Study of the effect of pre-crash seatbelts in side impact and the necessary work load of pre-crash seatbelts

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Abstract

The National Automotive Sampling System Crashworthiness Database System (NASS-CDS) contains cases of severe injury side-impact collisions despite the normal activation of occupant restraint devices. A likely cause is that an occupant was out of the intended protection area of the side airbag. In this study, MADYMO analysis was conducted to analyze the effects of a side airbag on an occupant in such a posture. Panelist evaluation was also performed to measure the load and time for a pre-crash seat belt to pull an occupant leaning forward back into the side airbag protection area. A THUMS version 5 was used to determine the effects of muscle activity on occupant's pullback time to eliminate individual differences between the panelists. The THUMS was controlled to simulate the behavior of a specific panelist. This study shows that the workload of a pre-crash seat belt is related to the pullback time, inertia and muscle activity required for an occupant to be pulled back to the side airbag protection area.

INTRODUCTION

Many studies have proven the importance of a side airbag in occupant protection [1-4]. NASS-CDS, however, includes torso injuries from intruding interior components on the side despite the fact that the side airbag deployed. One possible cause is that the severity of the collision had exceeded the intended design conditions. Another likely cause is that an occupant was out of the side airbag protection area at the time of a crash and could not enjoy appropriate protection from the device because, for example, he or she was leaning forward to look both ways at an intersection or to avoid danger. This study focuses on a driver who is leaning forward to look both ways for safety in a static vehicle without deceleration G-force, and aims to identify the following.

1) Effects of the protection performance of a side airbag on an occupant outside the protection area in a side impact event.
2) Requirements of a device for pulling a slouching occupant back into the protection area prior to a side impact collision.

METHODS

MADYMO

The MADYMO analysis in this study reveals how the protection performance of a side airbag affects an occupant out of the side airbag protection area in the event of a side impact. The analysis compares the load on the World SID AM50 torso between a normal seating posture and a leaning forward posture (Figure 1) by using the MDB side impact crash pulse shown in Figure 3. The side airbag was four-segmented and deployed in advance. Each segment was provided with airbag characteristics and door collision speed (Figure 2). The deployment behavior of the airbag was not considered.

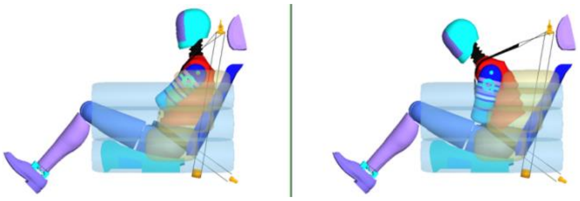


Figure 1.Normal seating posture (left) and forward bent posture (right)

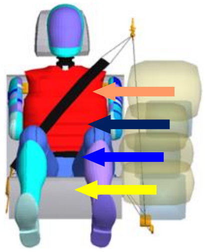


Figure 2. Side airbag model

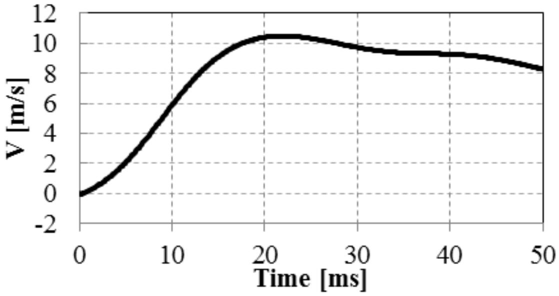
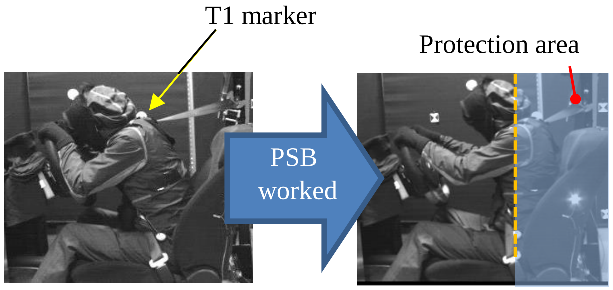


Figure 3. Change in door velocity in side impact

Panelists

A pre-crash seat belt is a device that can pull an occupant leaning forward back into the side airbag protection area. Panelists were evaluated to measure how long it took for a pre-crash seat belt to pull an occupant leaning forward back into the side airbag protection area in a mid-sized sedan mock-up (Figure 4). An optical tracking device was used to measure the behavior of a panelist with a tracking marker on his or her thoracic vertebra T1.The side airbag protection area defined in the evaluation is a zone large enough to hide the torso behind a deployed side airbag. Each panelist was told to lean forward in a seat of a static mock-up to simulate an occupant looking both ways at an intersection with poor visibility. The seating position was optimally adjusted to driving posture for each panelist. The arms were positioned to simulate a driver properly holding the steering wheel. The panelists were not informed in advance of when the pre-crash seat belt would work. After a while, the device was activated. All the panelists, different in body weight, were pulled back into the protection area by the same pullback load. The motion and pullback time of the torso were recorded.



Forward-bent posture Protection area

Figure 4. Panelist evaluation in static vehicle

THUMS

Finite element (FE) human body model

To measure how long it took for a pre-crash seat belt to pull an occupant leaning forward back into the side airbag protection area, the 50th percentile male THUMS version 5 was used. The THUMS version 5 can control muscle activity without individual difference. THUMS version 5 is a finite element human model containing all muscles in the body. It can simulate the posture of an occupant prior to impact and brace itself, enabling us to predict injury to an occupant in the similar posture. The THUMS has modeled muscles in major 262 body regions except for the face. Based on Literature [5], this study inferred muscles required for a pre-crash seat belt to pull the torso leaning forward back. Seven muscles in the neck, the torso or the lower limb, which work for forward or backward bending, were activated (Table1).

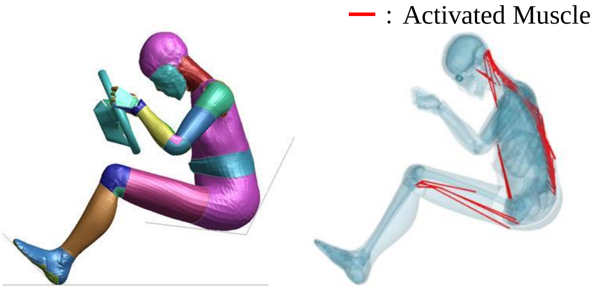


Figure 5. THUMS version.5.

Table 1. Activated muscle part

Body part	Muscle
Neck	Sternocleidomastoid
	Longus capitis
	Splenius capitis
	Semispinalis capitis
Chest & Abdomen	Rectus abdominis
	Erector spinae
Lower limb	Hamstrings

Muscle activity at the time of pre-crash seat belt activation In this study, occupant muscles were moved to change the posture when a pre-crash seat belt worked. A closed loop control system was used to predict occupant motion at the time (Figure 6). The activity data of muscles acting on postural change, obtained from the displacement and velocity of a chest, was fed back at fixed time intervals to simulate the occupant postural change [6]. The proportional-differential controller was used to handle the muscle activity data. Each muscle activity was controlled so that the displacement (proportional-control) and velocity (differential-control) of the THUMS T1 can be the same as those of the chosen panelist T1 respectively. The muscle strength was adjusted by time unit. Through multiple regression analysis, each muscle activity was expressed as a function of the displacement and velocity of the T1, which were incorporated into the closed loop control. From the above, if a load condition for the THUMS is milder than that for the panelist with a pre-crash seat belt, muscle activity is predictable. In other words, this study assumes that occupant's postural change is predictable. The panelist referred to in this analysis is a person of median weight of the population.

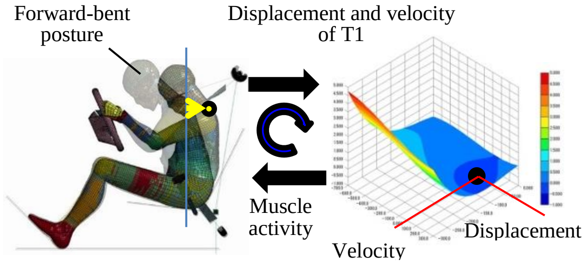


Figure 6. Closed loop control system for muscle activity.

Calculation conditions With various load characteristics, a muscle-active THUMS was analyzed to identify the workload and time required for a pre-crash seat belt to pull an occupant back into the protection area (Cases 1 to 4).The acceleration considered in the analysis is limited to gravity, not deceleration G-force.

A rigid seat was used. The defined protection area stretches to the point 140 mm behind T1 of a slouching torso (Figure 8).Workload was calculated from the product of the retractor load and the seat belt travel distance.

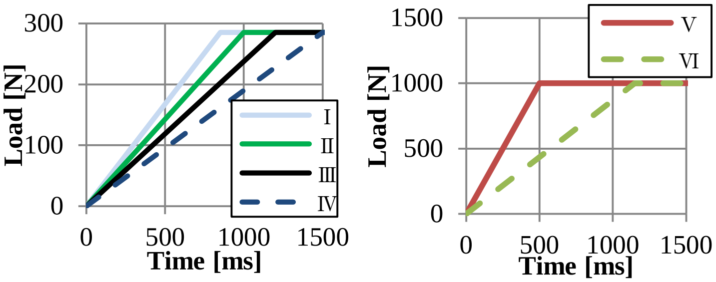


Figure 7. Load characteristics

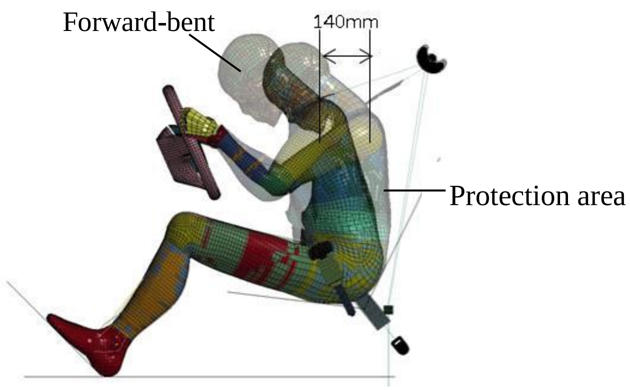


Figure 8. Defined protection area

Then muscle activity and inertia were examined in the following manner because they seemed to affect the workload. To examine the effects of muscle activity on the workload, Case 5, which belongs to the slow pullback side of the panelist results, was analyzed. With Cases 5 and 6 the effects of muscle activity on the workload were analyzed.-A muscle-inactive model was also used to examine the effects of inertia on the workload. Cases 7 and 8 underwent the same load characteristics as in Cases 1 and 4. Cases 9 and 10 simulated the pullback time in Cases 1 and 4.Furthermore, a muscle-active model was compared with a muscle-inactive one to analyze the effects of muscles on occupant behavior. Case 1 is muscle-active. Case 7 is muscle-inactive.

Table 2. Simulation Cases

Case	Load characteristics (Figure 7)	Muscle	Muscle active level
1	I	Active	Median
2	II	Active	Median
3	III	Active	Median
4	IV	Active	Median
5	I	Active	Slow
6	IV	Active	Slow
7	I	Inactive	-
8	IV	Inactive	-
9	V	Inactive	-
10	VI	Inactive	-

RESULTS

MADYMO

The region under the rib area of a slouching occupant outside the airbag protection area was subject to 56 percent higher force. This result proves that pullback by a pre-crash seat belt is effective in relaxing the force (Figure 9).

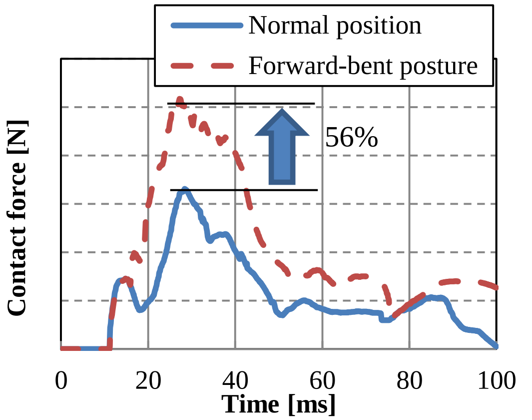


Figure 9. Contact force of rib with interior parts and airbag

PANELIST

The panelist evaluation shows variation in pullback time between individuals despite the same load application (Figure 10). The pullback time varied when the same load was applied to the same person. No positive correlation was found between pullback time and body weight.

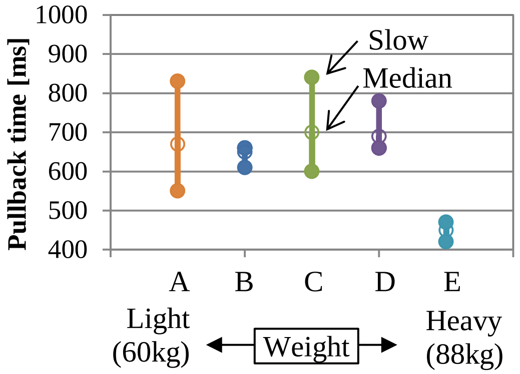


Figure 10. Pullback time under a load of 285 N

THUMS

The THUMS analysis finds the relationships between the workload and time required for pulling an occupant leaning forward back into the protection area. Under the condition that the load increases at a high rate, the pullback time is short but the workload is high (Figure 11). When the load increases at a mild rate, the pullback time is long and the workload is low. In short, high workload is required for short pullback time.

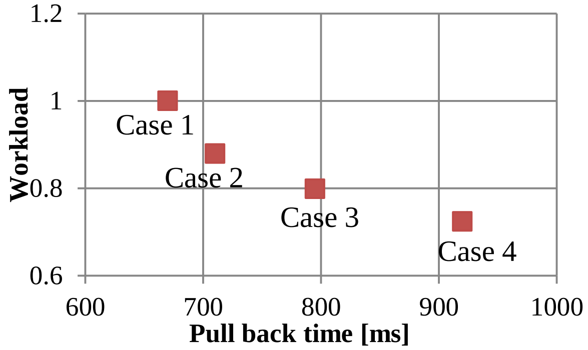


Figure 11. Workload and pullback time under different load characteristics.
(The workload of Case 1 is assumed as a unit of workload.)

Although rigid dummy evaluation yields the same amount of workload for the same displacement, this study produced different workloads. The possible causes are muscle activity and inertia.

Effects of muscle activity Regardless of difference in muscle activity, in both the median pullback time cases (Cases 1 and 4) and the long pullback time cases (Cases 5 and 6), higher workload was required for the shorter pullback case (Figure 12). Under the same load characteristics, the long pullback time cases (Cases 5 and 6) need higher workload. This confirms that occupant's muscle activity affects the workload.

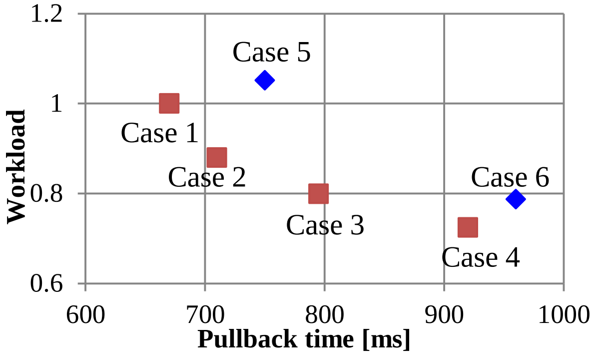


Figure 12. Workload and pullback time under different muscle activity.
(The workload of Case 1 is assumed as a unit of workload.)

Effects of inertia Under the condition that the load increases at a high rate (Case 7), the workload is higher than in Case 8, where the load increases at a mild rate (Figure 13). The similar result is found in Cases 9 and 10, which simulated the behavior of the muscle-active Cases 1 and 4 respectively (Figure 14).

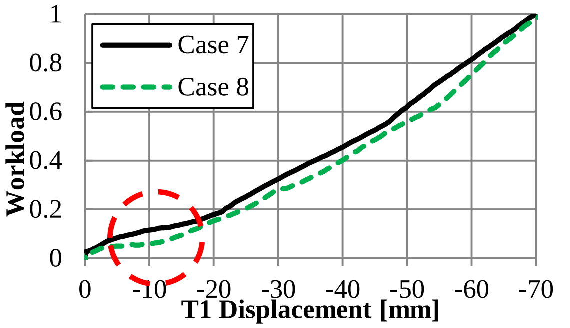


Figure 13. Workload and T1 displacement (The workload for a displacement of 70 mm in Case 7 is assumed as a unit of workload.)

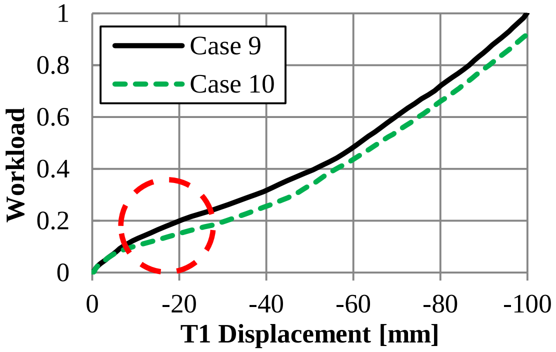


Figure 14. Workload and T1 displacement (The workload for a displacement of 100 mm in Case 9 is assumed as a unit of workload.)

The comparison between a muscle-active model and a muscle-inactive one finds how muscles affect occupant’s behavior (Figure 15). With the same load characteristics, the muscle-active model started to move later than the muscle-inactive one, but reached the protection area earlier.

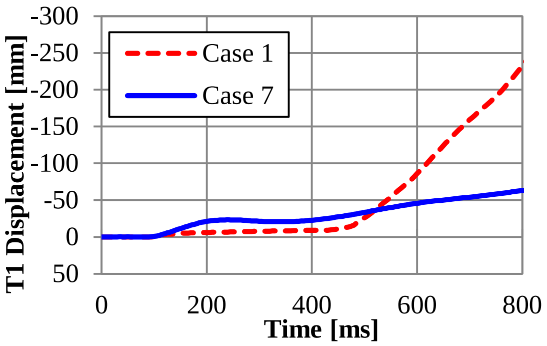


Figure 15. T1 displacement of muscle-active model and muscle-inactive model

DISCUSSION

Effects of difference in load characteristics on muscle activity

Figure 16 illustrates the muscle activity of T1 140 mm behind the forward head posture. The difference in erector spinae activity between Case 5 and Case 6, where the load characteristics are different from each other, was found to be smaller than the variation in the panelist evaluation between Case 1 and Case 5.

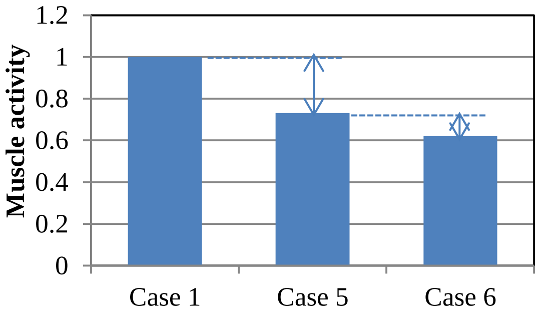


Figure 16. Muscle activity of erector spinae for a T1 displacement of 140mm.
(The muscle activity of Case 1 is assumed as a unit of muscle activity.)

Effects of inertia on workload

Difference in the workload appears when T1 starts to move (Figures 13 and 14) and is affected by inertia, by which T1 continues to stay in that position. Under the condition of a high load increase rate, a large amount of energy is required at the beginning of the movement, compared with the mild load increase condition. High workload is required for short pullback time because the shorter the pullback time is, the more strongly it is affected by inertia.

Comparison of muscle-active model with muscle-inactive model

Figure 15 shows the difference in T1 displacement between the muscle-active model and the muscle-inactive model. Figure 17 illustrates the activities of erector spinae and rectus abdominis of the muscle-active dummy. When an occupant starts to move backward, the rectus abdominis works to slow the movement. This means that the abdominal muscle contributes to slow pullback time. On the other hand, the erector spinae greatly work later and helps to shorten the pullback time.

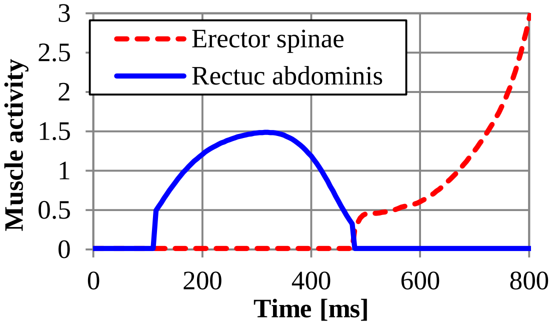


Figure 17. Muscle activity
(The muscle activity for a T1 displacement of 140 mm is assumed as a unit of muscle activity.)

LIMITATION

In the real world, occupant posture may be diverse; drivers hold a steering wheel differently, brace themselves differently, or lean forward at different angles. This study, however, evaluated a model leaning at a specific angle in a static vehicle. Since deceleration caused by pressing the brake may be involved in reality, the stated time and load required for pulling an occupant back into the protection area in this study are not necessarily applicable to any circumstance. This study does not consider whether or not an occupant can detect an approaching collision at the necessary timing to return to the protection area. For the reasons above, various conditions may need to be considered in the future.

CONCLUSION

Through the MADYMO analysis of the effects of restraint performance on a slouching occupant outside the side airbag protection area, and the panelist and THUMS version 5 evaluations of the muscle activity-involved requirements of a pre-crash seat belt for pullback, our findings are as follows.

1) The region under the rib area of a slouching occupant outside the airbag protection area was subject to 56 percent higher force. This means that the pullback into the protection area by a pre-crash seat belt is effective in relaxing the force applied on the chest.

2) High workload is required for pulling a slouching occupant back into the protection area in a short time. Inertia affects the workload. High erector spinae activity can speed backward leaning and decrease workload, resulting in a short pullback time.The variation in muscle activity found in the panelist evaluation is larger than the difference in muscle activity under the conditions of different load characteristics.

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