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BLiSS

Bioastronautics and Life Support Systems

XHAB-SMAT:

"Head and body monitoring sensorimotor assessment tool"

Agenda

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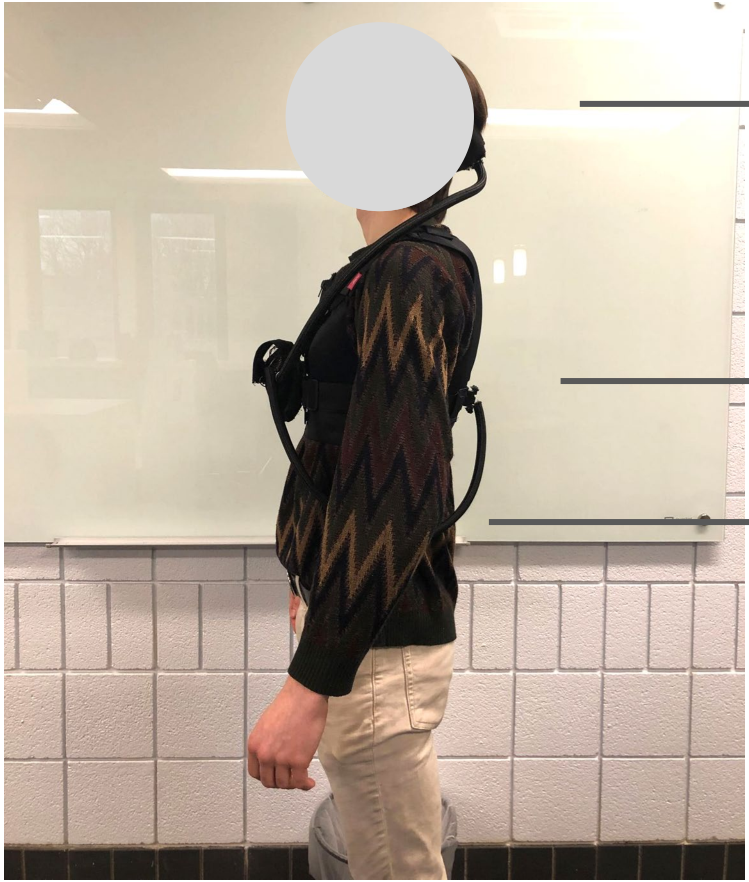
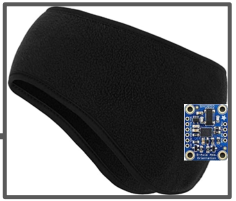
Previous Configurations

Hardware Configuration (Adafruit M5)

Hardware Configuration





Sports Headband
IMU Head Attachment

Compression Vest
M4 straps sewn in
Zipper open/close
IMU Torso Attachment

Wire Management Without interference of astronauts motion

Data Retrieval on M5

Timestamp (millis), IMU Locus, Accel X Y Z, Gyro X Y Z

```
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1479794.00, Torso, 1.30, 0.00, 0.10, -13.81, -25.06, 76.19,
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1486718.00, Torso, 0.23, -0.15, -0.14, 13.88, -0.06, -1.19
```

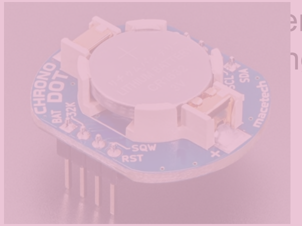
Notes on Data Retrieval:

Data Rate: Currently bottlenecked at ~3Hz
Possible hardware limitation
Once thought it was software

Method: Copied from Arduino serial port
Sent after tests to SMAT

Transitioned to Opal IMUs

Changes: Timestamp needs real-time
...ently relative
...ng ChronoDot RTC



Previous Discussed Configurations

#1 Sports Headband
With IMU attached in the back

#2 Ear Wrap / Headband
With IMU attached on one side of head

#3 Boxing Helmet
With IMU attached in the front

#4 Adjustable Helmet
With IMU attached in the back

#5 Over-Ear Headphones
With IMU attached on crown

#6 Skin-Safe Adhesive
With IMU (options) attached to:

(1) Behind Ear
(2) Forehead
(3) Spinal Region

Compression Vest + Adjustable Straps

7 Over-Ear Loop (single)
With IMU attached by ear

Recent Investigations

PCR Subsequent Designs

PCR Subsequent Designs - OPAL Earphone (M6)

Open Ear

Skin Adhesive

- Opal IMU:
  - completely wireless
  - high sampling rate
  - MotionStudio h5 → Python
- Balance Weight :
  25g Counterweight
- Skin-Safe Adhesive
  *Behind mount
- Open Ear BC-Headphones
  *Viable for audio instruction tests

PCR Subsequent Designs - OPAL Earphone (M6)

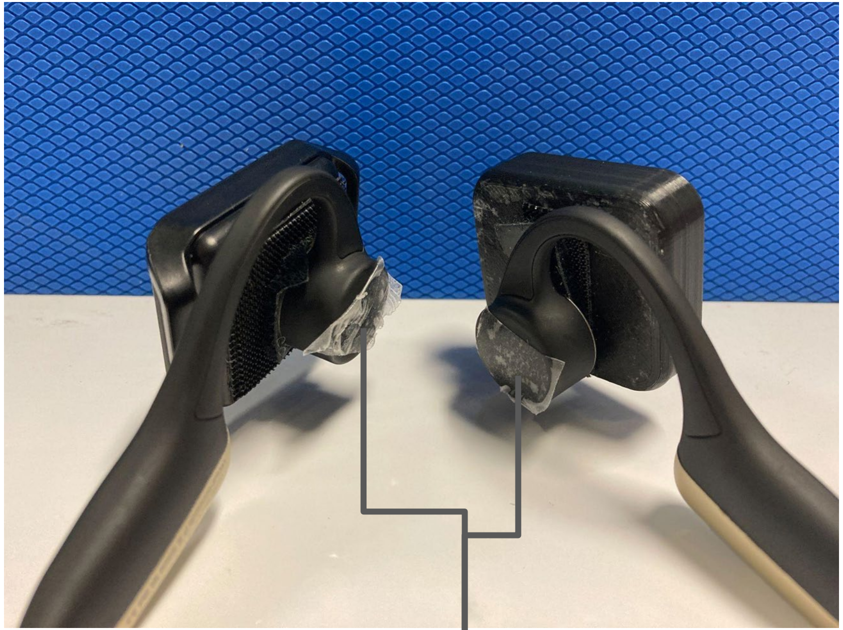
1 ● Opal IMU:
- completely wireless
- 120+ Hz sampling rate
- MotionStudio h5 → Python

2 ● Balance Weight :
25g PLA Block

3 ● Skin-Safe Adhesive
*On temples

4 ● Open Ear BC-Headphones
*Viable for audio instruction tests

PCR Subsequent Designs



Skin adhesive attached to bone conductors
*located on temples
*low skin shear location

Isometric view
*counterweight in front

*Velcro at ear position

PCR Subsequent Designs

1 ● Opal IMU:
- completely wireless
- 120+ Hz sampling rate
- MotionStudio h5 → Python

2 ● Improving M5 :
Headband Integration

3 ● Adjustability Around Opal
*Velcro straps on back of head

4 ● High Comfort
*Soft elastic material
*No skin adhesion

Meta Trade Study

TOPSIS MCDM Deliverable

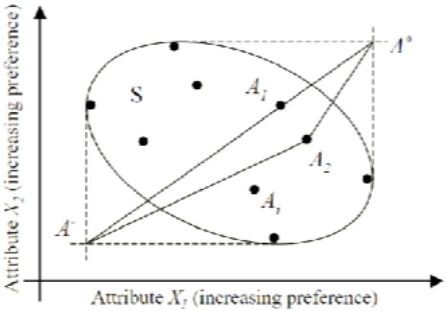
TOPSIS MCDM Deliverable

- TOPSIS - Technique for Order Preference by Similarity to Ideal Solution
  - More “bounded” than a classic trade study
  - Seeks to use *only our data* to judge an ideal alternative
  - Compares closeness-to-ideal of existing alternatives

Calculate the normalized decision matrix

$$
\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_M \end{array}
\begin{array}{c}
\begin{array}{cccccc} f_1 & f_2 & \cdots & f_j & \cdots & f_N \end{array} \\
\begin{bmatrix}
f_{11} & f_{12} & \cdots & f_{1j} & \cdots & f_{1N} \\
f_{21} & f_{22} & \cdots & f_{2j} & \cdots & f_{2N} \\
\vdots & \vdots & \ddots & \vdots & & \vdots \\
f_{i1} & f_{i2} & \cdots & f_{ij} & \cdots & f_{iN} \\
\vdots & \vdots & & \vdots & \ddots & \vdots \\
f_{M1} & f_{M2} & \cdots & f_{Mj} & \cdots & f_{MN}
\end{bmatrix}
\end{array}
$$

Determine distance to ideal and anti-ideal solution



Rank the alternatives




TOPSIS Criteria

Unobtrusivity
Motion inhibition (-)
Friction (-)
Strong pressure points (-)
COG offset (-)
Bulk (-) (in)
Irritation (during) (-)
Irritation (after) (-)
Don/doff time (-) (sec)
Don/doff intuition (+)
Adjustability (+)
Shear motion (-)
Claustrophobic (-)
Demeaning (-)
Mass (-) (g)

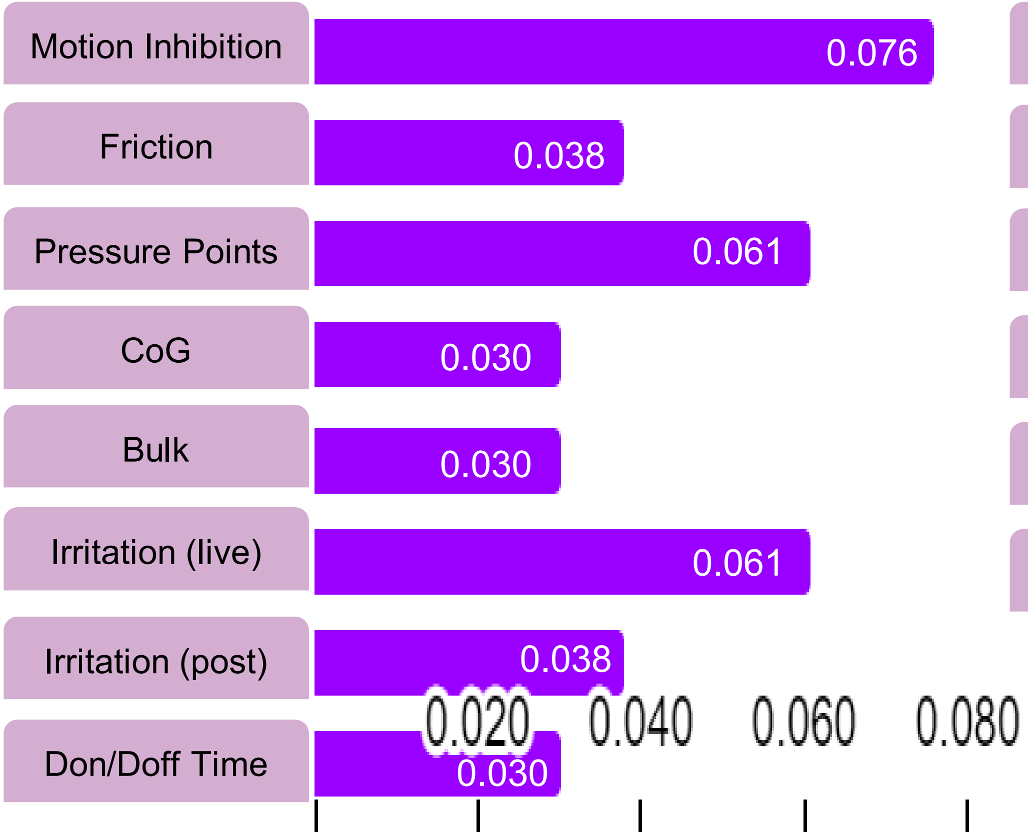
Efficiency
Data collection rate(+) (Hz)
Start/stop time(-) (sec)
Discharge time(+) (hr)
Calibration time(-) (sec)

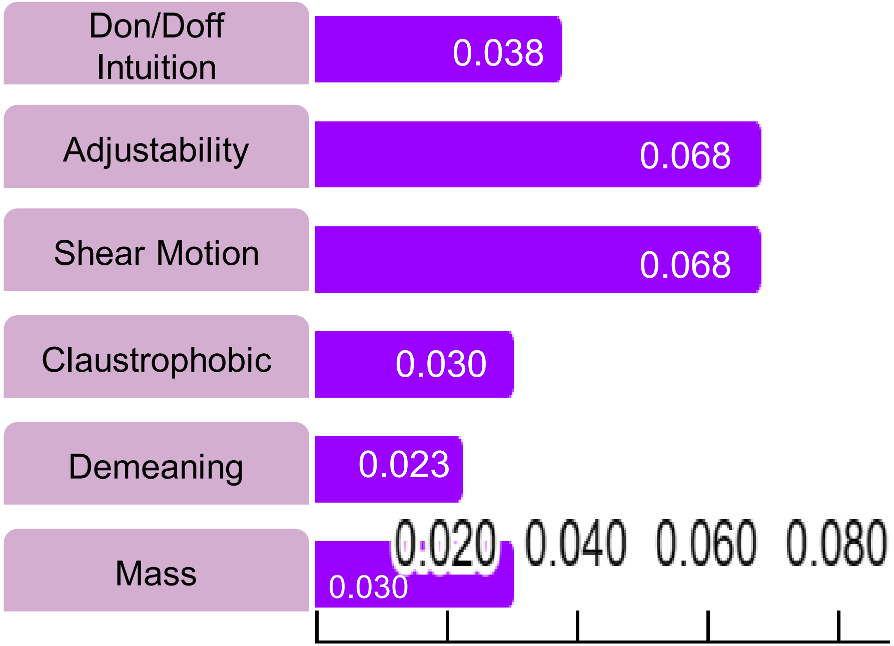
Structure
Complexity (-)
Repairability (+)
Strength (+)
Transportability (+)

Selected to encompass both unobtrusivity of the system as well as its technical attributes

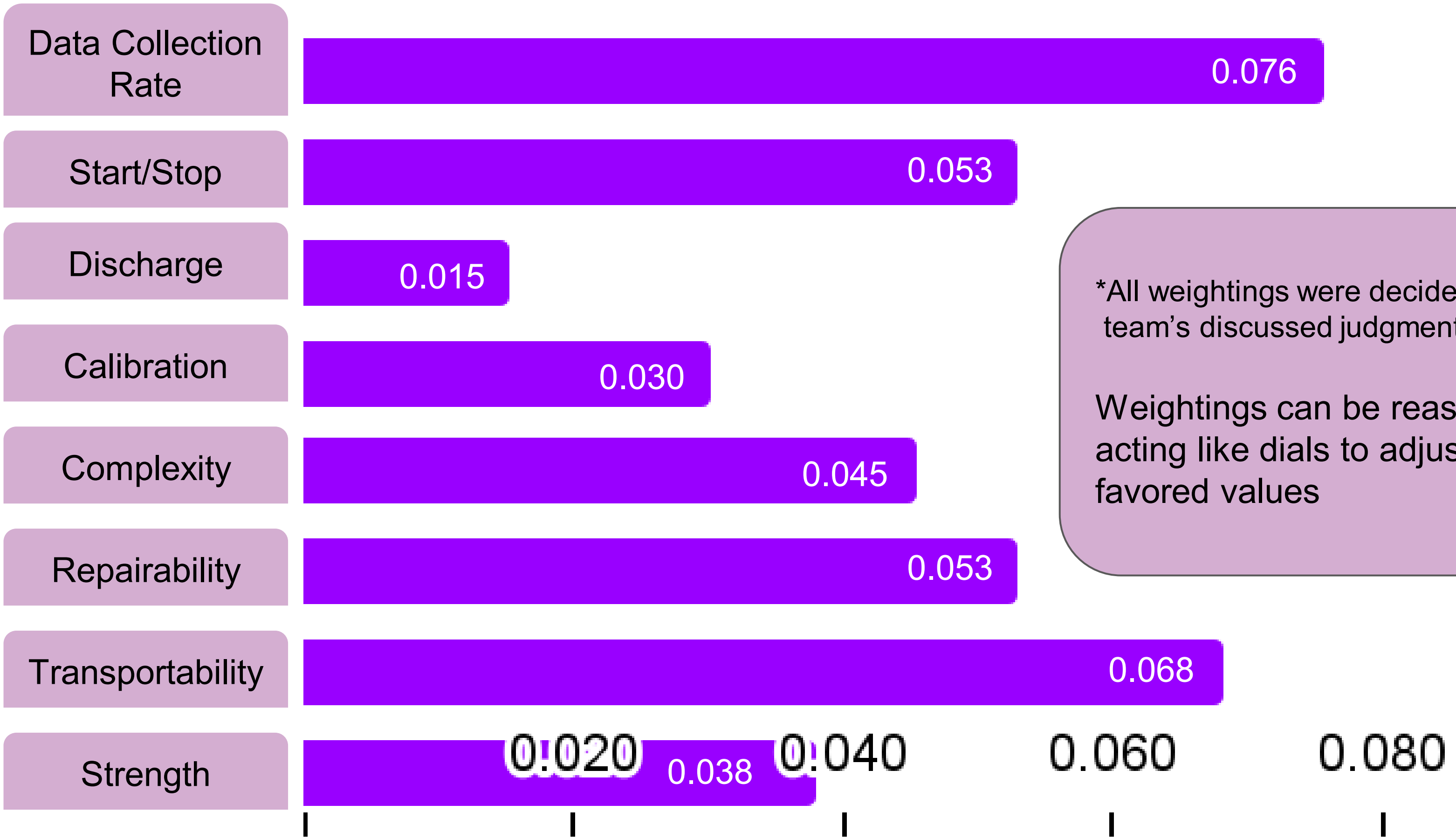
*(-) indicates that a higher value is poor
*(+) indicates that a higher value is favored
*Weightings of all criteria must sum to 1

TOPSIS Weightings: Unobtrusivity





TOPSIS Weightings: Efficiency & Structure



*All weightings were decided with TDI team's discussed judgment

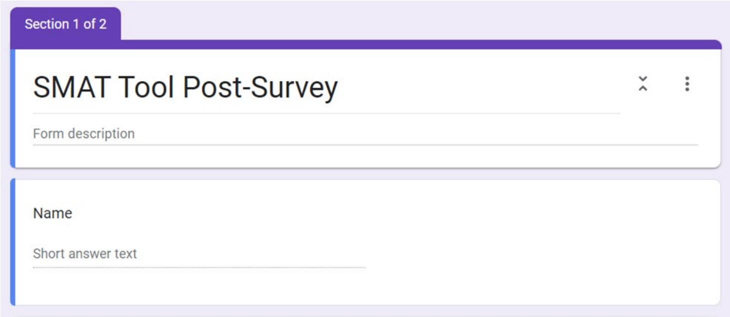
Weightings can be reassigned, acting like dials to adjust to favored values

TOPSIS Data Collection and Testing

- TOPSIS allows for input of quantitative and qualitative data of any unit or range

  Using this advantage → Data for criteria is collected through *surveys*, *tests*, and *inspections*

- Post-Test Survey

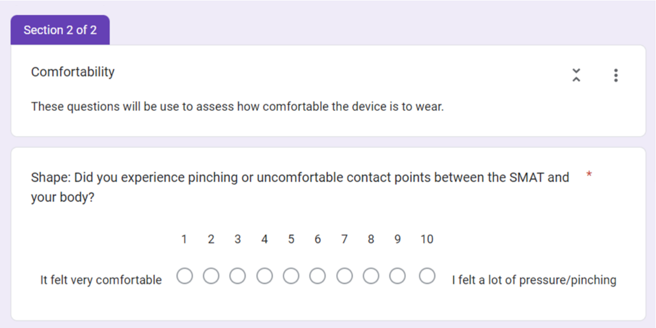

Section 1 of 2

SMAT Tool Post-Survey

Form description

Name

Short answer text


Section 2 of 2

Comfortability

These questions will be use to assess how comfortable the device is to wear.

Shape: Did you experience pinching or uncomfortable contact points between the SMAT and your body? *

	1	2	3	4	5	6	7	8	9	10	
It felt very comfortable	○	○	○	○	○	○	○	○	○	○	I felt a lot of pressure/pinching

*only a snapshot of full survey

- Out of Survey Testing

  Don/doff time
  Strength/Repairability
  Shear motion
  Transportability
  Start/stop time
  Calibration time

- Configuration Inspection

  Data collection rate
  Discharge time
  Mass
  Bulk (characteristic length)

More Detailed View of Out-of-Survey Testing

Don/doff time test:

- Hidden timer
- Start timing when told to put on SMAT
- Stop timing when it is put on
- Start timing when told to take off SMAT
- Stop timing when it is taken off

Bulk test:

- Measure the characteristic length (distance from body) of head part and torso part and add together

Shear motion test:

- Slow motion video on phone looking for shear motion
- Shake head back and forth
- Shake head up and down
- Make an infinity sign with your nose
- Quickly twist torso with fixed hips
- Bend over quickly to touch your toes
- Bend back quickly to open up your chest

Mass test:

- Mass it in grams

Data collection rate test:

- For Opal, read overall frequency of data input
- For Adafruit, count interval between timestamps in serial port and average and invert to find frequency

Start/stop time:

- Start timing when system power input is activated
- Stop timing when system begins to take data

Discharge time:

- Let run idle until death (and time)
- Let run while moving until death (and time)
- Take the minimum time of the above two
- Also consider producer listed times

More Detailed View of Out-of-Survey Testing

Calibration time:

- Start time when user is told to begin calibration pose and SMAT begins calibration
- Stop time when the tool is calibrated (to our standard)

Strength:

- Treat it like a risk matrix
- Rank severity of the break and likelihood of the break (determine either hypothetically or with a demo test)
- Total RPN will be inverted and set as the strength score

High severity Low likelihood	High severity High likelihood
Low severity Low likelihood	Low severity High likelihood

Repairability:

- For each break/failure mode of the system, rank how repairable that break is from 1 to 10, with 10 being the user can repair it on the spot while they are using it, and 1 being that the full system must be rebuilt with new parts
- Sum all of the repairability points, inverse, and set that as the repairability score

Transportability:

- Purely qualitative (with examples of transportation if we come up with good ones)
- 1-10 scale

Shear Motion Tests

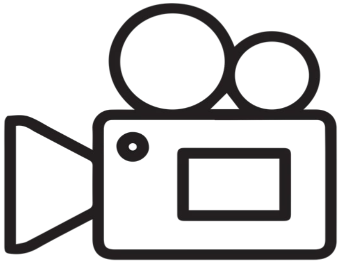
- Shear motion of a sensor attachment configuration can compromise data
  Quantifying shear motion is difficult or impossible with sensor data when considering S/N ratio
  Alternatively → qualitative observation of shear motion is a natural filter of unwanted motion larger than natural IMU noise

- Solution: Utilizing *slow-motion video* to analyse visual shear motion of IMU attachments

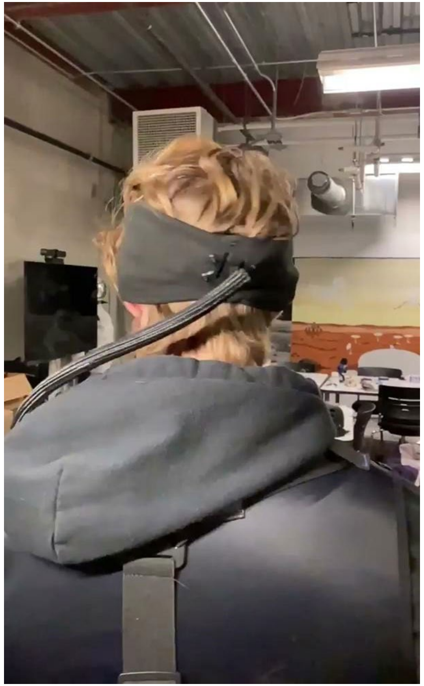
- Body motions for observing sensor shear motion:

Shake head back and forth
Shake head up and down
Make an infinity sign with your nose

Quickly twist torso with fixed hips
Bend over quickly to touch your toes
Bend back quickly to open up your chest
Raise arms quickly above head



Shear Motion Tests - Adafruit M5 Example



Head Back and Forth

Head Up and Down

Infinity Sign

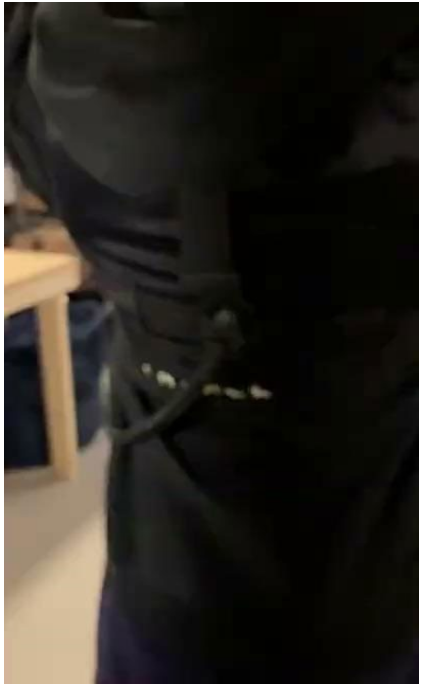
Large shear motion for comparison

Shear Motion Tests - Adafruit M5 Example

Twist at Hips

Touch Toes

Open Chest



Raise Arms

TOPSIS Deliverable - Filled

	Weights (1-10)	Weights (Normalized)	OPAL earphones with tape (M6)	OPAL M5	Adafruit Earwrap	Adafruit M5	Adafruit Boxing Helm	Adafruit Skater Helm
Criteria								
Unobtrusivity								
Motion inhibition (-)	10	0.076	2.333	1.667	2.5	3.5	5	3.667
Friction (-)	5	0.038	1.333	1	5.5	1.5	3	2.333
Strong pressure points (-)	8	0.061	0.667	0	1.5	0	5	1.333
COG offset (-)	4	0.030	5	2.667	5	3	5	3.333
Bulk (-) (in)	4	0.030	3.25	2.938	4.25	4.125	5.75	6.5
Irritation (during) (-)	8	0.061	1	1.667	3	2	4.5	2.667
Irritation (after) (-)	5	0.038	1.333	1	1	1	1	1
Don/doff time (-) (sec)	4	0.030	93.11	84.01	160.87	118.69	182.15	191.45
Don/doff intuition (+)	5	0.038	5	9.667	4	6.5	5.5	6
Adjustability (+)	9	0.068	6	8	5.5	8.5	8	8.667
Shear motion (-)	9	0.068	2.286	0	2.429	1.857	3.429	3.429
Claustrophobic (-)	4	0.030	1.333	1.333	3.5	2	7	3
Demeaning (-)	3	0.023	1.667	1.667	2	2.5	7	1.333
Mass (-) (g)	4	0.030	416.6	393.5	470.1	445.2	538.8	923.9
Efficiency								
Data collection rate(+) (Hz)	10	0.076	120	120	100	100	100	100
Start/stop time(-) (sec)	7	0.053	45	45	120	120	120	120
Discharge time(+) (hr)	2	0.015	8	8	7.63	7.63	7.63	7.63
Calibration time(-) (sec)	4	0.030	3	3	60	60	60	60
Structure								
Complexity (-)	6	0.045	3	3	4	4	4	4
Repairability (+)	7	0.053	4.222	4.25	3.538	3.538	3.429	3.429
Strength (+)	9	0.068	0.024	0.032	0.011	0.011	0.01	0.011
Transportability (+)	5	0.038	8	9	6	6	3	4

TOPSIS Deliverable - Filled

	Weights (1-10)	Weights (Normalized)	OPAL earphones with tape (M6)	OPAL M5	Adafruit Earwrap	Adafruit M5	Adafruit Boxing Helm	Adafruit Skater Helm
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Strong pressure points (-)	8	0.061	0.667	0	1.5	0	5	1.333
COG offset (-)	4	0.030	5	2.667	5	3	5	3.333
Bulk (-) (in)	4	0.030	3.25	2.938	4.25	4.125	5.75	6.5
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Don/doff time (-) (sec)	4	0.030	93.11	84.01	160.87	118.69	182.15	191.45
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TOPSIS Deliverable - Filled

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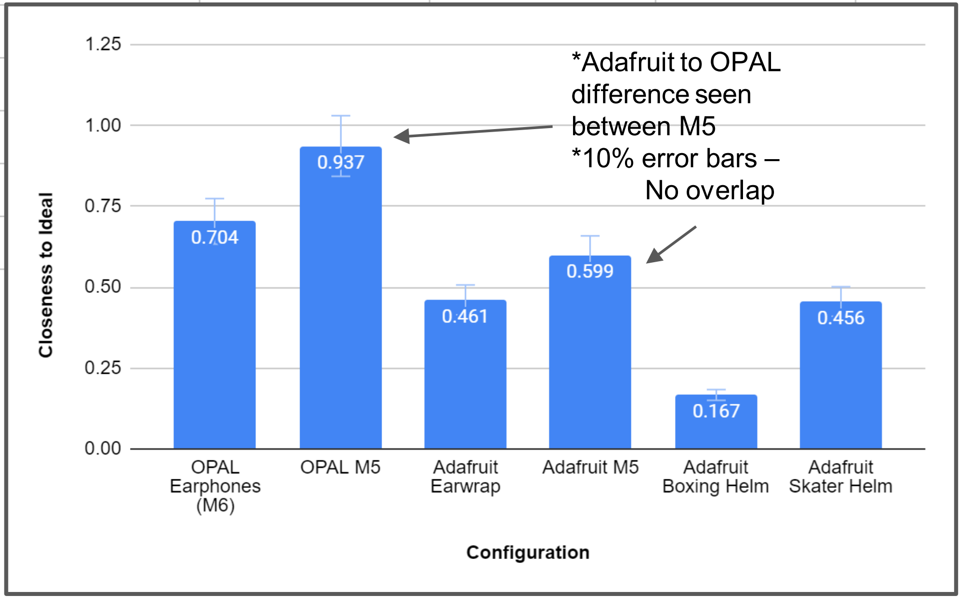
Efficiency								
Data collection rate(+) (Hz)	10	0.076	120	120	100	100	100	100
Start/stop time(-) (sec)	7	0.053	45	45	120	120	120	120
Discharge time(+) (hr)	2	0.015	8	8	7.63	7.63	7.63	7.63
Calibration time(-) (sec)	4	0.030	3	3	60	60	60	60
Structure								
Complexity (-)	6	0.045	3	3	4	4	4	4
Repairability (+)	7	0.053	4.222	4.25	3.538	3.538	3.429	3.429
Strength (+)	9	0.068	0.024	0.032	0.011	0.011	0.01	0.011
Transportability (+)	5	0.038	8	9	6	6	3	4

TOPSIS Deliverable - Results

	Closeness to Ideal	Closeness		Best Alternative	OPAL M5
OPAL Earphones (M6)		0.7041			
OPAL M5		0.9373			
Adafruit Earwrap		0.4613			
Adafruit M5		0.5995			
Adafruit Boxing Helmet		0.1665			
Adafruit Skater Helmet		0.4560			

Ranking:

1. OPAL M5
2. OPAL Earphones (M6)
3. Adafruit M5
4. Adafruit Earwrap
5. Adafruit Skater Helmet
6. Adafruit Boxing Helmet



Closest to Ideal Configuration

OPAL M5

Sport Headband + Compression Vest

Winning Attributes: **Zero shear motion**, **zero pressure points**, **minimal COG offset**, **minimal motion inhibition**

Future Configuration with NASA Manufacturing Capability

Key Requirements:

- ~Zero shear motion
- Simple Don/doff
- Unnoticeable wearability
- High sampling frequency (+100Hz)
- Wireless data transmission (low packet loss)
- Instant software communication set-up time

Customer Interests:

- Ear attachment
- Effective for headlocking metric

*The Ideal/Anti-Ideal values do not mean a lot alone, but comparing to what configuration gave the ideal can inform key qualities of the *ideal design*

TOPSIS Determined Ideal Configuration:

Idealized Entries	Motion inhibition (-)	Friction (-)	Strong pressure points (-)	COG offset (-)	Bulk (-)	Irritation (during) (-)	Irritation (after) (-)	Don/doff time (-)	Don/doff intuition (+)	Adjustability (+)	Shear motion (-)	Claustrophobic (-)	Demeaning (-)
Ideal	0.0157	0.0054	0.0000	0.0079	0.0077	0.0092	0.0146	0.0071	0.0236	0.0319	0.0000	0.0045	0.0038
Anti-Ideal	0.0471	0.0296	0.0562	0.0148	0.0171	0.0413	0.0195	0.0162	0.0098	0.0202	0.0378	0.0238	0.0197

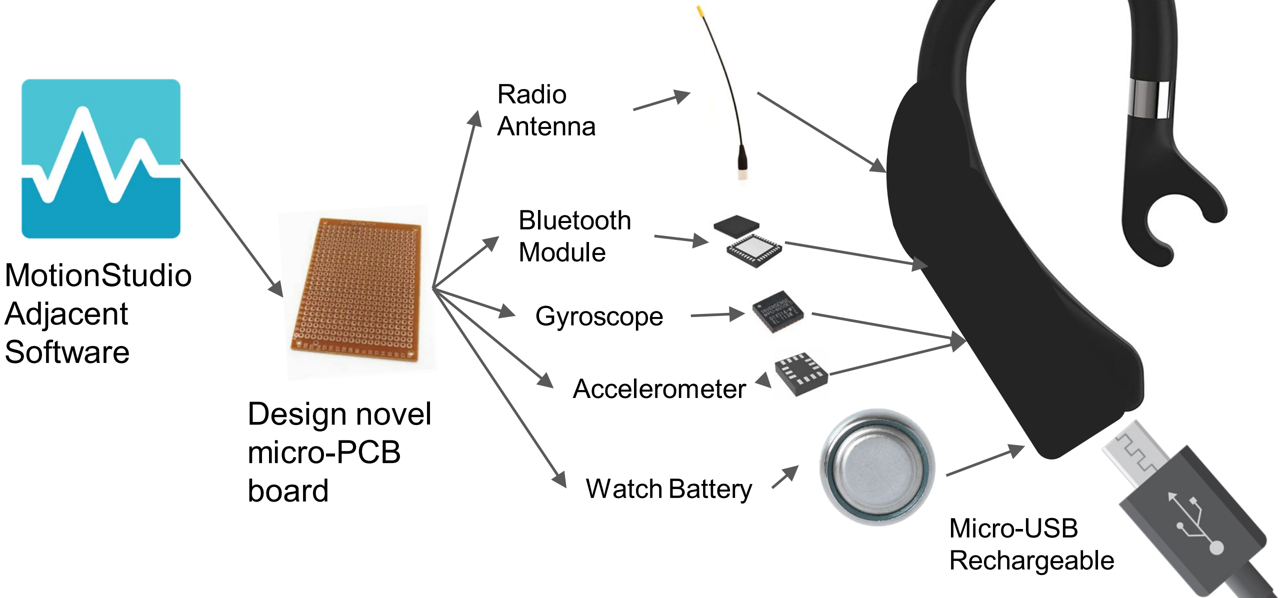
Mass (-)	Data collection rate (+)	Start/stop time(-)	Discharge time(+)	Calibration time(-)	Complexity (-)	Repairability (+)	Strength (+)	Transportability (+)
0.0086	0.0348	0.0096	0.0063	0.0007	0.0149	0.0245	0.0479	0.0220
0.0202	0.0290	0.0256	0.0060	0.0150	0.0199	0.0198	0.0150	0.0073

Future Configuration with NASA Manufacturing Capability

Key Requirements:
- ~Zero shear motion
- Simple Don/doff
- Unnoticeable wearability
- High sampling frequency (+100Hz)
- Wireless data transmission (low packet loss)
- Instant software communication set-up time

***Would consume years of design, testing, and manufacturing (including setting up manufacturing infrastructure)**

Customer Interests:
- Ear attachment
- Effective for headlocking metric

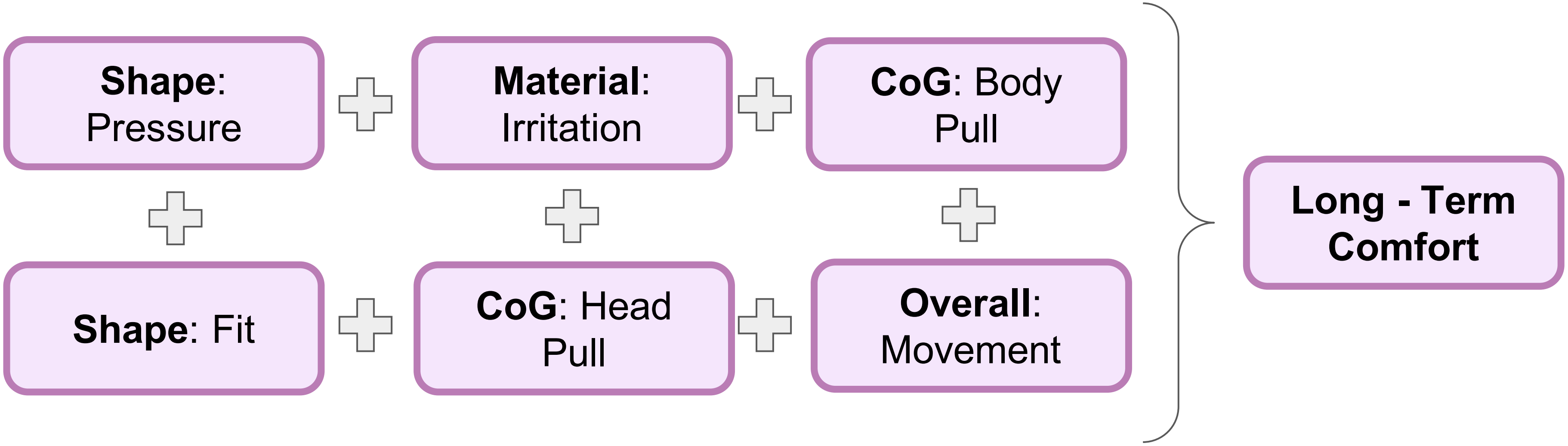


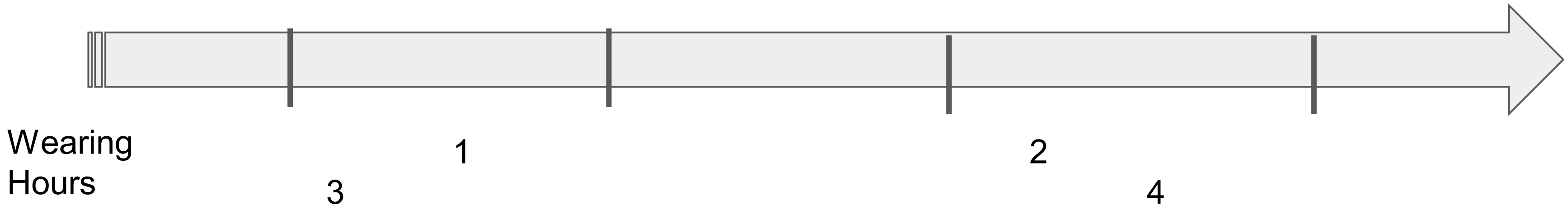
Symmetric dud for COG balance

Skin adhesive torso module to sternum

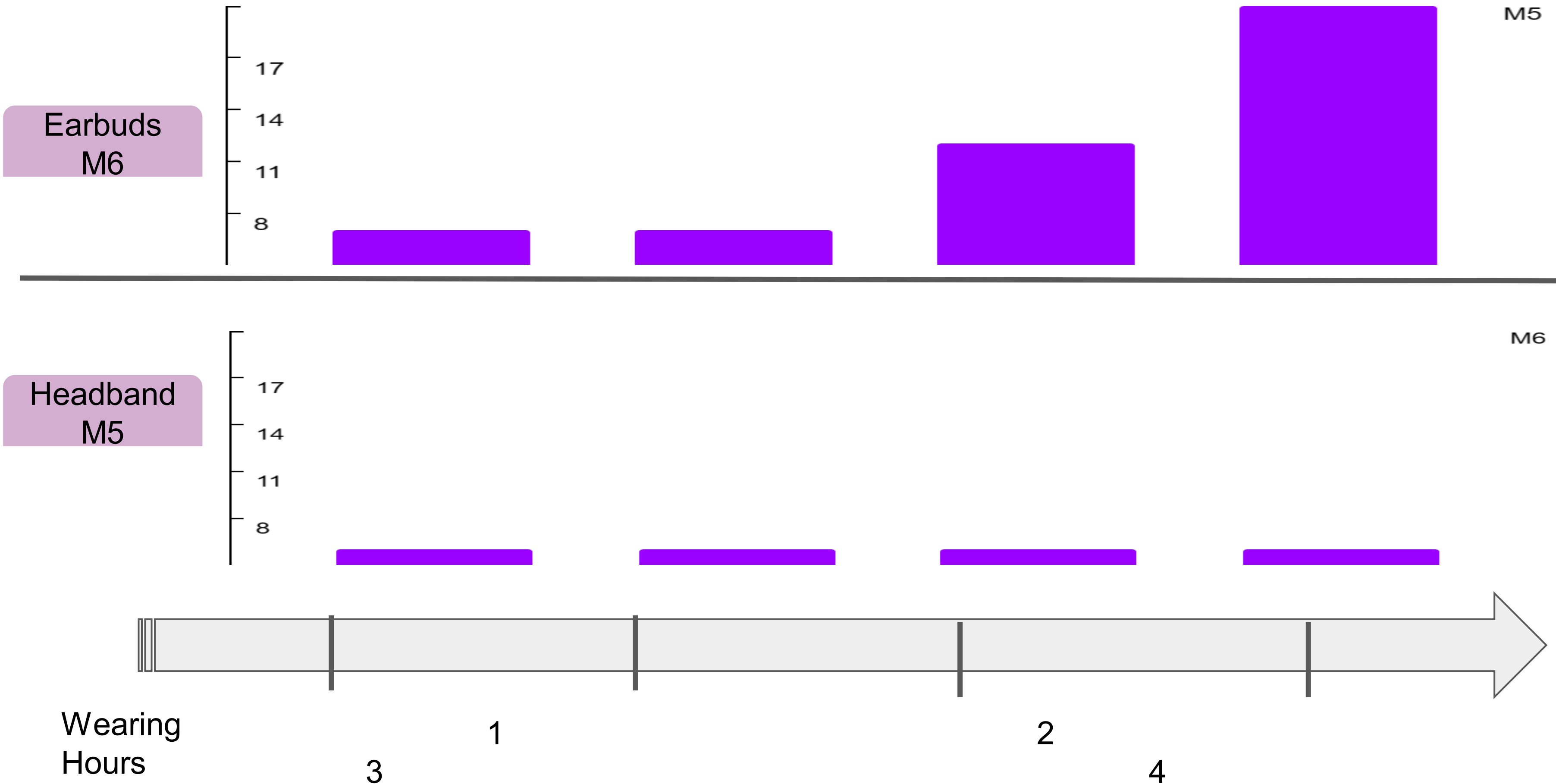
Unobtrusivity

Comfortability Rating: Long-Term





Comfortability Rating: Long-Term



Unobstrusivity Comments

M5: pressure from compression of the suit can be ignored, but if focused on it can be distracting, particularly at the shoulder blades and back of the head.

M5: It did not feel restrictive but I was being careful with it on.

M5: Pulling feeling on back of shoulders (though not noticeable until after a while)

M4: on either side of neck under jaw and front of head. Helmet shifted a lot on head

M6: Right ear moves. Head felt pulled down

M3: clautrophobic head

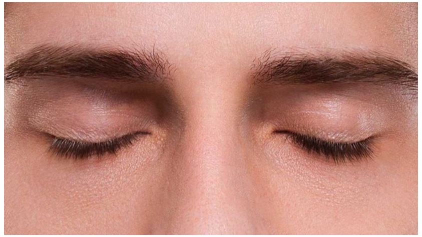
Testing

Impairment Devices

Foam Mattress

Drunk Goggles

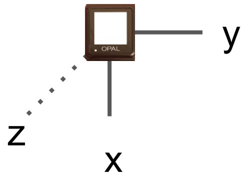
Neck Brace



Eyes Closed

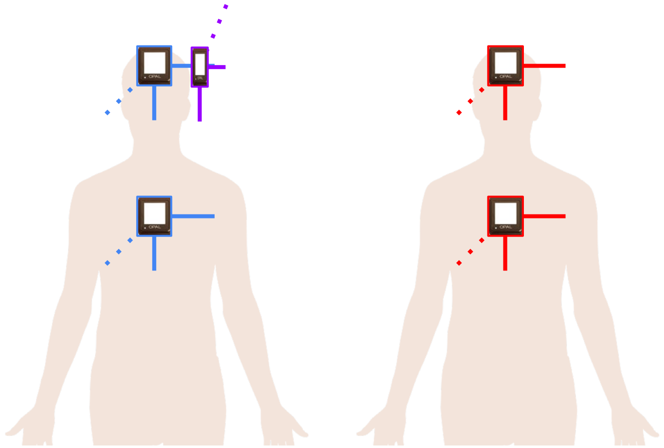
Reference Frames: Orientation

OPAL Orientation



Front

Back

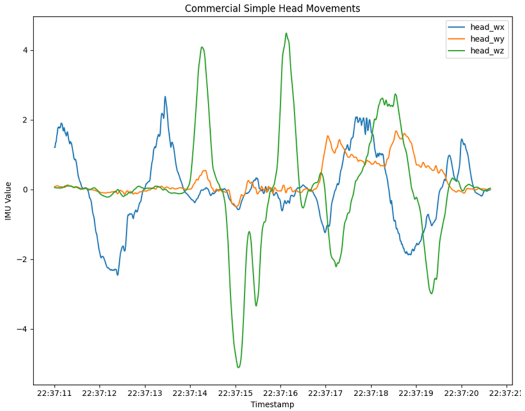


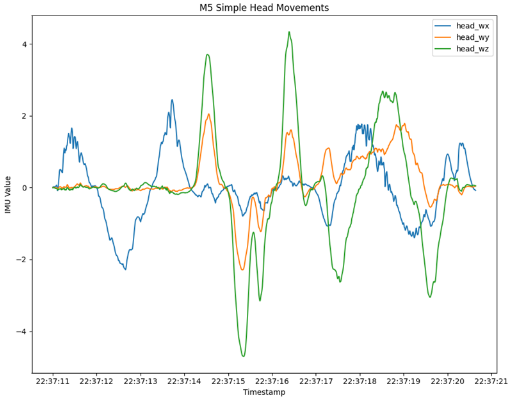
Commercial	Front	Ear	Back
<x,y,z>	<x,y,z>	<x,z,-y>	<x,-y,z>

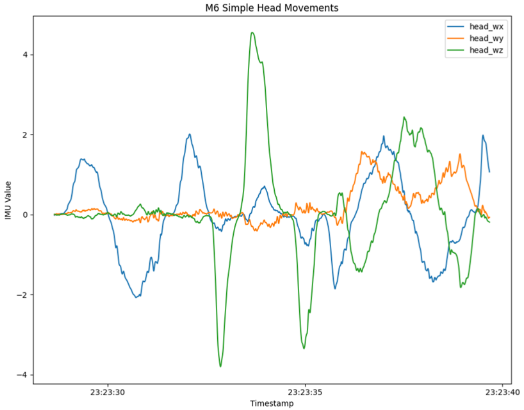
Commercial vs M5 vs M6

Commercial	M5	M6

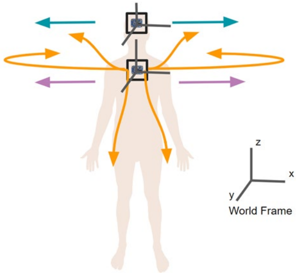








Metric Calculations



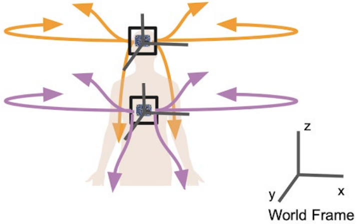
$$RMS = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{N}}$$

Sway

$$ML = RMS_{a_x}(Head) - RMS_{a_x}(Body)$$

$$AP = RMS_{a_y}(Head) - RMS_{a_y}(Body)$$

$$Sway = \sqrt{ML^2 + AP^2}$$



Head Locking

$$UD = RMS_{\omega_x}(Head) - RMS_{\omega_x}(Body)$$

$$SS = RMS_{\omega_y}(Head) - RMS_{\omega_y}(Body)$$

$$LR = RMS_{\omega_z}(Head) - RMS_{\omega_z}(Body)$$

$$Head\ Locking = LR + SS + UD$$

Testing Procedure Results

Testing Procedure

[Testing Procedures]

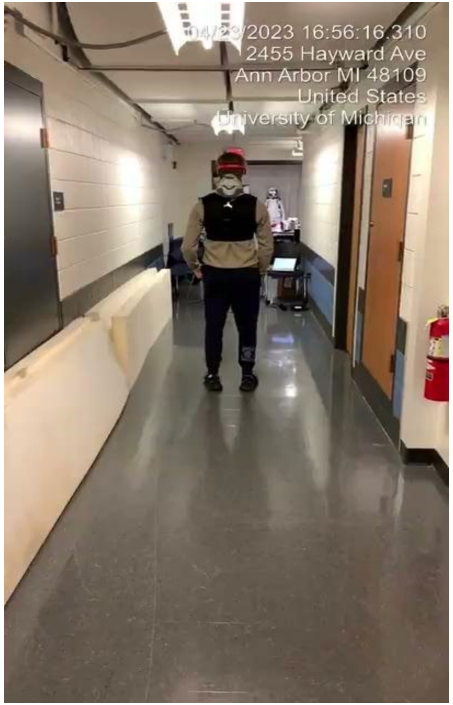
I — Calibration
- IMU Calibration

II — Tool Verification
- Head Movement
- Torso Movement

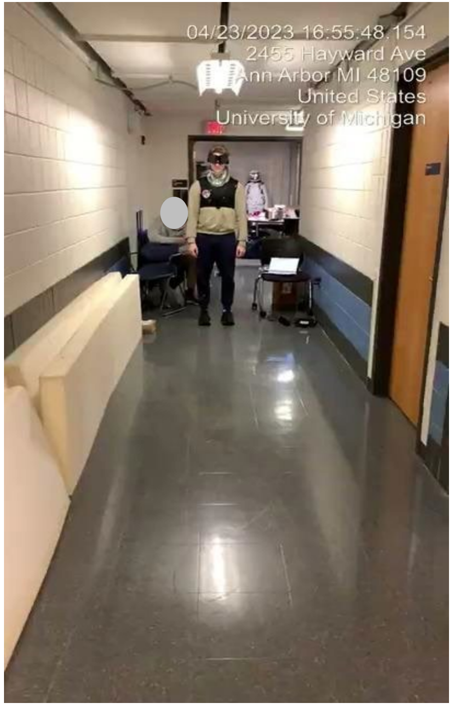
III — Standard Task Verification
- TUG
- OLB
- ROCK

IV — Field Task Verification
- Walk and Look
- Walk and Pivot
- Object Transfer

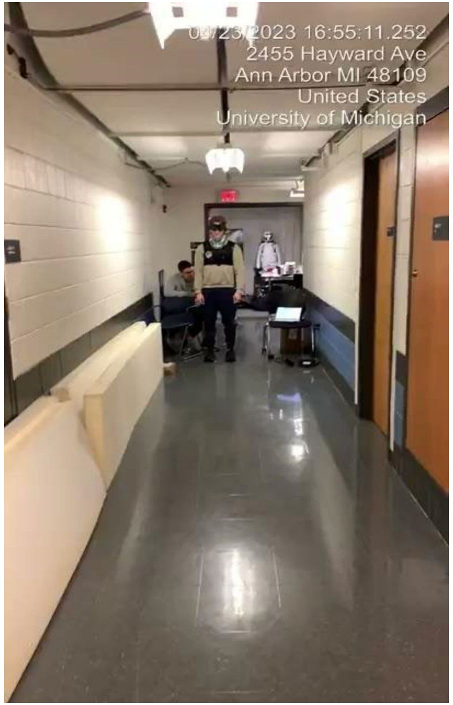
Field Task Verification



Object Transfer



Walk and Pivot



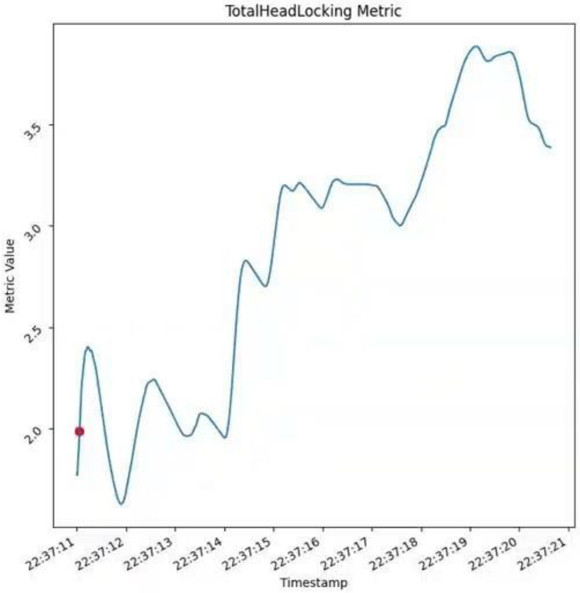
Walk and Look

Testing Procedure

II

Tool Verification

Head Movement

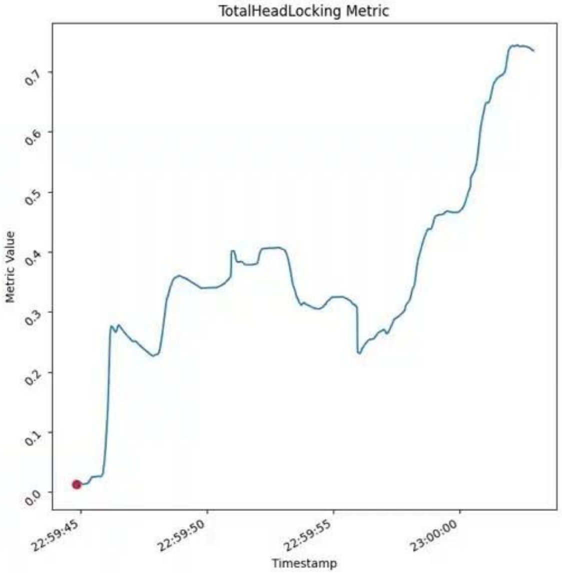


Testing Procedure

II

Tool Verification

Head Movement

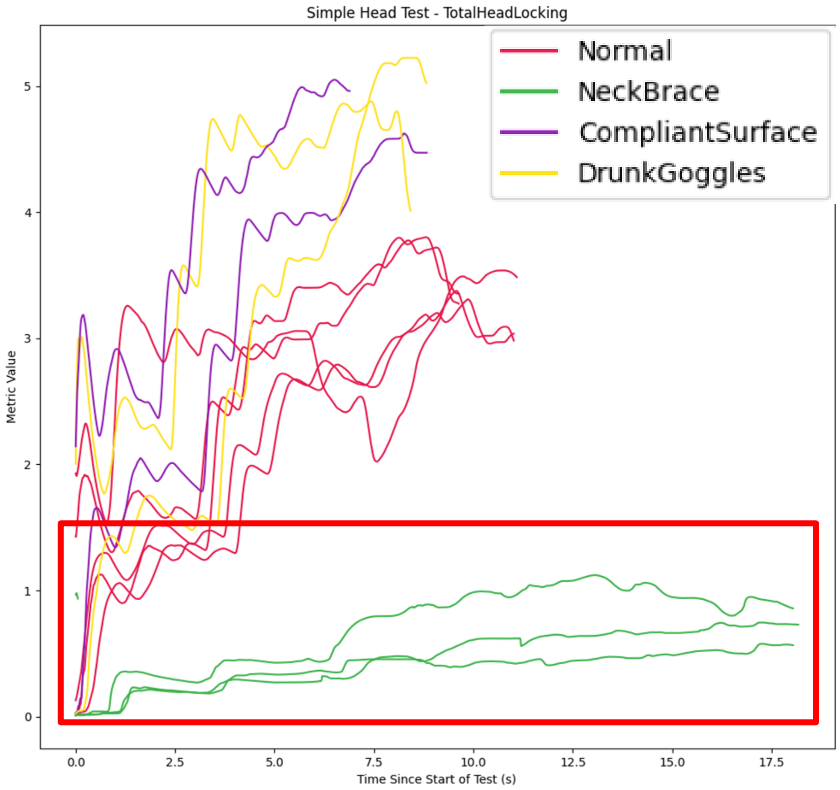


Testing Procedure

II

Tool Verification

Head Movement

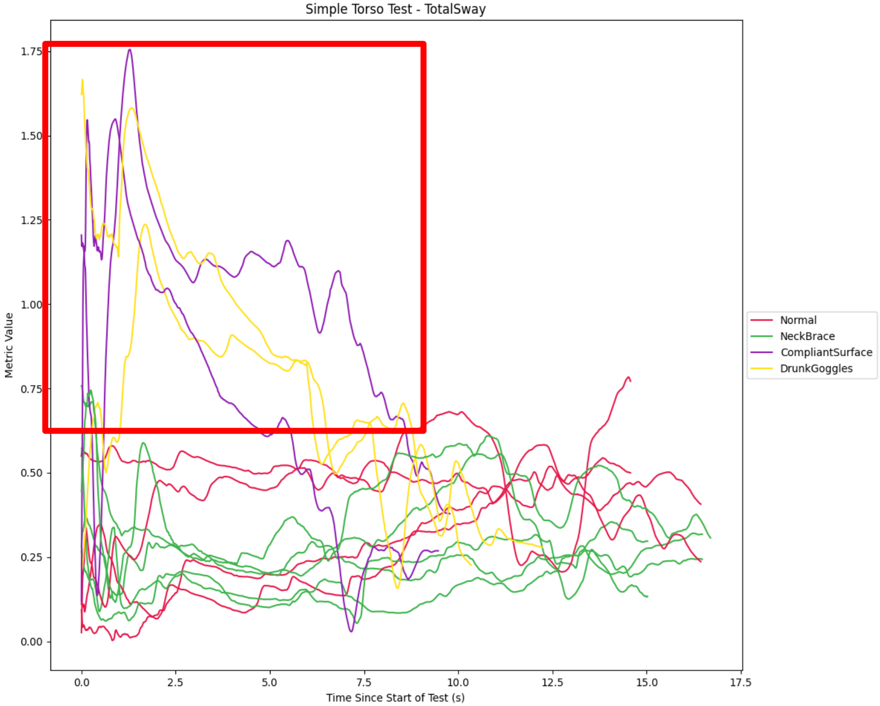


Testing Procedure

II

Tool Verification

Torso Movement



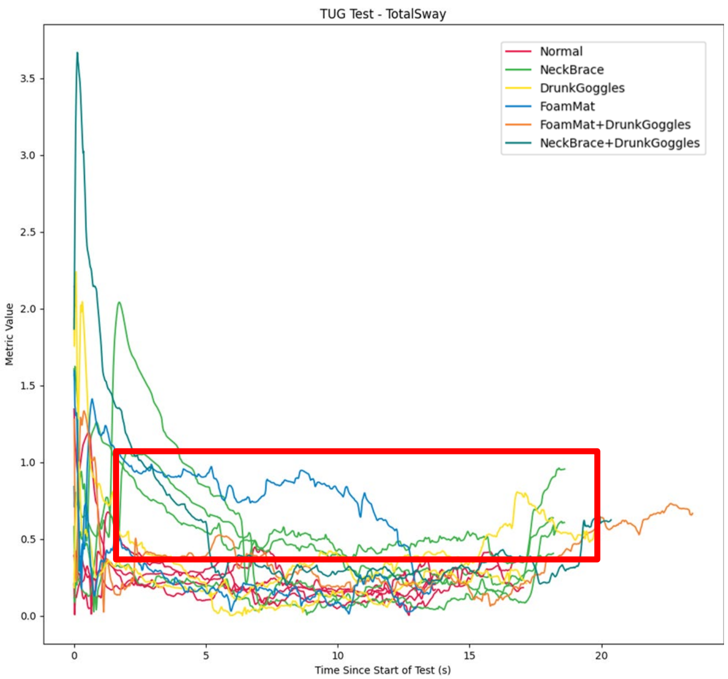
Testing Procedure

III

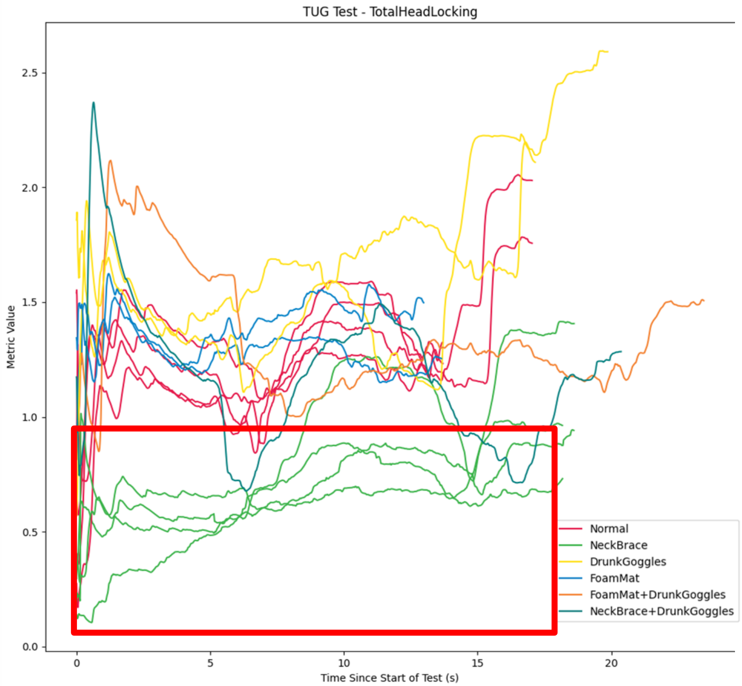
Standard Task Verification

TUG

Sway



Head - Locking



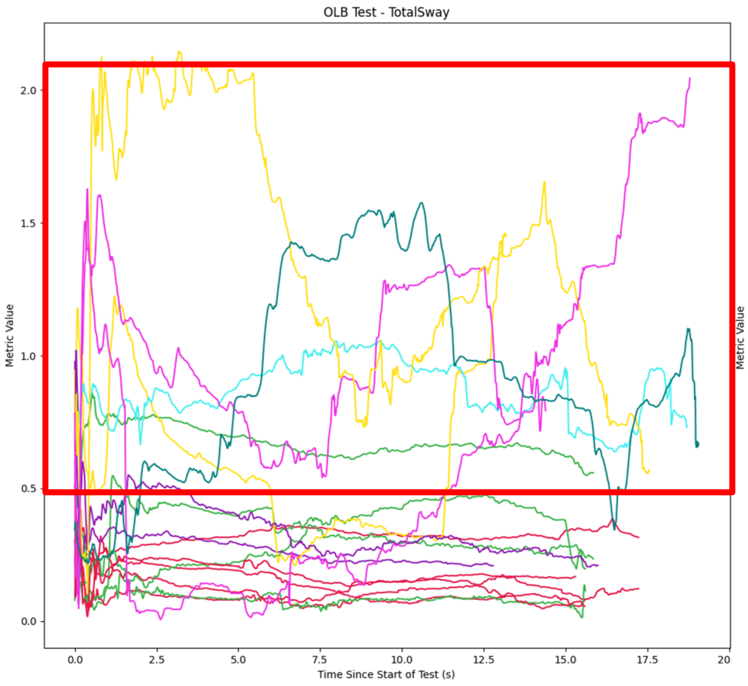
Testing Procedure

III

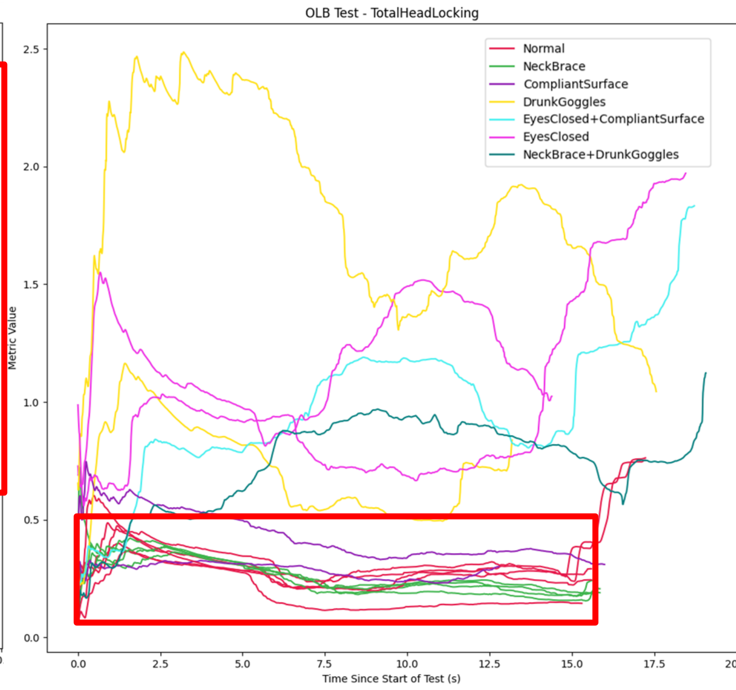
Standard Task Verification

OLB

Sway



Head - Locking



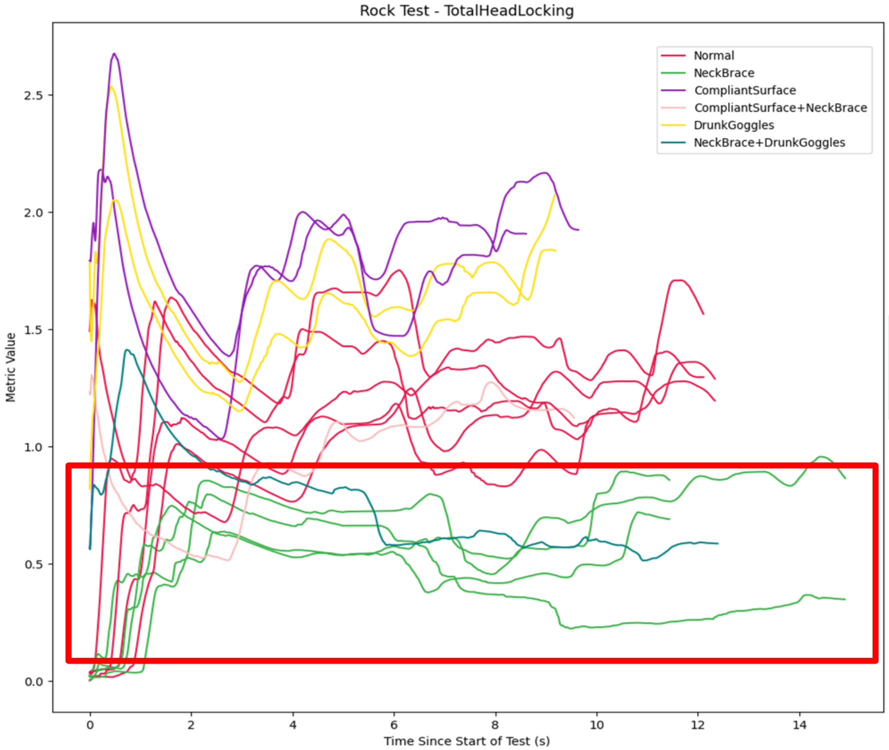
Testing Procedure

Head - Locking

III

Standard Task Verification

ROCK



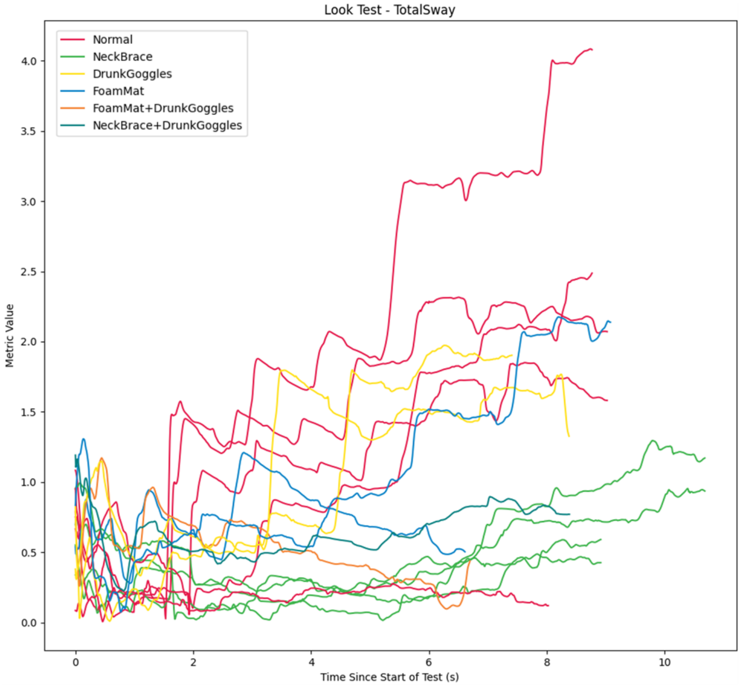
Testing Procedure

IV

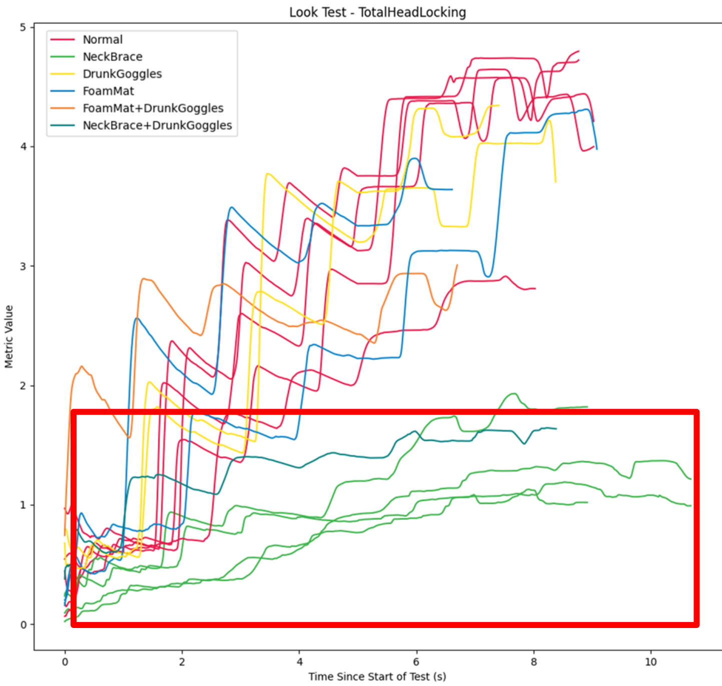
Field Task Verification

Walk and Look

Sway



Head - Locking



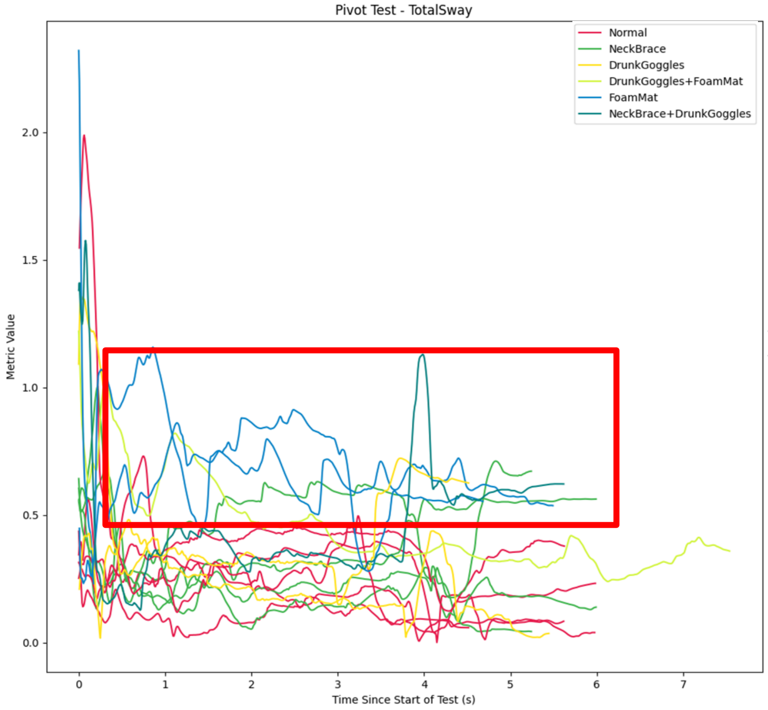
Testing Procedure

IV

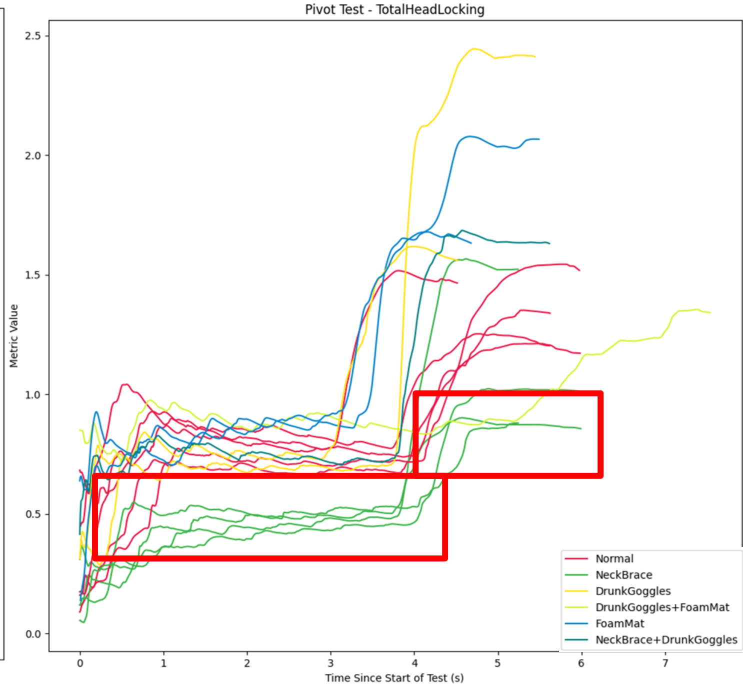
Field Task Verification

Walk and Pivot

Sway



Head - Locking



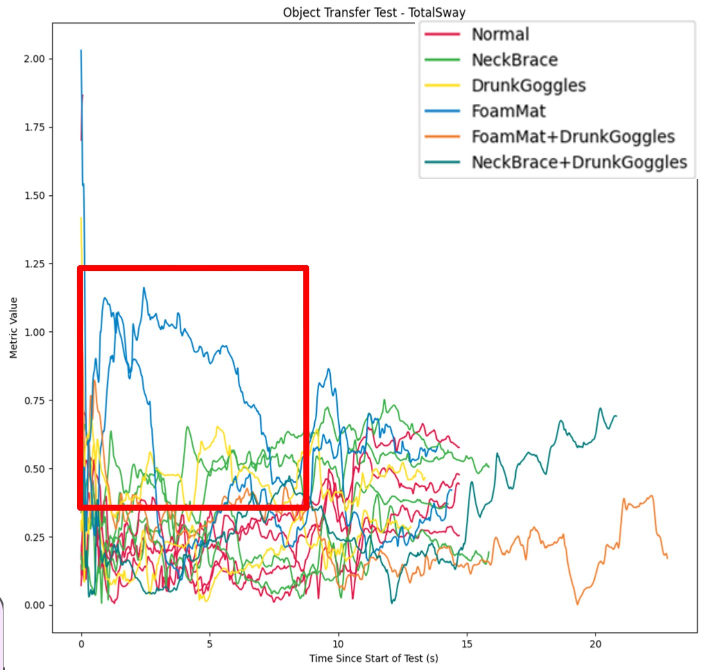
Testing Procedure

IV

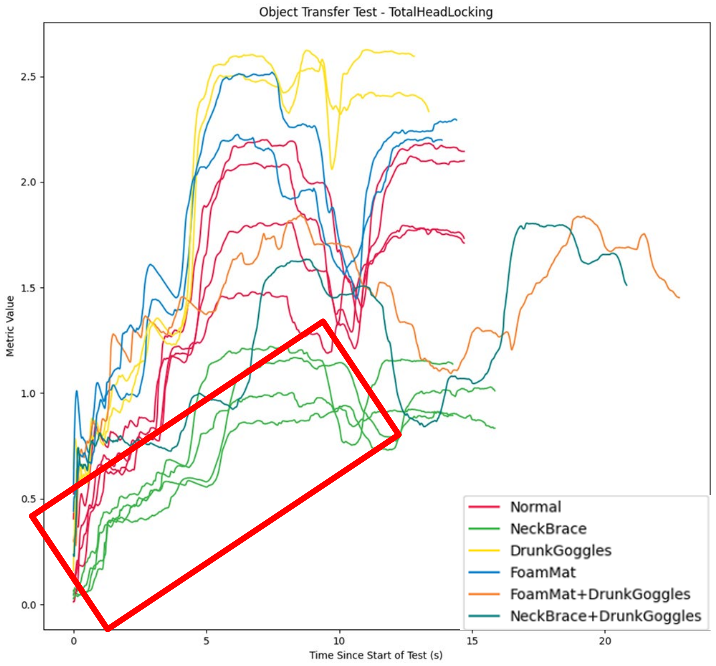
Field Task Verification

Object Transfer

Sway



Head - Locking

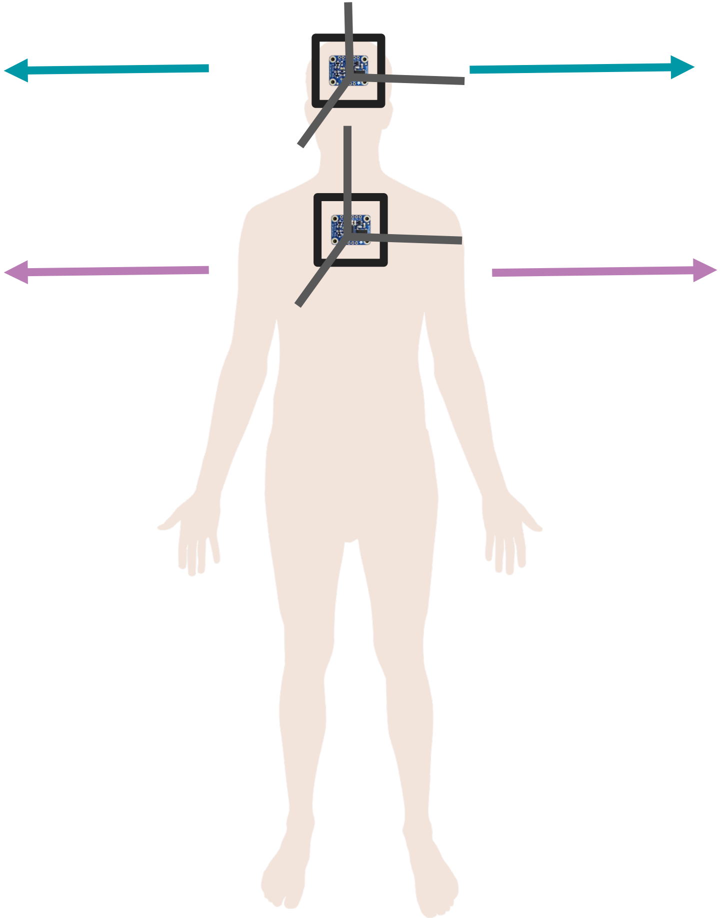


Metrics Conclusion

Sway Results

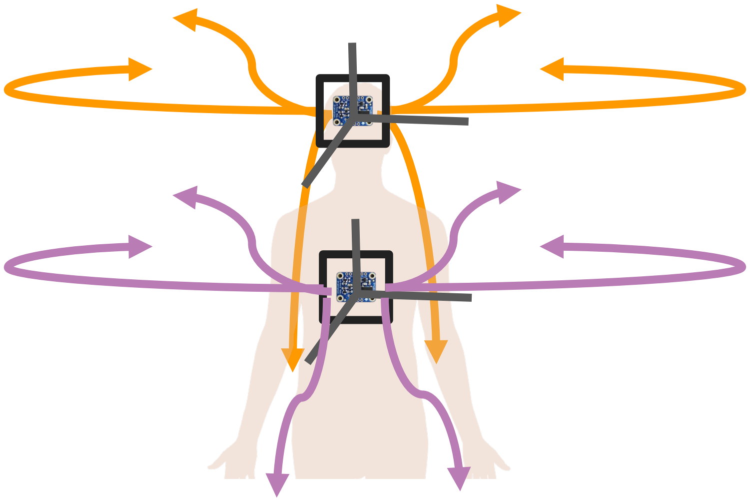
- Even with gravity removed, sway metric calculation does not produce separate curves
  - Tests may not be inducing enough sway
  - Metric calculation may not be capturing the distinct effects of sway

- Foam mat seems to produce the most amount of sway during tests



Head Locking Results

- Tests Integrating head movements have curves distinct from non-headlocking-impaired user
  - Tests without head movements may or may not
- Threshold values vary between tests
- Rolling window of sufficient size (>5 seconds) will typically produce distinct curves. Larger windows tend to increase separation.
- Neck brace induces the most amount of headlocking



Conclusion

Conclusion

- OPAL M5 configuration is most ideal – base design off this architecture
- Consider bringing on long-term engineering team for micro-configuration
- View TOPSIS for necessary SMAT criteria and adjust weightings as desired
- Headlocking and Sway can be determined with SMAT tool metrics
- Tiered testing validates a SMAT tool
  - One motion → One treatment → Complex motions and multiple treatments

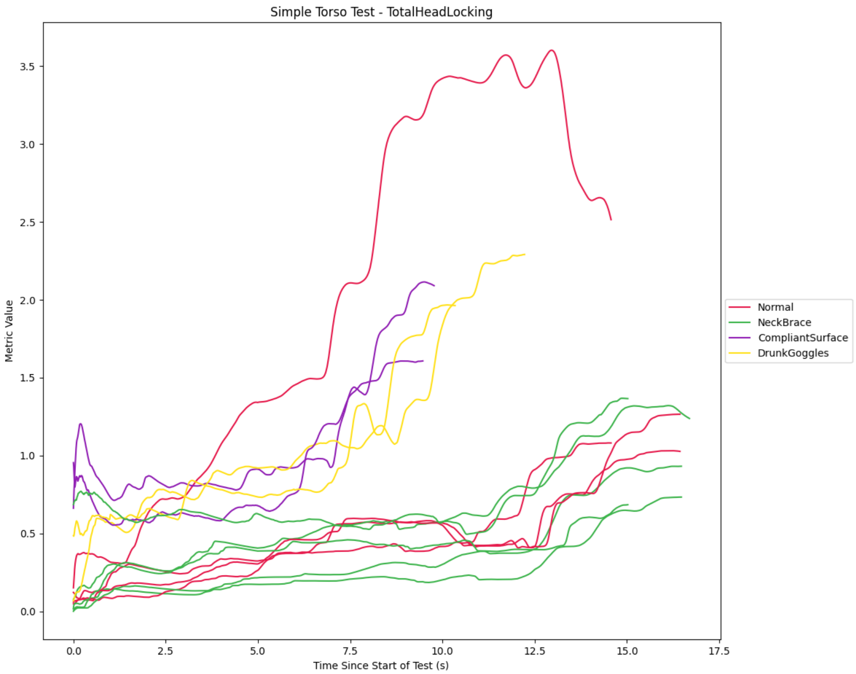
*Would you like a paper write-up of this academic year's work for your review? Receive in few weeks.

Thank you!

Questions?

Backup

Torso movement headlocking metric



Testing Videos

Nathan - M5, M6 - link

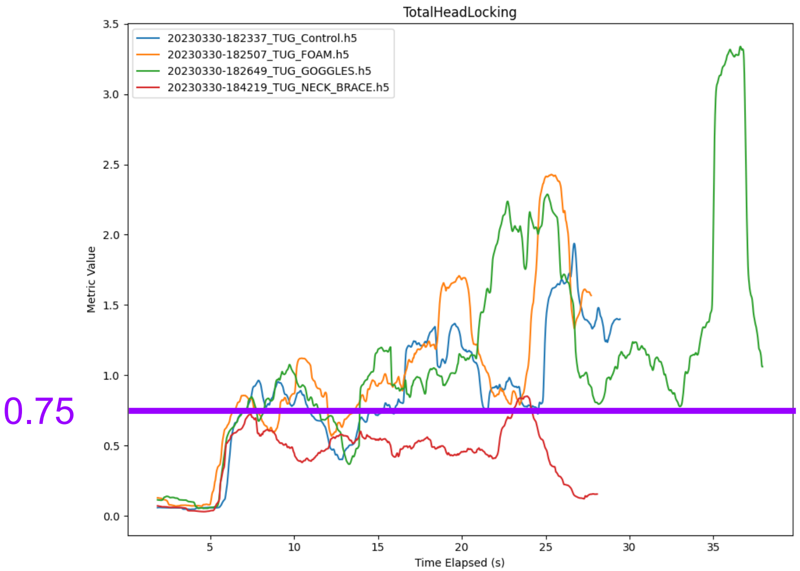
Derek - M5, M6 - link

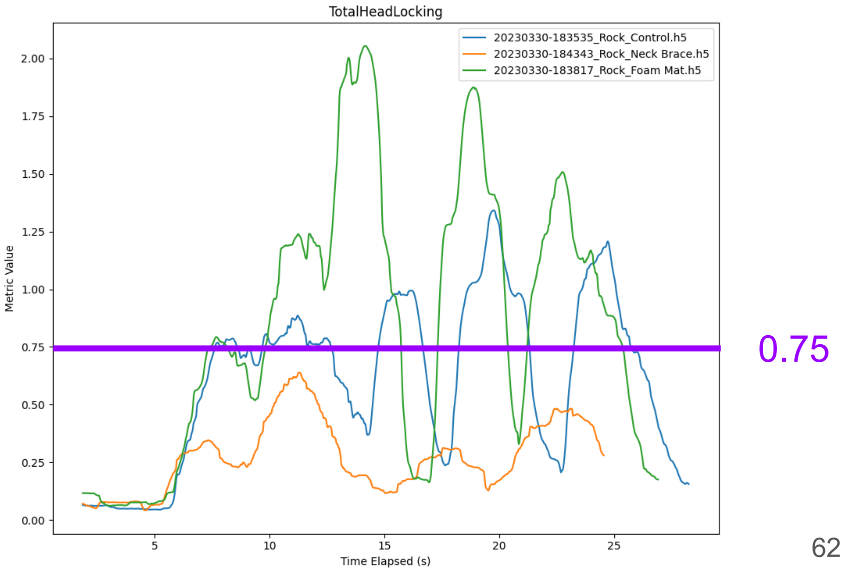
Derek - M5, M6, Commercial - link

Owen - Adafruit M5 - link

Head Locking

Calculation: RMS of relative angular velocity between head and torso about body-relative x, y, and z axes. Rolling window of approx. 2 seconds.
Simulation: Wear neck brace during test
Verification: Compare tests with and without head brace and check that curves are distinct





Head Locking - Next Steps

Separating Curves & Identifying Thresholds:

Idea: Percent time spent with TotalHeadLocking above **0.75** over a designated period of time.

- Should clearly separate curves based on TUG and Rock Test results.

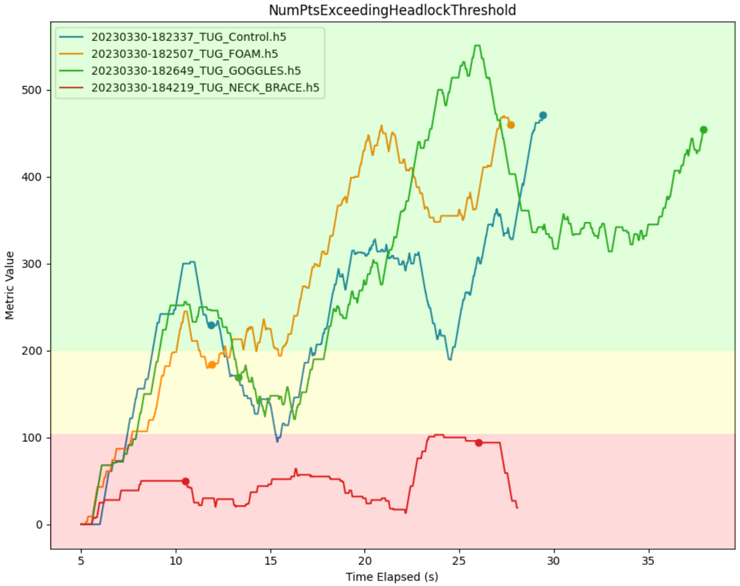
Collecting More Data:

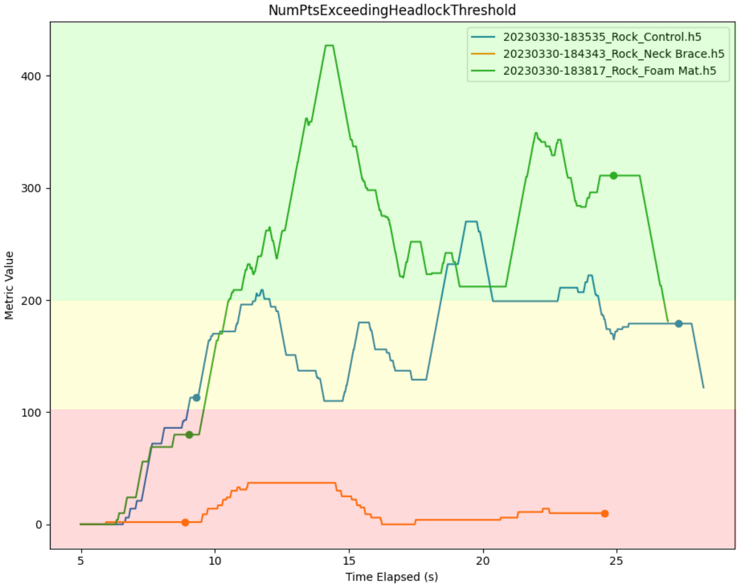
Rock and TUG Test results currently based on a single set of tests.

Collect same data from multiple people with varying demographics to better understand and verify metric.

Head Locking - 0.75 Threshold

First attempt using 0.75 threshold with a 5 second rolling window



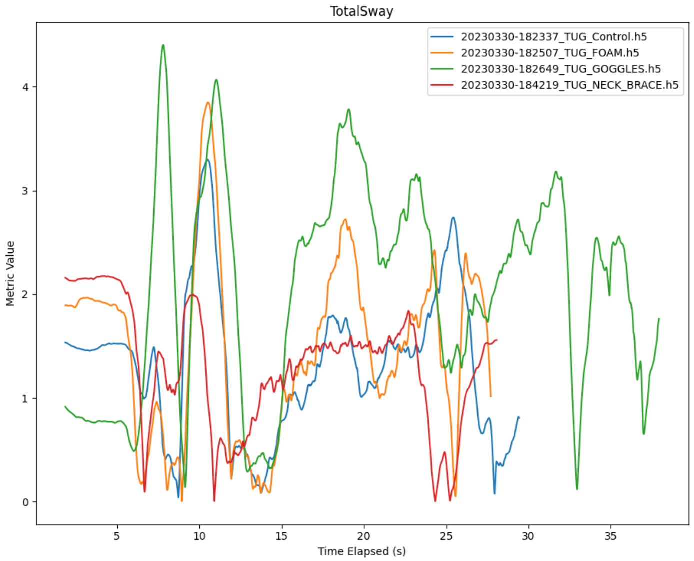


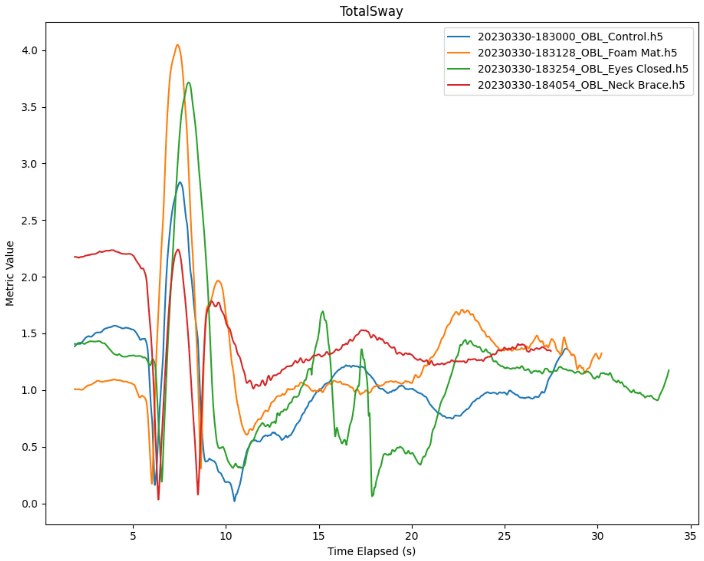
Sway

Calculation: RMS of acceleration in front-back and left-right (body-relative) axes. Rolling window of approx. 2 seconds.

Simulation: High density foam mat (TUG test and one legged balance)

Verification: Compare tests with and without head brace and check that curves are distinct





Sway - Next Steps

Reevaluate Metric Calculation

Acceleration based metric - need to eliminate gravity vector from data

- Use magnetometer or estimate orientation
- OR Inversely weight sway calculation on deviation from up axis deviation from local gravity vector (-9.81 for Earth on ground).

Could try gyroscopic sway.

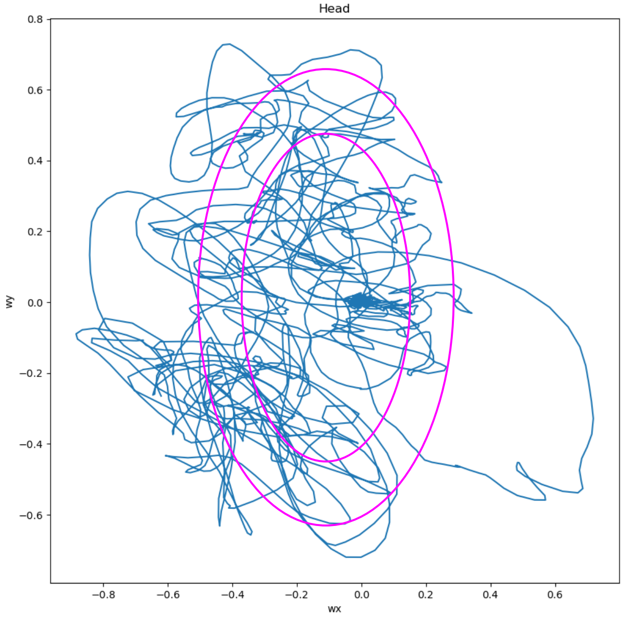
In process of using a double-banded ellipse about front-back and left-right axes and counting number of times threshold values are crossed.

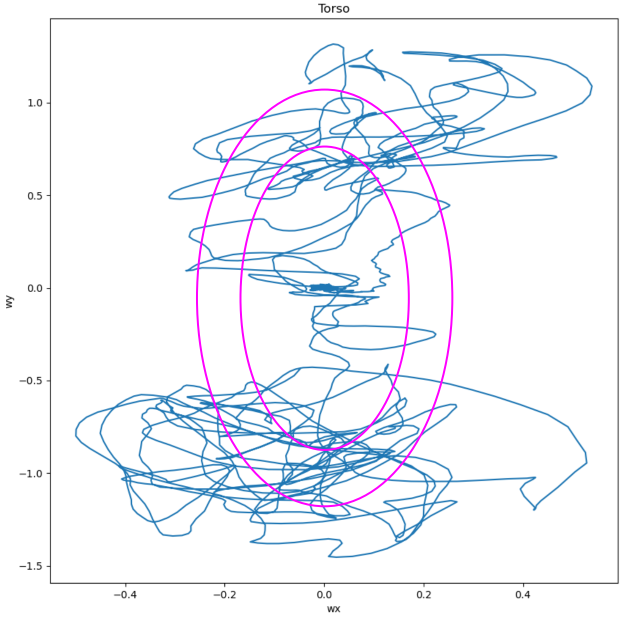
- Results pending

Sway - Double-Banded Ellipse*

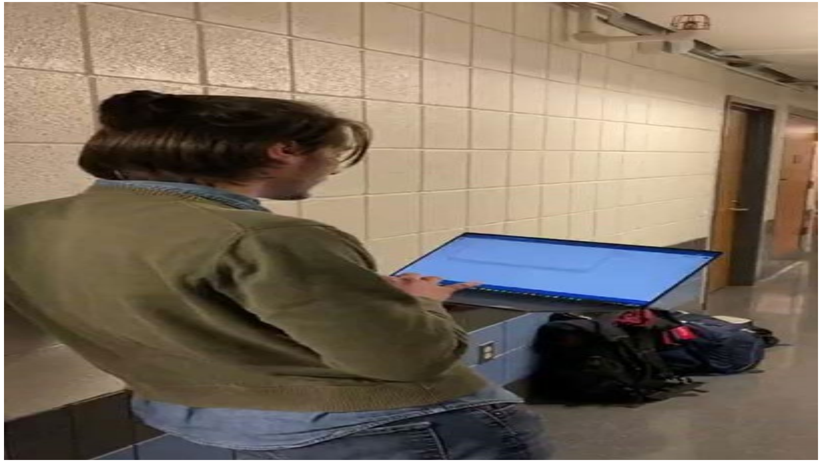
Calculation: Within a specified period of time, count the number of times the gyro (or accel) crosses the outer ellipse threshold after being inside the inner ellipse threshold, and vise versa.

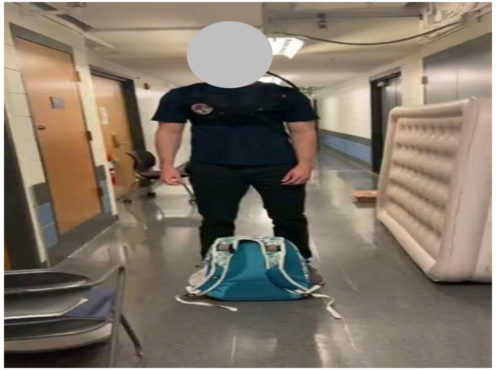
*Results Pending



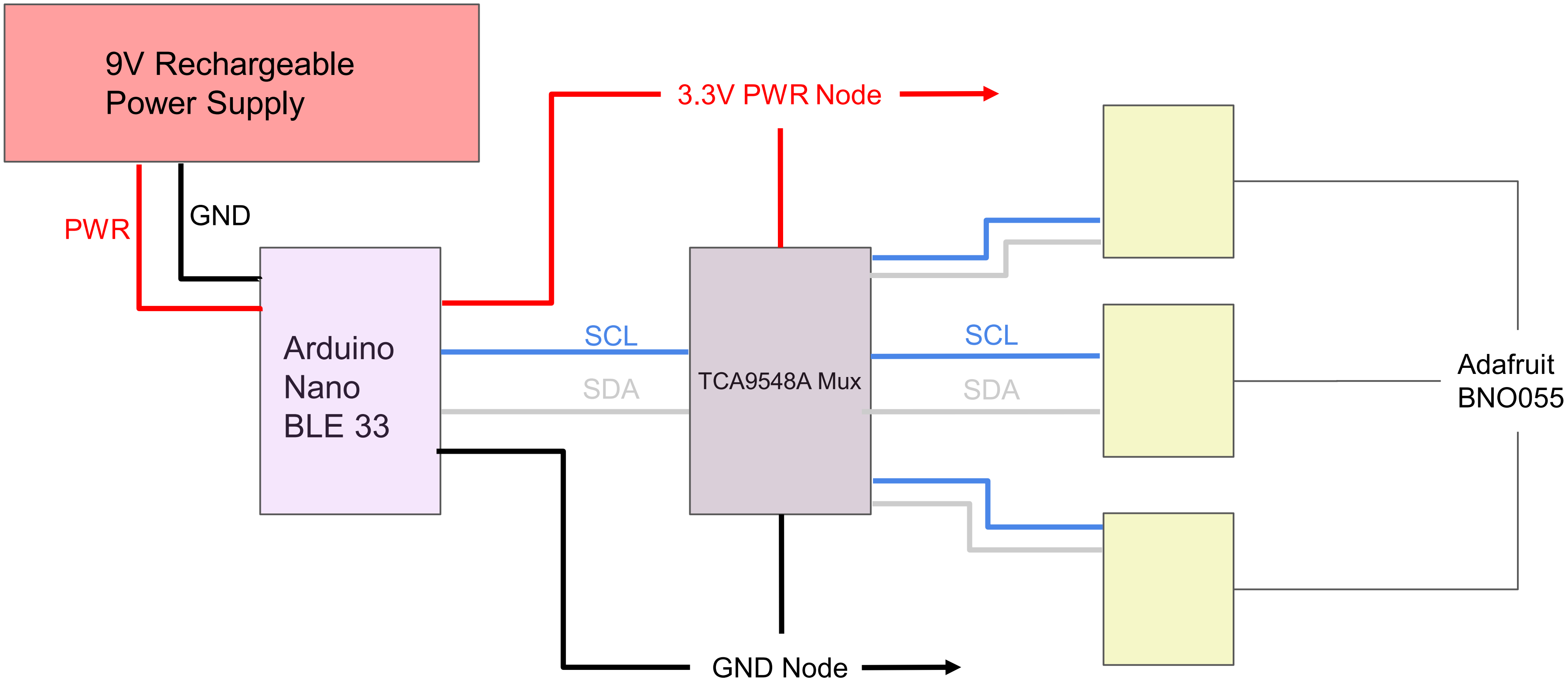


Videos of Testing M5

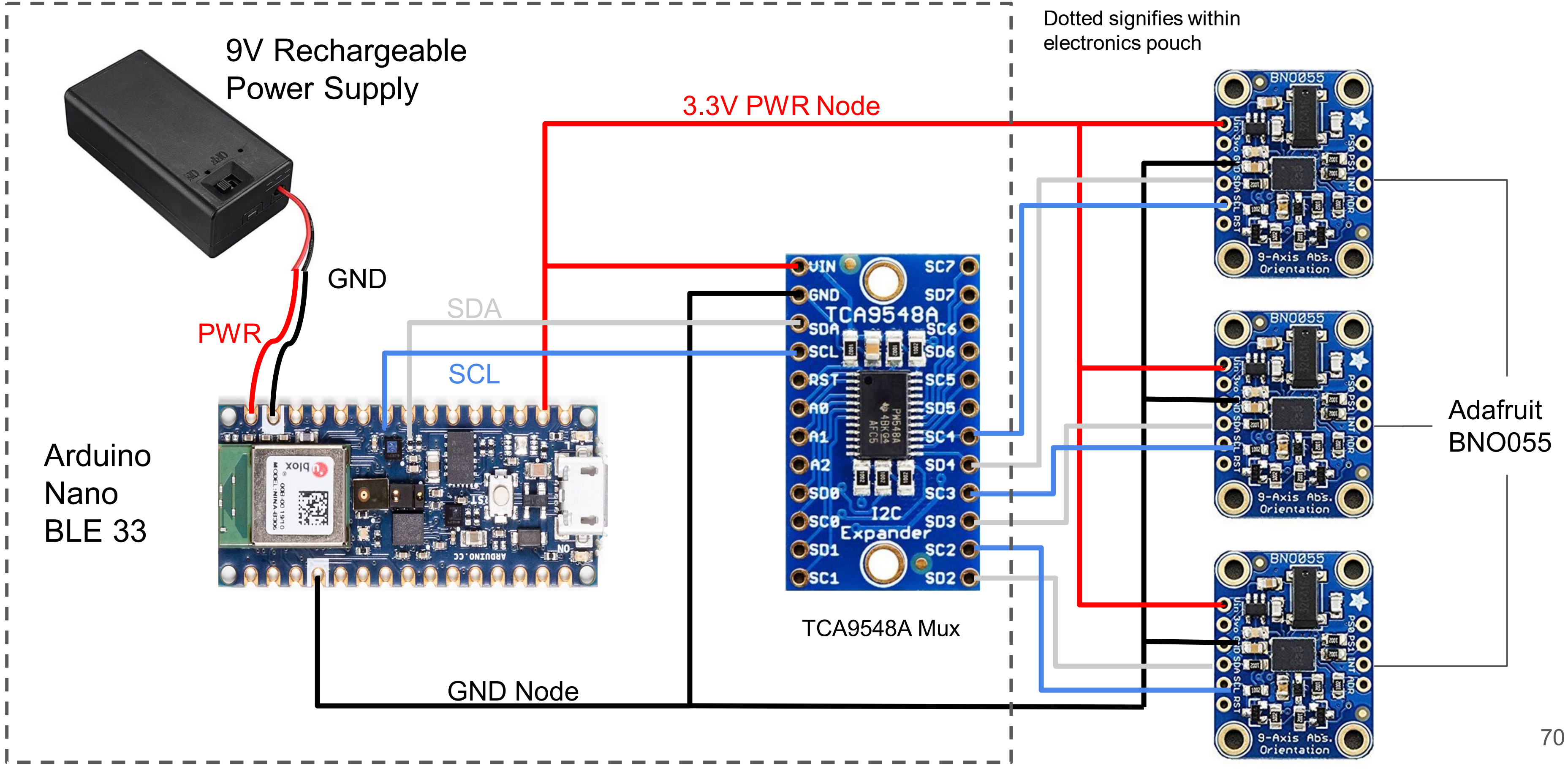




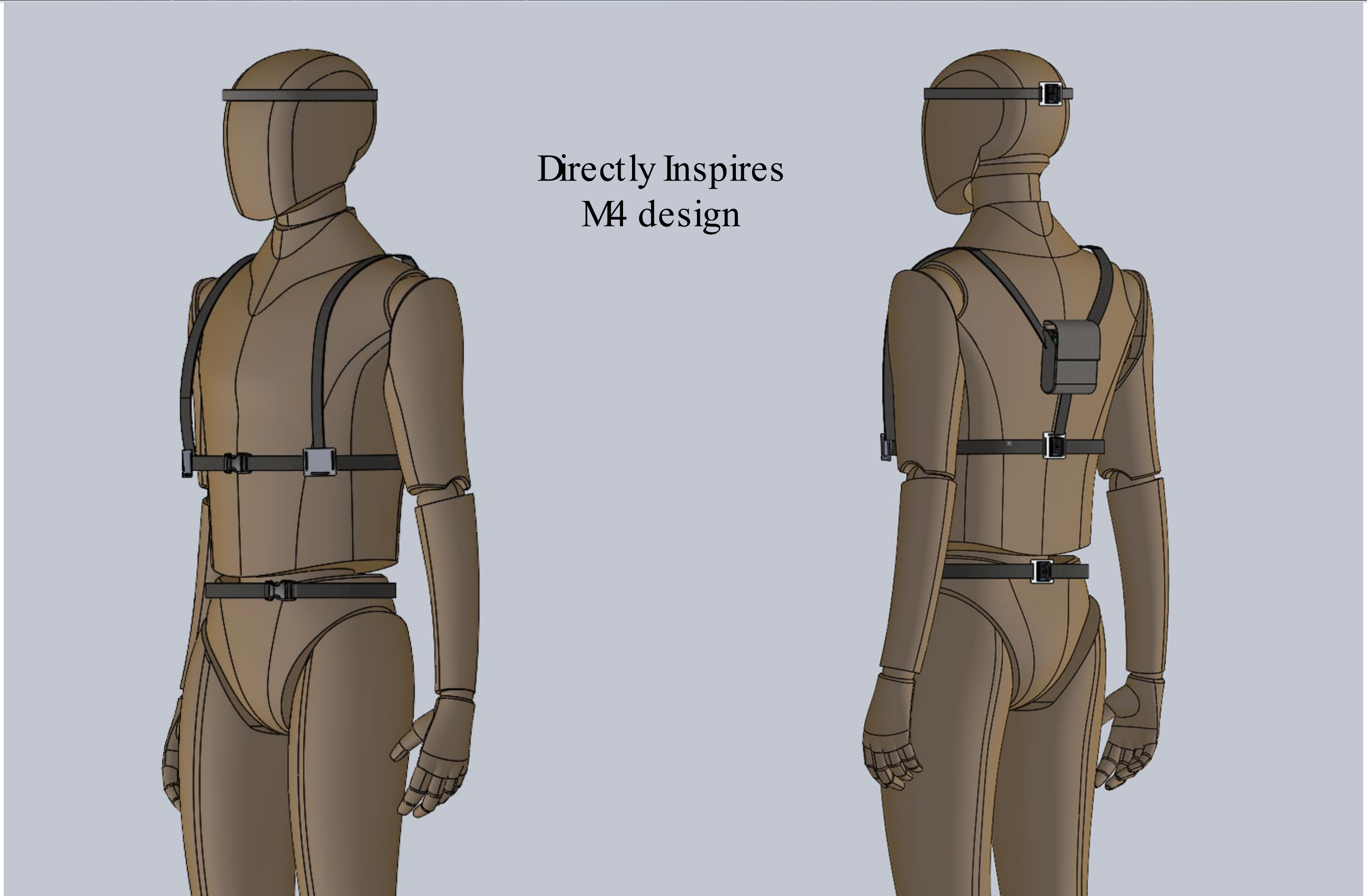
Sensor Suite Circuit Diagram Simple



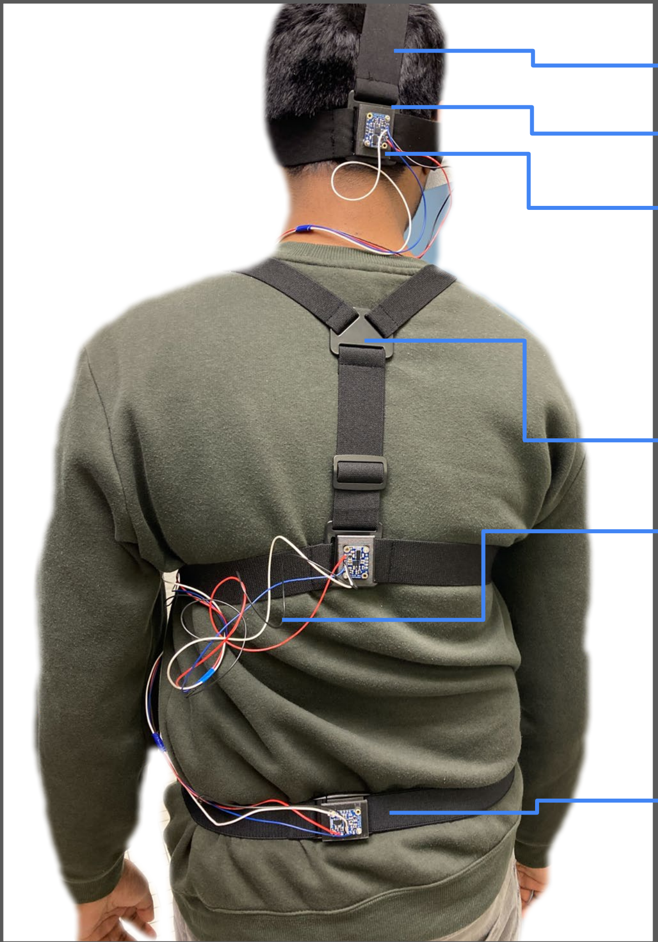
Sensor Suite Circuit Diagram Full



M3 CAD Model



M4 Prototype



GoPro Head Mount

NylonXCarbon Fiber IMU Mount

Velcro attachment

GoPro Chest Mount

Loose Wires /
Taped Bundles

Adjustable, Elastic Belt

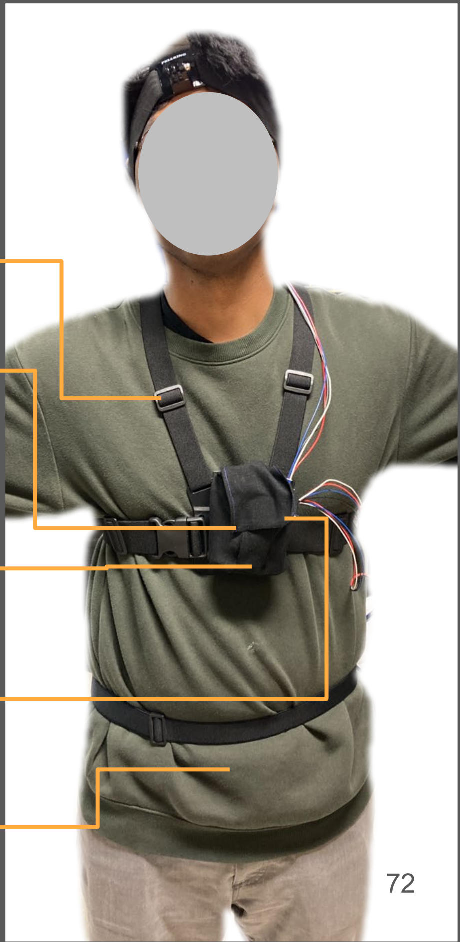
Adjustable Straps

Fabric Electronics Pouch
Nano, MUX, 9V Rechargeable

Battery Recharge Port
Cut out of pouch

Power Switch
Cut out of pouch

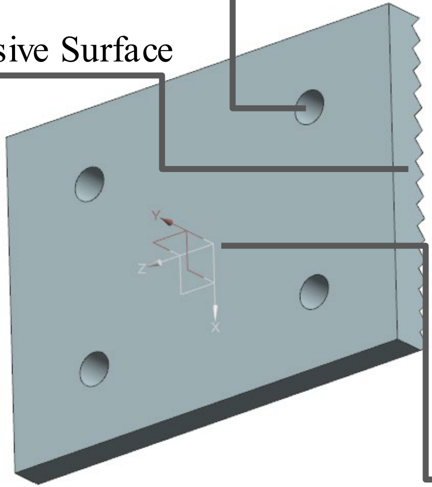
Over-the-clothing Fit



M4 Prototype Interface CAD

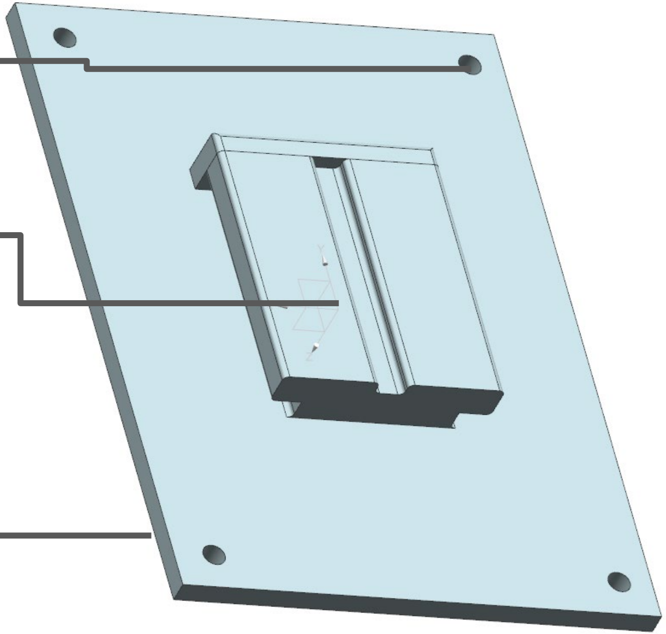
IMU Mount

3D Printed NylonX Carbon Fiber



Electrical Pouch Mount

3D Printed PLA



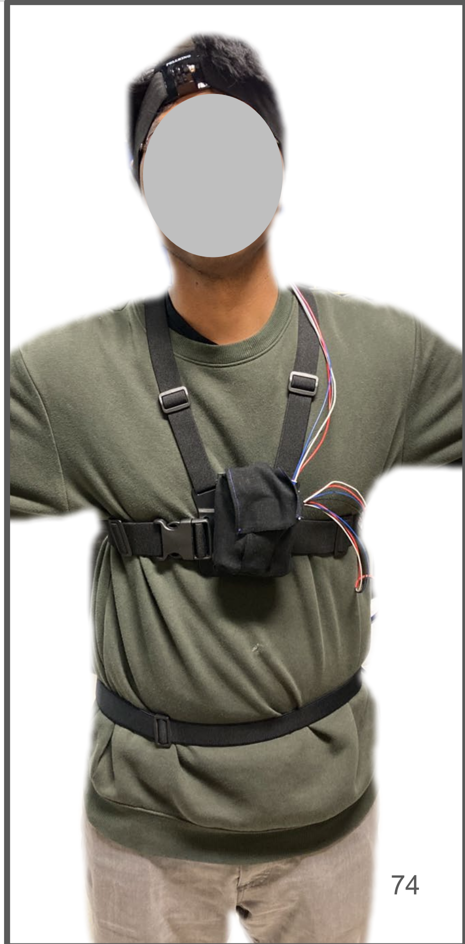
M4 Prototype - Lessons Learned

Downsides:

- Exposed IMUs have no protection
- Loose wires create snagging hazard
- Belt shifts if not overlapping pants
- GoPro Head mount is difficult to fit and uncomfortable
- Don/doff process is long and stressful to safety of the system

Positives:

- IMU velcro attachment is easy and more stable than expected (short COM moment on IMU)
- Adjustability and fitting of straps are simple and effective
- Electronics pouch at front makes on/off/reset easy and repeatable
- IMU locations and attachment methods are not obtrusive to the user's motion



M5 Prototype Design - *In Progress*

Sports Headband IMU
Head Attachment

.Longer lasting comfort
.Easy velcro IMU case
.High Compression
.Low Mass

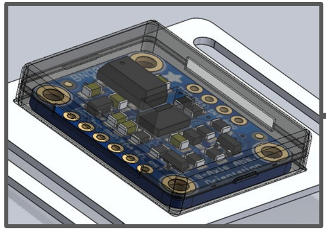
Compression Vest
M4 straps sewn in
Zipper open/close

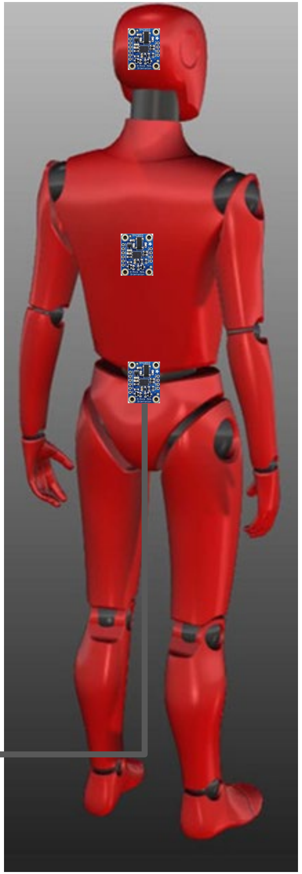
.Better force distribution
.Easy don/doff
.Variable sizes
.Easy sewn attachments

Adjustable Leg Straps
Sewn to suit for tension distribution

.Prevents hip IMU slide
.Better force distribution
.Adjustable
.Easy sewn attachments

IMU Casing
PLA 3D printed
Holes for wiring on top





Testing

Sensor Metric Verification Procedures

I — Pre-Survey
- Motion Sickness History
- Relevant Medical History
- Current Overall Fitness

II — IMU Calibration & Control Tasks
- Attach IMUs to Participant
- Calibration Pose
- Perform Tasks

III — Initiate Motion Sickness
- Use Motion Sickness Simulator
- Begin Motion Sickness Experience

IV — IMU Calibration & Sick Tasks
- Calibration Pose
- Perform Tasks

V — Final Survey
- Gauge Level of Sickness

Metric Verification Tasks

I — **TUG Test**

II — **One Legged Balance**

III — **Look Test**

Simulating Unhealthy Sway & Headlocking

I

Half-Filled Air Mattress

II

Balance Board

III

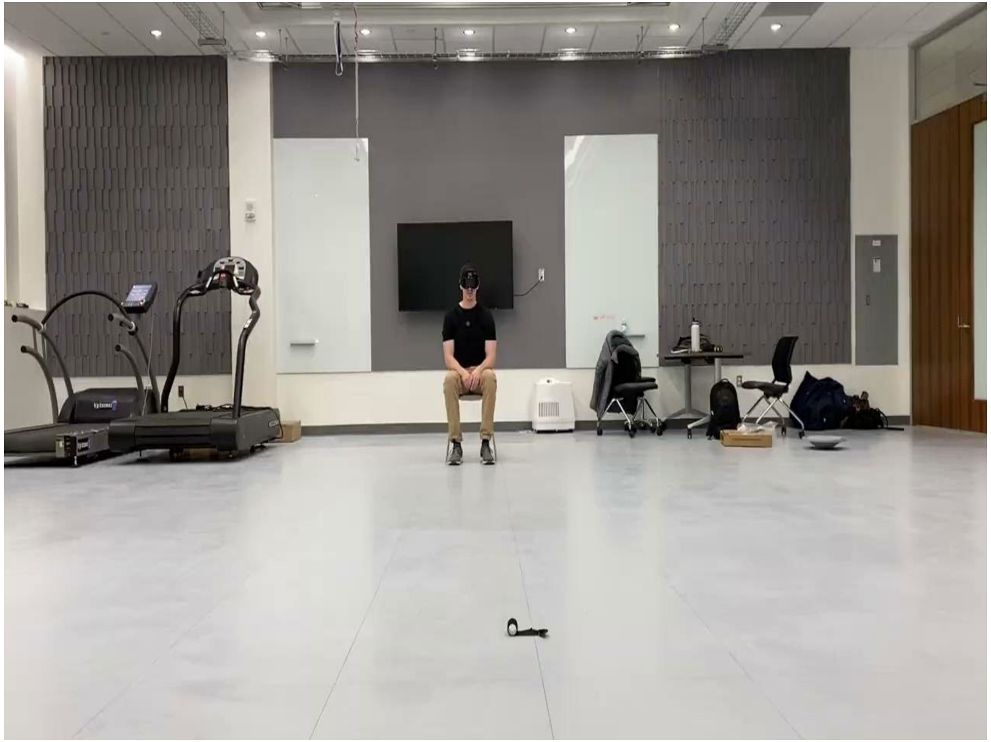
Drunk Goggles

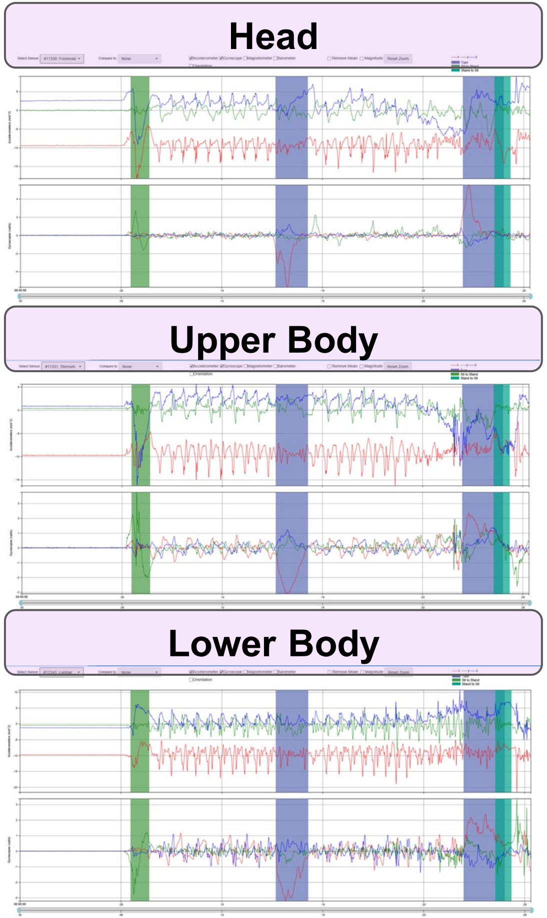
TUG Test:
Participant walks on not completely filled mattress to introduce sway in their movements

One Legged Balance Test:
Participant balances on board instead of solid ground to introduce sway and headlocking

All Tests:
Participant wears drunk goggles during all tests to introduce sway and headlocking

Preliminary Tests: OPAL IMU





Motion Sick Environment Plans

TUG- Have participants walk across a compliant surface to impair normal muscle coordination

- Inflatable air mattresses to test different amounts of compliance

One-Leg Balance- Have participants balance while causing sensory discombobulation

- Closed eyes, vision impairment goggles, balancing on a moving surface

Look Test- Restrict the participants movement in certain axis to encourage head locking

- Use a soft neck brace to limit head movements separate from the trunk

Motion Sick Environment Plans

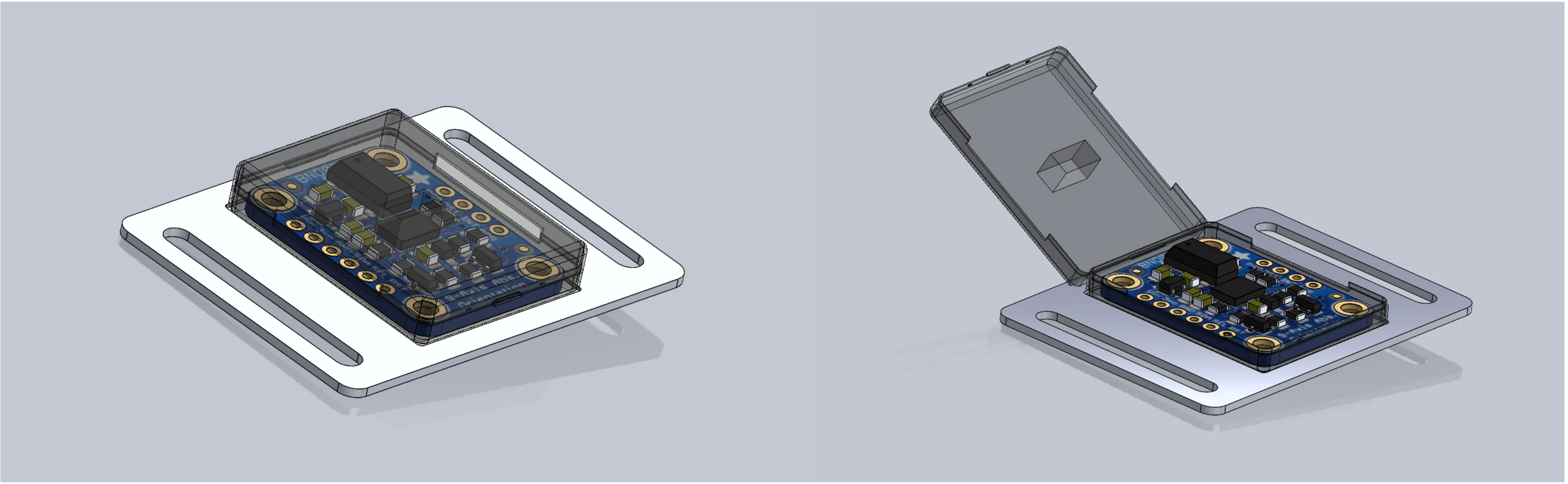
TUG (Timed Up and Go)	One Leg Balance	Look Test
Participants walk across a compliant surface to impair normal muscle coordination	Participants balance while causing sensory discombobulation	Restrict the participants movement in certain axis to encourage head locking
Inflatable air mattresses to test different amounts of compliance	Closed eyes, vision impairment goggles, balancing on a moving surface	Use a soft neck brace to limit head movements separate from the trunk

Conclusion

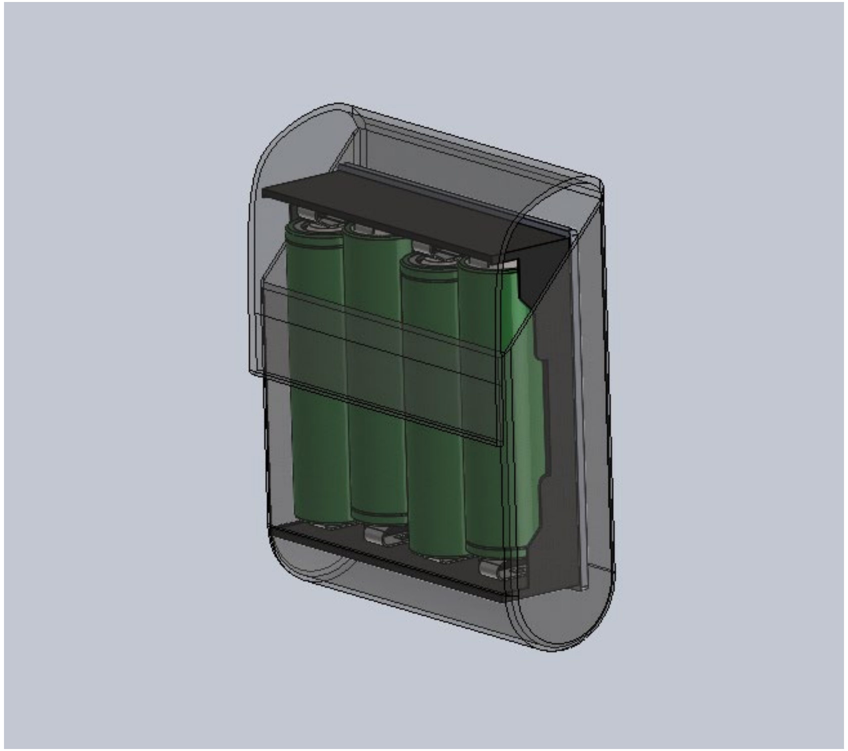
Future Directions

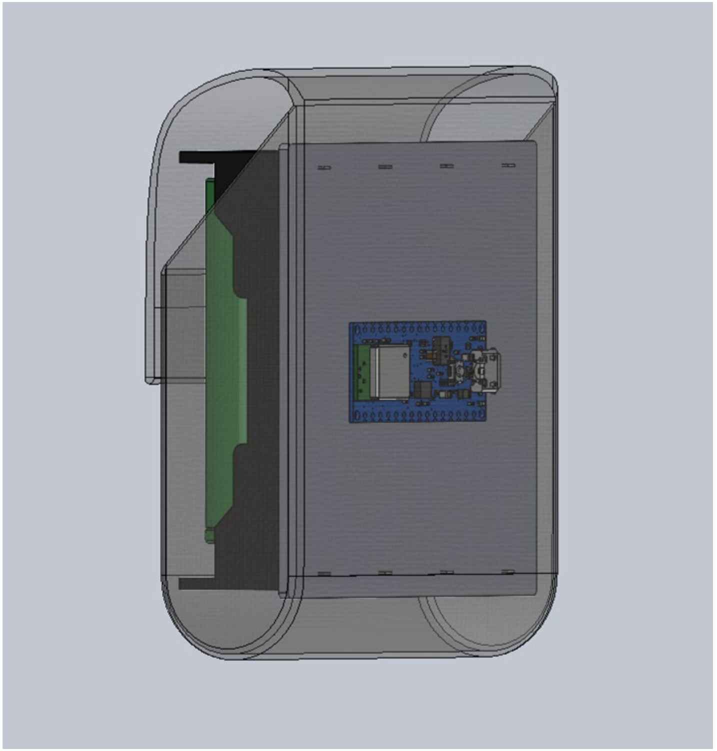
- Continue iterations of wearable device
- Test wearable devices, motion assessments, and analysis platform in tandem
- Continue requirement verification now on implemented SMAT
- Begin production of a finalized full system prototype
- Begin validation of customer requirements on a finalized full system prototype
    - Moving up the system engineering V

CAD Model - IMU

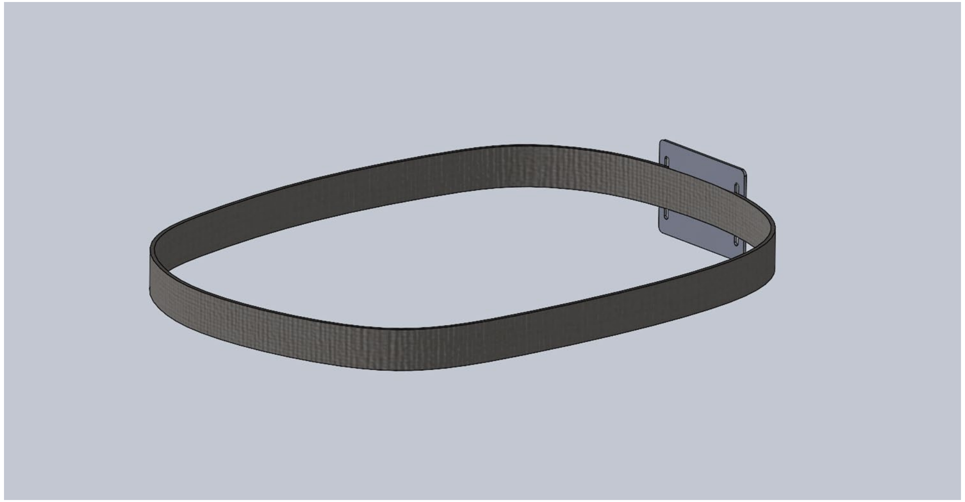


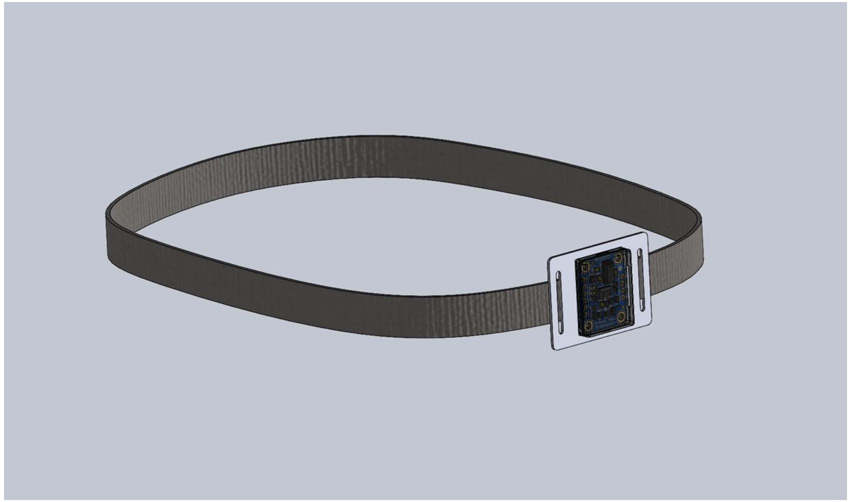
CAD Model - Power set & microprocessor





CAD Model - Head set





CAD Model - Torso Sensor Strap

CAD Model - Belts