THE COOPERATIVE CONTROL OF AEB ANS PASSIVE SAFETY SYSTEMS FOR MINIMIZING OCCUPANTS' INJURY IN HIGH VELOCITY REGION.

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ABSTRACT

AEB system is a representative safety system to help avoiding forward collision or mitigate the velocity resulting in reduction of occupant's injury risk. Fatality ratio increases rapidly in in high velocity region, but Euro NCAP, US NCAP and IIHS evaluate AEB system under the relative velocity of 60kph. In the aspect of injury risk, it becomes more important to maximize it's efficiency in higher velocity region and to investigate the effect of active and passive combined safety system because occupant's motion increases as the impact speed is reduced in pre-crash phase. Therefore, the control and design of active and passive safety measures need to minimize the occupants' injury through the cooperative control of AEB's braking profile and PSB (Pre-safe Seat Belt), airbags, motion of seat and steering Wheel.

For this, computer simulation is carried out in pre and post phase of crash. In active safety simulation, vehicle behavior in Pre-crash phase is correlated well between real car and model. The vehicle's behavior according to different braking profile is produced and it is used to reproduce the motion and injury of H-3 dummy and active human body model with the relation to airbag deployment in the passive safety analysis. Also, volunteer test for measuring occupants' behavior in order to validate simulation data and correlate between model and real human with the parameter change of PSB activation and AEB braking profiles.

From this study, it is found out that PSB activation time and load don't have much effect on injury, while braking profile is effective. In case of 40kph unbelted test mode, bottom-out between head and windshield, chest and crash-pad occur due to pre-crash motion and OOP situation. The airbag TTF also plays important role to reduce injury risk. The control of steering wheel and passenger seat gave little effect on injuries. From the volunteer tests, the occupant's motion was measured by video analysis and IMU sensor to verify simulation data.

The cooperative control of active and passive integrated safety system will be helpful to deduce occupants' injury in high velocity region when braking profile is controlled well by the communication with passive safety systems.

INTRODUCTION

AEB(Autonomous Emergency Braking) is a active safety system that can make a vehicle to avoid collision or mitigate the damage by urgently reducing velocity with the informations obtained using ADAS(Advanced Driver Assist System) sensors such as camera or radar. Camera and radar fusion as shown in Figure 1 is typically applied to AEB system due to the system's reliablity in recognition performance and as the performance of sensors are improved, some manufacturers are adopting single sensor AEB system for general use. Also, in US and Eropean market, OEMs are induced to make the system as standard safety measures by signing MOU with NHTSA and running dual rating with fitment rate policy in Euro NCAP test, respectively.
From the Thatcham's research report [2] in Figure 2 , if the system is applied to the market satisfying the fitmet rate Euro NCAP suggets, it is predicted that the fatalities will be decreased by the 50% of current number in 2025. Due to this benefit of the system, Euro NCAP is adding AEB VRU-P (AEB Vulnerable Road Users Pedestrian) night test and VRU-C (Cyclist) test to current assesment program in 2018 and IIHS already evaluate the system for TSP+ requirement in their test protocol.NHTSA is preparing for CIB/DBS tests in US NCAp test. AEB system become a most important active safety sytem such as airbag became a essential passive one now after it was firstly adopted and then have made a great contribution to reducing fatalities.

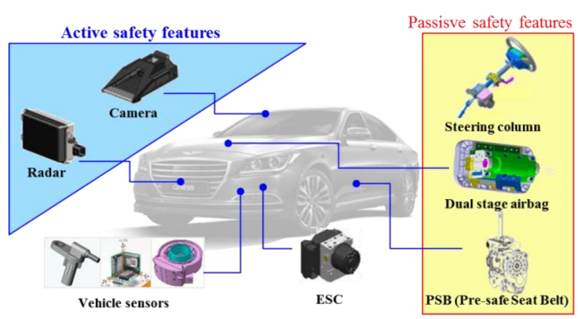


Figure 1. Active and passive safety system configuration.

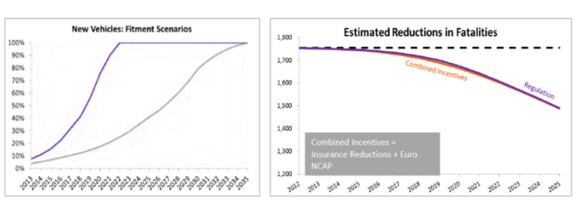


Figure 2. Expected reduction of fatalities with the fitment of Euro NCAP AEB.

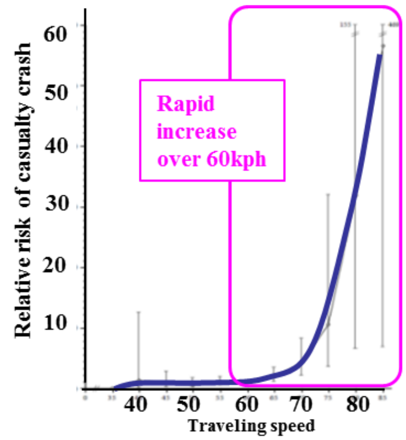


Figure 3. Traveling speed and the risk of involvement in a casualty crash.

Now, Euro NCAP AEB test aims that collision is avoided under the relative velocity of 60kph, and IIHS performs their AEB test by 40kph. But it is more important to maximize it's efficiency in high velocity region in order to save more lives and reduce occupants' severe injury, because the relative risk increases rapidly in high velocity region as shown in Figure 3 which represent that in a certain area with the limit speed the probability of casual creah steeply increase over 60kph resulting in twice the risk per 5kph [2]. In order to do this, we can advance the braking time using more acurate and number of sensors like corner radars. But in this case, the forward motion of occupants increase which can causes OOP (Out of Position) before crash and airbag deployment resulting in addition occupants' injuries as shown in Figure 4. And also the vehicle behabior like pitching and deeping from AEB activation can intensify the head and neck injuries. And also the increase of head and neck injuries should be seiously considered when conventional driver or passenger airbags are deployed just after system activation in high velocity crash from the occupant's forward movement is produced by AEB viewpoint of passive and active safety system integration.

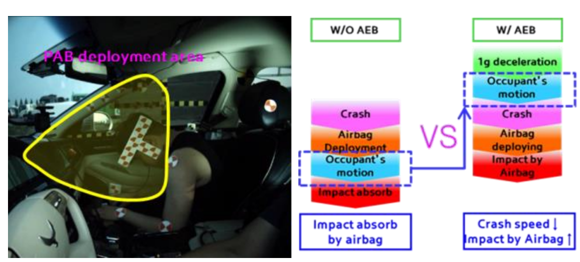


Figure 4. Occupant's behavior and the mechanism in pre-crash phase.

The main purpose of this paper is to find the methodology of cooperative control between AEB and passive safety systems considering braking profile, PSB (activation time, tension of belt webbing, unbelted condition), airbag shape and control, reward motion of seat and forward motion of steering wheel to minimize the occupants' severe injury in the high velocity crash when the collision is unavoidble. For this, we implemented computer simulations to get the vehicle's and occupants' behavior from AEB activation to just before crash in pre-crash phase and performed injury analysis in post-crash phase using Per-Scan, CarSim and MADYMO software. To correlate the the simulation data and verify the occupant's motion, volunteer test were carried out. From this study, we found out that which factors gave main effect on reducing occupants' injury and approach to analysis of more various kind of occupants' seating situations.

COOPERATIVE CONTROL OF ACTIVE AND PASSIVE SAFETY SYSTEM BY COMPUTER SIMULATION

The study of active and passive safety system with real crash test does not have too much of reliable accuracy because there are big difference of biofidelity between real human and crash human dummy like Hybrid-3 or THOR. So, as stated before, Pre-Scan, CarSim and MADYMO are used in pre-crash phase and in post-crash phase, respectively. Especially in MADYMO model, both of Hybrid-3 and active human dummy are compared in every test cases.

Model Preparation

Simulation model in active safety part A PreScan-CarSim coupled model was developed for integrated safety system investigation. The vehicle model of HMC Genesis G80 is built to simulate in all of the scenarios.

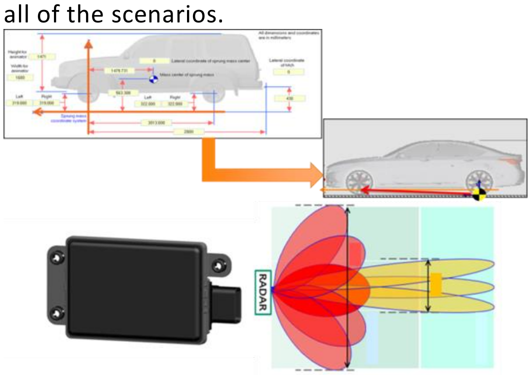


Figure 5. Vehicle model and sensor modeling

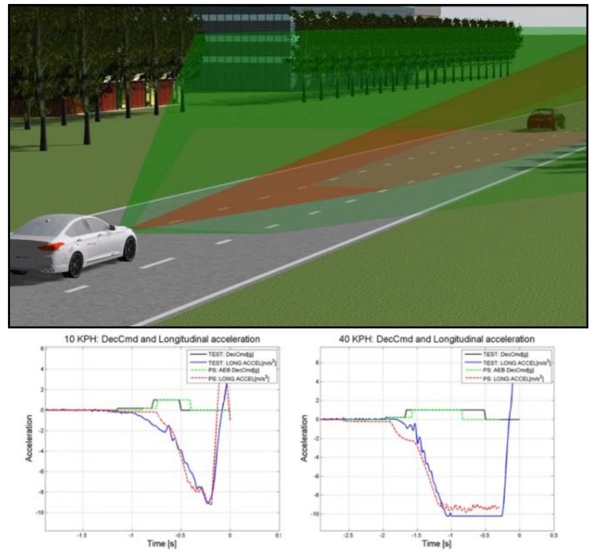


Figure 6. Validation of vehicle model's behavior

The vehicle geometry and sensor model were imported into PreScan (See Figure 5) and CarSim model was coupled with PreScan and verified by comparing with CarSim standalone. The ESC controller for longitudinal braking was implemented to reproduce the braking characteristic of G80 vehicle and the implemented ESC controller were verified by comparing the real vehicle test data within the speed range from 8 to 100kph with and without AEB braking input as shown in Figure 6. The AEB and PSB controller were coupled with PreScan and tested with two reference AEB loading conditions. Model showed acceptable to good correlation results so that it can generate the vehicle motion data for MADYMO occupant simulations.

Simulation model in passive safety part MADYMO models are set up to be used in the various load cases including Hybrid-3 (5 & 50%) and active human dummy model, driver and passenger airbags, pre-safe seat belt and vehicle (IP, steering wheel, seat, etc.) They are correlated with the crash test data of 40km/h unbelted and 56km/h belted USNCAP barrier test. Crash pulses are generated using FD-Curve method and pulse scaling, which is extrapolated to higher crash speed for the pulse prediction using a 56 km/h full width frontal FE simulation pulse as a reference pulse. The amount of vehicle pitching as function of the impact speed is also feed into the model. To decide air bag TTF, we follow 5'-30ms rule and modified them to correlate with test data, which matches with test data well (See Figure 7).

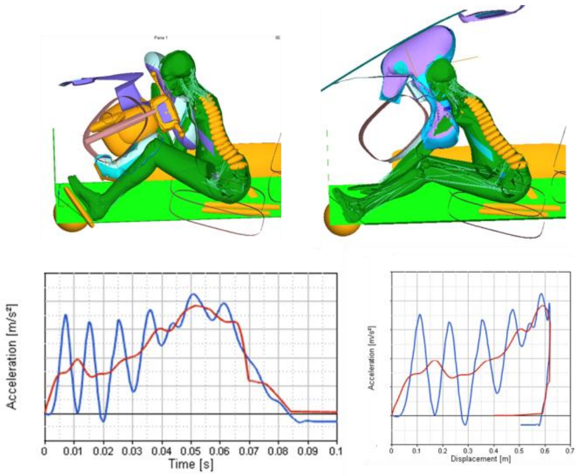


Figure 7. MADYMO Model and pulse generation

Effectiveness Analysis with Cooperative Control

Head motion and injuries according to braking profile and PSB effect In this simulation case, AEB braking type and PSB TTF are investigated. The step and ramp type of braking profiles are exerted and various PSB activation times before full braking by -0s, -0.2s, -0.4s, -0.6s are considered to reduce occupant's motion.
As a result, the braking profile doesn't give much effect on head motion due to seatbelt's restraint, whereas the change of AEB type has biggest effect on HIC 15. But the decrease of HIC15 is due to the reduction of collision velocity by ramp input.
When varying the PSB activation time before full braking, the earlier the PSB is triggered the less forward motion of the head occurs but gives not much effect on head and neck injury as shown in Figure 8.

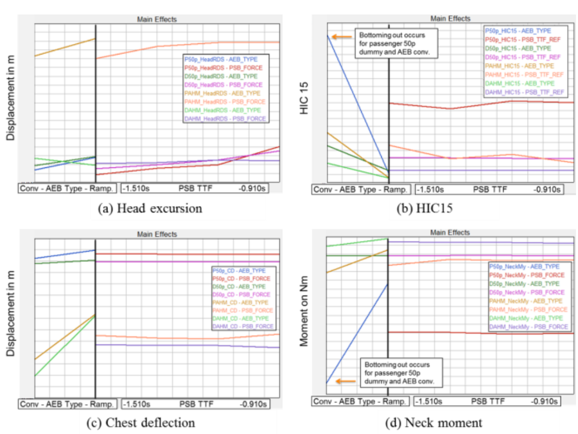


Figure 8. Head motion and injuries according to braking profile and PSB TTF and load).

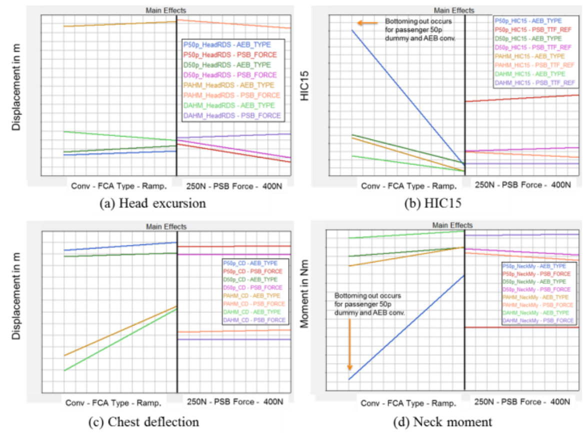


Figure 9. Head motion and injuries according to belt tension of PSB.

Addition of the PSB reduces the pre-crash forward motion of the occupant head around 40-56mm, when occupant is not fixing hands to steering wheel (AHM Driver). For two kinds of PSB belt tension of 250N and 400N, there were also not much difference in injury values as shown in Figure 9.
The trends of Driver AHM is different to the trends of H-3 dummy and passenger side which is an effect of the fixation of the hands to the steering wheel.

Head motion and injuries according to airbag control and design parameters In this section, the effectiveness of AEB braking type, DAB/PAB TTF, vent hole size and active vent on/off are investigated with the test matrix of 40km/h unbelted and 56km/h belted, 5% and 50% dummies. The impact speeds were same whether AEB is activated or not by changing initial velocity of vehicle.
Due to AEB, the driver moves in a OOP position during airbag deployment resulting in bottom-out

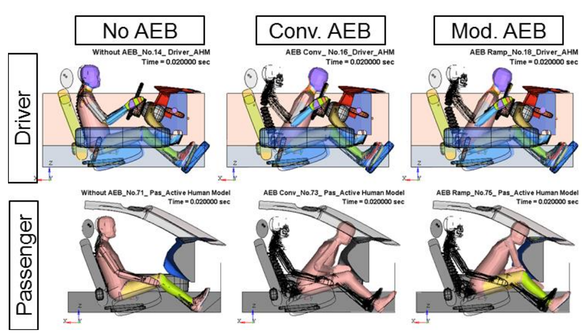


Figure 10. OOP motion in Driver/Passenger-side of 40kph unbelted case for 50% AHM (T=0ms).

between head and windshield, chest and crash-pad (See Figure 10). Simulations with occupant in OOP position can cause bad airbag deployment in some situations especially for 5% occupant.
In the belted USNCAP test mode by 56km/h, AEB improves the injury values in many cases even though it causes the increase of head premotion before collision rather than we expeted. The more forward motion due to emergency braking produces the earlier restraint of head by airbag. Also, the earlier coupling of belt forces results in higher pretensioner forces and earlier restraint by belt on the shoulder. In conclusion, the earlier restraint of belt and airbag has positive effects on the peak chest deflections and peak head acceleration as shown in Figure 11. But this can be changed by different design factors of seatbelt and airbag.
The earlier airbag TTF and active vent hole are helpful for USNCAP score. In this study, there is assumption that airbag TTF can be advanced with the decision of airbag deployment when detecting obstacles and making it sure the vehicle will collide with it using ADAS sensors. When the vent hole size and the size of passenger airbag from the side view become bigger, the injury risk increases. The neck injury shows different tendency between Hybrid-3 dummy and active human model.

Unbelted occupant's motion and injury risk according to braking profiles in OOP situation
The occupant's motion and injury risk with the same impact speed of 40km/h in unbelted test are investigated. The initial vehicle velocity varies according to deceleration command from 0.32g to 1.1g by changing braking profiles with both step and ramp type.
The head pre-crash motion of the occupant is limited up to 0.48g.

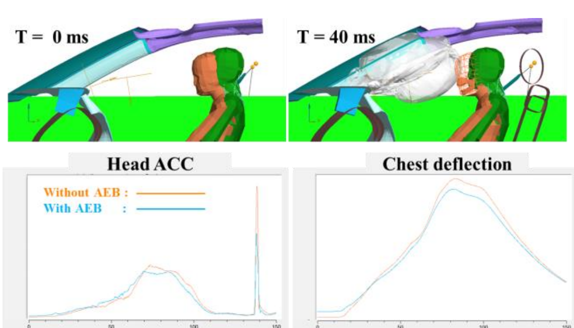


Figure 11. Positive effect of AEB and airbag coupling on occupant injury risk.

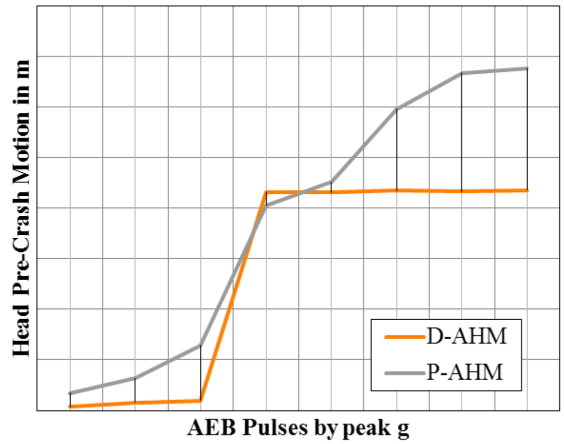


Figure 12. The head pre-crash motion by peak g.

Considering only the simulations with limited pre-crash motion, increased forward motion is improving or hardly changing the USNCAP score.

Belted occupant's motion and injury risk according to Steering wheel and seat pre-crash motion The reward motion of seat and forward motion of steering wheel are applied before full braking time by two levels in order to analyze the compensation effect of head motion when AEB is activated.
The motion of steering wheel and seat are not improving the overall injury values. The driver head is moving more while the hands are connected to the steering wheel and the head is pulled forward with the hands. The passenger shows no effect of the seat motion on the head pre-crash motion (See Figure 13).

VOLUNTEER TEST IN PRE-CRASH PHASE

The volunteer test of active and passive integrated safety system is carried out to verify the simulation results and to obtain the occupant and vehicle data which will be used for correlation between simulation and real test.

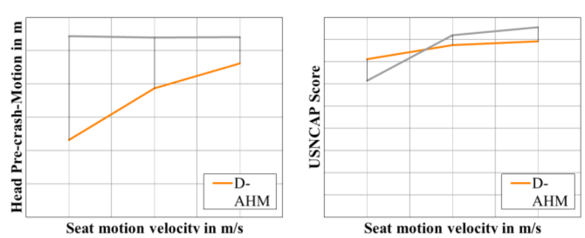


Figure 13. The head pre-crash motion and USNCAP score by seat and steering wheel.

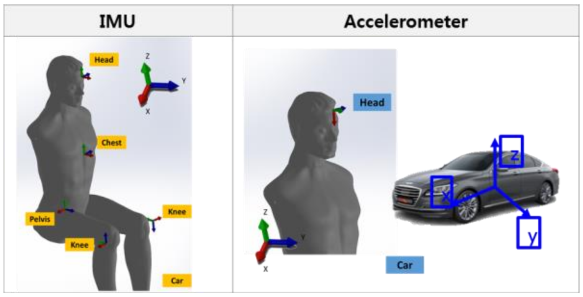
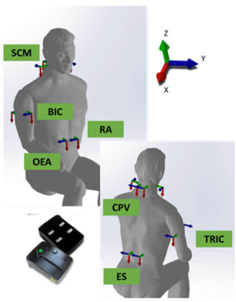


Figure 14. IMU, Accelerometer on body and car.



Muscle		Acronym
Sternocleidomastoideus		SCM
Cervical Paravertebral		CPV
Abdomen	Obliquus Externus Abdominis	OEA
	Rectus Abdominis	RA
Erector Spine		ES
Biceps brachii		BIC
Triceps Brachii		TRIC

Figure 15. EMG sensor position on body.

Configureation of Volunteer Test
We conducted volunteer test to acquire the occupant's behavior for general people who didn't have AEB activation experience before. High speed camera is equipped onboard and recorded passenger for the analysis of occupant motion by TEMA software which handles video processing. Markers for TEMA analysis, IMU and EMG sensors are attached on the volunteer's body as shown in Figure 14, 15, 16.

Test Results ans the Analysis

Max head excursion when PSB is on/off To verify the effect of PSB on occupant's head motion, random activations are applied for 1 volunteer. In this test scenario, max head excursion was 230mm when PSB is off and the average difference was 80mm according to on/off condition.

Figure 16. Markers for video analysis.

Table 1.
Max head excursion when PSB is on/off

	PSB on	PSB off	Difference
Max. Head excursion	150mm	230mm	80mm

Table 2.
Head excursion at crash

	AHM model	Volunteer	Difference
Head excursion at crash	100mm	155mm	55mm

The difference between simulation model and volunteer test result was 55mm, but this results in not too much of head injury in the CA model in belted test mode.

Volunteer test result according to AEB braking profile 12 volunteers participate in this test and three times of same condition were given for each occupant. 4 kinds of braking profiles with the different level by 0.35g, 0.6g, 1g of step type and 1g of Ramp type were applied. In some soft braking cases, the results were different than we expected.

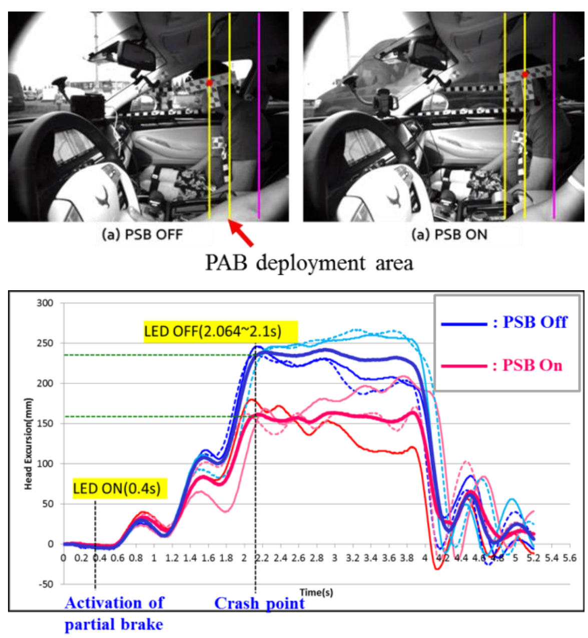


Figure 17. Occupant's behavior comparison.

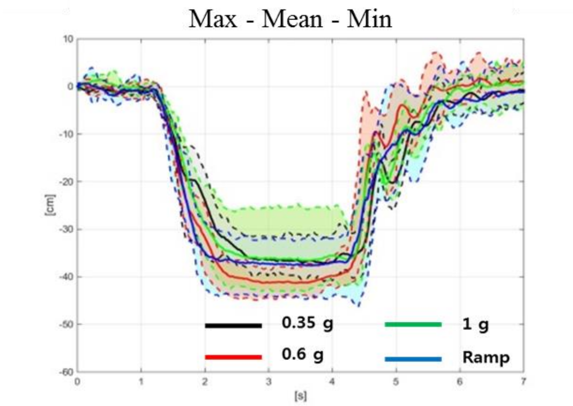


Figure 18. Corridor analysis of head motion.

With the low level of braking profile, the head motion was increased because seatbelt was locked in later time in comparison to high g control. The corridor analysis using the specific position of body and joint angle data obtained by IMU sensor is not effective and has comparatively small behavioral values (See Figure 18).

***Muscle activity* result according to AEB braking profile** In the viewpoint of injury caused by the coupling between muscle's fatigue and AEB braking, there's little probability of serious injury risk from the EMG data. The muscle activity with ramp type braking profile shows the most small level in comparison to with step type one as we can see in Figure 19. From this result, it can be inferred that the former one is beneficial for making comfortable feeling when AEB is activated.

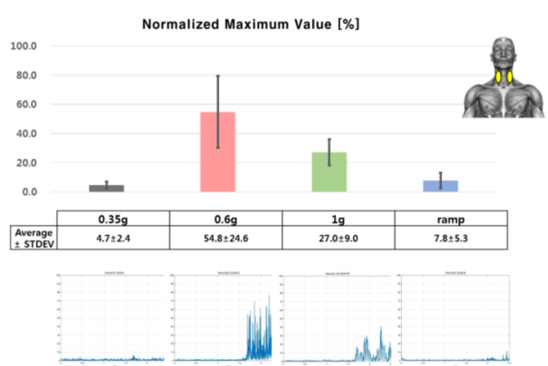


Figure 19. Muscle activity in the area of neck according to braking profiles.

CONCLUSIONS

AEB system is no longer a standalone safety system. It is to be integrated not only with autonomous vehicle but also passive safety system. AEB become an essential ADAS for both convenience and safety, so that the cooperative control between more advanced technology and conventional safety system can make it possible to cover wider range of crash speed for reducing occupants' injury risk. In the viewpoint of the latter connection, the effectiveness of AEB and restraint coupled safety system is investigated.

In this paper, there are major control factors that can reduce occupant's injury, which are braking profile, airbag TTF and its inner pressure. Neck injury is mostly affected by AEB. Especially, when occupant doesn't fasten the seatbelt, bottoming out between occupant and interior part occur due to OOP by AEB activation. This kind of severe accident case is directly related with autonomous vehicle. The AEB and restraint system control strategy to cope with OOP situation would be the next issue.

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