Sensitivity of Occupant Response to Seat Position Variations in Euro NCAP CP-551 Virtual Testing using THUMS and HIII

Marius Rees, Steffen Peldschus, Philipp Wernicke

I. INTRODUCTION

Human Body Models (HBMs) have historically been used primarily in research and development to improve the understanding of occupant biomechanics and injury mechanisms. More recently, their role has expanded towards regulatory and consumer testing applications. In particular, the Euro NCAP CP-551 protocol [1] introduces the use of HBMs for frontal impact assessment, including the evaluation of multiple seat positions. Currently, HBM-based metrics are mainly used for monitoring, with a transition to assessment already defined. While the protocol enables the use of qualified HBMs, the influence of the selected occupant surrogate model on the predicted occupant response is not yet fully understood. In addition to HBMs, anthropomorphic test devices (ATDs), such as the Hybrid III 50th percentile (HIII) and THOR-50M, continue to be widely used in safety assessment. The present study therefore investigates the sensitivity of occupant response to seat position variations across different model types, focusing on relative changes within each model rather than absolute differences between models.

II. METHODS

Simulations were conducted based on the Euro NCAP CP-551 virtual testing frontal impact protocol in a vehicle environment representative of a modern BMW sedan. Four seating positions were defined following the protocol-specified load cases. The target positions were derived using the prescribed ergonomic positioning procedure, based on anthropometric inputs and vehicle geometry. Position 1 represents the reference configuration, while positions 2–4 correspond to systematic variations in vertical and fore-aft seat adjustment (Fig. 1, *left*).

For each seating position, three occupant surrogate models were considered: THUMS v4.1; HIII 50th percentile; and THOR-50M. All models were positioned according to the calculated target locations of the seat and occupant reference points and restrained consistently across all configurations to ensure comparable initial conditions. The same crash pulse, boundary conditions and restraint system configuration were applied across all simulations in accordance with the protocol requirements. In the present study, results are reported for THUMS and HIII, while the analysis of THOR is ongoing and will be presented in future work.

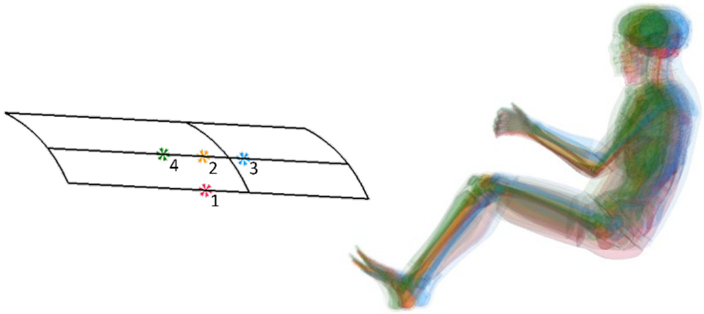

Fig. 1. Seating position definitions according to the Euro NCAP CP-551 protocol [1]. *Left*: seat adjustment space. *Right*: THUMS v4.1 in all positions.

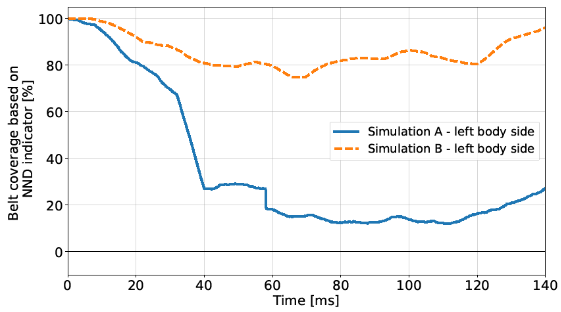

Fig. 2. Example time histories of belt coverage derived from the NND-based indicator [2]. Sim. A = low coverage = higher risk. Sim. B = high coverage = lower risk.

To assess the influence of seat position, results were analysed in terms of relative changes with respect to the reference configuration (Position 1, highlighted in red in Fig. 1). While multiple injury-related metrics were considered, this publication focuses on submarining-related belt behaviour. This behaviour is quantified using a

M. Rees (e-mail: marius.rees@bmw.de) and P. Wernicke are safety engineers at BMW AG in Munich, Germany. S. Peldschus is Professor for Forensic Biomechanics at Ludwig-Maximilians University in Munich, Germany.

nearest-node dynamic (NND)-based belt coverage indicator previously introduced in [2]. The indicator provides a time-dependent measure of lap-belt interaction with the pelvis at the anterior superior iliac spine (ASIS), expressed as a relative belt coverage. An example of two simulations is shown in Fig. 2. The minimum value of the belt coverage time history was extracted as a characteristic metric, representing the most critical belt position with respect to potential submarining.

III. INITIAL FINDINGS

Figure 3 shows the relative change in minimum belt coverage with respect to the reference configuration (POS1) for THUMS and HIII. For THUMS, POS2 and POS4 show an increase in minimum belt coverage of around 10% on the left side and up to approximately 20–25% on the right side, indicating a less critical belt position. POS3 shows a decrease of about 10% (left) and up to nearly 20% (right), representing the most critical configuration. This asymmetry suggests differences in belt–pelvis interaction between both body sides. For HIII, changes remain small, generally below 10%, but always positive. Slight increases in minimum coverage are observed for POS2 and POS3, particularly on the right side, while POS4 shows only minor improvements on both sides.

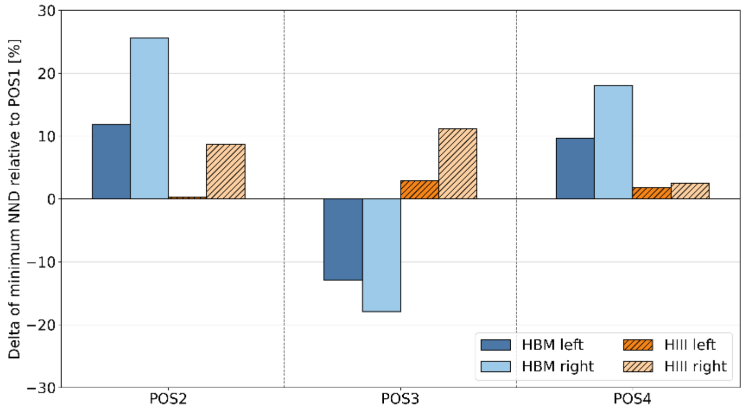

Fig. 3. Relative change in minimum belt coverage with respect to the reference configuration (POS1) for the left and right body side of THUMS and HIII.

IV. DISCUSSION

Seat position has an influence on belt–pelvis interaction and thus on submarining-related behaviour. This sensitivity is more pronounced for THUMS than for HIII, as THUMS shows both larger increases and decreases in minimum belt coverage, whereas HIII exhibits only small positive changes. Across the investigated positions, a consistent trend is observed, with reduced risk for a higher (POS2) and more forward (POS4) seating position, and an increased risk for a more rearward position (POS3). The lowest risk would be expected for the most forward position (POS4), as earlier foot contact can limit forward pelvis motion, stabilising pelvic rotation and promoting earlier belt engagement. However, this was not fully confirmed. POS2 shows comparable (left body side) with even larger improvements (right body side) than POS4 in some cases. This will be further analysed in future work.

Within the current Euro NCAP CP-551 protocol, HBMs are used for monitoring, with a transition to an assessment phase already defined. In this context, the inclusion of kinematics-based criteria, such as submarining, could be a meaniningful first step for HBM vehicle assessments. The NND-based indicator can serve as a suitable tool because it provides a computationally efficient approach to quantify belt–pelvis interaction and to compare seating configurations in a consistent manner. It may therefore serve as a basis for assessing the robustness of belt performance across seating positions. For this purpose, suitable evaluation criteria still need to be defined, for example which belt coverage levels can be considered sufficiently robust. This would require statistical analysis based on large simulation datasets, potentially supported by data-driven approaches such as reduced-order or surrogate modelling techniques to enable a statistical evaluation of the indicator.

The present study is limited to a single vehicle environment and specific modelling assumptions, including restraint system parameters and contact definitions such as friction. Future work will extend the analysis to additional models, including THOR and other HBMs, and will incorporate further injury-related metrics such as HIC, neck forces, chest compression and lumbar spine forces.

V. REFERENCES

[1] Euro NCAP, Technical Bulletin CP-551, 2025.

[2] Rees, *et al*., *IRCOBI*, 2025.