Time-Dependent Changes in Pelvic Posture of Occupants During Vehicle Travel

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I. INTRODUCTION

The pelvic angle of vehicle occupants significantly influences the interaction between the lap belt and the anterior edge of the ilium, thereby affecting the risk of submarining. Although this angle has been widely examined in laboratory settings, little is known about how it evolves during real-world vehicle trips. Markis [1], for example, noted only slight changes in shoulder belt position among rear-seat passengers while seated. Hansson [2] observed an average pelvic angle variation of approximately 5° in 20 front seat passengers during three short trips. Over longer periods, posture may shift gradually due to fatigue or physical discomfort. To explore this possibility, we measured the pelvic position and orientation of three participants seated in the front passenger seat and the rear seat during a vehicle trip lasting more than one hour.

II. METHODS

Pelvis Posture Measurements

The pelvic angle was measured using an angular sensor that detects gravitational direction (Fig. 1). The sensor was attached to the skin over the participant's iliac crest with medical tape while standing, allowing the indicated angle to represent orientation relative to horizontal (Fig. 2). While the participant was seated in the vehicle during the trip, the sensor angle α was continuously monitored to reflect deviations in pelvic angle from the standing posture. A sheet-type sensor, composed of 16 tape switches placed at 10 mm intervals was attached to the seat surface to estimate pelvis position. A low-pass filter (cutoff frequency 0.2 Hz) was applied to the sensor data.

The angle between the lap belt and the pelvis was calculated as follows. While the participant was standing, the locations of the ASIS and PSIS were identified by palpation, and their positions were measured. Based on these measurements, the angle $\theta_{\mathrm{S-AP}}$ defined as the angle between the direction of the angular sensor and the line connecting the ASIS and PSIS was determined. By adding $\theta_{\mathrm{S-AP}}$ to the sensor angle α, the ASIS-PSIS pelvic angle $\theta_{\mathrm{ASIS-PSIS}}$ (i.e., the angle between the ASIS-PSIS line and the horizontal) during sitting was calculated as:

$$\theta_{\mathrm{ASIS-PSIS}} = \alpha + \theta_{\mathrm{S-AP}} \quad (1)$$

The angle of the anterior edge of the ilium $\theta_{\mathrm{ASIS-AIIS}}$ (i.e., the angle of the line connecting the ASIS and the AIIS from the horizontal plane) which is directly related to lap belt engagement with the ilium, was approximated based on the regression between $\theta_{\mathrm{ASIS-PSIS}}$ and the $\theta_{\mathrm{ASIS-AIIS}}$, derived from CT images of 30 females [2]:

$$\theta_{\mathrm{ASIS-AIIS}} = 0.899 \times \theta_{\mathrm{ASIS-PSIS}} - 64.6° \quad (2)$$

The belt-pelvis angle θ_{BP} (i.e., the angle between the lap belt and the anterior edge of the ilium) was calculated:

$$\theta_{\mathrm{BP}} = \theta_{\mathrm{ASIS-AIIS}} - \theta_{\mathrm{Belt}} - 90° \quad (3)$$

Finally, the probability of submarining was evaluated based on θ_{BP} and the belt-ASIS overlap D, using criteria derived from human body model analyses by Takeuchi et al. [3].

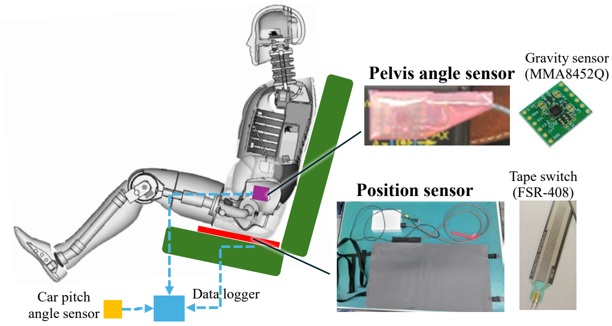

Fig. 1 Sensors to measure pelvis posture

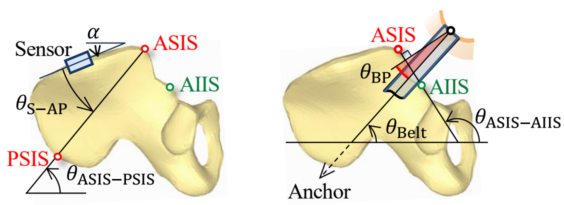

Fig. 2 Pelvis angle definition

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Participants

The study included three participants: Male 1 (167 cm, 65 kg), Female 1 (161 cm, 57.5 kg), and Female 2 (152 cm, 50 kg). Each participant was seated in the front passenger seat and the rear seat during trips (lasting one hour or more) that included expressway travel. In the rear seat, Male 1 was seated in a second-row captain's seat in an MPV, while Female 1 and Female 2 were seated in a flat-cushioned rear seat in a car. This study was approved by the Ethics Committee of the School of Engineering, Nagoya University (2024-23-29).

III. INITIAL FINDINGS

Pelvic position and angle were closely related; as the pelvis positioned anteriorly, it tilted rearward with a large pelvic angle. In the front passenger seat, both pelvic position and angle remained stable with pelvic angle variations within 8° for all three participants. In contrast, in the rear seat, pelvic position and angle varied considerably over time (Fig. 3). Initially, after sitting down, Male 1 adjusted his pelvic position and angle to find a comfortable posture. Subsequently, the pelvic angle and position showed cyclic variations of 30° and 150 mm changes, every 10 minutes. When participants fell asleep, they adopted a maximally slouched posture.

Fig. 4 shows the belt-pelvis angle θ_{BP} and the belt-ASIS overlap D over one cycle of posture change for Female 1 and Female 2 in the rear seat. Although the initial values of $(\theta_{\mathrm{BP}}, D)$ were far from the submarining threshold line, θ_{BP} increased while D decreased over time as the posture shifted from upright to slouched. As a result, the $(\theta_{\mathrm{BP}}, D)$ point for Female 1 exceeded the submarining threshold line with a submarining probability of 98%, while that for Female 2 approached the threshold with a probability of 23%. Female 2 initially adopted a slouched posture due to her short thigh length relative to the seat depth. However, her pelvic angle did not fall within the submarining area owing to her inherently upright pelvic orientation. Her torso was sometimes twisted, possibly to avoid prolonged slouching.

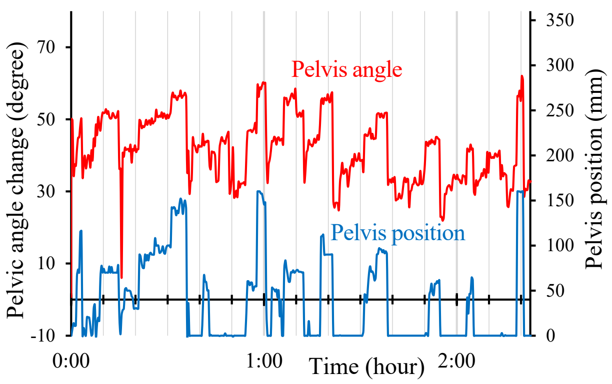

Fig. 3 Pelvic angle change from the standing height, and pelvic position for Male 1 in the rear seat.

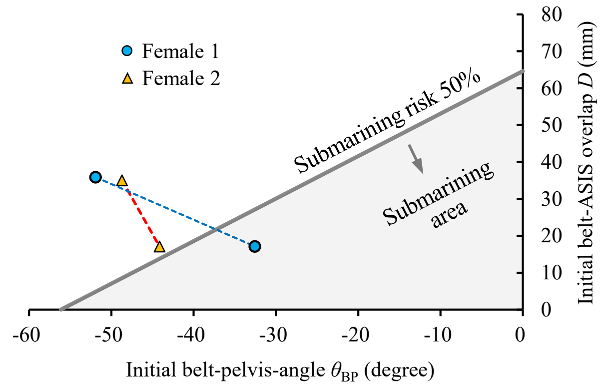

Fig. 4 Belt-pelvis angle and belt-ASIS overlap during one cycle of posture change for Female 1 and Female 2 in the rear seat.

IV. DISCUSSION

This study demonstrated that while the pelvic angle remained stable in the front passenger seat, it changed cyclically from an upright to a slouched posture over time in the rear seat. Even when the initial belt-pelvic angle and lap belt-ASIS overlap were within the non-submarining range, these parameters varied cyclically and could eventually exceed the submarining threshold. The reasons for the differences in posture changes between the front and rear seats remain unclear; seat geometry, such as a bucket-type seat cushion and lumbar support, may contribute. Seated posture is likely influenced by individual characteristics, relaxation levels, and fatigue, which may lead to poor test repeatability. Further research will explore the influence of seat design and individual factors such as age, height, and weight on cyclic pelvic postures, using a larger sample size.

V. FUNDING

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VI. REFERENCES

[1] Makris et al. IRCOBI 2023.
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[2] Hansson, Master's thesis, Chalmers University of Technology 2019.
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