STAPP CAR CRASH CONFERENCE
SHORT COMMUNICATION

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Occupant Torso Kinematics in Low Acceleration Time-Extended Evasive Swerving Events

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ABSTRACT – Low-acceleration time-extended (LATE) emergency manuever events often precede a crash. The inertial forces during such events have the potential to cause changes to the occupant's "state", which may result in profound consequences in restraint performance. The objective of this study was to develop a method to examine this in a controlled laboratory environment and specifically quantify the kinematic torso response of adult human subjects during simulated evasive swerving maneuvers. To this end, a customized laboratory test fixture was constructed to mimic lateral oscillatory swerving for a restrained occupant. Subjects were exposed to a series of 4 complete oscillatory cycles with peak lateral accelerations of approximately 0.75 g. Results from 8 healthy adult male subjects are presented.

INTRODUCTION

Motor vehicle crashes (MVCs) continue to be a prime contributor to mortality and morbidity for children and young adults worldwide [5]. One contributor to enhanced protection in MVCs is optimal position of the occupant relative to the restraint system. Sub-optimal pre-impact occupant position was a key component of the injury mechanism for children killed by frontal passenger airbag deployments in the early 1990s [6] as well as head injury causation scenarios for rear seat child occupants [2].

Pre-crash maneuvers are one of the primary reasons that an occupant can be out of position prior to the impact event. Previous research has shown 60% of crashes involve some form of pre-crash maneuvers [1]. Currently, there is limited understanding of occupant kinematic activity during pre-crash maneuvers and how this activity contributes to protection. Pre-crash maneuvers can be defined as low acceleration time extended (LATE) events. LATE events are a spectrum of dynamic impact avoidance maneuvers that are exhibited in critical driving situations [3]. The inertial forces during this pre-crash phase have the potential to cause alterations to the occupant's "state" (initial posture, position, muscle tension), which could cause the occupant to be less than optimally restrained. Evasive swerving, defined as a vehicle generating a primarily lateral sinusoidal or oscillating path, has been identified as an understudied LATE event [3].

To address this gap, we have designed a test fixture to examine evasive swerving in a controlled laboratory environment with the goal to quantify kinematic responses of adult and pediatric restrained human subjects during simulated evasive swerving maneuvers. The analyses contained herein describe a subset of those data, specifically the kinematic relationship between the shoulder belt and torso of adult human subjects during these maneuvers.

METHODS

Safe Volunteer Pulse: A safe and repeatable test fixture, custom constructed for this study, exposes subjects to low-severity, non-injurious loading conditions that mimic the pre-crash swerving event. A meta-analysis of previous laboratory, and on-road studies, consumer information programs and safety standards was conducted to determine the appropriate oscillatory acceleration and magnitude that is safe for human subject testing and also representative of dynamic pre-crash field data [4]. The study protocol was reviewed and approved by the Institutional Review Board of the Children's Hospital of Philadelphia and Drexel University.

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Figure 1 Sled Apparatus

Sled Apparatus: The LATE device consists of a 1.5 m x 0.9 m cart that slides along two parallel 3 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 production vehicle seat, a three-point seat belt and 3- degree of freedom adjustable B/C-pillar and D-ring structure was designed to mimic various front and rear passenger seating environments. An accelerometer (Endevco 7290a-10) measured the cart acceleration.

The apparatus was designed such that two different vehicle seats could be accomodated: a second row captain's chair from a recent model year minivan (standard seat) and a first row, more sculpted seat from a recent model year sports sedan. In this manuscript, only results from the standard seat are presented.

An automotive three point-belt system with three seat belt load cells was used, along with a electromechanical motorized seatbelt retractor (MSB), also known as a pre-pretensioner integrated into the shoulder belt. The pre-pretensioner was powered by a 12V-20A electrical output and was integrated into the sled trigger enabling it to be activated simultaneously at test start. The seatbelt achieved a pre-pretensioning load of approximately 200N.

Volunteers: Healthy male subjects whose weight and BMI were within 5th and 95th percentile for the subject's age (based upon CDC growth charts for children and CDC NHANES data for subjects 18+ years) were enrolled. The subjects were selected such that they resembled the broad range of occupant ages and sizes found in a motor vehicle.

Experimental Testing: Prior to testing, subject anthropometric dimensions were collected using body calipers and flexible measuring tape. These measurements, along with the adjustable restraint system, ensured similar belt fit across all subjects via the adjustable D-ring.

Subjects were positioned in a production vehicle seat and the shoulder belt spanned across the subject's right shoulder and buckled at their left hip. Subjects were exposed to oscillatory peak lateral accelerations of ~0.75 g. Each trial included 4 cycles with a frequency of 0.5 Hz. One complete cycle of oscillation required the seating compartment to travel 1.8 m laterally, in the +y direction (towards the volunteer's right) and then return 1.8 m back to the starting position. In total, each subject participated in five testing conditions, each repeated once for a total of 10. Test conditions were randomized within seat type (e.g. within the standard seat, baseline, bracing and pre-pretensioned seat belt were randomized). Repeat trials were not randomized. The two conditions that will be presented herein are baseline (relaxed posture, standard seat belt and seat) and a pre-pretensioned condition (relaxed posture, pre-pretensioner activated, standard seat).

Subject kinematic data was captured at 120 fps using an on board Optitrack Flex 13 motion-capture system with 8 infrared cameras (NaturalPoint Inc., Corvallis, OR). Spherical photo-reflective markers were placed on key anatomical landmarks, the restraint system, and various locations on the seating compartment.

Data Analysis: The parameter of interest for this preliminary analysis was the displacement of the mid-torso. A custom –made MATLAB (Mathworks, Inc., Natick, MA) program was used for analysis. The photo-reflective marker located on the supra-sternal notch (SSN) defined the torso midline. Displacement was measured by quantifying the motion of the marker in the lateral (y) direction, relative to initial position at event onset. +y represents the volunteer moving into the belt and outboard and –y is inboard and out of the belt. Marker trajectories are presented as change from initial position. In total, data from 10 adult subjects were collected; however, due to marker occlusions data from 8 adult subjects is presented.

RESULTS

The following represents torso kinematic data from 8 adult subjects (height: 177.8± 5.8 cm, weight: 74.7 kg ± 11.2 kg, age: 24.6 ± 3.6 years). Figure 2 depicts the average and standard deviation for the time series of the torso's lateral motion for the baseline and pre-pretensioned conditions. The subjects' motion is relative to the moving compartment. As the cart moves to the subjects' right, the initial movement is to the subjects' left, out of the shoulder belt. Subjects overall moved less in the pre-pretensioned condition than in the baseline condition. (Figure 3) and move more into the belt than out of the belt. In the baseline condition there was an average maximum lateral displacement of 83.8 ± 13.6 mm out of the belt and 150.1 ±25.8 mm into the belt. In the pre-pretensioned condition there was an average maximum lateral displacement of 39.4 ± 8.4 mm out of the belt and 80.0 ±15 mm into the belt.

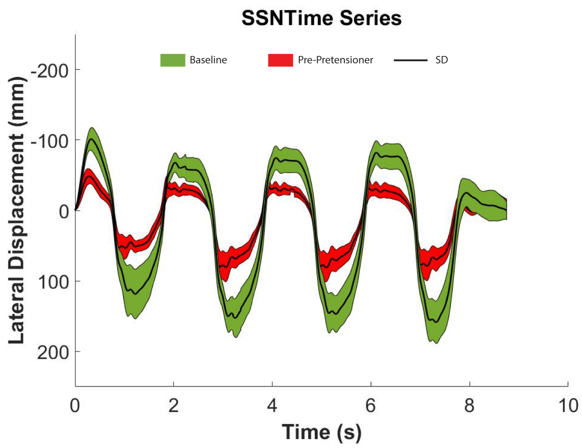

Figure 2. Group means and SD of the baseline and pre-pretensioned conditions.

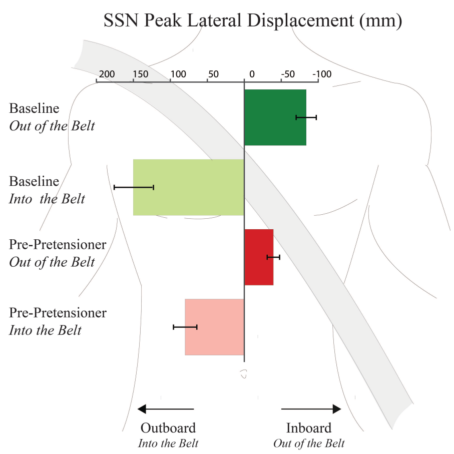

Figure 3. Average and SD of the maximum lateral torso displacement for the baseline and pre-pretension conditions

DISCUSSION

In this preliminary analysis, we report the torso kinematics of restrained adult volunteers subjected to lateral oscillatory motion representing evasive pre-crash swerving. Two conditions were evaluated – a baseline condition with a standard 3-point belt and a countermeasure condition with a pre-pretensioned seat belt. Two observations were made of the data. First, torso motion out of the belt was less than motion into the belt. This may be due to the subject activating their muscles to maintain postural control as they move away from the belt; whereas when they move into the belt, they rely on the seat belt to restrain them and thus are more relaxed leading to greater excursion. Future EMG data analysis is currently ongoing to confirm this hypothesis. Second, the addition of the pre-pretensioner resulted in reduced motion of the torso indicating effectiveness of the pre-pretensioner even in this lateral loading condition.

An analysis of 2D videos and preliminary 3D motion capture data from the tests revealed adult volunteers actively rotated their torso to the left as they moved out of the shoulder belt engaging the right shoulder with the belt. This may have contributed to the reduced torso movement observed in that direction. Further tests involve volunteers of different age groups, including children, and the ability to actively control occupant posture will be explored across age.

CONCLUSION

This study represents a preliminary 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 across a range of occupant ages. Future analysis will evaluate the kinematic response, across ages, of other novel countermeasures designed to mitigate pre-crash motion and quantify muscle response as a result of the varying conditions.

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