Effects of non-conventional driving posture on the passive safety of autonomous vehicles. A numerical study using the THUMS human model.

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I. INTRODUCTION

Nowadays, the application of the Human Body Models (HBMs) in the automotive field is rapidly increasing [1-3]. Their use allows to improve the passive safety of the vehicles, as well as to explore those aspects or "gaps" not covered by the traditional crash dummy models. Additionally, the rapid advent of fully Autonomous Vehicles (AVs) requires to study the new emerging passengers' safety scenarios. Accordingly, in this work, an investigation of the occupant protection in case of vehicle frontal impact is carried out, exploiting the opportunities opened by the HBMs. The occupant behaviour in a Level 3 AV crash is analysed. In literature, the effect of some unconventional postures allowed by the Highly Automated Vehicles (Level 4-5), in which the driver can be completely disinterested to the drive, are already investigated [4-6]. In these studies, the position of the seat can be re-oriented with respect to the driving direction, or the backrest can assume large tilt angles. In this overview, the aim of this work is to study to what extent the conditional automated driving (Level 3) can influence the passive safety of a vehicle. This technology requires the human to promptly react to a request of intervention. However, the driver can assume more relaxed positions (e.g. crossed legs, hands away from the steering wheel, etc.) with a consequent possible influence on the passive safety aspects. To this purpose, two drivers' out of design positions (OODPs) were defined and the numerical simulations of vehicle frontal impact were performed. These two postures assume a scenario in which the driver does not hold the steering wheel and the feet are not resting on any of the vehicle pedals. Furthermore, the response of the HBM was evaluated by using direct metrics based on the analysis of bone forces and deformations and internal organ's volume variations.

II. METHODS

The HBM "Total HUman Model for Safety (THUMS) 4.02 Academic Version", developed by the Toyota Motor Corporation, was used for the above-mentioned purpose. The numerical simulations were performed by using the LS-DYNA (LSTC, USA) solver in its explicit formulation. To modify the posture of the THUMS model from the standard seated configuration to the out of design positions the PIPER tool was used. This software links each FE part of the model to the corresponding anatomical structures. Therefore, any finite element simulation is not required to position the HBM. The vehicle used for the simulation consisted in a simplified model (sled test configuration) of an in-production vehicle, supposed to be equipped with Level 3 Autonomous Driving technologies. Two cases of frontal crashes were simulated. The HBM response to these impacts was obtained through sensors placed in the anatomical regions of interest. Additionally, the volume changes in the internal organs were examined.

III. INITIAL FINDINGS

The Figure 1 shows the three different postures considered for the impact simulations. The conventional driving posture is reported in Figure 1a. In both the OODPs the steering wheel and the seatback inclination are supposed to be fixed. In the OODP1, the H-point of the driver is in the standard position and the right foot of the HBM is placed on the vehicle floor, while the hands are not placed on the steering wheel. In addition, the right elbow is laid on the armrest integrated into the vehicle central console.

The Figure 1c shows the OODP2. The H-point of the driver is moved forward, according to a more relaxed posture. Moreover, the legs are crossed, and the left elbow is laid on the left door panel. The hands of the driver are not holding the steering wheel. The simulation results highlighted important differences in the HBM

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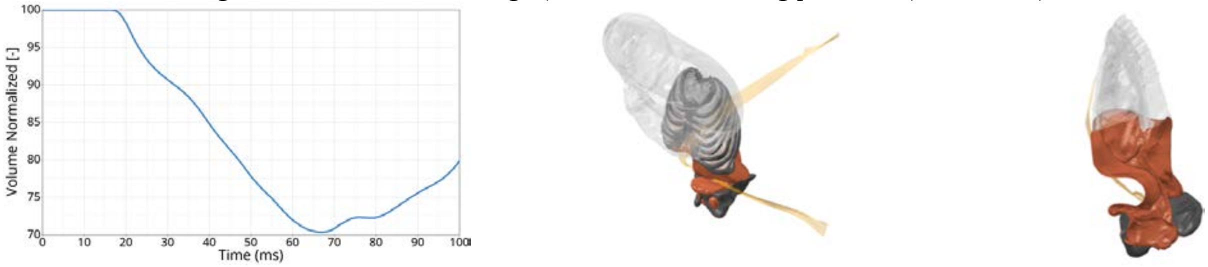
responses between the conventional position and the OODPs. For example, the Figure 2a shows the deformation of the abdomen soft tissues. The volume of this part decreases of about 30% during the impact. The analysis of this parameter highlights a submarining effect (Figure 2c). Indeed, the seat belt demonstrate an upward sliding with respect to the iliac crests, causing a considerable compression of the abdominal internal organs. Furthermore, the forward movement of the hipbone enhanced the impact force of the tibias against the dashboard. The force in the right tibia is approximately doubled in the OODP1 and quadrupled in the OODP2 with respect to the conventional posture. This is due to the shorter initial distance between the tibia and the dashboard in the OODP2. Considering the upper body part, important differences in the biomechanical parameters are present in the neck. In the early stages of the OODP2 simulation, the force peak was about 10 times higher than in the OODP1 and in the standard posture. In the subsequent instants, the neck force assumes an almost constant value but still significantly higher than in the conventional posture. This difference is due to the different position of the safety belt. Indeed, in the OODP2 the torso is more inclined backwards. As a result, the seat belt transfers more force to the neck than to the left side of the shoulder.

a b c

Figure 1: THUMS Positioning. a) Conventional driving position; b) OODP1; c) OODP2



a b c

Figure 2: Conventional driving posture simulation results. a) Abdomen volume variation vs time; b) Abdominal volume during impact (ISO view); c) Abdominal volume during impact (side section view)

IV. DISCUSSION

The influence that different driving postures can have on the passive safety of an Autonomous Vehicle (Level 3) was examined in this work. The study highlighted how even small changes with respect to the conventional driving posture (e.g. seat back inclination, legs and harms position, seatbelt position, etc), can lead to significantly different results in terms of human body responses. These ones were evaluated by measuring the forces and the deformations in different body parts. Moreover, the evaluation based on the volume-variation of the internal organs was introduced and it proved to be an important indicator, especially of the submarining effect. The evaluation of the neck forces revealed that this body segment is the most influenced one from the seat-belt position on the upper-body parts induced by the OODP. The assessment of leg's forces confirmed that a more relaxed posture allowed in the L3 autonomous vehicles requires attention to the lower parts of the dashboard design.

V. REFERENCES

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