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Collaborative Robots' Perceived Safety
CROPS

Deliverable 2.1: Discretisation of robot's parameters

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Contents

1 Introduction

In this deliverable, we present the discretization of robot's parameters based on user perception of the robot. The first aim of the experiment is to define the upper speed limit for discretized speed controls/scale. By determining an upper limit on the user's perceived safety of the robot's speed, we can better plan effective human-robot collaboration. Meaning that if the robot moves faster than this limit, it will be perceived as too dangerous by the users, which may negatively affect the efficiency of the collaboration. The second aim is to determine the minimal difference in two consecutive movement speeds that is still perceived by most participants. In other words, to determine the smallest (sensible) unit for a discretized speed control/scale. By setting the unit of the speed controller as slightly larger than the average smallest perceived difference in robot movement speed, we will ensure that the majority of robot users will actually perceive the difference in speed when making a one unit increase or decrease of the movement speed via the discretized controller. In the deliverable, we first present some theoretical background on speed perception, followed by the experimental procedure, design, and setup. Further, the robot's parameters and sample are discussed in detail. At the end, the results and future work are presented.

2 Theoretical background

We are visual creatures because we depend mainly on visual information. Within visual information, we pay particular attention to objects that are moving, which has its own evolutionary function (e.g., detecting a predator approaching). Speed perception refers to the ability of humans to estimate and discriminate the speed of objects (Wu et al., 2020). The speed of robotic motion has an important impact on robots safety perception (e.g., Koppenborg, 2015; Wang et al., 2019). Motion and speed perception have been studied extensively (for a review, see Burr & Thompson, 2011), but to date and to our knowledge, speed discrimination in observing robotic motion has not been studied in depth. More research has been done in assessing at what point the robot is moving too fast and is therefore perceived as less safe or unsafe.

2.1 Perception of a robot's movement speed in relation to perceived safety

The speed of the robot and the predictability of its movement has an important effect on users' perceived safety (e.g. Koppenborg, 2015). However, the results of existing studies on robot movement speed are inconclusive. Shomin et al. (2014) reported no differences in perceived safety between fast (750 mm/s) and slow (300 mm/s) movements of a ballbot, dynamically stable human size mobile robot. On the other side Kulic and Croft (2007) report that higher speed of laboratory-scale robot causes anxiety and higher levels of electrodermal activity. Or et al. (2009) reported that industrial robot (model MH33) movement at 100 mm/s resulted in lower ratings of perceived risk when compared to a speed of motion of 900 mm/s in virtual reality setting.

Rahimi and Karwowski (1990) conducted an experiment in a real industrial environment. The results indicated that robot size (small/big) and initial starting speed of the robot (10% and 100% of maximum speed) had significant effects on the selection of robot's safe speed. Participants selected lower safe speeds with the bigger robot (39.7 cm/s) compared to a smaller robot (66.6 cm/s). When the initial speed of the robot was low, the participants selected lower safe speed compared to a high starting speed. Duffy et al. (2006) conducted the same experiment, but in a virtual reality environment, and reported similar results.

2.2 Measuring speed discrimination

Speed discrimination has been studied extensively for 2D lateral motion for simple stimuli. Within the most commonly encountered range of speeds, people can discriminate between speeds that are only 5–7% different (e.g. de Bruyn et al., 1988; Orban et al., 1984). For 2D motion adult speed discrimination thresholds show a U-shaped function over the range of reference speeds used. Speed discrimination thresholds are best within a range of 4–64 deg/s, and become significantly worse with motion slower than 4 deg/s or faster than 64 deg/s (e.g. Orban et al., 1984; de Bruyn & Orban, 1988). Weber fractions around 0.15–0.35 for speed discrimination have been found using naive observers (Manning et al., 2018).

When interpreting speed information people also depend on other types of information, for example auditory cues and also on the duration of movement or distance travelled by the moving object. The finding that participants may use other cues than speed to complete the speed discrimination task is supported by numerous studies (e.g. Mandriota et al., 1962; Smith & Edgar, 1991). In traditional speed discrimination designs when there are more variables that vary together with speed, we cannot be sure if participants really discriminated speed based on the speed itself or if they relied on distance or duration, suggesting that if distance is kept constant, participant could use speed or duration to make judgments or the other way around (for a review, see McKee & Watamaniuk, 1994). To avoid this problem speed change discrimination tasks have been developed (Monen & Brenner, 1994; Snowden & Braddick, 1991). However in real life situations speed almost never occurs isolated from other types of information, so we decided to use a traditional speed discrimination task and we are aware of the fact that the participants could make judgments based on the movement duration (distance is held constants) or on the different noise levels due to different movement speeds.

2.3 Speed discrimination during colaboration with robot

In a psychophysical study aimed at obtaining information about human discrimination of speed in a human-robot collaboration (Schmidtler & Bengler, 2016), a simple staircase method and a reference speed of 0.5 m/s of the robot were used to measure the differential threshold. In the experiment, the modified Reis Robotics RV20-16 was used with linear and circular movements. They found a differential threshold of 11.6 % They also discovered that humans are more accurate in perceiving velocity differences for decreasing velocities then increasing velocities in imprecise passive haptic collaborations.

3 Experimental design and procedure

All measurements that were part of the experiment took place at the Faculty of Electrical Engineering, University of Ljubljana, in the Laboratory of Robotics. Participants were asked to come to the faculty where they were accepted by the executive researcher from the Department of Psychology. The participants first filled out an informed consent to participate in the experiment, then they reported their demographics (gender, age, level of education, occupation) and responded to the Robot acceptance scale. We also asked the participants about their past experiences about using robotic arms and other types of robots.

3.1 Measuring absolute threshold (AL) for the perception of unsafe robot's movement speed

We used eight different speed movements of the robot in the range from 0.3 m/s to 1 m/s with 0.1 m/s increments. The robot made a simple „grab-move-release" movement. There were three different conditions when participants were assessing the perceived safety of the robot's movement: (i): standing in front of the robot (the robot moved at the height of their chest), (ii) sitting in front of the robot (the robot moved at the height of their eyes) or (iii) standing on a podium (0.3 m high) in front of the robot (the robot moved at the height of their waist). All three conditions are presented in Figure 1. Every participant was exposed to each of the conditions only once, and the order of the conditions within each participant was randomized. Each participant provided one assessment of (un)safety per movement speed. We assessed the average threshold on the group level (from the psychometric curve based on the responses of all participants).

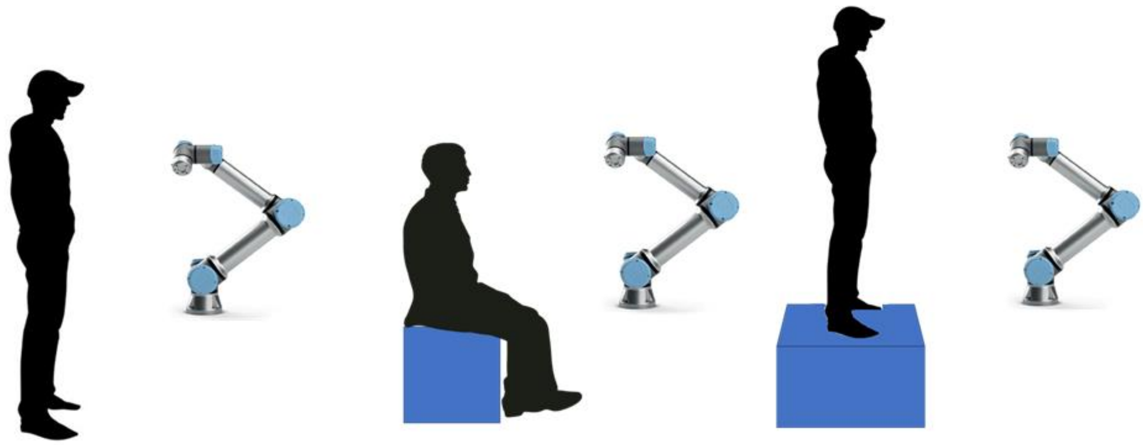

Figure 1: Conditions (i.e., positions of the participants) in evaluating the safety of the robot's movement

For each movement of the robot participants had to report whether they felt safe or unsafe when standing in a close proximity to the robot. Participants were instructed to imagine working with a robot (for example cooking together or assembling parts), when reporting about the perceived safety of the robot's movements at different speeds.

Before the start of this experiment, we familiarized the participant with the approximate range of movement speeds the robot arm is capable of (we presented the robot doing the same movement as in the experiment at 0.1 m/s, 0.5 m/s, and 0.9 m/s). During this presentation participants were standing at a safe distance (3 m) from the robot.

All participants responded about the perceived safety of the robot's motion in all three conditions. In all conditions, the participants were 0.9 m away from the robot's base (0.5 m away from the robot's tool).

3.2 Measuring difference threshold (DL) for the perception of different speed of robots' movements

The aim of the second experiment was to find the differential threshold (DL; i.e. the difference in speed of two consecutive movements that is perceived by 50% of participants) for discriminating the speed of robot's movement. We measured the DL at three reference speeds (Ss), i.e., 0.25 m/s, 0.5 m/s, and 0.75 m/s. Participants were presented with a randomized sequence of movement speed pairs (e.g., 0.25 and 0.28 m/s). Speed of the variable stimuli (Sv) was increased by 0.04 m/s. Each reference movement speed was compared to 6 higher movement speeds, e.g. 0.25 m/s was paired with 0.29, 0.33, 0.37, 0.41, 0.45 and 0.49 m/s; a total of 18 pairs of stimuli were presented to the participants. The position of the reference movement speed in each pair (i.e., presented first or second) was randomized as shown in the chapter 'Robot's parameters'.

The participants provided a Yes/No response to the question: "Did you perceive a difference between the two movement speeds?". The DL was (again) assessed on the group level (participants provided only one judgement per pair).

Participants were instructed to be at least 80% sure of their response (that the two motions differed in speed). In this way, we wanted to ensure that all participants had approximately the same decision criterion and thus to reduce the impact of interpersonal differences in reporting the perception of differences in the robot's movement speed.

4 Experimental setup

The experiment setup consisted of Universal robots UR5 with Weiss collaborative gripper and safety Sick NanoScan3.

4.1 Universal Robot 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 ±0.03 mm, and maximum 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.

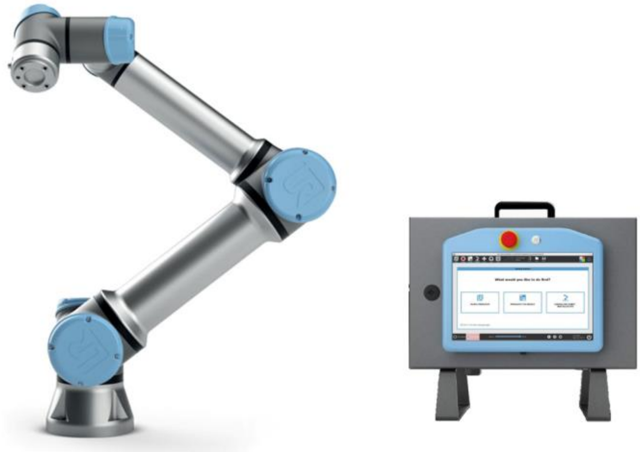

Figure 2: Collaborative robot Universal Robots UR5e with teach pendant.

4.2 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 visualization, 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.

4.3 Object

To simulate a pick and place task, the robot was holding in the gripper the object presented in the Figure 4. Neutral object was chosen, because we did not want it to attract special attention from the participants.

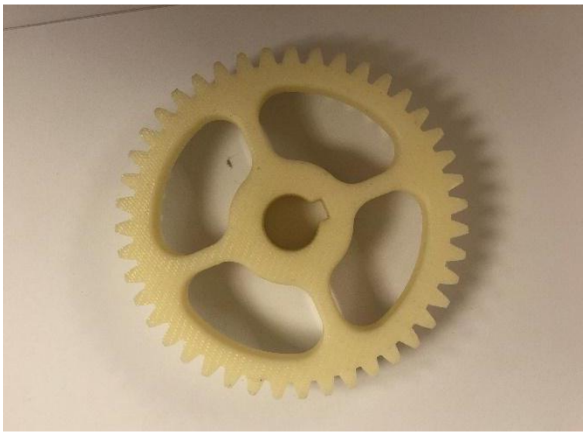

Figure 4: Object used for the experiment.

4.4 Finger 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. As the gripper is non-backdrivable, the object will stay safely gripped even in case of power loss to the gripper. Figure 5 presents the gripper fingers.

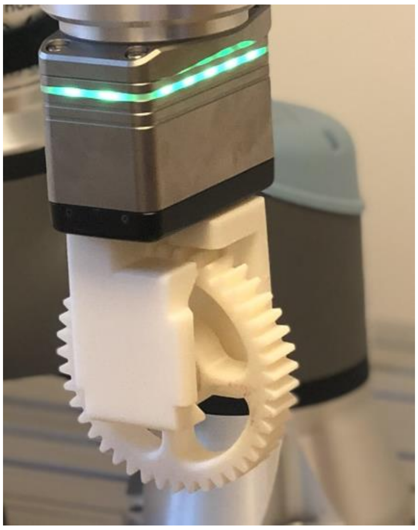

Figure 5: Fingers holding the object used for the experiment.

4.5 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 ≥ 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.

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.

5 Software

5.1 Experiment setup

Absolute threshold (AL): The robot movement is programmed to move linearly through four points in a »grab-move-release« movement. The robot is doing the same movement with 8 different speeds starting with 0.3 m/s up to 1 m/s with the step 0.1 m/s. Every speed is coded into a special ID presented in the chapter 'Robot's parameters'.

Differential threshold: The robot moves through four points in a »grab-move-release« movement. This movement is done two times at different speeds. Between the movements there is a pause of 2s. The speeds are coded in pairs as shown below in Table 1. The pairs always have one of the reference speeds (0.25 m/s, 0.5 m/s, 0.75 m/s). Each reference movement speed was compared to 6 higher movement speeds. Speed of the variable movements was increased by 0.04 m/s. The position of the reference movement speed in each pair (i.e. presented first or second) were randomized and also the pair sent to the robot was randomized as shown in the chapter 'Robots' parameters'.

The experimental setup is shown in Figure 7.

Table 1: Combination for differential threshold measurements.

Velocity pair (m/s)	
0.25	0.29
0.25	0.33
0.25	0.37
0.25	0.41
0.25	0.45
0.25	0.49
0.50	0.54
0.50	0.58
0.50	0.62
0.50	0.66
0.50	0.70
0.50	0.74
0.75	0.79
0.75	0.83
0.75	0.87
0.75	0.91
0.75	0.95
0.75	0.99

Figure 7: The robotic cell and the standing position marked on the floor.

5.2 Main control

For control of both experiments, a Matlab Gui was created as presented in Figure 8. The app includes Stop and Start button and selector for different combinations of robot parameters used in the study. With the press of a button Start, a combination ID from the selected combination list was sent to the robot. When the button Stop was pressed, the command to stop the movement was sent to the robot.

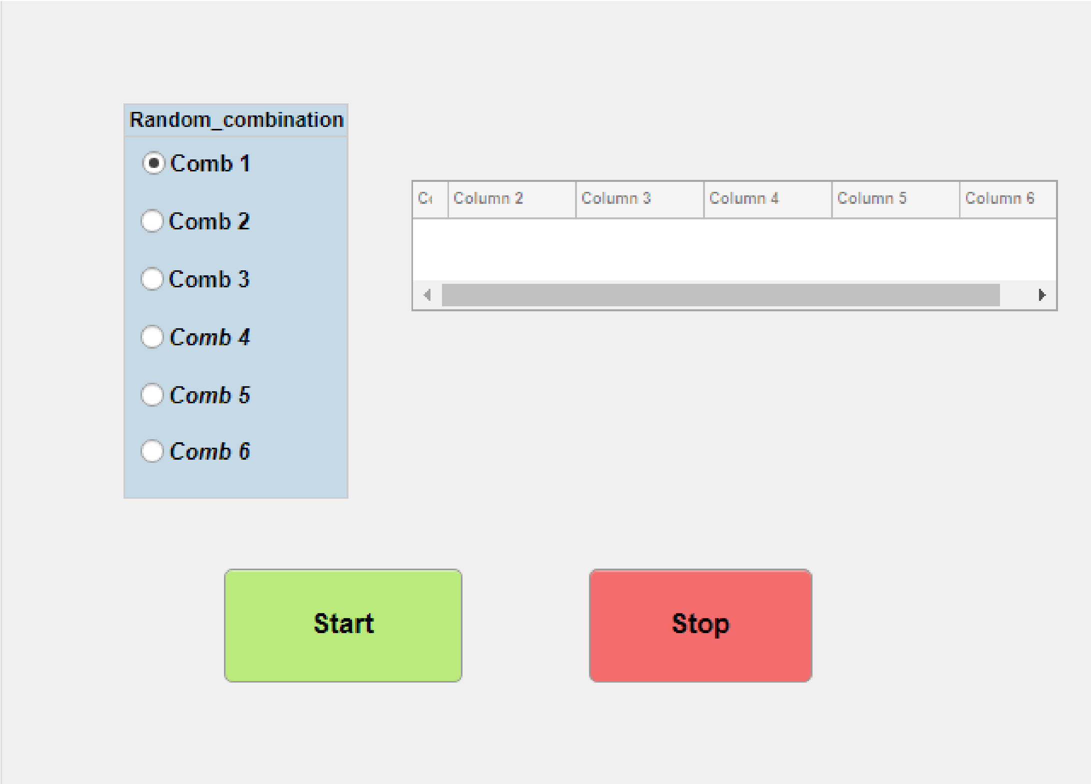

Figure 8: Main experiment control via Matlab GUI app.

5.3 Safety

SICK NanoScan3 sensor was used as a safety sensor. One safety protected field was defined, presented in Figure 9. Safety fields trigger the sensor's digital output which is connected through digital input to the robot controller. The protected field includes all the area that is below 0.8 m from the base of the robot or 0.4 m from the robots' tool. 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.

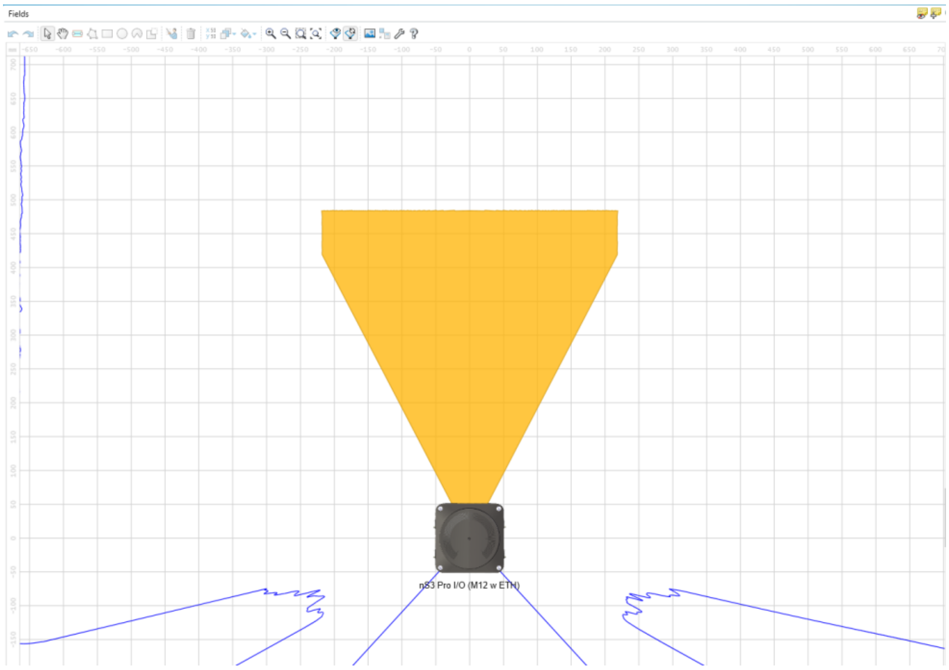

Figure 9: Protected field of the NanoScan3 sensor presented in the program Safety Designer.

6 Robot's parameters

This chapter presents in detail the robot movement velocities and combinations for both measurements.

6.1 Robot movement

Points used in the planning of robot motion are listed in Table 2. Points are expressed regarding the robot's base coordinate system. The Z coordinate which presents the height on which the robotic arm is moving changing regarding the height of the participant. To make the points specific for the different heights of the participants, a PolyScope function pose_add was used to add numbers to coordinate Z. The number that was added to the Z coordinate was calculated as shown below in the example. We calculated 80 % of human height (chest height of the human). We subtracted the difference from the floor to the base of the robot with that number and we got the Z coordinate. The points were used in both measurements: in measuring absolute threshold and measuring difference threshold.

Table 2: Points used in robot motion planning.

Movement type	***Points [X, Y, Z, Rx, Ry, Rz]***
Linear	[350, -450, Z/2, 2.221, -2.221, 0]
Linear	[350, -450, Z, 2.221, -2.221, 0]
Linear	[350, 450, Z, 2.227, -2.221, 0]
Linear	[350, 450, Z/2, 2.221, -2,221, 0]

Example 1: The code below shows calculating the Z coordinate and movement of the robot for the participant with height 175 cm for measurement of the AL.

```
Calculate Z-coordinate
humanHeight=175
Z=(humanHeight*80)- 95   # 95cm is the high from floor to the base of the robot
MoveRobot
p1=[350, -450, 0, 2.221, -2.221, 0]
p2=[350, -450, 0, 2.221, -2.221, 0]
p3=[350, 450, 0, 2.221, -2.221, 0]
p4=[350, 450, 0, 2.221, -2.221, 0]
p1Human=pose_add(p1,p[0, 0, Z/2, 0, 0, 0])
p2Human=pose_add(p2, p[0, 0, Z, 0, 0, 0])
p3Human=pose_add(p3, p[0, 0, Z, 0, 0, 0])
p4Human=pose_add(p4, p[0, 0, Z/2, 0, 0, 0])
movel(p1Human,a=acc,v=velocity)
movel(p2Human,a=acc,v=velocity)
movel(p3Human,a=acc,v=velocity)
movel(p4Humna,a=acc,v=velocity)
movel(p3Human,a=acc,v=velocity)
movel(p2Human,a=acc,v=velocity)
movel(p1Human,a=acc,v=velocity)
```

Example 2: The code below shows calculating the Z coordinate and movement of the robot for the participant with height 180 cm for measurement of the DL.

```
Calculate Z-coordinate
humanHeight=180
Z=(humanHeight*80)- 95   # 95cm is the high from floor to the base of the robot
MoveRobot
p1=[350, -450, 0, 2.221, -2.221, 0]
p2=[350, -450, 0, 2.221, -2.221, 0]
p3=[350, 450, 0, 2.221, -2.221, 0]
p4=[350, 450, 0, 2.221, -2.221, 0]
p1Human=pose_add(p1,p[0, 0, Z/2, 0, 0, 0])
p2Human=pose_add(p2, p[0, 0, Z, 0, 0, 0])
p3Human=pose_add(p3, p[0, 0, Z, 0, 0, 0])
p4Human=pose_add(p4, p[0, 0, Z/2, 0, 0, 0])
movel(p1Human,a=acc,v=velocity1)
movel(p2Human,a=acc,v=velocity1)
movel(p3Human,a=acc,v=velocity1)
movel(p4Human,a=acc,v=velocity1)
movel(p3Human,a=acc,v=velocity1)
movel(p2Human,a=acc,v=velocity1)
movel(p1Human,a=acc,v=velocity1)
wait(1)
movel(p1Human,a=acc,v=velocity2)
movel(p2Human,a=acc,v=velocity2)
movel(p3Human,a=acc,v=velocity2)
movel(p4Human,a=acc,v=velocity2)
movel(p3Human,a=acc,v=velocity2)
movel(p2Human,a=acc,v=velocity2)
movel(p1Human,a=acc,v=velocity2)
#example when ID==2 look in to the chapter random combinations
If ID==2
    velocity1=0.33
    velocity2=0.25
    call MoveRobot
```

6.2 Random combinations

The combinations of different movement velocities were programmed in different combinations of numbers/IDs. The IDs for measurements of the AL are shown in Table 3 and the IDs for measurement of DL are shown in Table 4.

To randomise the order of the movements, different combination arrays were created. The combination array that was used for the participant was picked randomly by the researcher.

The combination arrays for AL were:

```
Comb1=[9,5,8,6,10,7,4,11]
Comb2=[8,6,9,5,10,7,11,4]
Comb3=[4,8,9,6,10,7,5,11]
Comb4=[10,6,11,7,5,8,4,9]
Comb5=[8,6,11,5,10,7,4,9]
```

The combination arrays for DL are:

```
Comb1=[3,6,10,18,4,9,16,2,11,14,5,1,15,7,12,17,8,13]
Comb2=[4,11,3,12,6,17,9,15,1,8,18,14,7,13,5,10,2,16]
Comb3=[18,10,3,16,8,12,1,11,17,5,14,2,4,13,7,15,9,6]
Comb4=[2,8,6,17,10,4,11,15,3,9,16,1,5,13,18,7,12,14]
```

Table 3: IDs for measurement of the absolute threshold.

ID	*Velocity (m/s)*
4	0.3
5	0.4
6	0.5
7	0.6
8	0.7
9	0.8
10	0.9
11	1.0

Table 4: IDs of velocity pairs for difference threshold measurements.

ID	Velocity pair (m/s)	
1	0.25	0.29
2	0.33	0.25
3	0.25	0.37
4	0.41	0.25
5	0.45	0.25
6	0.49	0.25
7	0.50	0.54
8	0.58	0.50
9	0.50	0.62
10	0.50	0.66
11	0.70	0.50
12	0.50	0.74
13	0.75	0.79
14	0.83	0.75
15	0.87	0.75
16	0.75	0.91
17	0.95	0.75
18	0.75	0.99

7 Sample

Due to still ongoing government measures to contain the spread of the COVID-19 virus (e.g., faculties were still closed), only relatives and individuals who were on the faculty at the time of the measurements were included in the sample. All safety precautions (e.g., wearing masks) were followed. Thus, our sample was convenient, which means that the results are limited in their generalizability to a certain point.

There were 17 participants in total, nine of whom were men. The mean age of participants was 28.8 years (min = 22; max = 54; SD = 9.6). Nine participants had completed the second level of Bologna education, followed by seven participants who had completed the first level of Bologna education. The majority of participants were employed (N = 10), followed by six students. None of the participants had previous experience with this type of robotic hand at home or at work, four participants however had experience with using similar robots (e.g. experience during studies, experience with autonomous mobile robots, experience with home robots (e.g., iRobot Roomba, etc.)).

8 Results

8.1 Absolute threshold for the perception of unsafe robots' movements

We assessed the average absolute threshold for unsafe movements on the group level (from the psychometric curve based on the responses of all participants). The AL represents a speed where 50% of participants did not feel safe any more. Based on a linear interpolation the lowest AL was in the condition in which participants were sitting in front of the robot (0.72 m/s), followed by the condition in which participants were standing in front of the robot (0.77 m/s). The highest AL was when the participants were standing on the podium (0.83 m/s), as seen in the Figure 10.

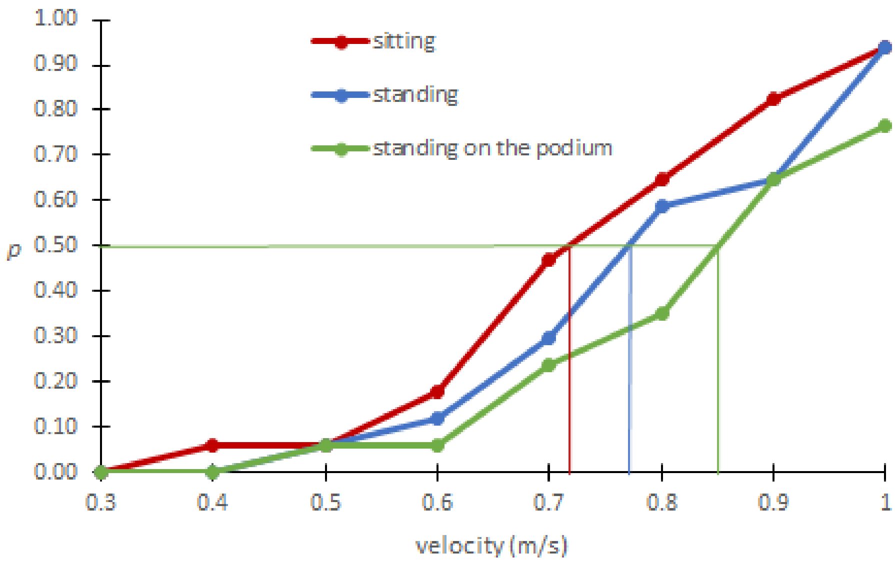

Figure 10: Psychometric curves for measuring AL at three different positions.

The results show that participants felt safer at higher speeds when they were standing on the podium and the robot was moving at the level of their waist. Participants might perceive that they were in a dominant position with respect to the robot, which may led them to feel safer at higher speeds. Participants felt safe at the lowest speeds when they were sitting in front of the robot, which was the position where the robot is moving at the level of their eyes. Combined with the fact that they were seated and could not easily move away, this might have an impact on them feeling unsafe at lower speeds. The AL for feeling unsafe in the condition where they were standing in front of the robot (and the robot was operating at the chest level) was higher than the one in the sitting condition and lower than the AL in the "standing on podium" condition. Participants could easily move away, which gave them a higher sense of safety, resulting in them feeling safer at higher speeds than when seated, but lower compared to when standing on the podium.

The results showed that when choosing the upper speed of the robot, we must also consider the physical position of the user in the process of collaboration. If the user is in a more dominant position when working with the robot, higher speeds can be chosen. However, the more the user is exposed to the robot or if the robot moves at the chest or eye level of the users, it is necessary to choose lower speeds to ensure optimal user experience.

We can conclude that the speed of 0.7 m/s is the speed where users would feel safe during cooperation with the robot regardless of their position, which would allow effective and comfortable human-robot cooperation.

8.2 Difference threshold for the perception of robots' movements

The DL was assessed on the group level (participants provided only one judgement per pair). DL is the value of change in speed required to perceive it in 50% of participants. DL was higher for higher speeds, meaning that participants were more sensitive for perceiving lower speeds, as seen in Figure 11.

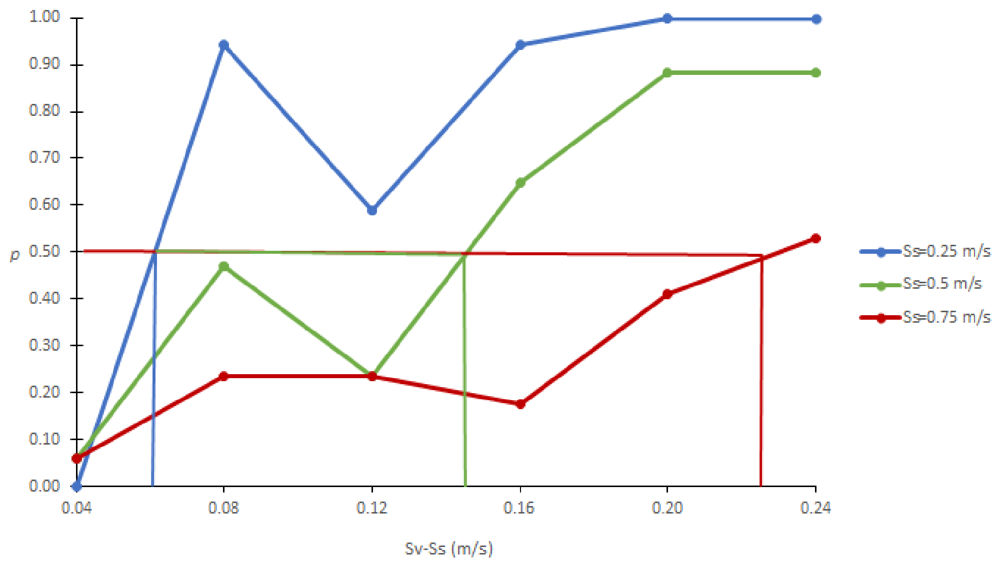

Figure 11: Psychometric curves for measuring DL at three different ranges of speeds.

DL for the slowest range of speed (Ss = 0.25 m/s) was 0.05 m/s and the Weber fraction was 0.20, meaning that the speed in the slow range must change for 20% to be noticable. DL for the medium range of speed (Ss = 0.50 m/s) was 0.13 m/s with the Weber fraction of 0.27, suggesting that the speed in the medium range must change for 27 % to be noticable. DL for the highest speed was 0.22 m/s with the Weber fraction of 0.29, suggesting that the speed in the fast range must change for 29% to be noticable.

When measuring DL at the lowest speeds, we see a large jump in the proportion of the perceived difference in speed at the pair Ss = 0.25 m/s and Sv = 0.33 m/s. In the next Sv (0.37 m/s), this proportion decreases sharply, which is unusual, since the proportion of the detected differences in speed is expected to increase as the difference between Ss and Sv increases. The reason for such results most likely lies in the fact that in the pair Sv = 0.33 m/s - Ss = 0.25 m/s Sv was played first and was therefore recognized as different, while in the next pair Sv = 0.37 m/s was played as the second and did not have this effect. This is in line with the results from the study from Schmidtler and Bengler (2016), where they report that people are more sensitive to perceiving differences in robots' movements, when they are presented with faster movement first. We checked this assumption and changed the order (played Sv as second) and could not notice the difference in speed. Based on this, we found that the order of Sv and Ss in the pair affects the perception of speed, with the greatest influence shown at the lowest speeds. Similar results can be recognized at medium speeds. At higher speeds we do not see this effect.

9 New protocol for measuring difference threshold

Based on the results of the experiment measuring DL, we designed a new protocol that addresses the shortcomings of the first. The most important change concerns the experimental design itself. Because we found that the order of Sv and Ss in the pair had an effect on speed perception (when Sv was first, participants perceived the speed difference earlier than when it was second), each participant would now have to evaluate each stimulus pair twice, once presenting Sv first and once second, so we will be able to assess the DL in the condition where the Ss will be presented first and the condition where the Ss will be presented second. In this way, we will estimate the effect of the position of the Ss on the DL for speed discrimination. In other words, we will assess the DL when the speed in the pair increases (the second movement is always faster that the first) and when the speed in the pair decreases (the second movement is always slower). Based on the values of DL and Weber fractions we have also determined new steps for all reference movement speeds; for the lowest speeds the step would be 0.03 m/s, for the medium speeds the step would remain the same (0.04 m/s), and for the highest speeds the step would be 0.05 m/s. The six variable stimuli for each series would remain the same. The last adjustment will refer to the manipulation of the participants decision criterion, i.e., the participants will be instructed to be 100 % sure in their answer about the perceived differences in speed. New velocity pairs are presented in Table 5.

Table 5: Velocity pairs for new measurements of difference threshold.

Velocity pairs (m/s)	
0.25	0.28
0.25	0.31
0.25	0.34
0.25	0.37
0.25	0.40
0.25	0.43
0.5	0.54
0.5	0.58
0.5	0.62
0.5	0.66
0.5	0.70
0.5	0.74
0.75	0.80
0.75	0.85
0.75	0.90
0.75	0.95
0.75	1.00
0.75	1.05

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