Parametric Study on the Influence of Impact Energy and Inflation Pressure on the Effectiveness of a Cervical Airbag

Juan M. Asensio-Gil, Ema Jokubaityte, Manuel Valdano, Nil Oleaga-Ortega, Lucas Llobet-Cusí, Francisco J. Lopez-Valdes

I. INTRODUCTION

Despite advances in cyclist safety, spinal injuries, especially upper cervical spine injuries, have not seen a similar decline in occurrence as other injuries and remain a critical concern that increases death probability by up to 15 times [1-3]. These cervical injuries are often the result of impacts to the head during collisions, highlighting the need for improved protective gear. Helmets, while effective against head and brain injuries, show mixed results regarding neck injury prevention [3-6]. Airbag helmets have shown promise in reducing impact forces and potentially mitigating neck injuries [7-9]. However, empirical data on their effectiveness in real-world conditions, particularly in preventing cervical hyperextension, is limited. This study builds on previous findings from [10], focusing on the effect of airbag inflation pressure and impact energy on the performance of cervical airbags in controlling head kinematics and neck hyperextension, addressing a gap in understanding the optimal configuration for injury prevention.

II. METHODS

The Finite Element Analysis (FEA) with LSTC LS-DYNA software was used to perform this parametric study. The MPP option with version 9.3.1 and single precision was utilised. A computer model based on the experimental study of [10] was created to enable kinematic validation of the computational model. This experimental study forced the neck hyperextension of a Hybrid III dummy through a 0.5 m free-fall, simulating a high-energy impact of a cyclist on a hard surface.

Computational model description and validation

The simulation system consisted of four components: the ATD Hybrid III 50th percentile male model version D01.11; a rigid table on which the dummy lay; an open-face helmet; and a cervical airbag. The helmet was modelled using 3D scanning of the experimental one, while the airbag manufacturer, EVIX, provided the 3D model of the airbag. The material properties of the helmet were simplified to those of a rigid body, as during the experimental test the helmet did not interact with any other component except for the airbag, a much softer material. The airbag material properties used were those of a standard motor-vehicle airbag. The mesh size of the helmet and airbag models ensured geometrical accuracy without compromising the simulation timestep, and standard mesh quality metrics were considered. Regarding the interaction between components and initial positioning, no relative motion between the head and helmet was captured during the experiment, so the helmet was constrained to a rigid component of the dummy. The airbag position during the simulation was controlled using three springs. The dummy was fixed to the table using two seatbelts at the thorax and pelvis, as in the experimental tests. The positioning of components was performed by image superposition and measurement of key landmarks.

The simulation system validation was carried out by comparing head kinematics (resultant linear acceleration and angular velocity) and neck hyperextension using visual assessment and CORA (CORrelation and Analysis, corridor and cross-correlation methods) in four different configurations: no airbag; and three configurations in which the airbag was inflated at different pressures (0.1 bar, 0.15 bar and 0.20 bar). The 0.5 freefall boundary condition was applied as an inverted fixed acceleration to the table using a CFC 180 filtered curve calculated from the mean outputs of the table accelerations of the experimental tests (which were proved to be repeatable). This boundary condition applied a 139 g acceleration in 10 ms. Table I shows the average CORA results obtained.

Simulation matrix and output data

The simulation matrix for the parametric study adjusted the airbag inflation pressure and impact energy. The

J. M. Asensio-Gil (e-mail: jasensio@comillas.edu; tel: +34686623353) and M. Valdano are PhD Candidates and Research Assistants, E. Jokubaityte is a B. Eng. and Research Intern and F. J. Lopez-Valdes is an Associate Professor and Researcher at MOBIOS Lab, Institute for Research in Technology (IIT), Comillas Pontifical University in Madrid, Spain. N. Oleaga-Ortega and L. Llobet-Cusí are co-founders of EVIX, located in Mataró, Spain.

airbag inflation pressure was varied from 0 bar (or no airbag present) to 0.5 bar, which is the largest potential functional pressure of the airbag. The impact energy was varied as a multiple of the free-fall height, ranging from 0.5 m to 1.5 m. The resultant linear acceleration and angular velocity of the head were output alongside the neck hyperextension angle. In addition, BrIC (CSDM-based) [11] and DAMAGE (MPS-based) [12] injury criteria were calculated.

TABLE I
CORA VALIDATION RESULTS

	Head lin. acc.	Head ang. vel.	Neck hypertext.
0 bar	0.699	0.842	0.965
0.1 bar	0.577	0.806	0.988
0.15 bar	0.656	0.800	0.957
0.2 bar	0.661	0.841	0.922

TABLE II
BRIC/DAMAGE AIS2 PROBABILITIES (%)

	0.5 m	1 m	1.5 m
0 bar	0.0/7.0	1.5/22.0	14.4/30.0
0.1 bar	0.0/11.0	6.5/34.0	25.3/45.0
0.3 bar	0.0/10.5	3.7/33.5	21.7/44.5
0.5 bar	0.0/10.0	2.9/33.0	21.2/44.5

III. INITIAL FINDINGS

Figure 1 shows the initial findings regarding the head resultant linear acceleration and angular velocity, the neck hyperextension angle, and Table II shows the calculated probabilities of AIS2 (Abbreviated Injury Scale, moderate injuries) for BrIC and DAMAGE criteria.

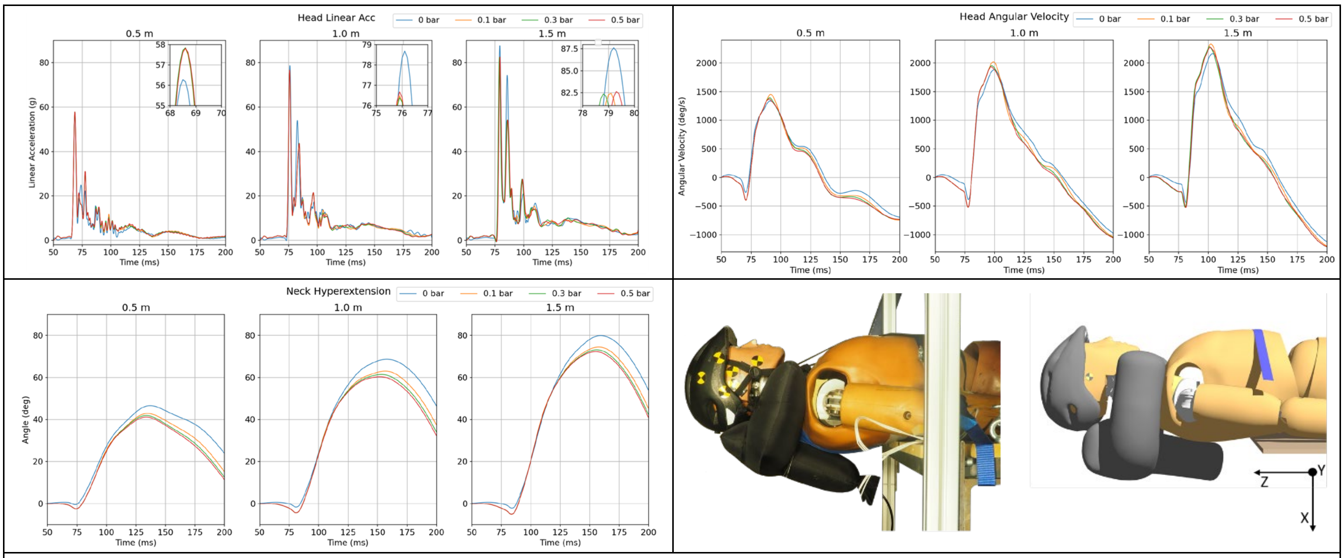

Fig. 1. Head linear acceleration and angular velocity, neck hyperextension. Coordinate system of impact setup.

IV. DISCUSSION

Higher inflation pressures reduced neck hyperextension while slightly increasing the rotational speed of the head. Moreover, the resultant linear acceleration on the head also seems to be reduced when introducing a cervical airbag at higher impact energies. However, these preliminary results point out a trade-off between reducing neck hyperextension and increasing head angular velocity, especially at higher energy levels. The addition of a ventilation hole, similar to that of motor-vehicle airbags, could have the potential to reduce the risk of brain injury while still decreasing neck hyperextension. Additionally, these findings indicate a threshold beyond which increased inflation pressures do not significantly affect the measured and calculated outputs. The main limitation of this study lies in the use of the Hybrid III ATD to study neck hyperextension [10].

V. REFERENCES

[1] Jackson, S. R., *et al.*, *Orthop Surg*, 2002.
[2] DePasse, J. M., *et al.*, *World Neurosurg*, 2019.
[3] Rivara, F. P., *et al.*, *Inj Prev*, 1977.
[4] Elvik, R., *Accid Anal Prev*, 2011.
[5] Sage, P. S., *et al.*, *Br J Neurosurg*, 2020.
[6] Olivier, J., *et al.*, *Int J Epidemiol*, 2016.
[7] Condrea, O. A., *et al.*, SIAR Congress, 2020.
[8] Stigson, H., *et al.*, IRCOBI Conference, 2017.
[9] Kurt, M., *et al.*, *Ann Biomed Eng*, 2017.
[10] Vives, *et al.*, IRCOBI Conference, 2023.
[11] Takhounts, E. G., *et al.*, *Stapp Car Crash J*, 2013.
[12] Ellway, J., *et al.*, TB035 Euro NCAP, 2022.

Parametric Study on the Influence of Impact Energy and Inflation Pressure on the Effectiveness of a Cervical Airbag

Juan M. Asensio-Gil, Ema Jokubaityte, Manuel Valdano, Nil Oleaga-Ortega,
Lucas Llobet-Cusí, Francisco J. Lopez-Valdes, Carmen M. Vives-Torres, Jaime Alvarez-Fernandez

ERRATUM

The purpose of this erratum is to acknowledge an update to the co-authorship of this communication. This study utilized validation data from the IRC-23-21 experimental study, experiments to which two additional colleagues also contributed. The updated footnote is also included in this erratum.

J. M. Asensio-Gil (e-mail: jasensio@comillas.edu; tel: +34686623353), M. Valdano and C. M. Vives-Torres are PhD Candidates and Research Assistants, E. Jokubaityte is a B. Eng. and Research Intern, J. Alvarez-Fernandez is an MSc Eng., and F. J. Lopez-Valdes is an Associate Professor and Researcher at MOBIOS Lab, Institute for Research in Technology (IIT), Comillas Pontifical University in Madrid, Spain. N. Oleaga-Ortega and L. Llobet-Cusí are co-founders of EVIX, located in Mataró, Spain.