provided by the vehicle dynamic model and the occupant was modified. This windscreen has been moved 100mm forward to prevent any hard contacts with the occupant’s head, hence allowing all the FMVSS208 criteria to be achieved.

Results are summarised in the tables below:

Table 5: 50th percentile AHBM model. Pre-braking 0ms. TTF 10ms

50th percentile AHBM model. Pre-braking 0ms TTF 10ms					
Major head neck and chest injury values		**FMVSS208**	**Mobile Phone**	**Radio**	**Armrest**
	Run number	39	31	40	41
Head	HIC (15 ms) [-]	213	448	7	12
Neck	Nij [-] Tension-Extension	0.05	0.21	0.05	0.04
	Nij [-] Tension-Flexion	0.04	0.17	0.03	0.04
	Nij [-] Compression-Extension	0.27	1.1	0.2	0.04
	Nij [-] Compression-Flexion	0.05	0.16	0.06	0.05
	Tension force [N]	376	88	249	305
	Compression force [N]	219	788	182	200
	Flexion [Nm]	33	129	29	46
	Extension [Nm]	10	49	8	7
Chest	Accel (3 ms) [g]	10	16	5	5

From the results in Table 5 (normal FMVSS208 stance situation) , it can be seen that all the figures are within the legal limit, except the case for the occupant holding a mobile phone which suggest a NIJ (Compression- Extension) above 1. Identical results have been obtained with a pre-braking delay of 0ms and 200ms respectively, in combination with airbag firing times of 10ms and 20ms.

Table 6: 50th percentile AHBM model. Pre-braking 400ms TTF 10ms

50th percentile AHBM model. Pre-braking 400ms TTF 10ms					
Major head neck and chest injury values		**FMVSS208**	**Mobile Phone**	**Radio**	**Armrest**
	Run number	50	56	54	52
Head	HIC (15 ms) [-]	105	65	61	110
Neck	Nij [-] Tension-Extension	0.6	0.48	0.3	0.6
	Nij [-] Tension-Flexion	0.08	0.09	0.07	0.06
	Nij [-] Compression-Extension	0.08	0.63	0.5	0.85
	Nij [-] Compression-Flexion	0.2	0.2	0.2	0.2
	Tension force [N]	967	893	838	898
	Compression force [N]	426	407	343	416
	Flexion [Nm]	102	82	67	110
	Extension [Nm]	20	18	19	19
Chest	Accel (3 ms) [g]	14	13	13	14

From the results in

Table 6, all the values in the table for a pre-braking lasting 400ms and an airbag with a time to fire of 10ms are within the legal limit.

It can be noted that, with the exception of the mobile phone case, the extreme values for tension force, compression force, flexion and extension are higher than in a normal FMVSS208 starting stance.

Table 7: 50th percentile AHBM model. Pre-braking 500ms TTF 10ms

50th percentile AHBM model. Pre-braking 500ms TTF 10ms					
Major head neck and chest injury values		**FMVSS208**	**Mobile Phone**	**Radio**	**Armrest**
	Run number	51	57	55	53
Head	HIC (15 ms) [-]	78	35	44	82
Neck	Nij [-] Tension-Extension	0.06	0.07	0.06	0.07
	Nij [-] Tension-Flexion	0.09	0.08	0.09	0.08
	Nij [-] Compression-Extension	0.6	0.35	0.18	0.67
	Nij [-] Compression-Flexion	0.2	0.09	0.11	0.13
	Tension force [N]	367	218	244	351
	Compression force [N]	131	106	145	116
	Flexion [Nm]	69	43	21	82
	Extension [Nm]	27	19	23	23
Chest	Accel (3 ms) [g]	11	9	10	11

All the values in the Table 7 for a pre-braking lasting 500ms and an airbag with a time to fire of 10ms are within the legal limit.

It can be noted that injury values are in general less than for time 400ms with an airbag time to fire of 10ms.

Compression and tension forces tend to be less than for the starting FMVSS208 scenario, but the flexion and extension are generally higher.

Table 8: 50th percentile AHBM model. Pre-braking 400ms TTF 20ms

50th percentile AHBM model. Pre-braking 400ms TTF 20ms					
Major head neck and chest injury values		**FMVSS208**	**Mobile Phone**	**Radio**	**Armrest**
	Run number	60	66	64	62
Head	HIC (15 ms) [-]	118	90	30	65
Neck	Nij [-] Tension-Extension	0.6	0.6	0.2	0.4
	Nij [-] Tension-Flexion	0.1	0.1	0.1	0.1
	Nij [-] Compression-Extension	0.8	0.7	0.3	0.7
	Nij [-] Compression-Flexion	0.2	0.2	0.2	0.2
	Tension force [N]	974	885	811	973
	Compression force [N]	410	420	367	494
	Flexion [Nm]	105	92	44	91
	Extension [Nm]	21	17	22	19
Chest	Accel (3 ms) [g]	14	14	13	15

All the values in the Table 8 for a pre-braking lasting 400ms and an airbag with a time to fire of 20ms are within the legal limit.

It can be noted that all the injuries, for all cases, have the same magnitude as for a pre-braking lasting 400ms with an airbag with a time to fire of 10ms.

It can therefore be proposed that up to a pre-braking duration of 400ms, a usual airbag triggering time (between 10 and 20ms) does not have a major influence on occupant injuries compared to a standard unbelted FMVSS208 test.

In Figure 24, looking at the FMVSS208 driving scenario, it can be clearly seen that the injury traces have the same shape and timing regardless of the airbag firing time.

The main difference is in Fx, where the airbag strikes the occupant in the 'x' direction, as it is its primary direction of deployment. As the airbag has a pressure-time inflation characteristic, it will create a different load level according to the time it is struck.

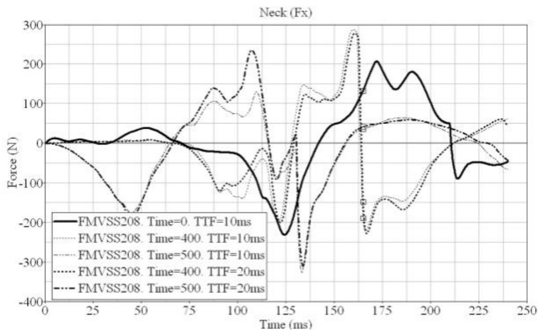


Figure 24: FMVSS208 driving stance. Neck Fx injuries

The neck tension and compression forces (Figure 24, Figure 25) in the neck are almost a perfect overlay, showing that the airbag firing time does not affect the injury patterns in FMVSS208 scenario.

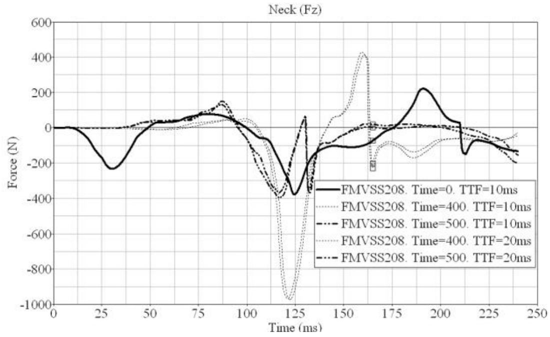


Figure 25: FMVSS208 driving stance. Neck Fz injuries

At time 130ms, 165ms and 212ms, it can be seen that the neck moments are asymptotic. This also ties up with a change of direction of the value of Fz, where neck compression is suggested.

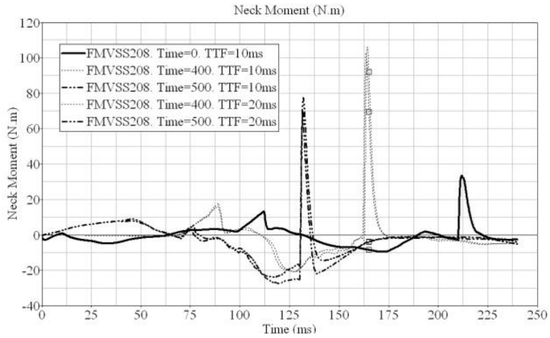


Figure 26: FMVSS208 driving stance. Neck My injuries

Simulations with asymptotic neck moments do indeed show that the occupant's head contacts the windscreen, as illustrated in Figure 26 and Figure 27.

Figure 27: Occupant's head contacting the windscreen

Table 9: 50th percentile AHBM model. Pre-braking 500ms TTF 20ms

50th percentile AHBM model. Pre-braking 500ms TTF 20ms					
Major head neck and chest injury values		**FMVSS208**	**Mobile Phone**	**Radio**	**Armrest**
	Run number	61	67	65	63
Head	HIC (15 ms) [-]	85	19	26	11
Neck	Nij [-] Tension-Extension	0.1	0.1	0.1	0.1
	Nij [-] Tension-Flexion	0.1	0.1	0.1	0.1
	Nij [-] Compression-Extension	0.6	0.1	0.1	0
	Nij [-] Compression-Flexion	0.1	0.1	0.1	0.1
	Tension force [N]	397	233	187	213
	Compression force [N]	150	118	157	154
	Flexion [Nm]	75	9	8	9
	Extension [Nm]	24	27	24	30
Chest	Accel (3 ms) [g]	11	9	11	9

All the values in Table 9 for a pre-braking lasting 500ms and an airbag with a time to fire of 20ms are within the legal limit and are the same level as with an airbag tiring time of 10ms.

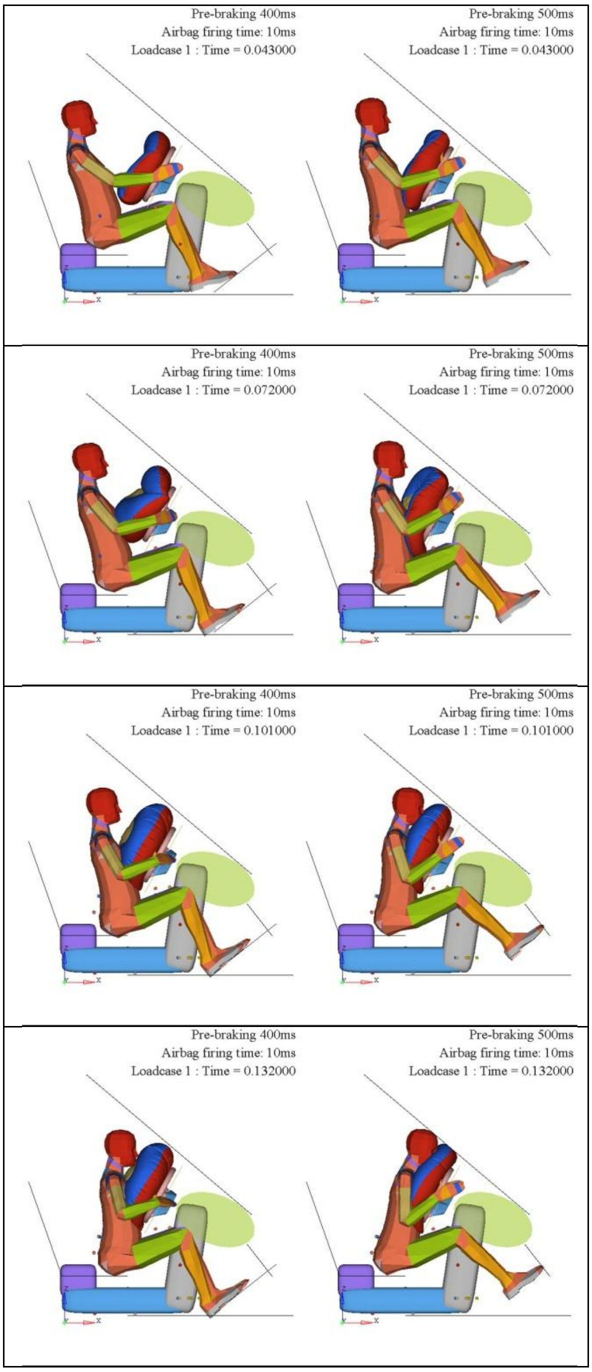
It can be noted that all injuries, for almost all cases, are less severe than the corresponding ones for a pre-braking lasting 400ms with an airbag fire time of 20ms. This is counter intuitive, as the occupant is closer to the steering wheel and moving toward the airbag at a higher speed.

Looking at the occupant kinematics (Figure 28), it can be noted that the occupant's legs are impacting the knee bolster.

Upon contact with the knee bolster, the torso rotates about the hip joint. At this point, the occupant is not sitting straight anymore and slouches on the airbag.

As the occupant is not sitting straight, its head position relative to the windscreen is different than for the scenario where the pre-braking lasts 400ms.

This is the reason why the neck moments generated by the head contact to the windscreen is less severe for a pre-braking of 500ms than for 400ms.



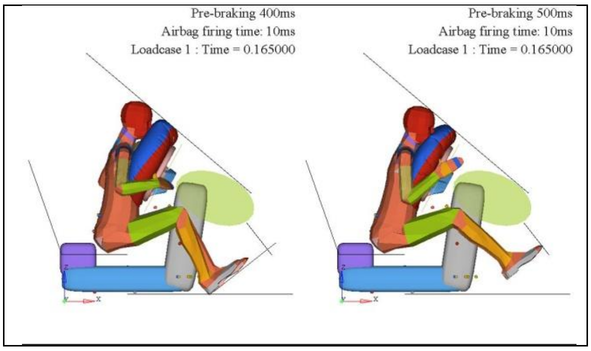


Figure 28: Occupant Kinematics Comparison between 400ms and 500ms pre-braking duration

CONCLUSIONS

This paper reviewed the kinematics and potential injury levels from different unbelted driving stances (established by the PRISM project) caused by an active safety scenario comprising of a pre-braking event followed by a 25mph FMVVS208 impact phase, using an Active Human Body Model.

It showed that using a constant pre-braking load was a too severe loadcase and that the vehicle pre-braking nose dive may have further effects on the occupant's kinematics and relationship between its position in the vehicle and the airbag system.

It was found that the unbelted driver's pre-braking kinematics were different according to the starting driving stance (FMVSS208, adjusting the radio, holding a mobile phone and driving with the arm on the armrest). It was however also found that prior to any hard contact inside the vehicle interior; the occupant's velocity was independent of the starting driving stance, as would be expected

For a standard FMVSS208 occupant starting position, subjected to a pre-braking followed by a vehicle impact phase, it has been shown that the airbag firing time (for which the extremes where set to 10 and 20ms) did not have any major influence on the shape and magnitude of the tension/ compression loads and the neck moments.

It was found that the kinematics of the AHBM is the same for the first 200ms of the pre-braking phase in all models, as the braking pulse is low and is overtaken by the seat friction.

It follows that for a pre-braking lasting 500ms before vehicle impact occurs; the occupant's kinematics are modified because of the interaction with the knee bolster, forcing the torso to rotate about the hips, hence avoiding direct head contact with the windscreen.

FURTHER WORK

Further research will consider looking into more detail in the mobile phone, armrest and radio stances and comparing their outcomes with the findings generated by the standard FMVSS208 driving stance.

Occupant injuries from accident avoidance by swerving and breaking could also be considered and compared with the ones from this paper forward pre-braking [18].

This study should be extended to look into longer duration pre-braking phase and extend the scope to duration greater than 500ms as well as including arm and leg muscle activation.

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