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HARMONY LAB
Human-centered Automation & Robotics For Modern Optimized Built Environments

Physiological Responses in Human-Robot Collaboration for Wooden Frame Assembly: Effects of Robot Positioning, Grasping Orientation, and Speed

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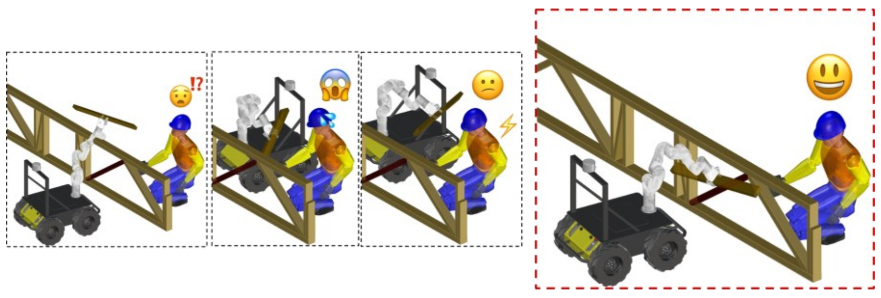
Motivation



This research is motivated by the potential and challenges of Human-Robot Collaboration (HRC) in the construction industry. The construction sector faces significant labor shortages and safety risks, for which collaborative robots (Cobots) present promising solutions. However, extant literature reveals limited research on optimal configurations of collaborative robots in construction tasks to ensure worker comfort, safety, and efficiency. Particularly, real-time monitoring of workers' physiological responses has significant value in optimizing human-robot collaboration but has not been thoroughly explored in construction environments. This study aims to address this knowledge gap by evaluating the impact of various robot configurations on construction workers through physiological measurements within the specific context of HRC implementation in construction-related tasks.

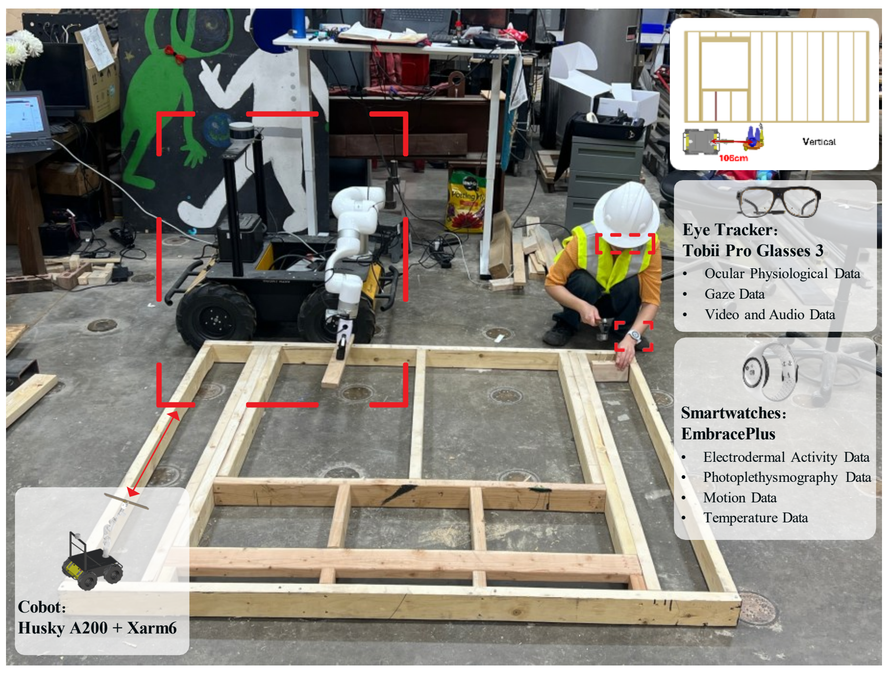
Research Question

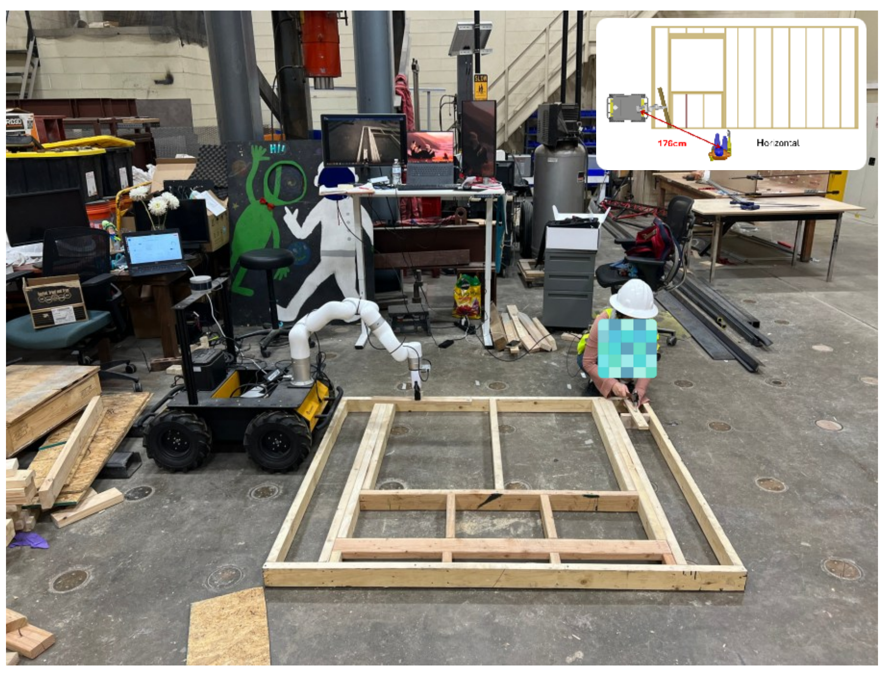
1. How do the initial position of the collaborative robot (same side or opposite side to the worker), grasping orientation of wooden components (vertical to worker, horizontal to worker, or no grasping), and variations in robot operation speed affect workers' physiological responses?
2. How can eye-tracking and physiological data identify optimal human-robot collaboration configurations to reduce workers' cognitive load and improve collaborative efficiency?

Contributions

Evaluated the impact of various robot configuration parameters (position, grasping orientation, and operation speed) on construction workers' physiological responses, revealing that eye-tracking data effectively detects worker distraction behaviors while traditional physiological indicators show minimal variation.

Methodology





Experimental Design:

In HRC tasks, humans and cobots are selected to jointly complete the installation of wooden frames, where their collaboration takes various forms, such as the cobot passing and handing over tools or components needed by humans, or jointly carrying heavy objects. This research's experimental scenario focuses on situations where humans and cobots work independently, examining whether changes in cobot configurations affect human work. Contact-based tasks such as handovers, joint carrying, and guidance are not discussed in this study.

Controlled variable experiments manipulating three key variables:

- Robot initial position (same side/opposite side)
- Grasping orientation (vertical/horizontal/no grasping)
- Operation speed (Two different speed levels)

Measurement Methods:

- Physiological indicators: Electrodermal Activity, Heart rate, Pulse, Temperature
- Eye-tracking metrics: Fixation duration, Pupil size, Gaze point, Eye movement

Analytical Methods:

This research primarily utilizes distance parameters calculated using Euclidean distance. Two key metrics are employed: Gaze_Distance and Robot_Proximity. Gaze_Distance measures the offset distance between the human gaze point and the work point, quantifying visual attention allocation during collaborative tasks and providing insights into the operator's focus during human-robot collaboration. Robot_Proximity calculates the minimum distance between the robot's end-effector and the human, using three distinct geometric models to account for different grasping orientations:

Blank:Represents the end-effector as a single point in space

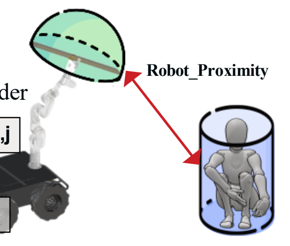
$$\text{distance\_B} = \min(\|\text{ee\_pose} - \text{human\_point\_i}\|_2) \text{ for all } i$$

Horizontal:Represents the end-effector as a horizontal cylinder

$$\text{distance\_H} = \min(\|\text{cylinder\_point\_i} - \text{human\_point\_j}\|_2) \text{ for all } i,j$$

Vertical:Represents the end-effector as a sphere

$$\text{distance\_V} = \min(\|\text{sphere\_point\_i} - \text{human\_point\_j}\|_2) \text{ for all } i,j$$



Experiments Setup

End effector	Speed X1	Speed X2
Vertical	SS_437	SS_442
Horizontal	SS_447	SS_450
Blank	SS_456	SS_459
End effector	Speed X1	Speed X2
Vertical	OS_313	OS_316
Horizontal	OS_325	OS_331
Blank	OS_334	OS_337

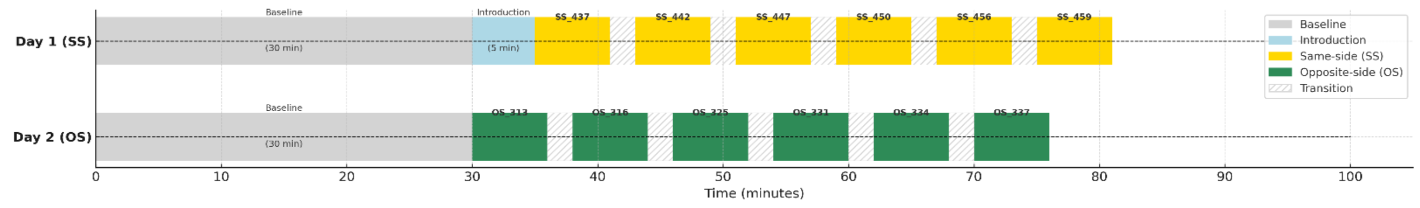
Task Description:

Paricipant requires for connecting and securing pre-positioned wooden components, while the collaborative robot is tasked with placing the remaining wooden components in the correct positions.

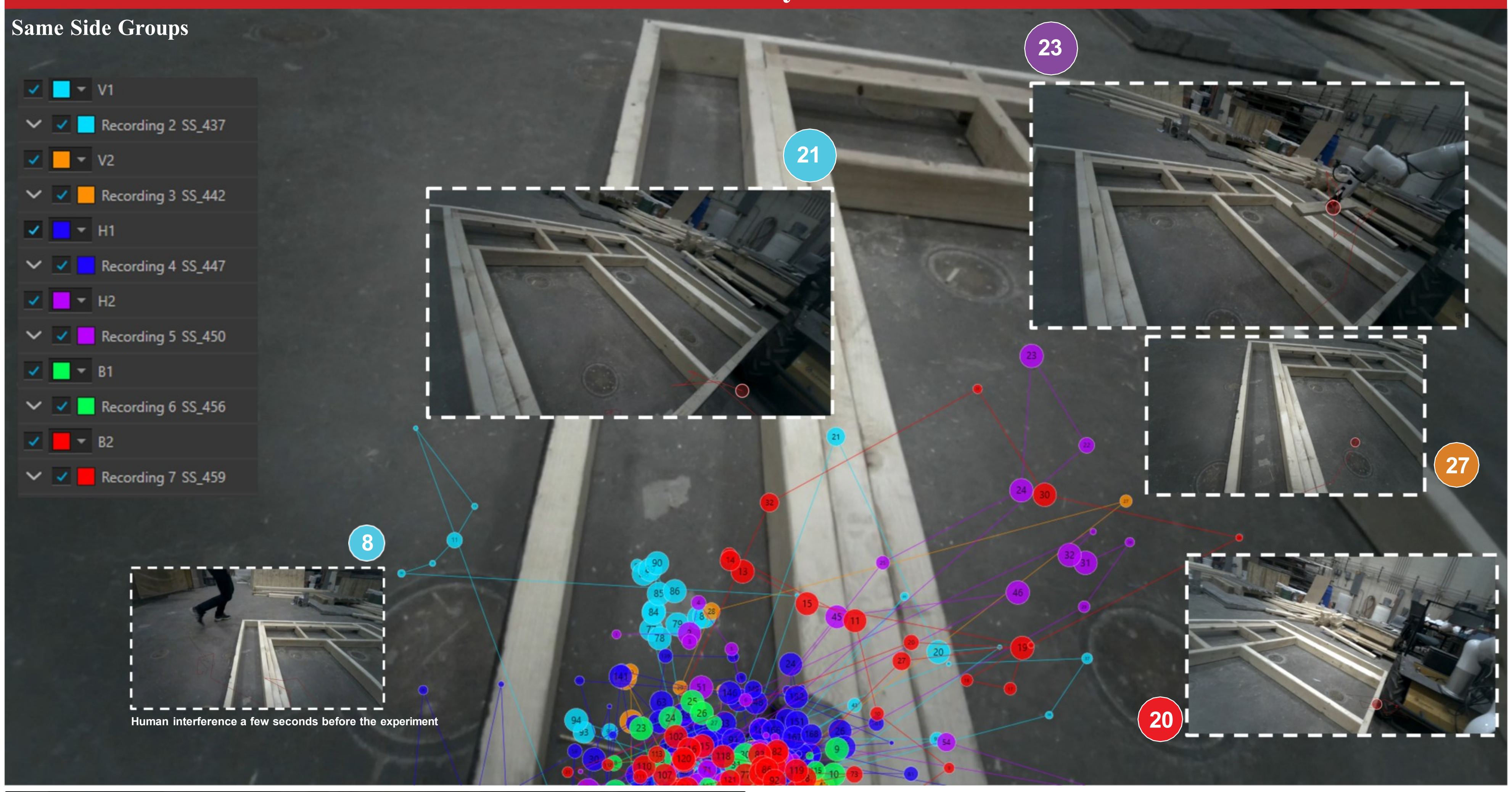
Equipment Configuration:

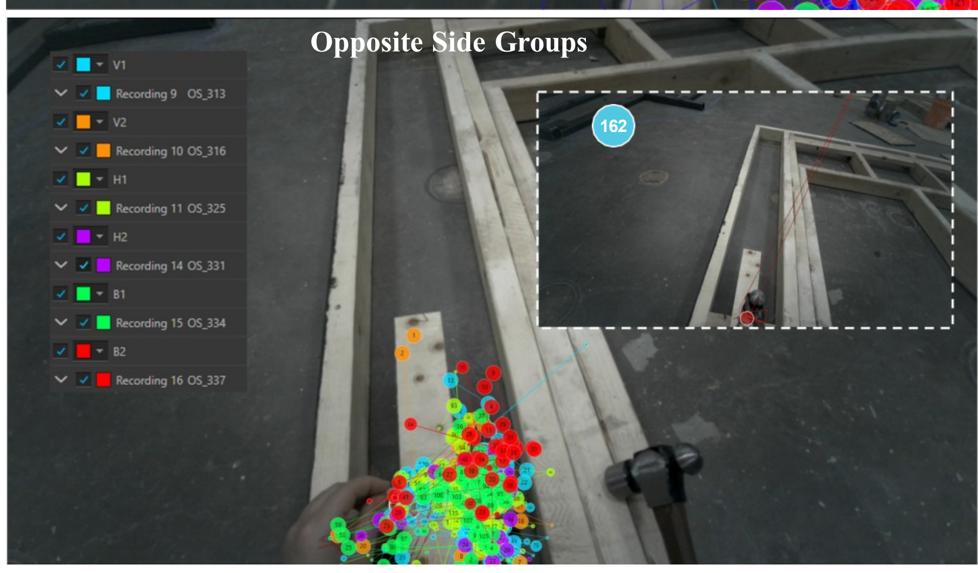
- Collaborative robot (adjustable in position, grasping orientation, and speed)
- Tobii Pro Glasses 3
- Embraceplus smart watches
- Wooden frame components and connection tools

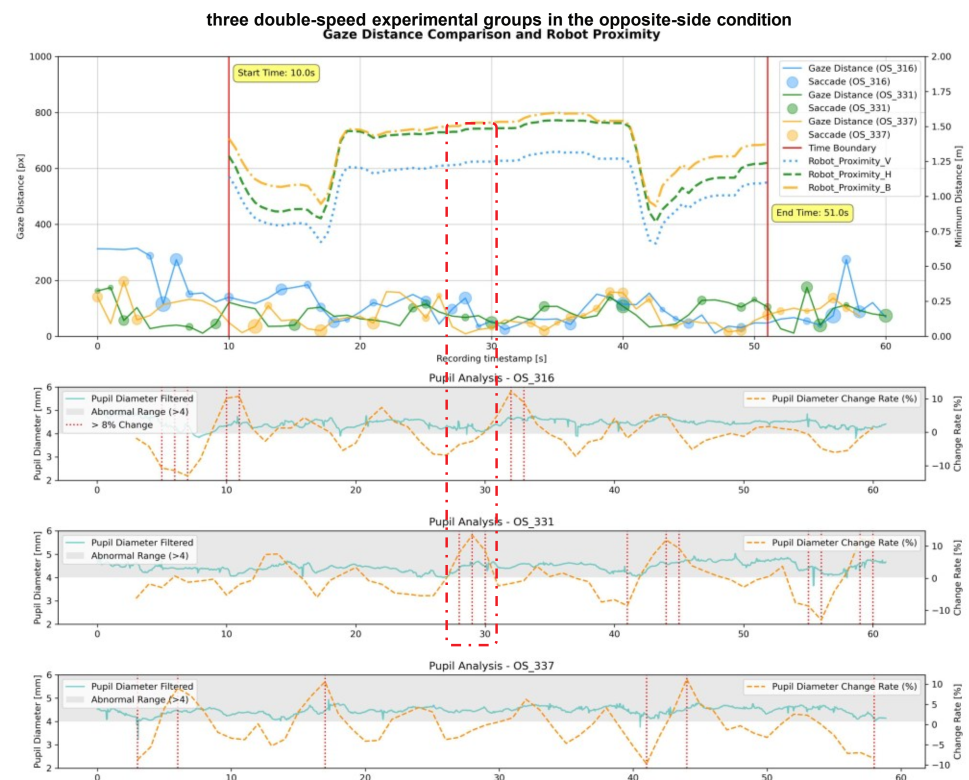
Experiment Procedure Timeline:



Results Analysis







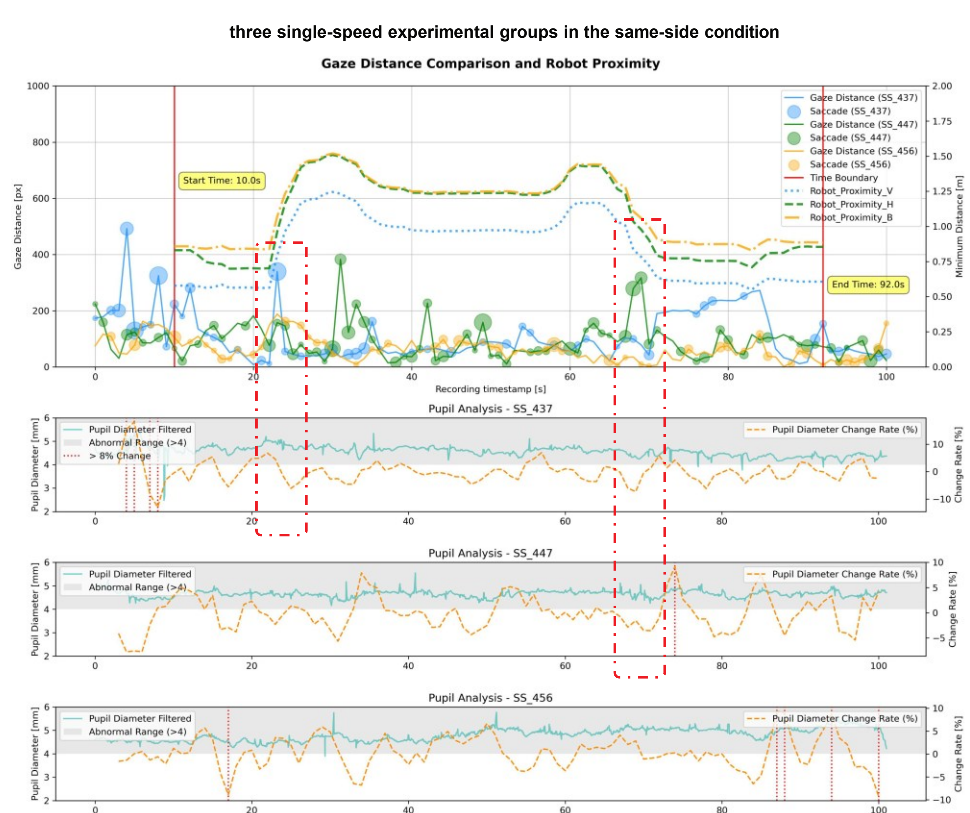
Eye Tracker Data Result

- **Focus Deviations:**
  - **In same-side conditions,** four groups (SS_437, SS_442, SS_450, SS_459) showed gaze shifts away from the work area.
    Three groups focused on the cobot:
    - SS_450: Longest fixation (~4s) on the end effector.
    - SS_437 and SS_442: Shorter fixations (~2s) on the lower wheel.
  - **In opposite-side conditions,** only OS_313 showed similar shifts (~1s), but not towards the cobot.
- **Distraction Analysis:**
  - **Metrics: Robot_Proximity, gaze distance, saccade timing, and pupil dilation.**
  - Examined three single-speed(same-side) and three double-speed (opposite-side) groups.
  - Red dashed boxes marked areas of eye movement fluctuations.
- **Key Findings:**
  - SS_437 and SS_447:

Attention shifted when Robot_Proximity values were minimal, with high-frequency saccades towards the cobot.

- OS_331:

Despite rapid pupil dilation, gaze remained on the work area.



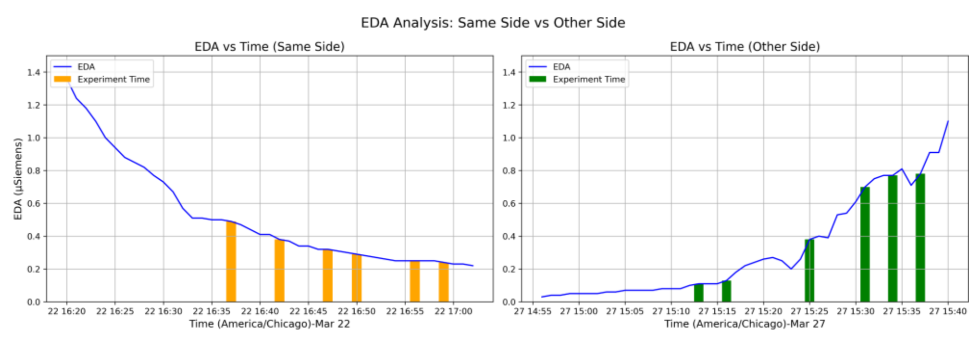
Embrace Physiological Data Result

- **Monitored Metrics (1/min):**

Heart Rate, Pulse, Temperature, Electrodermal Activity (EDA)

- **Observations:**
  - **Heart Rate, Pulse, Temperature:** No significant changes.
  - **EDA:** Different trends in same-side vs. opposite-side; changes within normal parameters.
- **Limitations:**

Insufficient sample size prevents conclusions on robot configuration impact



Conclusions

Key Findings:

- **Eye-Tracking:** Distractions observed when robots operated within personal space.
- **Physiological Data:** Minimal changes except for EDA differences between conditions.
- **Interviews:** Main distractions: physical proximity, operational sounds, curiosity.
- **Limitation:** Sample size insufficient to link physiological changes to robot configurations.

Future Work:

- Integrate contact-based tasks.
- Develop adaptive systems with real-time physiological feedback for dynamic robot adjustments.

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