Human-Human Co-manipulation

1 Task description

The experiment consists in manipulating an object (pipe) to bring it from a start to an end point (Fig. 1). The experiment starts with the pipe within a tube (Tube 1). First the pipe is taken out of Tube 1, and contact with the front wall of the pipe (wall closest to Participant 1) should be avoided. Then the pipe is moved around an obstacle to the entrance of a second tube (Tube 2). Finally the pipe is inserted inside Tube 2, and contact with the front wall of Tube 2 (wall closest to Participant 2) should be avoided. The motion is always performed from Tube 1 to Tube 2. The return motion is not recorded nor evaluated.

While in free space (after exiting Tube 1 and before entering Tube 2), there is no physical restriction on the tube motion. However participants are told that they must move around the obstacle, and not above.

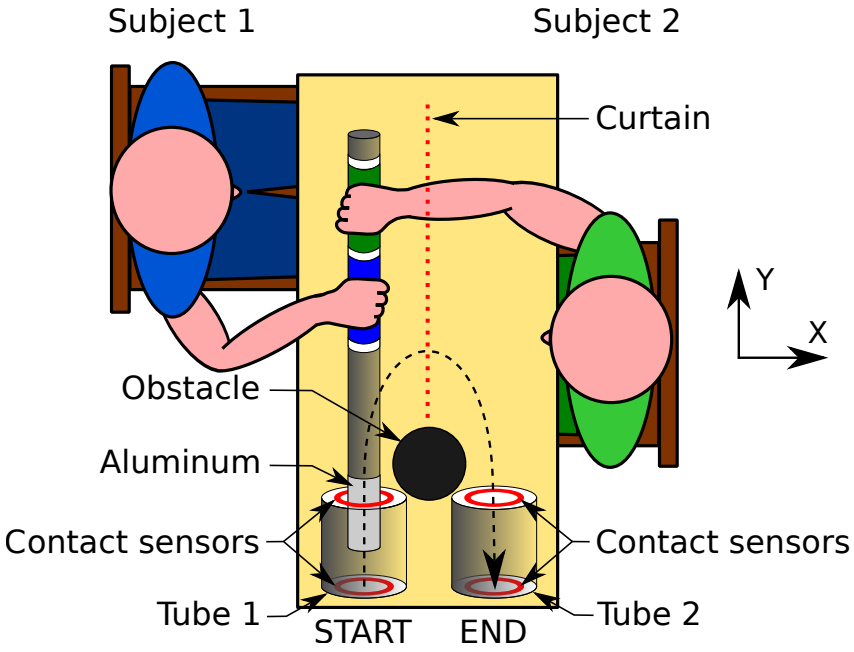

Figure 1: Top down view of the experimental set-up. The black dashed line represents the approximate trajectory of the pipe. The red circles are metallic rings embedded in the front and back walls of both tubes to detect contact with the pipe aluminum end. The red dashed line represents a curtain placed between both participants. The blue and green zones on the pipe represent the two handles positions.

1.1 Duration

The task starts with a contact on the back wall of Tube 1 and ends with a contact on the back wall of Tube 2 (back walls are walls farthest from participants). Participants are instructed to make these contacts to indicate that they start and end the manipulation. Participants do not see any timer during the experiment, but they are told that the whole manipulation (from Start to End) should not last longer that 15 s. If participants take significantly longer, they are told so and the trial is canceled.

1.2 Object

The object that is manipulated is a pipe of diameter 3 cm and length 50 cm (Fig. 2). Each handle is 10 cm wide. The part covered with aluminum foil is 8 cm long, so that it is impossible to detect a contact with the front and back walls of a tube at the same time. The pipe weighs 218 g

Each tube is 10 cm long, with a diameter of 8 cm. The diameter of the holes in the front and back walls of each tube is 4.5 cm. The obstacle is a vertical transparent cylinder of diameter 8 cm. Both tubes are set 13 cm apart (distance between the centers of the tubes).

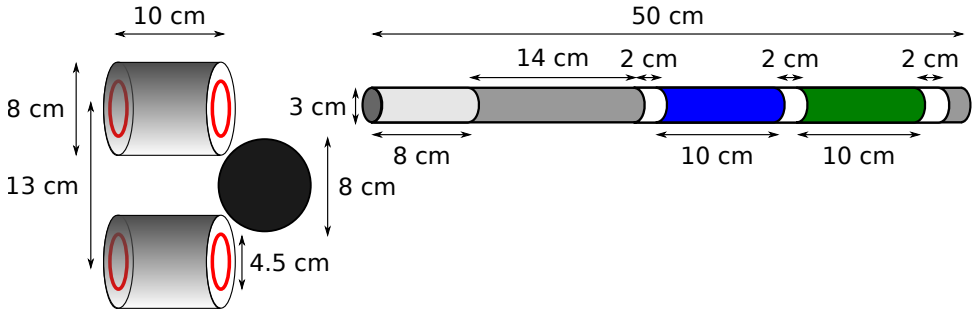

Figure 2: Dimensions of the pipe and tubes.

1.3 Human

Each participant is seated on a chair, with one chair on each side of the table. Before the experiment, participants can adjust the chair position to find a comfortable position. Participants are instructed to avoid moving their back during the task execution (they are not strapped). They hold the pipe with their right hand with a power grasp, placing their hand on one of the designated handles.

A curtain is placed between both participants to prevent visual contact during the task execution. Participants are instructed not to talk at all during the task execution, and not to talk about the experiment between trials.

2 Experimental design

2.1 Dyad experiment

In the *dyad* experiment, two participants manipulate the pipe together. Each participant seats on one side of the table (Participant 1 and Participant 2 in Fig. 1). Two handles are drawn on the pipe: Participant 1 holds the pipe on Handle 1 (blue in Fig. 1), while Participant 2 holds the pipe on Handle 2 (green in Fig. 1). The participants do not switch seat position, *i.e.* one participant is always Participant 1, and the other always Participant 2. Participants perform the task in 3 different conditions:

- *Natural behavior:* Participants are instructed to manipulate the pipe as naturally as possible (marked as *Cond_0L* in the data files);
- *Participant 1 Leader and Participant 2 Follower:* Participants are instructed that Participant 1 must lead the movement, while Participant 2 is only here to support and follow Participant 1 (marked as *Cond_1L* in the data files);
- *Participant 1 Follower and Participant 2 Leader:* Participants are instructed that Participant 2 must lead the movement, while Participant 1 is only here to support and follow Participant 2 (marked as *Cond_2L* in the data files).

The order of the 3 conditions is randomized across dyads to counter-balance any possible effect of learning.

Participants perform 5 trials for each condition, resulting in a total of 15 trials. For each of the 3 conditions, before starting the recording the participants can practice for at least 2 trials. There is an approximate 45 s break between each trial, but the exact duration of the break is not imposed (participants decide when they want to start the next trial).

2.2 Single experiment

In the *single* experiment, the participant manipulates the pipe alone. The participant holds the pipe on the middle of Handle 1 and Handle 2. There are 2 conditions in the *single* experiment:

- *Position 1:* The participant seats in Participant 1's position (marked as *Cond_S1* in the data files);
- *Position 2:* The participant seats in Participant 2's position (marked as *Cond_S2* in the data files).

The order of the 2 conditions is randomized across participants to counter-balance any possible effect of learning.

Participants perform 5 trials for each condition, for a grand total of 10 trials. Trials are separated by an approximate 45 break, and 2 to 3 practice trials are allowed at the beginning of each condition. Note that in the data files, trials are numbered from 1 to 10 (1 to 5 being the first condition and 6 to 10 the second condition).

3 Measurements

3.1 Motion capture

The motion of the participants' right arm is recorded with a Qualisys optical motion capture system. 6 reflective markers are placed on the participant's arm, and their 3D Cartesian positions are tracked. The position of the 6 markers are (Fig. 3):

- 1 on the Acromion (referred to as *Shoulder* in the kinematics data files);
- 1 on the Lateral Epicondyle of the Humerus (referred to as *Elbow* in the kinematics data files);
- 1 on the Ulnar-Styloid Process (referred to as *Hand1* in the kinematics data files);
- 1 on the Head of the 5th Metacarpal (referred to as *Hand2* in the kinematics data files);
- 1 on the Head of the 2nd Metacarpal (referred to as *Hand3* in the kinematics data files);
- 1 on the Radial-Styloid Process (referred to as *Hand4* in the kinematics data files).

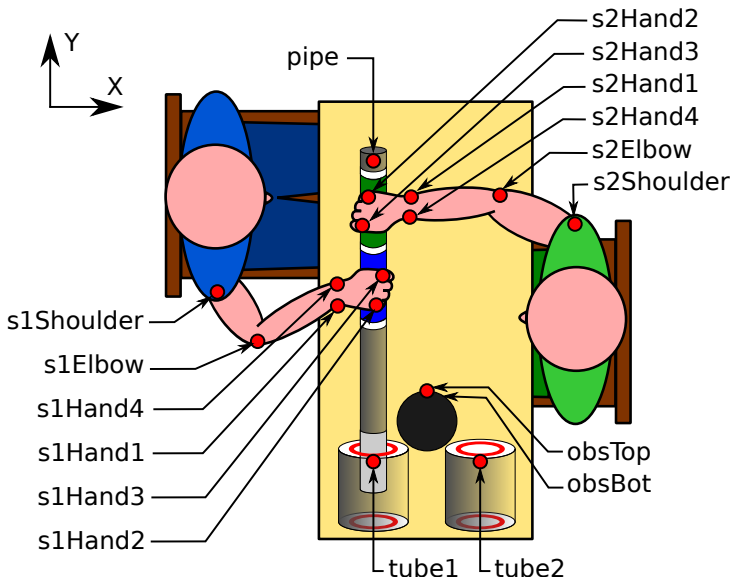

Figure 3: Positions of the Qualisys reflective markers: 6 markers are set on each participant's right arm, and 5 markers are set on the pipe, tubes and obstacle. Note that the *obsBottom* marker set on the obstacle is not visible, because it is vertically aligned with the *obsTop* marker.

In addition, 5 markers are placed on the pipe, tubes and obstacle (Fig. 3):

- 1 at the tip of the pipe which does not go inside the tubes (opposite to where the aluminum foil is). Participants were told to hold the pipe so that this marker was facing up (referred to as *pipe* in the kinematics data files);

- 1 at the top of the front wall of each tube (referred to as *tube1* and *tube2* in the kinematics data files);
- 1 at the top of the obstacle wall, farthest away from both tubes (referred to as *obsTop* in the kinematics data files);
- 1 at the bottom of the obstacle wall, farthest away from both tubes (referred to as *obsBot* in the kinematics data files);

The Qualisys data are recorded at 150 Hz.

3.2 EMG

In the *dyad* experiment, 6 wireless Deslys Trigno EMG sensors are placed on the participant's right arm, on the following muscles:

- Flexor Carpi Ulnaris;
- Extensor Carpi Ulnaris;
- Biceps Brachii;
- Triceps (lateral head);
- Deltoid, Anterior;
- Deltoid, Posterior.

The EMG signal is recorded a 2 kHz. For each participant, the maximum voluntary contraction (MVC) of each muscle is recorded prior to the experiment. Only the EMG signal is recorded during the MVC; the actual force produced is not recorded. The value of the EMG signal during the MVC is used in the post-processing step to normalize the EMG signal recorded during the task execution.

In the *single* experiment, only the 2 muscles in the forearm (Flexor Carpi Ulnaris and Extensor Carpi Ulnaris) were recorded.

3.3 Performance

During the presentation of the task, participants are instructed to avoid contact between the pipe and the front wall of Tube 1 (resp. Tube 2) while exiting (resp. entering) this tube. To detect such contacts, the end of the pipe is wrapped with aluminum foil, and metallic rings are placed inside the holes on the front and back walls of both tubes. A RaspberryPi is used to count the contacts on each ring.

The number of contacts between the pipe and the metallic rings on the front walls of the tubes is used as a performance measure. Only the onset of a contact is detected, so that whatever the duration of a contact, it counts as one contact only as long as it is maintained.

4 Data files

For each experiment EXP (*single* or *dyad*) there are 5 folders containing the data files:

- **EXP-qualisys-data:** Contains the Qualisys .qtm files of all recorded trials. For the dyad experiment, each file is named "Dyad_X_Cond_Y_Trial_Z.qtm" where X is the dyad number, Y one of the 3 conditions described in section 2.1 ("0L" for natural behavior, "1L" for Participant 1 Leader, "2L" for Participant 2 Leader), and Z the number of the trials. For the "single" experiment, the files are named "Single_X_Cond_Y_Trial_Z.csv" where X is the participant number, Y one of the 2 conditions ("S1" when the participant seats as Participant 1, "S2" when the participant seats as Participant 2), and Z the number of the trial. Note that trials are numbered from 1 to 15 so that the order in which the 3 conditions were performed for this specific dyad can easily be retrieved (1 to 5 being the first condition, 6 to 10 the second condition, and 11 to 15 the third condition).

- **EXP-kinematic-data:** Contains the motion capture data of all recorded trials in .csv files. Each file is named "Dyad_X_Cond_Y_Trial_Z_Kinematic.csv" (in the *single* experiment "Dyad" is replaced by "Single"). The motion capture data are the trajectories of the 3D Cartesian position (X, Y, Z with Y parallel to the tubes axis and Z up) of the Qualisys markers set on the participants' right arm and on the pipe, tubes and obstacle. Units are *mm*. When a marker is lost for a duration too long to interpolate reliably, the corresponding X, Y, Z values of the corresponding time frames are empty.

- **EXP-EMG-data:** Contains the EMG signal of each of the EMG sensors placed of each of the participants' right arm (12 sensors in total) in .csv files. Each file is named "Dyad_X_Cond_Y_Trial_Z_EMG.csv" (in the *single* experiment "Dyad" is replaced by "Single"). Units are μV. Each EMG channel is designated by its Delsys number (can be between 1 and 16). The matching between the EMG channels and the participants' muscles is given in the configuration file. Note that the data from the Qualisys and from the EMG are synchronized because they were all recorded using the Qualisys software (recording of Delsys EMG signal is embedded in the Qualisys software).

- **EXP-performance-measure-walltouches:** Contains the pipe/tubes front walls contact signals of all recorded trials. Each file is named "Dyad_X_Cond_Y_Trial_Z_Performance.csv" (in the *single* experiment "Dyad" is replaced by "Single"). The columns *input1*, *input2*, *input3*, *input4* correspond to contacts between the pipe and the following walls of the tubes:

  - *input1:* back wall of Tube 1;
  - *input2:* front wall of Tube 1;
  - *input3:* front wall of Tube 2;
  - *input4:* back wall of Tube 2;

  A 1 indicates that a contact is detected for the corresponding input, at the time indicated in the first column. Each file should contain at least 2 lines of data: one

contact on *input1* to indicate the beginning of the task and one contact with *input4* to indicate the end of the task. However, the start or end signals (*i.e.* these two lines) are missing in a small number of files because the participants did not make contact when starting/finishing the movement. Note that the contact detection is not synchronized with the Qualisys and EMG, so the timing of the contacts cannot be directly compared with the timing of the motion capture and EMG data.

- **EXP-MVC-calibration:** Each dyad contains 2 .csv files with the values of the EMG signal during the Maximum Voluntary Contraction (MVC) measurement. The 2 files correspond to each of the 2 participants in the dyad, and are named "ID_X_Pos_Y_Calibration .csv" where X is the participant ID, Y the position of the participant ("S1" for Participant 1, "S2" for Participant 2). Each file contains a line with first the EMG sensor ID, followed by the value of the signal during the MVC. Units are V. For the *dyad* experiment, the 6 EMG sensors are given in the following order: Flexor carpi ulnaris, Extensor carpi ulnaris, Biceps Brachii, Triceps Lateral Head, Deltoid, Anterior, Deltoid, Posterior. For the *single* experiment, "Pos_Y" disappears in the filename, and there are only 2 EMG sensors in the following order: Flexor carpi ulnaris, Extensor carpi ulnaris. For each muscle, the MVC is the maximum value of the EMG signal obtained during a "burst" force static contraction of 3 s, repeated 3 times with 60 s of rest between each contraction.

In addition, the dataset contains two Excel configuration files "**Configuration_Dyad .xls**" and "**Configuration_Single.xls**". These files contain the date and time at which the experiment was performed for each dyad/single, the dyad/single number, the participant(s) ID (used to anonymize the data), the seat position of each participant (in the *dyad* experiment only), the order in which the different conditions were performed, the matching between the EMG sensors ID and the muscles, lengths of the participants' arm segments, and information relative to physical condition of the participants. The upper arm length is measured from the Acromion to the Lateral Epicondyle. The forearm length is measured from the Lateral Epicondyle to the Ulna Styloid Process. The hand length is measured from the Ulna Styloid Process to the Head of the 5th Metacarpal, while the hand is aligned with the forearm.