Introduction

Importance of Cognitive Load Management:

- **High-Stakes Context**: In safety-critical surgeries, 50-60% of adverse events are due to preventable errors, largely influenced by human factors.
- **Impact on Patient Outcomes**: High mental workload among the care team is directly associated with poorer patient outcomes and decreased learning opportunities for trainees.
- **Surgeon Workload Variation**: Studies show a negative correlation between surgeon-perceived mental demand and performance, with 22% of surgeries being more difficult than expected, leading to higher workload ratings.
- **Error Probability**: Excessive workload not only degrades performance but also increases the likelihood of errors during procedures.

Measurement of Cognitive Load:

- Using physiological data from sensors like eye tracking glasses, EEG headset, heart rate variability
- High mental load is associated with change in heart rate, widening of pupil diameter, change in brain waves

Research Question: **Does an adaptive training based on workload detection help with skill acquisition?**

Eye Tracking Glasses

Wearable eye tracker designed to follow what the user is looking at in real time.

EEG Headset

Measures the electrical activity in the cerebral cortex, the brain's outer layer, during an EEG test. It is used to study brainwaves and patterns in the brain to understand how it works.

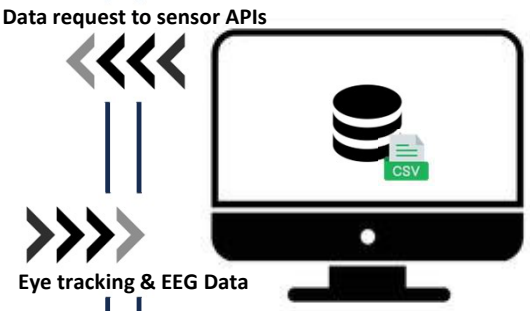
Workload Adaptive Training System Overview

Physiological Sensors

The following sensors are used to obtain the physiological data:

- **Tobii Glasses 3**:
  - Pupil Diameter
  - Gaze Entropy
- **Emotiv EpochX EEG Headset**: Used to track the brain waves (which indicate the cognitive state) and extract 84 features related to alpha, beta, theta and delta waves.

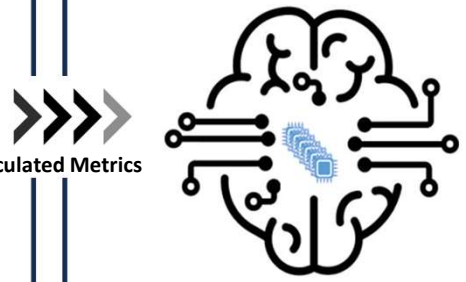
Data Acquisition Pipeline



Features of data acquisition pipeline

- Makes asynchronous calls (using asyncio) to Tobii & Emotiv APIs to retrieve data parallelly.
- Writes the raw data and computed metrics to a database in csv format.
- Spawns metric calculation functions as multi processes to calculate metrics parallelly in real time with a latency of 3s using last 10s data.

Machine Learning Model



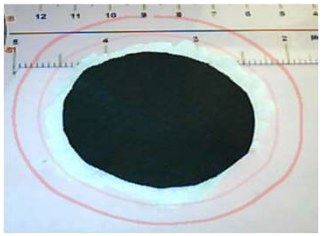
Prediction of Cognitive load

This model uses the 86 calculated metrics to make a prediction:

- High Workload [1]
- Low Workload [0]

The model is a neural network consisting of 3 fully connecting layers. A personalized model is created using **transfer learning** by using data from 2 dummy tasks which simulate high and low workload. This model is used for actual prediction to account for variations within participants.

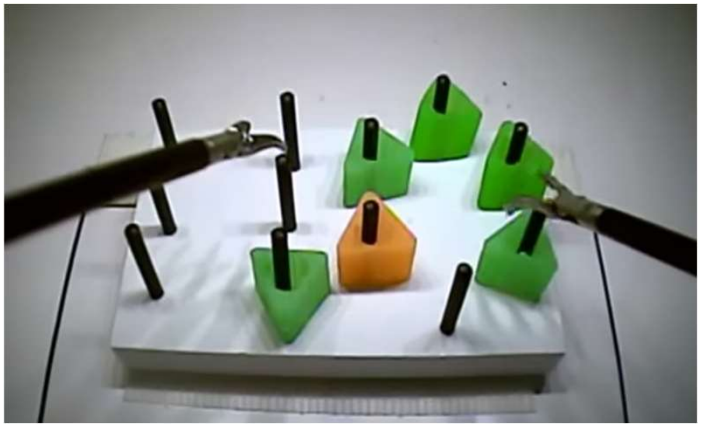
Workload Adaptive Tasks



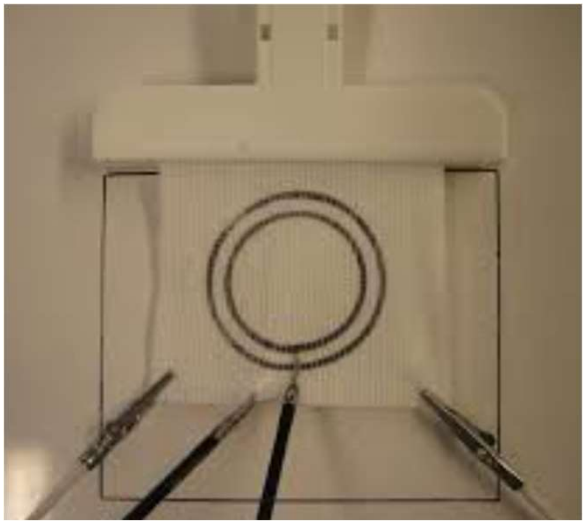
Features of Overlay

- The overlay adjusts the level of instructions given to the participant depending on the workload detected.
- The participant performs precision cutting task on the two shapes (with and without the overlay, i.e. 4 total tasks):

Matchboard Task



Peg Transfer Task



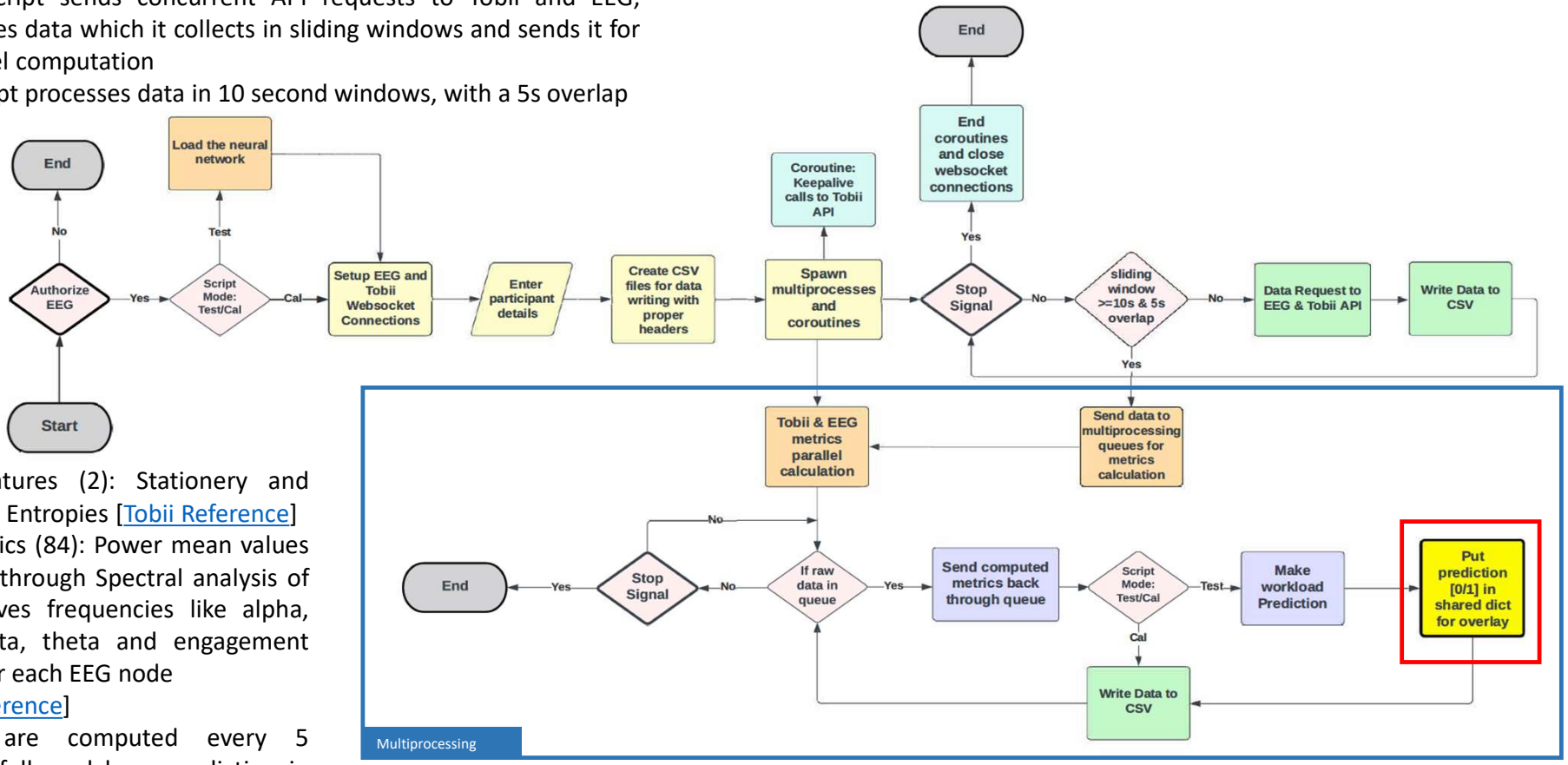
Precision Cutting Task

- **Laparoscopic Tasks**

Algorithm Flowchart

Data Acquisition Pipeline

- Uses asyncio and multiprocessing for increased efficiency and reduced latency to generate predictions in real time
- The script sends concurrent API requests to Tobii and EEG, receives data which it collects in sliding windows and sends it for parallel computation
- The script processes data in 10 second windows, with a 5s overlap

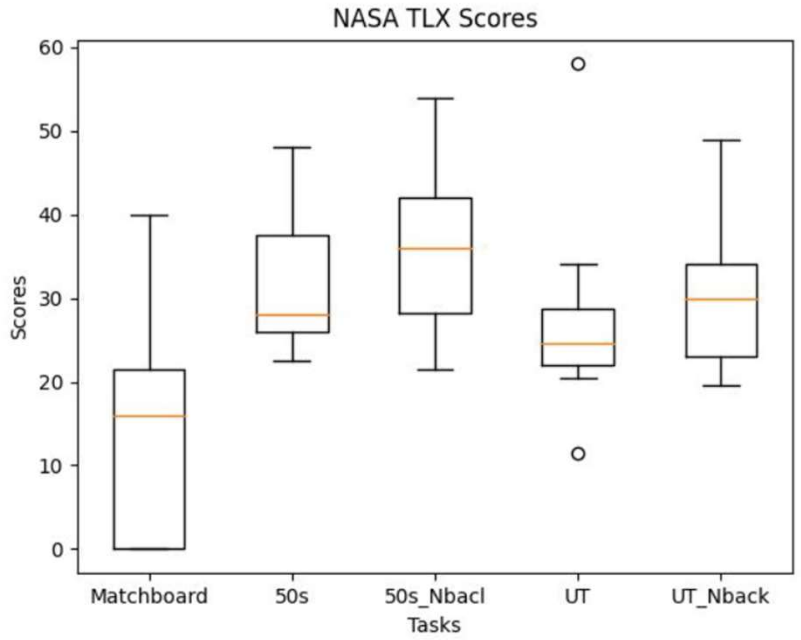


- Tobii Features (2): Stationery and Transition Entropies [Tobii Reference]
- EEG Metrics (84): Power mean values obtained through Spectral analysis of brain waves frequencies like alpha, beta, delta, theta and engagement indices for each EEG node [EEG Reference]
- Metrics are computed every 5 seconds, followed by a prediction in workload

Pilot Study Findings

- **Conducted a Pilot Study to collect data to train a neural network which predicts the mental workload**

- The study was conducted using 11 participants who performed 5 different tasks.
- **Main Findings**:
  - Participants associated the tasks with 2N Back test as the highest workload tasks
  - So, we figured that to induce a higher workload, we can use 2 N Back test
  - Collected data associated to high and not high mental workload.



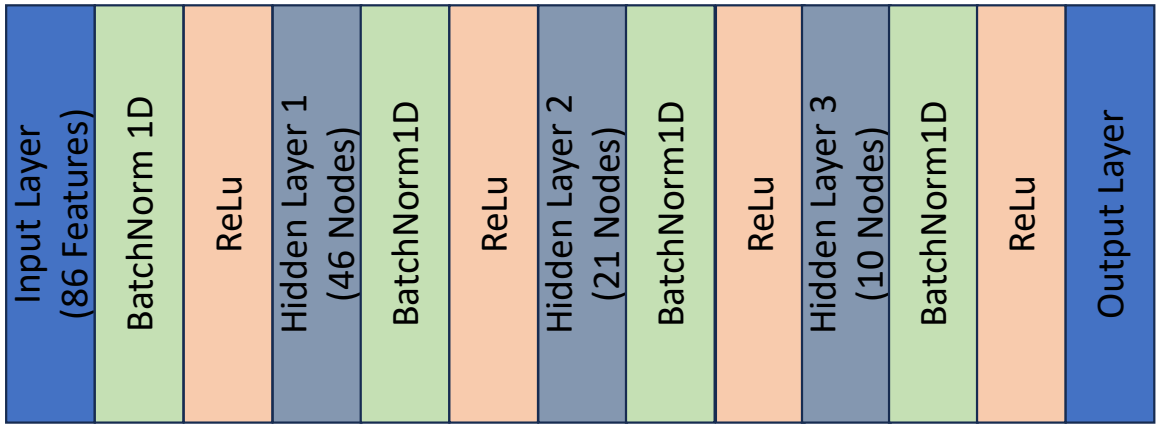
Tasks Performed:

- Matchboard: Letter matching using laparoscopes
- 50s – Peg Transfer Task in 50s
- 50s_Nback- Peg Transfer Task with 2 N Back Test
- UT – Peg Transfer Task till completion
- UT_Nback – Peg Transfer Task till completion with 2 N Back Test

ML Architecture

Model	Accuracy (%)
2 Layer NN (With autoencoder)	69
Random Forest (on encoded data)	79
3 Layer NN (w/o autoencoder)	89.8
Random Forest (w/o autoencoder)	94.85

Selected this model as:
- Can perform transfer learning
- A more generalized model can be used to generate a personalized mode



Neural Network Architecture

- The model consists of 3 fully connected (dense) layers.
- Batch normalization is applied after each layer except for the last one.
- A ReLU (Rectified Linear Unit) activation function is used after each layer, except the final layer, which outputs a single value.
- A sigmoid activation function is applied after the last layer to output a probability value, suitable for binary classification tasks.

Loss Function and Optimization:
- Binary cross entropy loss function is used, aligning with the objective of binary classification.
- The Adam optimizer is employed for training the model, known for its effectiveness in various scenarios.

Generalized Model

- **Neural Network Architecture**

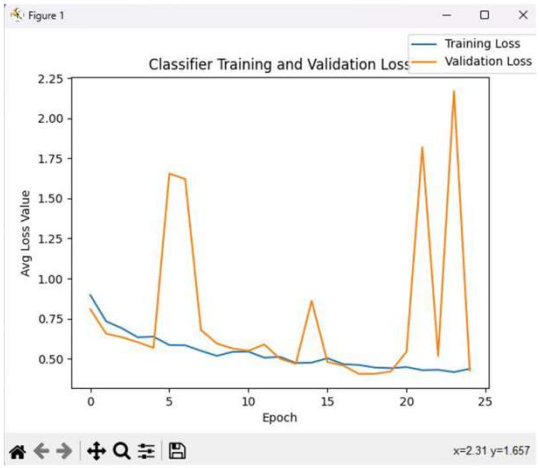
- The model consists of 3 fully connected (dense) layers.
- It is trained using Leave one out cross validation.
- A ReLU (Rectified Linear Unit) activation function is used after each layer, except the final layer, which outputs a single value.
- A sigmoid activation function is applied after the last layer to output a probability value, suitable for binary classification tasks.
- Binary cross entropy loss function is used
- The Adam optimizer is employed for training the model, as it provides an adaptive learning rate approach.

```
------------------- Neural Net ---------------
Accuracy: 0.897196261682243
Classification Report:
              precision    recall  f1-score   support

         0.0       0.89      0.98      0.94       328
         1.0       0.92      0.61      0.73       100

    accuracy                           0.90       428
   macro avg       0.91      0.80      0.84       428
weighted avg       0.90      0.90      0.89       428

Confusion Matrix:
[[323   5]
 [ 39  61]]
```



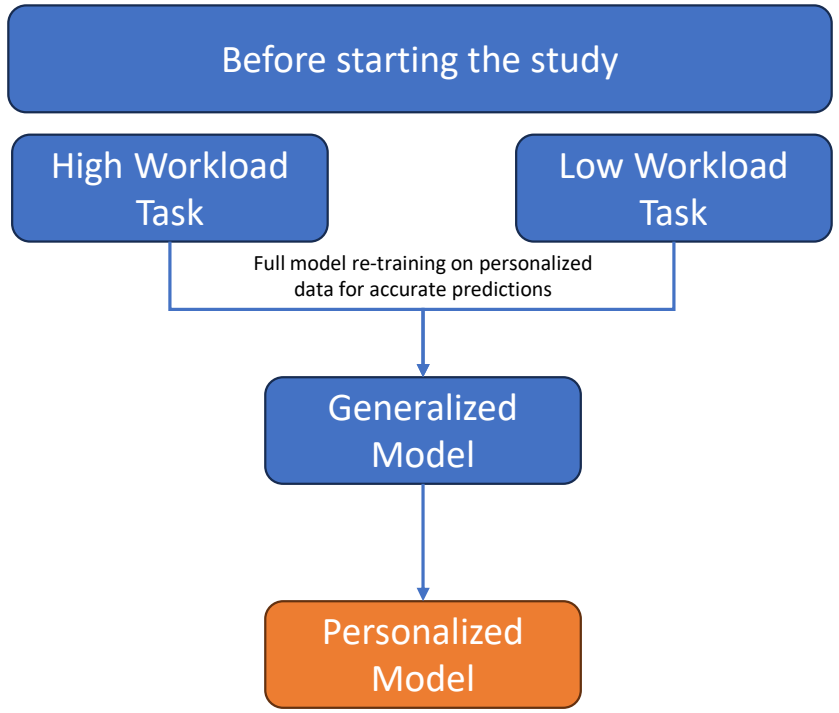
Transfer Learning

Transfer Learning

- To account for variation in sensor data for different participants, the concept of transfer learning is used.
- A pre trained general model is used as a starting point, which has been trained on a large dataset for high/low workload task detection
- New participants perform brief high and low workload simulating tasks. This data is used to retrain the model for minute personalization, which bears better predictions.

Re-Training Dataset (Workload)	Transfer Learning used	Accuracy (%)
High	Yes	91.85
High	No	87.4
Low & High	Yes	77
Low & High	No	61

Selected



Transfer Learning improves the prediction accuracy of High Workload

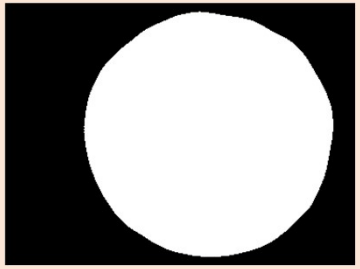
Overlay Design

- **BGR Color Space Calibration**: Utilizes user input to calibrate the target colors in the BGR (Blue, Green, Red) color space for accurate feature detection.
- **Region of Interest (ROI) Processing**: Identifies and isolates a specific region within the video frame for focused analysis and overlay application.
- **Filtering**: Applies a black & white mask based on calibrated BGR values to filter out relevant features from the background.
- **Contour Detection**: Uses Canny edge detection on the mask and contour finding algorithms to identify the shapes of objects within the ROI.
- **Contour Drawing and Overlay Creation**: Draws contours around detected features and adjusts the overlay's intensity based on the task difficulty.
- **Shared Memory for Inter-Process Communication**: Utilizes shared memory to dynamically adjust overlay parameters based on external inputs (workload changes).

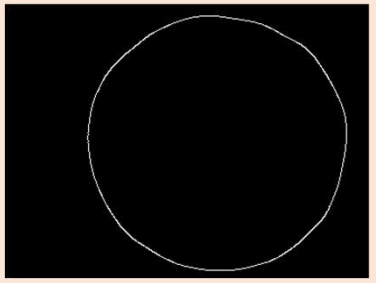
Contour drawing and superimposing on original frame

BGR Calibration
(Dots indicate region of interest)

Isolated ROI



Filtering



Contour Detection

Research Methodology

Phase 1: Generalized Model Calibration

Task 1: Simulates High Workload

Peg transfer Task

2 N Back Test

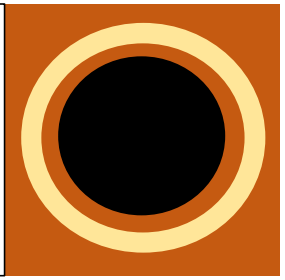
Task 2: Simulates Low Workload

Peg transfer Task

*Each task duration is 3 mins

Phase 2: Testing

Cut the target shape from the gauze by at a distance of at least 0.5 cm and at most 1 cm away (region highlighted). Incisions outside invite a penalty!

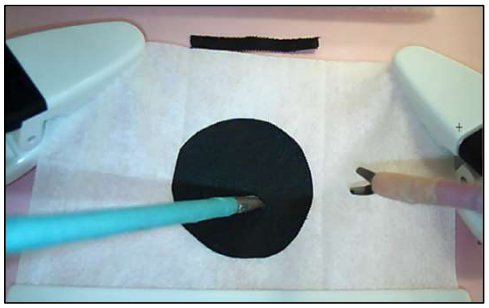


Can NOT cut in this region

Allowable region for cutting

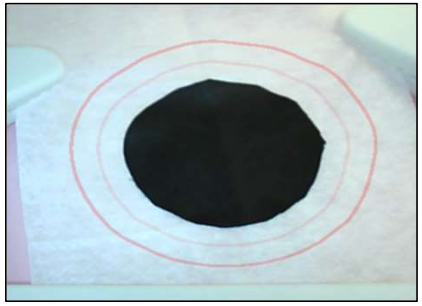
Instructions:

- Refer to the guiding lines in control tasks to adhere to the allowable region
- Use 0.5 cm reference in the frame to judge the distance for cutting from the edge

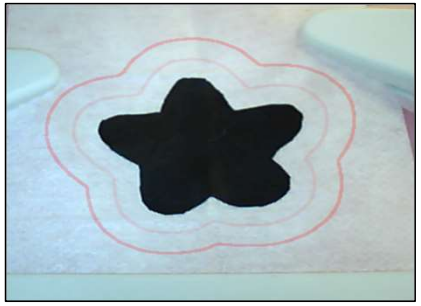


Task 1 (Control Task - Easy)

Task 2 (Control Task Hard)



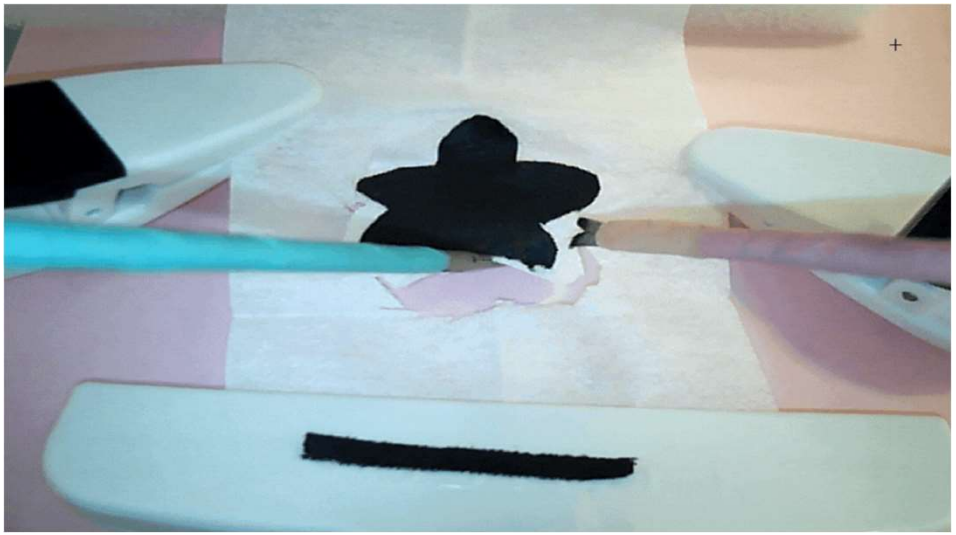
Task 3 (Intervention Task - Easy)

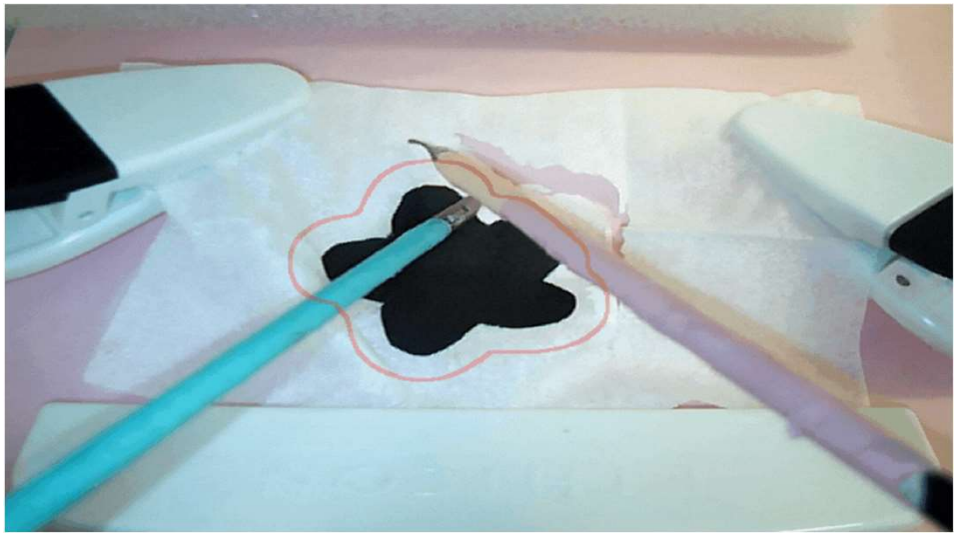


Task 4 (Intervention Task - Hard)

*Each task duration is 10 mins & Task order is randomized for each participant

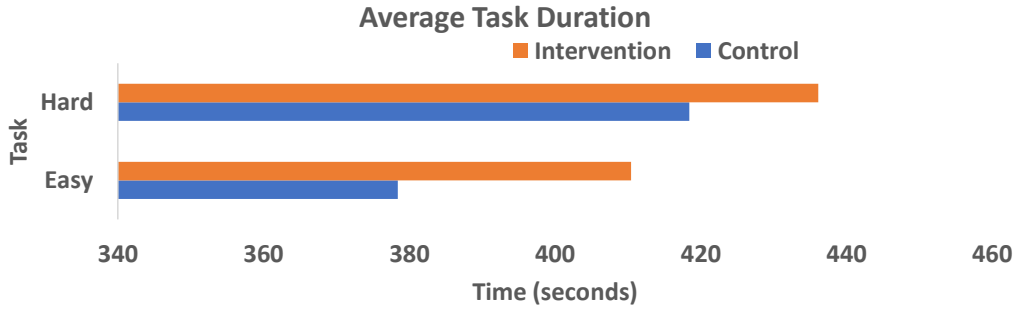
Results



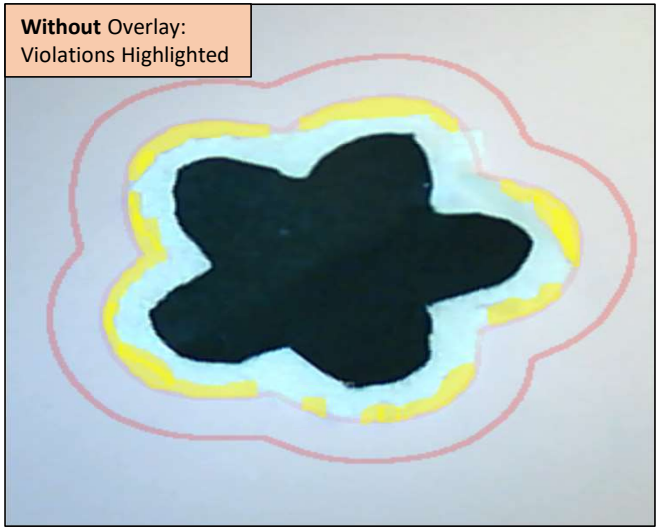


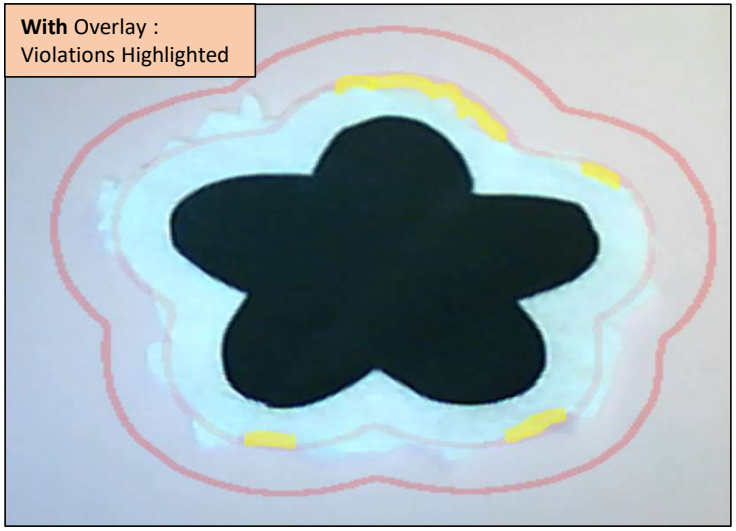
Many violations were observed without overlay

Participants performed better with overlay



Results





Score Calculation:

$$\frac{Perimeter\ of\ the\ inner\ shape\ with\ allowable\ cuts}{Perimeter\ of\ the\ inner\ shape} * 100$$

Average Scores (18 Participants)			Std_Dev
Easy	Control Task - Easy	40.79	26.39
	Intervention Task - Easy	69.17	16.97
Hard	Control Task - Hard	29.08	22.43
	Intervention Task - Hard	65.02	20.35
System Usability Score: 69.3 (SD = 17.2)			