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Dyadic Motor Behavior During Co-manipulation: A Study on Humans

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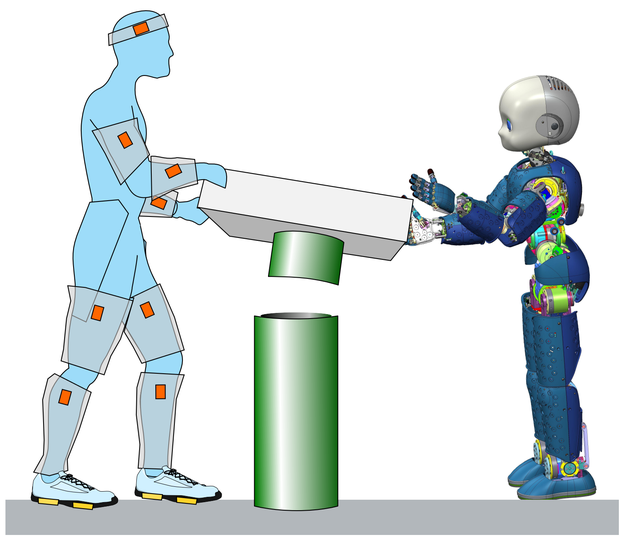
Introduction

Human-Robot Collaboration

- Control a robot to act efficiently with a human during a task that requires **co-manipulation**;
  - Human and robot co-manipulating a shared object
- Good collaboration is not only fast and/or accurate, but it is also legible
- Good collaboration feels natural!



- Planning and execution are a responsibility of all agents
  - The task requires **coordination** and **synchronization**
- Is there a **Leader**, or a **Follower**?
- So we look into natural motor behavior in human-human dyads!

Goal

- Design a task to Investigate how human-human (HH) dyads motor behavior is influenced by different leadership conditions (leader or follower) during an object co-manipulation:
  - **Hypothesis 1**: Arm stiffness is influenced by leadership conditions;
  - **Hypothesis 2**: Object's trajectory is influenced by leadership conditions
  - **Hypothesis 3**: Accuracy of the task execution is influenced by leadership conditions
- Investigate the same task, but with one human executing the task alone.

Methods

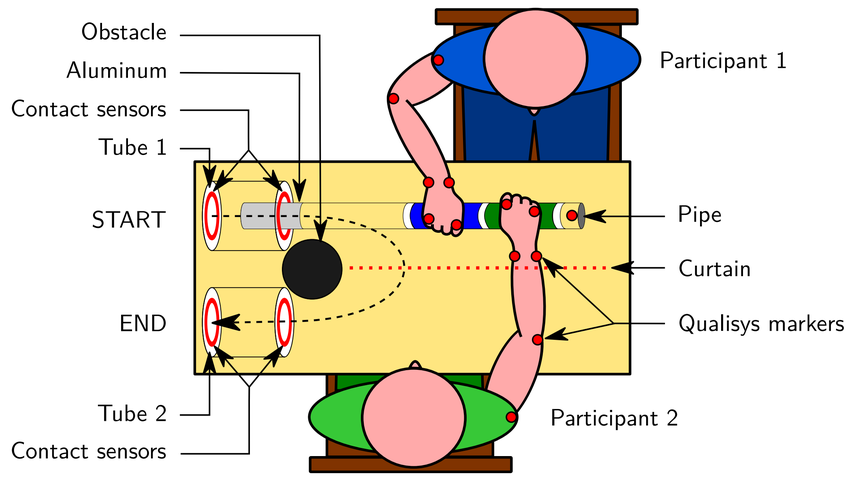
Co-manipulation by a Human Dyad

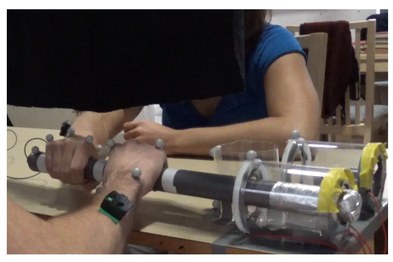
Task

- Collaborative extraction and insertion of a pipe in a tube
- Contact between the pipe and the tube should be avoided

Experiment

- 10 dyads
- 3 randomly assigned behaviors:
  - Participant 1 leader, Participant 2 follower
  - Participant 2 leader, Participant 1 follower
  - No pre-assigned leader behavior
- 5 trials per condition
- Practice trials between conditions





Sensors and Data

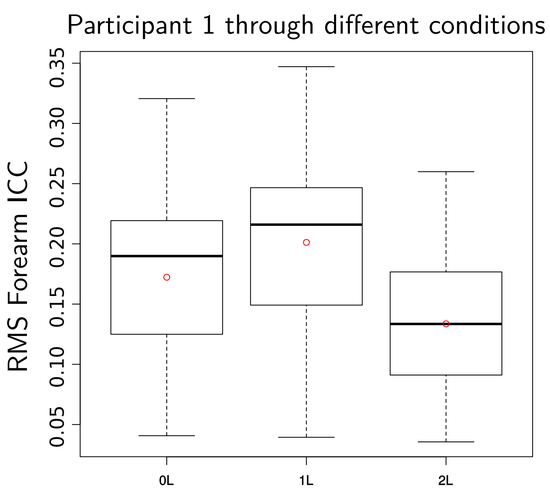
- Qualisys optical motion capture: 6 markers on each participant's right arm, 1 marker on the pipe
  → Arm kinematics
  → Pipe 3D trajectory
- Wireless EMG Delsys Trigno on 3 pairs of antagonistic muscles: forearm, arm, shoulder
  → Muscle activation → Index of Co-Contraction (ICC)
- Contact sensors on each tube (Quantitative measurement of accuracy)

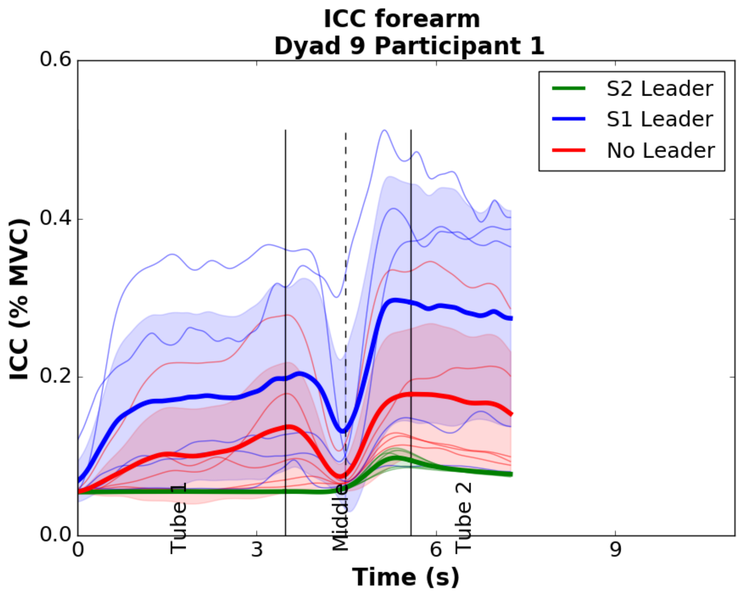
Index of Co-Contraction

- The ICC is an indirect measure of the arm stiffness, in here, calculated from a pair of forearm antagonist muscles EMG signals:

$$\mathrm{ICC} = min(u_{agonist}, u_{antagonist})$$

Participant 1 through different conditions



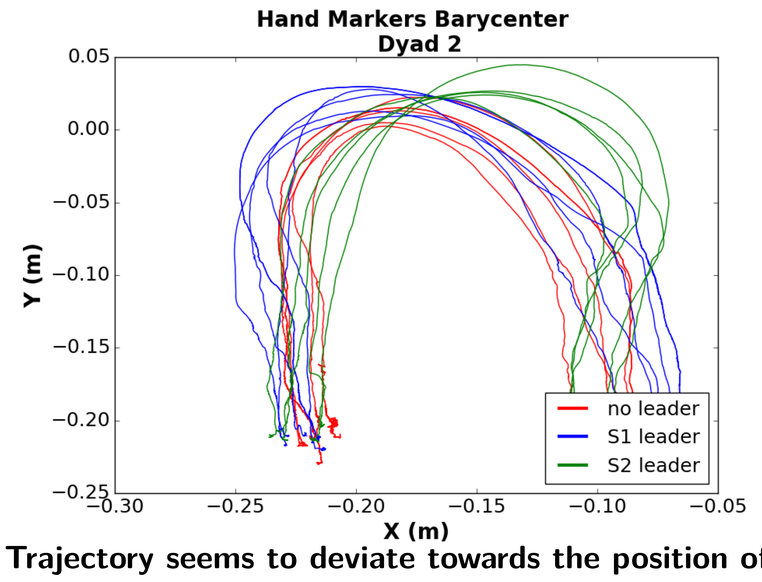


$$ICC_{follower} < ICC_{natural} < ICC_{leader}$$

- **Arm stiffness is modulated within the same participant for different conditions (Hypothesis 1)**
- **Trajectory deviation may be caused by the arm stiffness modulation.**

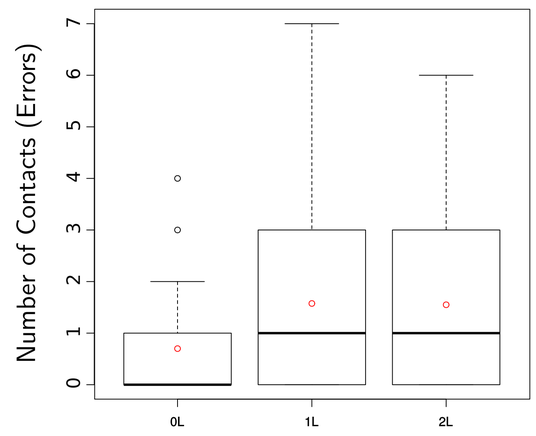
Results

Trajectory in Co-Manipulation



- **Trajectory seems to deviate towards the position of the participant that is the leader (Hypothesis 2)**
- When the pipe is closer to the participant, it is harder for the participant to move the hand in different directions (low arm manipulability values are expected)
- Each participant may have its own desired trajectory, that is chosen according to several criteria, including arm manipulability.

Contact Sensors



- **Less contacts when there is no pre-assigned leader (Hypothesis 3)**
- No clear difference between conditions in which there is a leader

Future Work

- Rigorous analysis of the trajectories
- Define manipulability metrics for a dyad, and apply them to all dyads
- Use the stiffness modulation from the human arm to modulate the stiffness of the robot in a human-robot collaboration

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