Effect of Stabilising Strategy on Head Kinematics of Occupants
Part I: Experimental Study

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I. INTRODUCTION

In contrast to the anthropomorphic test devices (ATDs), humans react with intent to external forces. The active human body model (HBM) that produces joint torques with proportional-integral-derivative (PID) closed-loop control has been developed to understand the physiologic response of human occupants. [1] A series of volunteer test has been performed as one of the tests to optimise the model parameters of the HBM. The objective was to inspect the head kinematics of subjects with the 6DOF driving simulator, which emulates various floor motions. [2] The lateral cyclic excitation motions were delivered to the test participants in four different intensities to understand the behaviour under the voluntary response in steady-state. [3] The subjects kept either the *reactive* or *proactive* strategy against the perturbations.

II. METHODS

The experiment was conducted on six Korean men in the twenties. The applicants were recruited in the range of 172 to 178cm in height and 73 to 83kg in weight. Head kinematics were measured on the forehead of the occupants using the inertial measurement unit (IMU) sensor (Shimmer3 IMU) at a frequency of 256Hz. A 6DOF driving simulator was used to generate the cyclic motions. The simulator was designed in two layers; the bottom layer that implements in-plane movements of surge (D_x), sway (D_y), and yaw (R_z), and; the top layer that implements out-of-plane movements of roll (R_x), pitch (R_y), and heave (D_z). A seat from a commercial vehicle was installed on the top layer.

Before the test, the applicants fully rested on the seat. Then, the five-minute experiment began with the first test condition out of eight in total. The eight conditions were combinations of four platform intensities and two stabilising strategies. The lateral cyclic motions were composed of rolling motion up to ±7° (θ_{floor}) and swaying motion up to ±280mm (Δ_{floor}) with a cycle of 4.8 seconds. The motion with the maximum range was set to 100% intensity, and the motions of 75%, 50%, and 25% were made with a linear reduction of amplitude. (Fig. 1 (left)) The lateral excitation motions used in this study were created as a signal that could happen in driving for tuning of the HBM, but not designed to describe a certain manoeuvre of a car. However, if to be compared, the signal may be more of a normal lane change rather than an evasive lane change in the pre-crash scenario: For a typical evasive lane change, the lateral acceleration has a maximum value of 1G. [4] Whereas, the signal used in the experiment were between 0.15g and 0.40g. The largest intensity was tested for the first and the smaller intensities followed in order. Five-minute breaks were given in between every five-minute test. The whole experiment was conducted twice to probe repeatability. The signs of the motions and measurements were set according to the right-handed Cartesian coordinate system shown in the figure (Fig. 1 (middle)); X-axis heading forward; Y-axis heading left; Z-axis heading upward.

To keep the movements of the applicants constant, clear instructions on how to perform two different strategies were given. (Fig. 1 (middle), (right)) In the *reactive* strategy, the participants were asked to relax and respond naturally after the platform motion. However, in the *proactive* strategy, the subjects were told to tense and respond intentionally prior to the motion. Especially for the *proactive* strategy, the applicants turned on the laser pointer attached on the forehead and positioned the red point on the target 130cm ahead. The target was a black hemispheric structure with a diameter of 15cm fixed on the bottom layer of the simulator, which means the hemisphere only followed the swaying motion of the platform.

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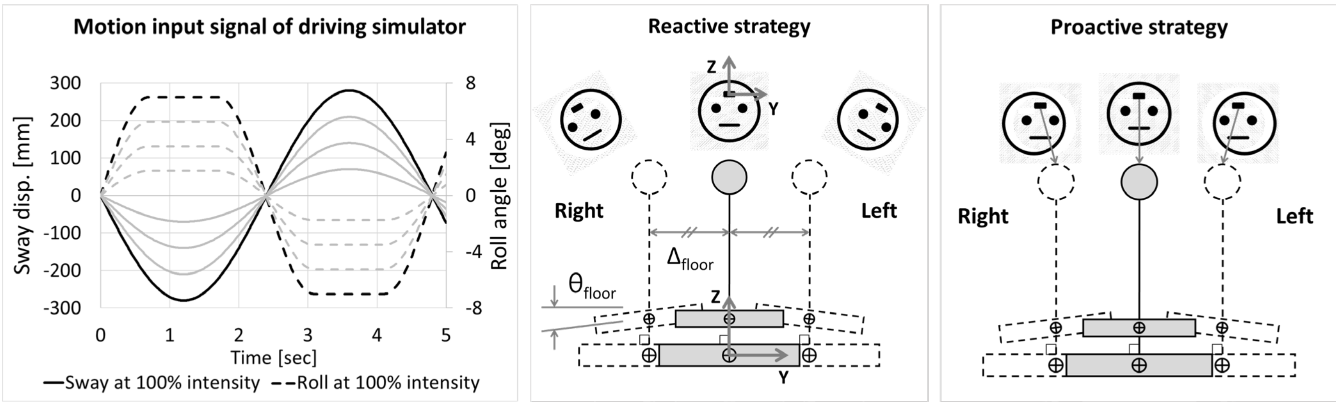

Fig. 1. One cycle of the motion input signal (left), schematic diagrams of reactive (middle) and proactive (right) strategies.

The data processing was all carried out using MATLAB from the data in steady-state. In each test session, a 48-second section containing 10 cycles of the signal was selected from the time after 150 seconds where the measured value was uniform. The acceleration of the head fixed local coordinate was first converted to the acceleration of the global coordinate using quaternions. The converted acceleration was then integrated twice to obtain the displacement of the head. Likewise, the angle was derived by the integration of the angular velocity. During the processing, band-pass filters (BPFs) were used to remove noise and integral constants. Frequencies within a range of 0.05 and 10Hz were passed after the process. The time of the cycle for both the displacement and the angle (Fig. 2 - 5) was coupled with the time from the curve of the motion input (Fig. 1 (left)), which was the fundamental cause of all events. The driving simulator only created the lateral motion, leading the response of occupants to stay in the lateral plane. Thus, the analysis of the head kinematics focused on roll and sway. Apart from the planar movement, yaw angle was analysed since it had shown visible differences between the test conditions.

III. INITIAL FINDINGS

The comparison of the head kinematics in four intensities and two strategies are shown below. The solid line is the mean value and the dashed lines are the range within ± one standard deviation (σ). As the intensity of the motion increased, the lateral displacement (D_y), the sway of the head increased linearly ($R^2_{reactive}$=0.9493, $R^2_{proactive}$=0.9556) regardless of the stabilising strategy. The amplitude in the proactive strategy was always smaller than that of the reactive, compared in the same intensity. The lateral displacement of the proactive strategy was 50.2% of the reactive, on average (probability value, $p<0.05$). Considering that the proactive strategy was the way of coping actively with the excitation while the reactive was responding passively to the excitation, the tendency seems reasonable. In the curve at 100% intensity, the displacement reached zero metres, the centre point at 0.38 seconds while the platform motion started from the centre point at zero seconds. In other words, the head motion showed a time delay of 0.38 seconds compared to the movement of the driving simulator at 100% intensity. The delay was shortened as the excitation intensities were weakened.

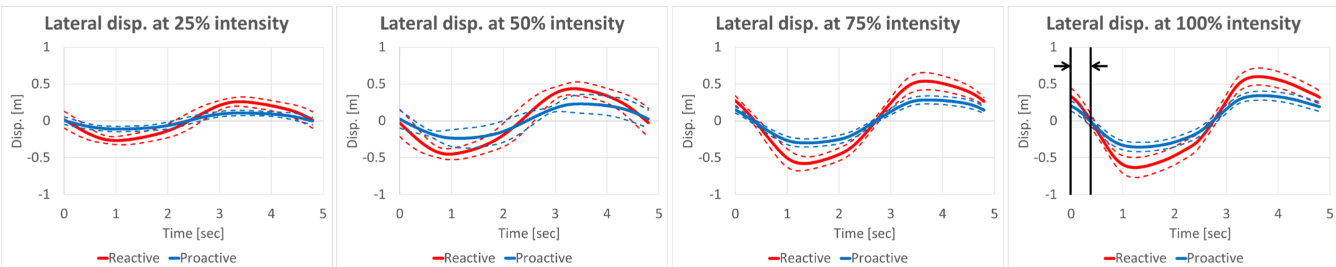

Fig. 2. Comparison of lateral displacement (D_y) of the head at four intensities

The roll angle (R_x) under the proactive strategy increased linearly (R^2=0.9514) as the intensity of the motion increased. However, the reactive strategy did not show high linearity (R^2=0.7668) between all four intensities.

Greater linear association (R^2=0.9645) was shown when the value of 100% intensity was excluded. Still, the angle under the proactive strategy was consistently smaller than that of the reactive in the same intensity. The roll angle of the proactive strategy was 35.7% of the reactive, on average ($p<0.05$), (Fig. 3). To place the laser point within the target, the larger angle was needed for the larger platform motion. In the curves of the roll angle, the angle had certain values other than zero at 0 and 2.4 seconds, the centre points. It implies that when the platform was passing through the centre point of the lateral motion at these times, the head was tilted to the opposite direction of the platform motion, not standing upright to the ground. Unlike the lateral displacement that had shown the same phase, the roll angles of the two strategies showed the opposite phase. The angle of the proactive strategy at 0 seconds was 0°, while the reactive was not zero: The occupant keeping the proactive strategy synchronised his or her response to the motion of the simulator, while the one keeping the reactive strategy followed with a delay. Comparing the time of the first highest angle in the reactive and the first lowest angle in the proactive strategy, a difference in time can be seen. The difference also showed the time delay between the two strategies. Besides, two fluctuations can be seen at each peak of the roll angles. As the platform swayed to the end from the opposite end, the head rolled larger than the platform due to the inertia. The occupant soon tried to roll back to a stable position, where the valley at the peak was made. When the platform returned to the other end, the inertia of the head tended to remain still caused roll, thus the roll angle reached the peak again. Then decreased to the opposite peak.

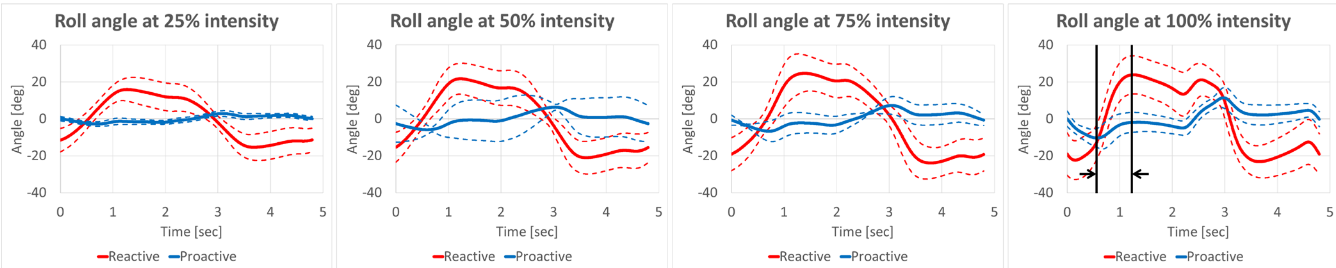

Fig. 3. Comparison of roll angle (R_x) of the head at four intensities

Although yaw (R_z) is not included in the motion of the simulator, noticeable differences in the yaw angle of the head were found between the two strategies (Fig. 4). Firstly, the yaw angle under the proactive strategy had a linear increase (R^2=0.9320) between four intensities ($p<0.05$). The reactive strategy showed a linear regression as well (R^2=0.8425) between the intensities, but lower. Like the roll angles, the yaw angles showed the opposite phase between the two strategies (Fig. 1 (middle), (right)). In the reactive strategy, the head was pointing outwards when the platform reached the maximum displacement, roll and yaw to the outer direction; however, in the proactive strategy, the head was pointing inwards at the end, roll and yaw to the centre. The roll angle and the yaw angle always appeared in the opposite phase. This showed that roll is coupled with yaw. While the phase was opposite between the strategies, the amplitudes were corresponding in size. The difference in the angles were less than 12% in every intensity. This is different from the roll angle, which differed depending on the strategies.

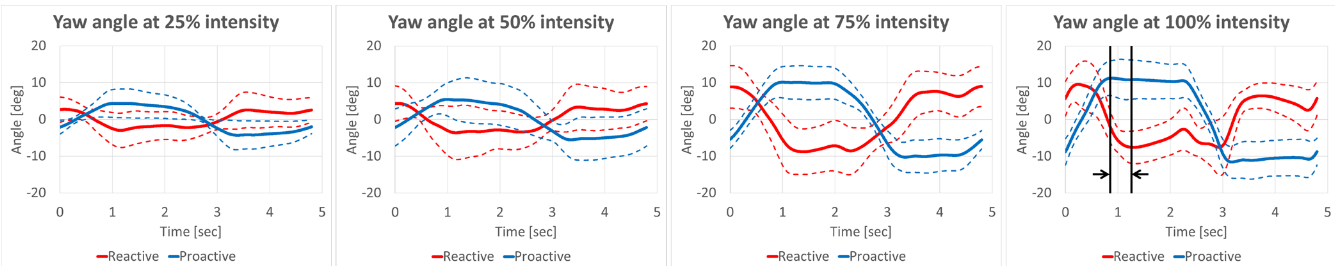

Fig. 4. Comparison of yaw angle (R_z) of the head at four intensities

After all, the kinematics were normalised to compare the head kinematics independently from the intensities. For normalisation, the motion of the occupants was divided by the motion of the driving simulator in each intensity. (Fig. 5) In the reactive strategy, as the intensity of the platform increased, the normalised values decreased. In contrast, in the proactive strategy, normalised values were constant without regard to the intensities. The result shows that in the reactive strategy, the rate of increase in the head kinematics was smaller than the rate of increase in the intensities. This could occur because the occupant was belted on the seat and the torso rotated around the pelvis. As the upper body rotated, the occupant resisted the growing motion not to fall, leading to a decrease in the rate at which the roll angle increased. At the same time, the lateral displacement appeared in the form of a sine wave for the roll angle. Accordingly, the combination of actions decreased the rate of increase. On the other hand, in the proactive strategy, the head simply moved as much as the platform did at each intensity. The same movement of the platform was needed to keep the body posture steady.

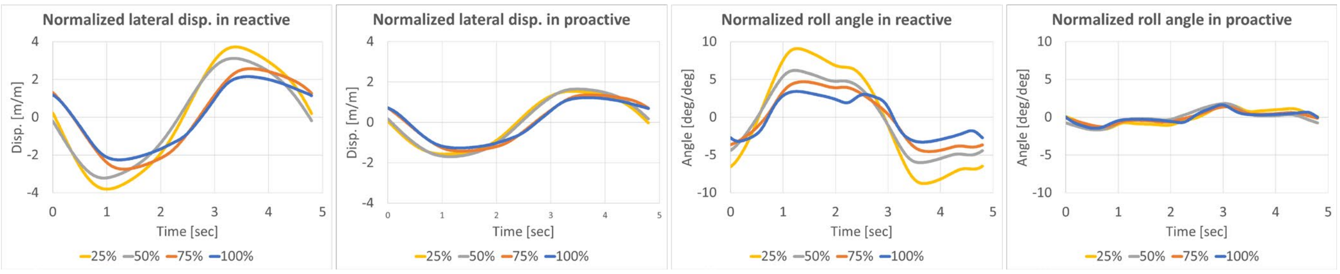

Fig. 5. Comparison of normalised lateral displacement (D_y) and roll angle (R_x) at four intensities

The differences between the maximum value and the minimum value are listed in TABLE I. The range calculated is the same as the range shown in the figures above. A standard deviation is not written in the table since the standard deviation in the figures above was calculated in every moment, while the range is calculated in the whole cycle.

TABLE I
RANGE OF HEAD KINEMATICS IN ALL TEST CONDITIONS

Condition	Reactive				Proactive			
	25%	50%	75%	100%	25%	50%	75%	100%
Roll [°]	31.3	42.8	48.5	47.0	5.6	12.2	13.9	21.7
Sway [m]	0.53	0.89	1.12	1.23	0.22	0.47	0.58	0.70
Yaw [°]	5.7	8.0	17.8	17.1	8.7	11.0	20.4	22.8

IV. DISCUSSION

In this experiment, the head kinematics of the male occupants were compared in different intensities considering the two stabilising strategies, which were *reactive* and *proactive*. Due to the limited resources, the numerical model of the 50th percentile male was first developed and for the same reason was tested the earliest in order. Analysis of other HBM in different body size and gender may be extended in further study. The motions provided from the driving simulator was not completely the same as the behaviour of driving vehicles, though it had been produced in various intensities. Additionally, the motions had limitations in producing due to the size of the simulator. Still, the motions required for the experiment were within the operating range and the kinematics had been analysed from the precise reproduction of the motions. In the second part of this study, the head kinematics will be used as input of virtual simulation, so-called *augmented simulation*, to obtain the body kinetics, especially the joint torques. Moreover, the outcomes of this research will be served as a validating data set for virtual human body modelling, which addresses the safety and comfort issues of the occupants in diverse seated conditions.

V. REFERENCES

[1] Manyong Han et al., Japanese Modelica Conference, 2018.
[2] Dongwook Shin et al., JSAE Annual Congress, 2019.
[3] Christine Holt et al., IRCOBI Conference, 2018.
[4] Philipp Huber et al., IRCOBI Conference, 2013.