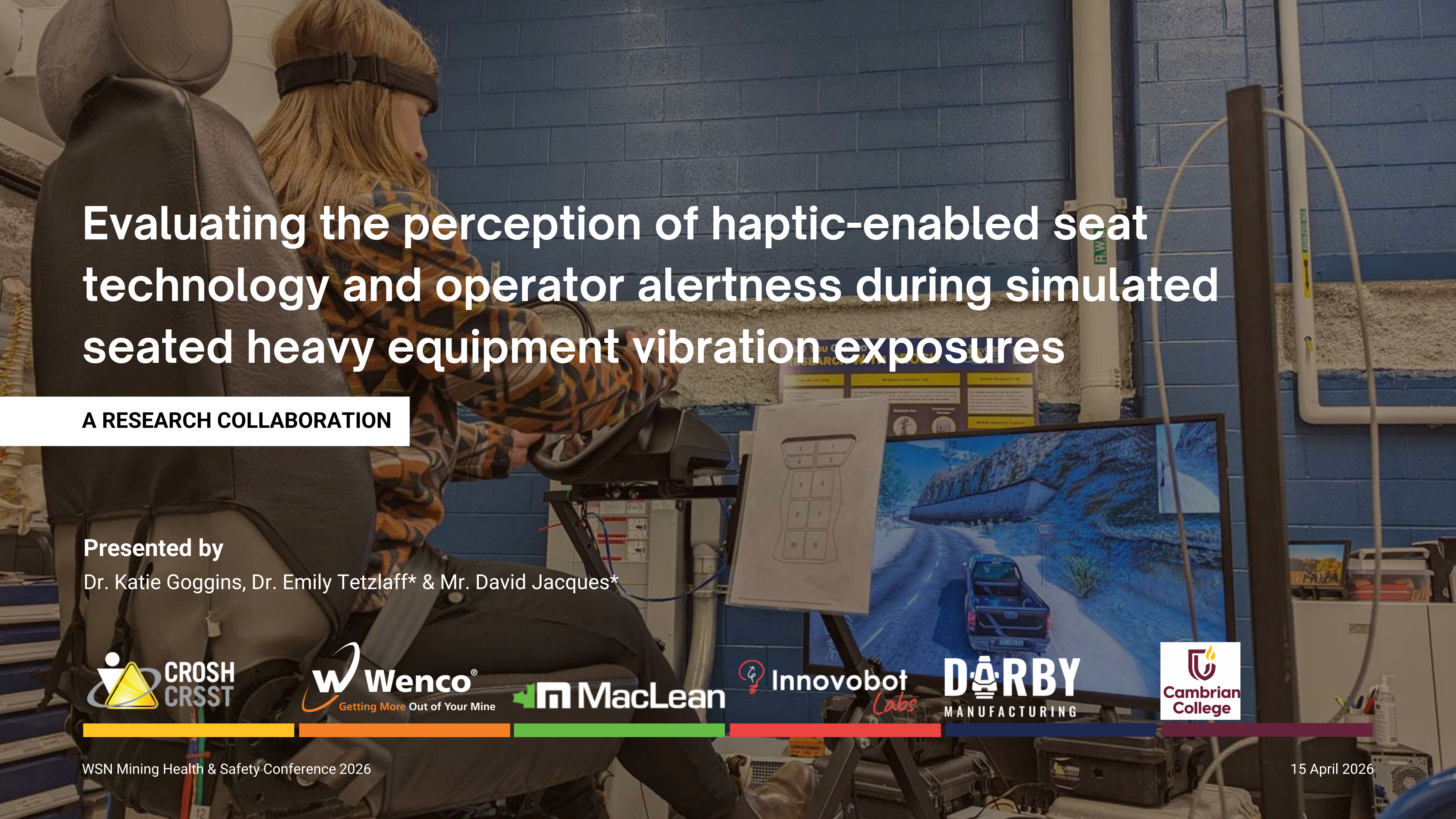


Evaluating the perception of haptic-enabled seat technology and operator alertness during simulated seated heavy equipment vibration exposures

A RESEARCH COLLABORATION

Presented by

Dr. Katie Goggins, Dr. Emily Tetzlaff* & Mr. David Jacques*

CROSH CRSST

Wenco® Getting More Out of Your Mine

MacLean

Innovobot Labs

DARBY MANUFACTURING

Cambrian College

Built Together: Industry–Research Collaboration

This study represents a collaborative effort between industry partners, researchers, and safety leaders across the mining sector. By combining operational experience with scientific rigor, we developed a practical, data-driven approach to advancing SIF prevention.

Research Centre

CROSH
CRSST

Academic Partners

Laurentian University
Université Laurentienne

Cambrian College

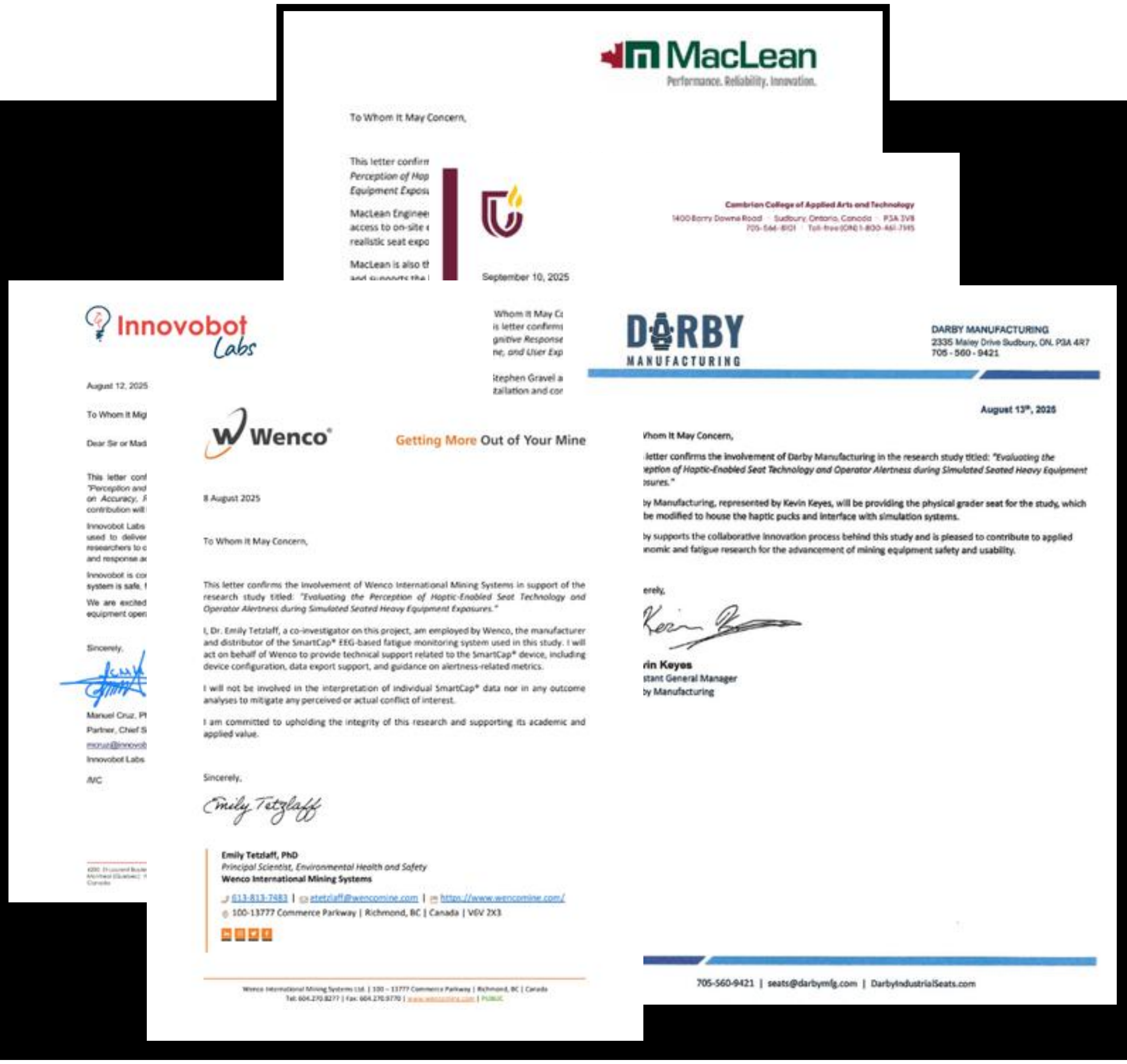
Industry Partners

Wenco®
Getting More Out of Your Mine

MacLean

Innovobot Labs

DARBY
MANUFACTURING



Wenco® Getting More Out of Your Mine

8 August 2025

To Whom It May Concern,

This letter confirms the involvement of Wenco International Mining Systems in support of the research study titled: *"Evaluating the Perception of Haptic-Enabled Seat Technology and Operator Alertness during Simulated Seated Heavy Equipment Exposures."*

I, Dr. Emily Tetzlaff, a co-investigator on this project, am employed by Wenco, the manufacturer and distributor of the SmartCap® EEG-based fatigue monitoring system used in this study. I will act on behalf of Wenco to provide technical support related to the SmartCap® device, including device configuration, data export support, and guidance on alertness-related metrics.

I will not be involved in the interpretation of individual SmartCap® data nor in any outcome analyses to mitigate any perceived or actual conflict of interest.

I am committed to upholding the integrity of this research and supporting its academic and applied value.

Sincerely,

Emily Tetzlaff

Emily Tetzlaff, PhD
Principal Scientist, Environmental Health and Safety
Wenco International Mining Systems
613-813-7483 | etetzlaff@wencomine.com | https://www.wencomine.com/
100-13777 Commerce Parkway | Richmond, BC | Canada | V6V 2X3

DARBY MANUFACTURING

DARBY MANUFACTURING
2335 Maley Drive Sudbury, ON. P3A 4R7
705 - 560 - 9421

August 13th, 2025

Vhom It May Concern,

letter confirms the involvement of Darby Manufacturing in the research study titled: *"Evaluating the ception of Haptic-Enabled Seat Technology and Operator Alertness during Simulated Seated Heavy Equipment osures."*

by Manufacturing, represented by Kevin Keyes, will be providing the physical grader seat for the study, which be modified to house the haptic pucks and interface with simulation systems.

by supports the collaborative innovation process behind this study and is pleased to contribute to applied nomic and fatigue research for the advancement of mining equipment safety and usability.

erely,

vin Keyes
stant General Manager
by Manufacturing

705-560-9421 | seats@darbymfg.com | DarbyIndustrialSeats.com

Cambrian College of Applied Arts and Technology
1400 Barry Downe Road · Sudbury, Ontario, Canada · P3A 3V8

Innovobot Labs

August 12, 2025

MacLean
Performance. Reliability. Innovation.

To Whom It May Concern,

*This study was conducted without external funding and was supported entirely through in-kind contributions from participating organizations.

Research Objectives

Evaluate participants' ability to accurately perceive the **location of haptic seat cues** (pucks) and measure their reaction time.

Assess whether changes in **participant alertness** are associated with reduced accuracy or slower reaction times to haptic cues.

Determine whether the **transmission of vibration** through the seat or the trunk/neck affects participants' reaction time and alertness in relation to the haptic seat cues.

Assess participants' perceptions of localized physical **discomfort, technology acceptance** and **usability** of the haptic system.

Background

Industry Need

MacLean Engineering is developing a next generation battery-electric grader for the surface mining market. During this development project, MacLean identified a potential interest towards the introduction of more novel solutions that included the adoption of haptic technologies.

MacLean was introduced to **Innovobot**, a Montreal-based company that specializes in haptic solutions across many industries. MacLean connected with **Wenco**, **CROSH**, **Laurentian University**, **Cambrian College**, and **Darby Manufacturing** to explore the potential benefits of introducing haptic sensors into the operator seat of heavy mobile equipment.

GR8 EV Grader
an 18ft battery electric pit-class grader

Methods

Vibration Profile Field Data Collection

Field data collection occured at **MacLean's Ducky Mine** in Lively, Ontario. Vibration analysis was conducted in accordance with ISO 2631-1 and carried out with the **Vibration Analysis Tool-Set** software distributed by NexGen Ergonomics.

Tri-axial accelerometers manufactured by NexGen Ergonomics, in conjunction with a MWX8 DataLOG II were used for WBV measurements. Slam Stick Accelerometers (S3-E25D40) by enDAQ used to record the vibration for recreation on the rotopod. From the measured vibration profiles, one sample each from the **low, moderate** and **high-risk category** were selected for recreation.

Methods

Haptic Seat

A haptic feedback system comprising **10 tactile actuators** (“pucks”) was developed. A modified industrial suspension seat was used to house the haptic pucks in the seat pan and backrest during the experimental conditions to provide localized tactile cues.

Each puck was connected via a wired harness using Ethernet cabling, which routed signals from the seat to an external control unit. The wiring harness was secured to the seat structure to prevent movement or cable interference during vibration exposure.

The external electronics module controlled activation of the individual haptic pucks and enabled the system to deliver **discrete tactile signals to specific seat locations**.

The puck design included a flat surface that rests on the seat foam with the actuator housing protruding into the foam cavity to ensure stable positioning and effective transmission of vibration to the seated occupant.

Innovobot Labs **DARBY MANUFACTURING** **Cambrian College**

Accelerating growth through deep tech innovation

We're a team of entrepreneurs, engineers and senior executives who have been in the trenches. We've experienced the challenges that come with developing products from a simple idea to a thriving, growing business.
We've managed complex projects and solved big problems within market constraints. We know how to successfully design, build and commercialize products.

DARBY MANUFACTURING

Your Industrial Seating Specialists

SEATS - PARTS - REPAIRS

Your accelerator
or transformative
nge

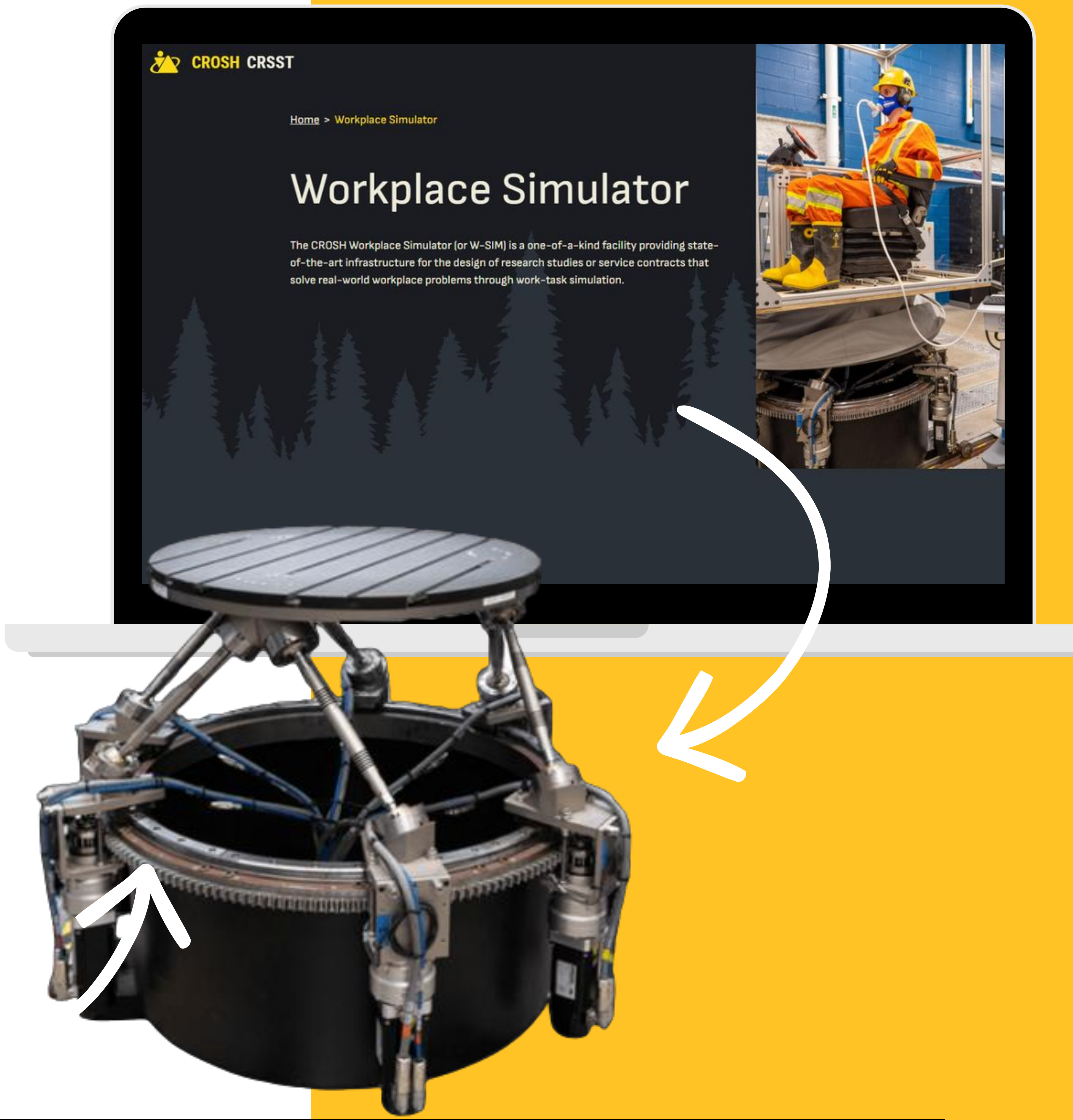
Methods

Vibration Exposure

The study occurred in the Workplace Simulation Laboratory located in the Cliff Fielding Building at Laurentian University. Testing was conducted using the Rotopod 3000.

The modified seat was mounted on the Rotopod to allow simultaneous delivery of seat-based haptic signals and simulated whole-body vibration exposures representative of industrial vehicle operation.

The **Rotopod**, or robotic platform, is a six-degree-of-freedom motion platform capable of replicating translation and tri-axial motion (i.e., x, y, z, roll, pitch, and yaw) to simulate vibration profiles representative of mining equipment operation.



CROSH CRSST

Home > Workplace Simulator

Workplace Simulator

The CROSH Workplace Simulator (or W-SIM) is a one-of-a-kind facility providing state-of-the-art infrastructure for the design of research studies or service contracts that solve real-world workplace problems through work-task simulation.

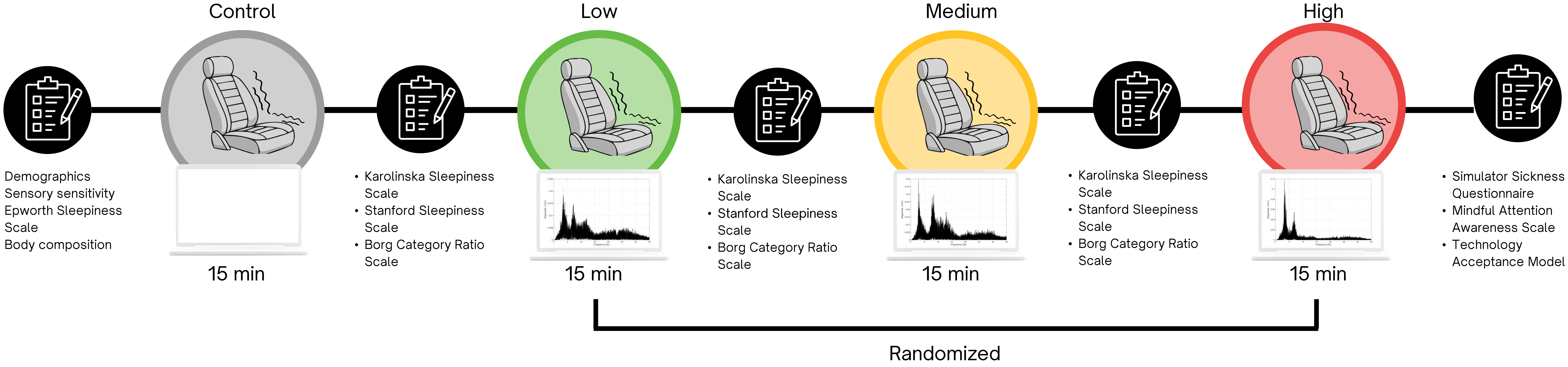
CROSH CRSST
centre for research in occupational safety and health at Laurentian University | centre de recherche sur la santé et sécurité au travail à l'Université Laurentienne

LaurentianUniversity
UniversitéLaurentienne

Methods

Haptic Signal Physical Perception

Participants completed a **control condition** and then were exposed to 3 **randomized field-simulated vibration profiles** (0-35 Hz). The tri-axial vibration exposures were selected to represent realistic operating conditions while keeping exposure levels below the limits set by ISO 2631-1. Participants played a construction simulator throughout each condition.



- Demographics
- Sensory sensitivity
- Epworth Sleepiness Scale
- Body composition

Control

15 min

- Karolinska Sleepiness Scale
- Stanford Sleepiness Scale
- Borg Category Ratio Scale

Low

15 min

- Karolinska Sleepiness Scale
- Stanford Sleepiness Scale
- Borg Category Ratio Scale

Medium

15 min

- Karolinska Sleepiness Scale
- Stanford Sleepiness Scale
- Borg Category Ratio Scale

High

15 min

- Simulator Sickness Questionnaire
- Mindful Attention Awareness Scale
- Technology Acceptance Model

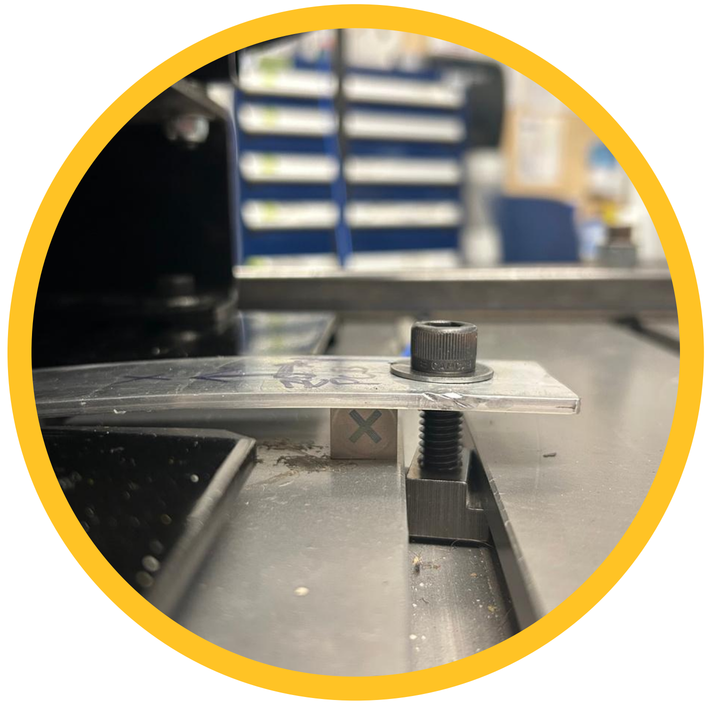
Randomized

Across each condition, participants received **30 randomized haptic prompts** at a standardized signal frequency via the **10 puck locations** embedded in the seat. The timing of signal activation was randomized by the haptic system software to ensure consistent stimulus delivery while preventing participants from anticipating cue timing.

Methods

Vibration Measurements

Whole-body vibration was quantified using three tri-axial accelerometers which measure acceleration simultaneously in three orthogonal axes (x, y, z). The accelerometers were positioned to capture vibration at the **seat input**, **seat interface** and participant's **head**.



Mounted directly on the Rotopod platform beneath the seat to measure the input **vibration from the motion platform**.

Secured to the top surface of the seat pan using a modified seat pad mounting method to capture the **vibration transmitted to the seated participant**.

Attached to the back of the participant's head with an adjustable strap and positioned as close as possible to the external occipital protuberance to measure **vibration transmitted to the head**.

These measurements were used to calculate two transmissibility metrics:

Seat Effective Amplitude Transmissibility (SEAT)
Calculated to evaluate the extent to which vibration is transmitted from the platform to the seat interface.

Seat-to-Head Transmissibility (STHT)
Calculated to evaluate the extent to which vibration is transmitted through the seat and propagated to the participant's head.

Methods

Alertness Measurements

Cognitive alertness was monitored continuously throughout all study conditions with the SmartCap System. The system uses five dry EEG electrodes integrated into a lightweight headband worn across the participant's forehead. The SmartCap continuously records EEG activity and processes the signal to classify neurophysiological patterns associated with alertness and fatigue.

EEG-derived alertness ("Level 2", "Level 3") and fatigue metrics ("Level 3+", "Level 4") were time-aligned with experimental condition markers, including the timing of haptic cue presentations, and participant responses recorded via the tablet interface.

Wenco®
Getting More Out of Your Mine

Data Collection

- 21 participants
- 11 males and 10 females
- Age 26.6 ± 9.2 years
- Mean height 173.45 ± 10.93 cm
- Mean body weight 78.57 ± 16.82 kg
- Mean BMI of 25.91 ± 4.01 kg/m²
- Mean body fat percentage 25.31 ± 6.40%

Objective 1

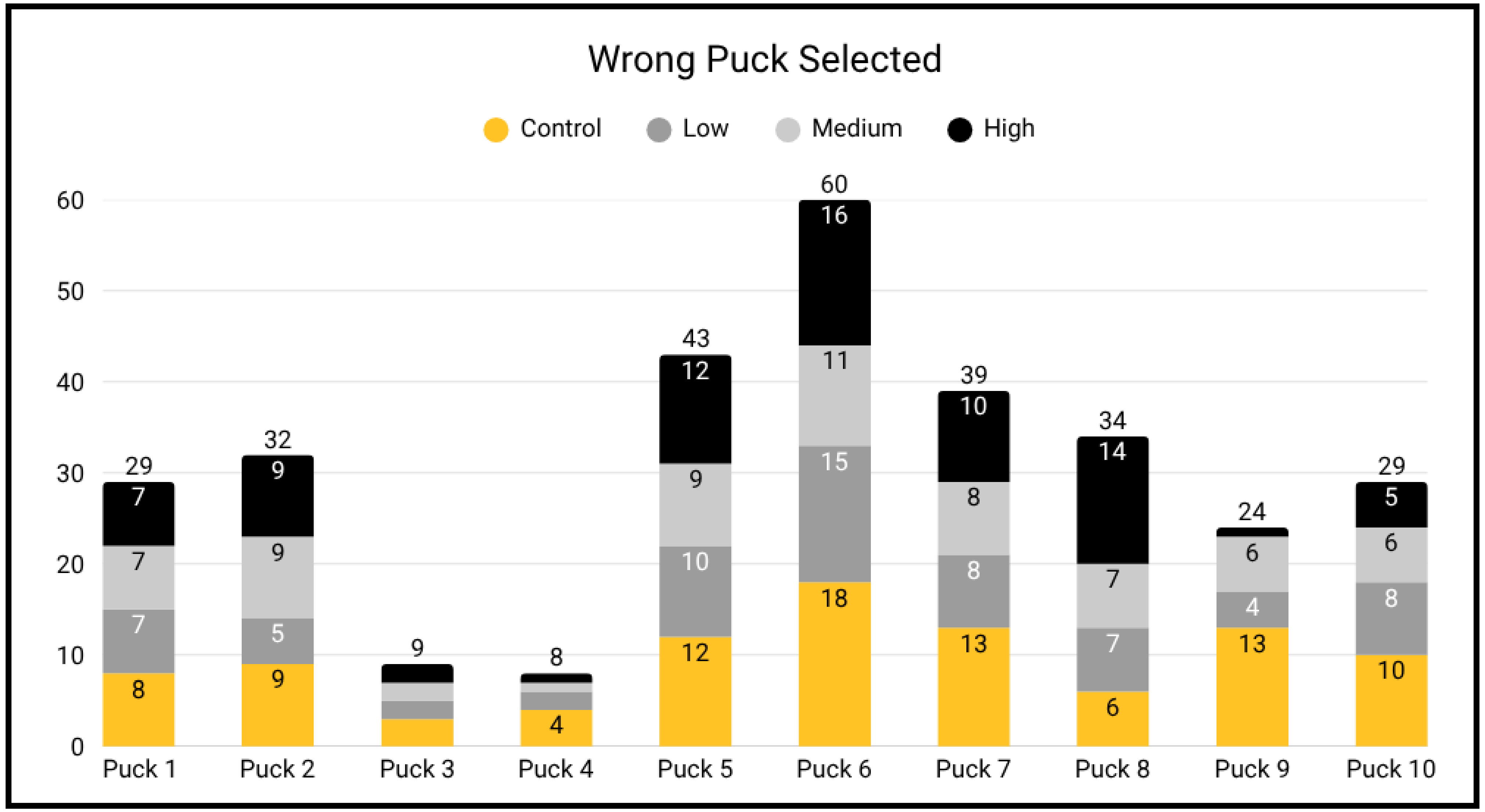
Results

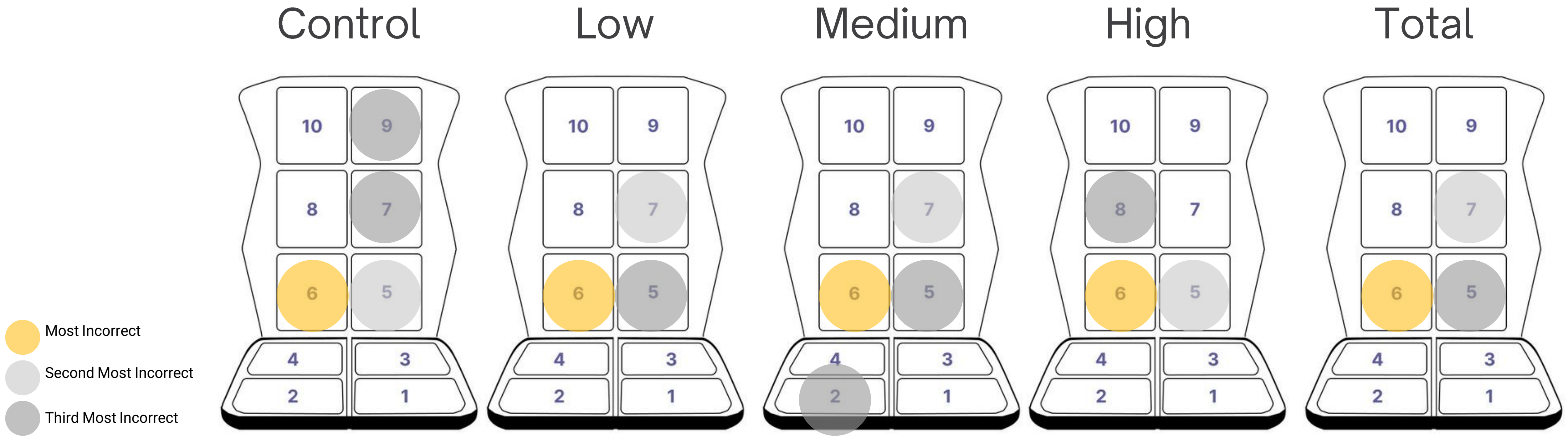
Haptic Signal Physical Perception: Correct Puck Identification

Perception accuracy was assessed by comparing the participant-selected puck location to the actual haptic puck activated by the system.

- All three exposure conditions showed high levels of accuracy
    - High: 87%
    - Moderate: 89%
    - Low: 88%
- Accuracy was lowest in the control condition (82%)
- Overall, there were 307 wrong puck selections
    - Control accounted for the most errors (n=96)
    - Puck 6 had the most incorrect results

- Most participants indicated that vibration prompts became easier to recognize over time
- Over 80% agreed or strongly agreed that they were successful at identifying the cues





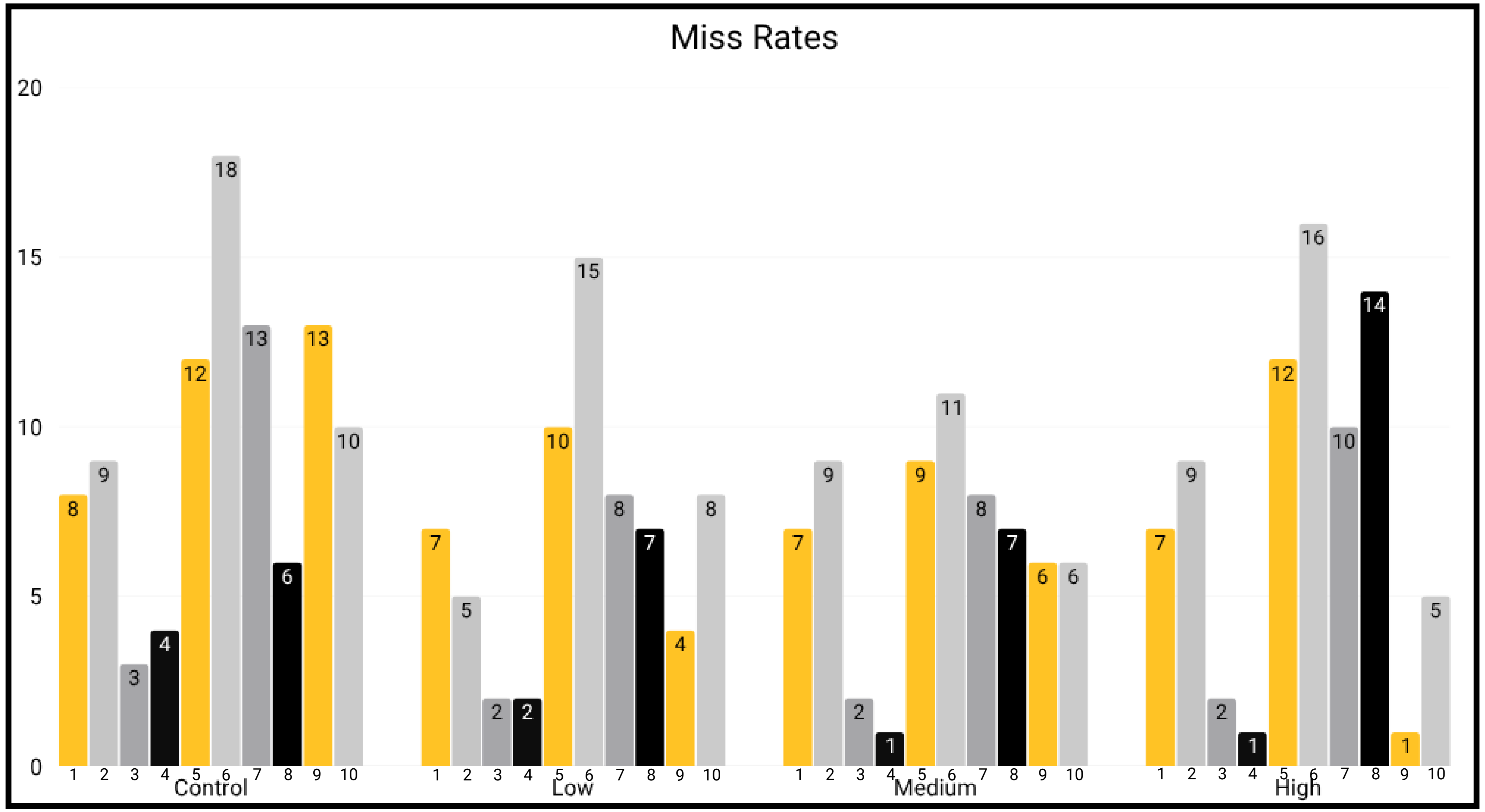
Objective 1

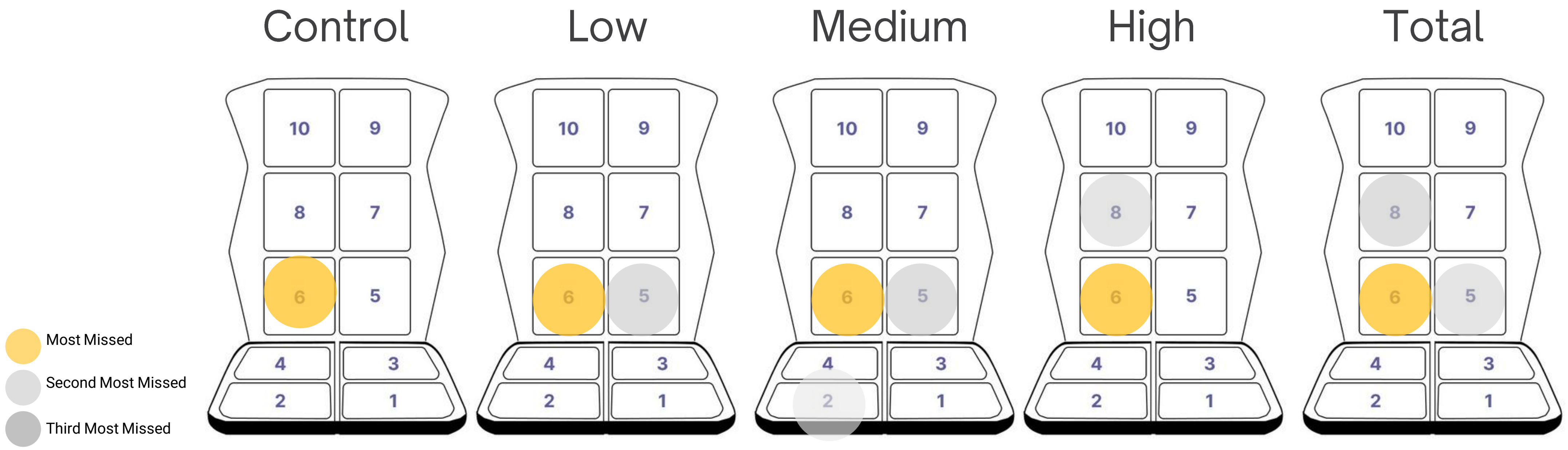
Results

Haptic Signal Physical Perception: Miss Rates

- Miss rates followed a similar pattern, with the vibration profiles showing similar results
  - high: 4%
  - moderate: 3.5%
  - low: 4%
  - control: 5%
- Overall, there were 71 missed cues
  - Control accounted for the most misses
  - Puck 6 had the most misses

- Participants generally found the vibration prompts both easy to notice and interpret
- Confidence in detecting the specific location of each prompt was slightly lower with specific areas identified as more difficult
- The majority of errors occurred in the low and mid back region, where participants sometimes misidentified adjacent prompts.



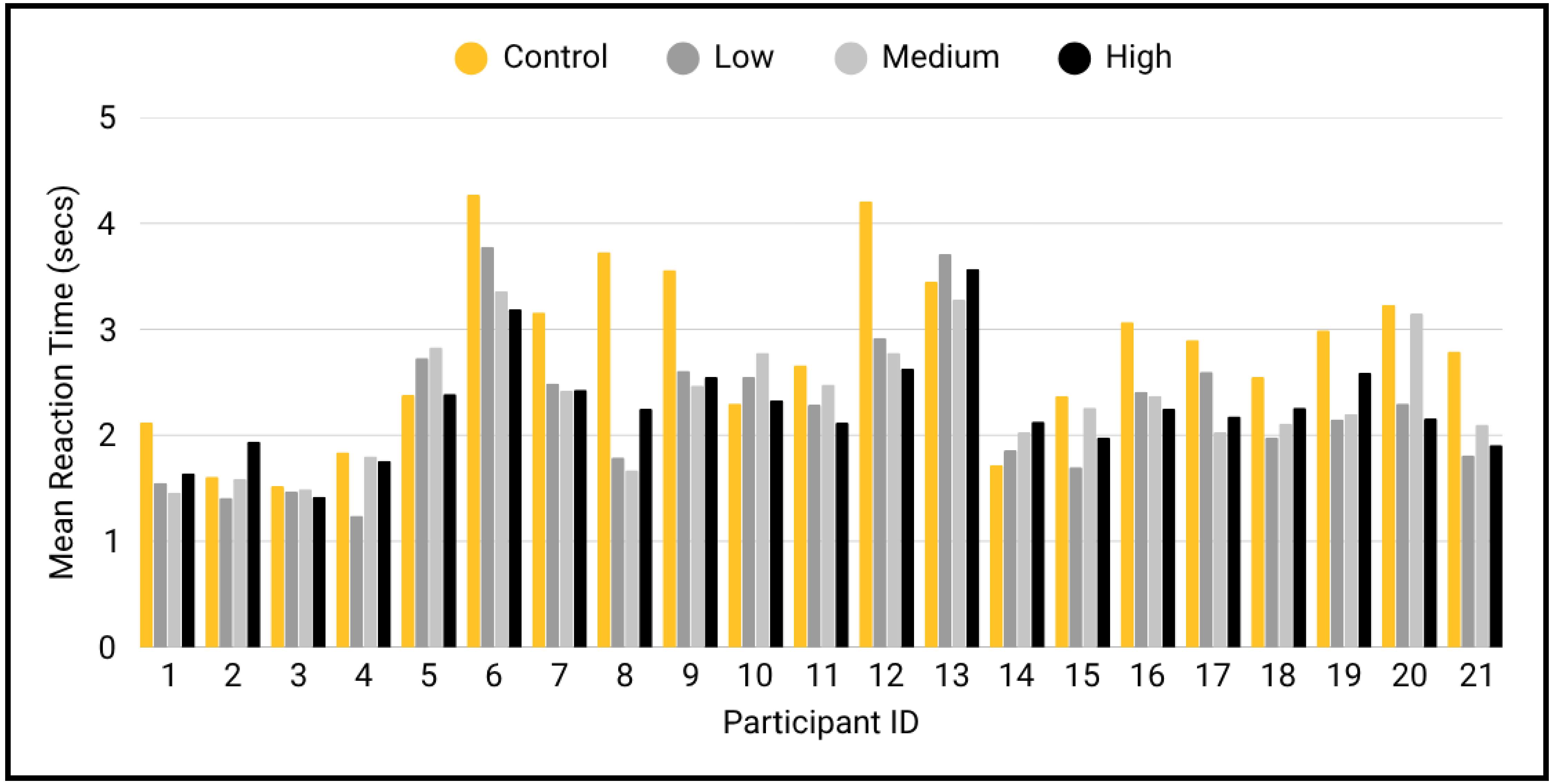


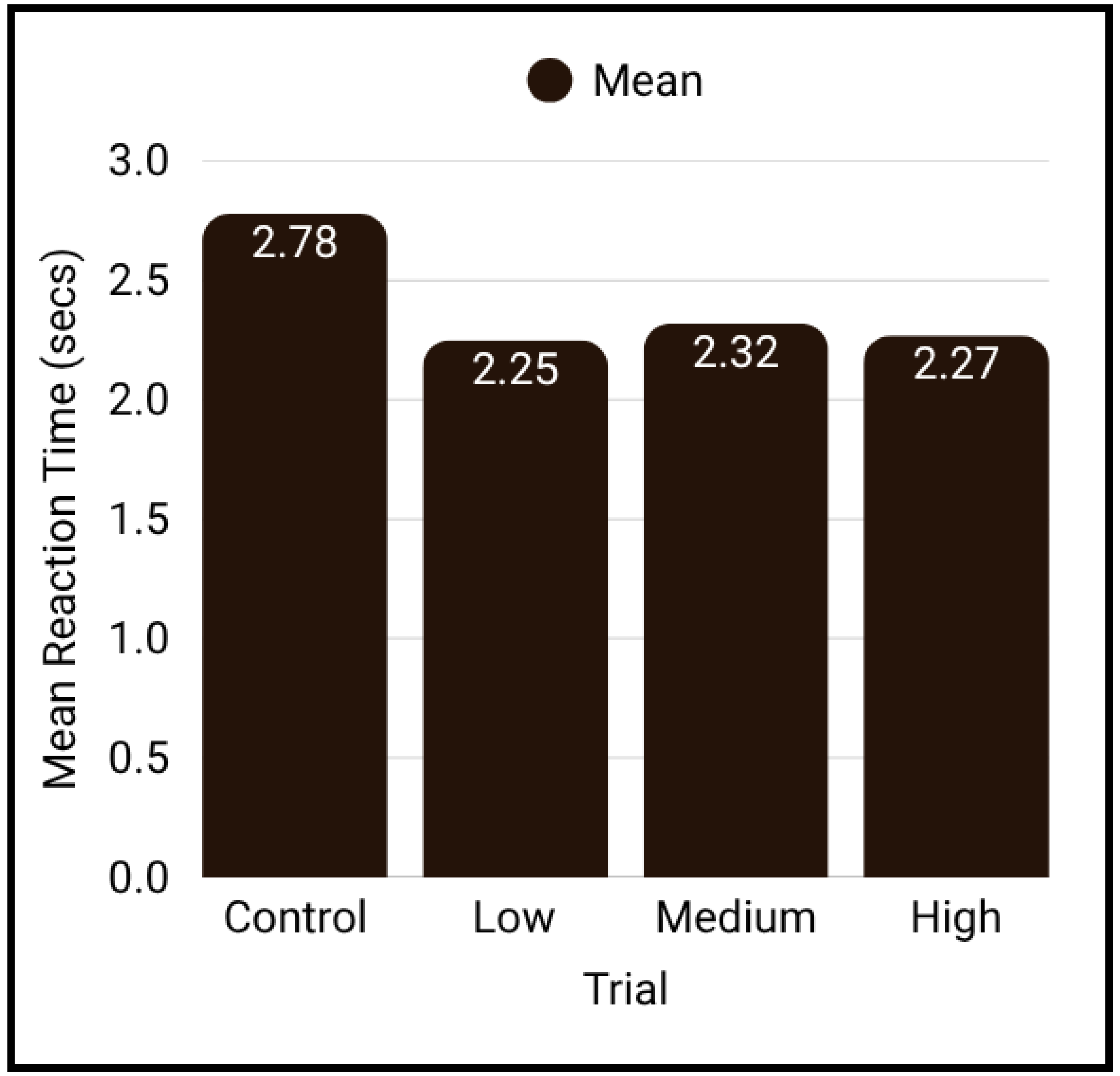
Objective 1

Results

Haptic Signal Physical Perception: Reaction Time

Reaction time was defined as the elapsed time from the onset of the haptic cue to the participant’s response on the steering wheel button. Reaction time was **slowest in the control condition** compared to the exposure conditions. The **low-vibration exposure produced the fastest mean reaction time, whereas the high- and moderate-vibration** conditions were similar.





Objective 2

Results

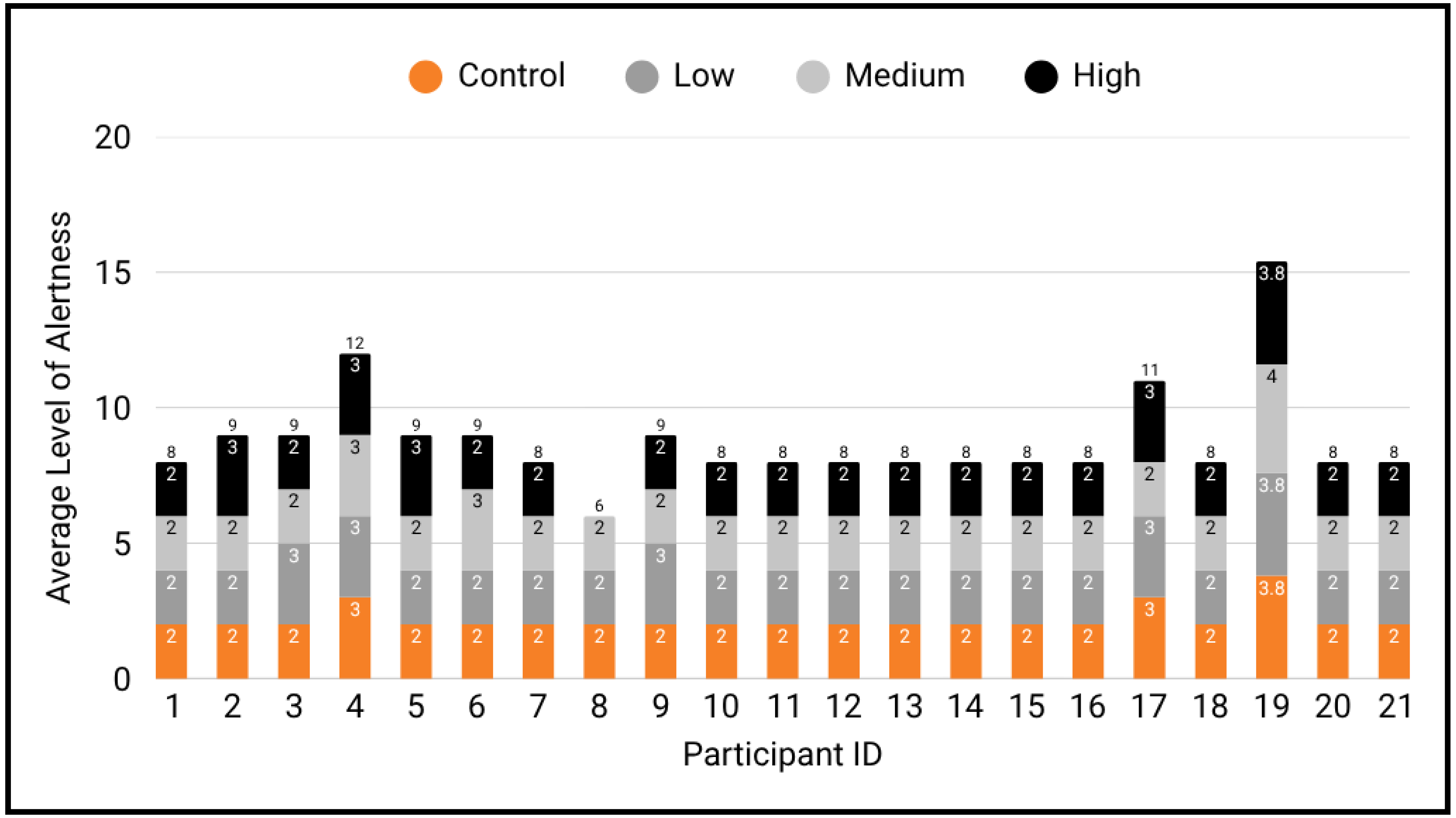
Alertness

The total number of SmartCap alerts recorded across all conditions was low, indicating that most **participants remained physiologically alert** during the 15-minute exposures.

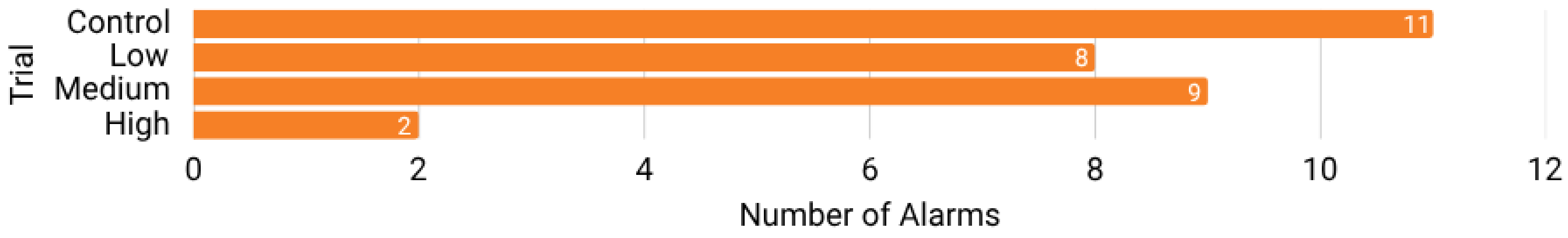
The **average SmartCap fatigue level** was **comparable across conditions:**

- control: 2.18
- low: 2.28
- moderate: 2.19
- high: 2.18

Where **alerts** occurred, they were **distributed across conditions** rather than concentrated within a specific vibration exposure level.



34 Total



Note: 1 participant accounted for 59% of alarms.

Objective 4

Results

Discomfort, Technology Acceptance & Usability

Overall, findings from the subjective questionnaires indicated a **generally positive user experience**, with **moderate adoption potential** alongside identified opportunities to **improve comfort, trust, and minimize distraction**.

Discomfort

- Overall discomfort was low to moderate across conditions
- Higher vibration → increased discomfort, especially in back and seat areas
- ~24% reported moderate seat discomfort; strong discomfort was rare (≤14%)

User Experience & Acceptance

- Generally positive experience; system perceived as enjoyable and comfortable
- Moderate willingness to use in practice (mixed agreement, high neutrality)
- Stronger willingness to recommend to others than to personally adopt

Usability & Distraction

- System seen as supportive for alertness, especially in longer-duration tasks
- Key concern: distraction/ annoyance (38%) and divided attention
- Users reported improved detection with familiarity and adaptation

Trust & Effectiveness

- Mixed trust in vibration prompts for fatigue management (split agreement/disagreement)
- Majority (57%) felt prompts could improve hazard awareness
- Perceived effectiveness varied by task (e.g., monotonous driving less consistent)

Next Steps

Future research will **extend from this laboratory study into an operational field environment** to enhance the occupational validity and better capture the interaction between fatigue, vibration exposure and haptic perception under real working conditions.

Additional Directions

- Evaluate the haptic alert system under authentic operational demands
- Examine differences between novices and experienced operators
- Explore potential for learning effects and adaptation to haptic cues over time
- Explore optimization of haptic signal characteristics, including puck placement, signal frequency, amplitude and timing, to improve detectability under varying vibration conditions
- Investigating multimodal alerting strategies to enhance system effectiveness, particularly in high-vibration or high-workload environments.

Thank You

DARBY MANUFACTURING

Kevin Keyes
Assistant General Manager, Darby Manufacturing
kevin@darbymfg.com

Cambrian College

Stephen Gravel
Manager, Centre for Smart Mining
Cambrian College
stephen.gravel@cambriancollege.ca

MacLean

David Jacques
VP Engineering, MacLean Engineering
djacques@macleanengineering.com

Wenco®

Dr. Emily Tetzlaff
Principal Scientist, Wenco
etetzlaff@wencomine.com

Innovobot Labs

Dr. Manuel Cruz
Chief Scientist & Head of the HMI Lab
mcruz@innovobot.com
Erin Ramsay
Vice-President, Strategic Partnership & Business Development
eramsay@innovobot.com

CROSH CRSST

Dr. Katie Goggins
Senior Scientist, CROSH
kx_goggins@laurentian.ca

Special thank you to all of the CROSH research team members, including **Dawson O'Hara** and **Courtney Lessel** for their work on this project.