

# Assessment of Ear- and Tooth-Mounted Accelerometers as Representative of Human Head Response

John J. Christopher<sup>1</sup>, Mark R. Sochor<sup>1</sup>, Joseph Pellettiere<sup>2</sup>, Robert S. Salzar<sup>1</sup>

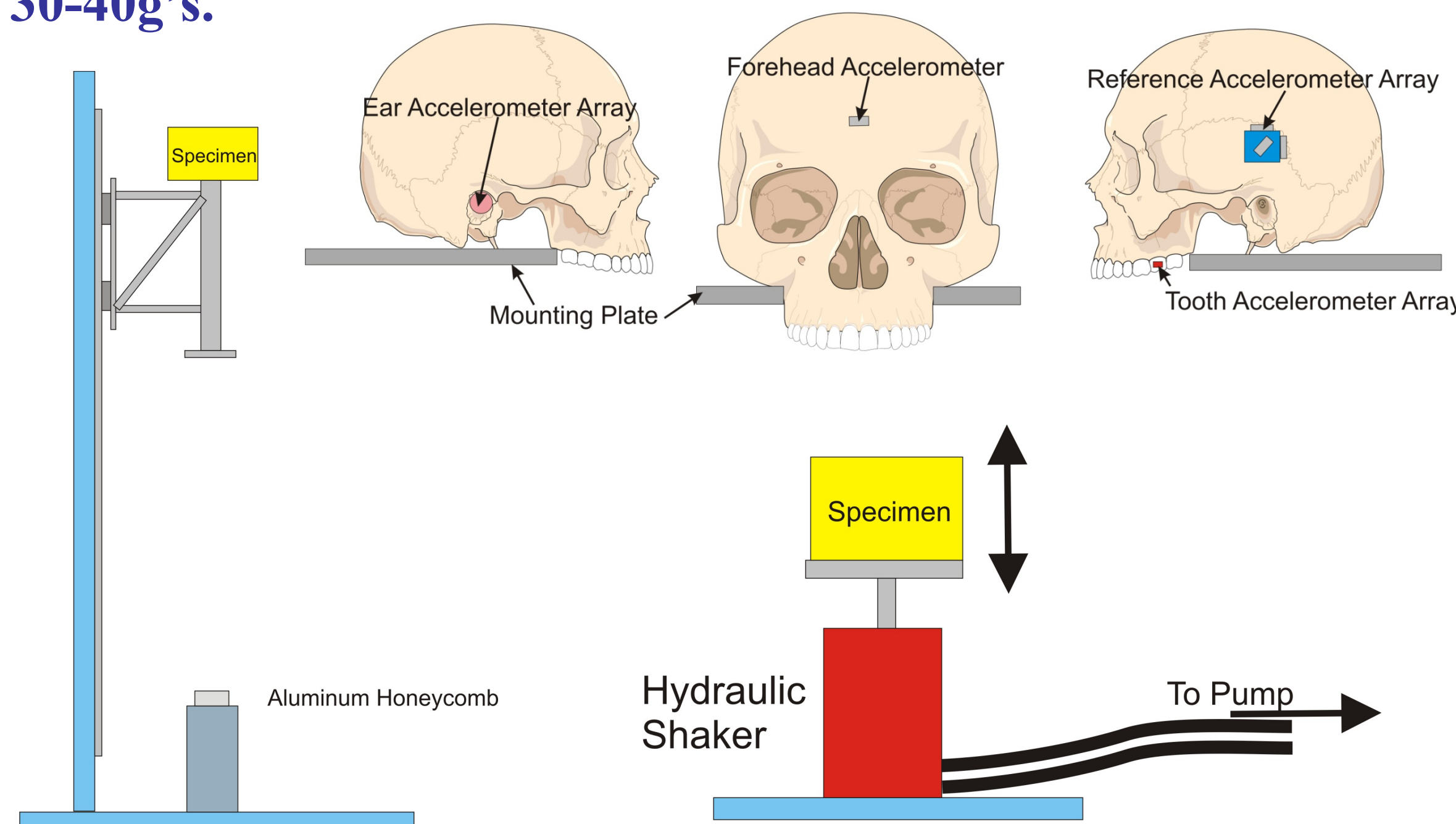
## Introduction

Due to widespread use of improvised explosive devices (IEDs) and subsequent blast related injuries including traumatic brain injury (TBI) in the current military conflicts, a significant effort has been made to record head accelerations through various helmet-mounted systems. By collecting and accurately measuring head accelerations and correlating with injury outcomes, injury criteria can be developed which will expedite diagnosis and treatment of TBI. While size and power requirements of accelerometers continue to be an obstacle to widespread monitoring of the general population, there has been significant progress in the size, power requirements, and suitable mounting locations for these monitoring devices. Previous studies have assessed various mounting locations including the ear. This study investigates if a tooth-mounted sensor compares with an ear-mounted sensor in representing the total head acceleration in three PMHS heads.



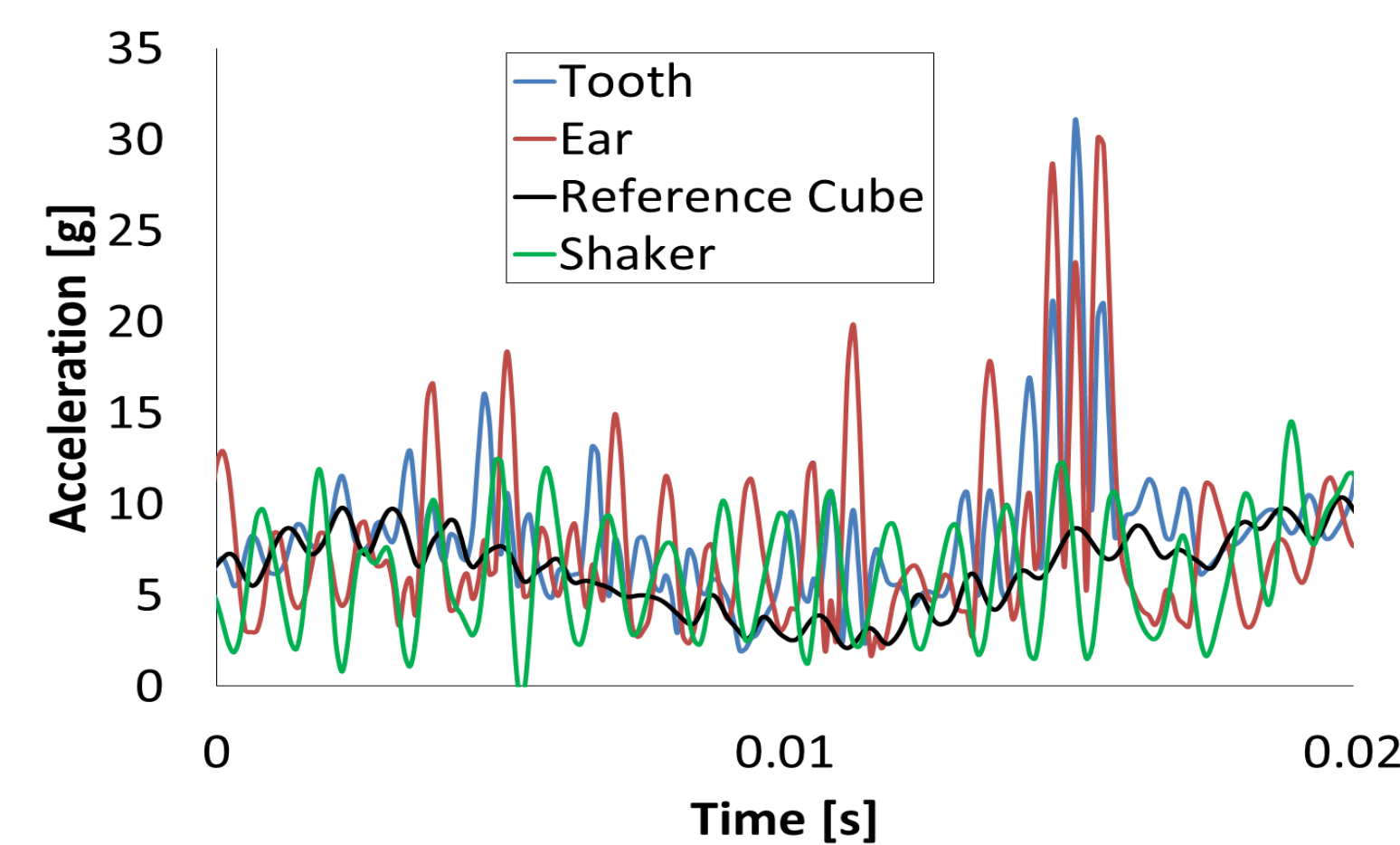
## Methods

- Three PMHS heads were selected for this study: one 24 year old female, one 62 year old male, and one 66 year old male.
- The specimens were prepared by removing the mandible as well as the cervical spine from the occipital condyle in order to rigidly mount the skull to both a drop tower fixture and a vertical hydraulic shaker.
- An 3-axis accelerometer array was placed in the ear canal using a stiff syntactic foam, similar to previous studies. A 3-axis array was also mounted to a rear molar with cyanoacrylate adhesive. A uniaxial accelerometer was fixed to the epidermis on the forehead. A rigidly mounted reference cube was mounted on the left side of the skull in line with the Frankfort plane, which was used as the reference head acceleration.
- Each specimen was loaded in the SAE X-, Y-, and Z- direction on both the drop tower and shaker.
- Target accelerations on the drop tower were 150g and the shaker was operating at ~9Hz with total accelerations reaching 30-40g's.

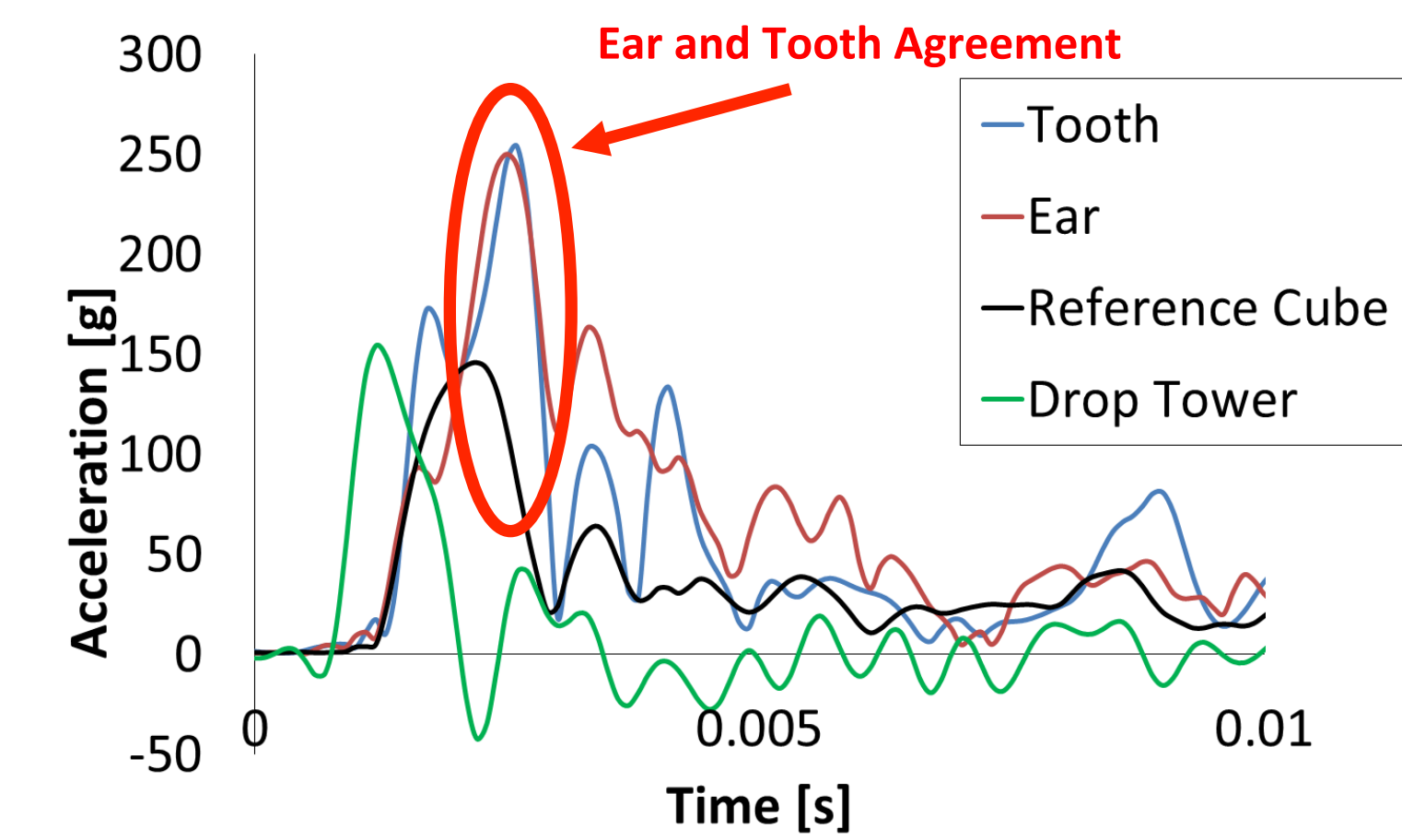


## Results

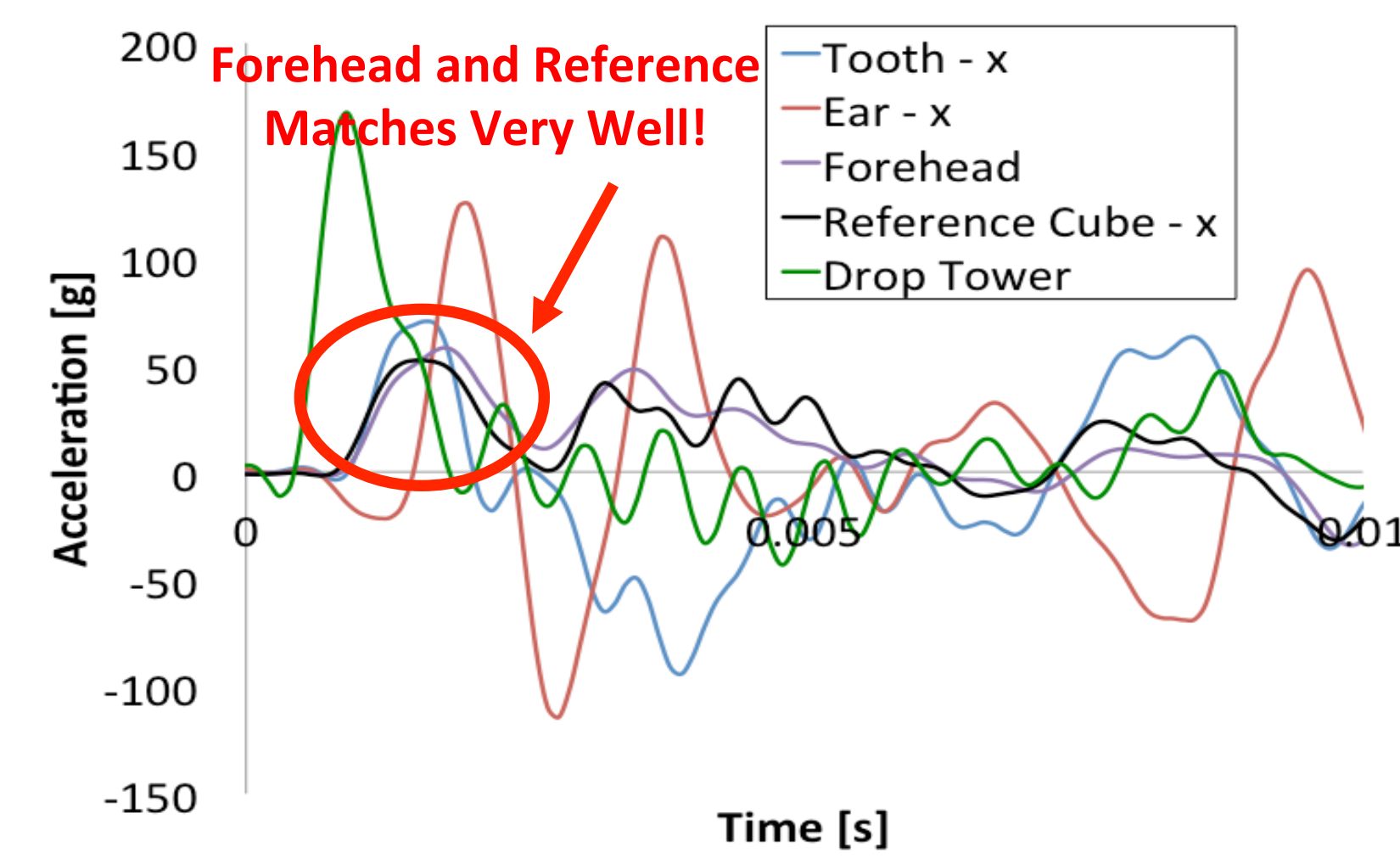
- For the low frequency input, the tooth and ear arrays followed similar trends of the reference, but showed more compliance and high frequency peaks in the data.
- Coordinates for the tooth and ear arrays were determined from CT analysis and a coordinate transformation was done to transform them to the reference array.
- The degree of coupling with the head depends on the direction of the load. SAE-X loading direction yielded the most compliance with the ear and tooth arrays, while SAE-Z and Y showed similar coupling patterns.
- There was close agreement between the skin-mounted forehead sensor and the reference array.



Specimen 1 – SAE-Z direction on the hydraulic shaker.



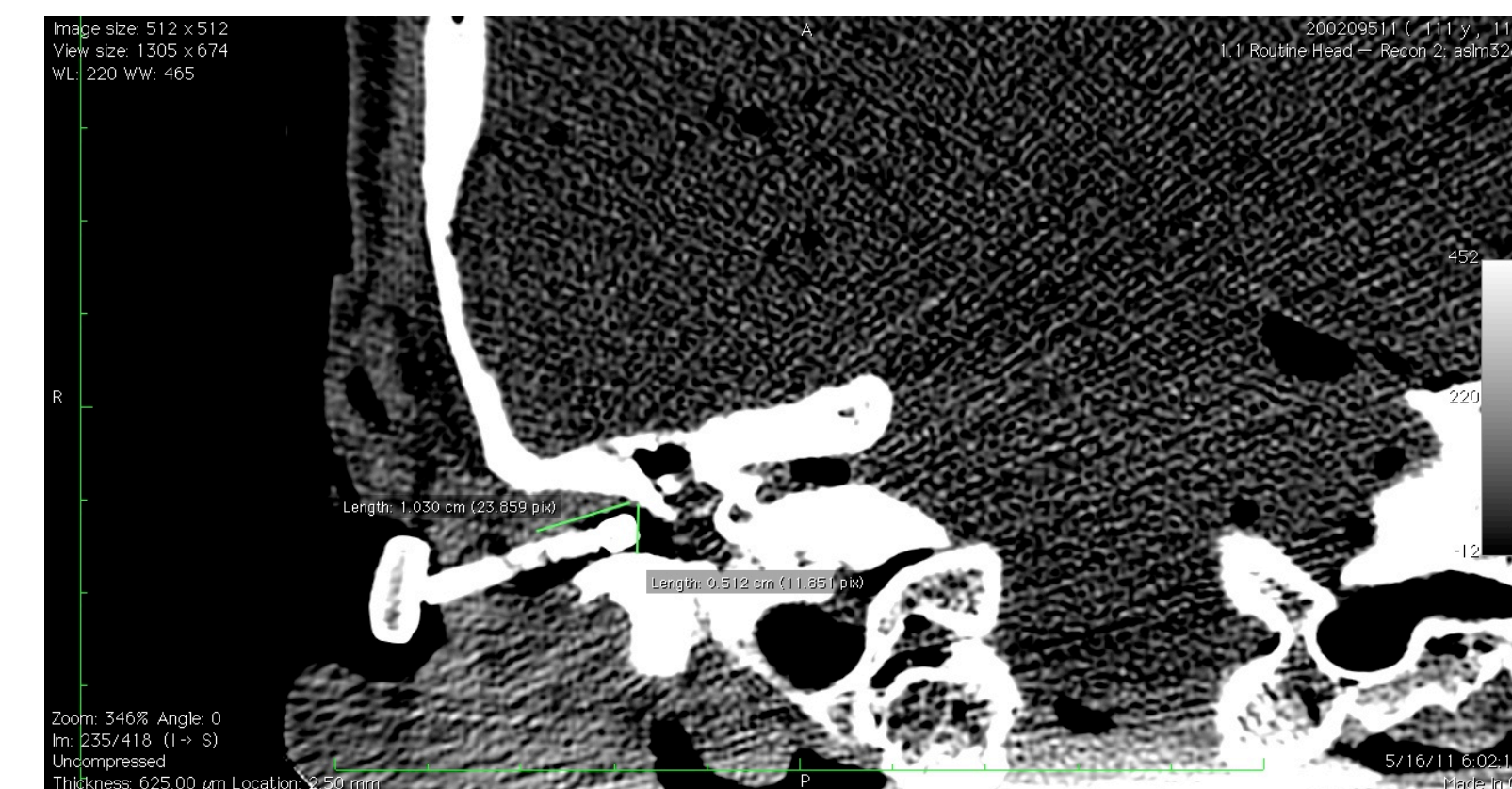
Specimen 3 – SAE-Z direction on the drop tower.



Specimen 3 – SAE-X direction on the drop tower.

## Discussion

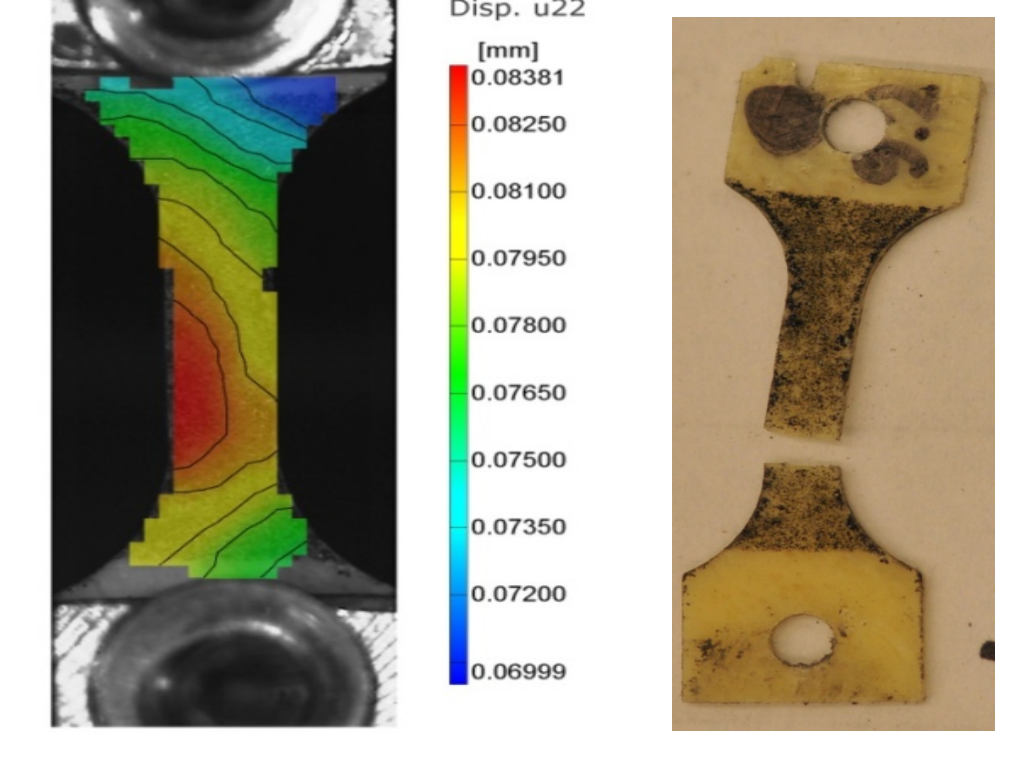
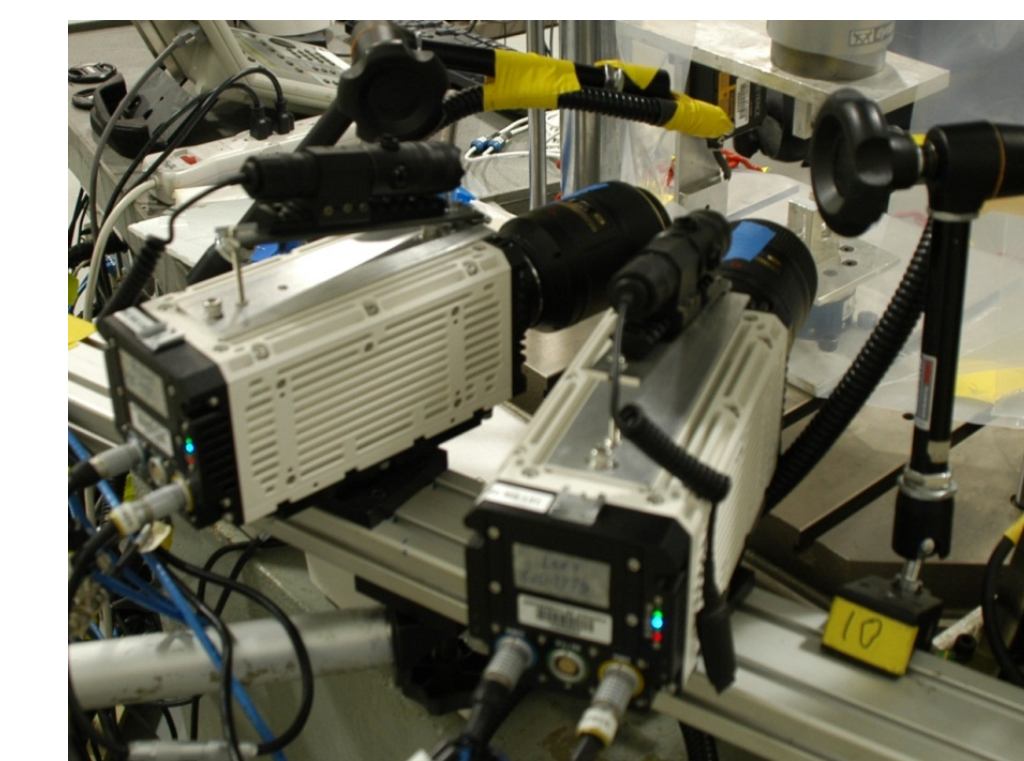
- Overall goal of monitoring and recording head accelerations is to further understand and predict TBI.
- In previous studies, helmet mounted sensors can decouple from the head.
- The goal of this study was to investigate a new mounting location for an accelerometer array.
- There are many instances where monitoring head accelerations is important: elderly living alone with the potential of falls, children playing sports, warfighters exposed to combat conditions.
- The monitoring sensors must be passive to the wearer and must be able to communicate actively with medical personnel.
- The information collected must be interpreted as head accelerations so that it can be compared to the best available injury criteria.
- Compliance from the tooth sensor is likely from the overall compliance of the periodontal ligament. More compliance was seen in the younger specimen, which would indicate a healthier ligament.
- Our data exhibited out of plane motion, which can be attributed to the skull deflecting, and compliance in our experimental setup.



CT image showing the ear array inserted into the ear canal of a specimen.

## Future Work

- Include rigidly attached angular rate sensors to quantify the amount of rigid body skull flexion that can be linked to concussions.
- Investigate the magnitude and distribution of skull flexion under uniform high-g loading. Evidence from this study suggests that there are skull deformations, but the locations and magnitude are unknown.
- Using ARAMIS, a 3D optical system will track skull deformation and determine the rate at which the skull locally deforms and rotates so that the results can be compared to established metrics for rotation rates that contribute to concussion.
- By having a better understanding of the possible local mechanisms that may contribute to mTBI, better safety systems, including helmet padding can be designed to better protect the wearer and prevent the harmful skull deformations.



The 3D ARAMIS optical system and an example of the color mapping displacement output compared to the real fracture.

## Acknowledgements

The Center for Applied Biomechanics at the University of Virginia gratefully acknowledges the support of the United States Army and the United States Air Force for their support of this research.

<sup>1</sup> – Center for Applied Biomechanics, U.Va.  
<sup>2</sup> – Federal Aviation Administration

## References

- American Academy of Neurological Surgeons, "Sports-Related Head Injuries," <http://www.aans.org/Patient%20Information/Conditions%20and%20Treatments/Sports-Related%20Head%20Injury.aspx>, September 2011.
- Fijalkowski, R.J., Stiemper, B.D., Pintar, F.A., Yoganandan, N., Gennarelli, T.A., "Influence of Angular Acceleration Duration on Functional Outcomes Following Mild Diffuse Brain Injury," presented at IRCOBI Conference 2007, Maastricht (The Netherlands), September 2007.
- Yoganandan, N., Li, J., Zhang, J., Pintar, F.A., Gennarelli, T.A., "Influence of angular acceleration-deceleration pulse shapes on regional brain strains," *Journal of Biomechanics* 41: 2253-2262, 2008. doi:10.1016/j.biomech.2008.04.019
- Hill, D., Knox, T., Crockett, D., "Monitoring Race Car Drivers Using Helmet and Head-Mounted Sensors," SAE Technical Paper 2000-01-3557, 2000.
- Begeman, P., Melvin, J., Troxel, T., Mellor, A., "Frequency Response and coupling of earpiece accelerometers in the human head," SAE Technical Paper 2006-01-3657, 2006.
- Panzer, M., Bass, CR, Salzar, RS, Pellettiere, J, Myers, B., "Evaluation of Ear-Mounted Sensors for Determining Impact Head Acceleration," presented at IRCOBI Conference 2009, United Kingdom, September 2009.
- Salzar, RS, Bass, CR, Pellettiere, J., "Improving Earpiece Accelerometer Coupling to the Head," SAE Transactions: *Journal of Passenger Cars-Mechanical Systems*, 1367-1381. Based on SAE Paper 2008-01-2978, 2008
- Ling, G. S.F., Ecklund, J. M., "Traumatic brain injury in modern war," *Current Opinion in Anesthesiology* 24:124-130, 2011, doi:10.1097/ACO.0b013e32834458da
- Abel, S.M., "Barriers to Hearing Conservation Programs in Combat Arms Occupations," *Aviation, Space, and Environmental Medicine* 79(6): 591-598, 2008, doi: 10.3357/ASEM.2262.2008
- Duma, S. M., Manogian, S. J., Bussone, W. R., Broolinson, P. G., Goforth, M. W., Donnenwerth, J. J., Greenwalk, R. M., Chu, J. J., Crisco, J. J., "Analysis of Real-time Head Accelerations in Collegiate Football Players," *Clinical Journal of Sport Medicine* 15(1), January 2005.
- Manogian, S., McNeely, D., Duma, S., Broolinson, G., Greenwalk, R., "Head acceleration is less than 10 percent of helmet acceleration in football impacts," presented at Rocky Mountain Bioengineering Symposium & International ISA Biomedical Sciences Instrumentation Symposium, Terre Haute, Indiana, April 7-9, 2006.
- Lesley, D.J., Pursevov, S., Shaw, CG, Parent, D, Riley, P, Kent, RW, Crandall, JR., "Assessment and validation of a methodology for measuring anatomical kinematics during impact loading," Proc. 38th International Workshop on Human Subjects for Biomechanical Research, National Highway Traffic Safety Administration, U.S. D.O.T. 2009