LASIR Laboratory for Systems Integrity + Reliability

School of Engineering

VANDERBILT UNIVERSITY MEDICAL CENTER

Direct, quantitative comparison of personal protective equipment during breaching: Measuring brain blast exposure

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VANDERBILT HEALTH

Disclosure

Tonia Rex, PhD; Douglas Adams, PhD; Janette Meyer, PhD; Garrett Thorne; & Sariah D'Empaire-Salomon are co-inventors on BIHF, patent-pending, US provisional patent application #63/751,564

Axon Defense Systems, LLC holds option for license on BIHF

VANDERBILT HEALTH

Repeat low-level blast exposure during military training

Service members are exposed to repetitive low-level blasts (rLLB) during breacher training.

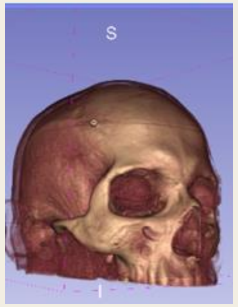
There is growing evidence that cumulative rLLB exposure causes lasting detrimental brain health effects.

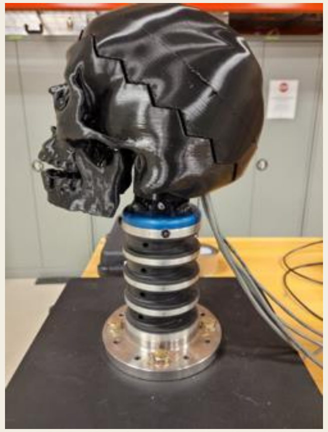
Current helmets are designed and tested for ballistic protection, not protection from blasts.

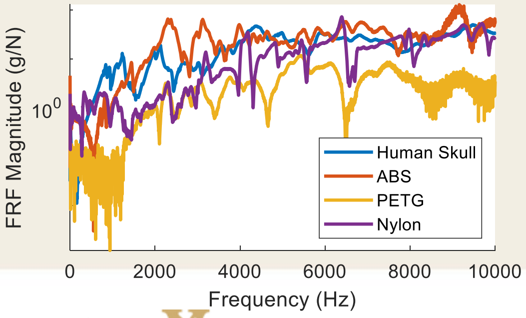
Need to protect service members now.

Biofidelic Instrumented Head-Form (BIHF)

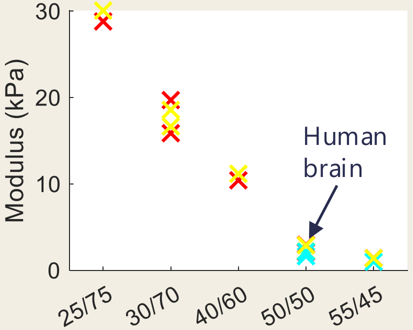
Skull model



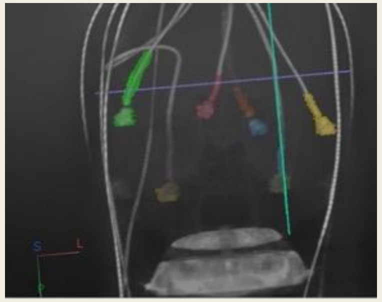


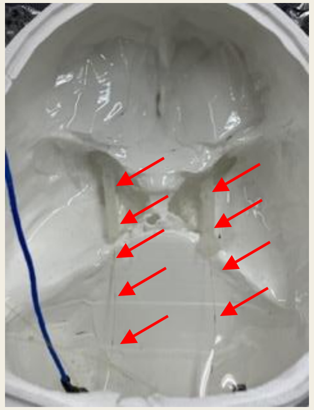


Brain model

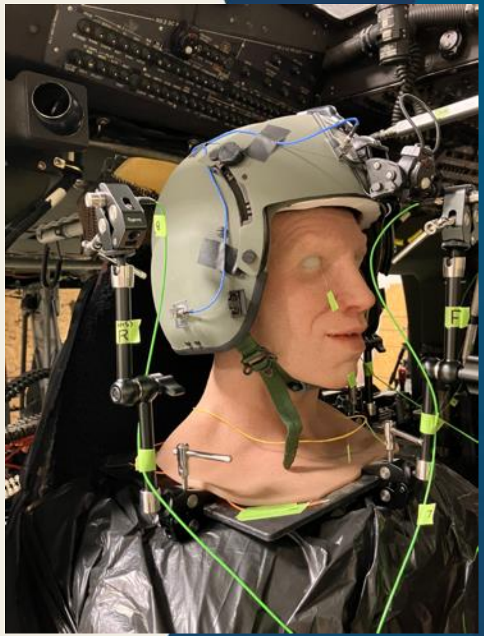


Sensors



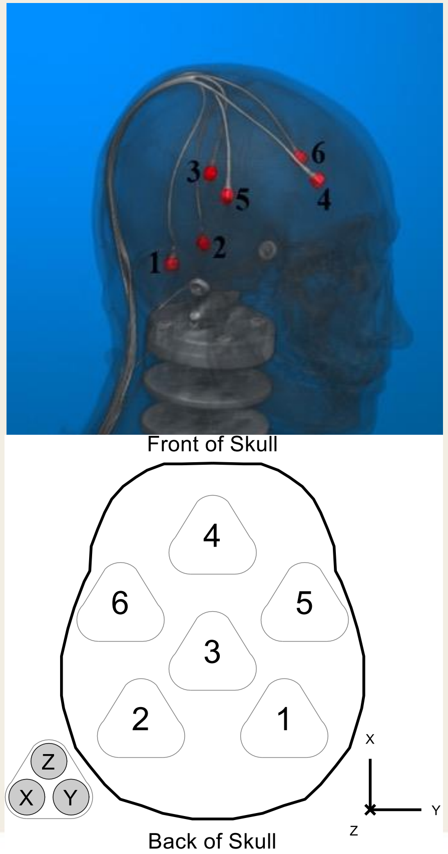


Final BIHF

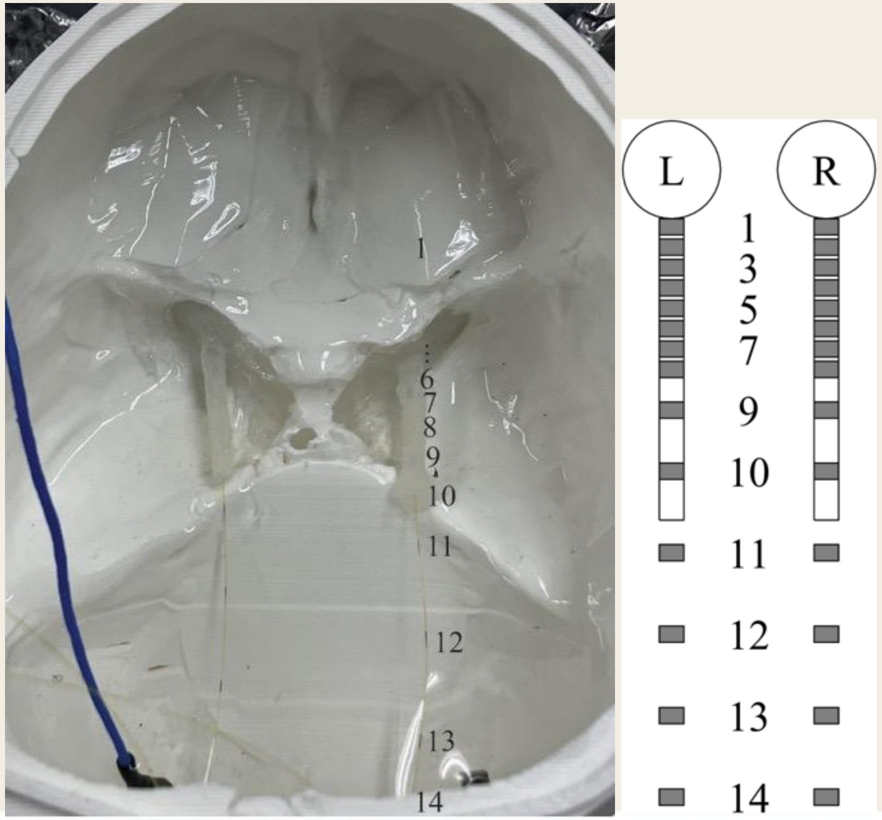


Sensors

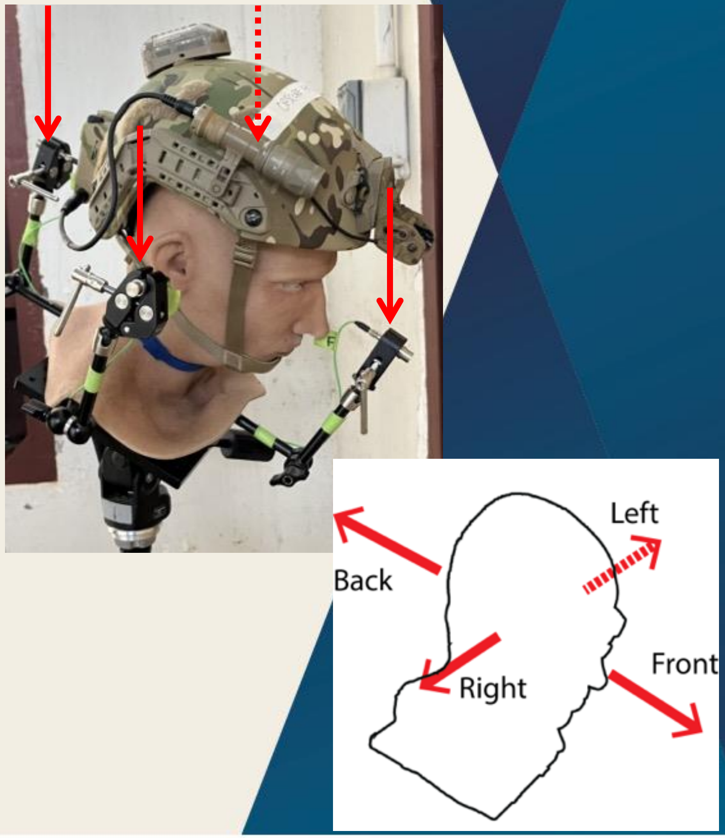
<u>Acceleration</u>
Six triaxial accelerometers in the brain model



<u>Strain</u>
Two, 14 sensor fiber optic strain arrays embedded in the eye/optic nerve model



<u>Pressure</u>
Four external pressure sensors



Breacher environment test set-up

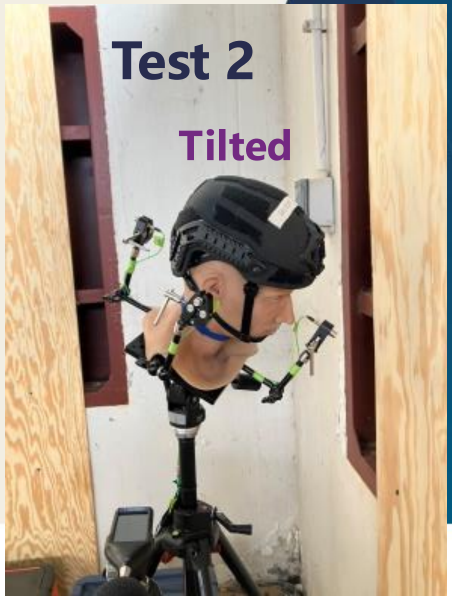
Blast exposures per BIHF configuration:
Five double strand,1x12”+1x16” machete door charges per BIHF configuration

BIHF configurations:

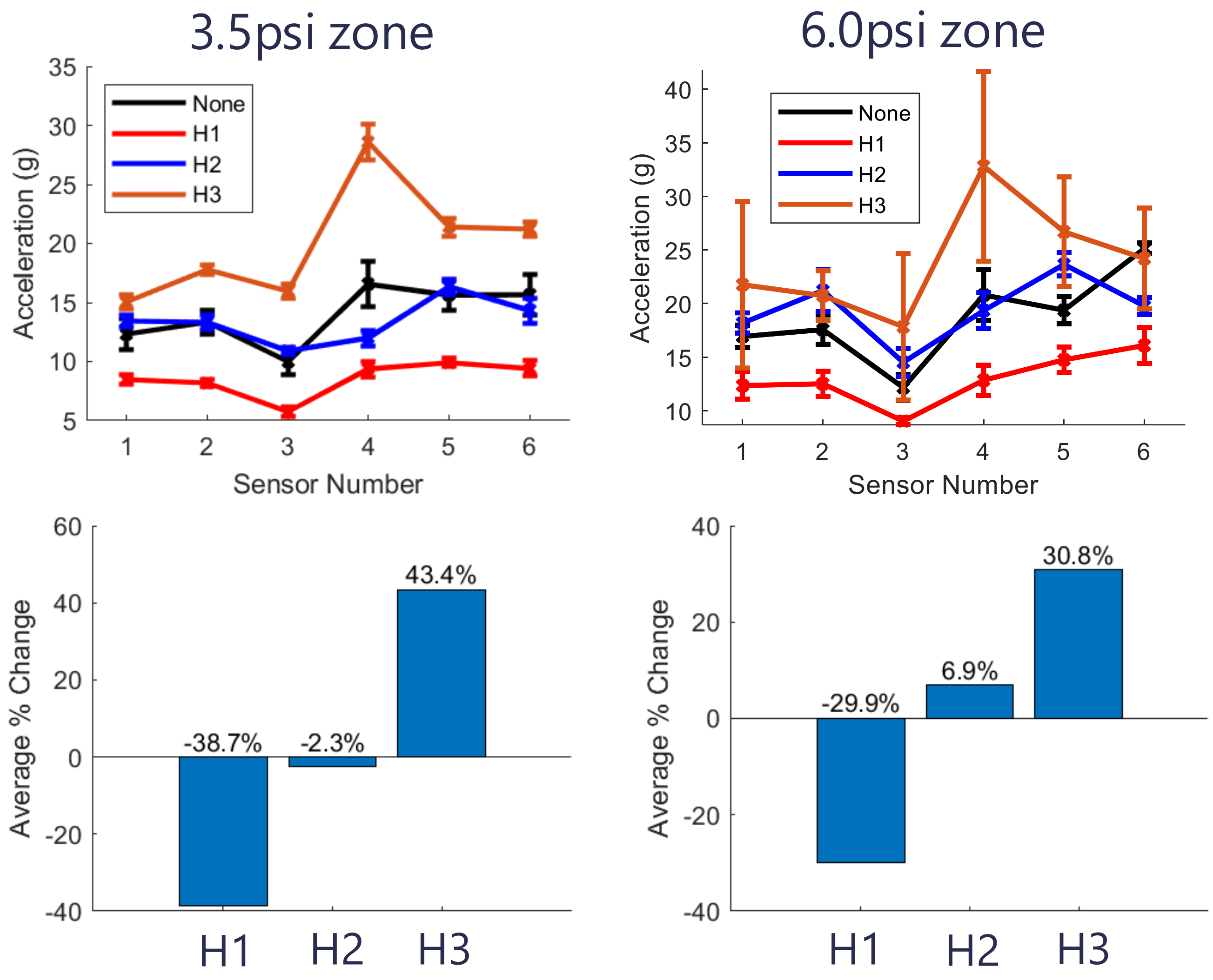
Test 1: Different locations and orientations to charge (0º or 90º), different helmets

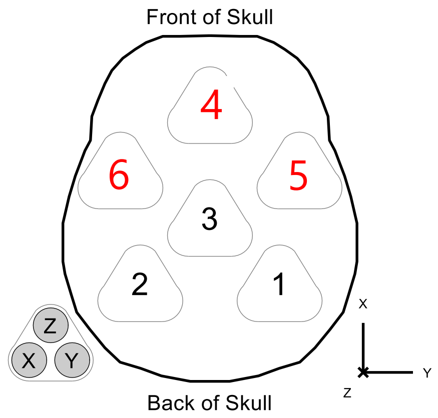
Test 2: Same position and head tilt; helmets, eye pro, helmet shield, ear pro

Same room for both tests



Peak accelerations in frontal lobe region, as expected when facing the charge





Representative brain area of accelerometers

1: Right Occipital Lobe region

2: Left Occipital Lobe region

3: Center, midbrain region

4: Frontal Lobe region

5: Right Temporal Lobe region

6: Left Temporal Lobe region

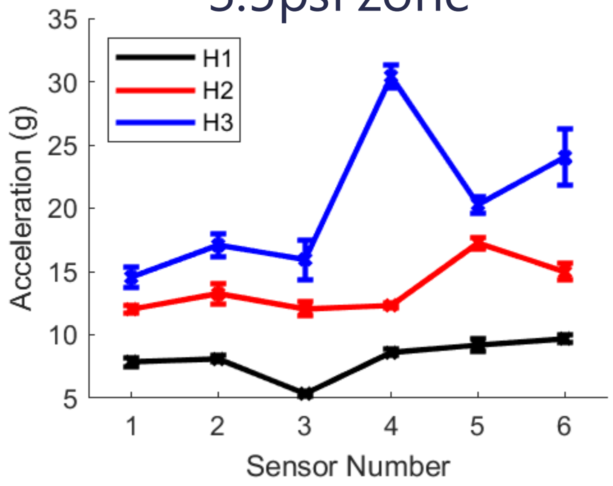
Helmet (H) 1 decreased accelerations in all brain regions compared to no helmet.

H2 performed similarly to no helmet.

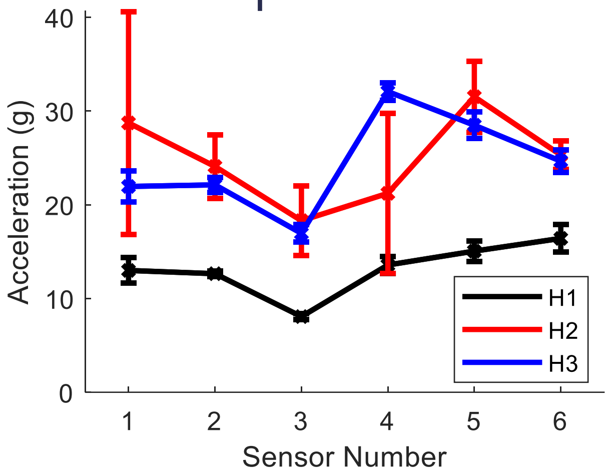
H3 increased accelerations in the brain.

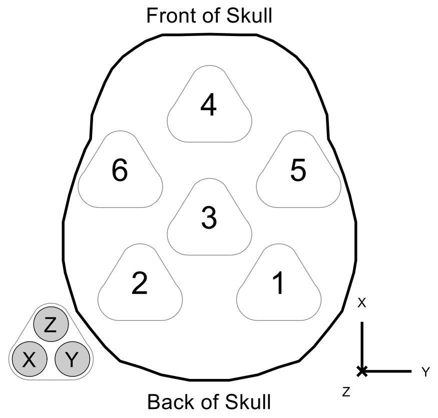
Similar acceleration pattern at 90º orientation to charge (right side towards explosive)

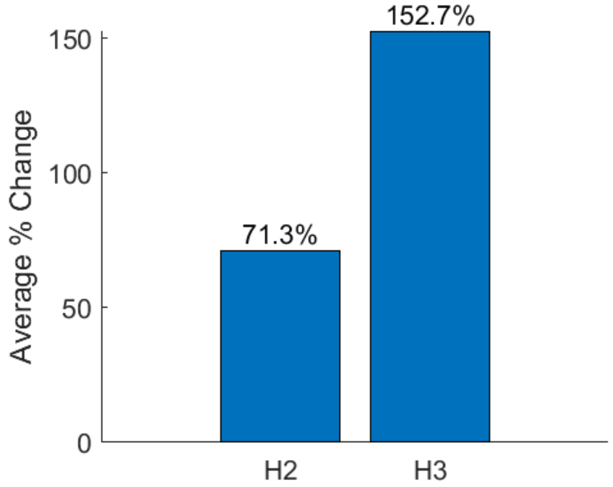
3.5psi zone

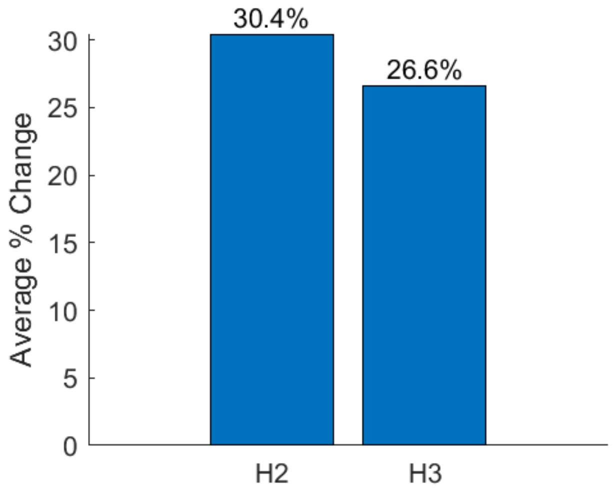


6.0psi zone









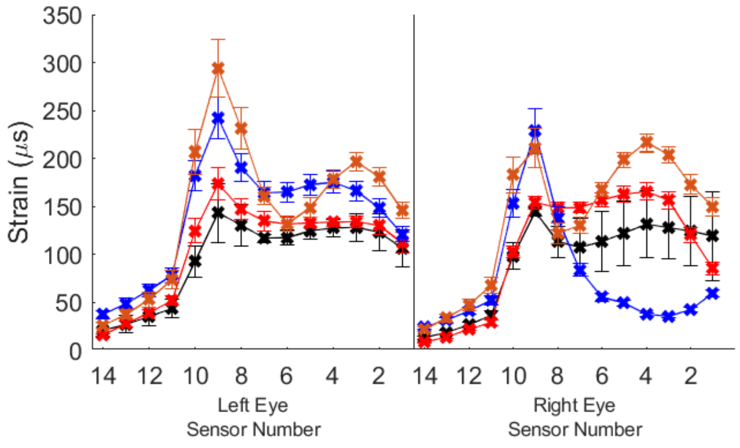
H1 performed similarly as in the facing door orientation

H2 and H3 increased accelerations particularly in frontal lobe region.

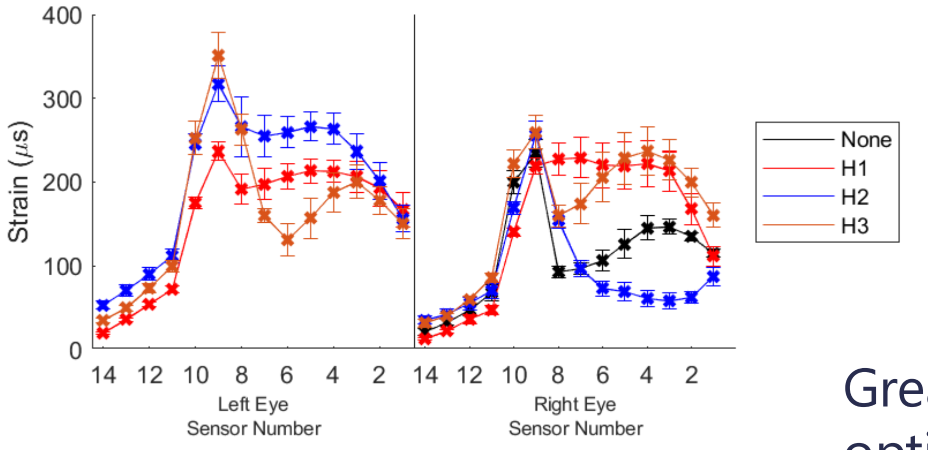
At 6psi, the least affected area is central brain, but this could be a limitation of our model.

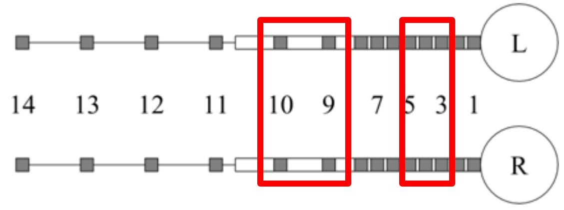
Optic pathway strain was elevated primarily in tract and medial optic nerve regions at 0^{o} orientation

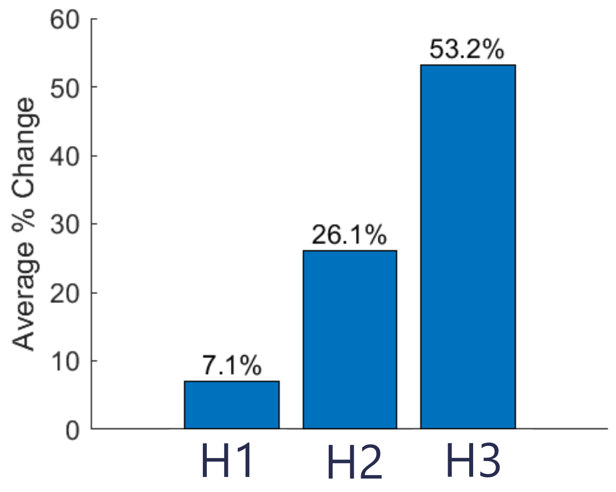
3.5psi zone

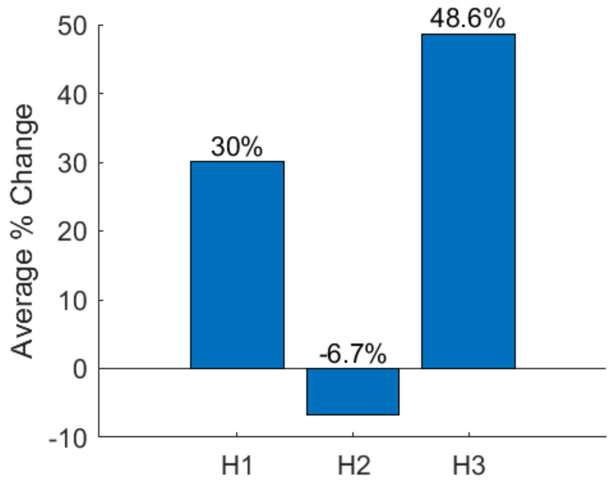


6.0psi zone









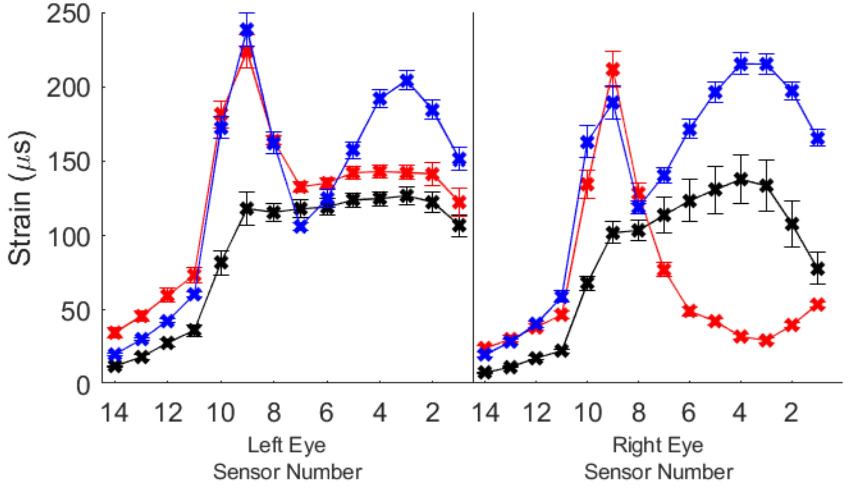
Greatest strain increases were in optic tract and medial optic nerve regions.

All helmets increased strain.

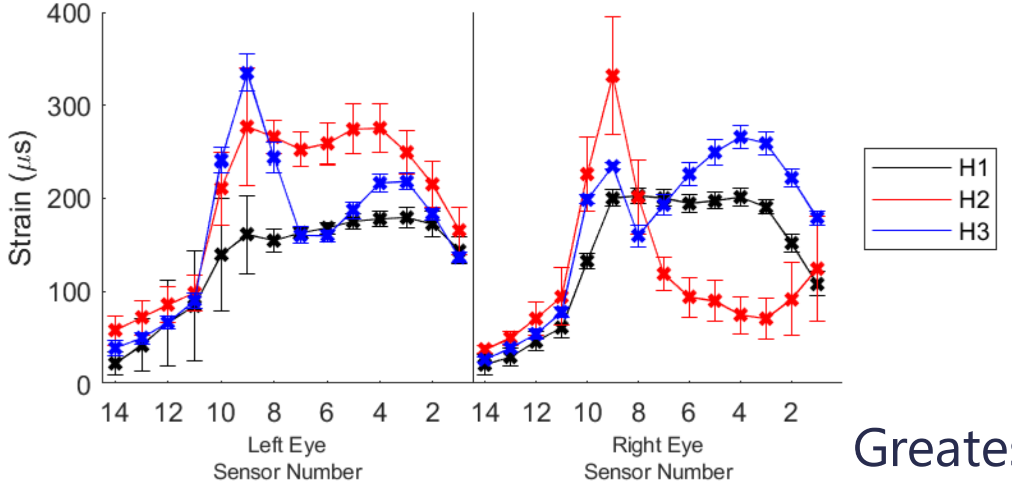
H2 was partially protective – only on the right side and only in the optic nerve region.

Strain effects at 90° orientation to charge

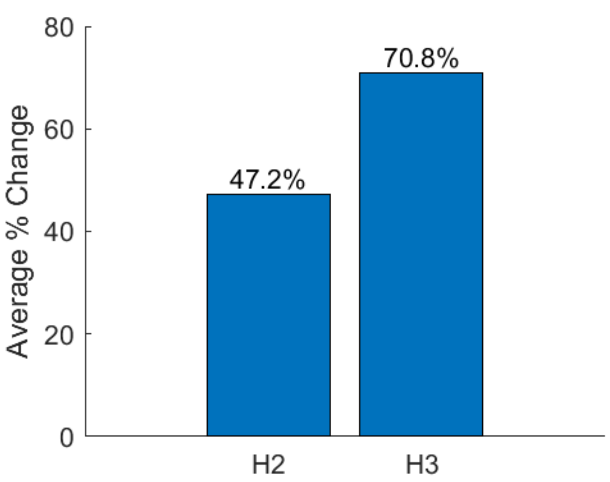
3.5psi zone

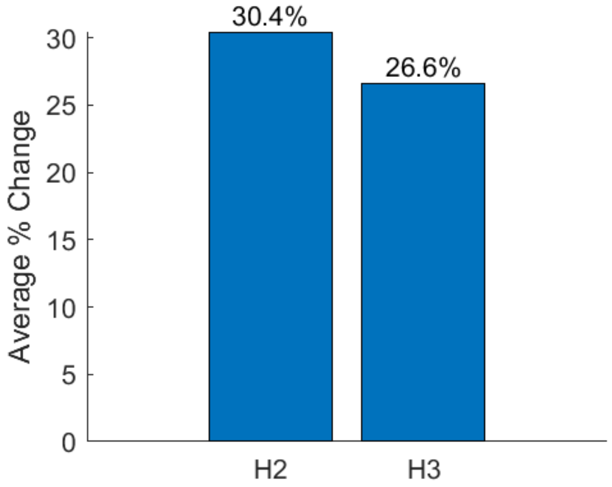


6.0psi zone



Similar pattern as face forward orientation, but lower levels overall





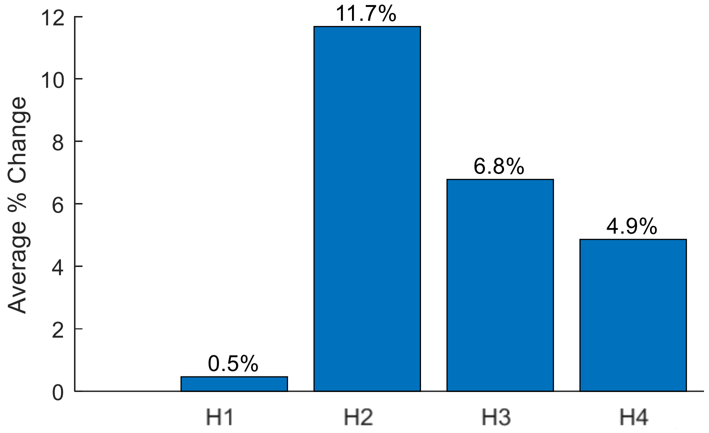
Greatest strain increases were in optic tract and medial optic nerve regions.

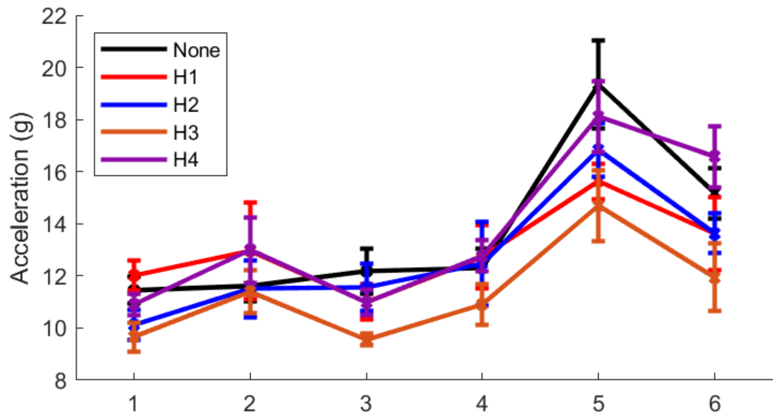
Helmets increased strain.

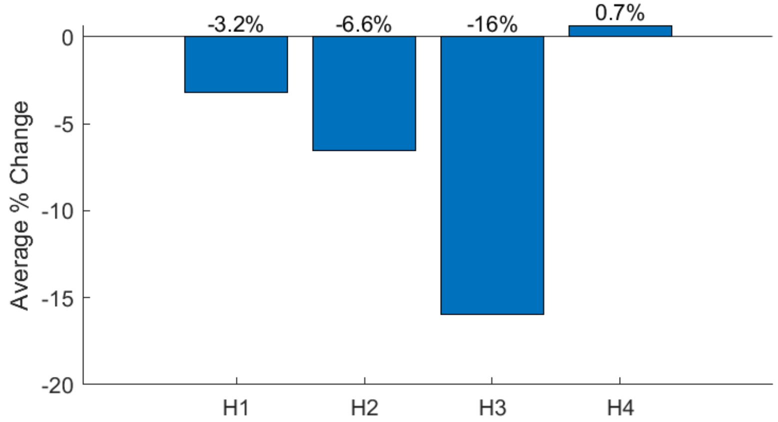
H2 was partially protective – only on the right side and only in the optic nerve region.

Temporal brain region most affected in the head tilted orientation: helmets are not equal

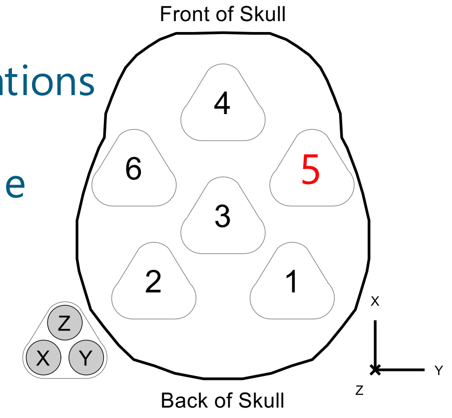
Input BOP compared to no helmet





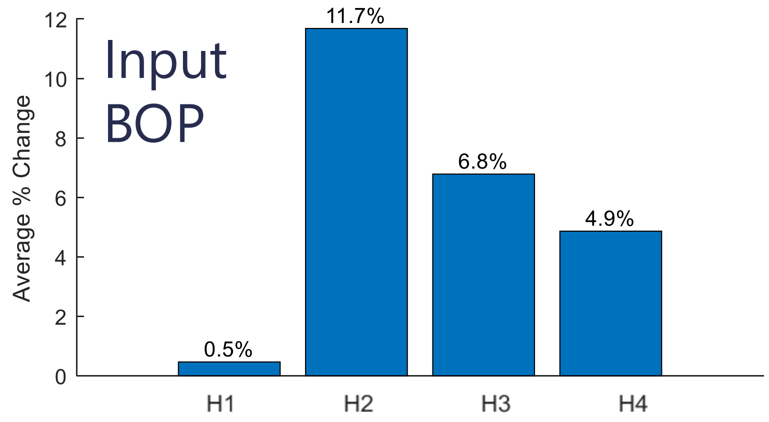


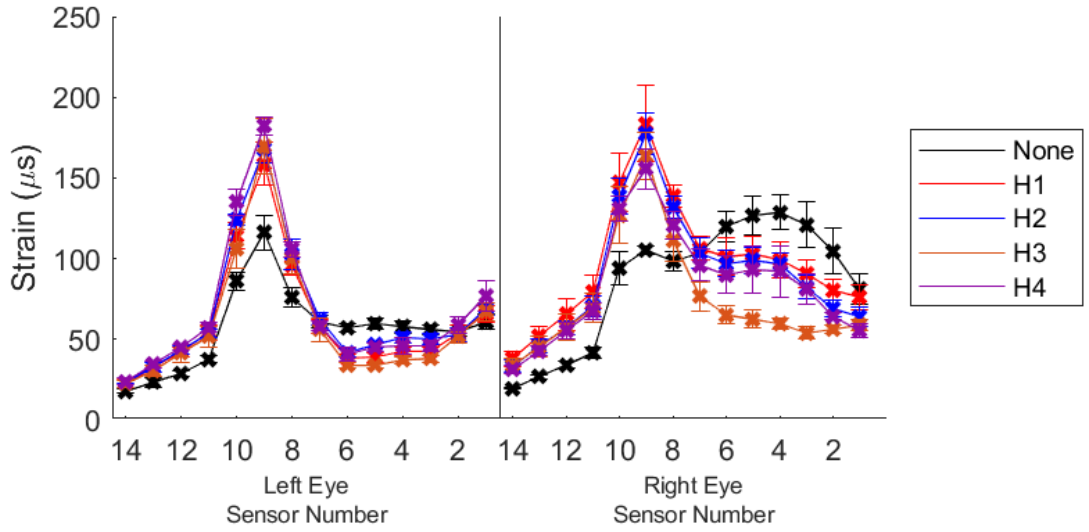
Highest accelerations in the temporal region of the side facing the door charge.

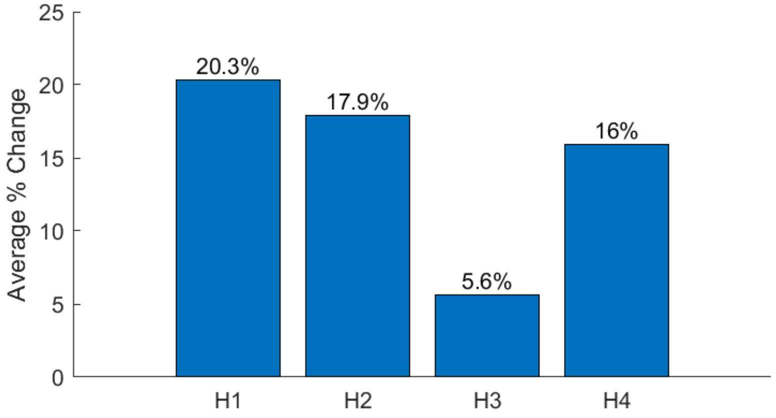


Accounting for variance in BOP input, H3 performed best, followed by H2.

Similar strain pattern in the tilted position: all helmets increased strain



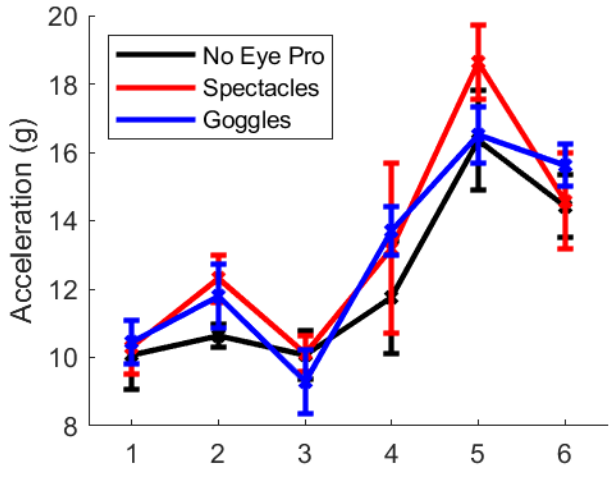


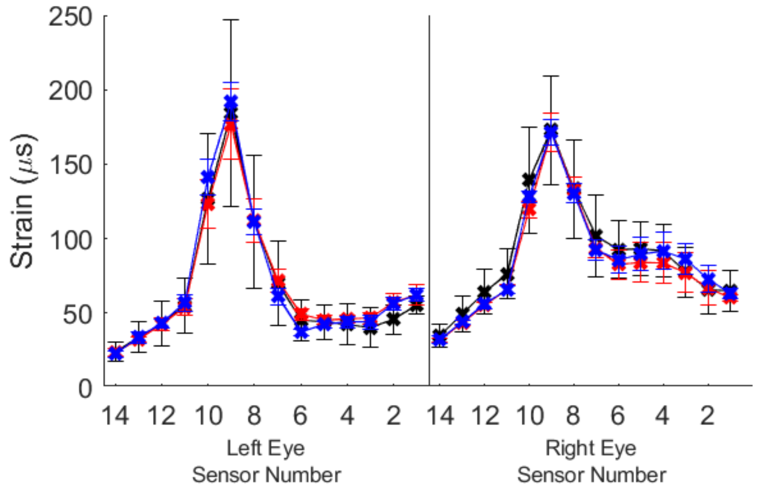


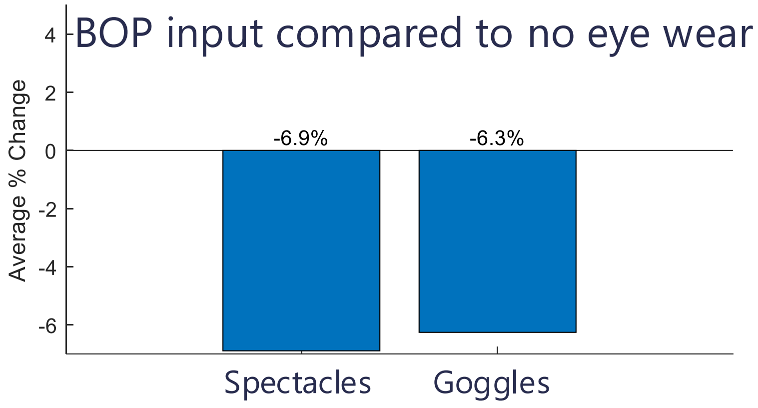
Strain was highest in optic tract region

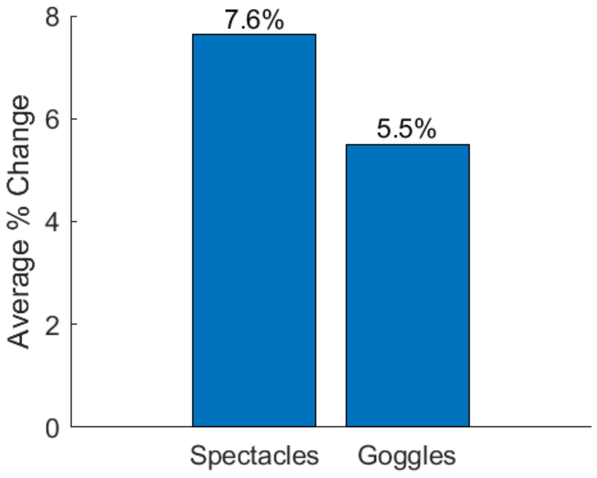
All helmets caused some decrease in strain in medial optic nerve, but increased strain in the optic tract

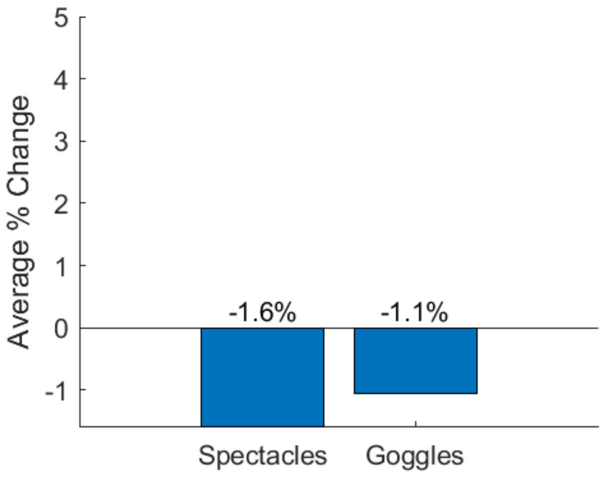
Goggles and spectacles do not protect against rLLB







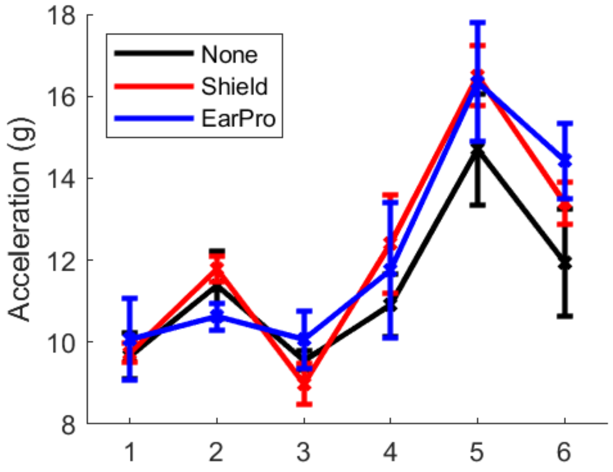


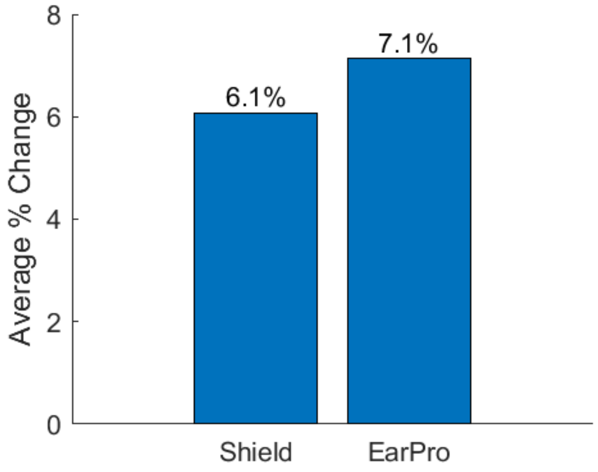


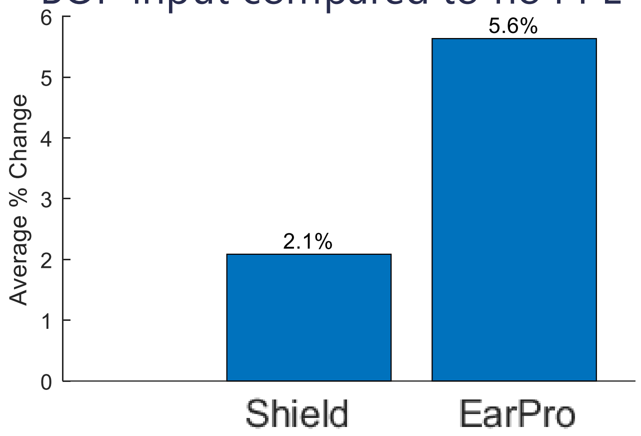
Acceleration within BIHF was increased with either eye pro despite lower input BOP.

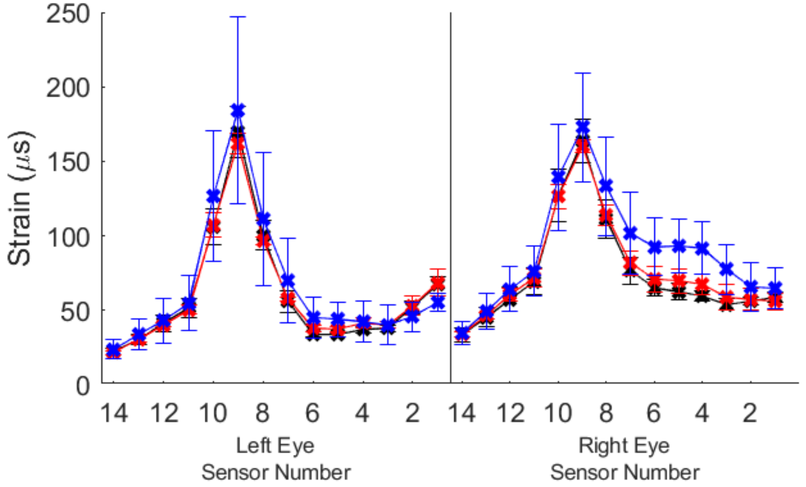
Strain within BIHF was not reduced when considering the lower input BOP

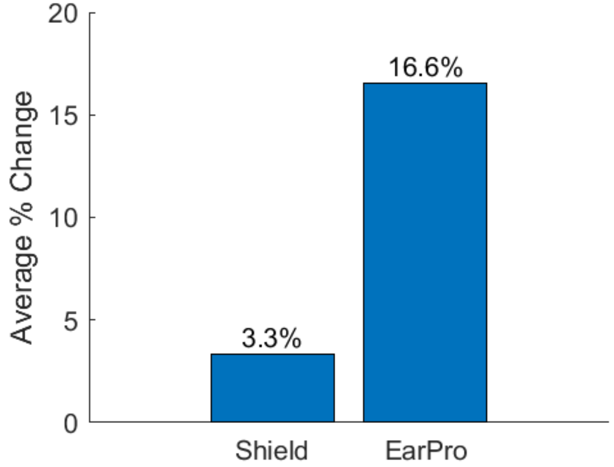
Both shield and Ear Pro increase acceleration in the brain in tilted head position











Ear pro is critical to protect the auditory system, but it increases brain accelerations.

The helmet shield was not protective in explosive breacher setting.

BIHF lacked a torso, which might be important for shield efficacy.

Breacher Site 2 test set-up

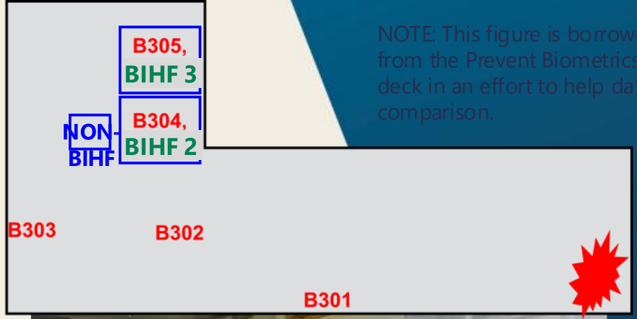
BIHFs were positioned near the most likely position of soldiers if they tactically stacked in the room

BIHF 2 positioned just around the corner relative to the blast site (first position in the stack; Front BIHF)

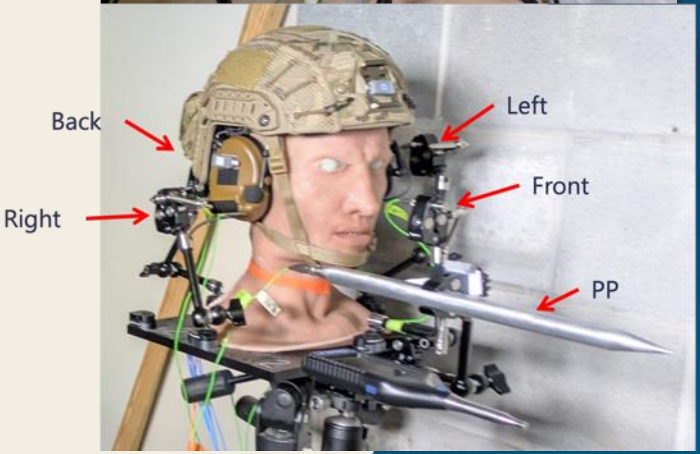
BIHF 3 positioned behind BIHF 2 (3rd or 4th position in the stack; Back BIHF)

Non-BIHF sensors centered widthwise and aligned with BIHF 2's pencil probes

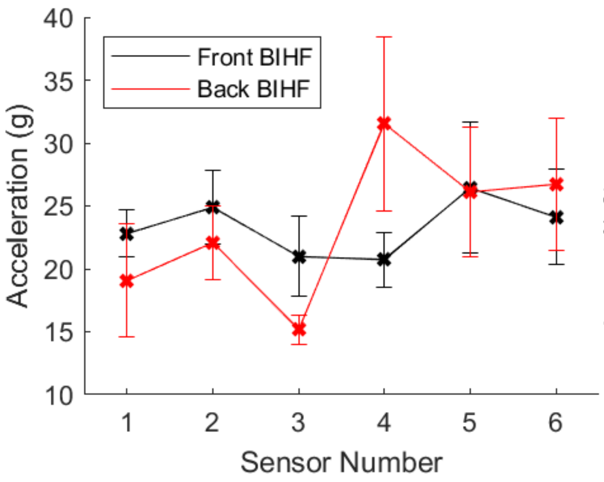
BIHFs always in same orientation.

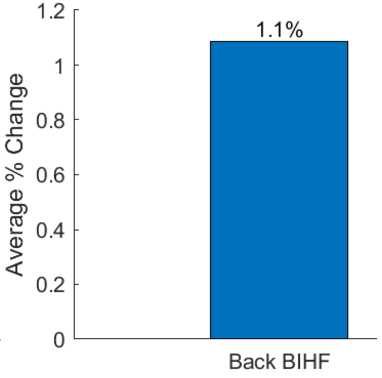


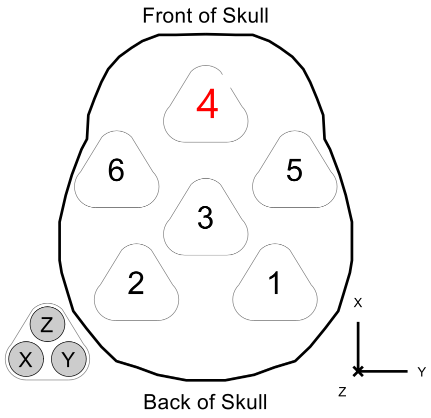
NOTE: This figure is borrowed from the Prevent Biometrics slide deck in an effort to help data comparison.

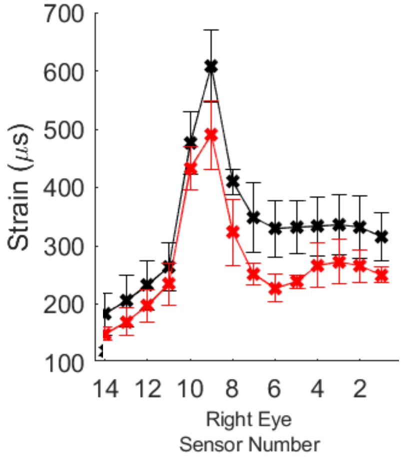


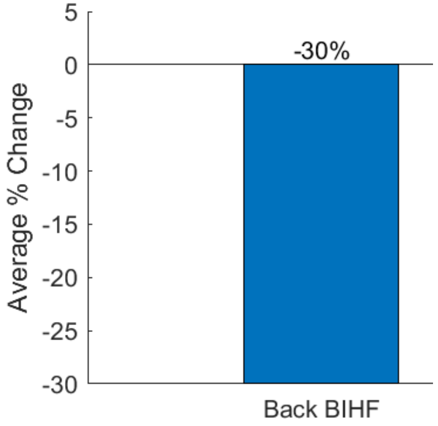
Influence of stack position on input BOP, and brain accelerations and strain



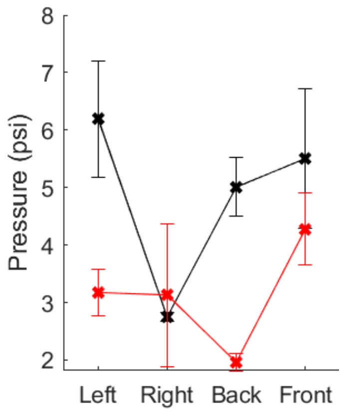


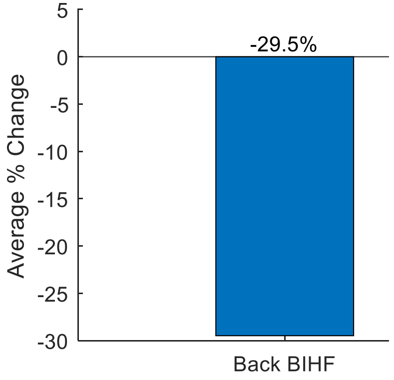






Input BOP





Overall relative brain acceleration was 30% higher in the Back BIHF when taking into consideration a 29.5% lower input BOP compared to the Front BIHF.

Acceleration was highest in the front of the brain.

Strain was reduced in the Back BIHF proportionally to the decrease in input BOP.

Summary

BIHF model optic pathway and brain measurements are reproducible

BIHF can be used to assess efficacy and interactions of different PPE in terms of strain and acceleration forces in the brain.

Overall, one helmet performed best

Goggles and spectacles do not protect against effects of rLLB in breacher environment

Both Ear pro and helmet shield increased brain accelerations and optic pathway strain

No significant differences were detected between the two “stack” positions

Conclusion: BIHF brain acceleration and strain differ based on PPE worn despite similar input BOPs

Team

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