A study of the effect of reclined seatback on the occupant kinematics in an autonomous emergency braking using a MADYMO active human body model

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Abstract

In the future car, the highly autonomous driving system will have the leading-role for controlling. The driver will release the car's control intervention and tend to find a more comfortable seated posture. It is predicted that highly reclined seatback posture would have a potentially higher rate in comparison with some other seated positions, especially in the long-range travel with the highly autonomous driving. The highly reclined seatback with the standard D-ring on B-pillar belt left along welt around the occupant's rib cage needs to be investigated the efficiency because it was concluded that the belts only work well when they're worn correctly. Also, earlier research has shown that a lack of awareness could significantly increase the response time of the driver and longer reaction time in pre-crash in autonomous driving. This work aims to evaluate the impact of the reclined rear seatback on the occupant kinematics in the autonomous emergency braking (AEB) maneuver. A computational method that used the MADYMO human body model to simulate the behavior of the occupant in various different reclined seatback angles during the AEB with a standard D-ring seatbelt system (D-ring on the B-pillar) and seat-integrated D-ring belt system (D-ring on the seat structure), and various muscle tension levels.

Keywords reclined seatback, human body model, occupant kinematics, pre-crash maneuvers, highly autonomous driving.

1. Introduction

The highly autonomous driving is predicted that will have a leading role in controlling the car. The drivers will focus on other activities during traveling. They can read books, can use computers or mobile phones, talk to other passengers freely, even they can take a snap. In long-range travel, the driver would have the trend to find a comfortable position by adjusting the seatback angle to a higher reclined position. However, the current restraint system was designed to protect the passengers in the standard position (the upright seatback posture). In particular, a test with a volunteer on the front seat in the fully reclined seatback with a standard seatbelt attached to the B-pillar of the vehicle was conducted as seen in Figure 9 of the

Appendix. We realized a significant gap between the shoulder seat belt and the upper torso. This gap could reduce the effectiveness of the seatbelt and this will be addressed in this paper.

In the past, the researchers in [1] were conducted a survey on the traffic crashes from 1995-2005 in United State using data from the Crash Injury Research and Engineering Network (CIREN) and the National Automotive Sampling System Crashworthiness Data System (NASS). They found many victims have their seats partially or fully reclined. Passengers may fully recline their seats while sleeping, especially on long trips. The survey showed up the chest, and spinal injuries with the shoulder belt appeared to be one mechanism in fully reclined occupants wearing a seatbelt and the positioning of the lap belt resulted in upper abdominal injuries. In the developing trend of highly autonomous driving, the new restraint system would be more suitable to the alternative positions as mentioned in [2] will be necessary. Therefore, the study on the occupant response in these alternative positions during some emergency maneuvers to provide the data set to the manufacturers will be very useful.

To examine the restraint system in a vehicle, dummies are usually used to assess and validate. However, dummies which were made of rubbers, foams, and metallic structures were not designed to simulate the human responses in such positions with the fully reclined seatback. The study in [3] showed the dummies exhibit a different kinematic chain in the reclined position than they do in the traditional upright position, especially have a large influence on the forces experienced by the lumbar spine sensors in the dummies. They also suggested using a human body model to investigate more closely what happens to the human spine during a frontal reclined crash. Whereas the human body model (HBM) with bones, muscles, and organs was predicted that it can get more closely investigating that of an actual occupant. Over the past years, a few researchers used HBM to simulate and estimate the human responses and the death risk during a frontal reclined crash. [4] used a HBM of Global Human Body Model Consortium (GHBMC) owned 50th percentile male to estimate the impact of the different reclined seatback angles, the seat cushion materials, and the different angles of the lap belt on the occupant kinematics during a frontal crash, while [5] also used GHBMS to perform some simulations to approach the influence of the reclined seatback on the pelvis rotation and lumbar spine torque. To show how the reclined seatback increases the injury severity and shifts injury pattern, [6] simulated the human response in a car with a standard D-ring seat belt (the D-ring on the B-pillar) by using a scaled Hybrid III 5th percentile ATD on the reclined seat. The study clearly indicated the unfavorable kinematics subjecting the front of the neck to interact with the locked shoulder belt and the lap belt slid over the pelvis and directly loaded into the abdomen.

These studies addressed the influence of the highly reclined seatback on the occupant kinematics and the restraint interaction in simulated frontal collisions by using the human body models. However, these studies did not cover the pre-crash phase which affects the posture of the occupant especially in an emergency braking maneuver and furthermore the muscle activation was not addressed, which is important for the posture during the pre-crash phase. On the other hand, the integrated safety system in the automated car requires data to predict the occupant kinematics in the pre-crash phase in order to evaluate the effect of a system active before the crash phase [7]. Therefore, the occupant response in the highly reclined posture during a pre-crash phase should be also focused to study. Additionally, the volunteer test with the seatback reclined during some pre-crash phases could be conducted successfully and it is potential to supply the data set to validate the human body model. As the knowledge of the authors, there is no paper focused on the occupant kinematics during an emergency braking maneuver with the fully reclined seatback. The aim of this study is to simulate the occupant responses in the different seatback angles during a braking maneuver by using a MADYMO active human model. We also examined the influence of the different muscle activities and the different D-ring positions as well as the seatback angles on the occupant kinematics to supply useful information to manufacturers to improve the integrated safety systems in the future car.

2. Study method.

In this study, an emergency braking maneuver of 3.1s was analyzed using MADYMO simulations. The models included a simplified vehicle interior and an active human model which can simulate the human postures and the muscle tension as well. At the first step, a simulation for the occupant in the standard posture (equivalent to 23° upright seatback) was imposed on a 1g deceleration braking pulse in 3.1s. The models have validated the body kinematics, the muscle activities, and the seatbelt behavior by comparing them to the volunteer data set to figure out the best setting parameters of the model. Afterward, the models were tuned to two different reclined occupant postures by keeping all setting parameters except the seatback angles, one for 38° reclined and one for 53° reclined. At last, the simulation results were collected, evaluated and given the conclusions.

Vehicle model.

Figure 10 in the Appendix shows the simplified interior model representing a cabin which includes the dashboard, front door trim, center console, front passenger seat, and seat belt. The distance of console and door trim, as well as the position of the front seat in relation to the dashboard and footwell, were derived from the test car used in [13]. The front seat model was created based on scan data of the original front passenger seat. The material data was characterized using the quasi-static loading of the vehicle seat (see Figure 1). The parameters of the damping, the elastic coefficient and the contact friction of the seat model were optimized in the MADYMO program as the input data for the next simulation basing on the validation results. The seat model has just tuned to three different seatback angles included 23° reclined (standard seatback), 38° reclined (half reclined seatback), and 53° reclined (fully reclined seatback) as seen in Figure 2, and kept all other setting parameters. The angles of seatback were set following the vehicle specifications of the manufacturer.

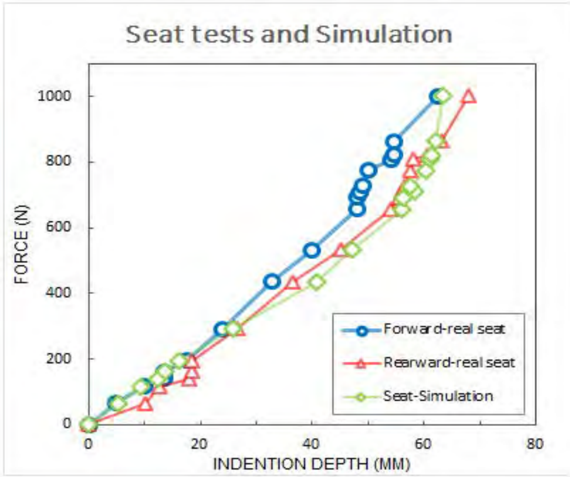


Figure 1: the front seat model and the comparing result to the seat tests with volunteers.

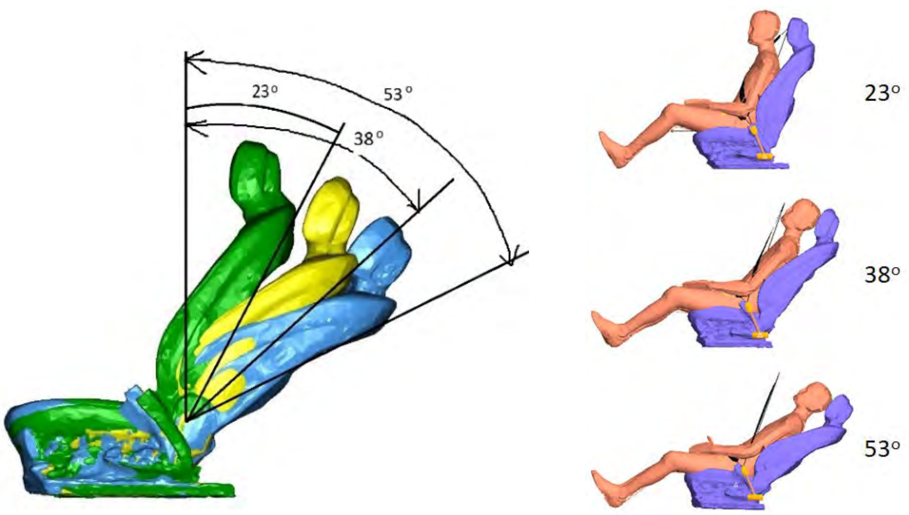


Figure 2: three different angles of the front seat model and the corresponding reclined postures.

The seat belt model has a typical configuration as described in [8]. The seat belt model consists of different sub-components as a buckle MB model attached to the seat, an anchor MB model and a retractor MB model attached to the vehicle. The acceleration threshold for the ball sensor of the retractor was set at 0.85g and for the webbing payout at 0.7g (the following part of this study will show the method to find out these parameters). The seat belt also has the function of pretension and load limited force but in this study, we did not focus on the impact of these elements, therefore they were disabled. The D-ring position was also corrected following to the real vehicle as seen in Figure 10 of the Appendix. It is a B-pillar D-ring standard seat belt model. To investigate the effect of D-ring position on the occupant kinematics during the braking maneuver, the seat belt models with D-ring position on the frame seatback (called seat-integrated D-ring) were built corresponding to three different seatback angle models. In this study, we did not try to build a seat model with seat-integrated D-ring correctly to the real one. The seat-integrated D-ring position was addressed using a D-ring position attached to the right-upper seat bolster of the seatback model.

Active human model (AHM).

In this study, we used a MADYMO mid-size male human body model representing the 50th percentile in the seated position to simulate the occupant sitting posture in three different seatback angles. As presented above, this is an active human body model version 3.0 which was developed by TNO Automotive Safety Solutions (TASS) BV, Netherlands in the MB and FE software package MADYMO version 7.7 [9]. The active human model consists of 190 bodies (182 rigid bodies and 8 flexible bodies). The first branch connects the head and vertebral bodies to the pelvis. Two branches attach the shoes and the bodies of the left and right leg to the pelvis. Separate branches connect the patella, toes and other bodies in the foot. Two branches attach the fingers and the bodies of the arm to the spine. The thumb is connected to the mid-hand joint on a separate branch from the fingers. The thorax and the abdomen each consist of 4 flexible bodies that divide the thorax and abdomen into horizontal slices. Attached to each slice at the left and right side and at the front, bodies have been placed for attachment of the force models. The thorax and abdomen bodies are divided over 3 branches (front, left and right) for each slice [10]. The model was verified by various loading tests, including a volunteer with the sled and with vehicle tests and post modem human substitute tests. The muscle model implemented in MADYMO is based on a description originally formulated by Hill. Unfortunately, the muscle activation of AHM hasn't been verified during the pre-crash phase. In this study, we also presented the validation results of muscle responses in the neck and the arms of AHM by comparing to the volunteer test data in some braking maneuver.

The AHM standard posture validation.

In order to optimize the setting parameters related to muscle tension of AHM, the seat belt activations, and the footwell force, the authors selected 3 papers that presented the volunteer test data of the low deceleration braking events. The data test including the occupant kinematics, the muscle tension, the footwell force, and the seat belt activations was collected to compare to the simulation results of the model with the AHM in the standard posture. The setting parameters of the standard posture model achieved from these processes will be applied for the half reclined (38o) and fully reclined (53o) posture remaining.

In [11], Jóna M. Ólafsdóttir et al. (2013) recorded the front right seat passenger volunteer kinematics, the electromyographic (EMG) responses and the vehicle interaction forces in 1.1g autonomous braking events in a test vehicle driving on relatively empty rural roads. 09 volunteers seated in the passenger seat, each volunteer was restrained with a standard seat belt that would be focused on this study and a reversible pre-tensioned belt as well.

In [12], Philipp Huber et al. (2015) presented a detailed analysis of occupant kinematics with up to 25 subjects under emergency braking maneuvers at 12 km/h and 50 km/h. Detailed vehicle and occupant kinematic corridors are also presented.

In [13], driving tests with a total number of 30 volunteers (24 males and 6 females) were performed in the test vehicle was a BMW 535i Touring (F11). The tests were chosen to simulate typical precrash scenarios such as partial- or full-braking before an impact. The Racelogic Video VBOX was used in order to record the volunteer motions during the tests. The motion of each passenger in each manoeuver was measured by video analysis with the software TrackIt (IAT Ingenieurgesellschaft für Automobiltechnik mbH), which allows visual tracking of several markers placed on defined body parts of the subjects.

Based on the information of the above papers concerned with the test car loading, the event time, the passenger seat characteristics, the standard seat belt, we used the AHM in the standard posture to simulate the volunteer responses. The simulation resulted in the model kinematics, the muscle model activation, the seat belt model responses, and the force of footwell. The AHM was changed the muscle setting correspondingly to get the best results. Figure 1-5 in the Appendix indicated the simulation results of the standard posture AHM in comparison to the volunteer data of the three papers which were mentioned above. As the author's opinion, the AHM can predict the occupant responds very well. The seat belt activations including the shoulder belt force and the belt pay-out are very close to the mean values of the volunteer data set as well as the footwell force simulation results. The muscle simulations at the neck and arm also got good results except for the anterior muscle at the neck (sternocleidomastoid muscle) will need to be improved due to the maximum peak reaction and the time reaction seemed to be much different.

Initial model setting and simulation matrix.

This study assumed an occupant seating on the front passenger seat with the different angles of the seatback in a low-deceleration braking event to investigate the occupant kinematics. The braking pulse applying for each case of simulations was similar and collected from the test vehicle in paper [13]. As mentioned above, 30 braking test times were conducted with a BMW 535i Touring (F11), it means 30 pulses were calculated to find out the average pulse which was the loading input of the MADYMO simulation. As shown in Figure 11 in the Appendix, the time-history curves of the forward deceleration representing the emergency braking maneuvers were 3.1s. The maximum deceleration generated by braking was peaked around

1g and had the onset at around 0.5s.

The coordinate axis system of the vehicle model as a reference coordinate system was set following ISO 8855-2011 [14] whereas the original coordination point (Zero: 0) was set at the point of H-point of the front seat model. The AHM v3.0 was initially seated on the seat model with the Hip-point set at 11 mm below and 16 mm rearward of the seat H-point as following the study of Matthew P. Reed [15]. The friction coefficient of seat cushion was set at 0.4 based on the validation model result of the AHM standard posture before performing proper equilibrium settling runs for the AHM model [16]. The purpose of this process is to ensure the AHM at the stable state without any loading force except for the gravity force. When the AHM found the equilibrium position, the initial position of the shoulder belt and the lap belt on the body of AHM were set as following the study [15]. Based on the mean values of that survey, the author set the middle point of the lap belt of the standard D-ring seat belt system is X = 94.6 mm and Z = 58.9 mm corresponding to the Hip-point, and the middle point of the shoulder belt was Y = -50 mm corresponding to the sternum point (see Figure 15,16 in [15]). However, for the seat-integrated D-ring seat belt, the shoulder belt was set with Y = 0.

As mentioned above, the study assumed the seatback reclined reward to 38º (half reclined) and 53º (fully reclined) from the standard position. The coordinate values of the point at head CG, C1, T1, T10, L1, hip, knee, and ankle were measured to monitor the occupant motion. Those points were calculated and converted into the reference coordinate system of the vehicle model. The displacement of each point was calculated assuming that the initial point without the braking maneuver was at 0.5s of each simulation. Furthermore, to investigate the effect of the muscle tension on the occupant kinematics in the three different seatback angles during the braking maneuver, the study assumed three levels of muscle tension of the AHM. The first level was called active muscle which was verified in the standard posture AHM (23º reclined.) wherein the neck activation was set at 80% of MVC (maximum volunteer contraction) [11], the spine activation at 100% of MVC, while the hip, elbow, and shoulder at the same level was 1% of MVC, the knee level was set at 30% of MVC. The second level was called partially relaxed muscle which was set the same level of muscle activation of the hip, elbow, shoulder, and knee to the values of the active muscle, except for the neck at 50%, spine at 50% of MVC. The third level of muscle tension of the AHM was the full relaxed wherein all the muscle tension was set at 1% of MVC. (0% MVC was eliminated to ensure the stable model during the simulation). Additionally, the position of the D-ring of the seat belt was predicted to impact on the occupant response, therefore two different positions of D-ring were simulated. One simulation for the standard D-ring seat belt which was defined and mentioned the D-ring position on the B-pillar (X = -279mm, Y = -280mm and Z = 605mm corresponding to the vehicle reference coordination system). One simulation for the seat-integrated D-ring seat belt with D-ring position was located on the upper right bolster, right shoulder seatback, 180mm of distance to the symmetrical plane of the seatback. Table I summarized 18 cases of all simulations.

Table 1: Simulation matrix

Case No.	The reclined seatback	The muscle tension	The D-ring position
1	Standard reclined	Active muscle	Standard B-pillar
2	Half reclined		
3	Fully reclined		
4	Standard reclined	Partial relaxed	
5	Half reclined		
6	Fully reclined		
7	Standard reclined	Full relaxed	
8	Half reclined		
9	Fully reclined		
10	Standard reclined	Active muscle	Seat-integrated
11	Half reclined		
12	Fully reclined		
13	Standard reclined	Partial relaxed	
14	Half reclined		
15	Fully reclined		
16	Standard reclined	Full relaxed	
17	Half reclined		
18	Fully reclined		

3. Results.

In order to investigate the effect of the reclined seatback on the occupant kinematics with the different muscle tension and the different D-ring seat belt position during the braking maneuver, 18 simulations were performed. In this section of the study, the maximum forward and the motion on the X and Z direction of the head CG, T1 were captured to indicate the effect of the reclined seatback. On the other hand, the rotation of the AHM pelvis around the Y-axis, the compression force of T12 and L5 on the spine was also plotted out as well as the shoulder belt force to indicate the effect of fully reclined seatback posture, and how those changed among three different postures. In addition, those factors also were plotted out in different cases with the different muscle tension levels and the D-ring position during the braking event. All simulations were performed from 0.5s to 3.1s following the history-time of the deceleration pulse in [13].

Figure 6,7 and 8 in the Appendix show the occupant behavior based on the AHM in case of the standard D-ring seat belt during the braking maneuver wherein 09 simulations indicated the effect of three reclined seatback angles in relation to three levels of muscle tension at 0.5s (initial phase), 1.0s, and 1.5s (forward phase) of the time-history of the maneuver. These figures did not show the maximum excursion of the upper torso of the occupant body, however, they indicated intuitively the change of occupant posture, the forward and downward displacement of the head CG and T1 as well as the change of distance from the head to the headrest (called the head's distance) of the seat of each case. At the initial phase 0.5s in Figure 6 of the Appendix, all cases had the AHM head contacting to the headrest except for the Case 1, Case 4, and Case 7 were 51mm of the head's distance. The distance value of the cases with 23º reclined seatback increased much at the middle time 1.0s while those distance values in cases of 53º reclined were smallest in the range of 46mm to 59mm (Figure 7 of the Appendix). At that moment, the cases corresponding to the full relaxed of muscle state had the head's distance were larger than other remaining states. It was 303 mm of Case 7 comparing to 182mm of Case 1 and was 163mm of Case 8 in comparing to 88mm of Case 2. Figure 8 of the Appendix indicated the posture of the occupant at 1.5s in the forward phase of the braking maneuver, the maximum and minimum distance of the head concentrated in the cases of fully reclined (53º reclined) as Case 3 and Case 9. They were 99mm of minimum and 555mm of maximum value. The partial relaxed cases (Case 4, Case 5, and case 6) almost had no different distance value while Case 7, 8, and Case 9 with the full relaxed muscle state had a bigger distance value than the other cases.

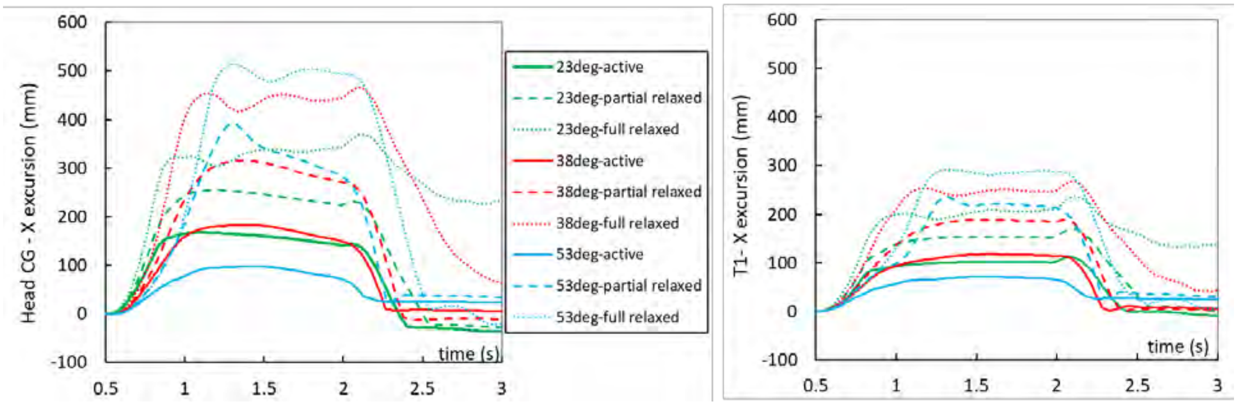


Figure 3: the forward excursion of head CG and T1 according to the case of the different reclined seatback angles and level muscle tension.

Figure 3 shows the forward excursions of the upper torso (head CG and T1) from the initial time (0.5s) to the end (3.0s) of the braking maneuver. Those included the initial phase, the forward displacement phase, and the backward phase, wherein the case of 53º reclined and full relaxed muscle tension was the biggest displacement of head CG and T1. In opposite, the case of 53º and active muscle tension was the smallest value of the displacement. These results based on the standard D-ring seat belt models.

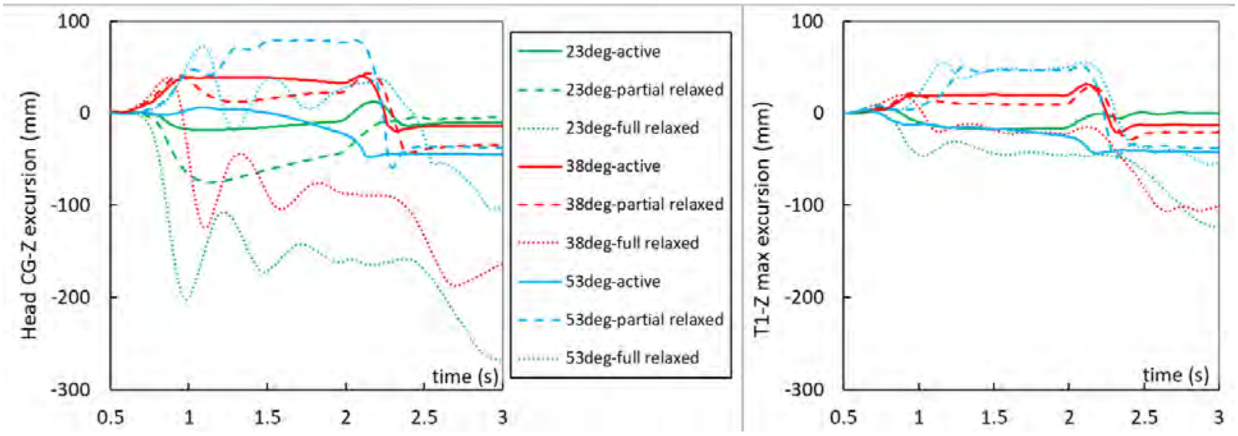
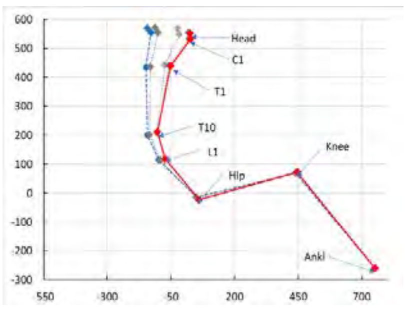
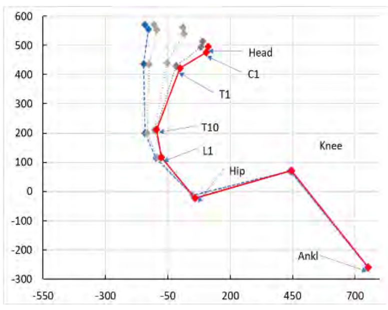
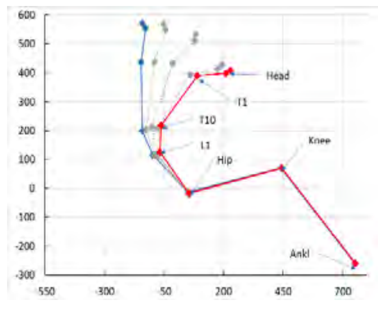
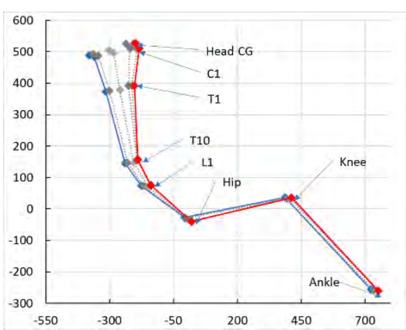
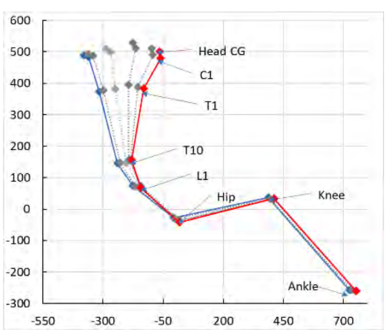
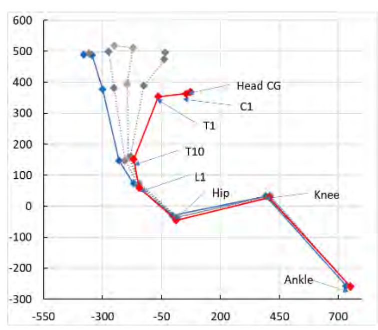
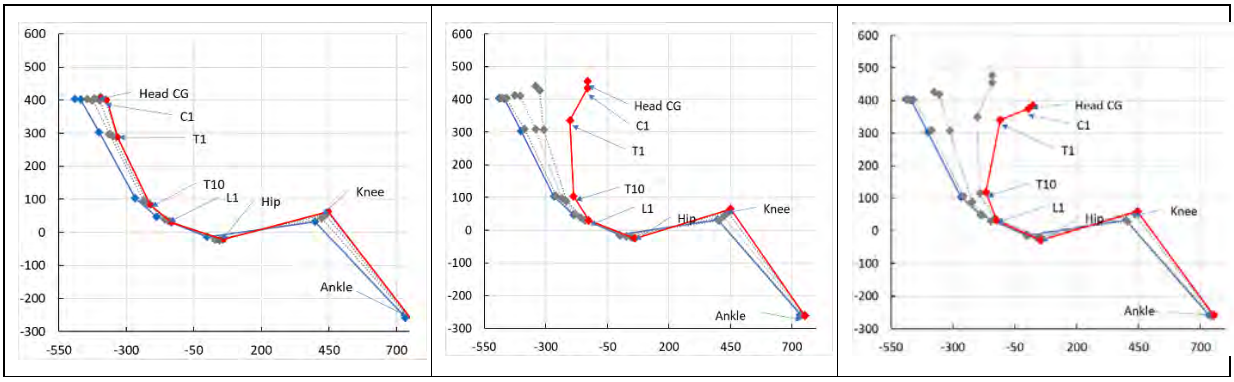


Figure 4: the downward/upward excursion of head CG and T1 according to the case of the different reclined seatback angles and level muscle tension.

Following the Z direction, the head CG and T1 also moved upward and downward. In the case of 53^o reclined and partially relaxed muscle tension, head CG and T1 moved upward around 80mm and 45mm correspondingly. The case of 53^o reclined and fully relaxed muscle tension had similar upward values. However, the case of 23^o reclined / fully relaxed muscle tension moved downward to around -270mm of head CG and -110mm of T1 as showing in Figure 4.

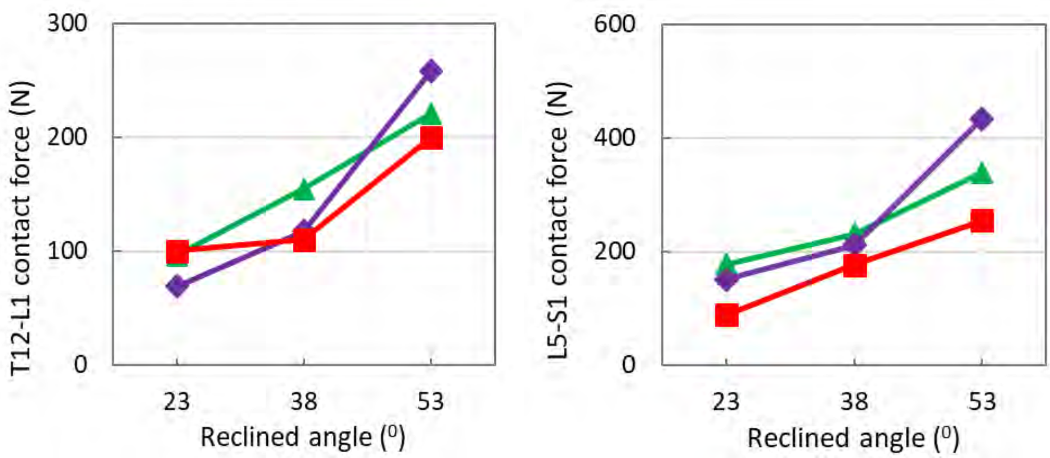
Table 2; the maximum displacement of the main body point in the XZ plane.

Case 1	Case 4	Case 7
		
Case 2	Case 5	Case 8
		
Case 3	Case 6	Case 9



To investigate the relationship between the initial point and the maximum displacement of the main point along the occupant body (head CG, T1, T10, L5, hip, knee, and ankle), the dot-blue line indicated the initial position at 0.5s in Table 2 of the Appendix while the solid-red line indicated the maximum displacement of those point in the symmetric vertical plane XZ. The cases wherein were the fully reclined seatback had significant forward displacement of the knee around 60mm while the standard reclined seatback almost had no significant displacement. The rotation of the upper torso in those cases with standard reclined seatback also had a significant increase in the comparison to the other cases (the behavior of L1-Hip around hip point).

Figure 5 shows the compression force of the contact T12-L1 and L5-S1 along the occupant's spine. The compression force of T12 in the cases of the fully reclined seatback was much higher than the cases of the standard reclined seatback. The compression force of L5 had a similar tendency to the T12 compression force. These plotted results had no significant different values of compression contact force of T12 and L5 among the cases of various muscle tension levels. Figure 5 also plotted out the maximum values of the shoulder belt and lap belt force in relation to the reclined angles and the muscle tension level. Active muscle tension helped mitigate the belt force in the fully reclined seatback while the partially relaxed and fully relaxed resulted in a similar value around 600N of the shoulder belt and 320N of the lap belt.



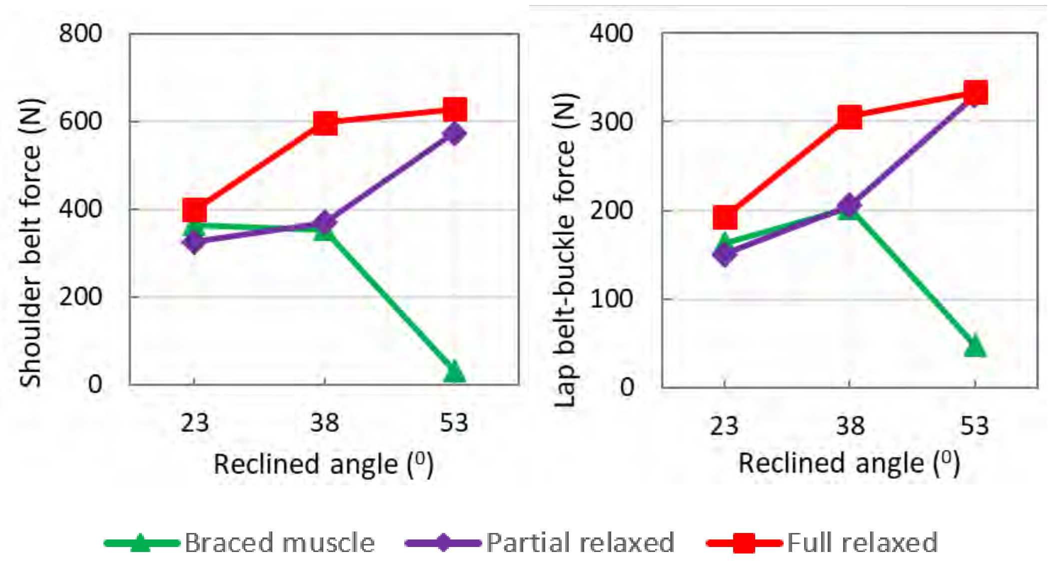


Figure 5: the contact force of T12, L5 and belt force in the relationship between the reclined seatback angle and muscle tension

4. Discussion.

This study used a MADYMO active human body model (AHM) to simulation the occupant response in various reclined seatback angles (standard reclined, half reclined, and fully reclined) in an emergency braking maneuver. 18 cases of occupant behavior simulation were analyzed to investigate the impact of the reclined angles, the muscle tension levels, and the different D-ring positions on the occupant response. Only the standard reclined seatback model (23^o) was validated by comparing it to the volunteer data set.

The standard reclined seatback (upright seatback) model validation.

As shown in Figure 1 to 5 in the Appendix, the standard reclined seatback model was verified based on the paper [11], [12], and [13]. Based on the [11] validation, the head displacement in the direction of the X-axis and Z-axis stayed in the volunteer data corridors. The T1 displacement and the seat belt reaction results were very close to the mean value of the volunteer data, and the vehicle test data. As seen in Figure 1 of the Appendix, the AHM head was rotated around the Y-axis in counter-clockwise at around 1s of the time-history while the volunteer nearly kept at 0^o due to the anterior/posterior muscle activations (Sternocleidomastoid muscle SCM and Splenius Capitus muscle CPVM) at neck to keep the volunteer eyes in the horizontal plane. The SCM and CPVM of the AHM also activated at 1s when the deceleration pulse reached to the maximum value to keep the eyes horizontally. However, the maximum co-contraction of the SCM was smaller than the average value of the volunteer and the CPVM activation had a signification delay in comparison to the average volunteer data as shown in Figure 3 of the Appendix. In order to improve the AHM head rotation, the response of the neck should be verified in the next study. The response of the AHM in Figure 5 of the Appendix was good. The forward displacement of head, shoulder, elbow, chest, pelvis, and knee was plotted out by the red curves which were in the volunteer data corridor of [13], however, in this Figure, the seat belt model was not validated. The seat belt model in this study just was validated based on the data from [11], and then the verified parameters of the seat belt were used as inputs for simulating BMW 5 touring (F11) seat belt behavior. This means it still has got a gap in this study because of lacking the data to make sure two seat belt systems in two test vehicles having a similar characteristic. However, using the vehicle model based on BMW 5 touring (F11) will be a potential success in validating the AHM in a fully reclined posture when conducting the volunteer test on this car.

Figure 4 of the Appendix shows the validation result of the AHM in the standard posture, it indicated the head and the torso response of AHM (the blue curves) lying in the volunteer data corridors except for the torso rotation around the Z-axis. The AHM torso seemed not to rotate while the volunteer rotated more than that. Those were supposed that the seat belt restricted the shoulder right of the body, and the upper torso of the volunteer was more flexible than the AHM, therefore the shoulder left kept moving forward. The result of the footwell force response in Figure 2 of the Appendix let us know partially how the lower limb (hip and legs) of AHM reaction during the maneuver but there is still a lack of validation analyzing the lower limb muscles. The activation of those muscles did not investigate in this section. The paper [11] supplied the validation data of the M-BF (biceps femoris longus), M-RF (Rectus-femoris), and M-TA (Tibialis-anterior) of the volunteer leg muscles but as the author mentioned above, the muscle model of AHM was only validated in the crash and has never investigated in the pre-crash phase. Therefore, the work in the future on the leg muscle model to verify and validate the response will be very useful for improving the AHM.

The muscle tension and reclined angle study.

To investigate the effect of muscle tension in relation to the reclined seatback angles in the similar condition of the D-ring position and the braking maneuver on the occupant kinematics and the seat belt activation, the maximum values of head, T1 displacement, and pelvis rotation was plotted out in Figure 6 as well as the contact force of T12 and L5 in Figure 5. Basing on those, some evaluations were given.

The muscle tension reduced the forward excursion of head, T1 and pelvis rotation while it has no significant difference in the forward excursion of the hip. When the reclined seatback angle increased the contact force of T12 and L5 also increased (Figure 5). It means it was the higher lumbar compression load when the inclined seatback angle increased. The hip excursion in X-axis increased very much at the highly reclined seatback. In opposite, the rotation of the pelvis around the Y-axis was lower at the higher reclined seatback angle. In the comparison of head and T1 in X displacement, those factors did not pitch significantly at the highly reclined seatback.

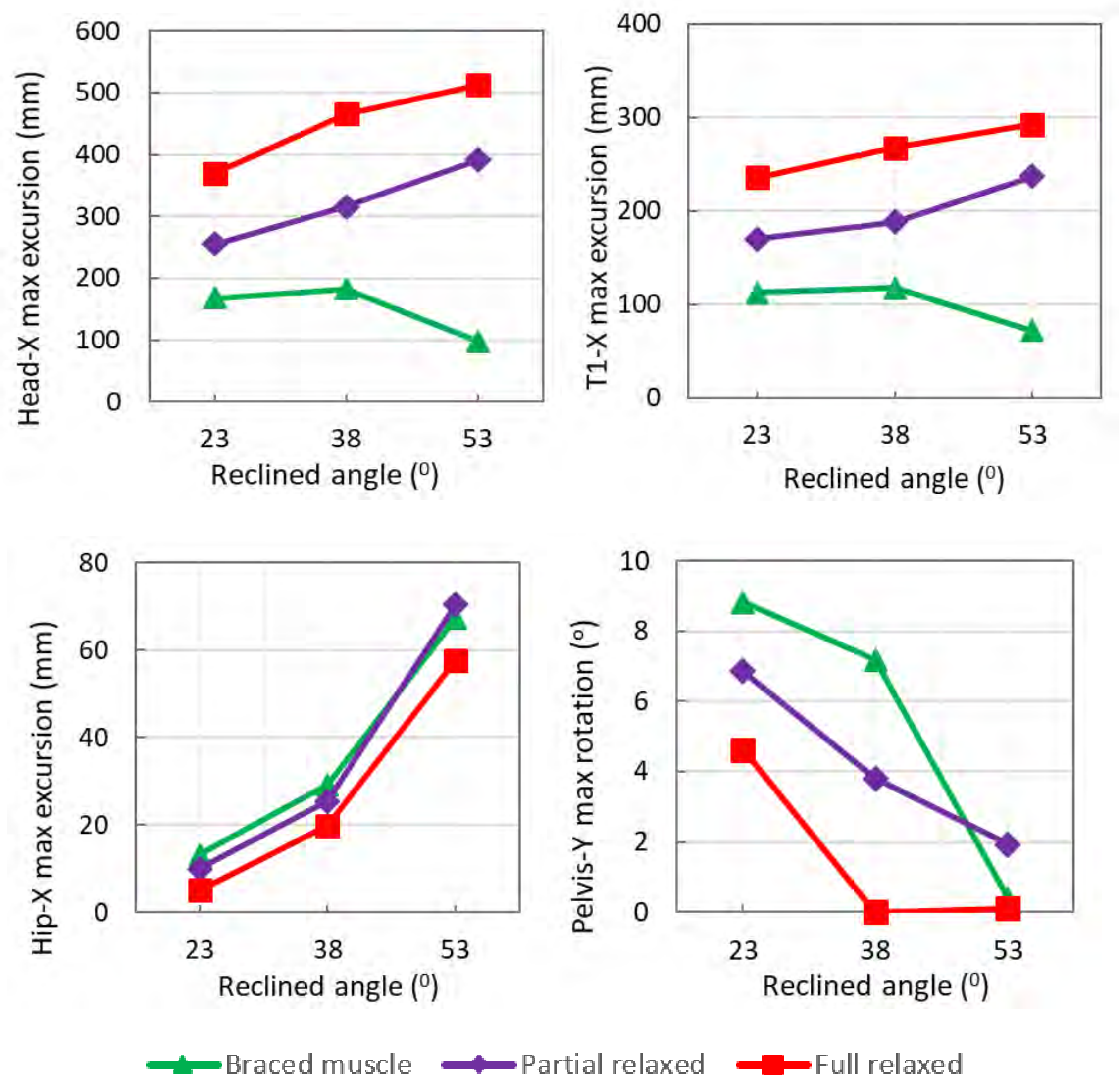


Figure 6: the effect of muscle tension and reclined angle at a similar D-ring position

Figure 7 illustrates the activation of the seat belt system in the different reclined angles and the various muscle tensions. At fully reclined seatback, the seat belt force reduced closely to 0N in case of active muscle because the shoulder belt nearly had no contact with the occupant's chest as the above comment in the first part of this study. The high muscle tension level helped restraint the chest forward, the lap belt also reduced but higher than 0N because the hip slipped forward along the seat cushion. With the lower reclined angle, it seems that was no significant difference in the seat belt force values. In case that muscle tension was relaxed or partially relaxed, seat belt force increased when the reclined seatback angle increased.

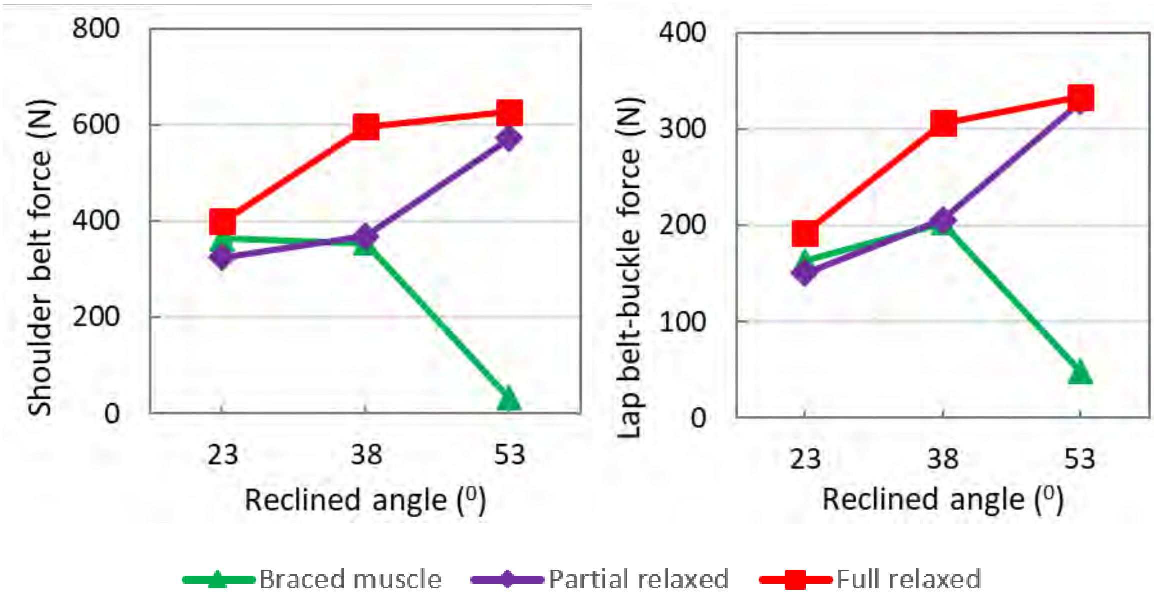
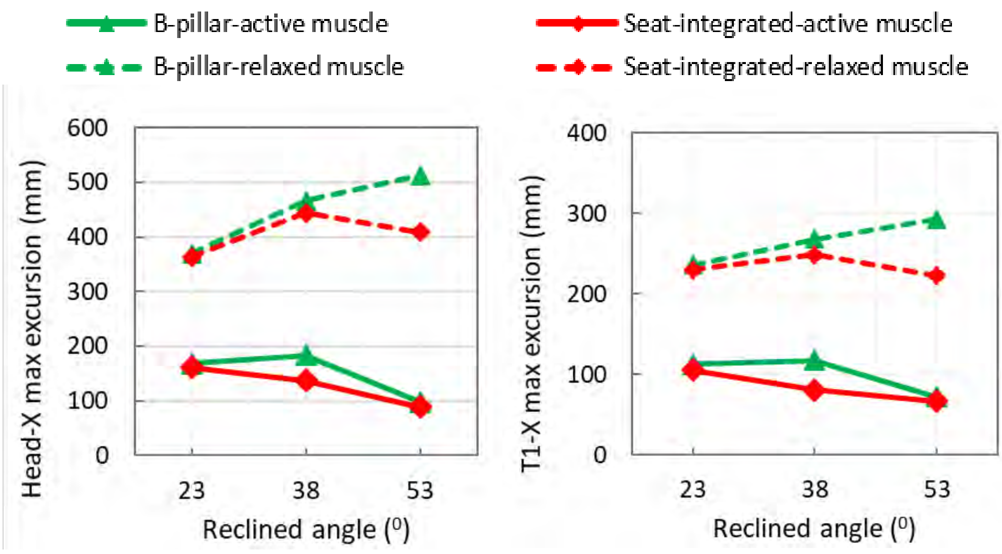


Figure 7: Seat belt activation in various reclined seatback angle and muscle tension.

As mentioned above, this study assumed that the occupant body was two levels of relaxed muscle tension, one is partially relaxed in which the activation of the neck and spine were 50% of MVC and another one has fully relaxed in which the activations of all muscles were only 1% of MVC. These level tensions were maintained during the braking maneuver 3.1s. That means the muscle contraction of the AHM would not change in the whole event. However, it is predicted that the muscle contraction would change the state when the occupant aware of the maneuver happening and the brain had enough time to transfer the signal to the muscles to change the muscle activations. The body kinematics will change after then. The AHM at fully reclined seatback posture in this study was set at the state that has no change the muscle tension during the event. The model should be investigated in the future relating to this matter.

The D-ring position and reclined angle study.



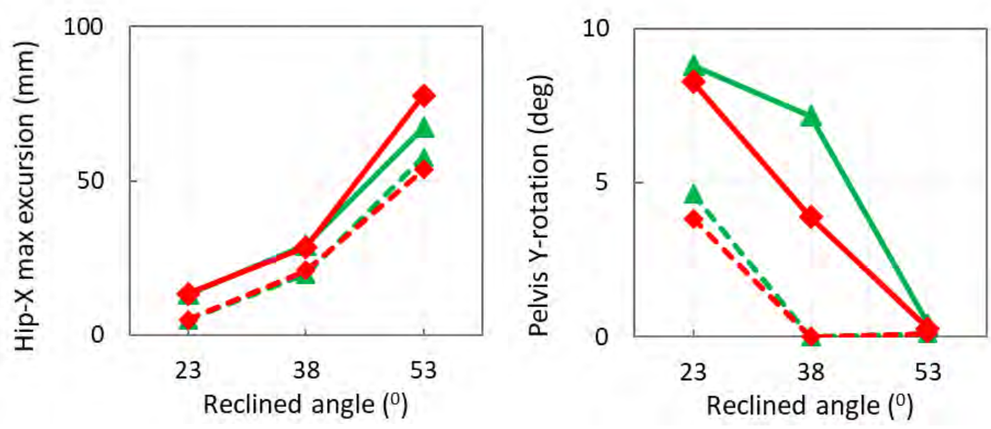
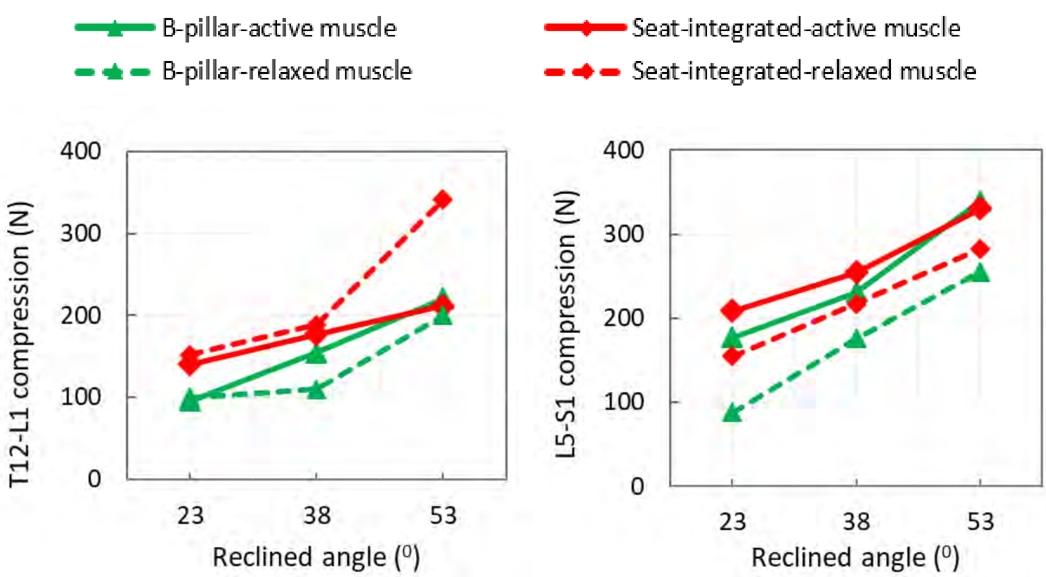


Figure 8: the effect of D-ring position on the upper torso kinematics.

This part of the study assumed the AHM in various D-ring positions (one for B-pillar D-ring and one for seat-integrated D-ring) with the different reclined seatback angles. As seen in Figure 8, when the muscle tension was active, the maximum values of the head, T1, hip displacement, and pelvis rotation had no big difference. This means that when the D-ring position had no significant effect on the occupant response at the same posture. When the reclined seatback angle increased, the displacement of head and T1 had no big change but the hip displacement increased at highly reclined seatback while the pelvis rotation around the Y-axis tended to reduce. However, when compared to the relaxed state of the muscle, the D-ring position impacted significantly on the head and T1 displacement at a highly reclined seatback angle. The seat-integrated D-ring helped reduce the pitch of the upper torso (head, T1 displacement reduced). Look at the maximum values of the lumbar compression loads in Figure 9, when the muscles were active level, the lumbar compression loads (T12 and L5 compression) seemed not to have big different value, the position of D-ring did not impact.



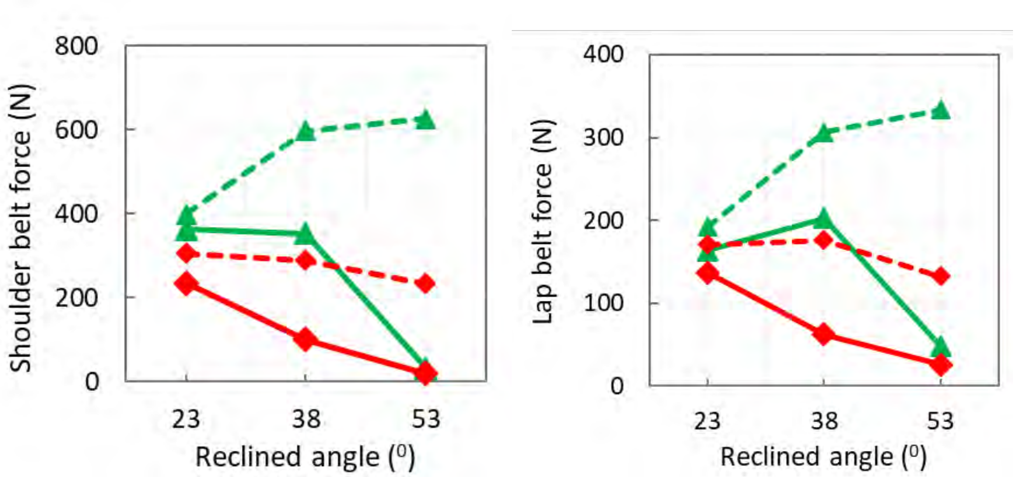


Figure 9: the effect of D-ring position on the lumbar compression load and the seat belt activation

To see the effect of D-ring position on the seat belt activation, the seat-integrated D-ring reduced the shoulder belt and lap belt force at the highly reclined seatback. When the occupant seated in the standard position, the D-ring position almost did not influence on the seat belt activation.

5. Conclusion.

This study was successful in using a human body model with active muscle and a simple vehicle model to investigate the effect of the various reclined seatback angles on the occupant kinematics during an emergency braking maneuver. In addition, the study also showed the impacts of muscle tension and the D-ring seat belt position on the occupant response. The data of those investigations are very important for the integrated safety system during the pre-crash phase. The study altered three different postures to evaluate the influence of reclined seatback: 23^o reclined (standard posture), 38^o reclined (half reclined posture), and 53^o reclined (fully reclined posture) wherein only the standard 23^o reclined posture was validated by the volunteer data. The half reclined and fully reclined posture just kept all set of parameters as the standard posture had. In the braking maneuver, the fully reclined posture was predicted that can perform well with the volunteer in the real test car in the real-time traffic. That would be the next step of this study in the future to make the evaluations in this one more rigid.

6. Acknowledgment.

The authors would like to appreciate to TNO Automotive Safety Solutions (TASS) for their support in developing the human body model.

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8. Appendix.

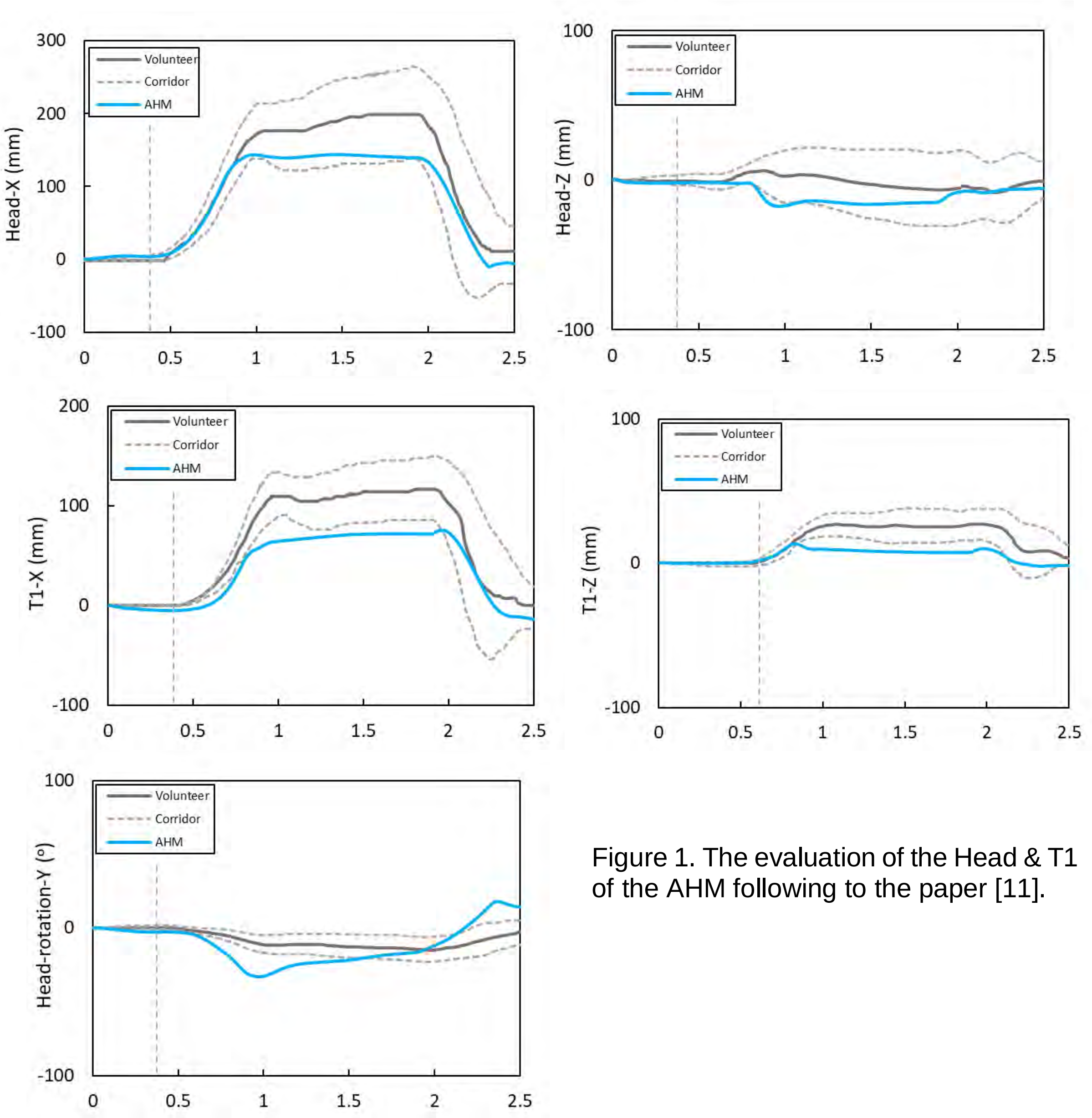
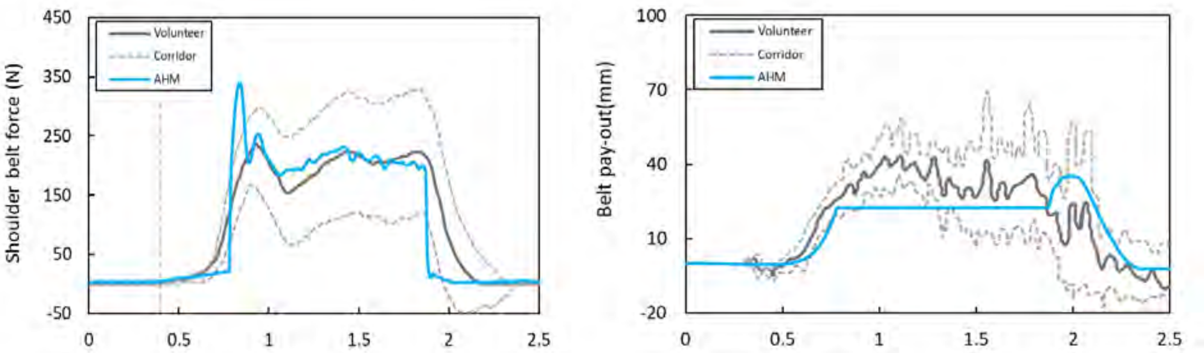


Figure 1. The evaluation of the Head & T1 of the AHM following to the paper [11].



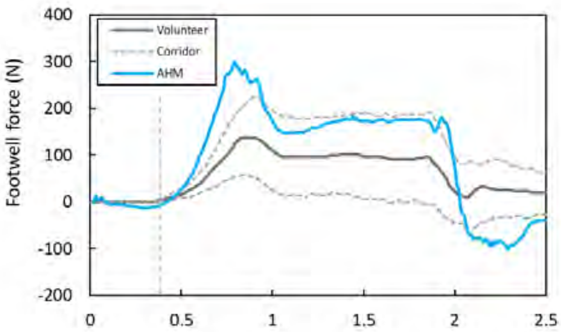


Figure 2. The evaluation of the Shoulder belt, belt pay-out & Footwell force of the AHM following to the paper [11].

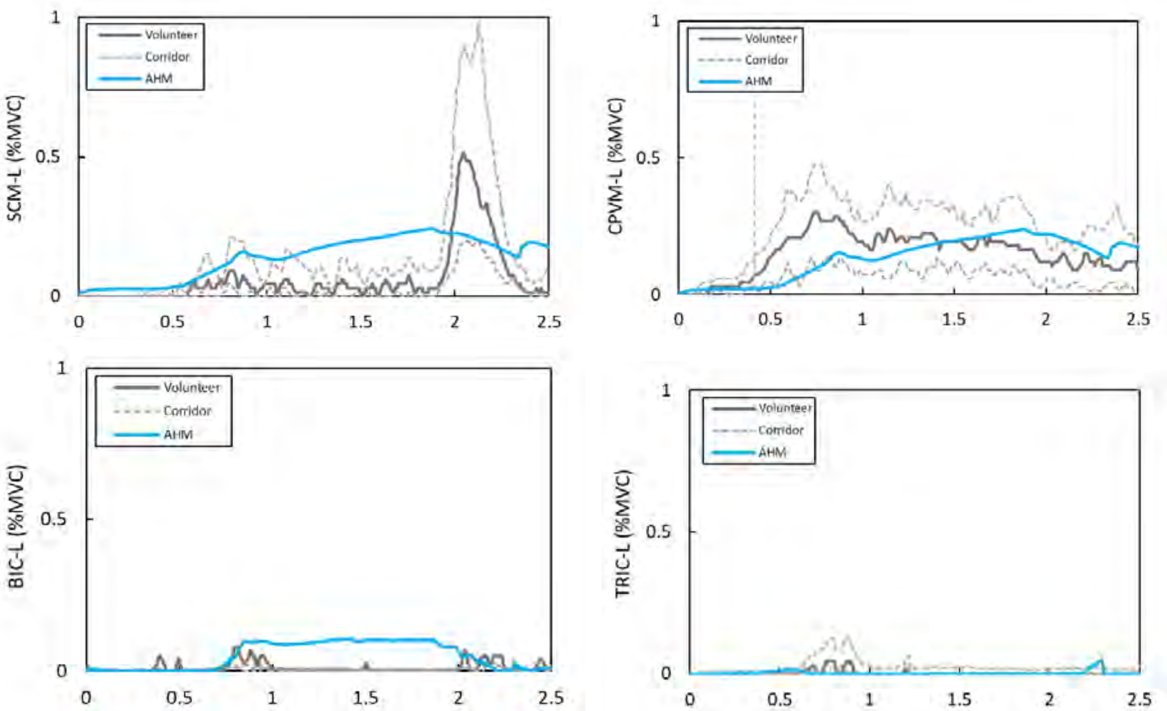


Figure 3. The evaluation of the muscle activation at the neck & arm of the AHM following the paper [11].

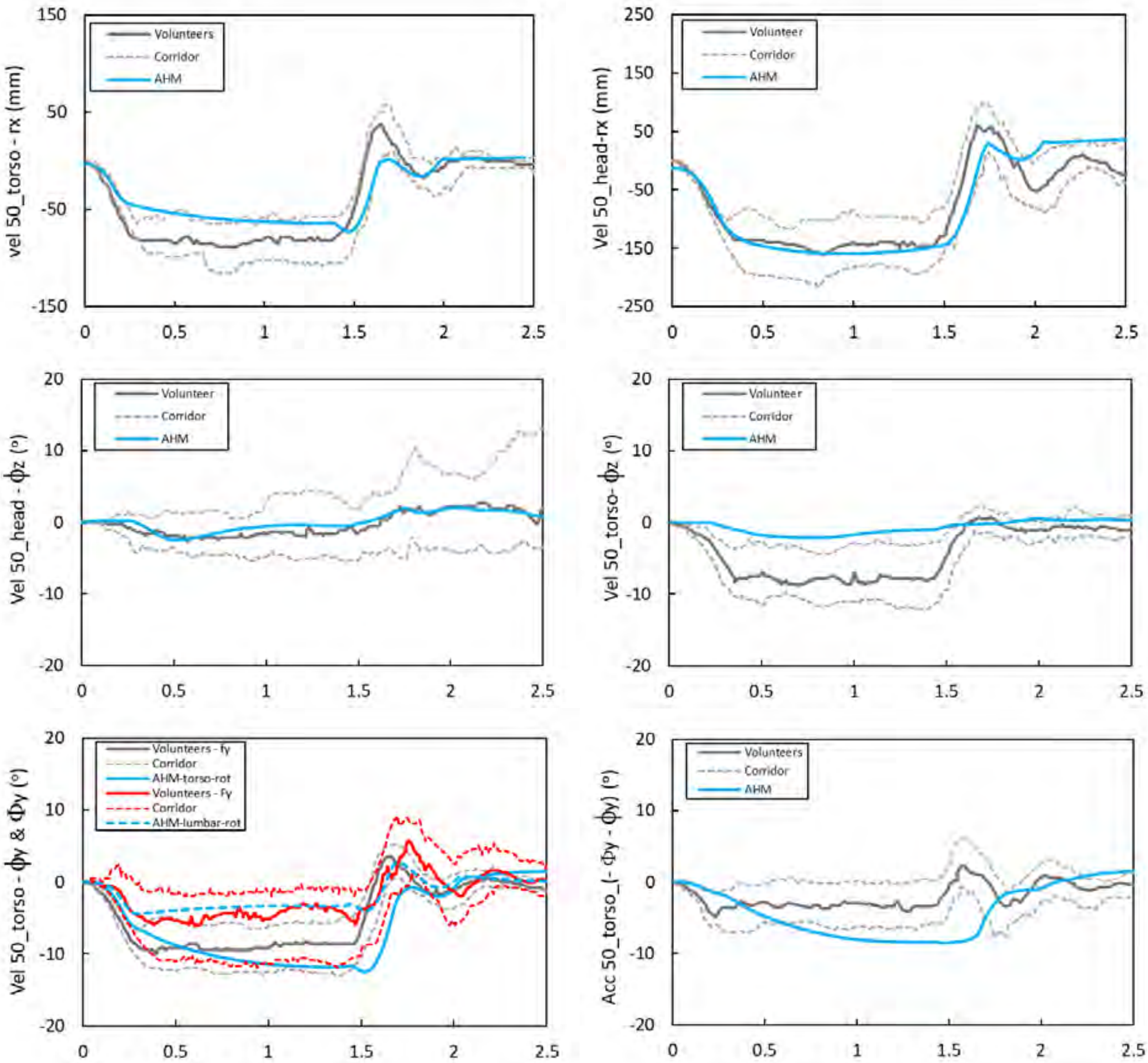
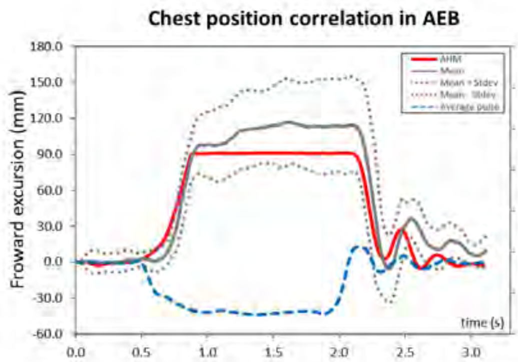
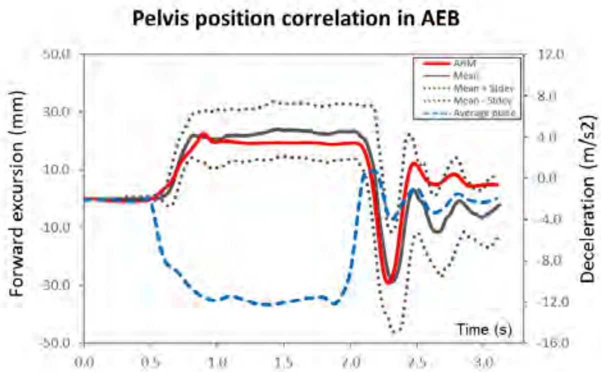
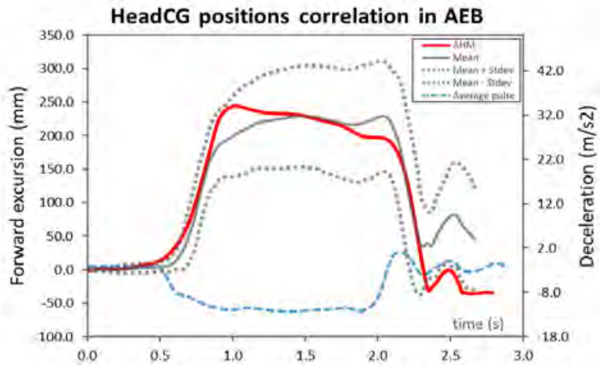
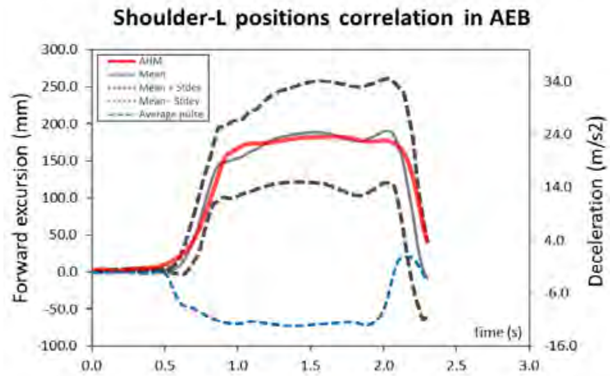


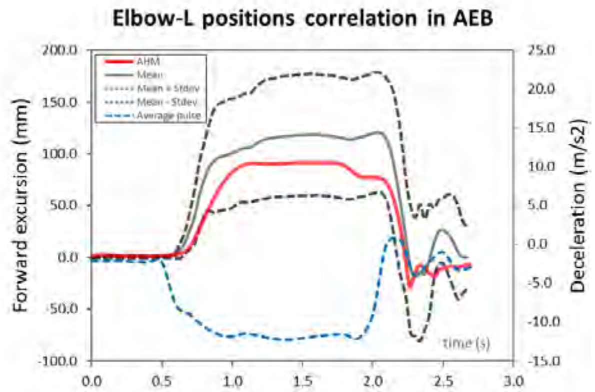
Figure 4. The evaluation of the head & torso kinematics of the AHM in the braking maneuver (initial velocities of 50 km/h) following the paper [12].

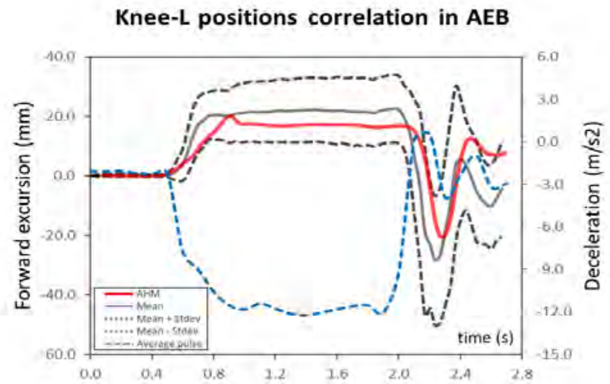












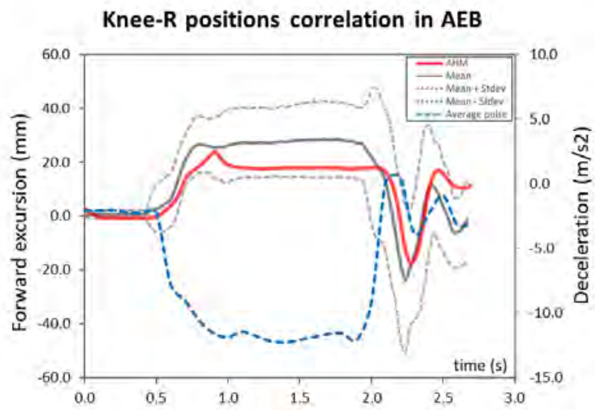


Figure 5. The evaluation of the forward displacement of Head CG, Chest, Pelvis, Shoulder-L, Elbow-L, and Knees of the AHM in a braking maneuver simulation following to the paper [13].

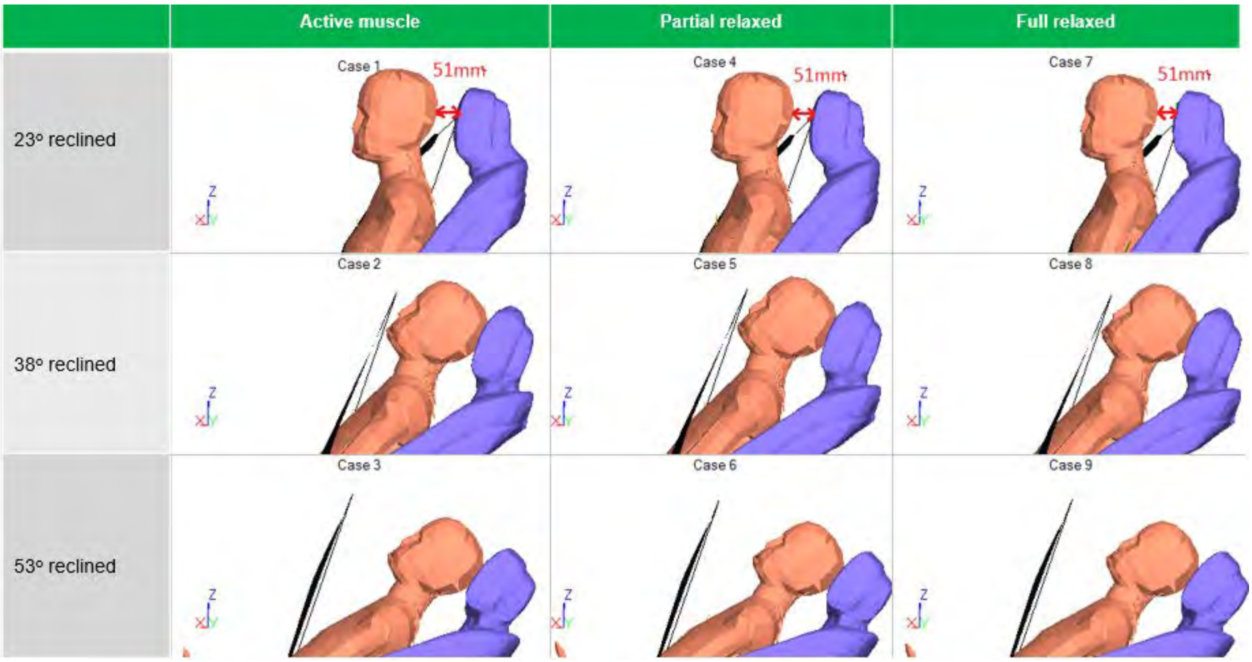


Figure 6: the occupant posture in case of standard D-ring seat belt at 0.5s time-history of the braking maneuver.

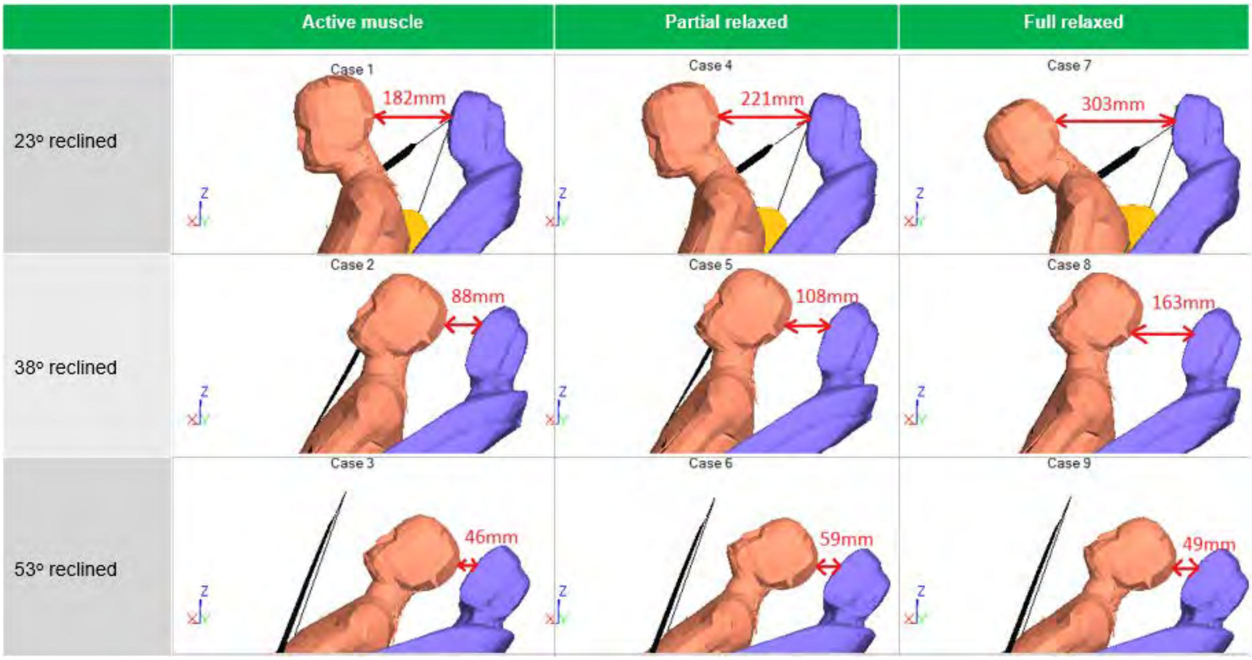


Figure 7: the occupant posture in case of standard D-ring seat belt at 0.8s time-history of the braking maneuver.

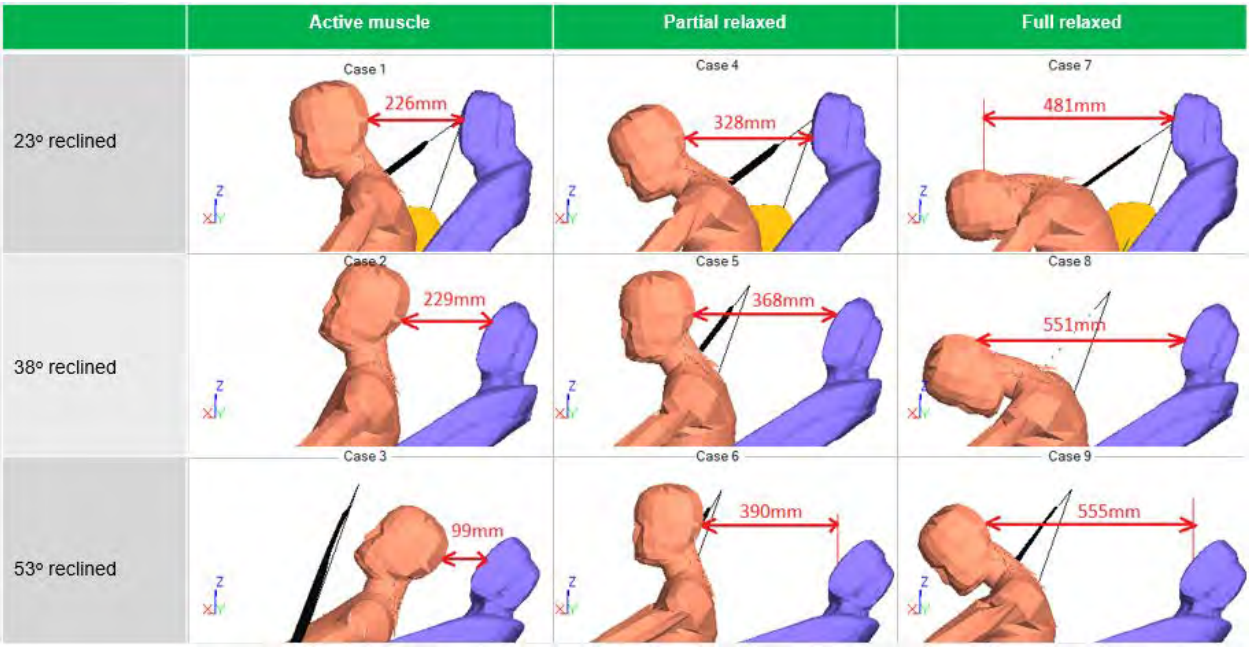


Figure 8: the occupant posture in case of standard D-ring seat belt at 1.5s time-history of the braking maneuver.

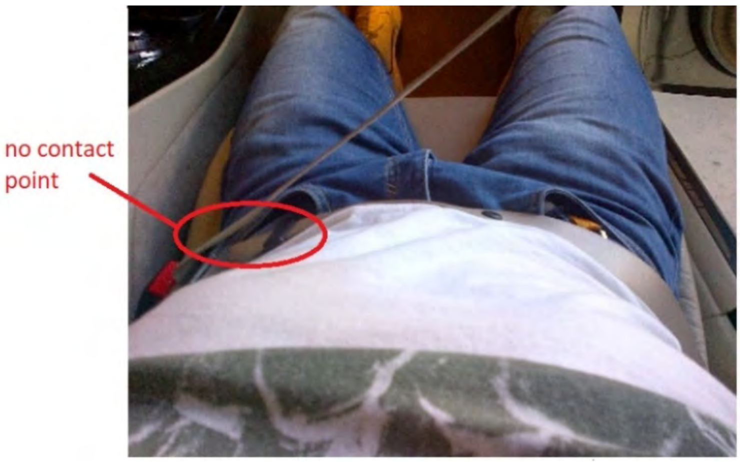


Figure 9: The shoulder seat belt doesn't contact to the body with the fully reclined seatback in BMW 535i Touring (F11).

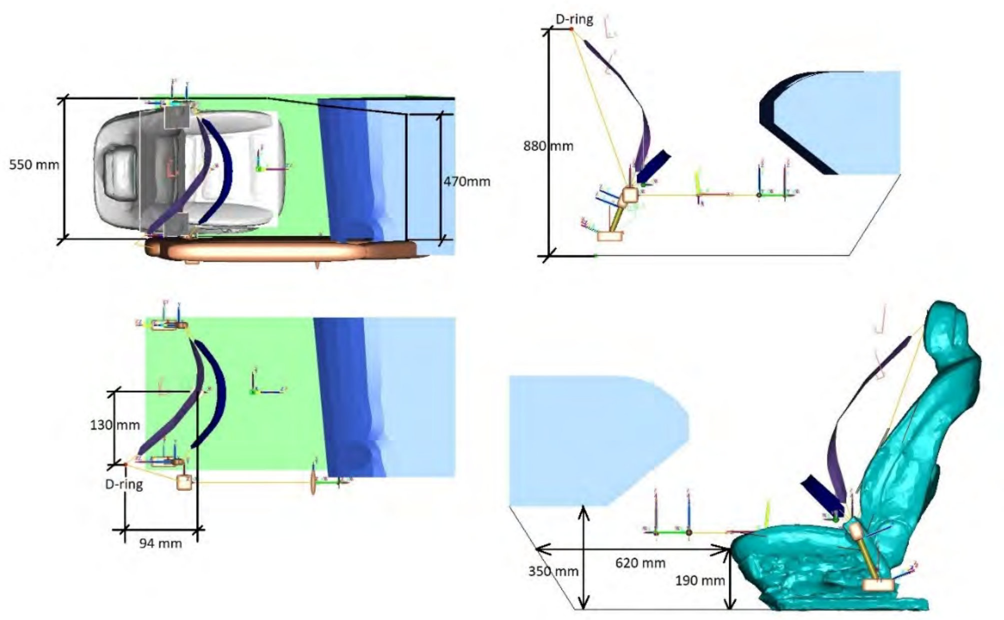


Figure 10: the simplifier vehicle model.

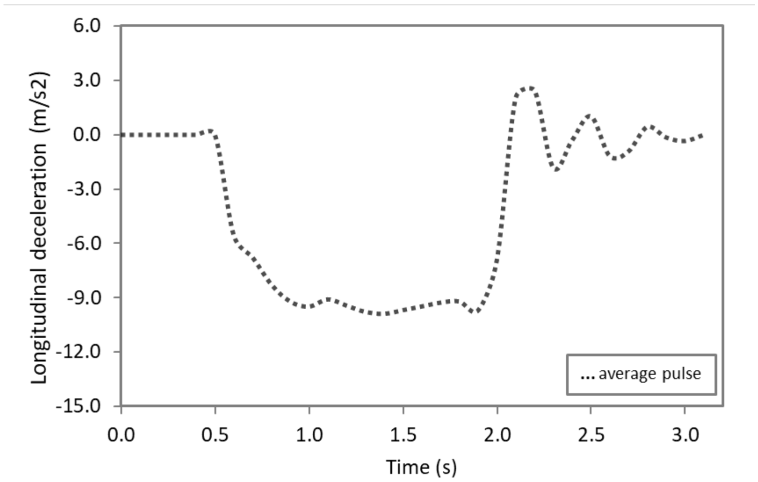


Figure 11: the average pulse of 30 braking maneuvers in [13].