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An Experimental Confirmation of the Occupant Kinematic Response for Out of Position and Belt Tensioning Effect during Collision Avoidance System

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ABSTRACT – The methodology of ensuring safety to occupants' is one of the major challenges about the Integral safety system. Many studies have focused on verification to securing occupants' restraint during collision avoidance, but the out-of-position (OOP) parameter was not considered sufficiently. The aim of this study is to verify the occupant's kinematic response at OOP seat conditions via the sled platform which simulated the collision avoidance system. In this experiment, 18 volunteers' motion was measured by infrared cameras and electromyography sensors. According to results, the OOP seat made frontal head motion to 1.5±0.5 times higher than normal seat position (NSP) in braking maneuver. In swerving maneuver at the NSP seat, however, the neck joint peak was represented 0.2 sec quicker, 3 times longer, and higher than the OOP seat. For future work, this study proposes that kinematic compensation of the occupant's response should be considered with countermeasure onto seat position change.

INTRODUCTION

Automation of road transport is currently a clear trend. Many technologies that will be required for full automation are already being developed and tested globally (Forum, 2019), furthermore, the safety level of passenger cars has also increased considerably. A further increase through conventional passive restraint systems, however, is seemingly limited. The securing safety method of the passenger is to avoid unexpected critical situations during normal driving.

Integral safety systems like the collision avoidance safety system is operated on two types under 1g, autonomous emergency braking (AEB) and autonomous emergency swerving (AES), automatically and influence the car's kinematics before impact and so they can avoid or mitigate accidents. Under these circumstances, however, it is necessary to validate the potential effect of kinetic response. Furthermore, not only these car maneuvers but also selected seat positions onto personal preference require consideration for exposed to unconfirmed "inadvertent" or unintentional position, out-of-position (OOP), seat. In this regard, Bastien and Blundell shed light on that occupants could undergo serious injuries when postured supine too non-contact to shoulder belt (Bastien and Blundell, 2010).

For understanding these challenges, the occupant's kinematics has to need a way of approach with a biomechanical view. The purpose of this study, thus, is to verify the occupant kinematic response at OOP seat conditions and to explain the tendency of these motion during collision avoidance systems.

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METHODS

Eighteen healthy young male adults (mean age: 24.3) with no history of injury or other spine problems participated. *Table 1* shows the volunteers average height, weight, and body mass index (BMI). The participated volunteers have separated to 6 for AEB and 12 for AES, respectively. Prior to the collision avoidance system experiments, all volunteers provided informed consent and the study design was approved by Sejong University Institutional Review Board (IRB: SJU-2018-001).

The OOP seat hasn't obvious criteria to define generally, but that is important parameter (Strother et al., 1994). Total two kinds of seat positions, like as shown *Table 2*, were selected to represent NSP and OOP seats.

The sled consisted of two system components for operating. The actual vehicle's passenger seat (Genesis EQ-900, Hyundai) was mounted, and operated on a 4-meter-long rail with servo motor. The passenger seat was controlled by the integral motor controller to make the OOP seat condition, and this seat included a pre-tensioning belt with a 3-point form. The acceleration waveforms of collision avoidance systems were simulated with reference to the real car test result offered by Hyundai motors. In addition, a three-axis accelerometer (Model 4000A & 4001A Accelerometer, TE Connectivity) was equipped on the sled plate for compare input with output (CORrelation and Analysis score: higher than 0.8) (see *figure 1*).

A three-dimensional (3D) motion capture system with sixteen infrared cameras (T-20, Vicon Motion Systems Ltd.; sampling rate: 200 Hz) was used in parallel with an EMG sensor (Trigno Wireless EMG System, Delsys, Inc.; sampling rate: 2 kHz) to quantify the kinematics (e.g., angle, angular velocity and acceleration, linear velocity and acceleration) and moment characteristics of the body during experiments. A total of 49 retro-reflective markers were adhered to each subject at key anatomical locations and 25 were adhered to the sled (Beeman et al., 2012). EMG electrodes were attached onto the skin over major muscle of the subject where Twelve positions of volunteer's body according to the anatomical description provided by Cram et al. (Cram, 1998) Just before start to the experiment, the muscle condition of each subject was confirmed on real time and proceed in the relaxed state.

RESULTS

AEB EXPERIMENT

When the OOP seat position, the phenomenon to increase 1.5 times anterior head displacement was occurred (*figure 2*). In contrast, chest and pelvis displacement haven't different conspicuously for seat positions but there some potential risk was detected of the belt contacting motion that occurs at the OOP seat. In addition, the statistical significance of cervical and abdominal muscle activation represented to volunteers of the OOP seat condition.

AES EXPERIMENT

Compared to head and chest displacements of lateral direction, the motion at the OOP analogize with the NSP (*figure 3*). However, the stereoscopic trajectory of head motion had a difference (*figure 4*). The occupant's neck joint motion peak at NSP seat has occurred 0.2 sec quicker, 3 times longer, and higher than the OOP seat. In addition, only the SCM (SternoCleidomastoid-Muscle) muscle activity was noted just a little significant, and the other muscle activity was less than 20% to MVC (Maximal. Voluntary Contraction).

DISCUSSION

According to EMG signals analysis, the results suggest that the occupant reactions to the external force have a large variability even for the same seat condition as well as within the same percentile volunteers. Furthermore, the muscular response when detected in real-time has the difference because considered to relatively differ MVC ranges for each volunteers' muscle activation level. On the other hand, volunteers' Initial muscle condition was ambiguous to define which was a really relaxed state. Therefore, the more specifical criteria of muscular responses were required to analyze the EMG signals.

Through experiments, this study may anticipate that the seat back angle control was the most valuable parameter to predict occupants' reactions. Regarding the result, the seat position advantage of the occupant restraint effect was respectively different depends on the collision avoidance scenario maneuvers. Thus, this study suggests that occupants' restraint compensation to unconfirmed “inadvertent” or unintentional seated posture through collision avoidance systems' external force requires via quantitative seat position control mechanism.

CONCLUSION

In conclusion, this study may valuable to confirm the occupants' kinetical responses for experiment information and quantified motion tendencies, and to propose the possibility of optimized occupant seat control for safety during the collision avoidance systems.

ACKNOWLEDGMENTS

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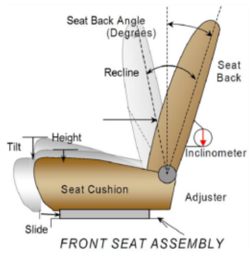
Table 1. Human volunteer subject information

	Age	Height (mm)	Sitting height (mm)	Weight (kg)	BMI (kg/m^2)
Subject 1	23	1772	957	80.9	25.8
Subject 2	22	1778	964	76.5	24.2
Subject 3	24	1777	950	73.9	23.4
Subject 4	23	1748	936	80.0	26.2
Subject 5	25	1755	914	78.5	25.5
Subject 6	23	1781	955	70.3	22.2
Subject 7	24	1741	920	76.2	25.1
Subject 8	21	1736	970	78.2	25.9
Subject 9	29	1770	950	74.0	23.6
Subject 10	24	1780	870	70.1	22.1
Subject 11	28	1722	960	82.9	28.0
Subject 12	24	1793	940	76.8	23.9
Subject 13	29	1750	860	71.5	23.3
Subject 14	24	1768	980	81.4	26.0
Subject 15	23	1724	910	70.1	23.6
Subject 16	25	1775	990	81.5	25.9
Subject 17	23	1722	955	70.5	23.8
Subject 18	23	1743	950	73.9	24.3
Avg.	24.3	1757.5	940.6	76.0	24.6
S.E.	0.5	5.2	7.9	1.0	0.4

Table 2. Seat position setting values



	NSP	OOP
Seat Position	Mid (5°)	Rear (27°)
Seat Back Angle	5.0± 1.0°	27.0 ± 1.0°
Slide	168.0± 0.3mm	255.0 ± 0.0mm
Recline	52.0 ± 1.0°	76.0 ± 1.0°
Tilt	29.0 ± 0.0mm	30.0 ± 0.0mm
Height	55.0 ± 0.0mm	55.0 ± 0.0mm
Head Rest Vertical	40.0 ± 0.0mm	41.8 ± 0.1mm
Head Rest Slide	51.0 ± 0.0mm	60.7 ± 0.5mm

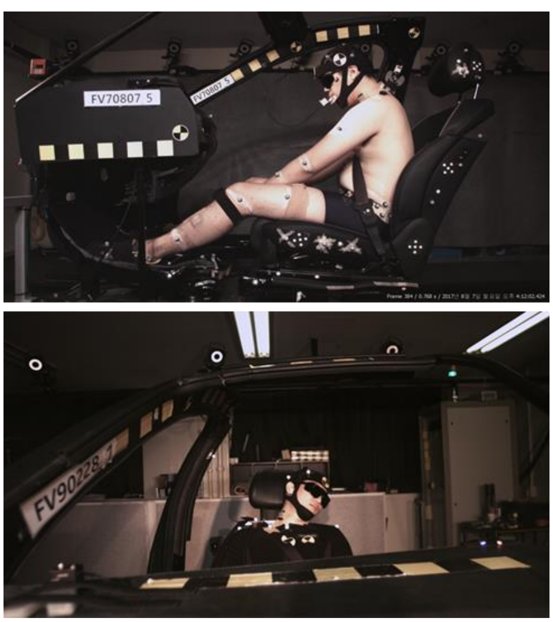


Figure 1. Experimental setup

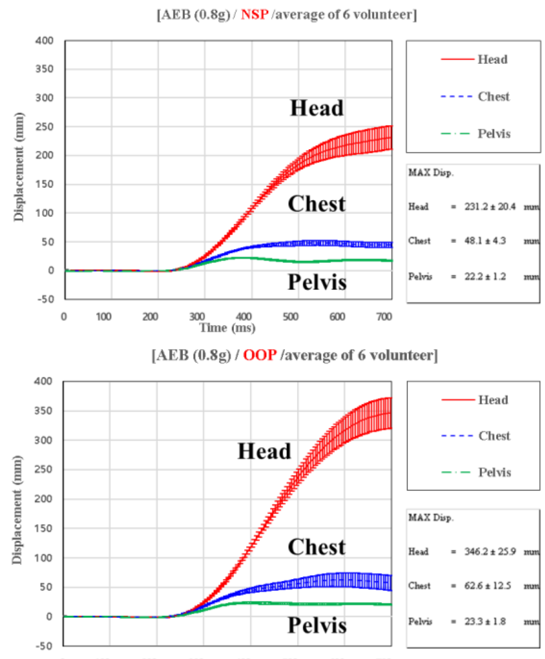


Figure 2. Representative comparison plot of NSP and OOP for AEB function.

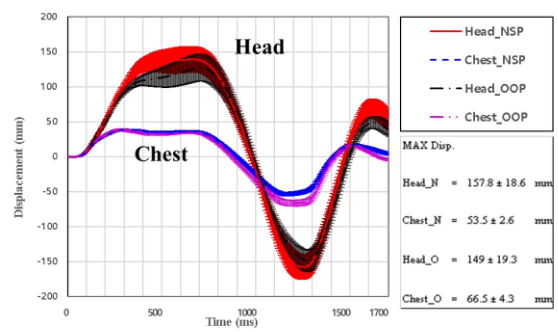


Figure 3. Representative comparison plot of NSP and OOP for AES function.

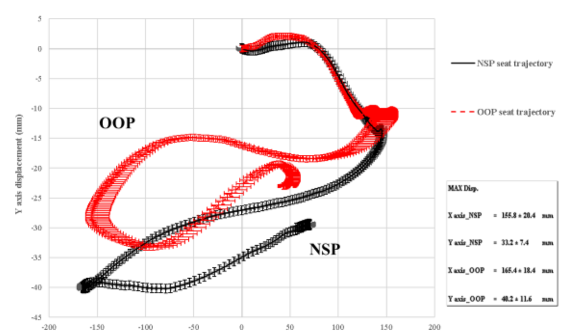


Figure 4. Comparison of head motion trajectory of NSP and OOP' during the AES operating.