From lesion detection to VR exposure therapy: machine learning applications in medical contexts

Harmouche, Rola; Debanné, Philippe

NRC·CNRC

From lesion detection to VR exposure therapy: Machine learning applications in medical contexts

Rola Harmouche, PhD
Biomedical Data Intelligence, Medical Devices Research Center

Career Path – Data analysis to understand and improve human health

Started off in Medical Image Analysis

Machine learning for lung analysis – Brigham and Women's Hospital and the Harvard Medical School

Analysis and explainable machine learning from image and biosensor data - National Research Council Canada

How can an ML algorithm make an impact in a clinical setting?

The need should be one outlined by clinicians / stakeholders

Outcome should make clinical sense and should help in clinical decision-making scenarios

Inputs/predictors used should be meaningful and make sense given the context

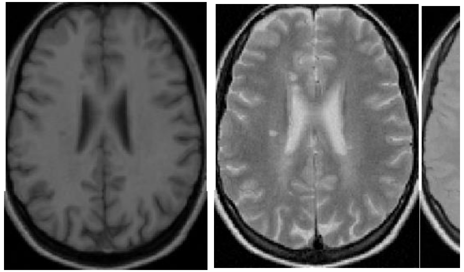
Results validated in clinical settings and trusted by clinicians to increase uptake

Implementation can scale / be integrated into clinical workflow

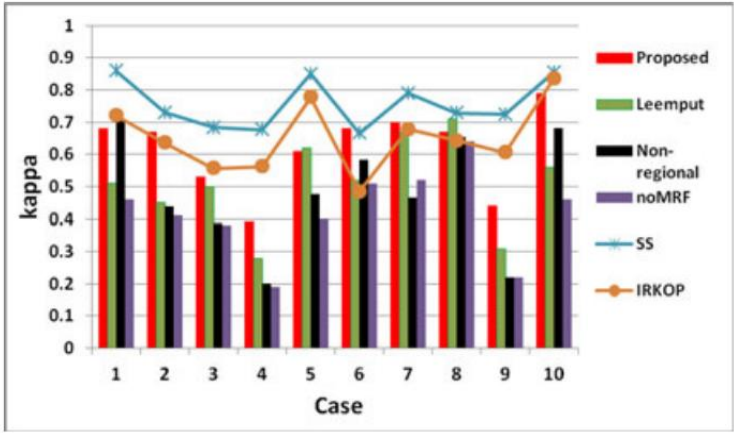
Multiple Sclerosis (MS) Lesion Detection from MRI

MS disrupts communication between the central nervous system and the rest of the body with unpredictable effects

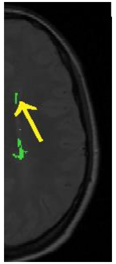
Automated lesion detection leads to more objective assessments in disease management and clinical trials



(a) 3 MRI modalities give complemer



Quantitative results from a multisite cohort of 100 patients



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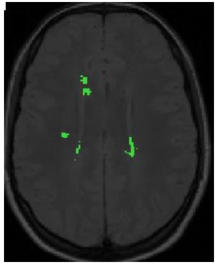
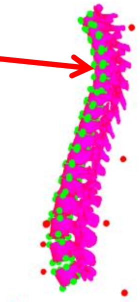


(g) Silver standard

R. Harmouche et. al. Probabilistic Multiple Sclerosis Lesion Classification Based on Modeling Regional Intensity Variability and Local Neighborhood Information. IEEE Transactions on Biomedical Engineering. 62(5): 1281-1292, 2015.

Full body geometric models from medical images - LIV4D

Construct a full body geometric model for surgical simulations to study the non linear effects of internal structure movement on external surface



2D X-ray

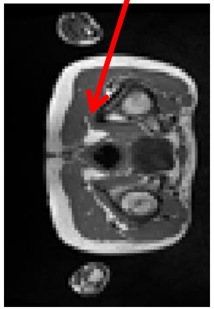
3D vertebral reconstruction

+

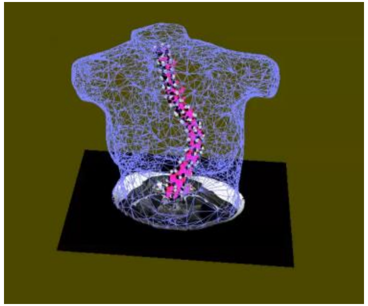
Surface topography

+

Soft tissu



Magnetic resonance imaging



Full body model

Deformable registration using landmarks

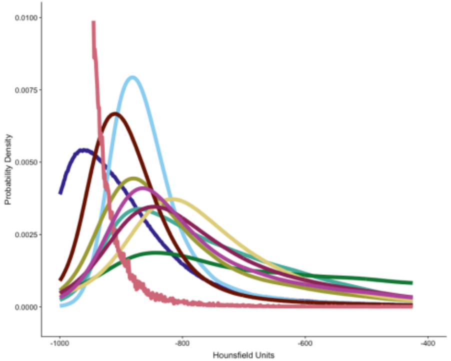
3D articulated and deformable registration

R. Harmouche et. al. Multimodal image registration of the scoliotic torso for surgical planning. BMC Medical Imaging. 13(1), 2013.

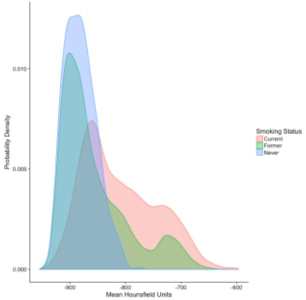
Characterisation of lung disease from CT scans

Automated pipelines for end-to-end large scale lung image analysis (disease quantification)

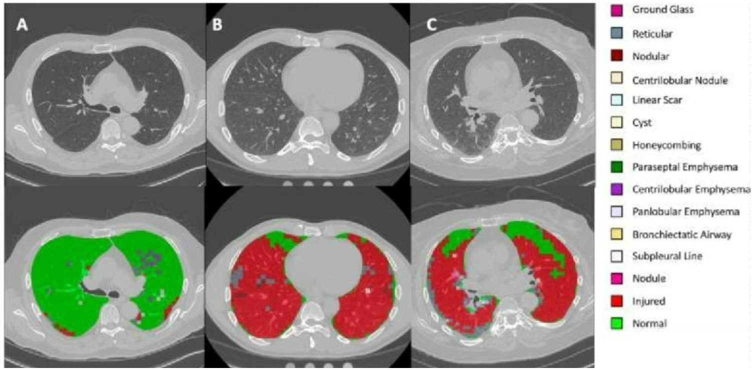
- Can we predict the onset of disease?



Local density histogram obtained using kernel density estimation (KDE)



Training cases (30 by 30 ROIs) from never smokers used to identify a distribution of normal tissue, outliers re-classified as injured tissue



Deployed on a multi-site cohort of over 10 000 CT images

- Incorporate distance to pleural surface in feature vector
- A new class of injured tissue, not visually different from normal tissue on CT associated with adverse clinical outcomes, independent of emphysema and fibrosis (e.g. 6-min walk test, risk of death)

R. Harmouche et al. Objectively Measured Chronic Lung Injury on Chest Computed Tomography. Chest 156(6). 2019.

From Academia to the National Research Council (NRC)

Academic positions are very competitive and my main career goal is to continue making some impact on Canadians' health

NRC is a hybrid between industry and academia, delivering value to Canadians in 3 ways

- We advance scientific and technical knowledge
- We support government policy objectives
- We support business innovation

182 buildings 24 laboratory sites from Vancouver to St. John's

National Research Council - Biomedical Data Intelligence (Medical Devices Research Center)

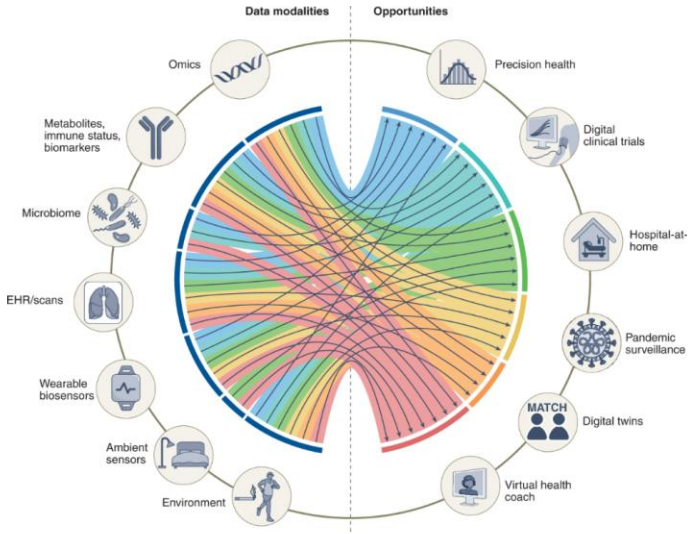
We apply data science and machine learning techniques to analyze and interpret biomedical data

Objective is to extract meaningful insights, patterns, and relationships from various sources of data to understand human behavior and health

Applications include:

- Assessment and monitoring of behavior and health problems

- Informing, personalizing, and monitoring intervention to address those problems



https://www.nature.com/articles/s41591-022-01981-2

Biomedical Data Intelligence - challenges

- Working with clinical, industrial, and academic collaborators
  - Don’t always have the same aims, reconcile academic contributions and contributions to Canadians, SMEs…
  - Learning curve to gain domain expertise
  - Data is often limited or needs to be acquired

- Working with mobile sensors as opposed to medical images
  - Data is often noisy, missing, coming from multiple sources and obtained in uncontrolled environments.
  - Device compatibility
  - User adherence

Integrating Explainable Machine Learning in Clinical Decision Support Systems : Study Involving a Modified Design Thinking Approach

Challenge 1:

How can we mathematically render black box models to be explainable

Challenge 2:

How can we present explainable models in highly useable interfaces so clinicians will use them

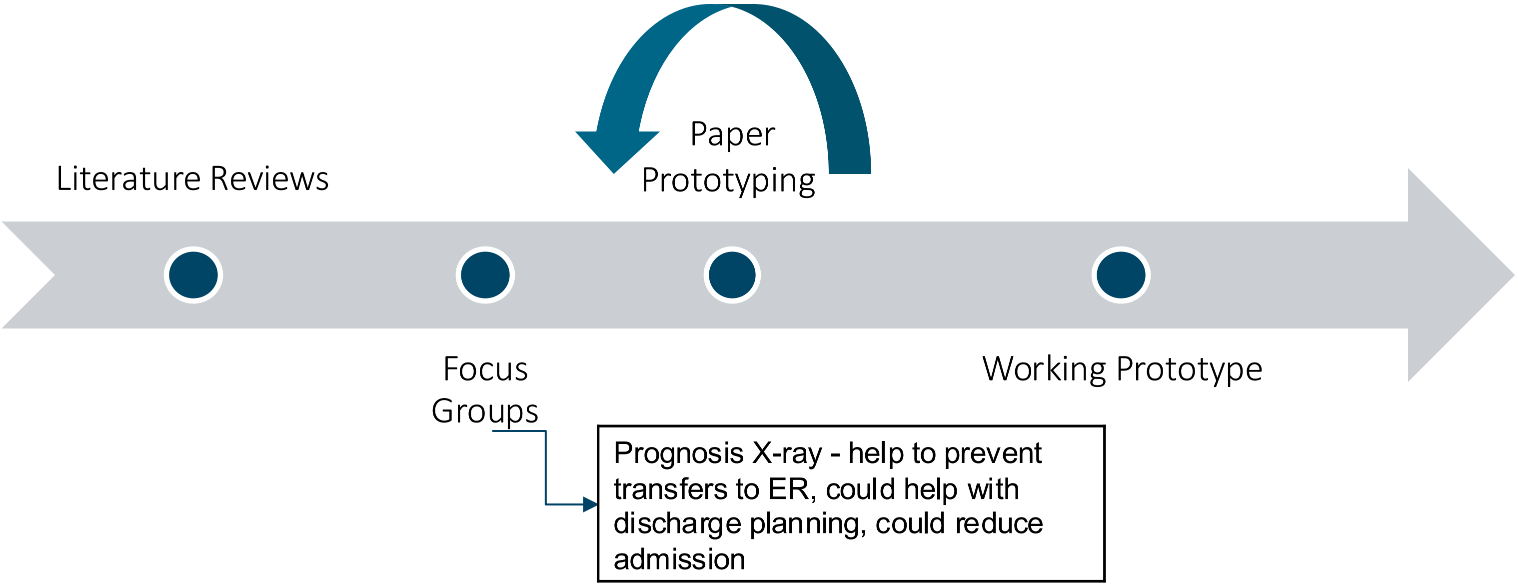
Collaborate on the design of an explainable machine learning application in response to the covid19 pandemic to increase uptake by clinicians

Design thinking approach with user-centered development

EMPATHISE & DEFINE
Consult experts to better understand the design challenge

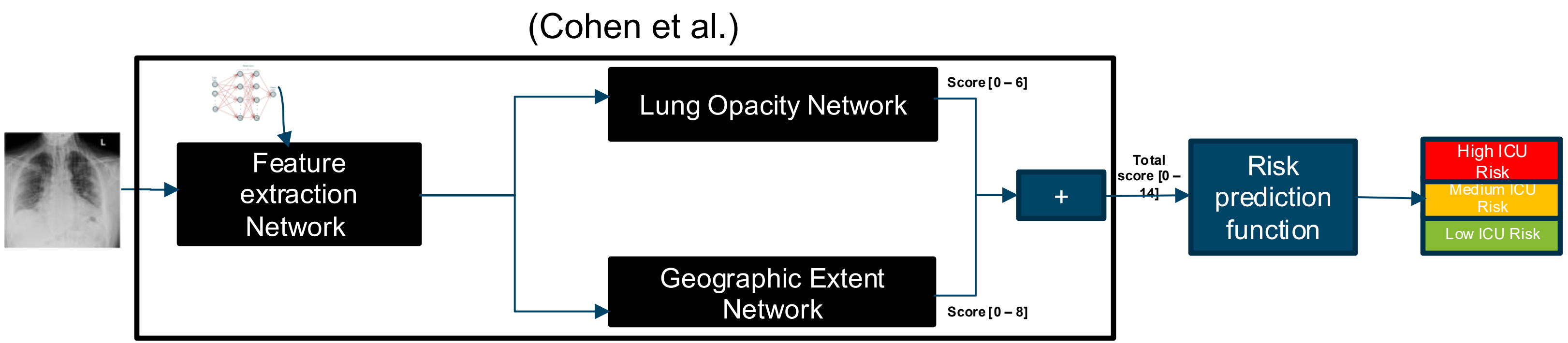
IDEATE & PROTOTYPE
Brainstorm approaches, iterate design on scaled down versions

TEST
Test best solution



Machine Learning Problem

Challenge: Predict Covid-19 patient prognosis from CXR data

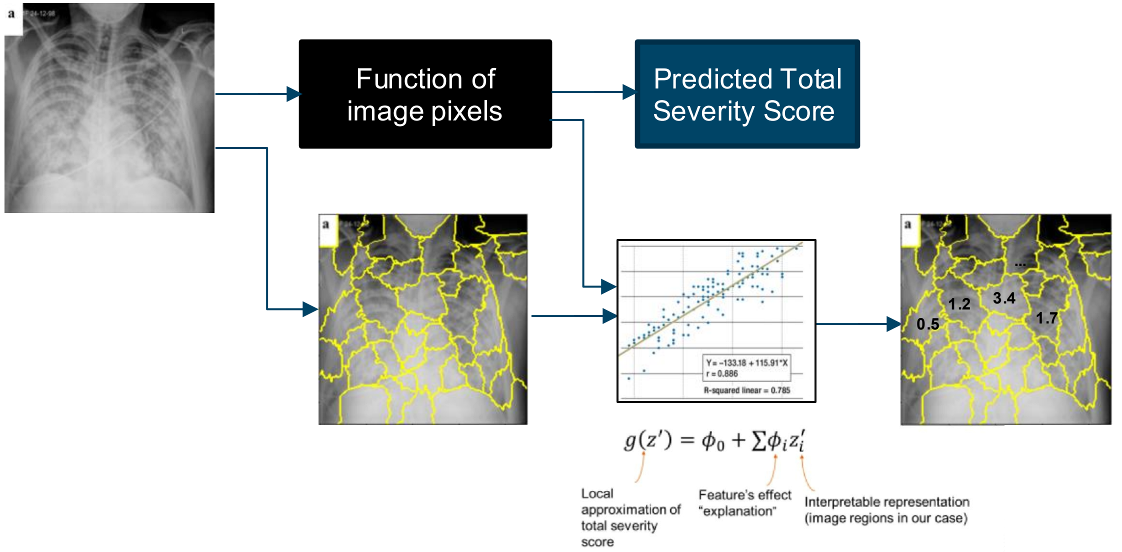


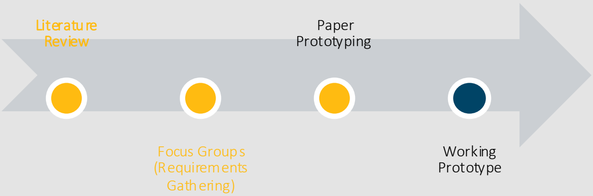
Public Test Dataset

950 x-rays representing 472 unique patients

Some lab, vitals and demographic patient information

Incorporating Explainability using LIME

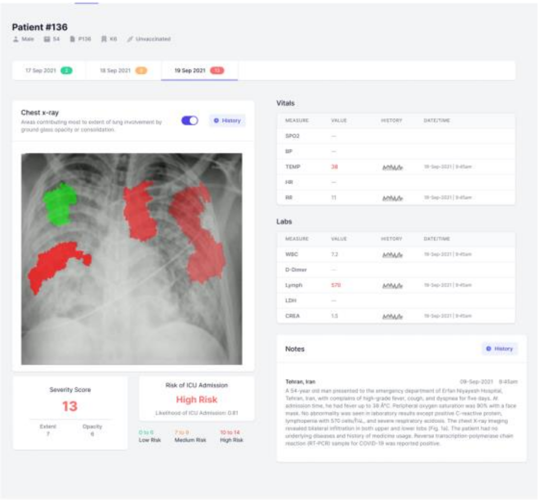




Paper prototype

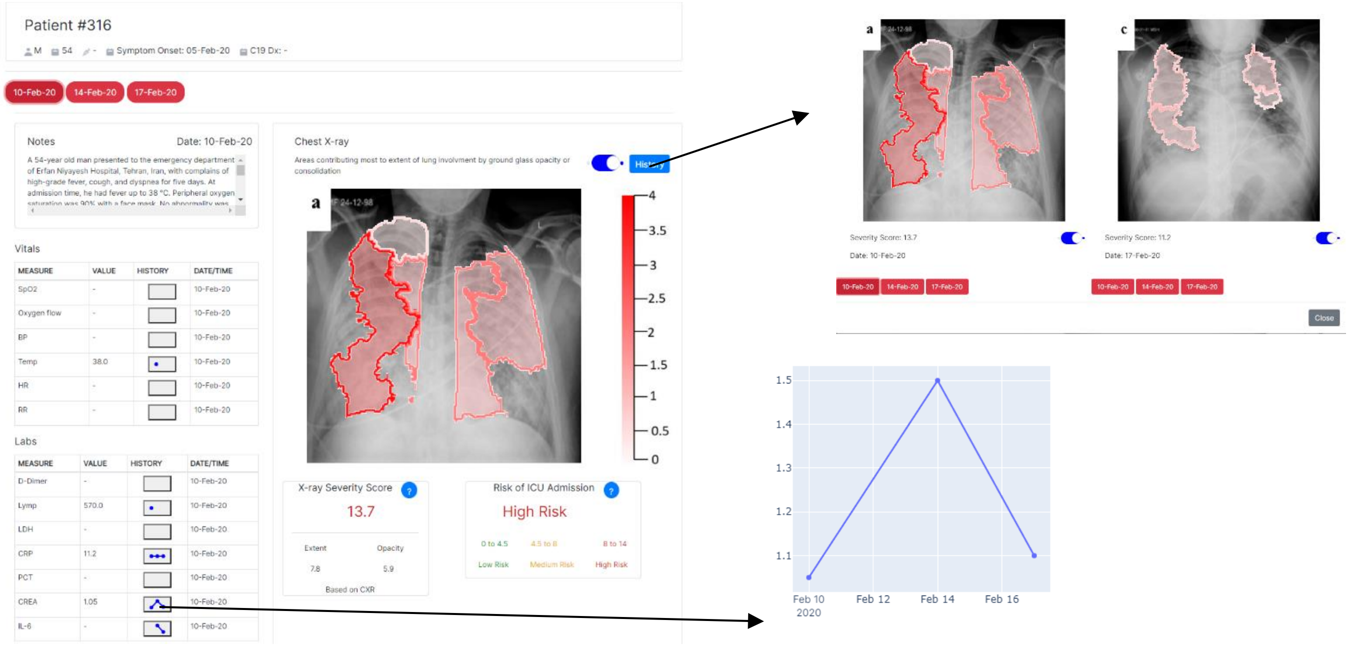
- Are we displaying all of the required information for the given task
- Does the app facilitate action towards the next step in a clinical workflow
- Do prediction changes yield clinically consistent and relevant changes to the explainability

Tonekaboni, S., et al. (2019). What clinicians want: contextualizing explainable machine learning for clinical end use. Machine learning for healthcare conference, PMLR.



- Design Iteration Sessions with physicians
- Each component of the application discussed in informal review sessions
- Ex. Clinicians found having the image and severity placed on the right followed their thinking process more

Final Prototype



Shulha M, Hovdebo J, D'Souza V, Thibault F, Harmouche R. Integrating Explainable Machine Learning in Clinical Decision Support Systems: Study Involving a Modified Design Thinking Approach. JMIR Form Res. 2024 Apr 16

Conclusions

Physicians found the design of the prototype elegant, and domain appropriate representation of data was displayed in the tool

Our interface incorporating explainable machine learning has the potential to improve transparency and increase confidence in machine-learning-based clinical decision support tools.

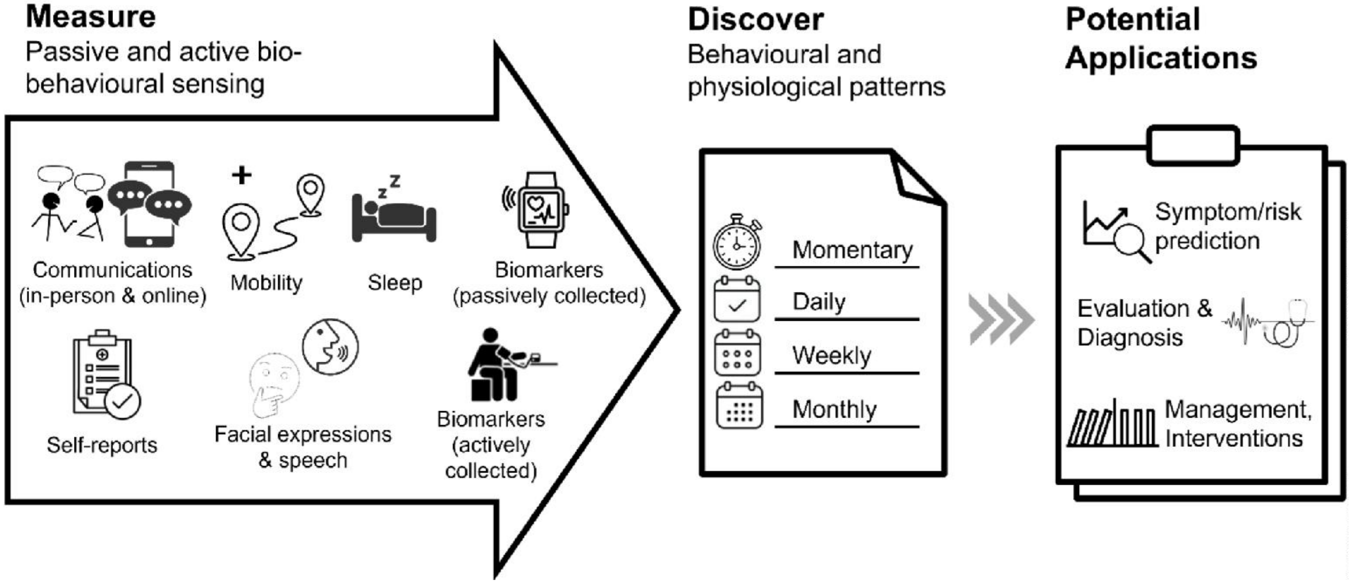
Future work includes A/B testing and more objective feedback during testing.

Limitations

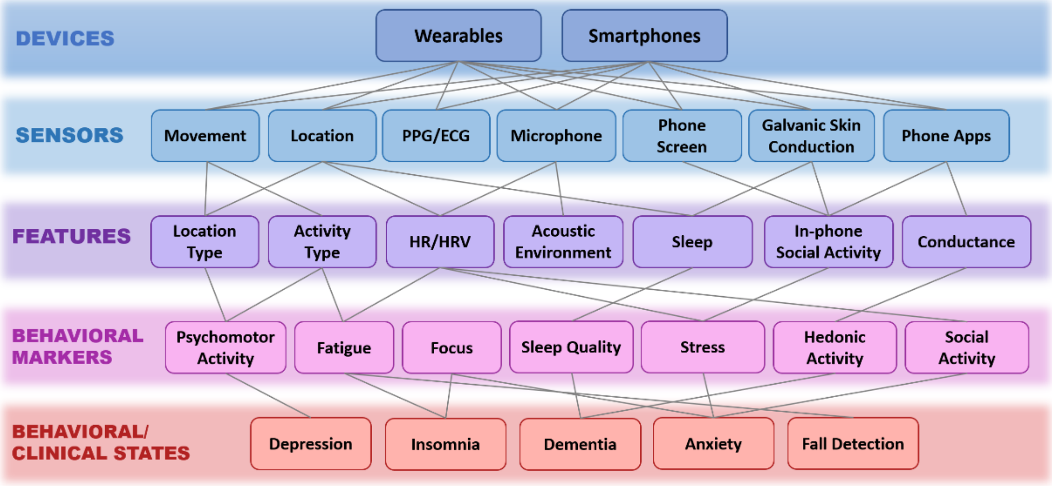
- Working on the development of a tool for condition/disease that is rapidly evolving
- Working with public data sets

Digital phenotyping: what it is and what can we do with it

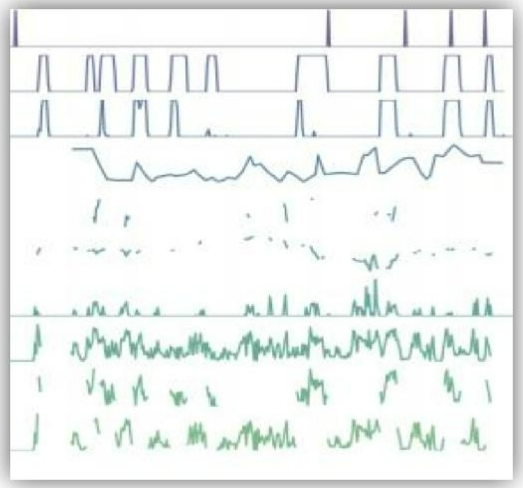
Use of data collected from various digital devices such as wearables, connected objects and smartphones (sensors and apps) to extract meaningful patterns and correlations to eventually gain insights into human behavior and health status



Digital phenotyping: a deeper dive into the process



Minute-level behavior-gram



Domain knowledge and feature engineering is key

Development of solutions for data collection and processing

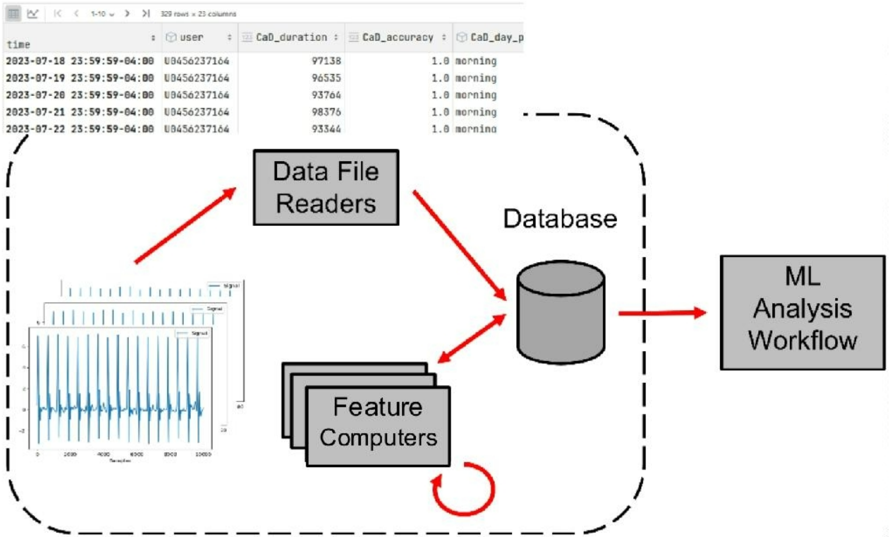
DigiSensing (smartphone app.)

EMA / surveying

Cognitive tests

Sensor integration

Kendra (Python Library)



Aging in Place - Digital phenotyping of modifiable risk factors for insomnia

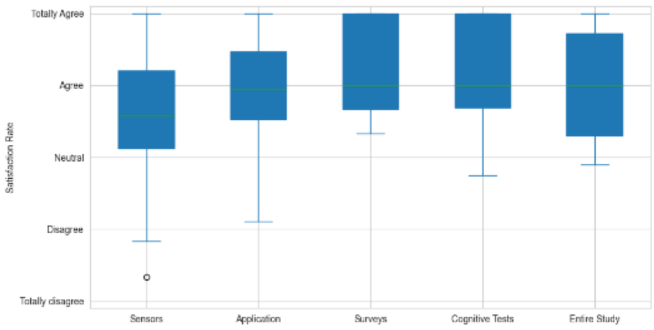
Academic partner:

- CRIUGM - Centre de Recherche de l’Institut Universitaire de Gériatrie de Montréal / Royal Ottawa
- Intervention platform (e-SPACE) promoting risk factor reduction with a focus on sleep and anxiety

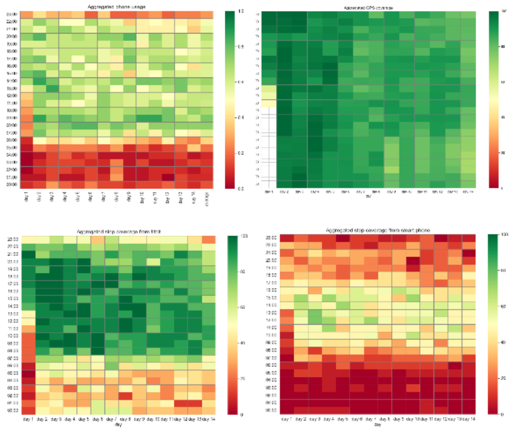
Project phases:

- Preparation: Adapt an available research-grade phenotyping application, sensors integration, surveys definition, ethics, etc. *completed
- Proof-of-concept: Assess the feasibility of the approach without the intervention for ~25 participants over 2 weeks *completed
- Pilot: Leverage the phenotyping approach to inform / personalize cognitive behavioral therapy for insomnia for ~50 participants – 14 week intervention *ongoing

Proof-of-Concept – Feasibility analysis



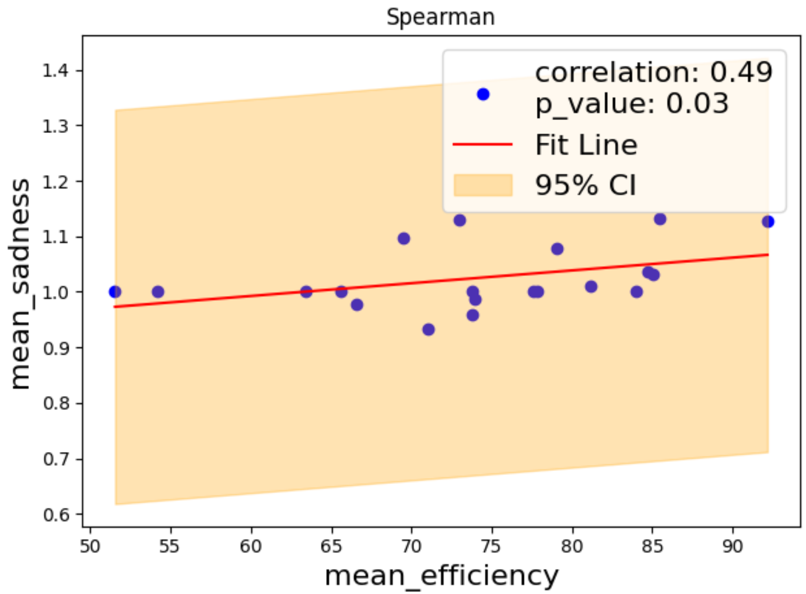
User Experience

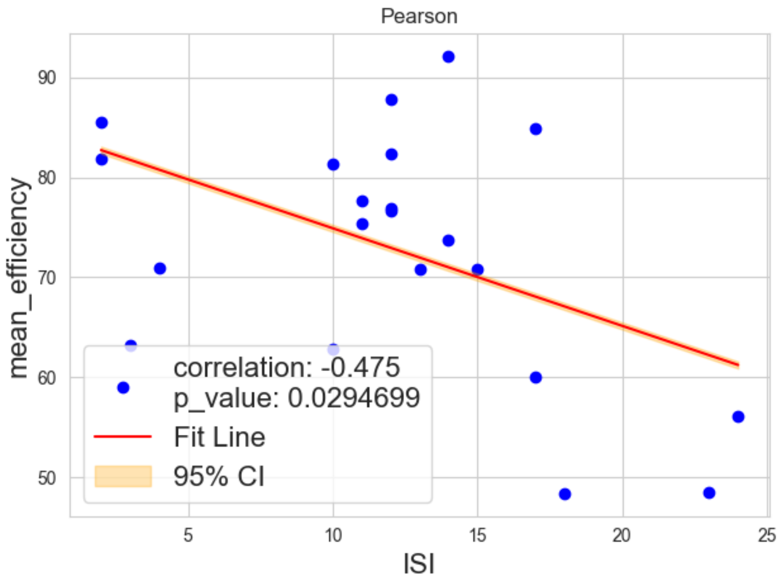


Passive data coverage

4 Abstracts accepted at Canadian Sleep Society Conference (Montreal 2025), journal paper to be submitted.

Feasibility analysis – Correlates with outcomes

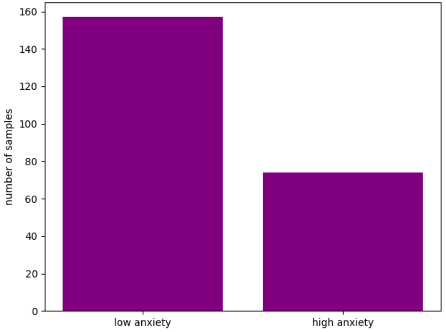




Insomnia severity index

Passive Sensory Data → **Machine Learning** → Daily Anxiety

ML-based Anxiety Detection



Output: Daily Anxiety from surveys

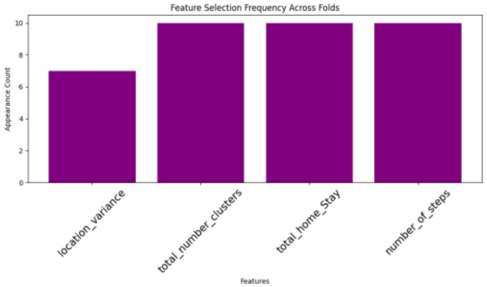
Features: Step, Calls, GPS

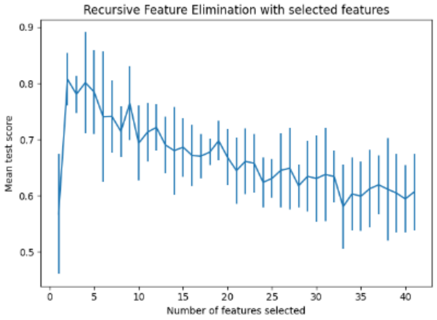
Size of the dataset: 231 input samples

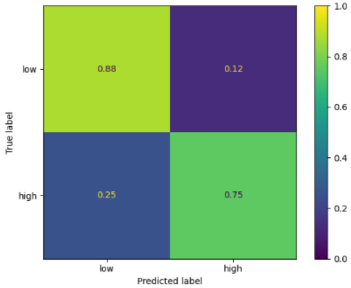
Cross Validation Strategy: 10-Fold

Feature Selection Method:
Recursive Feature Elimination with Random Forest

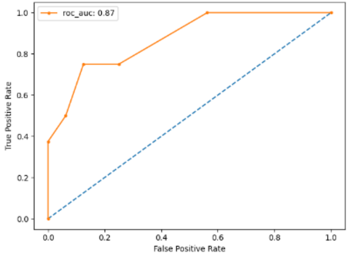
Model: Random Forest





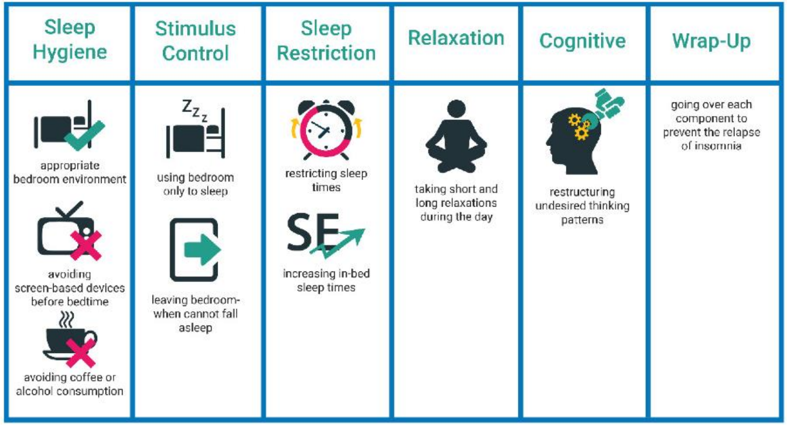


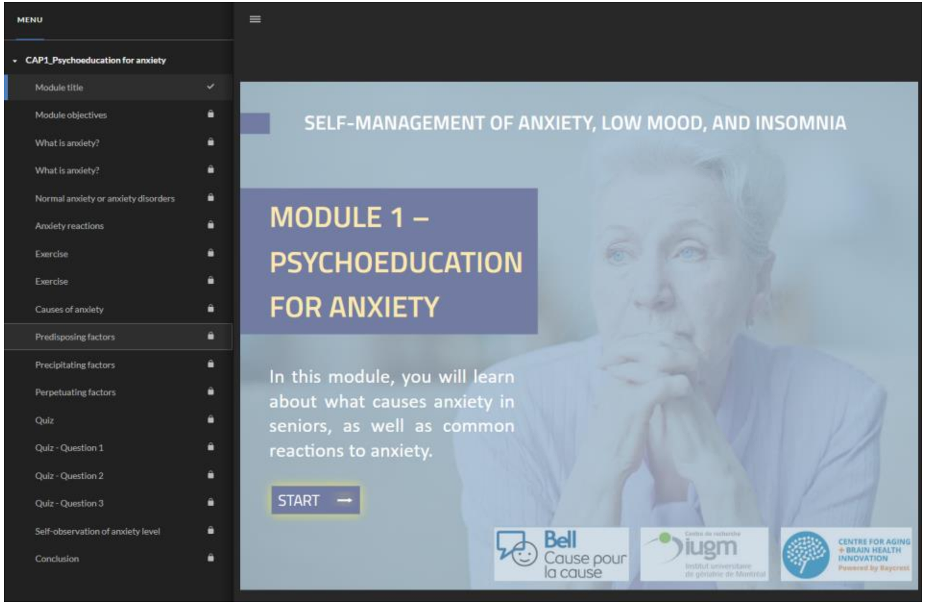
Accuracy: 0.82
Precision: 0.88
Recall: 0.78
F1: 0.82



Pilot Study: Digital Phenotyping in cognitive behavioral therapy for insomnia

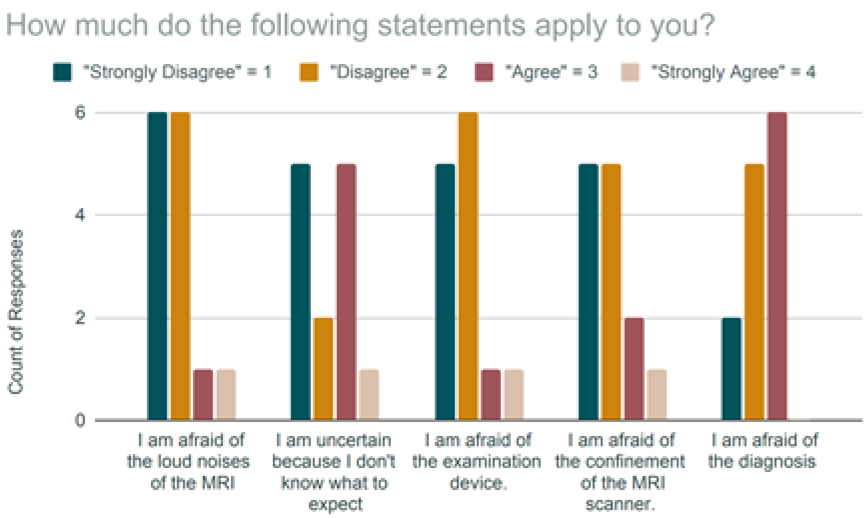
Multi-component intervention





- N = 50
    - Group 1 (N=25): sleep window based on sleep journal
    - Group 2 (N=25): sleep window based on sensor data
- 10-week intervention teaching good sleep hygiene

Reducing anxiety prior to MRI examination using VR, biosensors, and AI



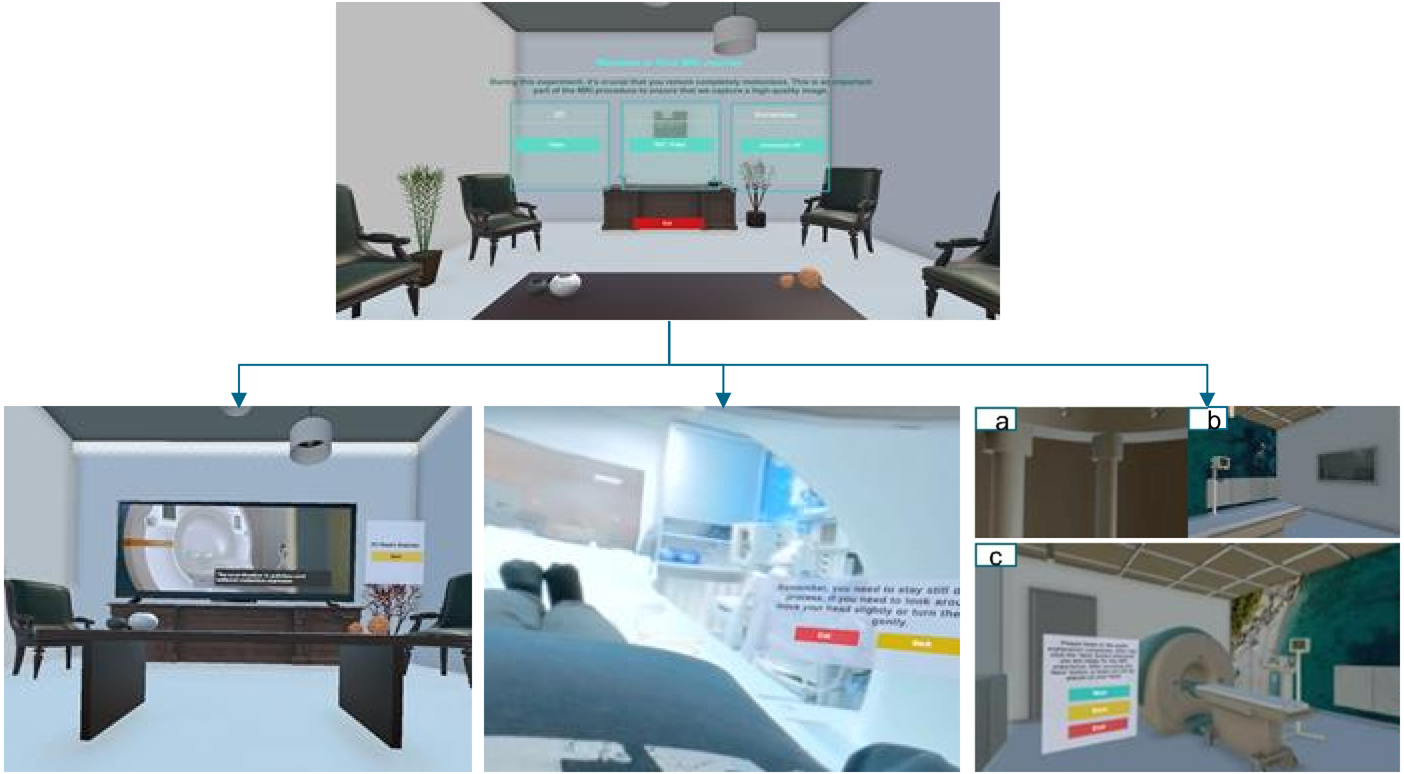
Collaborative research project with Germany and Concordia

- appointment cancellations
- Need for sedation
- Delays or avoidance of necessary examinations
- Degraded image quality due to patient movements
- The necessity for repeat scans
- Unnecessary burden on clinical resource
- Financial losses

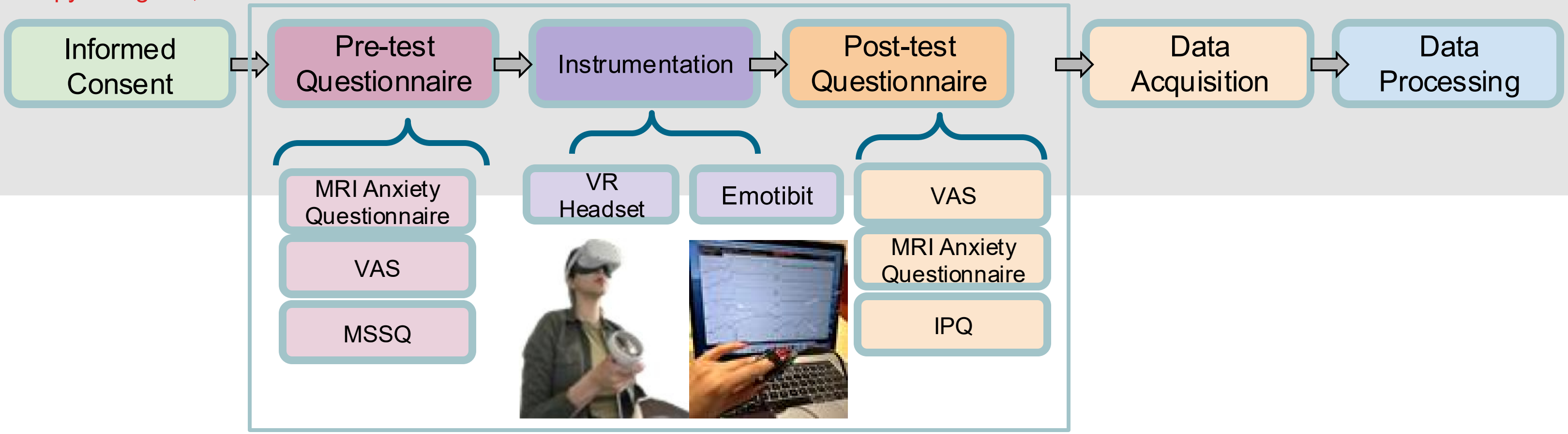
Dr. Sebastian Bickelhaupt
Sarah Seidnitzer
Uniklinikum Erlangen

Prof. Marta Kersten
Hamideh Hosseini
Concordia MONTRÉAL

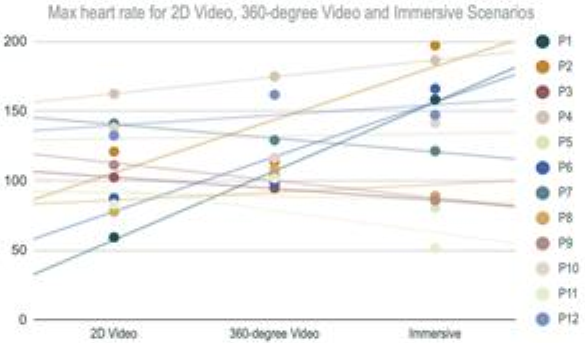
Feasibility study: Evaluating the Impact of Immersiveness in Virtual Reality Simulations on Anxiety Reduction for MRI Procedures



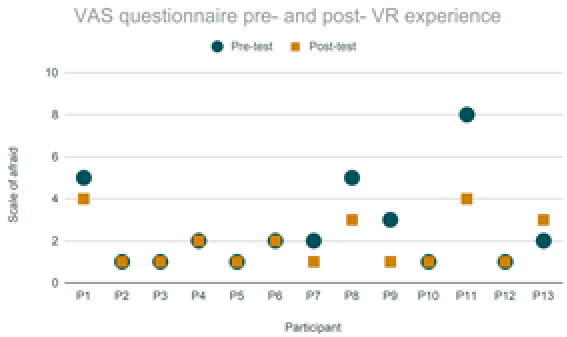
Exposure therapy using VR, biosensors and AI



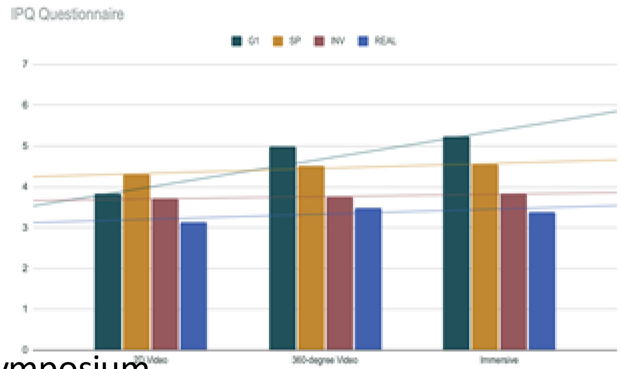
Hypothesis 1, which proposed that participants would exhibit higher heart rates during the immersive VR scenario compared to the 2D or 360-degree video scenarios, was not supported by the data. Despite, it appears that the immersive scenario generally induces higher maximum heart rates compared to the other scenarios.



Hypothesis 2, which predicted that participants with higher pre-experience anxiety would report lower anxiety levels post-experience, regardless of the scenario order, was supported



Hypothesis 3, which proposed that participants would feel more immersed in the fully immersive VR scenario, was not supported.



Submitted to IEEE VR, outstanding poster award at FRQ-S AI and Digital Health Symposium

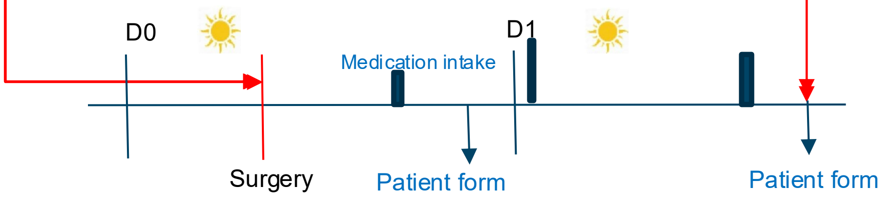
Machine learning analysis of outcomes and perioperative clinical and sensor data

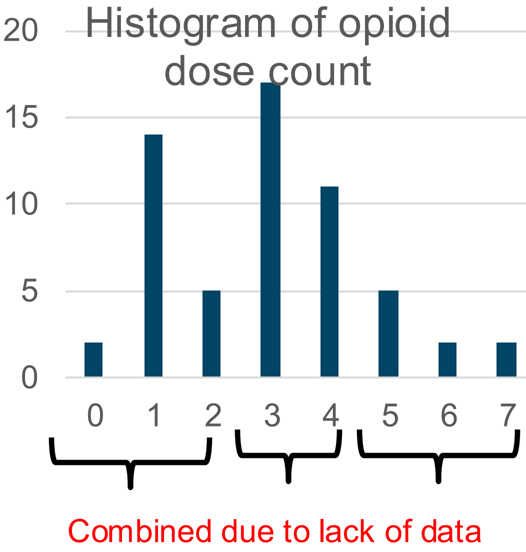
- Mobility and pain are two of biggest determinants of postoperative discharge for knee and hip replacement
- Understand the relationship of the wrist-worn sensor mobility data to
  - clinical measures of outcome (self-reported)
  - other phenotypes in the perioperative period.
- Framework for flexible incorporation of features based on input data provided, and of new analyses using the existing or new features

Effect of self-reported pain and use of co-analgesics during surgery on opioid usage the day after surgery

Random forests with K-fold analysis, K=4

Feature ranking	Feature importance
1. Pain during physiotherapy	0.230
2. Pain getting out of bed	0.160
3. Spinal fentanyl (co-analgesic)	0.122
4. Anesthetic volume	0.115
5. Ketorolac (co-analgesic)	0.099





mean +/- standard deviation of the score: 0.502 +/- 0.062

Surgery

Thank you

Rola Harmouche• Research Officer • rola.harmouche@nrc-cnrc.gc.ca

Medical Application of Zetane Software for the Democratization of Neural Networks

Zetane: A Quebec-based company that has built an artificial intelligence engine with the aim of driving the democratization and explainability of AI.

Develop a proof-of-concept application using Zetane's engine in order to test and demonstrate their technology

Application context

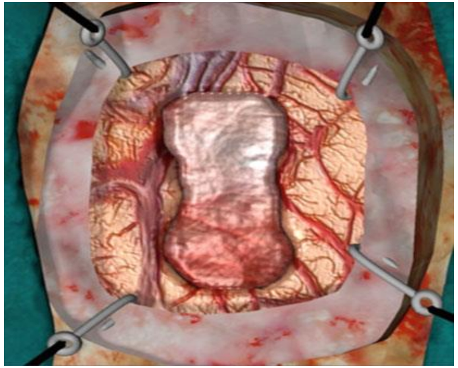
Prediction of the quality of a surgical simulation procedure.

Quality defined from simulator metrics

A meningioma-like tumor as a surgical task

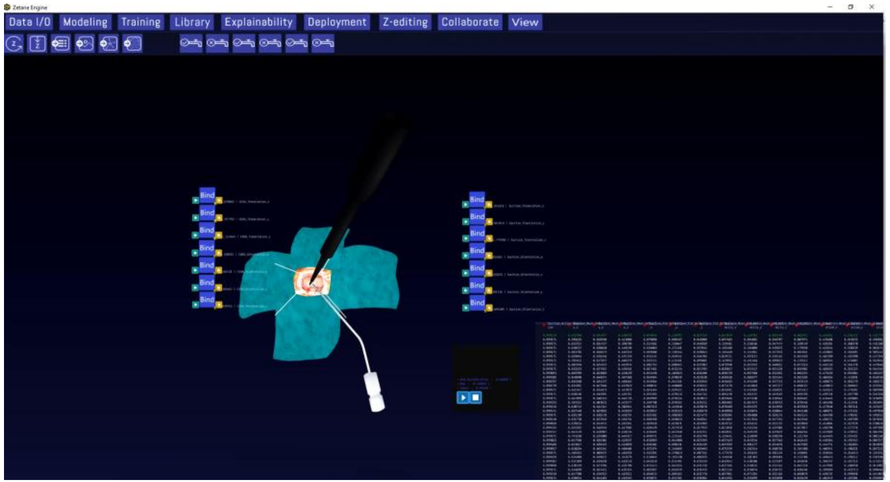
Ultrasonic aspirator for tumour removal (CUSA) and a suction tool

Data from the AANS Young Neurosurgeon Committee Top Gun event in 2011 (not much data to work with)

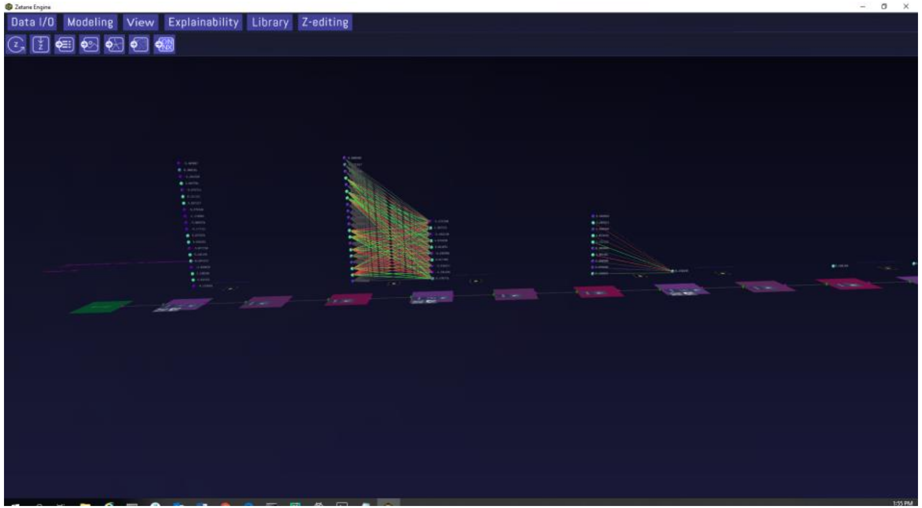


View of the surgical site as appearing in NeuroTouch during the study.

General project design



Representation of the surgical simulation scene and visualization of the tool manipulation in the Zetane Engine.



Representation of the neural network in the Zetane Engine. Inputs are related to tool activity. Output related to quality of the surgical simulation procedure.

Definition of continuous features, output, and NN

Input features:

- Frequency of activation of each tool
- Mean and standard deviation of the velocity, acceleration in each of the x, y, and z directions
- Absolute rotation path of the tool

Output Definition:

- Function of brain volume removed, tumor volume removed, CUSA and suction toolpath length , time that excessive force was applied by each of the CUSA or suction

Neural Network Design:

- Simple design with 2 hidden layers, ReLU activation function, learning rate of 0.01, Stochastic gradient descent optimizer, Mean squared error loss, Other attempts were made