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CoLLaboratE

Co-production CeLL performing Human-Robot Collaborative AssEmbly

D2.8 – Behavioral Experiments to Demystify and Improve Key Human Factor Aspects of HRC

Due date: M37

Abstract:

The present document presents the work that has been done for the T2.4: Behavioral Experiments to Demystify and Improve Key Human Factor Aspects of HRC. It is part of the framework design, requirements & social studies feedback. The report includes the findings of a literature review that was conducted to identify the state-of-the-art behavioral interventions that can be used in the use cases with the purpose to facilitate Human-Robot Collaboration (HRC). Furthermore, it includes the design and results of a preliminary study that was performed to test a potential behavioral intervention, as well as the design and results of a confirmatory study to further examine the role of different touching styles in HRC.

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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EXECUTIVE SUMMARY

A successful implementation of industrial HRC can enhance quality and the resilience of the manufacturing, increase production output, and last but not least reduce product cost. The main goal of the T2.4 (which is related to this deliverable) is to apply state-of-the-art behavioral interventions to facilitate the successful HRC in the use cases.

A very important element of a successful HRC is human trust towards robots. Humans must trust that the robot protects the interests and welfare of all the human members of the HRC team. Trust is crucial in developing an effective human-machine interaction. The level of trust human put on any robotic partner is very critical, especially in high-risk situations.

One of the most popular ways to facilitate HRC that has been used by studies is anthropomorphism. Anthropomorphism is an inductive process, where nonhuman agents get attributed distinctive human characteristics, such as conscious feeling.

Findings of previous studies show that anthropomorphism can be used to stimulate robot trust and facilitate a successful HRC [1] [2]. Therefore, we decided to use anthropomorphism to try to facilitate HRC in the use cases of CoLLaboratE. To ensure the success of our interventions we decided to pre-test some of the most suitable of them for the use case. To test the techniques we designed laboratory studies in which we implmented the techniques and assess their impact on human trust and the acceptance towards robots. Specifically, we examined how anthropomorphic touching (i.e., handshake) versus non-anthropomorphic touching and no touching affected human trust towards robots.

In addition to the study investigating the effect of anthropomorphic touching on HRC, we conducted an additional study with which we investigated the influence of video's on HRC. Concretely, we searched for an intervention that could be applied to different kind of robots and in different fields. After an extensive literature review, we found the effect of asking employees to imagine the future HRC contact with the robot. In the study presented in the current deliverable, we investigated wether presenting participants with a video representing the real HRC contact, versus a video representing a general introduction of the robot without presentation of the real HRC contact and a control video, could foster willingness to collaborate with the robot, perceived trust toward the robot, and perceived interaction quality.

This version of D2.8 is the final version of the deliverable. Last year, a preliminary version of the deliverable was submitted (D2.7), in which only the antropomorhic touch study was reported. In this final version, we improved the report of the antropormophic touch study and added the new study on the real HRC video.

Table of Contents

ABBREVIATIONS AND ACRONYMS

Partner's short name	Partner's full name
AUTH	ARISTOTLE UNIVERSITY OF THESSALONIKI
CERTH	CENTRE OF RESEARCH AND TECHNOLOGY HELLAS
ARMINES	ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPMENT DES METHODES ET PROCESSUS INDUSTRIELS
JSI	INSTITUT JOZEF STEFAN
IDIAP	FONDATION DE L'INSTITUT DE RECHERCHE
UNIGE	UNIVERSITA DEGLI STUDI DI GENOVA
KU Leuven	KATHOLIEKE UNIVERSITEIT LEUVEN
LMS	UNIVERSITY OF PATRAS
CRF	CENTRO RICERCHE FIAT SOCIETA CONSORILE PER AZIONI
BOR	BLUE OCEAN ROBOTICS
ASTI	AUTOMATISMOS Y SISTEMAS DE TRANSPORTE INTERNO SA
KOL	KOLEKTOR ORODJARNA NACRTOVANJE IN IZDELAVA ORODIJ TER ORODJARSKE STORITVE D.O.O.S
ARCELIK	ARCELIK A.S.
ROMAERO	ROMAERO S.A.

Abbreviation	Definition
WP	Work Package
D	Deliverable
EC	European Commission
EU	European Union
HRC	Human-Robot Collaboration
OLS	Ordinary Least Squares regression
WTC	Willingness to Collaborate

1 INTRODUCTION

The main goal of T2.4 is to identify and apply behavioral intervention to facilitate the HRC in the use cases. A behavioral intervention is any planned action that targets to alter the psychology and/or behavior of people towards a given direction, in the case of T2.4 towards the facilitation of HRC. To be able to do this the appropriate intervention should be identified. Therefore, an extensive literature review was conducted to map the potential behavioral interventions. The literature review examined the state-of-the-art insights about the interaction of human and robot as well as other technologically advanced non-human agents (e.g. avatars) and identified prominent and promising areas of intervention.

The results of literature review were used as a guide to pick some interventions that deemed to be suitable for the robots of the use-cases. In the current deliverable we focused on two possible interventions: (1) antropormophic touch and (2) real HRC video. However, before implementing them, the notion of the interventions had to be tested in laboratory studies in highly controlled conditions to assess the degree of suitability of the intervention. Therefore, a set of studies were designed to test the interventions. For the anthropomorphic touch study, a small preliminary study was conducted in May 2019. The results provided a first insight into the potential of a antropormophic touch intervention. In the first semester of 2020, based on the results from the preliminary study, we conducted a laboratory study to further examine the role of different touching styles in HRC. For the real HRC video study, two online studies were conducted in the summer of 2021.

2 STUDY 1 – ANTROPOMORPHIC TOUCH

2.1 LITERATURE REVIEW ON ANTROPOMORPHISM AND HRC

2.1.1 HRC and Trust

According to the International Organisation for Standardisation [3] HRC is a “special kind of operation between a person and a robot sharing a common workspace”. A successful implementation of industrial HRC can enhance quality and the resilience of the manufacturing, increase production output, and last but not least reduce product cost [4]. Until recently, a very close collaboration between industrial robots and human workers has traditionally been stalled largely due to safety concerns. Companies were trying to mitigate accidents that cause injury to the human operator. Recent technological advancements, however, have dramatically increased the potential of HRC as collaborative robots which started to become more lightweight, compact and designed with human safety as a priority [5]. What is more, health and safety regulations are also being advanced to reflect the advancements in robot design which in turn allow some closer cooperation between the robots and the operators [3]. Thus, HRC is expected to greatly increase in the near future.

For a human-robot team to accomplish its goals and be successful, humans must trust that the robotic member of the team will protect the interests and welfare of all the individuals on the team. Trust is “the attitude that an agent will help achieve an individual’s goals in a situation characterized by uncertainty and vulnerability” [6] and thus, it is crucial in developing an effective human-machine interaction. The level of trust human put on any robotic partner is very critical, especially in high-risk situations [7]. Trust is particularly important in these high-risk contexts as it directly affects peoples’ willingness to accept information coming from the robot, follow robots’ suggestions, and as a result benefit from the advantages robotic systems can provide [8]. Trust therefore can greatly affect the decisions that humans will make in uncertain or risky environments (when it comes to HRC) [9]. For example, the less trust an individual places on a robot, the sooner he or she will intervene as a task progresses toward its completion and this might potentially compromise the success of the task [10].

Although people might interact daily with machines that both appear and behave like humans, trust between a human and a machine is unique and it often varies in initial perceptions, monitoring behaviors and judgments [6]. In human-automation interaction, a unique phenomenon known as "automation bias" takes place and causes people to ascribe higher authority, greater expected performance and higher initial trust to machine-like agents [11] than human agents [12]. Despite the fact that human agents gather initial higher liking, a bias for trusting machine-like automation seems to persist [11] [12]. Nevertheless, this initial trust in machine-like agents can quickly collapse once a machine appears to be less consistent and perfect as expected and fail to meet people's high expectations [13]. These results indicate that in cases of extremely high levels of trust, people tend to rely excessively on technological agents, whereas in cases of low levels of trust, people tend to disuse technological agents [6] [12].

Literature findings show that trust is an important element in a successful HRC. Therefore, trying to increase the levels of trust humans place on robots is of utmost importance to facilitate HRC in the use cases.

2.1.2 Anthropomorphism and HRC

One of the most popular ways to facilitate HRC that has been used by studies is anthropomorphism. Anthropomorphism is an inductive process, whereby distinctive human characteristics, such as conscious feeling, are being attributed to nonhuman agents [14]. The very essence of anthropomorphism seems to lie in the attribution of humanlike characteristics, motivations, intentions and emotions to imagined or real behavior of nonhuman agents [15].

Nevertheless, anthropomorphism goes beyond attributing superficial human characteristics (like a humanlike face or body) to attributing essential human characteristics to the nonhuman agent, such as a humanlike mind, capable of generating thoughts and emotions [14]. As the "theory of the mind" assumes, people tend to attribute a "mind" to other human beings in order to explain the behavior of any independently acting agent and predict its behavior [16]. Thus, the presence of a humanlike mental state, such as intention, emotion, cognition, is the defining feature that distinguishes humans from other agents [14]. Several theories of humanness confirm that humanness is being interpreted in terms of the emotion that implicates higher order mental process [17] and traits that involve cognition and emotion [18].

In order to explicate people's need to anthropomorphize, scholars tried to determine the psychological factors that cause people to use anthropomorphic explanations of nonhuman agent's behavior. Research suggests that people are more likely to anthropomorphize when anthropocentric knowledge is accessible and applicable, when motivated to be effective social agents and when lacking a sense of social connection to other humans [15]. Human desire for social connection and their need to explain, to predict, and consequently to control other agents are the two fundamental motivations that trigger anthropomorphism [16].

Anthropomorphism is a critical parameter not only in understanding human-computer interactions but also for improving the usefulness of certain technological agents [15]. Although external appearance is crucial to the way humans perceive other objects anthropomorphism is more of a process of inference about unobservable characteristics of the nonhuman agent, rather than descriptive reports of a nonhuman agent's observable behavior [15]. For example, by building nonhuman agents with the necessary features that will allow them to perceive the world as humans (e.g. using two cameras as eyes), engineers might achieve human-computer interaction in the same way as humans interact with each other [19].

But the most important issue regarding anthropomorphism (see nonhumans as a human) remains whether people will accept nonhuman agents and treat them with respect as moral agents or merely as objects. Nonhuman agents that have humanlike mental capacities are presumed to have the ability of autonomous self-directed behavior and therefore, its actions can be considered as intentional. Human-like robots that both appear and behave like humans are treated less harshly than machine-like robots [20], due to the fact that people can more easily relate and empathize with them [21]. Increased familiarity with an agent can decrease feelings of unease towards a technological agent's appearance [22] and thus, interaction may be the key to enhance anthropomorphism and alleviate unnerving feelings towards robots.

2.1.3 Anthropomorphism and Trust in Robots

Humanlike appearance and behavior of technological agents are the most important features that can affect trust in nonhuman agents and thus, by adding these anthropomorphic features, engineers can indeed increase trust [2] [12]. Robot voice and eye gaze are some influential human features in human-robot social interaction. Service robot's voice pinch can create positive feelings towards humans and thus, robots with a higher pinched voice are perceived as more attractive and pleasant [1]. Anthropomorphized vehicles with human features like voice and gender are considered to be more trustworthy and even in case of an accident, people were more relaxed and couldn't blame their vehicle for an accident caused by another driver [2].

Stanton & Stevens [23]reported an unpredicted effect of the eye gaze on human-robot interaction. On the one hand, robot gaze can improve human performance on easy trials due to performance anxiety experienced during difficult trials, but on the other hand, robot gaze has a significant positive impact upon human's compliance and trust on difficult trials. Moreover, an experimental study in humanoid robots displaying gaze turn-taking cues revealed not only the positive effect of perceived anthropomorphism on trust but also the moderating role of the level of human-robot interaction comfort on perceived anthropomorphism [24]. People that feel comfortable interacting with robots, experience positive emotions that cause them to process interaction cues less carefully and pay attention only to superficial features, such as appearance, than those experiencing negative emotions of discomfort [25]. Therefore, humans that feel comfortable interacting with robots tend to anthropomorphize robots with human-like appearance, whereas humans that feel less comfortable interacting with robots tend to anthropomorphize robots with human-like social functioning features [24]. These results imply that it depends on the desired interaction outcome whether engineers will enhance specific anthropomorphic features, such as social functioning or appearance, in order to achieve higher levels of acceptance and trust.

The results of the aforementioned studies show that anthropomorphism can indeed be used to induce more trust in human-robot interaction.

2.1.4 Uncanny Valley

Although anthropomorphism is a quite effective as a technique to make robots more likable and as a result to create trust has some pitfalls. Mori [26] formulated the uncanny valley theory to describe the emotional reaction towards anthropomorphic robots. As it can be depicted in Fig. 1, as the human likeness of a non-human agent increases, people's emotional response to the stimulus becomes more positive. However, as human likeness reaches near perfection, people's emotional response starts declining and can become strongly negative. The region which immediately follows the start of the decline is the uncanny valley. Consequently, the uncanny valley theory assumes that negative emotions can be the result of a non-humans agent's placement on a continuum of human likeness. Researchers have proposed a variety of reasons to explain the phenomenon (e.g the fact that some human replicas elicit the uncanny feeling), including social, cognitive, evolutionary, and psychodynamic approaches [27]. The fact remains that anthropomorphism can sometimes backfire and lead to the opposite results when it comes to robot likeness and trust.

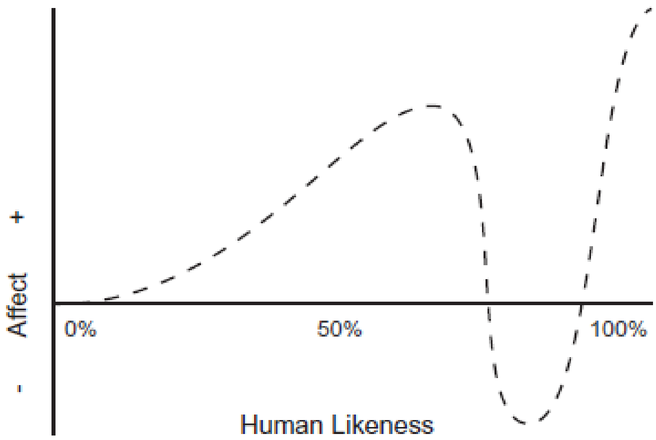


Figure. 1. The uncanny valley function, as proposed by Mori (1970)

2.1.5 Conclusion literature review

Trust is one important element for a successful HRC, therefore trying to stimulate it is of utmost importance. Many studies in the past tried to increase robot likeness, acceptance, and trust by trying to make robots look or behave more anthropomorphic [24]. Findings show that anthropomorphism can be a promising way to stimulate robot trust and facilitate a successful HRC [1] [2]. Therefore, we decided to use several ways of anthropomorphism to try to facilitate HRC in the use cases of CoLLaboratE. However, as Uncanny Valley theory suggests, anthropomorphism can potentially backfire and fail to yield the expected results. Therefore, we decide to pre-test some of the anthropomorphic techniques which are suitable for the use case, which had not been tested before in previous studies. To test the techniques we designed laboratory studies carefully implementing the techniques and assess their impact on human trust and the acceptance towards robots.

2.2 ANTROPOMORPHIC TOUCH STUDIES

2.2.1 Preliminary study

The goal of the study is to test whether an anthropomorphic gesture (handshaking) from a robot can create more trust in humans as compared to non anthropomorphic gesture (grab the handle).

2.2.1.1 Method

The experiment took place in the lab of AUTH with a 7 dof robotic manipulator. As participants for the experiment, we used students of AUTH. 25 participants were invited to the lab (7 Female, M_{age}=21.76, SD=3.36).

2.2.1.2 Procedure

Participants were randomly assigned to one of the two conditions of the study: 1) non-anthropomorphic condition where participants had to “move” a collaborative robot sideways (left to right and vice versa) and the 2) anthropomorphic condition whether participants had to perform a handshake with the robot. The robot used in the experiment was a KUKA LWR4+ 7dof robotic manipulator. The method used to program the robotic arm to perform the two actions (non-anthropomorphic and anthropomorphic) was a kinematic control method for physical human-robot interaction which achieves a fast motion synchronization given a preset internal robot handshake motion and a compliance level that reflects the robot's level of passiveness [28]. Figure 2 demonstrates a handshake with the robot.

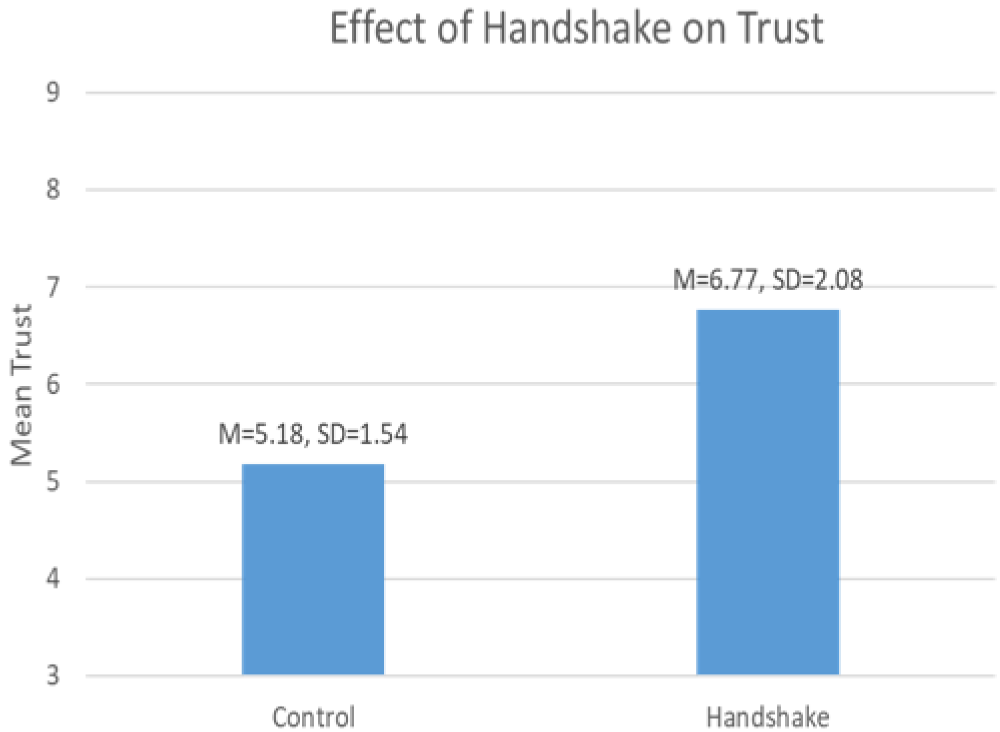
After performing the action with the robot participants were asked the following questions:

How much do you trust the robot? (1 Not at all – 9 Very much so).
How much do you trust the robots in general? (1 Not at all – 9 Very much so).
How willing would you be to cooperate with the robot? (1 Not at all – 9 Very much so).
How willing would you be to cooperate with the robots in general? (1 Not at all – 9 Very much so).
The last part consisted the demographic questions part (age, gender, level of education).

Figure. 2. Handshake with the robot

2.2.1.3 Results

The results revealed that handshaking created more trust towards the robot of the study and more willingness to collaborate. As shown in Figure 3, the difference between the control and the anthropomorphism condition was statistically significant for both trust (t(23)=-2.190, p=0.039) in the robot from this study and willingness to collaborate with the robot from this study (t(23)=-2.520, p=0.019). However, handshake did not seem to result in more trust (t(23)=-0.397, p=0.695) and willingness to collaborate (t(23)=-0.258, p=0.799) with robots in general.



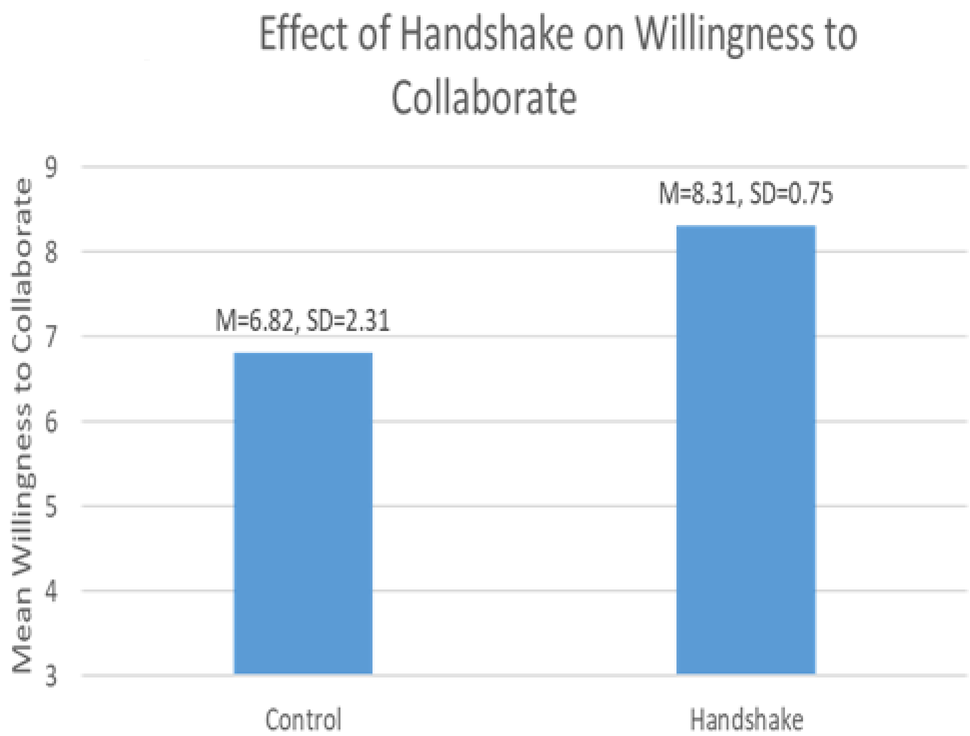


Figure 3. Results of the preliminary study

The results study indicate that a handshake can be used to increase the trust and willingness to collaborate with robots. Note that we found the effect only for the robot used in our experiment, However, the sample size in the present study was quite small. Therefore, we wanted to try to replicate the results in a second study with a larger sample.

2.2.2 Main study

The goal of the main study was to try to replicate and extend the results of the preliminary study with a larger sample size. Specifically, we examined how different touching styles (i.e., anthropomorphic touching, non-anthropomorphic touching, no touching) affect human trust towards robots.

2.2.2.1 Method

The experiment was conducted in the lab of AUTH with the KUKA LWR4+ robot. A total of 96 young adults (57 females, 38 males, 1 undisclosed; M_{age} = 20.99, SD_{age} = 2.83) participated in the between-subject experiment. Participants were mostly students from various faculties of two public universities in Greece. They were recruited through email advertisements. Four participants were excluded from the analysis, as due to a technical error we could not calculate all metrics.

2.2.2.2 Procedure

Participants were welcomed and assigned randomly into one of the three conditions: 1) no touching condition where participants had to watch the collaborative robot perform a movement sideways (left to right and vice versa), 2) non-anthropomorphic touching condition where participants had to grab the grip of the robot and perform a sideways movement (from left to right and vice versa) and 3) anthropomorphic touching condition where participants had to perform a handshake with the robot. After that participants were moved to another room and placed in front of a desktop where they were asked to fill in the questionnaire of the study.

2.2.2.3 Measures

We measured several dependent variables after human-robot interaction (Table 1).

Self-reported Trust: Participants were invited to rate on a 9-point scale of two statements assessing the extent to which they trusted the robot:

1) How trustworthy did the robot appear to you? (1 = Not at all – 9 = Very much so; [29])
2) I would trust the robot to do its job (1 = I completely disagree – 9 = I completely agree; [30]).
3) The two items were highly correlated (r = 0.74) and therefore combined.

Behavioral Trust: Participants were asked if they wanted to perform two additional tasks with the robot at the end of the questionnaire. First, they were asked if they wanted to let the robot touch them on the cheek. Secondly, they were asked if they wanted to play the trust fall game with the robot (deliberately allow themselves to fall, trusting the robot to catch them). We aggregated the answer in a measure with three levels (0=Refused to perform any of the tasks, 1=Agreed to perform one of the two tasks, 2=Agreed to perform both of the tasks). In reality, the participants were not actually expected to perform the tasks and they were debriefed about this deception after the end of the study.

Human-likeness: Participants were invited to rate on a 9-point scale one statement on human-likeness:

1) To which extent do the robot appears human (1 = Non-human–9 = Very human-like; [31]).

Eeriness: Participants were invited to rate on a 9-point scale one statement on eeriness:

1) To which extent do the robot appears strange/familiar (1 = Very strange–9 = Very familiar; [31]).

Table 1

Measurement items used in the Anthropomorphic Touch main study

Variables	Scale
Self-reported trust	
How trustworthy did the robot appear to you?	1 Not at all – 9 Very Much so
I would trust the robot to do its job	1 I Completely Disagree – I completely Agree
Human-likeness	
How human-like does the robot appears to be	1 Non-human- 9 Very human-like
Eeriness	
How strange/familiar does the robot appears to be	1 Very strange- 9 Very familiar

Effort applied from and to the robot during touching: The effort put from the participants to the robot and vice versa during touching was measured by the energy transferred by the human to the robot and vice versa. This is calculated based on the estimated interaction force provided by the robot and the measured end-effector velocity calculated via numerical differentiation of the robot's pose. More specifically, let $F = [f^T \ \tau^T]^T \in \mathbb{R}^6$ be the generalized forces applied on the end-effector of the robot with $f \in \mathbb{R}^3$ being the force and $\tau \in \mathbb{R}^3$ being the torque, and let $V = [\dot{p}^T \ \omega^T]^T \in \mathbb{R}^6$ be the generalized velocity of the end-effector, with $\dot{p} \in \mathbb{R}^3$ being the translational and $\omega \in \mathbb{R}^3$ being the angular velocity. The total power of the interaction is found by:

$$P(t) = F^T V.$$

Due to the nature of the direction of the measured forces, negative values of P reflect a flow of mechanical energy from the human to the robot, while positive values of P reflect a flow in the opposite direction (Fig. 4). Hence, the maximum power transferred from the human to the robot is calculated by:

$$P_h = \sup\{-P\,(t) : t \in [0, T]\},$$

where T is the total duration of the interaction. Similarly, the maximum power transferred from the robot to the human is calculated by:

$$P_r = \sup\{P\,(t) : t \in [0, T]\}.$$

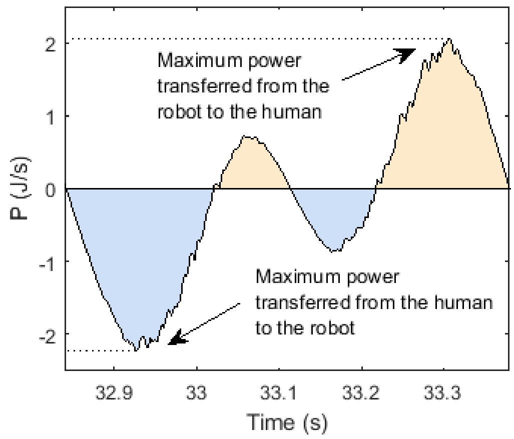


Figure 4. Transferred power between the human and the robot. Cyan region: total energy transferred from the human to the robot, yellow region: total energy transferred from the robot to the human.

We calculated two different measures: One for the effort applied from the human to the robot and one for the effort applied from the robot to the human. The higher the value of the measurement the higher the effort put applied by the participant and/or the robot.

2.2.2.4 Results

Our analysis revealed that there is no statistical difference between the conditions for both self-reported and behavioral trust (Table 2). When it comes to human-likeness, there was no difference between no touching and anthropomorphic touching condition (t(60)=-0.69, p=0.49), as well as between non-anthropomorphic touching and anthropomorphic touching (t(55)=1.43, p=0.16). However, there was a significant difference between no touching and non-anthropomorphic touching (t(63)=-2.07, p=0.04). In the non-anthropomorphic touching condition, the robot was perceived as more human than in the no-touching condition (Table 3). With regard to the eeriness, there was no significant difference between no touching and non-anthropomorphic touching (t(63)=-1.58, p=1.19) and between non-anthropomorphic and anthropomorphic touching (t(55)=-76, p=0.45). However, there was a significant difference between no touching and anthropomorphic touching (t(60)=-2.55, p=0.01). Anthropomorphic touching was perceived as less eerie than no touching (see table 2). There was no difference between conditions for the effort applied from the robot (t(55)=0.85, p=0.39). However, we found a significant difference between the non-anthropomorphic touching and anthropomorphic touch for the effort applied to the robot (t(55)=2.48, p=0.016). In the non-anthropomorphic condition, the robot applied more effort to the participants than in the anthropomorphic condition (Table 3).

Table 2

T-test result for trust items

	Self-Reported Trust		**Behavioral Trust**	
Conditions	t	p	t	p
No touching – Non-anthropomorphic touching	0.38	0.70	0.18	0.85
No touching – Anthropomorphic touching	-0.73	0.47	0.17	0.86
Non-anthropomorphic touching Anthropomorphic touching	-1.20	0.24	-0.20	0.98

Table 3

Means and standard deviations for all dependent variables between the three experimental conditions

	No touching	Non-anthropomorphic touching	Anthropomorphic touching
Self-reported Trust	6.64 (1.60)	6.50 (1.35)	6.9 (1.19)
Behavioral Trust	1.40 (0.69)	1.37 (0.76)	1.37 (0.63)
Human-Likeness	4.43 (2.12)	5.47 (1.88)	4.78 (1.74)
Eeriness	4.57 (1.60)	4.57 (1.95)	5.63 (1.64)
Effort Applied to the Robot		7.94 (5.73)	8.38 (6.73)
Effort Applied from the Robot		6.53 (6.73)	4.49 (2.69)

To assess the moderating role of the effort put from and to the robot we conducted two different series of Ordinary Least Squares (OLS) regression analysis. In the first series, we used the different conditions (0=Non-anthropomorphic touching, 1=Anthropomorphic touching) and the effort applied from the robot to the participant during touching, as dependent variables (note that we left out the no-touch condition as there was no physical interaction in this condition). In the second series, we used the different conditions (0=Non-anthropomorphic touching, 1=Anthropomorphic touching) and the effort applied from the participant to the robot during touching. We found no significant interaction between the conditions and the effort applied from the robot to the participants in any of our dependent variables (Table 4). However, we found a significant interaction between the conditions and the effort applied from the participants to the robot during touching on three dependent variables: self-reported trust, behavioral trust, and eeriness (Table 5). The direction of the interaction as well as a simple slope analysis (one standard deviation above and below the mean of the effort applied to the robot; [32]) show that for low levels of effort from human to robot, the handshake had a positive effect on the dependent variables (participants trust more and considered the robot more familiar). For high levels of effort from human to robot, the regression did not reveal any significant effects. The results remain the same when control for gender effects.

Table 4

Results for moderation and simple slope analysis for the effort put from the robot

State	Effect of condition	Effect of the effort	Interaction
Self-reported Trust	b=0.198 t=0.513 p=0.610	b=-0.054 t=-1.128 p=0.264	b=-0.127 t=-1.267 p=0.211
Behavioral Trust	b=0.005 t=0.025 p=0.979	b=0.003 t=0.109 p=0.913	b=-0.045 t=-0.829 p=0.411
Human-Likeness	b=-1.391 t=-2.745 p=0.008	b=-0.194 t=-3.067 p=0.003	b=-0.192 t=-1.456 p=0.151

Eeriness	b=0.516 t=0.991 p=0.326	b=0.052 t=0.805 p=0.424	b=-0.148 t=-1.096 p=0.278

Table 5

Results for moderation and simple slope analysis for the effort put to the robot

State	Effect of condition	Effect of the effort	Interaction
Self-reported Trust	b=0.409 t=1.230 p=0.224	b=0.007 t=0.276 p=0.783	b=-0.126 t=-2.330 p=0.024
Behavioral Trust	b=0.020 t=0.111 p=0.912	b=0.015 t=1.018 p=0.313	b=-0.067 t=-2.254 p=0.028
Human-Likeness	b=-0.781 t=-1.669 p=0.101	b=-0.058 t=-1.506 p=0.138	b=-0.134 t=-1.778 p=0.083
Eeriness	b=0.425 t=0.938 p=0.353	b=0.055 t=1.481 p=0.144	b=-0.216 t=-2.938 p=0.005

Figure 5. Results for the interaction between condition and effort applied to the robot

The results revealed no effect of touching on trust towards the robot. However, they revealed a positive effect of non-anthropomorphic touching (compared to no touching) on human-likeness and a positive effect of anthropomorphic touching (compared to no touching) on familiarity. Furthermore, our results revealed that the amount of effort applied from the human to the robot can act as a moderator of the effect of anthropomorphic touching (compared to non-anthropomorphic touching) on the feelings of trust and familiarity towards the robot.

2.2.3 DISCUSSION

Human-robot interaction (HRI) is becoming more frequent day by day, however, many aspects of people's physiological, emotional, and behavioral responses remain unclear. An important feature of HRI is non-verbal communication such as touching. Research has tried to clarify the effect of touching (anthropomorphic and/or non-anthropomorphic), however, the results are contradictory. Some studies have shown positive effects of touching compared to no touching, while others report zero or negative effects. We conducted a study to explore whether anthropomorphic touch compared to non-anthropomorphic touch and robot motion (no touching) can influence the perceptions of human-likeness, eeriness, and trust. Moreover, we tested how the effort applied during touching from and to the robot can influence the results.

When it comes to human-likeness and eeriness the results exhibited an unexpected pattern. On the one hand, the non-anthropomorphic touching made the robot appear more human-like than the no touching condition, but this was not the case for the anthropomorphic touching (the difference with no touching condition was positive but not significant). On the other hand, the anthropomorphic touching made the robot look less eerie (more familiar) than in the no touching condition, however, the non-anthropomorphic touching did not yield the same effect (participants found the robot less eerie in the non-anthropomorphic touching condition compared to no touching but the difference was not significant). We did not find any significant differences in both self-reported and behavioral trust across three conditions. Furthermore, for three out of four dependent variables we found that the effect of anthropomorphic touching (when it is compared with the non-anthropomorphic touching) is moderated by the effort applied from the participant to the robot during the interaction. We found that for low levels of effort, the handshake has a positive effect on the dependent variables (participants trust more and considered the robot less eerie). We are currently working on a publication of the results of the anthropomorphic touch study.

3 STUDY 2 – REALISTIC HRC VIDEO

3.1 LITERATURE REVIEW

As stated above, the main goal of T2.4 is to identify and apply behavioral interventions that could facilitate the HRC in the use cases. In the first studies described in the second section of this deliverable, researchers of KU Leuven investigated whether an anthropomorphic touch of the robots could lead to higher levels of trust in the robot and a higher HRC. The results of this first study seems promising as anthropomorphic touching (when it is compared to non-anthropomorphic touching) seems to facilitate trust and collaboration but it is moderated by the effort applied from the participant to the robot during the interaction.

However, the use of anthropomorphic touch is not applicable to all kind of robots. For example, the robot that is used in this second study (UVD-robot) has no human-like features such as hands or arms. It is therefore impossible to let this robot perform an anthropomorphic touch. This is exactly why this second study was computed. With this second study, we aimed at investigating another behavioral intervention that is successful in fostering HRC, but that could be applied to all kind of robots independent of the presence of humanlike physical features.

3.1.1 HRC and imagined contact

During a second extensive literature review, the term of imagined contact gained our interest. Imagined contact (IC) is defined, by [33] (pg. 234), as the 'mental simulation of a social interaction with members of an outgroup category'. In social psychological studies, IC was revealed as an effective way to foster collaboration with members from outside groups [34]. Concretely, an IC that was similar to the real contact was effective in stimulating positive effects during interactions. In a more recent study, the idea of IC was applied to HRC. Concretely, [35] investigated whether imagining an interaction with a robot in a realistic way (highly similar with the real interaction) would lead to a higher perceived HRI quality than imagining an interaction with a robot in a less realistic way (less similar with the real interaction). Their results indicated that participants perceived the HRI quality as higher and displayed more social behavior towards the robot when the imagined task was more similar to the real interaction that followed [35]. The results of [35]'s study suggests that if individuals can imagine a realistic interaction with a robot before engaging in the real HRI, they will be more positive towards the robots and the interaction, which leads to an increased HRC.

3.1.2 present study

Based on the results of [35], we could argue that stimulating IC in individuals could lead them to experience HRC as more positive, and thus resulting in a better HRC in the long-term. However, asking individuals to imagine a realistic collaboration with a robot might be difficult to control in everyday life, making it difficult to apply in work and industrial settings. It might be impossible for an employer to control if all his employees, required to collaborate with robots, really did imagine a realistic contact beforehand.

The current study aims at providing a solution to this problem, by investigating whether presenting individuals with a video showing a realistic HRC contact, as an alternative to asking individuals to imagine this contact, might have the same positive effect on the real HRC than suggested by [35]. The current study was conducted in collaboration with Blue Ocean, which provided a robot that could be used for the study. We decided to use the UVD-robot (https://uvd.blue-ocean-robotics.com/) because of it's implementation in different domains (medical, commercial,…) and the fact that it requires a collaboration with a human. The human is required to stay close to the robot, to guide the robot and to evaluate the robot's work. We believe that the proposed intervention could be applied to any kind of robots, as the goal is to present individuals with a video showing them how they will have to collaborate with the robot to accomplish a task (which can be of any type) in the future. If the intervention seems successful, stakeholders will have to film a realistic collaboration with their own robot (robot and employee performing the task they are required to fulfill), and present this video to other employees to stimulate a positive HRC. The use of a video allows us to design a flexible intervention that can be easily applied in different domains (e.g. industry) and with different robots.

In the current study, participants will be asked to imagine that they will start a new job in a hospital as a "Disinfection Manager", for which they will be required to collaborate with the UVD-robot. Three videos will be computed, the first video (unrelated) will show participants a guided-tour of the hospital for which they will be working, the second video (unrealistic HRC) will show participants with a general introduction of the UVD-robot, while the third video (realistic HRC) will show participants with a realistic collaboration with the UVD-robot. Following the results of [35], we expect that participants viewing the realistic HRC video will be more willing to participate and trust the robot in the future than participants viewing the two other videos.

3.2 STUDIES

3.2.1 study A

The goal of study A was to investigate the influence of the intervention on participants and to test whether our different hypotheses could be supported. Based on the literature, we hypothetized that:

(1) participants in condition 3 will have higher levels of willingness to collaborate (WTC) with the robot than participants in condition 1 and condition 2;
(2) participants in condition 3 will have higher levels of perceived trust towards the robot than participants in condition 1 and condition 2;
(3) participants in condition 3 will have higher levels of perceived interaction quality than participants in condition 1 and condition 2;

3.2.1.1 Methods

Participants and design. In total, 305 individuals participated in the online survey. Four participants were excluded from the analyses because their responses were not complete. The sample's age ranged from 18 to 55 years old (M= 24.99, SD= 6.82), with 112 men, 185 women, and 4 others. Participants were randomly divided into three groups, 101 participants were assigned to the first condition (control, condition 1), 100 participants were assigned to the second condition (the robot presentation condition, further called the presentation condition, condition 2), and 100 participants were assigned to the third condition (the realistic HRI condition, further called the HRI condition, condition 3).

Procedure. Participants were recruited through the online platform Prolific (https://prolific.co/). Participants received a participation fee through their Prolific account after completing the survey. After receiving a notification of participation, participants were redirected to the Qualtrics survey. Before answering the questions, an informed consent (Annex A) was presented and participants had to agree with it to be presented to the first question. The survey starts with demographical questions, such as gender, age, professional status and education. Thereafter, participants were randomly divided across the three conditions and presented with their condition's video (+- 2 minutes). The hyperlinks of the three video's can be found in Table 6. After watching the videos, participants were asked to fill in questionnaires on WTC [36], perceived trust [36], and perceived interaction quality [35]. After filling in the questionnaires of the dependent variables, participants had to fill in questionnaires of control variables: overall attitude towards robots [4], negative attitudes towards robots [37], and the Big Five personality traits [38]. All variables (except for the Big Five personality) were measured on a 7-point scale (1 = "Strongly disagree/not at all" to 7 = "Strongly agree/very much"). Note that the Big Five personality was measured on a 5-point scale (1 = "Strongly disagree" to 5 = "Strongly agree"), consistent with practice in literature. At the end of the survey, participants were given the opportunity to leave comments for the researchers.

Table 6
Hyperlinks to the video's used as intervention in the HRC video study

Condition	Hyperlink
Condition 1	https://youtu.be/vkSC1Sy1-Bw
Condition 2	https://youtu.be/-Q9EY8oiMsk
Condition 3	https://youtu.be/QQTo72dxMkA

Analysis. In study A, we are comparing three different conditions on three different dependent variables. Therefore, we computed one-way ANOVA's in the statistical analyses program R. To investigate the correlation between dependent variables and control variables, we computed a correlation plot in R.

3.2.1.2 Results

Willingness to collaborate (WTC). No significant differences between the three conditions were found for the dependent variable WTC (F(2,298) = .14, p = .87). Figure 6 displays the results: Participants in condition 3 (M = 5.26, sd =1.27) did not experience higher levels of WTC than participants in condition 2 (M = 5.28, sd = 1.32) or condition 1 (M = 5.19, sd = 1.16).

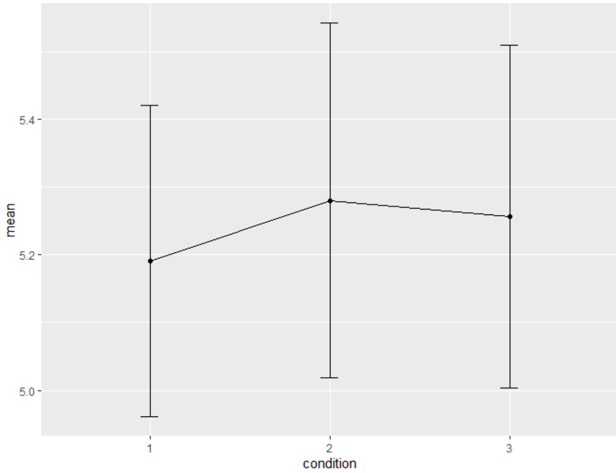


Figure 6. Mean WTC by Condition

Perceived trust. As for WTC, no significant differences were found between the three conditions for the second dependent variable perceived trust ($F(2,298) = 2.09$, $p = .13$). Figure 7 diplays the results: Participants in condition 3 (M = 5.37, sd = 1.39) did not experience higher levels of perceived trust than participants condition 2 (M = 5.70, sd = 1.0) or condition 1 (M = 5.54, sd = 1.0).

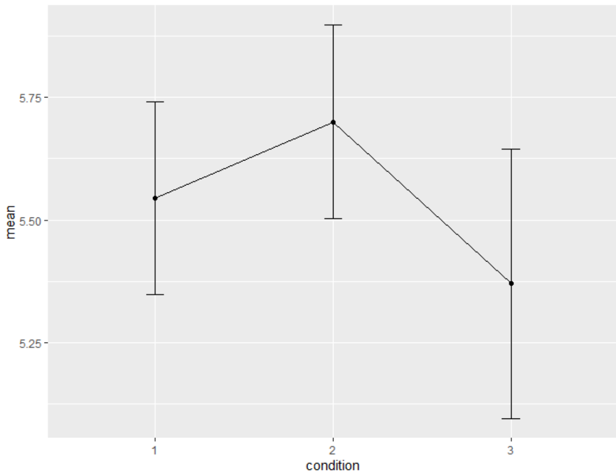


Figure 7. Mean perceived Trust by Condition

Perceived Interaction Quality. As can be seen on Figure 8, and as for the WTC and perceived trust, no significant differences were found between the three conditions for perceived interaction quality ($F(2,298) = .87$, $p = .42$). This means that participants in condition 3 (M = 5.13, sd = 1.39) did not perceived higher levels of trust than participants in condition 2 (M = 5.17, sd = 1.29) or condition 1 (M = 4.95, sd = 1.10).

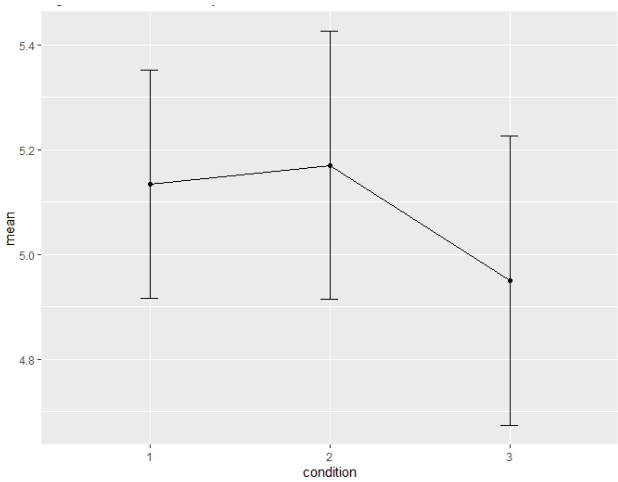
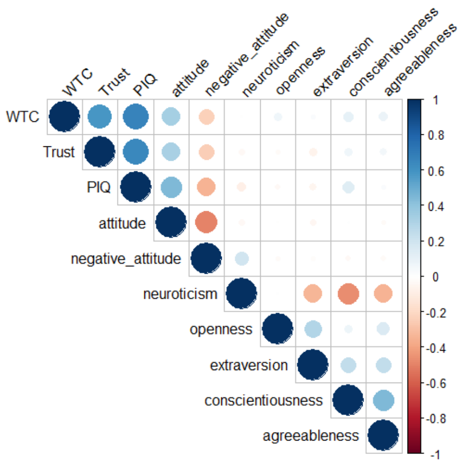


Figure 8. Mean Perceived Interaction Quality by Condition

Correlation with control variables. As can be seen on the Figure 9, the three dependent variables (WTC, perceived trust, perceived interaction quality) are positively correlated to individuals' attitude towards robots. Concretely, the three dependent variables are positively related to positive attitude towards robots and negatively related to negative towards robots, suggesting that individuals who are already positive towards robots will be more likely to collaborate with robots, trust robots, and experience the interaction as qualitative; while individuals who are negative towards robots will be less likely to collaborate or trust robots.



Note. A positive correlation is indicated by a blue color, while a negative correlation is indicated by a red color. The strenght of the correlation is displayed by the size of the circle. A larger circle indicates a stronger correlation, while a smaller circle indicates a weaker correlation.

Figure 9. Correlation between dependent variables (WTC, Trust, PIQ) and the control variables

Exploratory Analysis Gender. In this exploratory analysis, we investigate with the help of two-ways ANOVA's if there is a significant interaction between the variables gender and condition on the three dependent variables investigated above. For dependent variable WTC, the interaction term was significant ($F(3,293) = 3.21$, $p = .02$), meaning that in condition 1 and condition 2 women had higher levels of WTC while men had higher levels of WTC in condition 3 (Figure 10). The main effect of gender was, similar to the main effect of condition, not significant ($F(2,293) = 1.55$, $p = .21$). For the dependent variable perceived trust, both the interaction effect ($F(3,293) = 1.37$, $p = .25$) and main effect of gender ($F(2,293) = 2.34$, $p = .10$) were not significant. For the dependent variable perceived interaction quality, the interaction effect was marginally significant (F(3,293) = 2.44, p = .07) and the main effect of gender (F(2,293) = 2.18, p = .12) was not significant.

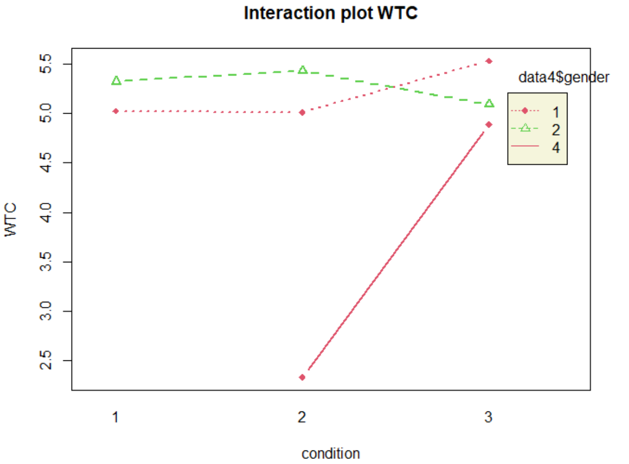


Figure 10. Interaction plot showing the relation between condition variable and gender on dependent variable WTC

3.2.2 study B

The goal of study B was to replicate and extend the results of study A, to investigate the investigate the robustness of the gender effect found in the exploratory analyses of the previous study, and to investigate the possible effect of condition on anthropomorphism. The gender effect found in the previous study is investigated further in study B, as it could be interesting to know if a different intervention is needed for male than female employees.

3.2.2.1 Methods

Participants. 465 individuals participated in study B. Of those, fourteen participants were excluded from the analyses because their responses were not complete, resulting in a sample of 451 participants. The sample's age was a bit older than in the previous study and ranged from 18 to 70 years old (M= 28.41, SD= 9.21), with 222 men, 223 women, and 6 others. Participants were randomly divided into three groups, 147 participants were assigned to the first condition (control, condition 1), 153 participants were assigned to the second condition (the robot presentation condition, further called the presentation condition, condition 2), and 151 participants were assigned to the third condition (the realistic HRI condition, further called the HRI condition, condition 3).

Procedure. The procedure of study B was similar to the procedure of study A, presented above. With the exception of the measurement of anthropomorphism, which was not present in study A. The measurement of anthropomorphism [39] was placed after the measurement of the previously mentioned dependent variables (WTC, perceived trust, and perceived interaction quality) and before the measurement of the control variables.

Analysis. The goal of study B was to replicate and extend the results of study A, and to investigate the influence of anthropomorphism on the different dependent variables. As with study A, one-way ANOVA's in the statistical analyses program R were computed. The effect of condition on anthropomorphism was similarly measured using one-way ANOVA. To investigate the correlation between dependent variables and control variables, we computed a correlation plot in R.

3.2.2.2 Results

Willingness to collaborate (WTC). In contrary to study A and as can be seen on Figure 11, a significant difference between the three conditions was found on WTC (F(2,448) = 5.73, p = .004).

The contrast analysis revealed that participants in condition 3 (M = 5.10, sd =1.53) experienced lower levels of WTC than participants in condition 2 (p= .005) (M = 5.59, sd = 1.20) or condition 1 (p= .02) (M = 5.51, sd = 1.34), while condition 2 and condition 1 did not significantly differ from each other (p= .87).

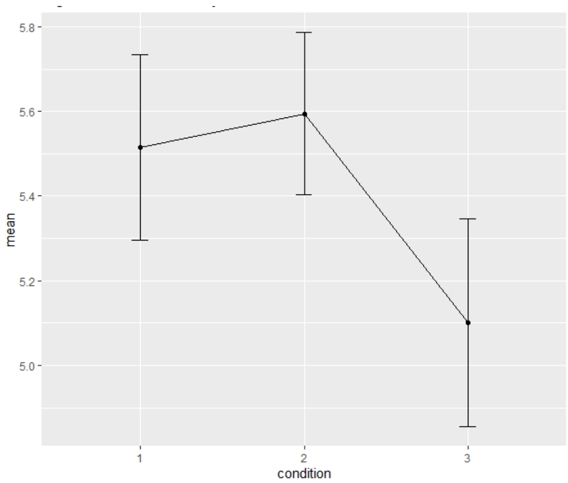


Figure 11. Mean WTC by Condition

Perceived trust. For perceived trust (Figure 12), a significant difference between the three conditions was also found ($F(2,448) = 10.87$, $p < .001$). The contrast analysis revealed that participants in condition 2 (M = 6.04, sd = .93) experienced lower levels of trust towards the robot than participants in condition 3 (p < .001) (M = 5.43, sd =1.35) and participants in condition 1 (p= .01) (M = 5.65, sd = 1.18).

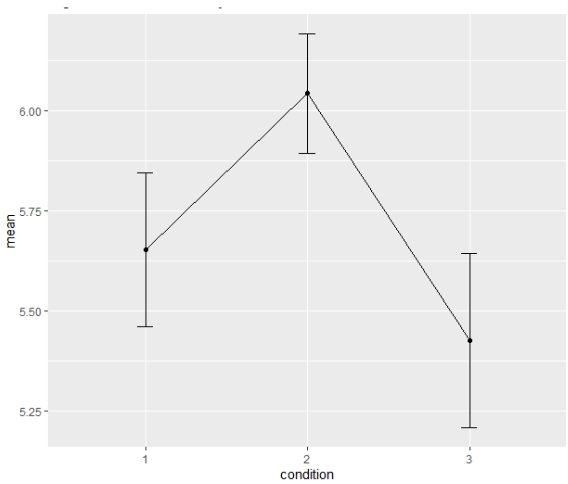


Figure 12. Mean Perceived Trust by Condition

Perceived Interaction Quality. Similarly, for the variable perceived interaction quality (Figure 13), a significant difference between the three conditions was found ($F(2,448) = 5.66$, $p = .004$). The contrast analysis revealed that participants in condition 3 (M = 4.99, sd =1.40) experienced lower levels of perceived interaction quality than participants in condition 2 (p= .003) (M = 5.50, sd = 1.29), but did not significantly differ from condition 1 (p= .06) (M = 5.35, sd = 1.38). Participants in condition 2 and condition 1 did not significantly differ from each other (p= .62).

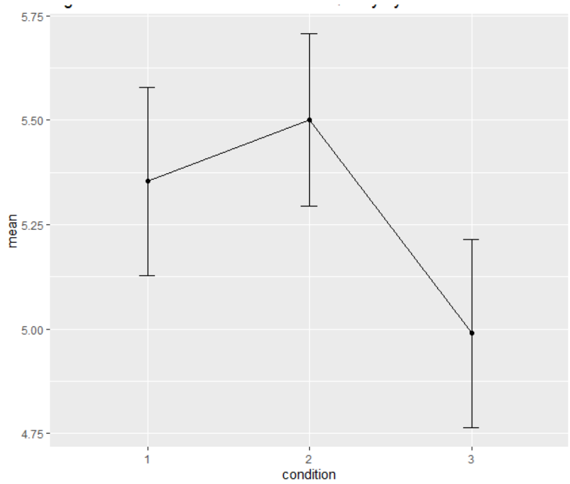


Figure 13. Mean Perceived Interaction Quality by Condition

Anthropomorphism. The effect of condition on the reported levels of anthropomorphism (Figure 14) by the participants was investigated, a significant effect of condition was found ($F(2,448) = 3.60$, $p = .03$). The contrast analysis revealed that participants in condition 2 ($M = 4.16$, $sd = 3.00$) attributed higher levels of anthropomorphism to the robot than ($p = .02$) participants in condition 3 ($M = 3.28$, $sd = 2.62$), and did not differ from participants in condition 1 ($p = .69$) ($M = 3.88$, $sd = 3.13$).

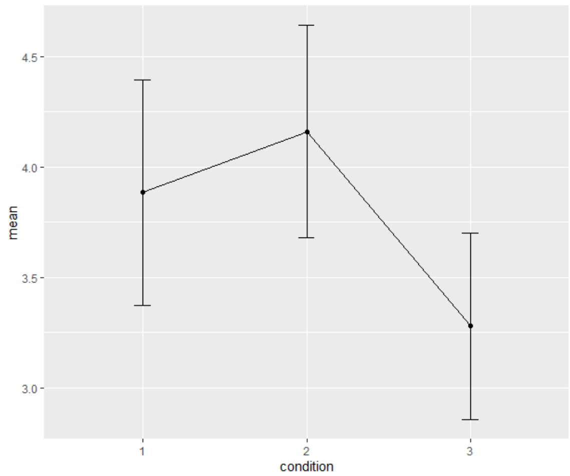
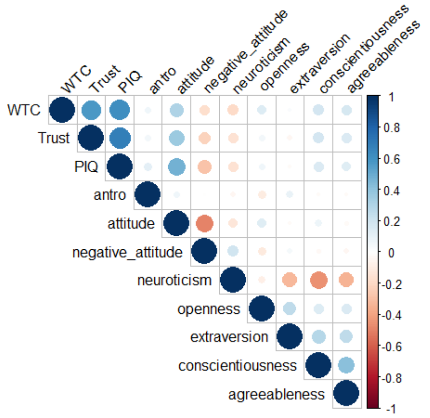


Figure 14. Mean Antropomorphism by Condition

Correlation with control variables. As can be seen in Figure 15, WTC, perceived trust, and perceived interaction quality are correlated to individuals' attitude towards robots. Concretely, this means that participants who are already positive towards robots will be more likely to collaborate with robots, trust robots, and experience the interaction as qualitative; while participants who are negative towards robots will be less likely to collaborate or trust robots. Additionally, WTC, perceived trust, and perceived interaction quality are correlated with personality traits neuroticism, conscientiousness and agreeableness. This means that participants scoring higher on neuroticism will be less likely to collaborate, trust, and rate the interaction with the robot as high quality, while the opposite is true for participants scoring higher on conscientiousness and agreeableness. The dependent variable anthropomorphism is not strongly related to any of the control variables.The effect of condition on the control variables "attitude" and "negative" attitude was investigated wit the help of a one-way ANOVA analysis. The results revealed that condition had no significant effect on attitude ($F(2,448) = .60$, $p = .55$), nor on negative attitude ($F(2,448) = .11$, $p = .89$).



Note. A positive correlation is indicated by a blue color, while a negative correlation is indicated by a red color. The strenght of the correlation is displayed by the size of the circle. A larger circle indicates a stronger correlation, while a smaller circle indicates a weaker correlation.

Figure 15. Correlation between dependent variables (WTC, Trust, PIQ, antropomorphism) and the control variables

Exploratory Analysis Gender. In study A, a significant interaction between condition and gender on the depend variable WTC was found, suggesting that men in condition 3 were more likely to collaborate with a robot than men in condition 1 or condition 2, while women in condition 3 were less likely to collaborate with the robot than women in condition 1 or condition 2. In study B, we failed to replicate this gender effect as no significant interaction nor main effect was found for the three dependent variables WTC ($F(2,443) = .25$, $p = .78$; $F(3,443) = .72$, $p = .54$), perceived trust ($F(2,443) = .29$, $p = .75$; $F(3,443) = .97$, $p = .41$), and perceived interaction quality ($F(2,443) = .19$, $p = .83$; $F(3,443) = 1.81$, $p = .14$).

3.2.3 discussion

Based on [35], we stated that presenting participants with a realistic video of HRC they will experience with the robot would lead them to be more open and prone to collaborate with the robot, trust the robot and rate the interaction quality higher.
We failed to confirm this hypothesis in study A, with the exception of a gender effect on WTC. Concretely, male participants seemed to be positively influenced by our realistic HRC video intervention and reported higher levels of WTF.
In study B, we again failed to confirm our hypotheses and to replicate the gender effect found in study A. However, study B highlighted new significant effects that could be interesting to consider. Results of study B revealed that participants in condition 2 reported higher levels of trust towards the robot, and rated the robot as more anthropomorphic. Concretely, this suggests that presenting individuals with a video of the future collaboration with the robot is not necessary, and even inefficient, in promoting a positive HRC. However, presenting individuals with a general introduction of the robot, they will be collaborating with, is sufficient in increasing trust towards the robot and anthropomorphic aspects of the robots. As both perceived trust and anthropomorphism were previously related to more positive human-robot interactions [40] [41], it could be interesting to use the intervention to increase trust and anthropomorphic aspects of the robots in employees. A suggestion for stakeholders looking to improve HRC in their

employees, would be to prepare an general presentation of the robot and show it to the employees before theur first contact with the robot.
The failure to replicate the gender effect found in study A could be explained by the fact that the sample was unbalanced in the first study and balanced in study B. The unbalanced sample of study A might have lead to a significant gender effect by accident, however the balanced sample of study B shaded lights on that accident.
The fact that the "introduction of the robot" video condition leads to higher levels of trust and anthropomorphism seems to suggest that a detailed video presenting a realistic interaction is not necessary to foster HRC. Presenting individuals with a clear and objective introduction and explanation of the robot might be enough. Another possibility could be that the relatsic HRC video did not elicit positive emotions in participants due to the type of robot used in this study. The UVD-robot is a hygenical robot using UV-lights to clean and disinfect the room, it might be that participants were afraid of the consequence sof using UV-lights, which was clearly showed in the realistic HRC video condition, leading to less willingness to interact with this type of robot. Follow-up studies using another type of robot should be conducted to test this possibility in more details.

3.2.3.1 Limitations of the current study

Due to the covid-19 regulations at the time of the study, the current study was conducted online. However, it might be that presenting a realistic HRC with the UVD-robot in real life could increase willingness to interact with the robot more strongly, as participants will be able to clearly see how the robot works and that the robot is harmless for humans' health and safety.
Another limitation of an online survey is the fact that attention of participants could not be controlled. Participants were asked to watch a video as intervention, and a timer was added to the survey to make sure that participants couldn't switch to the next page before the end of the video. However, we were not able to control wether participants switched to another browsing page during the video or not. If participants were not attentionnely watching the intervention video, that might have influenced the results.
A final limitation, again related to the online design of the study, is the fact that a real collaboration was not possible after the intervention and before measurments. The effect of the intervention might have been stronger if participants had a real collaboration contact with the robot after being presented with the video, similar to the design of [35].

4 CONCLUSION

For the current deliverable, two kinds of intervention were tested: (1) anthropomorphic touch and (2) realistic HRC video. The effectiveness of both interventions was tested with two studies, resulting in the reporting of four studies in this deliverable.
Concerning the anthropomorphic touch intervention, the results suggests that (1) the non-anthropomorphic touching made the robot appear more human-like than the no touching condition but this was not the case for the anthropomorphic touching, (2) anthropomorphic touching made the robot look less eerie (more familiar) than in the no touching condition, however, the non-anthropomorphic touching did not yield the same effect, and (3) for three out of four dependent variables we found that the effect of anthropomorphic touching (when it is compared with the non-anthropomorphic touching) is moderated by the effort applied from the participant to the robot during the interaction.
Concerning the realistic HRC video, the results suggests that exposing participants to a video presenting a realistic HRC is not effective in increasing willingness to collaborate with a robot, trust towards the robot, and the perceived quality of the interaction. However, the results of study B seem to suggest that presenting participants with a general introduction of the robot might lead

to higher trust towards the robot and attributing a higher anthropomorphism score to the robot, which could help foster human-robot interaction.

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6 ANNEXES

6.1 ANNEX A

Informed consent used in the real HRC video study

Dear Participants,

Welcome to our study. This short study aims to collect information regarding robots and takes roughly 8 minutes. Please read the instructions, questions, and scale labels carefully. There are no right or wrong answers.

Subject's rights: Participation in this study is totally voluntary, you are under no obligation to take part in this study. The data that you provide will be very useful for our study. If you decide to participate, you will be asked to sign a consent form. You have the right to withdraw from the study at any time and without giving a reason.

Anonymity and data confidentiality: The information you provide will be confidential. Once the data is analyzed, a report of the findings may be submitted for publication. Only broad trends will be reported and it will not be possible to identify any individuals. A summary of the results will be available from the researcher on request once the study is complete.

If you have any questions or require any further information, please contact the researchers or research supervisor.

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By clicking "I agree to participate", you acknowledge that you have read and understood the information provided above.