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Enhancing Occupant Safety by Pre-active Seat Control for Out-of-seat Position before Autonomous Emergency Braking Operation

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ABSTRACT

The pre-active safety seat (PSS) is a recently developed active safety system for securing occupant safety in out-of-seat position (OOSP), which was applied in the Hyundai Genesis G80 in 2020. However, there has not been sufficient quantifiable verification supporting the effectiveness of the PSS. The present study was performed to determine the effectiveness of the PSS for occupant safety in OOSP and to identify areas for additional improvement. Six test conditions were considered to determine the effectiveness of the PSS for augmentation of occupant safety in OOSP. Ten healthy men participated in the tests. Compared with the no PSS condition, maximum head excursion and neck rotation were significantly decreased in the PSS condition by 0.31–0.79-fold and 0.33–0.48-fold, respectively ($p < 0.05$). The PSS condition in which the seat pan was moved forward to the mid position showed a greater effect in reducing the characteristic motions related to submarining, compared with the condition in which the seat pan was moved rearward to the mid position ($p < 0.05$). These results suggested that PSS augments occupant safety in OOSP. This study provides valuable insights in ameliorating risks to the occupant in unintended seat positions before braking and/or collision.

Introduction

Advanced driver assistance systems are technologies to improve vehicle safety. Autonomous emergency braking (AEB) is an active advanced driver assistance system that has been successfully implemented to improve vehicle safety since the 2000s.[1] Since its commercial development, AEB has been continuously tested and verified by the European New Car Assessment Program and National Highway Traffic Safety Administration;[2,3,3–5] it has been shown to prevent fatalities and serious injuries in collisions.[6,7] Furthermore, the National Highway Traffic Safety Administration and Insurance Institute for Highway Safety announced that all vehicles produced by the 20 major automotive manufacturers must be equipped with AEB by September 1, 2022.[8]

The protective capability of restraint systems is greatest when the occupants and their surroundings are in the normal seated position (NSP) at the start of the impact. However, real-world accident field data show that in many instances, especially when severe injury occurs, both seats and occupants are not in the designed position at the time of impact. This is presumably because the occupant selects a comfort-emphasizing seating position. Most previous studies of AEB set the occupant's posture as the NSP. Although the NSP is the standard seating condition in crash tests, this condition has limitations for understanding the effects on the occupant in an out-of-seat position (OOSP).[9–12] AEB has been reported to reduce the rates of front-impact collisions by 27%, rear-end collisions by 27–50%, and injuries from rear-end collisions by 35–56%.[13,14] Therefore, although AEB effectively reduces collisions, the possibility of collisions remains above 50%.

To ensure occupant safety in OOSP, previous studies outlined the requirements for active safety systems that change the seat configuration before the event of a forward/rear collision or sudden braking/turning.[12,15–20] In 1996, Saab, Mercedes Benz, BMW, Toyota, and Volvo introduced passive safety seat mechanisms with proactive head restraints and reactive seats.[15] Daimler Chrysler, BMW, Toyota, and Transport Research Laboratory reported the concept of adjusted seat position, which shifts the seat position from forward to the rear before impact.[16,18–20] Transport Research Laboratory performed several sled tests and reported supplementary effects on occupant safety related to the reduction of neck rotation, chest excursion, and/or pelvic excursion when the seat was moved forward from the rear. The Transport Research Laboratory sled test results demonstrated augmentation of occupant safety with a front adjusting seat pan, but these tests were only performed using 5th and

50th percentile male anthropomorphic test devices; they did not consider OOSP or quantify seat control strategies. Furthermore, Daimler Chrysler, BMW, and Toyota presented only conceptual reports without showing an actual device. In 2020, Hyundai Motor Company acquired a patent for a pre-active adjustment safety control system; it applied the pre-active safety seat (PSS) in the Genesis G80.[21] The main function of the PSS is to adjust the position of the seat pan and the angle of the seat back when the possibility of a collision exceeds the expected value, placing the seat in a predetermined state when the seat position or angle of the seat back is not in the intended position. Theoretically, the PSS is an ideal safety assistance system for occupants in an OOSP. However, because of its relative novelty, there has not been sufficient quantifiable verification supporting the effectiveness of this system.

This study was performed to determine the effectiveness of the PSS for occupant safety in OOSP and to identify possible improvements. To improve PSS, tests were performed to confirm the effects of moving the seat pan forward or rearward to the rear during seat back straightening before AEB operation.

Results

Characteristics of motion responses during PSS operation

Figures 1 and 2 show the time-dependent excursions of the head, torso, pelvis, as well as rotations of the head, torso, and neck in the sagittal (x-z) plane, for each test condition. There were no significant differences in excursions or rotations between PSS_Off15 and PSS_Off27 ($p > 0.05$). These conditions had the largest standard errors among test conditions. PSS_Off15 and PSS_Off27 had maximum head excursions of 270.2 ± 70.8 mm and 210 ± 67.7 mm, respectively; maximum torso excursions of 31.5 ± 15.4 mm and 43.0 ± 13.4 mm, respectively; maximum pelvic excursions of 17.1 ± 6.0 mm and 25.5 ± 10.0 mm, respectively; and maximum neck rotations of 37.9° ± 7.4° and 38.5° ± 9.0°, respectively.

The maximum head excursion and neck rotation in PSS_On15R and PSS_On27R were significantly decreased, compared with those values in PSS_Off. The occupant motion characteristics in PSS_On15R and PSS_On27R were generally uniform and showed small standard error compared with those values in PSS_Off. The maximum head excursions in PSS_On15R and PSS_On27R were 55.4 ± 11.7 mm and 70.1 ± 9.4 mm, respectively; these were 216 ± 14.5 mm and 147 ± 13.5 mm less than in PSS_Off15 and PSS_Off27, respectively ($p < 0.05$). The maximum neck rotations in PSS_On15R and PSS_On27R were 20.9° ± 1.7° and 20.3° ± 0.2°, respectively; these were 15.2° ± 0.1° and 19.3° ± 0.1° less than in PSS_Off15 and PSS_Off27, respectively ($p < 0.05$). However, the torso and pelvis excursions significantly varied only in PSS_On27R ($p < 0.05$). The maximum torso excursion in PSS_On27R was 20.0 ± 3.6 mm, which was 21.5 ± 2.7 mm less than in PSS_Off27 ($p < 0.05$). The maximum pelvic excursion in PSS_On27R was 11.9 ± 5.9 mm, which was 12.8 ± 3 mm less than in PSS_Off27 ($p < 0.05$).

The maximum head excursions in PSS_On15F and PSS_On27F were significantly decreased, compared with those values in PSS_Off. The occupant motion characteristics in PSS_On15F and PSS_On27F were generally uniform and showed small standard error, compared with PSS_Off. The maximum head excursions in PSS_On15F and PSS_On27F were 65.2 ± 24.5 mm and 126.5 ± 37.0 mm, respectively; these were 216 ± 14.2 mm and 63 ± 13.5 mm less than in PSS_Off15 and PSS_Off27, respectively ($p < 0.05$). The pelvic excursion in PSS_On27F and neck rotation in PSS_On15F significantly varied ($p < 0.05$). The maximum pelvic excursion in PSS_On27F was 13.4 ± 0.9 mm, which was 12.8 ± 2 mm less than in PSS_Off27 ($p < 0.05$). The maximum neck rotation in PSS_On15F was 25.4° ± 3.6°, which was 11.4° ± 0.7° less than in PSS_Off15 ($p < 0.05$). In addition, the maximum head excursion in PSS_On27F was 0.6 ± 0.3-fold greater than in PSS_On27R ($p < 0.05$). The maximum neck rotations in PSS_On15F and PSS_On27F were 0.2 ± 0.1-fold and 0.7 ± 0.1-fold greater than in PSS_On15R and PSS_On27R, respectively ($p < 0.05$).

Characteristics of shoulder and belt tension during PSS operation

Figure 3 shows the time-dependent tensioning forces in the shoulder and lap belts for each test condition. The maximum shoulder belt tensions increased after 1200 ms, but there were no significant differences across all test conditions ($p > 0.05$). The activation of shoulder and lap belts generally occurred between 1200 and 1500 ms. However, in PSS_On15F and PSS_On27F, the lap belt activities occurred at approximately 600 ms when PSS was operating; the maximum shoulder belt tensions were lower than for the other conditions.

Characteristics of muscle activity during PSS operation

Figure 4 shows the maximum activities of the major muscles for each test condition. The maximum muscle activities showed significant differences in only three muscles: left sternocleidomastoid (SCM) muscle, right splenius muscle, and right longissimus muscle ($p < 0.05$). Maximum left SCM muscle activity in PSS_Off27 was 20.4% ± 4.7% maximal voluntary contraction (MVC); maximum left SCM muscle activity in PSS_On27R was 47.8% ± 6.1%MVC, which was 1.3 ± 0.2-fold greater than in PSS_Off27 ($p < 0.05$). Maximum right splenius muscle activity in PSS_Off15 was 7.0% ± 1.9%MVC; maximum right splenius muscle activity in PSS_On15F was 26.6% ± 13.5%MVC, which was 2.8 ± 1.1-fold greater than in PSS_Off15 ($p < 0.05$). Maximum right longissimus muscle activity in PSS_Off15 was 9.5% ± 1.4%MVC; maximum right longissimus muscle activity in PSS_On15R was 23.6% ± 6.3%MVC, which was 1.5 ± 0.4-fold greater than in PSS_Off15 ($p < 0.05$). The other muscle activities did not show significant differences ($p > 0.05$) and all remained below 20%MVC.

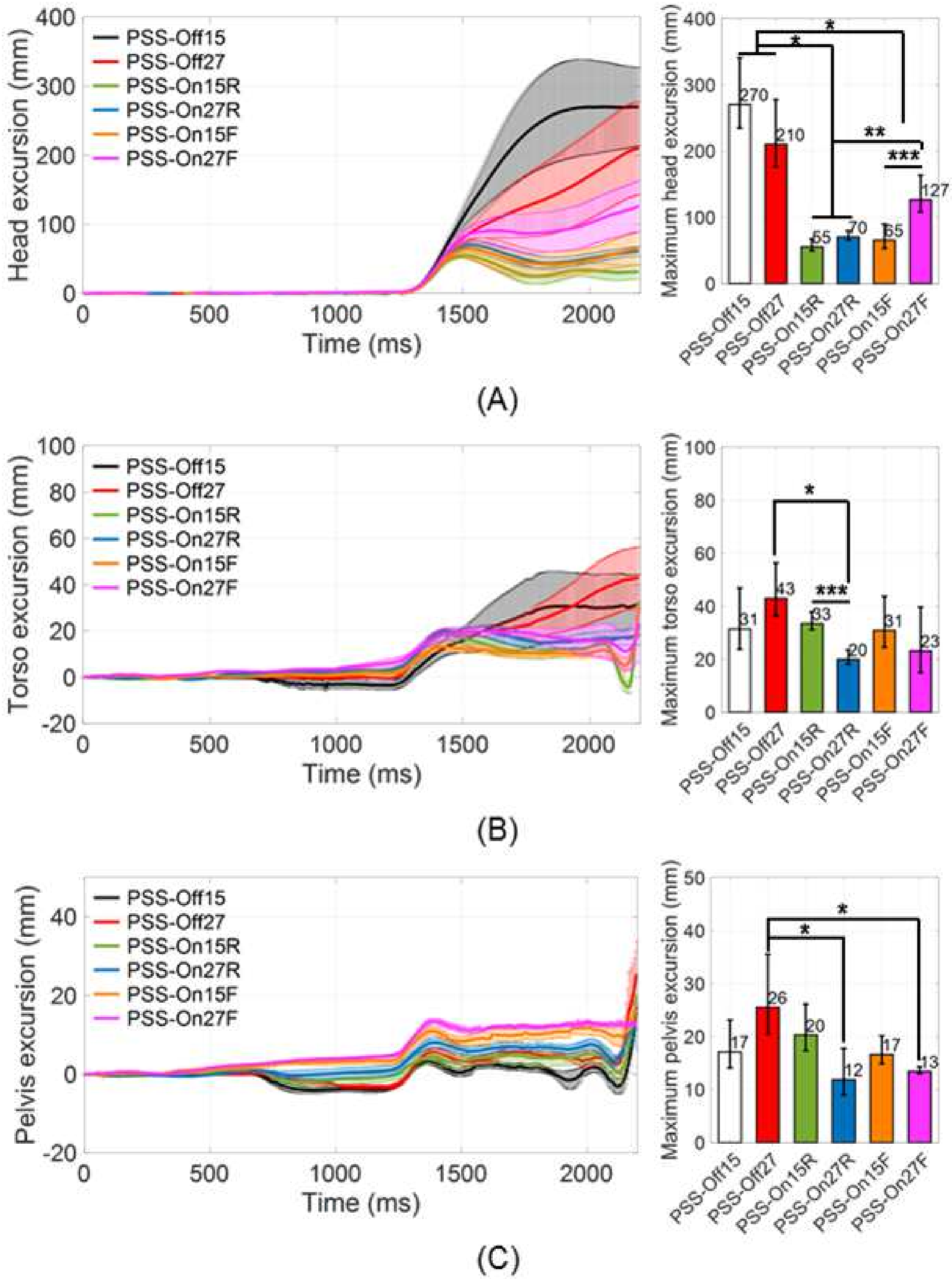

Figure 1. Time-dependent excursions in the sagittal (x-z) plane for (A) head, (B) torso, and (C) pelvis (*: $p < 0.05$ for comparison of PSS application; **: $p < 0.05$ for comparison of seat pan movement modes in PSS; ***: $p < 0.05$ for comparison of initial seat back angles)

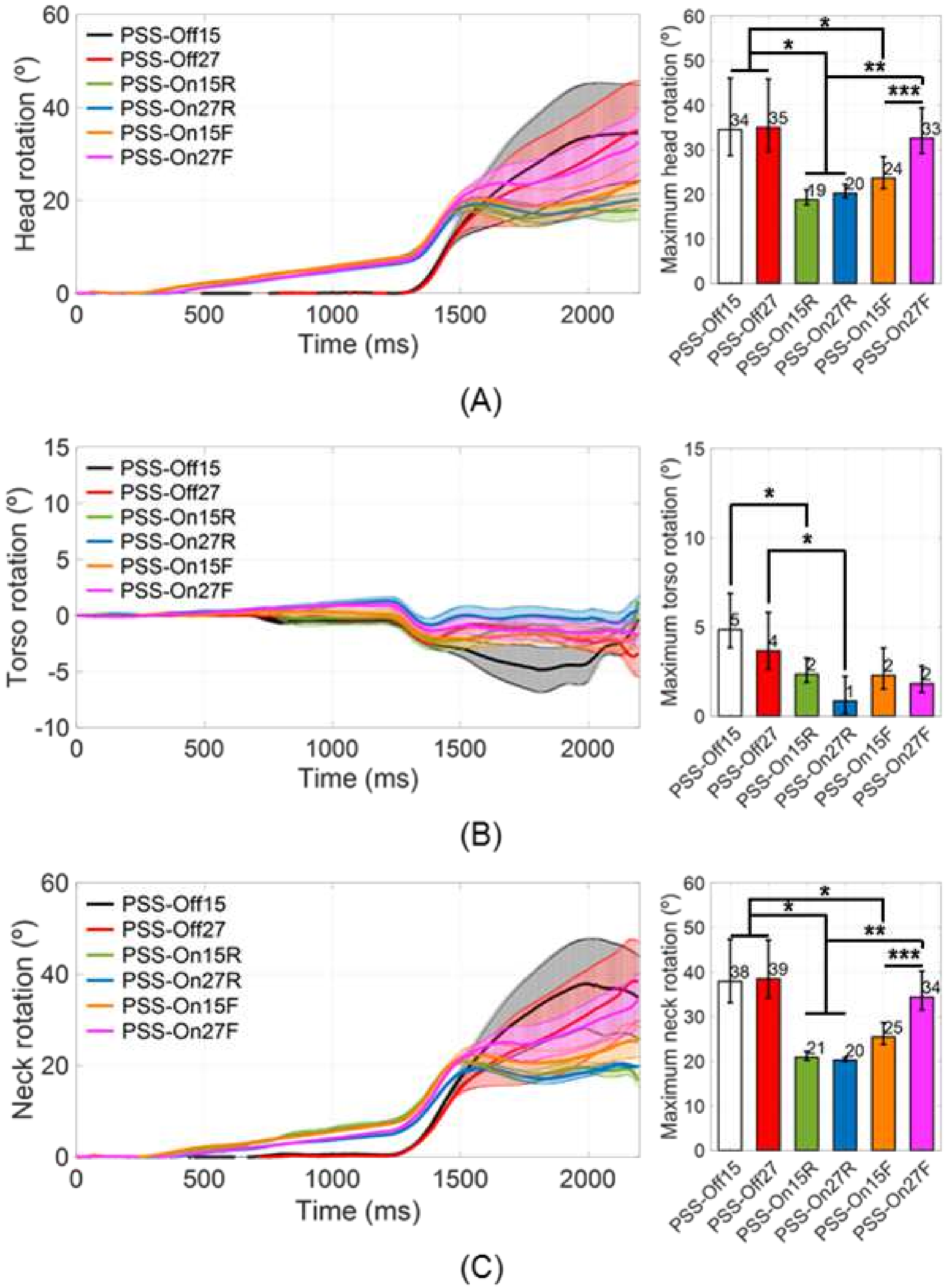

Figure 2. Time-dependent rotations in the sagittal (x-z) plane for (A) head, (B) torso, and (C) neck (*: $p < 0.05$ for comparison of PSS application; **: $p < 0.05$ for comparison of seat pan movement modes in PSS; ***: $p < 0.05$ for comparison of initial seat back angles)

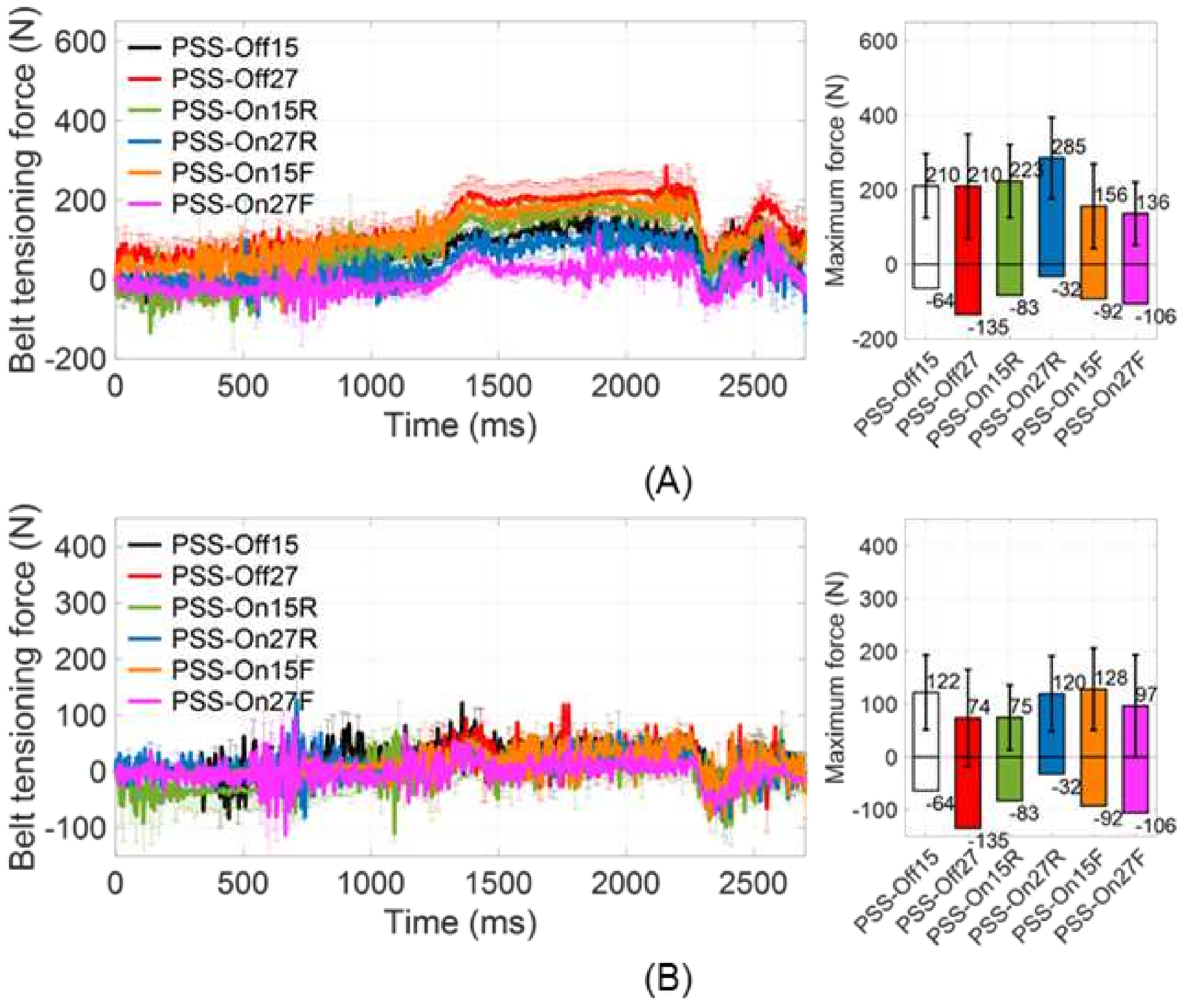

Figure 3. Time-dependent belt tensions for (A) shoulder and (B) lap belts

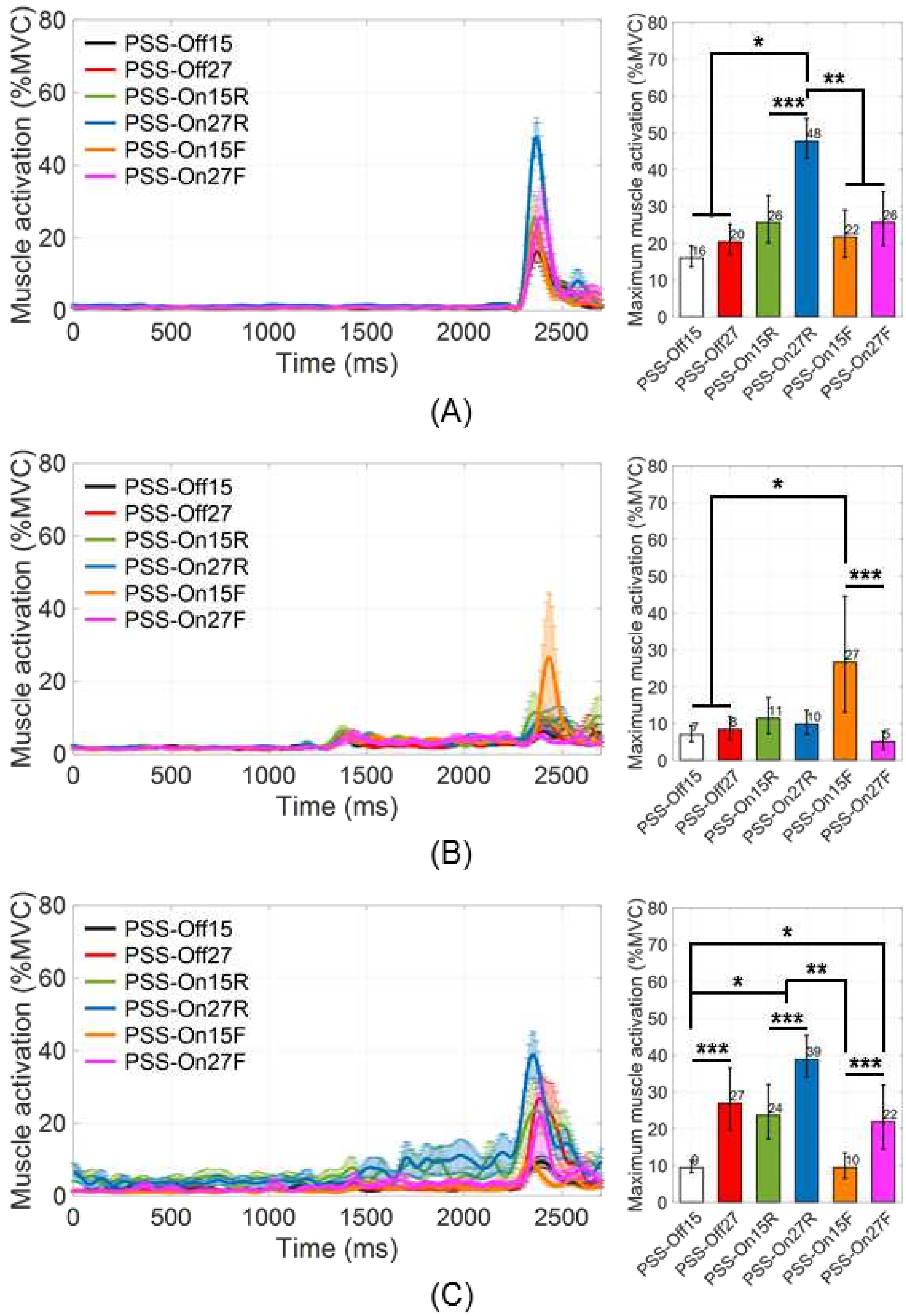

Figure 4. Time-dependent muscle activation for (A) left SCM, (B) right splenius, and (C) right longissimus (*: $p < 0.05$ for comparison of PSS application; **: $p < 0.05$ for comparison of seat pan movement modes in PSS; ***: $p < 0.05$ for comparison of initial seat back angles)

Discussion

The results of the present study showed that PSS is effective as an active safety system for ensuring occupant safety in OOSP before AEB operation. In the near future, occupants are likely to adopt various postures for comfort before partially or fully autonomous driving, but there have been insufficient data regarding the safety of occupants in such postures. Several experimental and/or finite element model studies were performed to examine the responses of the occupant in unintended seat positions.[12,22,23] These studies verified the risk of unintended seat positions, but they did not propose means of counteracting these risks for occupant safety. In the development of an active safety system, it is important to ensure occupant safety before braking and/or collision in unintended seat positions. In addition, information regarding the characteristics of human responses during operation of the safety system will allow safety improvement by controlling the interactions of active and passive safety systems. This study confirmed the effectiveness of PSS operation to improve the interactions of active/passive safety systems and determined the characteristics of human responses during operation of the safety system. Therefore, this study provides valuable insights to ameliorate risk to the occupant in unintended seat positions before braking and/or collision.

In the two-stage braking maneuver for AEB operation, to operate maximum braking acceleration of 1 g at 50 km/h, AEB decelerates gradually from TTC 1.6 s.[9,24] Previous studies reported that AEB at TTC 1.6–0.6 s decelerates to 0.2–0.6 g; this phase is defined as the partial braking phase.[25] Considering the above AEB operating mechanism, the tests in this study were performed in the partial braking phase exhibiting acceleration to 0.4 g for 1000 s. We assumed that continued adjustment of the seat position during AEB operation would lead to unpredictable conditions and increase risk to the occupant because of incomplete PSS operation. Therefore, PSS operation was performed in TTC 2.6 to 1.6 s, which is before the partial braking phase of AEB. TTC is a theoretical concept and it can differ from real-world conditions; thus, a collision can occur before the maximum braking operation of AEB. To adjust from the fully reclined seat to NSP, PSS required at least double the 1 s of TTC 2.6 to 1.6 s. Because of the designed time algorithm for completing PSS operation within 1 s and verification of the test environment only in the partial braking phase, the present test results may have limits for fully considering PSS. To our knowledge, this study represents the first attempt to determine the effectiveness of the PSS for counteracting risk to the occupant in OOSP. Despite the limits of the PSS operation process, the tests in the present study considered the safety of the occupant against unpredictable risks during incomplete PSS operation. Furthermore, the characteristics of occupant responses in the partial braking phase could be utilized to gain fundamental insights to facilitate the improvement of active safety systems, such as PSS strategies. From this perspective, the experimental parameters for the PSS were sufficiently covered, and our results can be considered both valid and reliable.

The understanding and utilization of the PSS operating mechanism can be beneficial to ensure occupant safety, adjusting both the seat and occupant to the intended design position before the time of a collision. The protective operation of restraint systems is greatest when occupants and their ambient environment are in the intended design position (i.e., NSP) at the start of the collision.[9–12] However, real-world accident records indicate that, in many instances, both the seats and the occupants are not in the intended design position at the time of a collision. Therefore, the functional mechanism of the PSS to adjust the seat position of the occupant to NSP before a collision is important. The results of the present study showed that, regardless of whether the seat pan shifted forward or rearward, the occupant's frontal motion with PSS operation was generally decreased and the motion characteristics showed a small standard error range, compared with PSS_Off conditions. In particular, PSS_On27R and PSS_On27F showed reduction of the characteristic motions related to submarining (e.g., upper body hovering and falling, as well as pelvic slipping).[12] These results indicated that the PSS had a protective effect when the occupant's seat position was adjusted closer to NSP. However, the head excursion and neck rotation were 2 and 1.5-fold greater in PSS_On27F than in PSS_On27R, respectively. To confirm whether there were differences in PSS effectiveness because of postural adjustment between PSS_On27R and PSS_On27F, we compared the occupant's postures at 1200 ms when PSS operation was completed. As shown in Figure 5, the changes in torso rotation angle by PSS operation in PSS_On27R and PSS_On27F were from 63.1° ± 0.4° to 68.0° ± 0.3° and from 63.7° ± 0.7° to 68.5° ± 0.6°, respectively; these were not markedly different. In contrast, the changes in head rotation angle in PSS_On27R and PSS_On27F were from 44.3° ± 1.8° to 40.0° ± 1.7° and from 41.0° ± 1.8° to 36.0° ± 1.5°, respectively; these represented a difference of approximately 5° between the two conditions. The results indicated that PSS_On27R and PSS_On27F had different neck rotation angles for each posture with differences in head rotation angle and head center of gravity. Occupants in PSS_On27R tended to lean more heavily on the headrest, which may have been because of the difference in center of gravity caused by the lower body posture and seat pan location. Furthermore, this difference led to pelvic-on-femoral osteokinematics. If seat pan location is moving rearward, as in PSS_On27F, with the supralumbar trunk stationary on the seat back, anterior pelvic tilt (flexion) could occur and the lumbar spine would have more curvature toward the front. Therefore, this seat control strategy could result in the lumbar spine center of gravity moving to the front, which may affect the upper body center of gravity in the initial posture; this would result in greater excursion than in PSS_On27R. These observations suggest the importance of the initial seat position in PSS operation from a biomechanical perspective; all PSS strategies provided better safety to the occupant in OOSP.

Although there were differences among test conditions in the maximum shoulder and lap belt tensions, the activities of the shoulder and lap belts were not significantly different across test conditions ($p > 0.05$). The maximum left SCM muscle activity in PSS_On27R was 1.3 ± 0.2-fold greater than in PSS_Off27; the maximum right splenius muscle activity in PSS_On15F and right longissimus muscle activity in PSS_On15R were 2.8 ± 1.1 and 1.5 ± 0.4-fold greater than in PSS_Off15, respectively ($p < 0.05$). These observations suggested that the possibility of muscle restraining activity was ameliorated, compared with PSS_Off. However, the muscle activities measured in all seat positions peaked at approximately 2400 ms after activation of partial braking, at approximately 100–200 ms after the excursions had reached their maximum values. In addition, all muscle activities of the occupants were below 50% of the MVC values. These results may have been limited by the low-speed conditions-the partial braking phase of AEB-used in the tests. Therefore, further research is needed to quantify the actual risk of muscle injury. In this study, although the muscle activities during PSS operation were within 50% of the MVC values and were not expected to reflect a risk of muscle injury, these results are valuable for improving the overall understanding of occupant motions during AEB with PSS.

Several factors that can directly or indirectly influence the responses of occupants during the tests (e.g., habituation, lack of awareness, and startle response) have been studied.[12,17,26,27] Blouin et al.[27] noted the effects of habituation and acoustic startle stimulus of the test platform on resulting occupant responses. They suggested that it is important to perform tests without

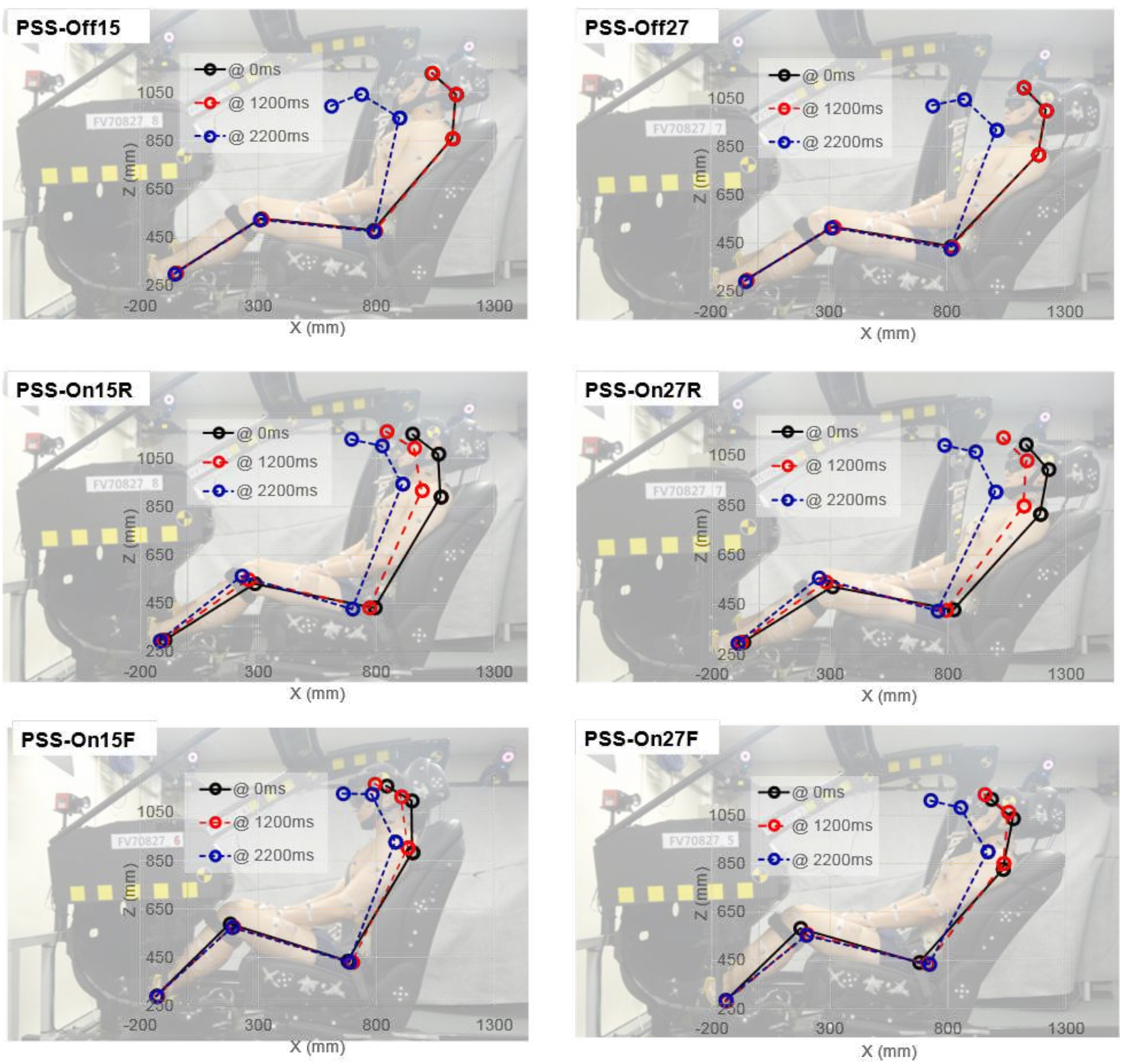

Figure 5. Frontal motion trajectories of an occupant in the sagittal (x-z) plane

habituation and acoustic startle stimulus to clearly observe occupant responses. Beeman et al.[26] studied the effects of contracted muscles on occupant kinematics and kinetics; they showed that muscle condition before the test had a significant effect on the occupant motion response. These studies suggested that effective exploration of experimental parameters would facilitate better characterization of occupant motion responses.[12,17] Therefore, although the objective of the present study was to examine the test parameters of the PSS that influence the results, comprehensive observation was not possible because of limitations regarding the test environment and conditions. The selection of PSS strategy was also restrictive because of considerations regarding test volunteer safety. However, because the occupant motion characteristics for the OOSP measured here were similar to the characteristics reported in previous studies, the experimental parameters may have been sufficient and our results can be considered both reliable and valid.[12] Furthermore, the results of this study are highly meaningful because we identified the effectiveness of PSS implementation during AEB operation. Importantly, the acquisition of human characteristics for PSS effectiveness in this study was novel and the test parameters were covered sufficiently; thus, our results can be considered reliable and valid. These results represent essential information regarding the improvement of safety device effectiveness to ameliorate occupant restraint and counteract any deterioration of occupant safety. Further studies are required to devise a PSS mechanism suitable for a more diverse range of emergency maneuvers, such as evasive swerving, to further improve occupant safety. This study provides a basis for obtaining a clear understanding of occupant motion responses for active PSS and for the identification of potential discomfort or injuries to the occupant during AEB operation.

Overall, the results of the present study indicated that the PSS can improve occupant safety in OOSP during AEB operation. The occupant's frontal motion was generally decreased with PSS operation; the characteristics of frontal excursion showed a small range of standard error, compared with the PSS_Off condition. In the fully reclined seat position, PSS operation led to a reduction of the characteristic motion associated with submarining of the occupant.

In conclusion, PSS operation can improve the safety of occupants in OOSP. However, the occupant safety effects according to various PSS operation strategies must be further verified. To secure occupant safety with various PSS operation strategies, additional confirmation is required for more diverse emergency maneuvers, such as evasive swerving and/or the use of recent occupant restraint configurations (e.g., belt-in-seat components). Moreover, if the PSS control system can perform with better classification of the occupant's condition (e.g., body type, awareness/lack of awareness, and upper body center of gravity) in autonomous vehicle driving, the optimized algorithm for PSS strategies may provide greater occupant safety improvements.

Methods

Volunteers

The test group consisted of 10 healthy men in their 20s who had no prior histories of cervical spine injury or degenerative changes. The selected volunteers were ± 2.5% for height and ± 1.5% for weight of the 50th percentile male hybrid III dummy (Table 1). Informed consent to publish was obtained from all the volunteers to include the images and information in the manuscript.

Table 1. Volunteer characteristics

Test subject (Initial)	Height (mm)	Sitting height (mm)	Weight (kg)	BMI (kg/m2)	Leg length (mm)	Knee width (mm)
S1 (KJY)	1788	948	71.8	22.46	930	115
S2 (JYH)	1782	941	80.2	25.26	910	117
S3 (PMY)	1802	949	78.9	24.3	910	120
S4 (MHW)	1771	951	72.9	23.24	910	120
S5 (KMG)	1800	930	84	25.93	940	115
S6 (KCH)	1781	908	72.9	22.98	920	110
S7 (KJH)	1813	957	82.8	25.19	930	115
S8 (LGR)	1789	949	79.2	24.75	930	105
S9 (KSW)	1803	942	76.5	23.53	920	115
S10 (LSH)	1787	949	80	25.05	900	110
Avg.	**1792**	**942**	**78**	**24**	**920**	**114**
S.E.	**1.26**	**1.41**	**0.43**	**0.12**	**1.25**	**0.47**

Test platform and configuration

The test platform is shown in Figure 6 (A). The test buck was composed of a passenger seat from a Genesis EQ-900 (Hyundai Motor Group, Seoul, Korea). A servo motor (APM-FGP150GMK, 15 kW capacity, 1500 rpm; LS Mecapion, Gyeonggi-do, South Korea) was used to control the test environment. A three-dimensional motion capture system with 16 infrared cameras was used to measure occupant excursion with a sampling rate of 200 Hz (T-20s; Vicon Motion Systems Ltd., Oxford, UK). To track the excursion of the test volunteers, a customized marker set based on a general plug-in-gait set was used.[26,28] The excursions of body parts were measured with three virtual central markers that were determined by the following actual reflective markers: five at the head, seven at the torso, and eight at the pelvis. To define accurate measurement of the excursion, an absolute coordinate system was defined through the baseplate of the sled; relative coordinate systems were defined by virtual central markers in the headrest, seat back, and seat pan (Figure 7). To assist in the interpretation of excursion measured by the three-dimensional motion capture system, two high-resolution cameras (Q-MIZE HD v2, 500 fps; AOS Technologies, Dättwil, Switzerland) were installed at the front and left sides of the AEB test platform. To confirm the shift in center of gravity, two six-axial load cell sensors (CWW11-K100 & UMMA [100 kgf], sampling rate: 2 kHz; DACELL, Qingdao, China) were attached beneath the seat and footrest, respectively. Two seatbelt tension transducers (LBT-E, sampling rate: 2 kHz; Kyowa Electronic Instruments, Tokyo, Japan) were used to measure the shoulder and lap belt restraining forces. All kinetic measurements were filtered through a low-pass filter with channel frequency class 60 Hz, conforming to the SAE J211 filter standard.[29,30] To measure muscle activities of the test volunteers, a wireless surface electromyogram (EMG) (Tringo Wireless EMG System, sampling rate: 2 kHz; Delsys, Inc., Boston, MA, USA) was used in parallel with the three-dimensional motion capture system described above (Figure 6 (B)). The wireless surface EMG was attached to the neck joint region (sternocleidomastoid, splenius capitis, and trapezius muscles), the abdomen region (rectus abdominis, externus abdominis, longissimus, and iliocostalis muscles), and the lower extremity region (rectus femoris, tibialis anterior, bicep femoris, and medial gastrocnemius muscles). The EMG signal data were analyzed using EMGworks software (ver. 4.0; Delsys, Inc.). The EMG signal data were sequentially processed by a fourth band-pass filter (10–1000 Hz), rectified using a root-mean-square technique, and normalized based on the measured maximum voluntary contraction (MVC) by each muscle.26 Therefore, all measured muscle activity is presented as %MVC.

AEB and PSS operations

A two-stage braking maneuver of a typical vehicle kinematic algorithm was presumed to reproduce AEB operating conditions. According to general vehicle kinematics, at time-to-collision (TTC) 1.6 s, maximal deceleration of 0.4 g and other evasive actions (braking or steering) remain possible.[25] At TTC 0.6 s, with persistent braking from TTC 1.6 s, the collision is considered to be unavoidable and maximal deceleration is increased to 0.8 g.[24] The AEB in this study was designed with a step-function waveform exhibiting acceleration to 0.4 g for 1000 ms and deceleration to 0.8 g for 500 ms (Figure 8). The reliability of simulated input acceleration for reproducing AEB was validated by the correlation and analysis score, in comparison with results obtained using an accelerometer (model 4000A & 4001A accelerometer; TE Connectivity, Schaffhausen, Switzerland) attached to the test buck. The correlation and analysis scale is an objective rating method developed by Gehre et al.,[31] where a minimum score of 0.7 is the criterion for reliability. The correlation and analysis scores of all resultant output acceleration, compared with simulated input, exceeded 0.85. Therefore, the AEB test platform used in the present study was reliable and suitable for reproducing real-world conditions.

The theoretical target of the PSS is to change the OOSP seat to a safer position with the seat back as upright as possible and seat pan moved to the middle position before TTC 1.6 s. However, the operational specification of the electrical seat control system for the PSS is restricted to < 10°/s in the seat recliner and 60 mm/s in the seat pan slider because of the maximum allowed voltage capacity that can be provided to the seat from the battery. Considering these operational restrictions, we presumed that continuing to operate the PSS after TTC 1.6 s would increase the risk of injury to occupants because of posture changes during AEB deceleration. The PSS operation phase was therefore increased by approximately 1 s via TTC 2.6–1.6 s, which is the operating phase of forward collision warning before braking.[24,32]

Test procedure

The test procedure matrix is shown in Table 2. The initial OOSP seat back angles that may be associated with risk of injury when occupied were the fully reclined seat angle (27°) and half-reclined seat angle (15°). The position was changed via PSS operation to upright by as much as 10°. There were two seat pan moving modes in the PSS: rearward (beginning at 240 mm) to the mid position (179 mm) and forward (beginning at 120 mm) to the mid position (179 mm). Six test conditions were examined to identify the effectiveness of the PSS for augmentation of occupant safety in OOSP and to identify areas for additional improvements: 1) PSS Off with 15° reclined seat angle (PSS_Off15); 2) PSS Off with 27° reclined seat angle (PSS_Off27); 3) PSS On and the seat pan moved rearward to the mid position with 15° reclined seat angle (PSS_On15R); 4) PSS On and the seat pan moved rearward to the mid position with 27° reclined seat angle (PSS_On27R); 5) PSS On and the seat pan moved forward to the mid position with 15° reclined seat angle (PSS_On15F); and 6) PSS On and the seat pan moved forward to the mid position with 27° reclined seat angle (PSS_On27F). Here, five volunteers were randomly selected and assigned to each condition. To obtain the mean measurements and filter out the outliers, tests for each seat configuration were conducted three times for each volunteer. Volunteers were allowed a 30-min break between repeated tests to minimize the effects of muscle fatigue. To simulate feasible conditions when a vehicle is being driven, each volunteer maintained the specified seated posture before the test, with as little tension as possible.[27] To check the relaxed muscle state before the test, sufficient time was provided for the volunteer to adapt to the specified posture; EMG signals were confirmed with monitoring to ensure that they remained stable in the relaxed state.

Statistical analysis

We applied one-way analysis of variance followed by Bonferroni's post hoc test to analyze differences in the kinematic characteristics (e.g., forward linear excursion, excursion traces, and rotational angle) among all test conditions. In all analyses, $p < 0.05$ was considered to indicate statistical significance. Adjusted 95% confidence intervals were estimated for all parameters.

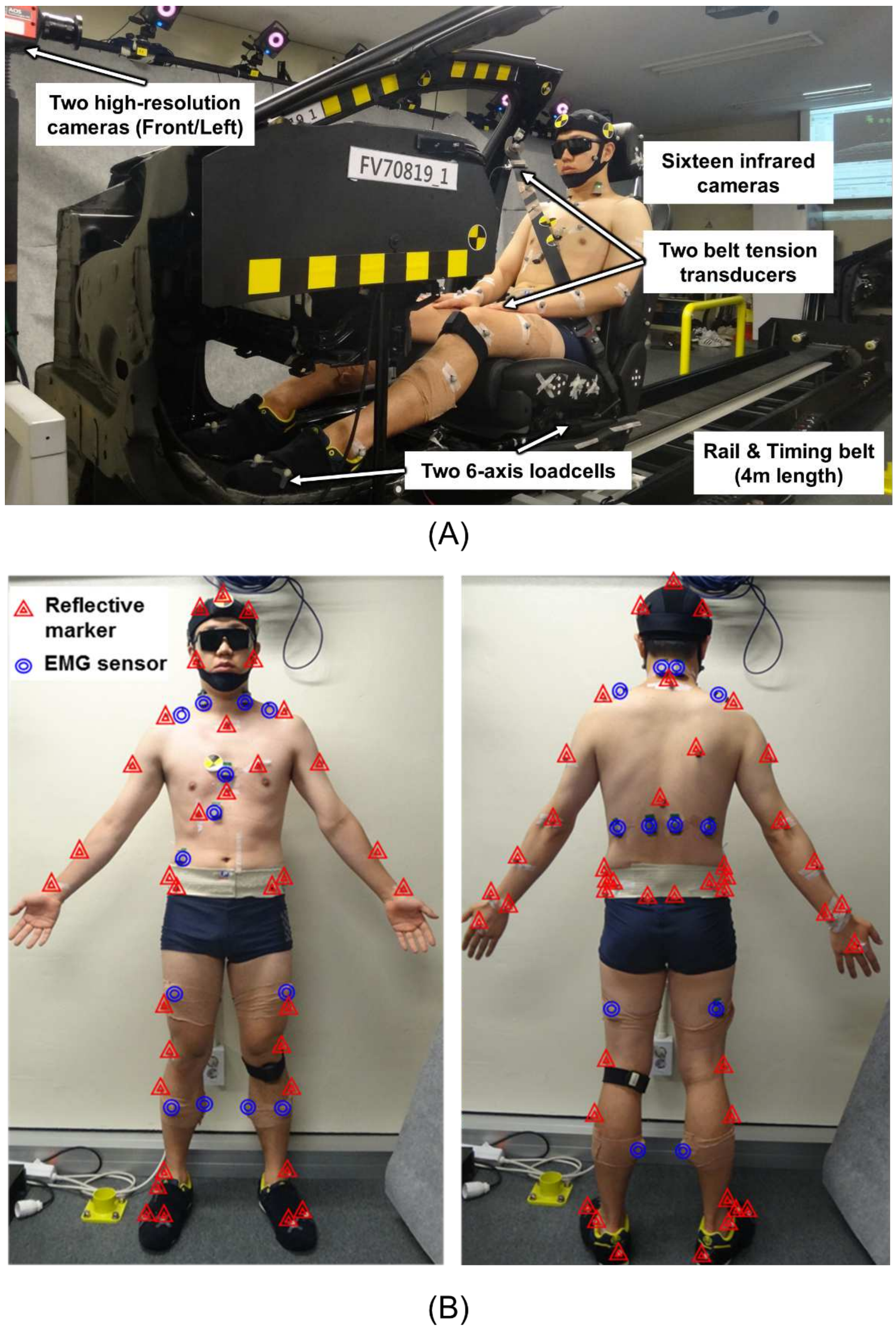

Figure 6. (A) PSS test platform. (B) Locations of the reflective markers and wireless surface EMG sensors

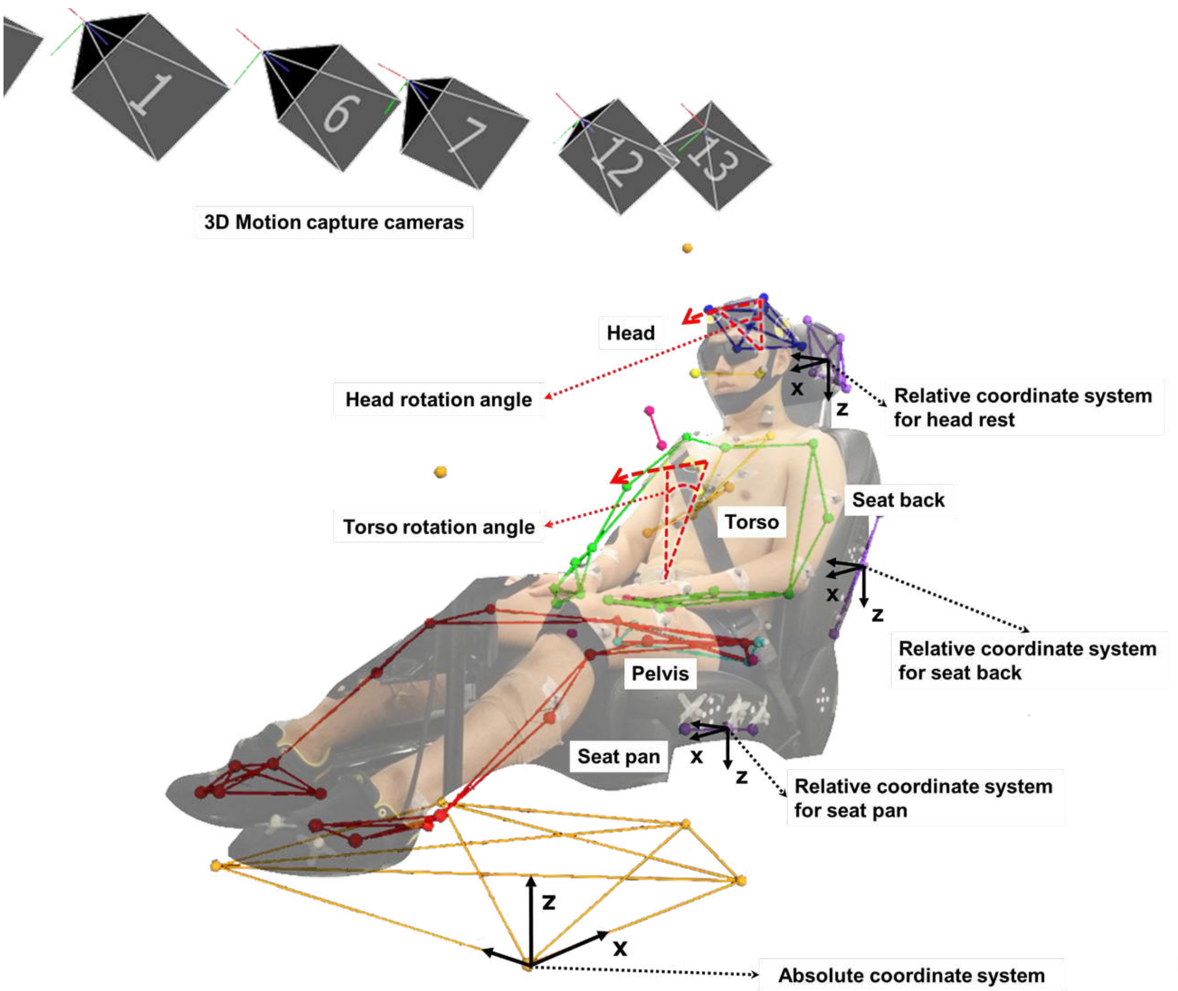

Figure 7. Definitions of head and torso angles and absolute and relative coordinate systems, as well as the segment model constructed by connecting the markers with lines

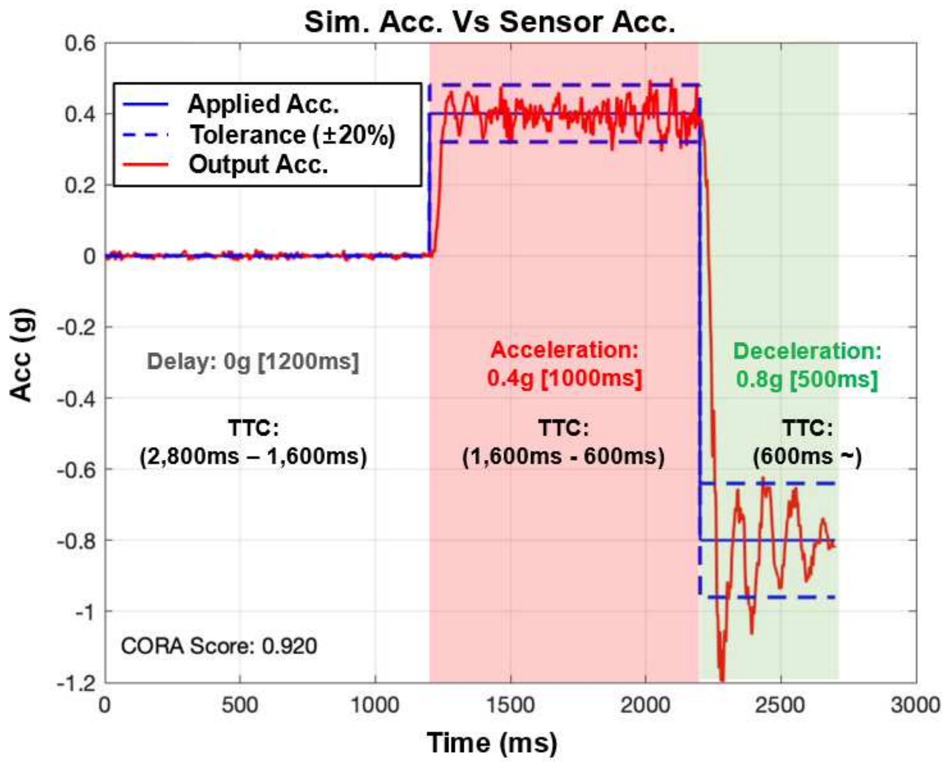

Figure 8. Characteristics of acceleration simulated for AEB operation based on the TTC algorithm. The acceleration simulated for AEB operation was validated by comparison with acceleration measured on the test buck

Table 2. PSS test matrix

Test Condition		Seat Pan Movement	Seatback Angle	Trial Counts (volunteers*repeat)	Muscle Condition
PSS OFF	PSS-Off15	Rear	15º	15 (5*3)	Relaxed
	PSS-Off27		27º	15 (5*3)	
PSS ON (Rear to Mid)	PSS-On15R	Rear → Mid	15º → 5º	30 (10*3)	
	PSS-On27R		27º → 17º	30 (10*3)	
PSS ON (Fore to Mid)	PSS-On15F	Fore → Mid	15º → 5º	15 (5*3)	
	PSS-On27F		27º → 17º	15 (5*3)	

Data availability

All datasets generated during the present study are available from the corresponding author.

Ethics declarations

All volunteers provided informed consent and the test process was approved by Sejong University Bioethics Committee, Institutional Review Board (IRB number: SJU-2018-001). Volunteers have performed tests in accordance with relevant named guidelines and regulations, and informed consent was obtained from them.

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Author contributions statement

M.K., H.K., and D.L. designed the research; M.K. and D.L. wrote the manuscript; M.K., Y.C., and S.K. performed the tests; M.K., Y.C., and S.K. conducted the analysis; M.K. and H.K. interpreted the results; H.K. and D.L. supervised the research; All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.