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# Collaborative Robots' Perceived Safety CROPS

## Deliverable 1.3: Robot scenarios – observing the robot

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## 1 Introduction

In this document, robot scenarios for the experiment with observations of the robot are described. We first depict the procedure of the experiment that is followed by a description of hardware and software equipment used in the experiment. Further, measured parameters are stated. In the last two chapters, the robot's parameters and sample are discussed in detail.

## 2 Procedure of Experiment 1

All measurements that are a part of Experiment 1 will take place at the Faculty of Electrical Engineering, University of Ljubljana, in the Laboratory of Robotics. Participants will be asked to come to the faculty where they will be accepted by the executive researcher from the Department of Psychology. First, the researcher will take them to the room in front of the laboratory, where she will explain the purpose of the study and its framework. Before starting, the participants will read and sign the informed consent that is necessary for participation in the study. The participants will then fill in demographic questions, personality questionnaire BFI-K and the short Robot Acceptance Scale. This part of the measurements will take approximately 10 minutes.

The participants will then go to the lab with the researcher who will familiarise them with the laboratory setting/environment. The researcher from the Faculty of Electrical Engineering will place a skin conductivity and heart rate sensor on their fingers. The device is painless and does not interfere with the participant's activity.

Participants will be introduced to a robot at a distance (6.5 m from the robot) where we assume that everyone feels safe and they will respond to the experimental questions for the first time (self-reported research questionnaire (RQ) during the experiment). The questions will be presented on a tablet. RQ refers to the research questions administered during each trial; the participants will respond to four questions: the experienced degree of pleasure and arousal, perceived safety of the robot and intention to collaborate with the robot. After responding to the RQ items, the game (driving a car) will appear on the tablet. Participants will start their approach towards the robot and at the same time play the game, i.e. drive the car on the road by tilting the tablet sideways, making sure the car stays as close to the middle of the road as possible. The game represents an additional task (besides moving towards the robot), so the participants will have to divide their attention between the robot and the game. This will serve as a simulation of a real work setting, in which employees are collaborating with robots (or are just carrying out the task in the vicinity of a robot). They will approach the robot until they still feel completely safe and then stop when their perceived safety decreases. After stopping and looking at the robot (the participants will also mark the end of their first approach by pressing the corresponding button on the tablet; this action will also stop the game), they will again respond to the RQ items. The participants will be presented with their answers, given at the starting position of the trial, so they will only have to change the answers where there has been a change since the initial state. The distance from the participant to the robot, measured by the laser sensor at the robot, will be designated as comfort zone 1. Then, if the participant wants and/or feels safe, they will have the opportunity to (a) get closer to the robot, (b) stay where they are, or (c) move further from the robot. The distance at which the participant will stop represents their comfort zone 2. At this point, the experimental questions are again displayed on the tablet with the values they have given at the comfort zone 1, and

again only those ratings are changed where feelings have changed. Comfort zone 1 represents the distance to the robot at which the participant still feels safe in the divided attention condition. In contrast, comfort zone 2 represents the distance between the participant and the robot when the participant can focus his full attention on the robot. Participants are then asked to go back to one of the three starting points: 1 (5.5 m away), 2 (6 m away) or 3 (6.5 m away) and continue with the next trial (the robotic arm starts with its next movement). The starting points are chosen at random so that the participants will have a more challenging time developing response strategies that could introduce a systematic bias into the measurement process (e.g., counting the steps and determining how many steps get them to a specific position). Participants will have to repeat this multiphase approach towards the robot for each of the 24 experimental conditions (i.e., two tools x two robot movement speeds x six types of robot movements). The sequence of experimental conditions will be random for each participant.

Before the experiment, each participant will be given three trial practices to familiarise herself with the procedure. These results will not be recorded. After the three trial practices, the entire process of moving and responding to the RQ items during each trial will take about 45 seconds. The procedure of experiment 1 is shown in the following schema (Figure 1).

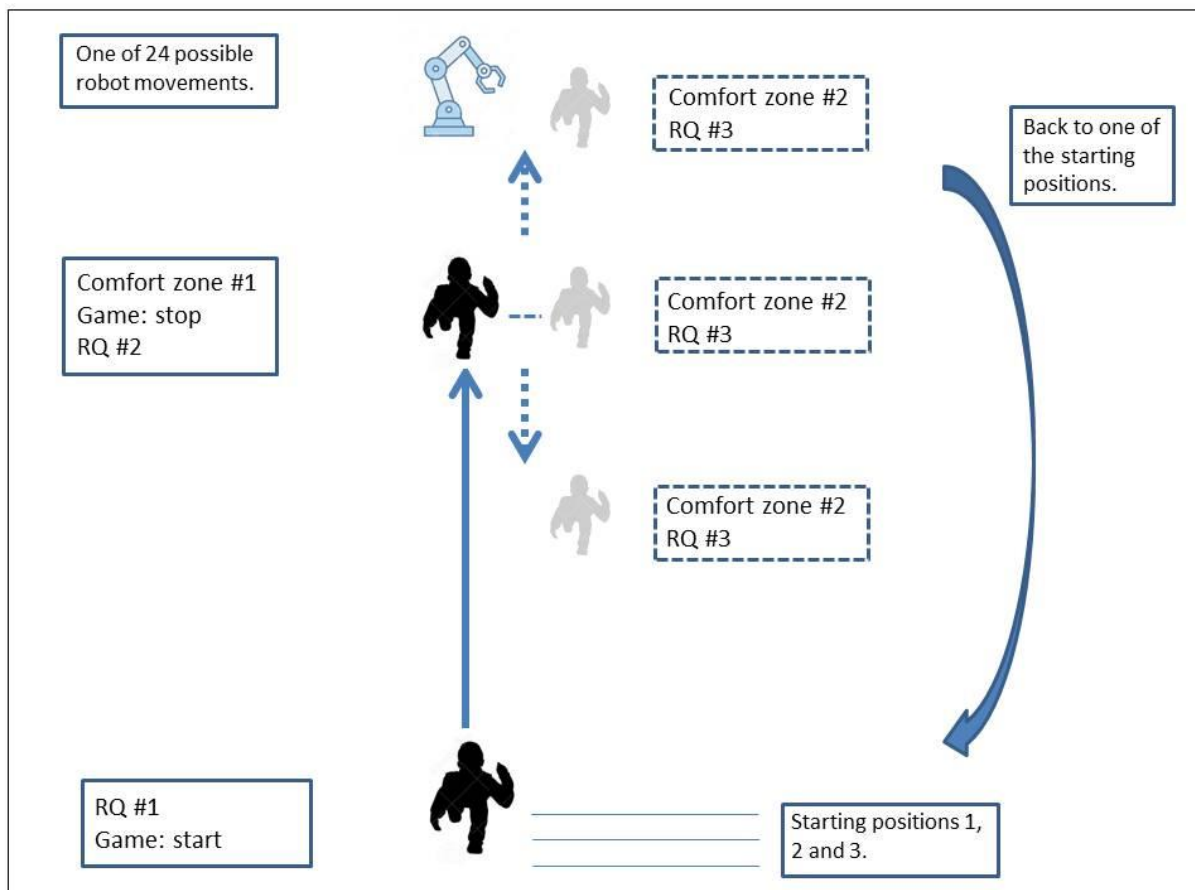


Figure 1: The graphical representation of the procedure of Experiment 1. RQ refers to the research questions administered during each trial; the participants will respond to four questions: the experienced degree of pleasure and arousal, perceived safety of the robot, and intention to collaborate with the robot.

### 3 Experimental setup

The experimental setup comprises of collaborative robot Universal Robots UR5e with Weiss collaborative gripper, safety scanner SICK NanoScan3, inertial measurement unit, BIOPAC sensory system for measuring physiology parameters, and a tablet.

#### 3.1 Universal Robots UR5e

The Universal Robots UR5e is an advanced, lightweight industrial collaborative robot built for medium-duty applications with payloads up to 5 kg. It has six degrees of freedom, repeatability of  $\pm 0.03$  mm, and maximal TCP speed up to 1 m/s. The workspace of the UR5e robot extends up to 850 mm. Universal Robots e-Series robots are equipped with a range of built-in safety functions as well as safety I/O and digital and analogue control signals to connect to other machines and additional protective devices. For programming a hand-held teach pendant with touch screen is used. The robot controller is installed with PolyScope 5.7 firmware. The robot can also be controlled from an external PC connected via TCP/IP Ethernet connection. The robot with the appropriate teach pendant is presented in Figure 2.

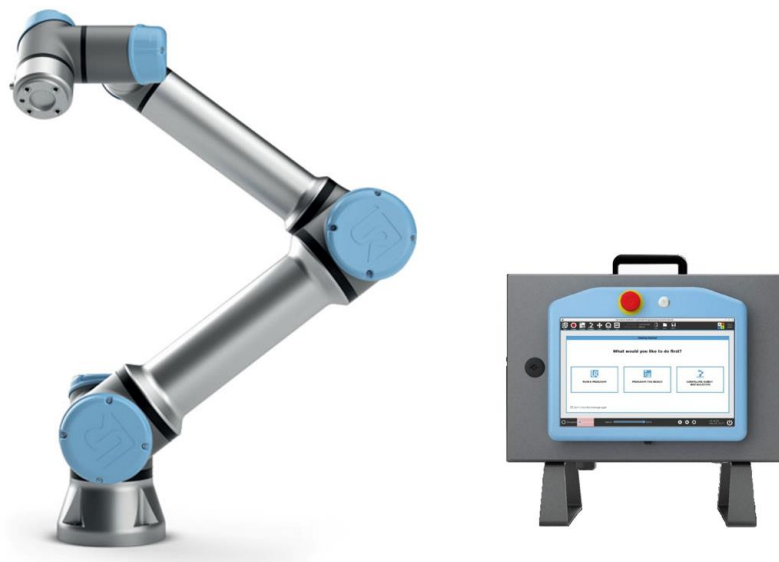


Figure 2: Collaborative robot Universal Robots UR5e with teach pendant.

#### 3.2 Gripper Weiss CRG 30-050

The collaborative gripper Weiss CRG 30-050 is a part of GRIPKIT (see Figure 3), a bundle of the gripper with peripherals for easy integration into the robotic system. Servo-electric gripper module is intended for collaborative applications. It enables gripping force up to 30 N, stroke 50 mm, sensorless force control, integrated part detection and monitoring, gripping force retention, LED ring for status visualisation, and IO-Link interface. Rounded edges and inherent safe gripping force make the GRIPKIT a flexible tool for collaborative robots, which meets recommendations for collaborative robotic of the ISO/TS 15066 standard. GRIPKIT is fully compatible with most models of Universal Robots and integrates seamlessly with the Polyscope programming environment via an easy-to-use URCaps plug-

in. The gripping width and gripping force can be easily specified on the teach pendant of the robot and thus optimally adapted to the gripping workpiece. The URCaps version installed for the gripper module is 2.2.1.



Figure 3: Weiss GRIPKIT: gripper CRG 30-050, mounting accessories, IO-Link connections, and URCaps software.

### 3.2.1 Fingers design

Gripper Weiss CRG 30-050 comes with no fingers attached. To ensure a safe and firm grip, we developed and manufactured specialised fingers. Fingers were designed via positive/negative principle in combination with tools' harnesses. Design is shown in Figure 4. Both designs utilise chamfers to (a) help to ensure repeatable grip, and (b) ensure a safe and firm grip. As the gripper is non backdrivable, the tool will stay safely gripped even in case of power loss to the gripper.

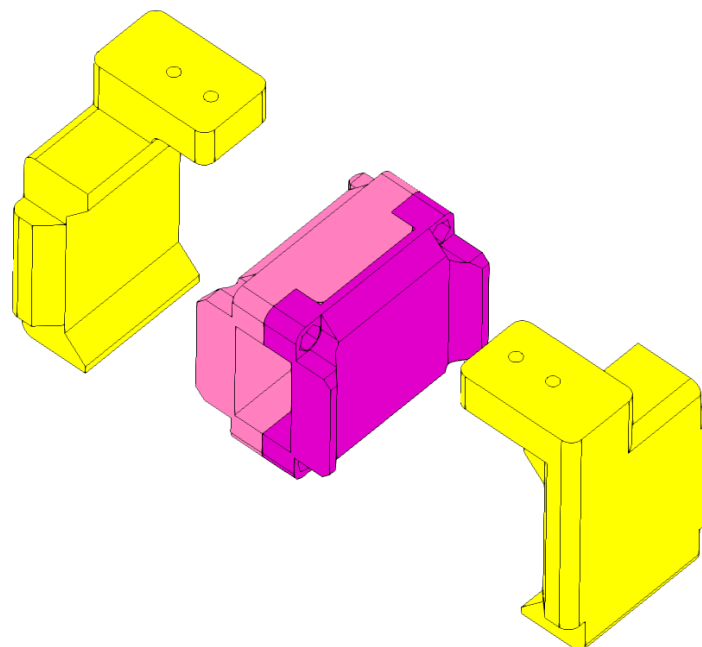
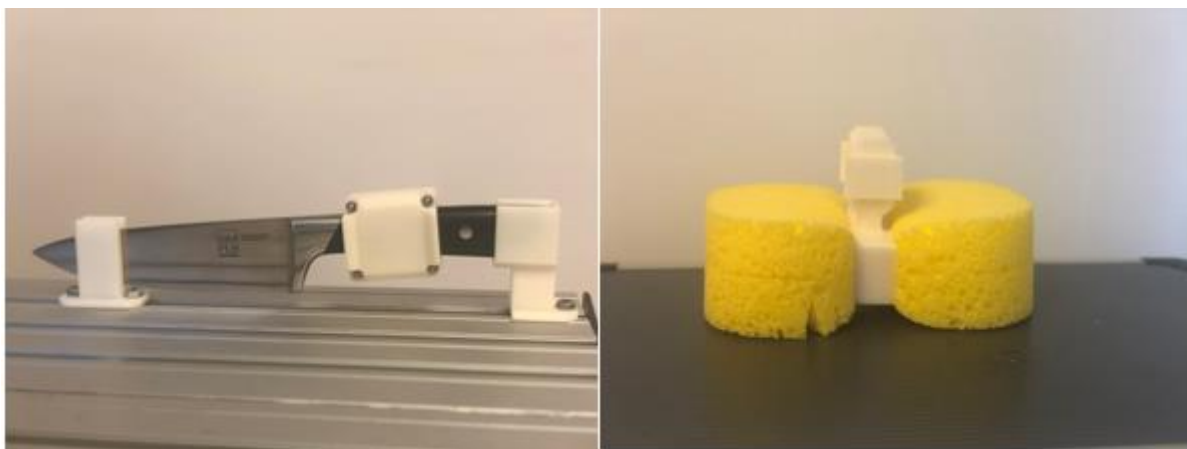


Figure 4: Design of fingers (yellow parts) and knife harness (magenta parts).

### 3.3 Tools

During the experiment, the robot will operate with two different tools: a safe tool and a dangerous tool.

Sponge used for washing a car represents a safe tool. With its soft, flexible, and rounded construction, it represents no real threat to the participant. In case of contact, the impact force spreads through a large area, thus minimising the transfer of energy. Also, the internal constitution of the sponge acts as a damper. As a dangerous tool, a chef knife with a 15 cm blade was selected. The edge of a knife was blunted prior to the experiments to ensure additional safety. Both tools were fitted with 3D printed harnesses to ensure safe grip under all conditions. Tools used in the experiment are shown in Figure 5.



*Figure 5: Dangerous tool and safe tool with harnesses ensuring a safe and firm grip.*

### 3.4 Safety laser scanner SICK NanoScan3

Safety laser scanner NanoScan3 by SICK (Figure 6) delivers high-precision measurement data and is extremely resistant to light, dust, or dirt. The safety laser scanner operates on the principle of time-of-flight measurement. It emits light pulses in regular, very short intervals. If the light strikes an object, it is reflected. The safety laser scanner receives the reflected light and calculates the distance to the object based on the time interval between the moment of transmission and moment of receipt. The sensor has 9 m protected field range, 275° scanning angle and up to 128 freely configurable fields. The response time of the laser is  $\geq 70$  ms.

The sensor can be easily configured via program Safety designer; parameters such as safety fields, range of measurements, data output and other configurations can be changed from the program. The fields can be set as protected or as warning fields. Besides, the sensor can be used as a LIDAR as it continuously streams measured data via UDP connection.



Figure 6: Safety sensor SICK NanoScan3 can be used as a safety device and/or as a LIDAR by streaming measured data via UDP connection.

### 3.5 Inertial measurement unit (IMU)

An inertial measurement unit (IMU) is an electronic device that measures and reports a body's specific movement and orientation of the body, using a combination of accelerometers, gyroscopes, and magnetometers. Main components of the IMU (Figure 7) developed at Laboratory of Robotics, are STM32L476 ARM microcontroller, 9-DOF IMU sensor MPU9250, MS5611-01BA03 barometric pressure sensor, UWB radio module DWM1000, USB 2.0 port, ADP5350 battery charger with 3 LDOs and 240 mAh rechargeable battery.

Devices can operate in single mode or star network mode, where remote devices receive instructions and synchronisation signals from the master device. By default in all modes, sensor data is sampled and sent every 10 ms. Master receives data from remote IMU devices and proceeds data for further processing over the USB port. Remote devices send their own address, battery level, 16-bit counter and 16-bit 3D IMU data (accelerometer, gyroscope, and magnetometer) to the master device. With a fully charged battery, the remote device can operate around 6 hours in network mode.

In the experiment, the combination of one master IMU (receiver) and one remote IMU will be used. The IMU will be donned onto the participant's forehead, thus measuring any head movement (voluntary moves and reflexes).

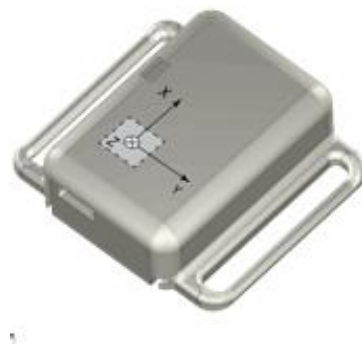


Figure 7: 9DOF wireless inertial measurement unit developed at the Laboratory of Robotics, ULFE.



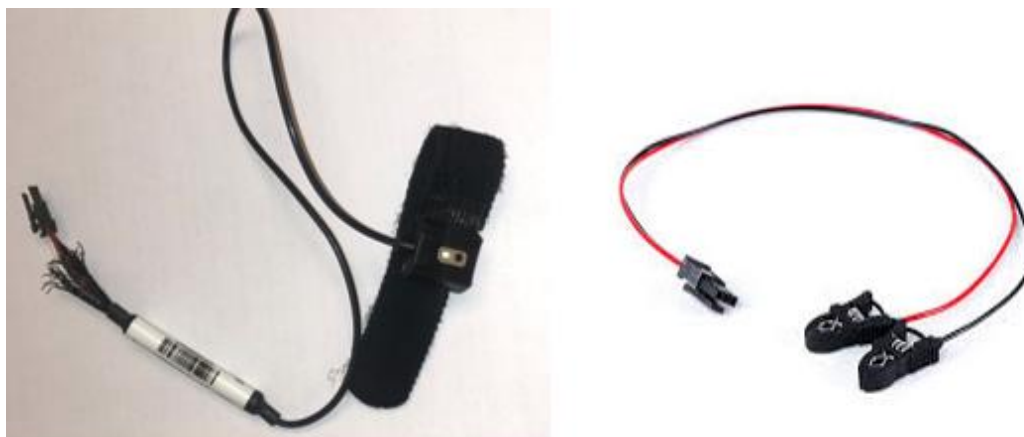
### 3.6 BIOPAC sensory system

The BIOPAC sensory system is used to measure the participants' physiological arousal. The system is comprised of two sensors: PPG sensor (Figure 8 left) and EDA sensors (Figure 8 right), transmitter, and logger.

A photoplethysmogram (PPG) is an optically obtained plethysmogram that can be used to detect blood volume changes in the microvascular bed of tissue. The change in volume caused by the pressure pulse is detected by illuminating the skin with the light from a light-emitting diode (LED) and then measuring the amount of light either transmitted or reflected to a photodiode. Since light is more strongly absorbed by blood than the surrounding tissues, the changes in blood flow can be detected by PPG sensors as changes in the intensity of light.

Electrodermal activity (EDA) is an electrical property of the human skin dependent on changes of the sympathetic part of the person's autonomic nervous system. EDA of a person changes as a result of changes in a person's psychological state. Conversely, if a participant is neutral, EDA will generally be low. Measuring EDA involves measuring skin conductance. Measuring is done by placing two electrodes on the participants' fingers, and a low constant voltage applied (not felt by the participant). Then the current flowing of the applied voltage is measured and converted to conductance by Ohm's law. Skin conductance is measured in units of microsiemens, with normal human EDA ranging from 1 to 20 microsiemens.

The placement of the sensors on the participant's fingers is shown in Figure 9. Captured data from both sensors are transmitted through the transmitter to the logger and saved as LOG data that is post-processed with the AcqKnowledge Research BIOPAC software.



*Figure 8: BIOPAC sensory system: PPG sensor for assessing heart rate (left), and EDA sensors for assessing skin conductance (right).*



Figure 9: Placement of the BIOPAC sensors on the participant's fingers.

### 3.7 Tablet Samsung Galaxy Tab 6 Lite

As a user interface device, a 10.4" tablet Samsung Galaxy Tab 6 Lite will be used. Participants will use it for answering the questionnaires and also for playing the game mimicking the attention needed for workers to finish their task.

### 3.8 Software

#### 3.8.1 Factory task simulation

To simulate the attention needed for workers to finish their tasks in the presence of robots, a simple car driving game was developed in the Unity environment. The game has to be challenging enough to require some attention while playing. The game's design includes steering a car along the curved road (Figure 10). The game is intuitive to play but still requires substantial attention from the player while playing.

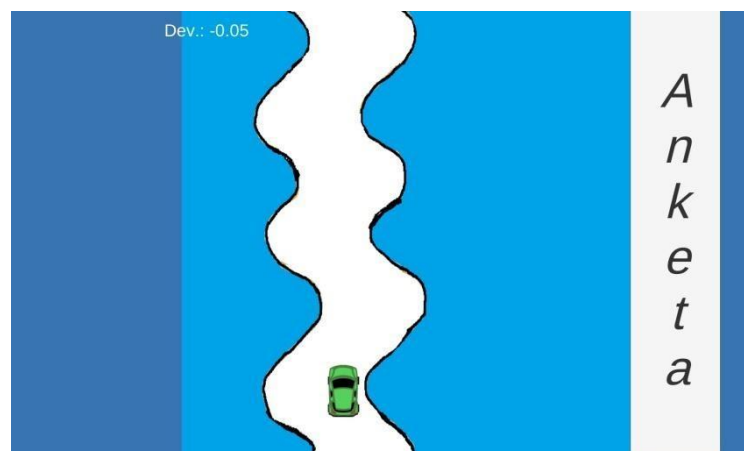


Figure 10: Participants will be dividing their attention between the driving task and a moving robot.

The road used in the game is pre-drawn in the length of 2 m. When the car comes to the end of the road, a new road is generated. A new road is randomly rotated around X or Y-axis, preventing the repetition of curves, and then stitched to the previous road. In this way, an infinite road is obtained.

The car has a pre-set constant forward speed. For steering a tilting action is used: by tilting the tablet left/right, the car will move left/right. During the game, the deviation of the car from the centre of the road is calculated. Empty objects are set along the road; when the car collides with them, a collision point is obtained. The deviation is defined as the distance between the road centre and collision point.

The game is connected via an UDP connection with the Matlab app used by the researcher to control the experiment. The game can be started from Matlab. In the other direction, the data about deviation are sent and saved in Matlab.

In addition to the game for divided attention, the tablet is also used as an input device for the participants. RQ and instructions are also integrated into the game. The selection of the active scene is made via Matlab. The answers from the questionnaires are saved in a text file, and after the end of the measurements, the text file is sent via email to the researcher.

### 3.8.2 Main control

For control of the experiment, a Matlab GUI based app was created as presented in Figure 11. The app includes *Start* and *Stop* buttons, a button for logging events *PersonMove*, and selector for different combinations of robot parameters used in the study.

The app is connected with the robot via TCP/IP communication while with Unity application on tablet communicates via UDP connection.

With the press of a button *Start*, a combination ID from the selected combination list is sent to the robot and to Unity, where the proper experimental combination is started. Also, logging data from all sensors is triggered.

When the button *Stop* is pressed, the command to stop the movement, leave the tool, and go back to the home position is sent to the robot. Pressing the stop button also disables the possibility to move through different scenes of the Unity application.

Button *PersonMove* is used for logging the specific events of person movements, such as participant started to move towards the robot, participant stopped at the comfort zone 1, and participant stopped at comfort zone 2.

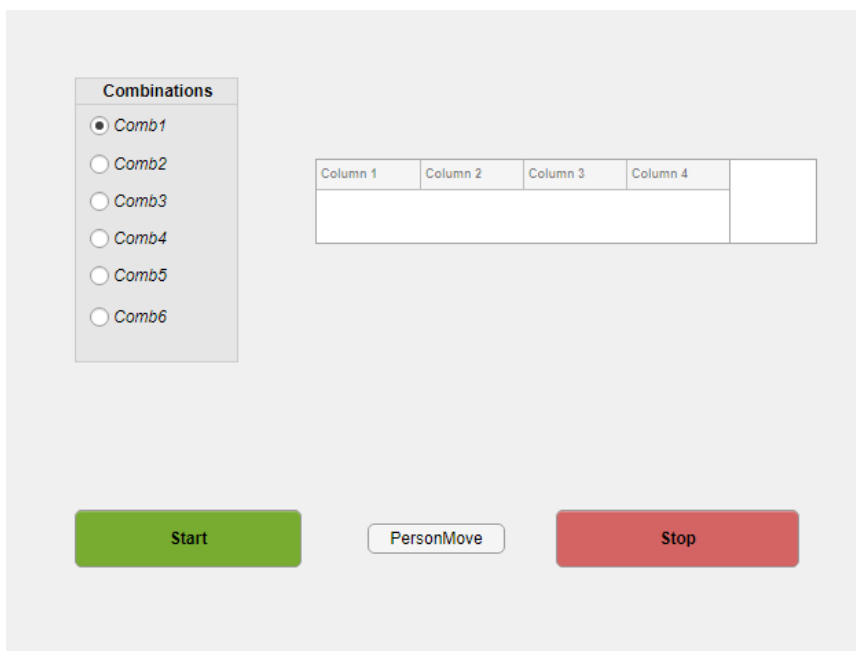


Figure 11: Main experiment control via Matlab GUI app.

### 3.9 Experimental setup

The experimental setup is presented in Figure 12 and Figure 13.

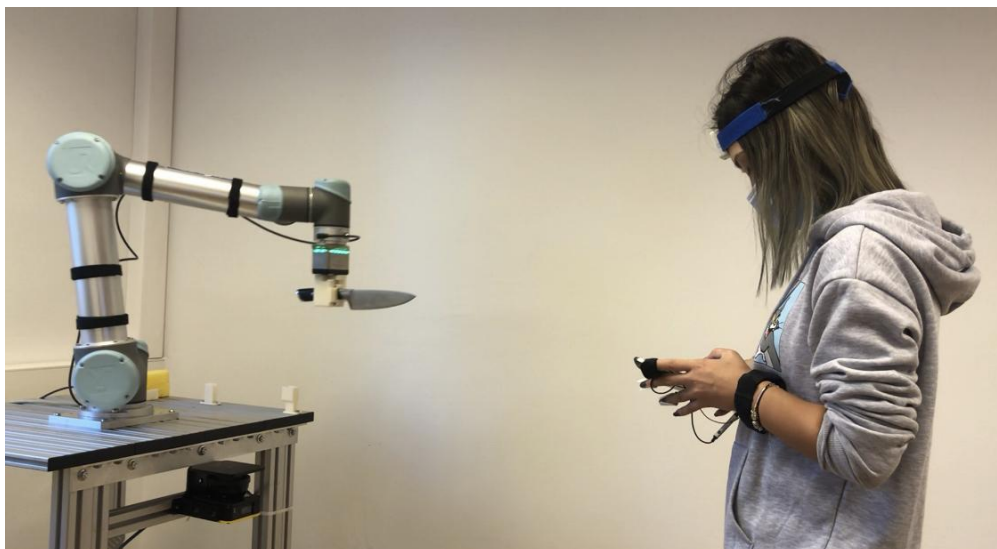


Figure 12: Participant during the experiment.



*Figure 13: Experimental setup: two starting positions and the robotic cell.*

## 4 Measured parameters

### 4.1 Participant's event log

In the Matlab app there is a button implemented for the leading researcher of the experiment to log three important events: (a) when the participant starts moving toward the robot, (b) when she/he reaches the comfort zone 1, and (c) when she/he reaches the comfort zone 2. These logs enable easier post-processing of other data. The example of the log is shown in Figure 14.

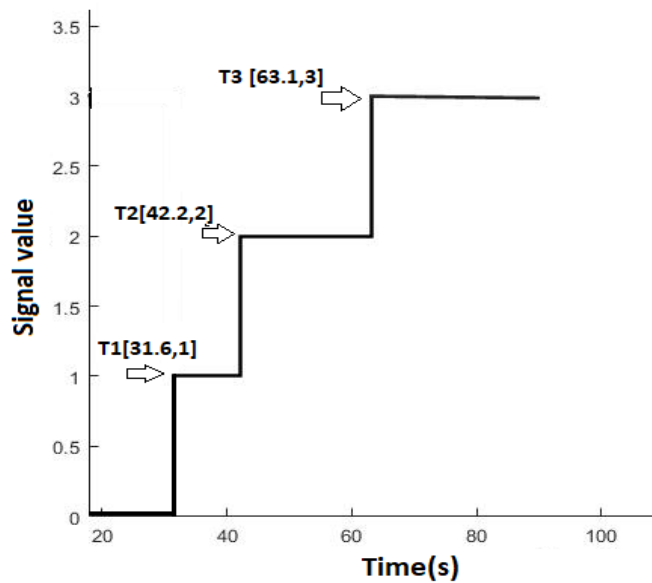


Figure 14: Event log: value 1 - participant starts moving; value 2 - participant stops at comfort zone 1; value 3 - participant stops at comfort zone 2.

## 4.2 Distance from the robot

The data from SICK NanoScan3 are obtained throughout the whole experiment. For every movement, we have logged three events: first is the starting position, then the comfort zone 1, and comfort zone 2. The starting position for every combination of parameters is picked randomly between three starting positions with the Unity application. First starting position is set 5.5 m from the robot, the second is 6 m, and the third 6.5 m. The distances were selected via the assumption that everyone feels safe with so much distance between him/her and the robot.

From data collected during the experiment, two distances are assessed by comparing event log times with distance measurements. Example of the measurement is shown in the three graphs in Figure 15, where the distance is noted with  $R$ . The distances are obtained for each experimental combination. The results shown are distances from the sensor to the participant; an additional 0.45 m should be added to get the distance from the participant to the robot base.

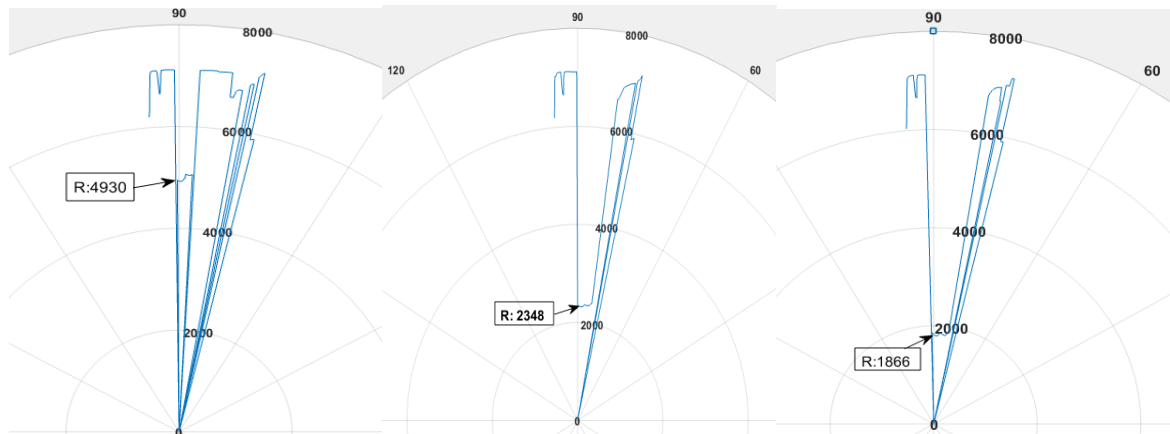


Figure 15: Data from the laser sensor are shown in polar coordinates. Radius  $R$  represents the distance to the participant. Left: starting position; middle: comfort zone 1; right: comfort zone 2.

### 4.3 Game deviation

While the participant is playing the game, the deviation is calculated as presented in Chapter 3.8.1. The average absolute deviation is obtained from the data. This parameter is associated with the amount of attention put on the game; the higher the deviation the less attention was put on the game. The example graph of the obtained deviation is presented in Figure 16.

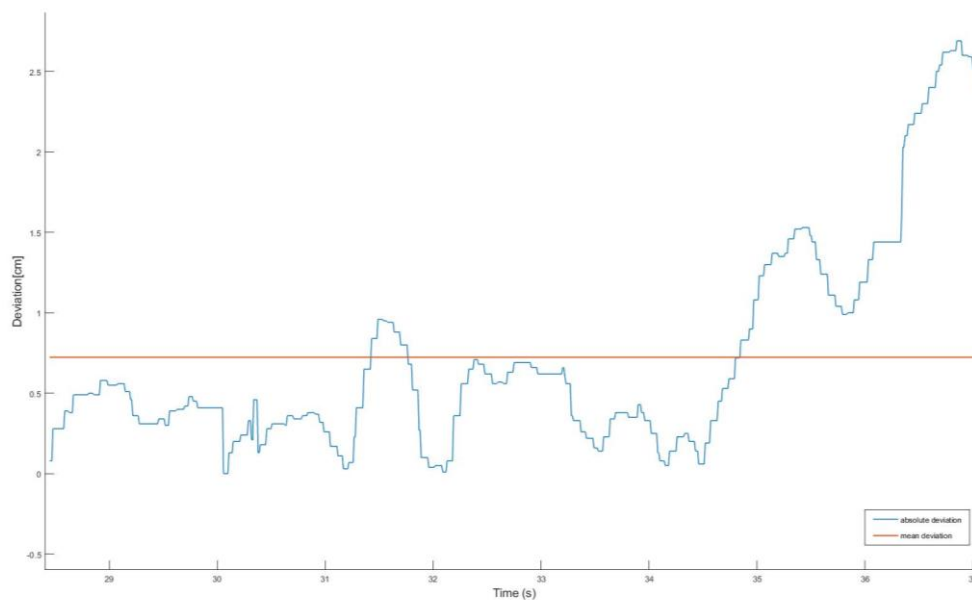


Figure 16: Game deviation over time. The yellow line presents the average absolute deviation.

## 4.4 Inertial data

The inertial data are the most relevant when the participant is moving towards the robot while playing the game. The analysis of accelerometer data in X and Z direction and gyroscope data in the Y direction of the IMU's local coordinate system indicates up and down head movements. Example data are shown in Figure 17. The number of head movements can be directly connected to the number of times the participant looked in the direction of the robot, thus losing focus towards the game/task.

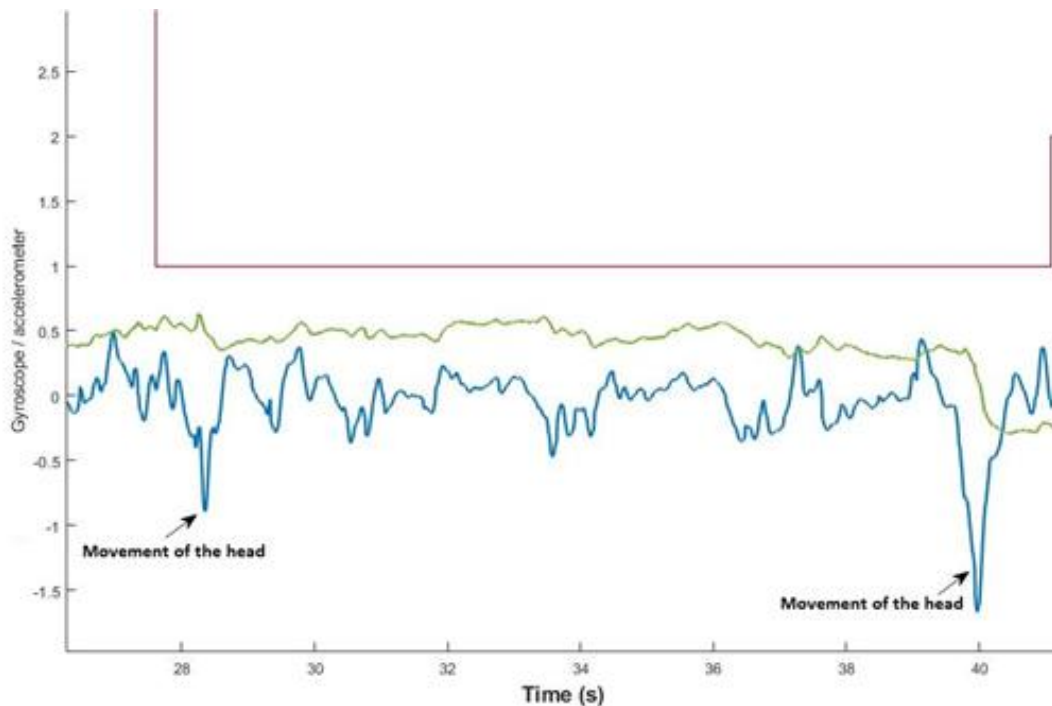


Figure 17: Accelerometer (blue line) and gyroscope (green line) data obtained by the IMU. The red line represents the participant's event log.

## 4.5 Physiology data

Objective measurements of participant physiological arousal are obtained by the BIOPAC system. Firstly, data is visually inspected for any influential parameters that can be identified. Then the mean values of EDA and PPG signals during baseline are calculated and compared to mean values of EDA and PPG signals during each event, thus giving us a relative change of signals. Example measurement is shown in Figure 18. The analysis will show any correlations between the participant's arousal in the vicinity of the robot that is moving with different tools, velocities, and kinematics.

The BIOPACK sensory system does not have any external synchronisation port. The synchronisation is done by the system obtaining computer clock from the PC and then synchronised by time stamps.



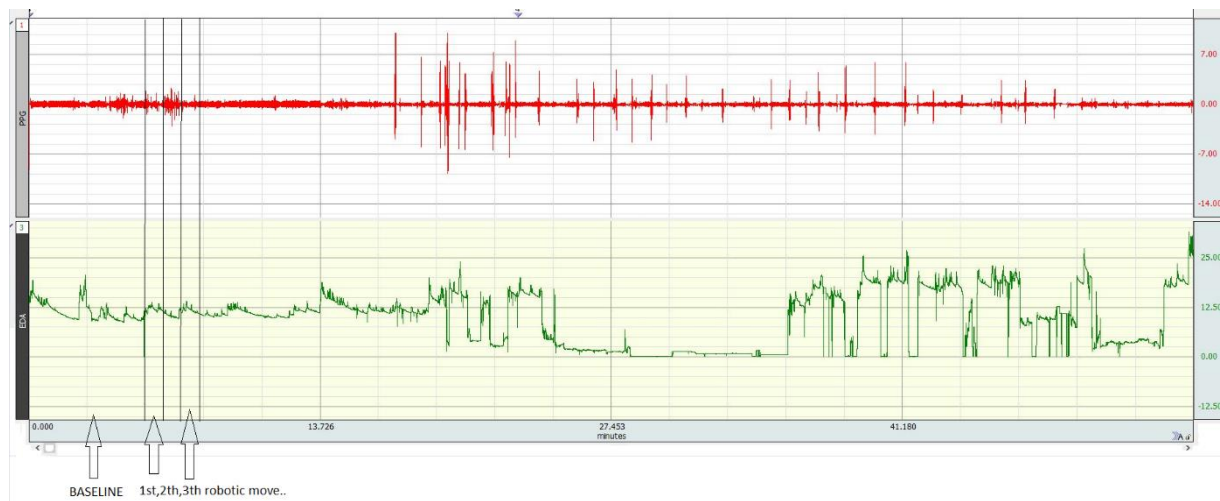


Figure 18: An example measurement of heart rate (red line) and skin conductance (green line).

## 5 Safety

Although the robot UR5e is a collaborative robot, hence should be safe, we implemented two additional levels of safety.

### 5.1 Fail-safe gripper design

For tool handling, we used collaborative gripper kit GRIPKIT from Weiss. We developed custom fingers, and appropriate harnesses for tools used that enable repeatable grip with self-aligning function. Also, by using tapered edges around fingers and harnesses, we ensured tight and secured contact between the used tool and the gripper. The solution is presented in details in Chapter 3.2.

### 5.2 Safety sensor SICK NanoScan3

Besides measurement function, SICK NanoScan3 is also used as a safety sensor. Two safety fields were defined: a protected field and warning field, both presented in Figure 19. Safety fields trigger sensor's digital outputs which are connected through digital input to the robot controller. Warning field is in the area from 0.9 m to 1 m away from the base of the robot while the protected field includes all the area that is below 0.9 m from the base of the robot.

When a person enters a warning field, a reduced mode is triggered by the robotic controller. The robot arm decelerates to satisfy the set Reduced mode limits (system set to *Most Restricted*). The safety system guarantees that the robot is within reduced mode limits less than 0.5 s after the input is triggered. When a person steps out of the warning field, the robot controller changes from reduced to normal mode and continues with the program.

When a person enters the protected field, a safeguard stop is triggered and remains active until it is reset. While in the safeguard stop state, the robot arm will not move. The reset can be triggered only

when the signal of the sensor is high, e.g., when a person is no longer in the protected field. After reset the robot continues from the point where it was stopped.

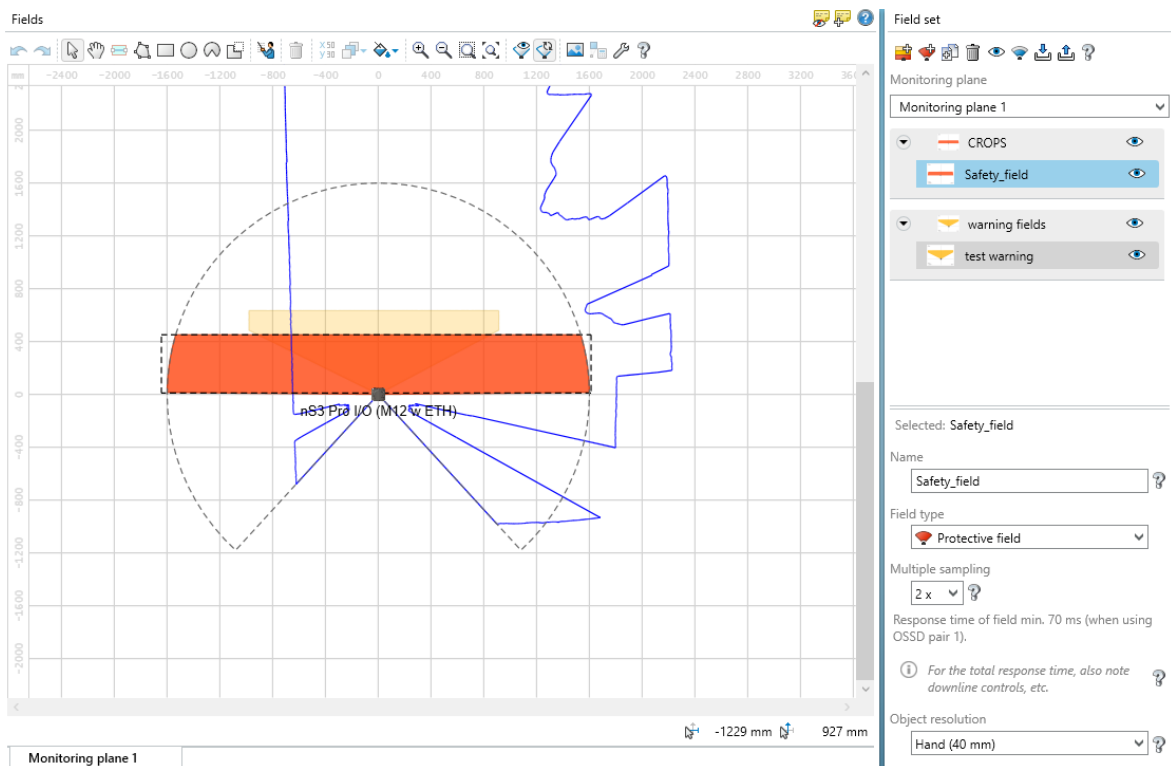


Figure 19: Protected and warning field of the NanoScan3 sensor presented in the program Safety Designer.

## 6 Robot's parameters

The 24 experimental conditions represent all possible combinations of the tool used (2), speed of movement (2), and type of movement (6).

### 6.1 Tools

As presented in Chapter 3.3, two tools will be used:

- Tool 1 – sponge used for a car wash (safe tool)
- Tool 2 – chef knife with 15 cm blunted blade (dangerous tool).

### 6.2 Velocity

In the experiment, two velocities will be tested:

- 0.3 m/s – slow velocity;
- 1 m/s – fast velocity.

In Table 1, velocities and accelerations for different motions types are presented. Acceleration was selected in a way that acceleration/deceleration did not take more than 10 % of whole robot motion duration.

Table 1: Velocity used in the experiments

Type of motion	Velocity (m/s)	Acceleration (m/s <sup>2</sup> )
Linear	0.3 and 1.0	5
Circular	0.3 and 1.0	2
Random	0.3 and 1.0	5

For circular motion, acceleration has to be lowered to 2 m/s<sup>2</sup> due to safety errors triggered by high accelerations.

### 6.3 Kinematics

With kinematic parameters, two parameters were coupled:

- type of motion;
- the direction of motion.

In Table 2, all used combinations are listed.

Table 2: Different kinematic combinations used in the experiment.

Type of motion	Direction
Linear	Left/Right
	Forward/Backward
	Up/Down
Circular	Left/Right
	Up/Down
Random	A random move consists of different points in the robot's workspace that are combined into one move.

### 6.4 Motion

Points used in the planning of robot motion for individual parameter combination are listed in Table 3. Points are expressed regarding the robot's base coordinate system. To make movements more randomised, a PolyScope functions *pose\_add* and scaled *random* are used to add a random number to the defined point in the direction X, Y or Z.

**Example.** When the robot is moving linear left/right, that is in Y direction regarding the base coordinate system, the function *pose\_add* adds a random number between [-100, 100] to the X and Z coordinates. With this, each point is different, thus preventing participant familiarisation with the motion. The example code is shown following.

1. MoveLin\_LR
2. p1=[380,-450,300,2.221,-2.215,0]
3. p2=[380,450,300,2.221,-2.215,0]
- 4.
5. p1\_off=pose\_add(p1,p[(random()\*200-100)/100,0,(random()\*200-100)/100,0,0,0])
6. p2\_off=pose\_add(p2,p[(random()\*200-100)/100,0,(random()\*200-100)/100,0,0,0])
- 7.
8. movel(p1\_off,a=acc,v=velocity)
9. movel(p2\_off,a=acc,v=velocity)

Table 3: Points used in robot motion planning.

<b>Movement type</b>	<b>Points [X, Y, Z, Rx, Ry, Rz]</b>	<b>Randomised direction</b>
<b>Linear Left/right</b>	[380,-450,300,2.221,-2.215,0]	X, Z
	[380,450,300,2.221,-2.215,0]	
<b>Linear Forward/Backward</b>	[550,-350,300,2.227,-2.215,0]	Y, Z
	[-100,-350,300,2.227,-2.215,0]	
<b>Linear Up/Down</b>	[500,-200,500,2.227,-2.215,0]	X, Y
	[500,-200,80,2.227,-2.215,0]	
<b>Circular Left/right</b>	[350,-500,300,2.221,-2.221,0]	X, Z
	[400,450,300,2.227,-2.221,0]	
	[600,60,300,2.226,-2.221,0]	
	[350,500,300,2.227,-2.221,0]	
	[300,500,300,2.227,-2.221,0]	
<b>Circular Up/Down</b>	[300,-200,800,2.227,-2.215,0]	X, Y
	[700,-200,200,2.227,-2.215,0]	
	[600,-200,600,2.227,-2.215,0]	
	[700,-200,70,2.227,-2.215,0]	
<b>Random move #1</b>	[100,-460,480,2.393,-2.450,0.763]	X, Y, Z
	[700,-200,200,2.086,-2.485,0]	
	[600,-200,400,2.195,-2.721,0.920]	
	[700,-200,80,2.086,-2.485,0]	
	[600,-50,300,2.226,-2.221,0]	
	[600,-340,300,2.226,-2.221,0]	
	[350,500,300,2.227,-2.221,0]	
	[350,300,450,2.165,-2.349,0]	
<b>Random move #2</b>	[300,-500,400,1.296,-2.980,0.911]	X, Y, Z
	[150,-500,200,1.296,-2.980,0.911]	
	[500,200,300,3.255,-1.525,0.373]	
	[400,400,300,3.255,-1.525,0.373]	
	[400,-50,400,2.467,-2.062,0]	
	[600,-40,40,2.221,-2.221,0]	

<b>Rand move #3</b>	[350,500,250,2.227,-2,221,0] [400,-500,300,2.227,2,221,0] [400,-500,400,2,227,-2,221,0] [400,-500,100,2.227,-2,221,0] [400,500,450,2,227,-2,221,0] [600,-200,400,2,195,-2,721,0,920] [600,-200,200,2.086,-2,485,0] [600,-200,90,2.086,-2,485,0]	X, Y, Z
<b>Rand move #4</b>	[700,-200,200,2,086,-2,485,0] [400,300,500,2.298,-2,278,0,154] [300,-400,500,2,298,-2,278,0,154] [450,50,300,2.226,-2,221,0] [450,-400,300,2.226,-2.221,0] [600,-200,400,2,195,-2,721,0,920]	X, Y, Z

### 6.5 Randomised combinations

The combinations of different movement types, velocities and tools are programmed in a different combination number/IDs from 1 to 24. In Table 4, the combinations and their IDs are presented. To randomise the order of the movements, five different combination arrays were created. The combination array that is used for the participant is picked randomly by the researcher.

The combination arrays are:

- Comb1= [3,15,22,1,5,9,14,12,17,19,21,2,13,6,23,8,16,10,24,11,20,7,18,4];
- Comb2=[5,8,3,14,17,4,7,6,9,2,21,13,12,10,15,23,18,1,19,20,16,22,11,24];
- Comb3=[9,2,7,21,10,16,5,8,11,24,3,12,13,1,14,15,18,17,6,19,4,22,23,20];
- Comb4=[13,2,5,10,17,6,3,12,9,20,11,8,24,14,23,16,7,18,21,1,19,22,4,15];
- Comb5=[17,3,20,15,9,16,5,24,1,22,19,21,2,6,18,11,14,7,23,4,8,13,10,12];

Table 4: Combination IDs and appropriate parameters

<b>Combination ID</b>	<b>Velocity (m/s)</b>	<b>Acceleration (m/s<sup>2</sup>)</b>	<b>Movement type</b>	<b>Tool</b>
1	0.3	5	Linear Left/Right	Safe tool
2	0.3	5	Linear Left/Right	Dangerous tool
3	1	5	Linear Left/Right	Safe tool
4	1	5	Linear Left/Right	Dangerous tool
5	0.3	5	Linear Forward/Backward	Safe tool
6	0.3	5	Linear Forward/Backward	Dangerous tool
7	1	5	Linear Forward/Backward	Safe tool

8	1	5	<i>Linear Forward/Backward</i>	Dangerous tool
9	0.3	5	<i>Linear Up/Down</i>	Safe tool
10	0.3	5	<i>Linear Up/Down</i>	Dangerous tool
11	1	5	<i>Linear Up/Down</i>	Safe tool
12	1	5	<i>Linear Up/Down</i>	Dangerous tool
13	0.3	2	<i>Circular Up/Down</i>	Safe tool
14	0.3	2	<i>Circular Up/Down</i>	Dangerous tool
15	1	2	<i>Circular Up/Down</i>	Safe tool
16	1	2	<i>Circular Up/Down</i>	Dangerous tool
17	0.3	2	<i>Circular Left/Right</i>	Safe tool
18	0.3	2	<i>Circular Left/Right</i>	Dangerous tool
19	1	2	<i>Circular Left/Right</i>	Safe tool
20	1	2	<i>Circular Left/Right</i>	Dangerous tool
21	0.3	5	<i>Random move 4</i>	Safe tool
22	0.3	5	<i>Random move 1</i>	Dangerous tool
23	1	5	<i>Random move 2</i>	Safe tool
24	1	5	<i>Random move 3</i>	Dangerous tool

## 7 Sample

### 7.1 Demographic variables and attitudes towards robots

#### 7.1.1 Age

There is a general belief that older adults have more negative attitudes towards technology (and robots) compared to younger adults, but the empirical evidence is not conclusive. We can find studies (a) that claim older people have more negative attitudes, e.g., Chien et al. (2019, they used the implicit association test), Hudson et al. (2016, they studied attitudes towards assistive robots for the care of elderly), (b) some that claim the opposite, e.g., Nomura et al. (2009), and (c) some that found no association between attitudes towards robots and age, e.g., Backonja et al. (2018) who studied the social impact of robots; similar findings were reported by Naneva et al. (2020) in their systematic review. To gain further insights into this issue, we will sample the participants from two age groups, i.e. persons aged 18–25 years and persons who are more than 50 years old.

#### 7.1.2 Gender

Several studies about attitudes towards different robots found that males generally have more positive attitudes towards robots than females (Kuo et al., 2009; Gnambs & Appel, 2019; Stafford et al. 2014). However, Naneva et al. (2020) reported that participants' gender was not associated with their affective attitudes toward social robots, cognitive attitudes, general attitudes, acceptance, or anxiety. To control for the possible effect of age, we will try to achieve equal representation of both genders in our sample.

### 7.1.3 Experiences with robots, achieved education, and profession

It has been shown that positive experiences can influence the development and formation of more positive attitudes towards specific objects. Chien et al. (2019) reported that both younger and older adults adopt a more positive attitude after interacting with a robot. Face-to-face interaction with a robot generally evokes more positive feelings towards robots than any form of indirect contact, such as watching a video of the robot (Naneva et al. 2020).

Individuals' achieved education and type of profession/occupation, and subsequent working experience can also influence attitudes towards robots. Nomura et al. (2009) found that educational background/profession is a significant predictor of positive attitudes towards robots, especially if one has a background in natural sciences and technology. Therefore, we will collect data regarding the participants' education and profession in order to obtain and include potentially important covariates in the model for predicting perceived robot safety and other robot-related variables.

## 7.2 Sample in Experiment 1

One of our research questions in Experiment 1 is also if and how are certain demographic variables (age, gender, educational background and previous experience with similar robots) linked to the dependent variables measured in the experiment (e.g., acceptance of the robots, overall perceived safety of the robot movements, etc.).

Our sample will represent two age groups: younger adults (individuals in the transition to adulthood in the age group 18-25 years of age) and adults over 50 years of age. In each of the two groups, there will be approximately equal proportions of female and male participants. We will also try to ensure the same proportion of participants with a scientific-technical field of study or profession and participants with a social science background or profession.

We will employ the snowball sampling, accompanied by the quota sampling technique to achieve the desired demographic structure of the sample. We have prepared two types of invitation: an invitation in the form of an infographic (Figure A1 in the Appendix), and an invitation letter (Figure A2 in the Appendix). The snowball sampling will be carried out by:

- posting an invitation on the Facebook page of the Department of Psychology, University of Ljubljana,
- posting an invitation on the Facebook page of the Faculty of Arts, University of Ljubljana,
- posting an invitation on the Facebook page of the Faculty of Electrical Engineering, University of Ljubljana,
- sending an email invitation to the Society of psychology students (the email will be then forwarded to current and former psychology students),
- sending an email invitation to all of the employees from the Faculty of Arts and Faculty of Electrical Engineering (including secretaries, accountants, etc.), University of Ljubljana and
- sending an email invitation to companies that are near the Faculty of Electrical Engineering (so that it will be convenient for potential participants to come to the lab).
- All the executive researchers will also forward the invitation to their friends and acquaintances.

## 8 References

- Backonja, U., Hall, A.K., Painter, I., Kneale, L., Lazar, A., Cakmak, M., Thompson, H.J. & Demiris, G. (2018), Comfort and Attitudes Towards Robots Among Young, Middle-Aged, and Older Adults: A Cross-Sectional Study. *Journal of Nursing Scholarship*, 50, 623–633. <https://doi.org/10.1111/jnu.12430>
- Chien, S.-E., Chu, L., Lee, H.-H., Yang, C.-C., Lin, F.-H., Yang, P.-L., Wang, T., & Yeh, S.-L. (2019). Age Difference in Perceived Ease of Use, Curiosity, and Implicit Negative Attitude toward Robots. *ACM Transactions on Human-Robot Interaction*, 8(2), 1–9. <https://doi.org/10.1145/3311788>
- Gnambs, T., & Appel, M. (2018). Are robots becoming unpopular? Changes in attitudes towards autonomous robotic systems in Europe. *Computers in Human Behavior*. <https://doi.org/10.1016/j.chb.2018.11.045>
- Hudson, J., Orviska, M., & Hunady, J. (2016). People's Attitudes to Robots in Caring for the Elderly. *International Journal of Social Robotics*, 9(2), 199–210.
- Kuo, I. H., Rabindran, J. M., Broadbent, E., Lee, Y. I., Kerse, N., Stafford, R. M. Q., & MacDonald, B. A. (2009). Age and gender factors in user acceptance of healthcare robots. *RO-MAN 2009 - The 18th IEEE International Symposium on Robot and Human Interactive Communication*. <https://doi.org/10.1109/roman.2009.5326292>
- Naneva, S., Sarda Gou, M., Webb, T.L., & Prescott, T. J. (2020). A Systematic Review of Attitudes, Anxiety, Acceptance, and Trust Towards Social Robots. *International Journal of Social Robotics*. <https://doi.org/10.1007/s12369-020-00659-4>
- Nomura T, Kanda T, Suzuki T, & Kato K (2009) Age differences and images of robots: social survey in Japan. *Interaction Studies*, 10(3), 374–391. <https://doi.org/10.1075/is.10.3.05nom>
- Stafford, R.Q., MacDonald, B.A., Li, X., & Broadbent, E. (2014) Older People's Prior Robot Attitudes Influence Evaluations of a Conversational Robot. *International Journal of Social Robotics*, 6, 281–297. <https://doi.org/10.1007/s12369-013-0224-9>



## 9 Appendix A1

VABILO K SODELOVANJU V RAZISKAVI

# ZAZNANA VARNOST ROBOTA

Raziskava se bo izvajala na **Fakulteti za Elektrotehniko** (Tržaška cesta 25, 1000 Ljubljana)

Za **več informacij** in **sodelovanje** v raziskavi lahko pišete na mail: **raziskava.crops@gmail.com** (vodilni raziskovalec doc. dr. Luka Komidar - luka.komidar@ff.uni-lj.si)

*Raziskavo izvajata:*  
Filozofska fakulteta UL (Oddelek za psihologijo) in Fakulteta za elektrotehniko UL (Laboratorij za robotiko).

### Namen raziskave

Ugotoviti, ob **kakšnem gibanju robota** se ljudje **počutijo varno**.

### Potek raziskave (45 - 60 min)

#### Izpolnjevanje vprašalnika

o osebnostnih lastnostih in stališčih do robota.

#### Sodelovanje v eksperimentu z robotom

v katerem boste imeli možnost spoznati robotsko roko, ki nam v prihodnosti lahko v veliki meri olajša opravljanje težkih in ponavljajočih del.

### Udeleženci

K raziskavi lepo **vabljeni vsi med 18. in 25. letom** ter **starejši od 50 let**.

*Skozi celotno raziskavo bo poskrbljeno za vašo varnost.*

Univerza v Ljubljani  
Filozofska fakulteta  
Oddelek za psihologijo

Univerza v Ljubljani  
Fakulteta za elektrotehniko

Raziskava je financirana s strani programa Horizon 2020.

European Commission

Horizon 2020  
European Union Funding  
for Research & Innovation

Figure A1: The infographic invitation to participate in the Experiment 1.

## 10 Appendix A2

### Vabilo k sodelovanju v raziskavi

#### KAKO SE POČUTIMO OB INTERAKCIJI Z ROBOTOM?

- VABILO K SODELOVANJU V RAZISKAVI -

Vabimo vas k sodelovanju v raziskavi **»Zaznana varnost sodelovalnega robota«**.

Na Oddelku za psihologijo Filozofske fakultete Univerze v Ljubljani v sodelovanju s Fakulteto za elektrotehniko raziskujemo, ob kakšnem gibanju robota se ljudje v interakciji z njim počutijo varno. Raziskava bo izvedena v okviru načrtovanih aktivnosti znotraj evropskega projekta CROPS: Collaborative Robots' Perceived Safety, ki je kratek (9-mesečni) projekt v okviru projekta H2020: COVR (<https://safearoundrobots.com/>).

V raziskavi lahko sodelujejo vsi med **18. in 25. letom** starosti in **starejši od 50 let**.

Če se boste udeležili raziskave, bo vaša naloga sodelovanje v eksperimentu. Eksperiment bo potekal tako, da bo robot izvajal naključne gibe, vi pa boste med tem igrali enostavno računalniško igro. Vaša naloga bo, da se boste robotu približali do točke, kjer se še počutite varno. Tekom eksperimenta vas bomo večkrat vprašali po vaših občutkih prijetnosti, umirjenosti in zaznane varnosti gibanja robota. Pred samim eksperimentom boste rešili tudi dva kratka psihološka vprašalnika o vaših osebnostnih lastnostih in stališčih do robotov. Vse skupaj vam bo vzelo približno 45 minut in največ eno uro vašega časa. Eksperiment bo potekal na Fakulteti za elektrotehniko (Tržaška cesta 25, 1000 Ljubljana).

Za udeležbo v raziskavi ne boste prejeli nobenega nadomestila, поближе pa boste spoznali robota oz. robotsko roko. Ko bodo zbrani podatki obdelani, boste lahko po želji prejeli povratne informacije o svojih občutkih tekom eksperimenta.

V primeru, da vas sodelovanje v raziskavi zanima, se nam prosim javite na elektronski naslov [raziskava.crops@gmail.com](mailto:raziskava.crops@gmail.com) in v kratkem vas bomo kontaktirali glede razpoložljivih datumov.

V primeru dodatnih vprašanj se lahko obrnete tudi na vodilnega raziskovalca, doc. dr. Luko Komidarja ([luka.komidar@ff.uni-lj.si](mailto:luka.komidar@ff.uni-lj.si)) ali na Komisijo za etiko Filozofske fakultete ([info@etika.ff.uni-lj.si](mailto:info@etika.ff.uni-lj.si)).

V upanju na vaš odgovor vas lepo pozdravljamo,

Izvedbeni raziskovalci:

doc. dr. Luka Komidar, Oddelek za psihologijo, FF UL

izr. prof. dr. Anja Podlessek, Oddelek za psihologijo, FF UL

doc. dr. Gaja Zager Kocjan, Oddelek za psihologijo, FF UL

Kristina Rakinić, strokovna sodelavka, Oddelek za psihologijo, FF UL

Sara Seršen, študentka študijskega programa 2. stopnje Psihologija na FF UL

asist. dr. Sebastjan Šlajpah, Fakulteta za elektrotehniko UL

Kristina Nikolovska, raziskovalka v laboratoriju za robotiko, Fakulteta za elektrotehniko UL

red. prof. dr. Matjaž Mihelj, Fakulteta za elektrotehniko UL

Figure A2: The letter invitation to participate in the Experiment 1.