Tracking Occupant Head Movements During Braking Events

Monica L.H. Jones[1], Carl S. Miller[1], Sheila Ebert[1], Anne Bonifas[1], Byoung-Keon Daniel Park[1], Matthew P. Reed[1], Jason Hallman[2], and Rini Sherony[2]

[1]University of Michigan Transportation Research Institute USA
[2]Toyota Collaborative Safety Research Center, USA

1. Abstract

Accurate tracking of occupant head movements in response to abrupt vehicle maneuvers, such as emergency braking, may provide information useful to evaluate the performance of vehicle safety systems. Driver and passenger response to hard braking have been investigated in previous studies. Methodologically, participants were typically well aware of the purpose of the testing and/or instrumented extensively. The effects of these rapid vehicle motions on unaware vehicle occupants have not been well quantified. In a pilot study, data were gathered from 7 adults (3 female and 4 male), ranging in age from 18 to 58 years, stature from 1574 to 1885 mm, and BMI from 18 to 38 kg/m^2. Surface geometry of the occupant's head was recorded using hand-held scanners. A midsize sedan equipped with an inertial measurement unit was used to conduct vehicle maneuvers on a closed test track facility. Video cameras in the test vehicle recorded passenger movements. The camera system was spatially calibrated using a FARO Arm coordinate digitizer. Head surface data were aligned with 3D kinematic trajectory data computed from camera images and peak excursions were quantified. The results demonstrated reliable tracking of head position and orientation through the movement. These data have value for validating computational simulations of pre-crash responses.

2. Introduction

Analysis of the National Motor Vehicle Crash Causation Survey (NMVCCS), a dataset of on-scene information about the events and associated factors leading up to crashes involving light vehicles, determined that up to 40% of crashes were preceded by a vehicle maneuver. Braking was the most common pre-crash maneuver, followed by steering and steering with braking. Pre-crash maneuvers may become more common with the introduction of crash avoidance technologies such as automatic emergency braking. While the frequency of occupants being unaware of an impending maneuver or crash is unknown, the effects of rapid vehicle motions on unaware vehicle occupant kinematics currently are not well understood.

Several previous studies have gathered data on occupant responses to aggressive vehicle maneuvers. Testing methodologies have varied from simulated or impact sled test conditions (Ejima et al. 2009; Hault-Dubrulle 2011) to in-vehicle testing (Morris and Cross 2005; Carlsson and Davidsson 2011; Östh et al. 2013; Ólafsdóttir et al. 2013;

Kirchbichler et al. 2014; Huber et al. 2015). Methodologically, participants were typically well aware of the purpose of the testing and/or instrumented extensively. As a result of the test preparation, the initial state of the participant may have been different from a typical vehicle occupant. The available data demonstrate that awareness reduces excursions, so the boundary cases for restraint system design are not meaningfully represented in the responses of unaware occupants. The current pilot study aimed to develop an experimental approach and platform for studying vehicle passenger responses to abrupt vehicle maneuvers. Accurate tracking of head location is one critical aspect of the needed methodology. This paper demonstrates that 3D head geometry aligned to 3D kinematic data can be used to produce useful estimates of occupant head movement in response to a braking event.

3. Methods

The study protocol was approved by the University of Michigan Institutional Review Board (IRB) for Health Behavior and Health Sciences (IRB # HUM00120296). Participants were recruited through online postings. Each participant was briefed that they are participating in a study of vehicle ride and handling and that they might experience rapid braking or vehicle maneuvers typical of automated vehicles of the future. Written consent was obtained prior to commencing the study.

Four women and five men were tested in this pilot study. Anthropometric data were gathered from each participant to characterize overall body size and shape. The standard anthropometry measures listed in Table 1 were obtained using manual measurements. All measurements were obtained from the participants in their own clothing. The participants ranged in age from 18 to 58 years, stature from 1574 to 1885 mm, and BMI from 18 to 38 kg/m^2.

Table 3.1 Participant Characteristics (N=9)

Measurement	Min	Max	Mean
Age (yr)	18	58	33
BMI (kg/m^2)	18	38	25
Weight (kg)	47	126	77
Stature	1574	1885	1751

3.1. Vehicle Instrumentation

The in-vehicle test was performed with an instrumented 2008 Honda Accord. The vehicle was equipped with a high-end inertial measurement unit (IMU) near the mass center of the vehicle that recorded acceleration and angular rate along three axes.

Three Point Grey Blackfly S cameras were rigidly mounted to the vehicle interior to collect images at 60 Hz. Cameras viewed the passenger from three different angles and locations within the vehicle space. Figure 3.1 illustrates the camera placement within the test vehicle. Custom software was developed to synch the camera images with the inertial measurement unit.

Fig. 3.1 Test vehicle exterior (left) and interior camera placement (right)

Prior to beginning participant testing, the camera system was spatially calibrated using a FARO Arm coordinate digitizer to record calibration target locations placed throughout the data capture volume space. Quadrant target stickers were placed at different locations in the vehicle interior that could be viewed by multiple cameras. Three-dimensional coordinate locations were collected for each point with respect to the vehicle coordinate system. These quadrant targets remained in the vehicle during testing and were tracked along with the participant landmarks. The optical images were calibrated and processed using TEMA Automotive version 4.1-003 by Image Systems Motion Analysis. The orientation and location of each camera relative to the quadrant targets was computed for each frame to correct for small camera movements that may result during vehicle test maneuvers due to imperfections in the camera mounts. A lens distortion correction was also calculated prior to participant testing using a calibration board containing a grid with known point distances and TEMA software.

3.2. 3D Surface Head Geometry

A hand-held infrared scanner (Cubify Sense) and a structured light Artec scanner were used to record contours of each participant's head. Surface contour data were merged and post-processed in Geomagic Studio software. The locations of surface landmarks on the participants were recorded via skin targets stamped on the skin prior to scanning and manually extracted from surface scan data using a custom script in Meshlab software (meshlab.org). Figure 3.2 shows a representative head scan and corresponding landmarks.

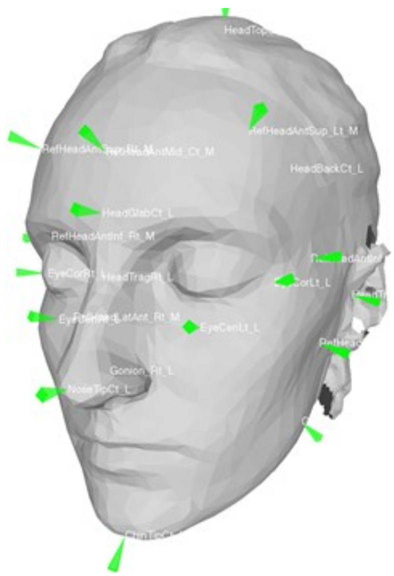

Fig. 3.2 Representative head scan and illustration of digitizing points and extracting anatomically derived landmarks in MeshLab.

3.3. Protocol

In-vehicle testing was conducted on the University of Michigan Mcity facility, which is a closed test track that enabled the use of scripted routes to achieve consistent acceleration levels under the driver's control. In each test drive the participant was seated in the front passenger seat with the seat placed in the most rearward position. The participant adjusted the seat back angle to achieve a comfortable posture and donned the seat belt. The investigator ensured that the belt was reasonably snug and appropriately positioned. A FARO Arm coordinate digitizer was used to record the initial three-dimensional locations of landmarks on the participant's body and on the vehicle, seat, and belt. In addition, a stream of points with approximately 5-mm spacing was recorded along the edges of lap and shoulder portions of the belt between the anchorages and latch plate. Throughout each test drive participants were asked to sit with feet translated forward until they were resting on heels and hands on thighs to avoid any bracing or leaning against the floor, door, or armrests.

Because the purpose of this research study was to obtain “unaware” vehicle passenger motions in response to vehicle maneuvers, a dummy questionnaire intended to distract attention from the primary objective was administered to employ some obfuscation. After a five-minute acclimation period, the driver reached a speed of approximately 50 km/hr and applied sudden, maximum braking to a stop. Following this trial, the investigator performed a second run with a rapid, rightward lane change. Data was recorded continuously from the cameras and the inertial measurement unit that quantified vehicle movements.

3.4. Digitizing Head Kinematic Data

Kinematic tracking of the movement of head landmarks during the braking event was performed using TEMA software. In addition to the vehicle quadrant targets, nine participant landmarks were digitized frame by frame (60 frames per second) from the three camera views of the participant in the passenger seat: six reference landmarks were tracked on the head, and three on the belt at the clavicle, sternum, and the latch plate (Figure 3.3).

Fig. 3.3 Points tracked in TEMA software.

To collect 3D kinematics, each point needed to be tracked by only two cameras at any given point in time, but three cameras were used to reduce the data loss due to points being obscured by passenger motion. Vehicle quadrant targets were tracked using the quadrant symmetry function, which calculates the intersection of the light and dark regions of the target within a search area and calculation area set by the user. Because quadrant targets are tracked using a calculation of pixel intensity over a set area, the tracked data has high accuracy. Participant points were tracked using both the circular symmetry or correlation functions. The circular symmetry function searched each successive image for the circular target contained within the size of the target square over the search area. When a point became partially obscured or moved significantly out of the plane of the camera, the point was tracked using the correlation option, which searches each successive frame for the part of the image contained within the correlation circle over the search area.

3.5. Aligning 3D Surface Head Geometry with Head Kinematic Data

Manually extracted landmarks and vertex data from the surface contour of the participant's head were aligned to the TEMA extracted digitized head kinematic data using a least-squares fit on landmark locations. The maximum forward displacement of the head (the change in distance between the initial posture and the most forward translated location that occurred in the initial response to the evasive vehicle maneuver) was determined using the aligned landmarks (Figure 3.5).

4. Results

Figure 3.4 illustrates a passenger's head kinematics in response to the abrupt braking maneuver for a representative participant. The maximum head excursion was predominantly aligned with the principal direction of the acceleration. Figure 3.6 shows the result of aligning the 3D surface head geometry to the 3D head kinematic trajectory at both the starting position and maximum head displacement.

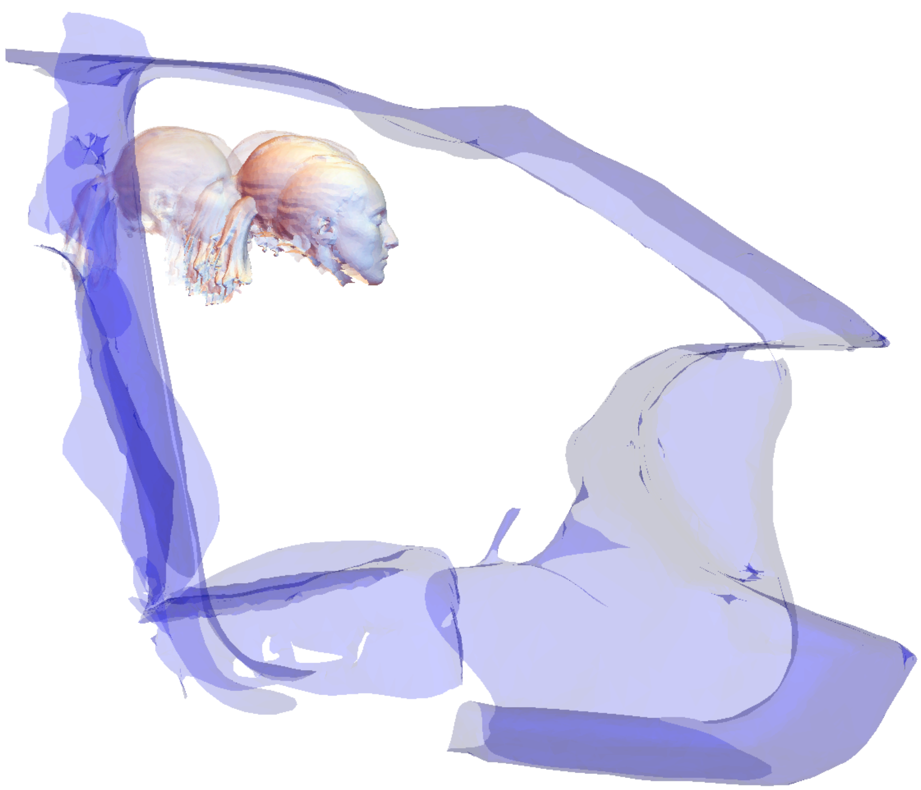

Fig. 3.4 Mapping aligned landmarks and head scan to 3D head kinematic trajectories during braking.

Head excursions measured at the glabella landmark ranging from 166 to 270 mm (mean = 210 mm; SD = 43 mm) along the axis of acceleration were observed. Figure 3.5 shows the trajectory of the head (defined by the glabella landmark) in response to the abrupt braking event across all participants. Data were aligned on the starting point of the braking event [t = 0].

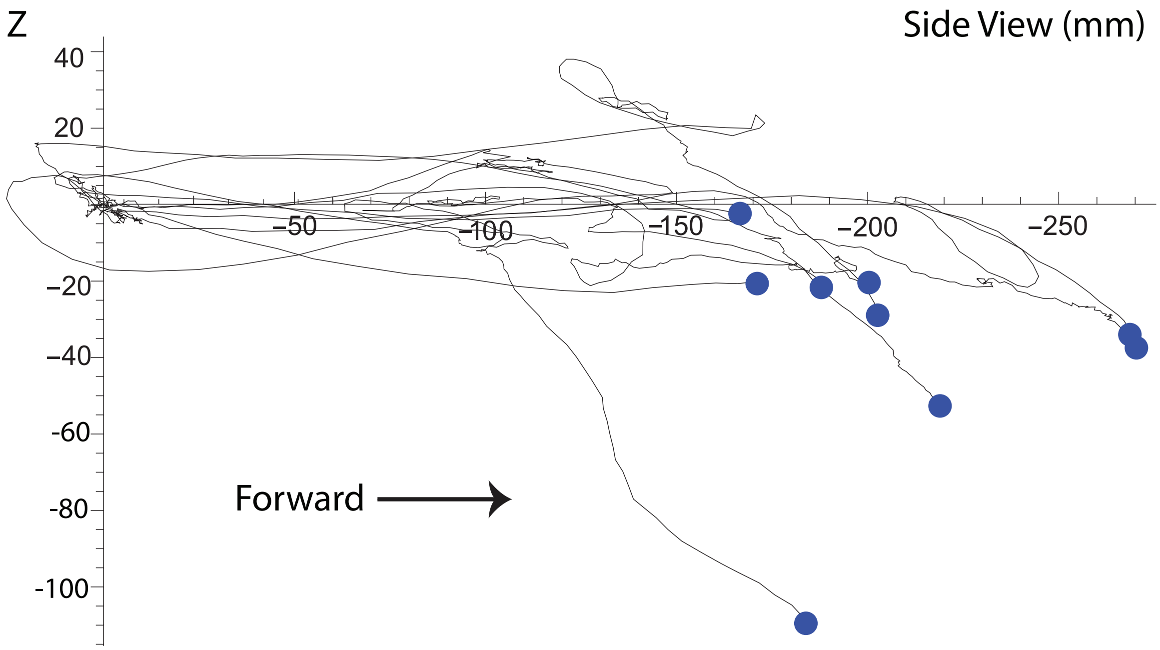

Fig. 3.5 Plot of the maximum forward and vertical displacement of the head during abrupt braking maneuver.

Fig. 3.6 Aligned 3D head surface geometry in the starting position (transparent) and final maximal forward excursion (opaque).

5. Discussion

This pilot study demonstrated the combination of 3D surface scanning and landmark-tracking methods to obtain full 3D head location during a vehicle maneuver. The method allows post-hoc measurement of clearances to the vehicle header, which is otherwise difficult to measure. A limitation of this approach is that landmark occlusion can compromise tracking. Additional cameras can help to reduce that possibility.

Future research will expand the number of subjects to enable evaluation of the associations with passenger covariates, such as age and body size. These data may be used to develop and tune models of pre-crash occupant motions.

Computational human body models that are capable of representing the effects of human muscle activations and occupant kinematics may help enhance future restraint systems and crash avoidance technology. The outcome of this research will be quantification of occupant motions as a function of vehicle accelerations and occupant characteristics. This information may provide further validation data and support human model development and application to understand the potential consequences of such motions for occupant protection if the system is not successful in avoiding a crash.

6. Acknowledgement

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