A Novel Methodology for Evaluating Occupant Response in Low Acceleration Time-Extended Events

Thomas Seacrist, Jason R. Kerrigan, Christine Holt, Sriram Balasubramanian,
Acen Jordan, Richard W. Kent, Kristy B. Arbogast

I. INTRODUCTION

Motor vehicle crashes (MVC) remain a leading cause of mortality and morbidity for children and young adults worldwide [1]. Head injuries, specifically, are the most common serious injury sustained by children in MVCs [2-3], with head contact to the vehicle interior being the primary causation scenario for injury [4]. Most previous automotive safety research has emphasised the impact phase of MVC and current automotive safety countermeasures, such as airbags and seatbelts, are designed primarily to minimise the adverse events resulting from crash forces during impact. However, it is also necessary to study the pre-crash manoeuvres preceding impact, such as evasive swerving or lateral furrowing. Previous research has shown that 60% of crashes involve some form of pre-crash manoeuvre [5]. These events, although low acceleration, take place over a relatively long time-frame compared to the impact event and are thus termed low acceleration time-extended (LATE) events. LATE events modify the occupant "state" (initial position, posture, muscle tension), potentially leading to decreased effectiveness of the restraint system and increased likelihood of head contact with the vehicle interior. Prior analysis of the National Highway Traffic Safety Administration (NHTSA) databases identified pre-crash manoeuvres as a contributing factor to head impact with the vehicle interior [4]. Additionally, as active safety technologies (AST) come to fruition, automated vehicle manoeuvres that occur prior to a crash may result in increased frequency and magnitude of displacement of the occupant state. Hence, it is paramount to study the motion of the occupant during LATE events because the optimal performance of restraint systems requires an accurate assessment of the pre-impact position of the occupant. This paper describes the development of a methodology to evaluate occupant response in LATE events, utilising both human volunteers and post-mortem human subjects (PMHS).

II. METHODS

The initial focus of this laboratory test method was to provide the oscillatory loading experienced by an occupant during pre-crash emergency swerving. A meta-analysis of previous laboratory and on-road studies was conducted to determine the appropriate oscillatory acceleration and magnitude that is safe for human volunteer testing and also representative of pre-crash field data. Based on this analysis, a novel, non-injurious test fixture, known as the LATE device, was designed to mimic pre-crash swerving (Fig. 1). An occupant compartment capable of mimicking various automotive seating environments was also designed (Fig. 2).

The study protocol was approved by the Institutional Review Board at the Children's Hospital of Philadelphia. Healthy volunteers (9–40 yrs) will be exposed to a series of oscillatory accelerations with varying parameters. Details of the loading conditions are provided in the Initial Findings, below. Volunteers will be restrained using a standard three-point belt. Kinematics will be evaluated using photo-reflective markers placed on key anatomical landmarks, including the head, torso and extremities, and tracked via cameras onboard the seating compartment. Muscle response will be quantified using surface electromyography (EMG) electrodes placed on the musculature of the neck, torso, abdomen and extremities. To establish maximum voluntary contraction, subjects will push with maximum effort against a load measurement device for each muscle group. Dynamic muscle response will be normalised by maximum voluntary contraction and correlated with the kinematics. Novel countermeasures to mitigate pre-crash motion will also be evaluated. The human volunteer data will inform pre-crash positioning for PMHS tests, which will allow for countermeasure assessment into an injurious regime of loading.

III. INITIAL FINDINGS

Results of the meta-analysis are listed in Table I. Previous pre-crash swerving research ranged from 0.5 to 1.2 *g*'s. Based on these data, the LATE device was developed to mimic pre-crash swerving. The LATE device is

T. Seacrist (e-mail: seacrist@email.chop.edu; tel: +1 267 426 5432) is a Project Manager and K. B. Arbogast is Co-Scientific Director at the Center for Injury Research and Prevention at the Children's Hospital of Philadelphia. J. R. Kerrigan is an Assistant Professor and R. W. Kent is a Professor in the Department of Mechanical and Aerospace Engineering at the University of Virginia. C. Holt is a PhD student and S. Balasubramanian is an Assistant Professor in the School of Biomedical Engineering, Science and Health Systems at Drexel University, Philadelphia. A. Jordan is a mechanical engineer at Jordan & Co., Carmel, USA.

capable of delivering up to 1 *g* of sinusoidal oscillatory acceleration. This loading environment was determined to be safe for the study population based on amusement park standards (ASTM F2291).

TABLE I
PREVIOUS PRE-CRASH MANOEUVRE STUDIES

Reference	Peak Accel	Population	Manoeuvre	Primary Metric
Laboratory Testing				
Ejima *et al.*, 2012	0.6 *g*	Adult (n=3)	Lateral Acceleration	Kinematics, EMG
Kirschbichler *et al.*, 2011	0.5 *g*	Adult (n=11)	Lateral Acceleration	Kinematics, EMG
Parenteau *et al.*, 2006	0.7 *g*	Adult (n=3)	Fishhook	Kinematics
Van Rooji *et al.*, 2013	0.7 *g*	Adult (n=10)	Lateral Acceleration	Kinematics, EMG
Closed Track / On Road Testing				
Bohman *et al.*, 2011	0.9 *g*	Paediatric (n=16)	Sharp Turn/Curve	Kinematics
Howe *et al.*, 2002	0.6, 0.8 *g*	N/A	Resonant Steer, Fishhook	Vehicle Dynamics
Huber *et al.*, 2013	1.0 *g*	Adult (n=21)	Lane Change	Kinematics, EMG
Kirschbichler *et al.*, 2014	1.0 *g*	Adult (n=57)	Lane Change	Kinematics
Breuer *et al.*,1998	1.2 *g*	N/A	Lane Change	Vehicle Dynamics
Kim *et al.*, 2013	10 *g*	N/A	Slalom	Vehicle Dynamics
Stockman *et al.*, 2013	0.8 *g*	Paediatric ATD	Sharp Turn/Curve	Kinematics

The LATE device consists of a 1.5 m x 0.9 m cart (Fig. 1, circled) that slides along two parallel 3.7 m steel rails via near-frictionless Teflon shoes. The cart is actuated via a Scotch yoke mechanism consisting of a sprocket, driven by two WEG W21 5 HP motors, which is coupled to a sliding yoke on the bottom of the cart. An occupant compartment consisting of a second row captain's chair, three-point belt and B/C-pillar with an adjustable D-ring was designed to mimic various front and rear passenger seating environments. The occupant compartment is mounted to the cart such that the motion is perpendicular to the occupant. Recruitment and testing of volunteers is underway. Subsequent PMHS tests are forthcoming.

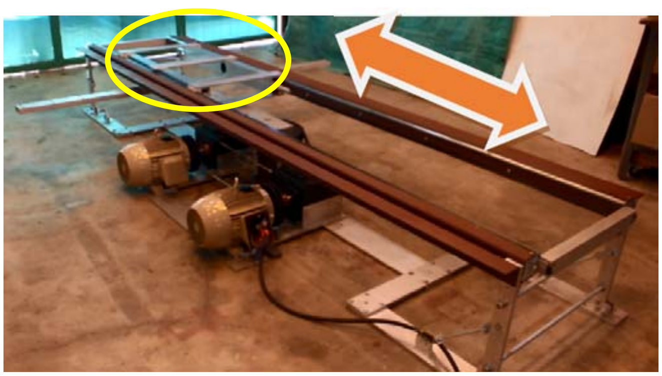

Fig. 1. LATE Device.

Fig. 2. Occupant Compartment.

IV. DISCUSSION

The development of the LATE device represents the first step in a broader line of research aimed at quantifying and mitigating occupant pre-crash motion. Whereas previous research has focused on vehicle dynamics or limited age ranges, this line of research represents the first effort at evaluating LATE events in a controlled laboratory environment using human volunteers across a range of occupant ages. These data will provide restraint manufacturers with fundamental biomechanics data of occupant motion and positioning prior to impact in order to: 1. provide fundamental validation data for advanced computational human body models that incorporate muscle activity; 2. guide design of AST to minimise occupant motion during these manoeuvres; and 3. influence restraint design to ensure that restraints can accommodate variations in occupant state and maximise protection offered.

V. References

[1] WHO, *Global Status Report on World Safety*, 2009.
[2] Arbogast, K. B. *et al*., *IRCOBI*, 2005.
[3] Howard, A. *et al*., *J Trauma*, 2004.
[4] Bohman, K. *et al*., *Traf Inj Prev*, 2011.
[5] ITARDAS, 2007.