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Braking Effects on Occupant Kinematics and Injury during the Full Frontal Impact simulation using Human Model

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Abstract:

Background: Advanced Driver Assistance Systems (ADAS) in combination with the updated passive safety systems is the key to reduce future crash severity and improve the occupant protection performance. The autonomous braking system is able to reduce crash speeds and the crash severity levels significantly. Occupant kinematics would be changed due to certain pre-impact braking, which has not been considered in most in-lab crash tests.

Objective: This study aims to assess the effects of different pre-impact braking events on the occupant kinematics, as well as the injury possibility, by using full frontal impact simulation.

Method: MADYMO simulation and validation of a 50km/h frontal crash test were carried out for the following detailed investigation of dummy forward displacements due to pre-impact braking. The influences of different pre-impact scenarios (with the initial velocity of 80km/h, all leading to equal 50km/h before the crash phase), are considered in terms of vehicle accelerations. Occupant kinematics and potential injury possibility under different braking load cases were analyzed in the study by introducing the human body model. The evaluation is mainly concerning about dummy kinematics as well as contact risk between the dummy and vehicle interior. Besides, the study reviews the contribution of the human model in comparison with the dummy model and discusses the potential of using the human model for detailed simulation.

Results: The result shows that the occupant kinematics of the impact with pre-impact braking is different with that of the C-NCAP 50km/h frontal impact. This difference makes the dummy have high risk of airbag flapping, and the belt retractor has less efficiency in pretensioning (the maximum pull-in amount was reduced about 13mm).

Conclusions: This study recommends changes to occupant restraint systems to fit requirements of occupant forward displacement caused by pre-impact braking. The in-lab crash test considering emergency braking prior to the impact is highly recommended as well for detailed study, for further improvement of the occupant protection performance.

Keywords: Braking effect, Occupant kinematic, MADYMO simulation, Human model

1 Introduction

Pre-crash braking systems are being employed in vehicles on the market currently, and the performance of them is being improved with the availability of more accurate sensor technology and risk estimation algorithms[1]. Autonomous braking systems are able to reduce collision speeds, and therefore severity levels significantly. The Advanced Driver Assistance Systems (ADAS) in combination with the updated passive safety systems is the key to reduce future crash severity and improve the occupant protection performance[2]. The integrated safety is already implemented in the development of new cars, but so far the conventional crash tests do not take into consideration specific impacts of pre-crash braking. As a consequence, the influences of dipping of the vehicle front and possible pre-crash displacements of the occupants have not yet been considered in these crash tests[1,3]. The posture of the occupants prior to the possibly unavoidable crash is known to have a large effect on the injury reducing performance of the restraint system [4]. Ejima et al. performed a series of tests with volunteer seated on rigid seats, restrained by a three-point belt system and subjected to a 600 ms 0.8 G constant deceleration. For a tensed volunteer, kinematic figures indicate that head forward displacement was in the order of 100 mm at 200 ms after impact, while T1 forward displacement was in the order of 25 mm and hip forward displacement around 10 mm. For a relaxed occupant restrained by a lap belt only, the head displacement was in the order of 600 mm at 600 ms after impact with T1 displacement around 400 mm[5].

Integrated vehicle safety is also a challenge for simulation models. Because the restraint systems are developed with different crash tests and simulations, which usually do not take into consideration the effect of the pre-crash braking [6]. Furthermore, a reproducible assessment of the additional benefit of vehicle safety systems, which prepare the occupants for the imminent impact, is not possible [3].

Additionally, most crash tests and simulations are evaluated with Hybrid III dummy models. Several studies have suggested that the Hybrid III dummy is not a good human surrogate in pre-crash maneuvers. Subsequently, the applicability of simulation models based on the Hybrid III dummy may be limited for studying pre-crash maneuvers [7].

Today, human models are frequently used for improvements in occupant and pedestrian protection[6]. In this study, a human model from the MADYMO database is introduced into a validated MADYMO simulation model, for the kinematics comparison and further detailed study. The difference between Hybrid III dummy and Human model was analyzed. To assess the effects of different pre-braking events on the occupant kinematics, as well as the injury possibility, different pre-crash scenarios with the initial speed at 80km/h, all leading to equal closing speeds (50km/h, as that of the C-NCAP full frontal impact), are introduced for the following occupant kinematics analysis and injury evaluation.

2 Method

For this study, a MADYMO model correlated with a 50km/h full frontal crash test was introduced. For further detailed analysis of the effects of different pre-braking events on the occupant kinematics and the injury possibility. The 50% Hybrid III dummy was replaced by the human model from the MADYMO dummy database, as shown in Figure 1.

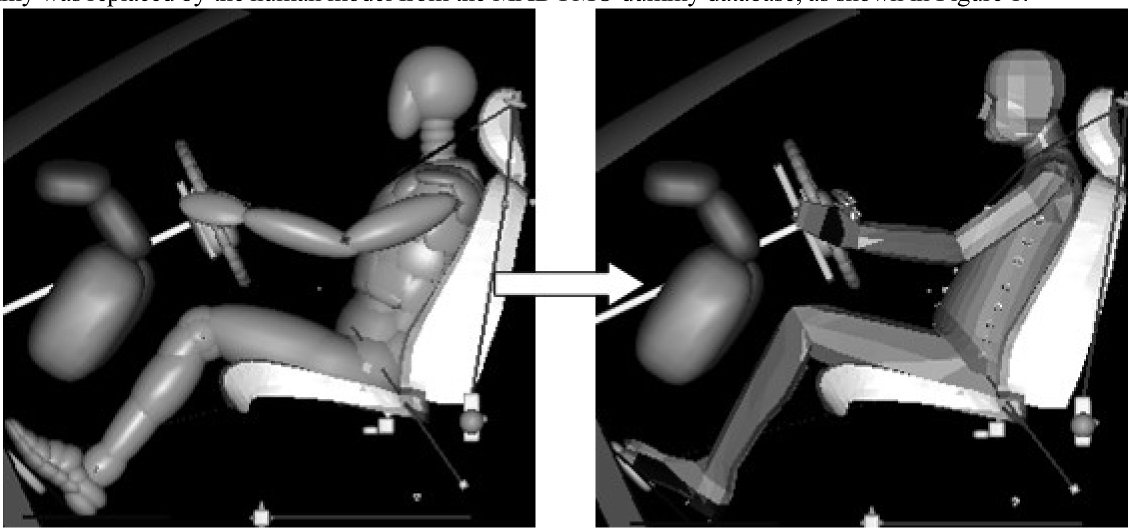

Figure1. The correlated model (left) and model with human model (right)

The shoulder belt forces output from the simulations indicate that the forces form both simulations correlate well with that of the test, while the peak lap belt force from the model with human model is less than that of the test, as shown in Figure 2 below. This is mainly due to the abdomen's deformation of the human model.

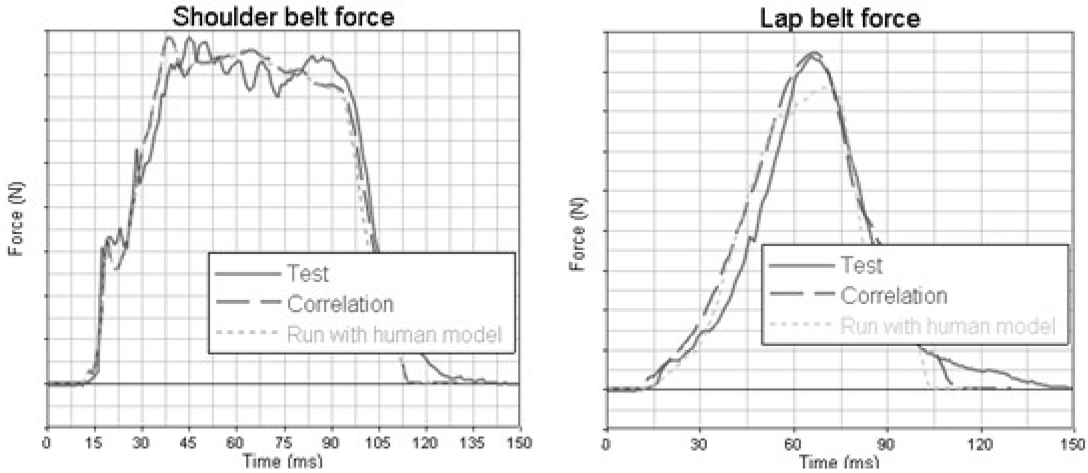

Figure2. Shoulder belt force comparison (left) and lap belt force comparison (right)

The dummy kinematics comparison is shown in Figure 3, which indicates that head displacement of the human model is larger than that of the Hybrid III dummy before the contact with the airbag. The simulations show that human dummy's spine and neck are more flexible than those of an Hybrid III dummy, which correlates well with the finding of the research [8].

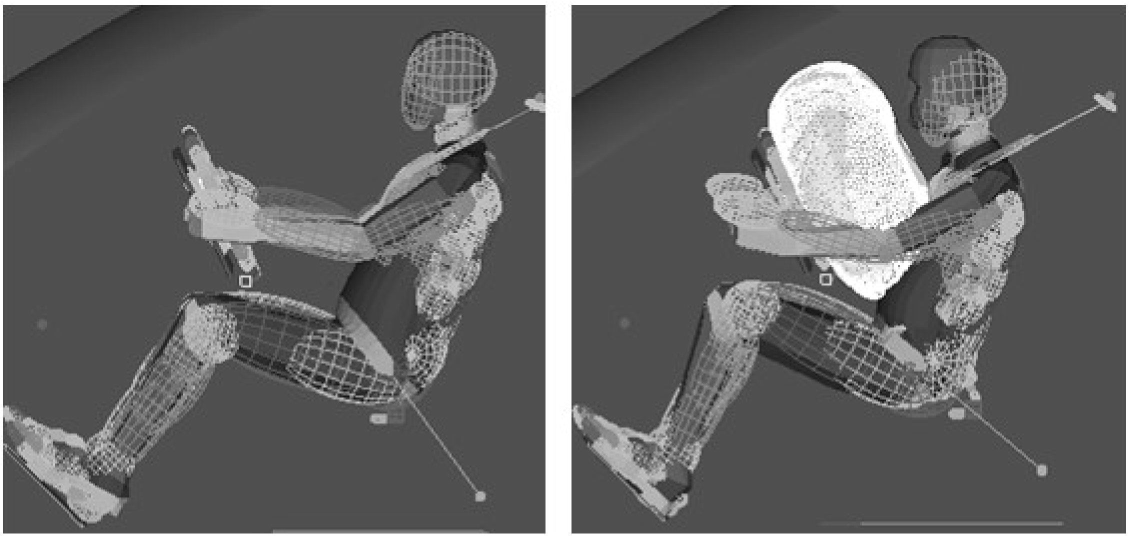

Figure3. Initial positions (left) and kinematics comparison (right)

The MADYMO model with the human model above will be used for the following detailed study on pre-crash braking effects on occupant kinematics.

Vehicle braking deceleration cannot exceed the road coefficient of friction and is accepted to be in the interval of 1.0"g" to 1.3"g" in very rare instances [8]. In this study, accelerations in X direction (without vehicle pitching), were applied on the occupant compartment model to evaluate vehicle braking effects. Two pulses （1: a brake assist system with modulated braking (BAS) and 2: an autonomous braking system (AUT)) approximating possible responses from two types of pre-crash braking systems were introduced for following analysis as in the research of [1]. Both braking pulses assume decelerations from 80 km/h to 50km/h, the pre-impact braking pulses and the total velocity changes are shown in Figure 4.

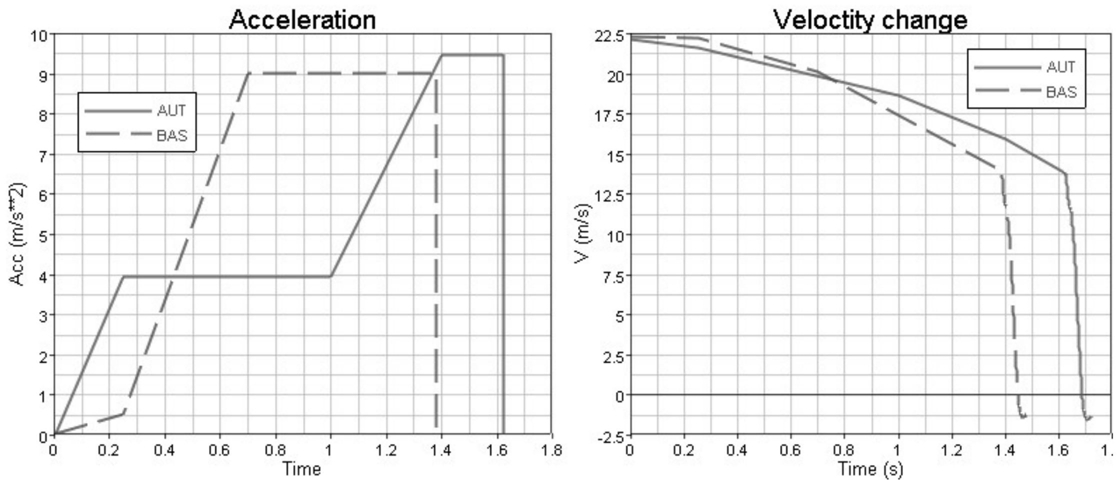

Figure4. Pre-impact braking pulses (left) the total velocity changes (right)

where BAS is the deceleration profile arising from a Brake Assist System in which the driver applied the brake while the system applies the amount of modulated braking necessary to prevent a collision with an object in front. AUT is the deceleration profile from an autonomous braking system that first applies partial braking at 4 m/s2, then full braking to assure collision avoidance.

3 Result s

The pre-impact braking pulses, together with the pulse of a C-NCAP 50FF test , were used as the input of the occupant compartment model. The occupant kinematics from the simulation show that there is a high risk of airbag flapping for the AUT simulation, in which the maximum head forward displacement due to the pre-impact braking was around 110mm, see Figure 5 left. The risk of airbag flapping is less for the BAS simulation, see Figure 5 right.

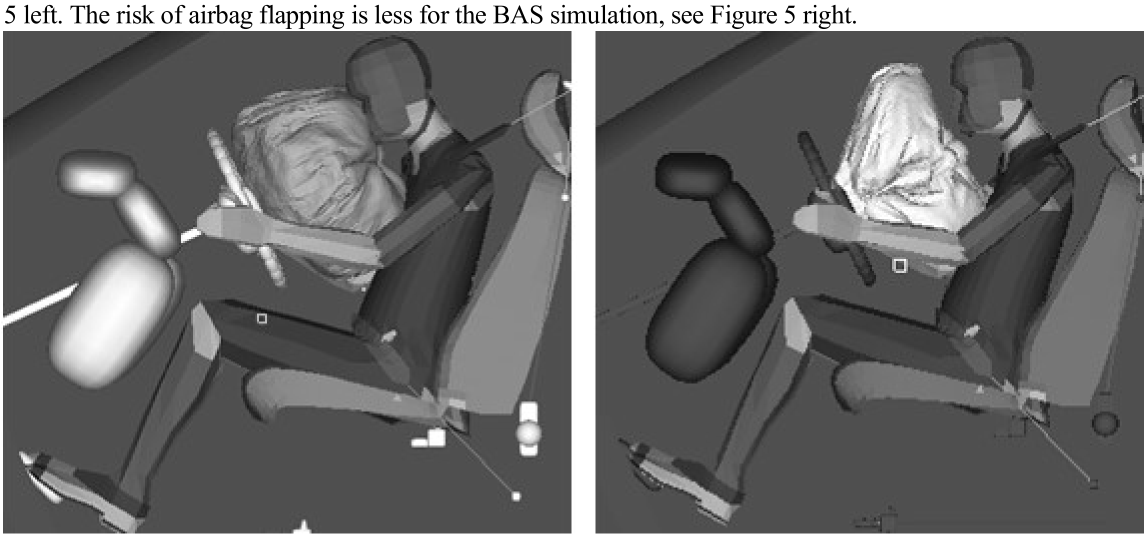

Figure5. dummy model kinematics of AUT simulation (left) and BAS simulation (right)

The pull-in length due to retractor's pretensioning of the original model is 68.7mm, while the length of the BAS model is 55.8mm and the length of the AUT model is 62.0mm, see figure below. The result indicate the pretensioner's efficiency of the impact with pre-impact braking is less than that of the original impact.

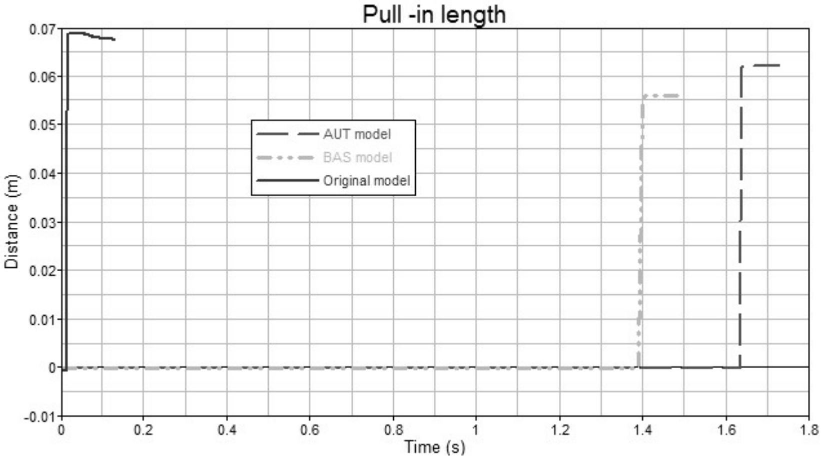

Figure6. Retractor's pull-in lengths of different models

The difference above is mainly caused by the occupant's forward displacements during the pre-impact braking phase. Comparing the should belt forces between AUT model and BAS model, it can be seen that both shoulder belt forces increase during the pre-impact phase, and the maximum force is under 200N, as shown in Figure 7.

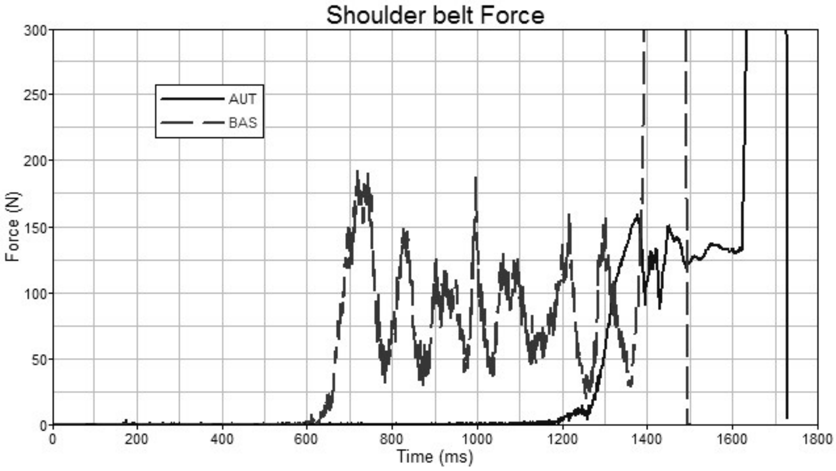

Figure7. Shoulder belt force during the pre-impact phase

The simulation result also indicates that there is little risk of hard contact between head and steering wheel, as shown in figure below.

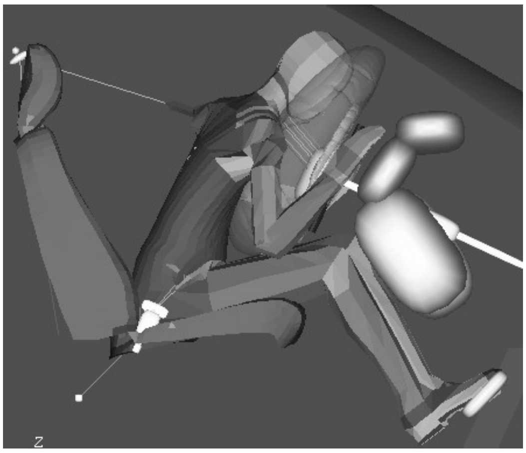

Figure8. No hard contact between head and steering wheel in the simulations

4 Conclusions

Based on the above study, the following conclusions are drawn:

1). Human dummy 's spine and neck are more flexible than those of the Hybrid III dummy model;

2). Pre-braking events have large effect on the occupant kinematics, especial for the head displacement;

3). Changes to occupant restraint systems to fit requirements of occupant forward displacement caused by pre-impact braking are highly recommended;

4). Further detailed research about in-lab crash test considering autonomous pre-impact braking prior to the impact is highly recommended as well;

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