The influence of the perception of social touch on human-robot interaction

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Abstract

With the growing advances in social robotics, a need arises for more seamless and intuitive interactions. State-of-the-art humanoid social robots can perceive their environment and interact similarly to humans. However, they often lack the ability to perceive complex social touch-based interaction. This limits research into natural social touch-based interaction.

This work aimed to evaluate a human-robot interaction in which a robot can react to induced touch-based interaction in a social context. A 3D printable touch-sensitive shell was created for a Furhat robot, which allows it perceive touch-interaction. A within-subject experiment was conducted to evaluate the perception of the ability to touch. Participants were asked to read to the Furhat while trying to keep its attention. While reading the story, the Furhat lost its attention over time. In one condition, the Furhat regained its attention after a certain amount of time. In the other condition, the Furhat only regained its attention when touched. Both conditions were evaluated using the Artificial Social Agent Questionnaire. This work found that there is a statistically significant difference between the scores produced by the Artificial Social Agent Questionnaire for the two conditions, specifically on the Natural Behaviour, Agent's Appearance suitability, Agent's Usability Performance, Agent's Sociability, User's Trust, User-Agent Alliance, Agents Attentiveness and Agent's Intentionality social constructs.

Keywords— Social robotics, Social touch, 3D printing, Furhat

1 Introduction

When interacting with a social robot, humans prefer an interaction similar to human-human interaction (HHI) [1, 2, 3, 4]. Since social robots are becoming more prevalent in our daily lives [3, 5, 6, 7, 8], a need for more seamless and intuitive human-robot interaction (HRI) arises. Many humanoid social robots already use cameras to see, microphones to hear, speakers to talk and have a way of communicating body-language-like signals [9]. However, in certain social situations, humans also use touch as a modality for interaction [10, 11].

Humans can decode information from social touch interaction, such as meaning, intent and emotion [12, 13, 14]. However, social touch happens in complex social contexts with factors influencing this decoding, other than the touch alone [15, 16]. These factors include the location of the touch, interpersonal relationships and gender. Jones et al. [17] described twelve distinct touch categories and their dependent factors. One touch category they found is highly distinctive and less dependent on these contextual factors, attention-grabbing touch. This touch category is used to direct the receiver's attention to something.

Within social robotics, interaction via social touch is an upcoming field [11]. In recent years, work has been focused on giving robots the ability to physically sense touch and train machine learning models to decode the social meaning of touch. However, this research has mostly been conducted on disembodied and non-humanoid robots [18, 19, 20, 21, 22].

Popular humanoid social robots, such as NAO [23], Pepper [24] and Furhat [25] currently lack sensors to perceive complex touch-based interaction, which creates a barrier for exploring social touch interactions with these types of robots. Next to this, when social touch interactions are researched with humanoid robots, it is often not done in a social context [21, 22], while this is very important in human interaction [13]. And on top of this, touching the robot with a certain intent is often prompted instead of naturally induced [12, 26, 27, 28].

Another important aspect to consider in HRI research is that similar to HHI, a reaction to the interaction is expected within a certain time [11, 29]. If this response is not in time or not in line with human expectations, it can harm social interaction. The effect of this timing has been researched in human-machine interaction [30] and is also an upcoming area within HRI [31, 32]. Although timing is important in HRI it is not safety critical and therefore these systems can be categorised as soft real-time systems [33].

This thesis aims to evaluate a human-robot interaction in which a humanoid social robot can react to touch, which is induced in a social context.

The research question to be answered in this thesis is:

How does the adequate reaction of a humanoid social robot to induced attention-grabbing touch influence the Human-Robot Interaction?

To be able to answer this research question, multiple sub-questions need to be answered first. The sub-questions proposed in this thesis are:

- Is touch a natural form of attention-grabbing behaviour in human-robot interaction, and what does this look like?
  - What should a touch-sensitive interface look like to support attention-grabbing touch behaviours?

- How can attention-grabbing touch be induced in a social context?
  - How can a touch-sensitive interface be designed for a social robot that has the affordance to induce attention-grabbing touch behaviour?
  - Which contextual factors play a role in inducing attention-grabbing touch?
  - What is the importance of timing in touch-based interaction?
  - What is an adequate reaction in touch-based interaction, and what does it depend on?
  - How can a soft real-time integration between a touch-sensitive interface and a social robot be realised?
- Which social human-robot interaction constructs are influenced by a social robot reacting to attention-grabbing touch?
  - Which contextual factors play a role in influencing the human-robot interaction constructs?

The contributions of this thesis are framed towards both the field of Robotics and Interaction Technology. By answering the main research question and the sub-questions, the contributions of this research are the following:

- A 3D printable touch-sensitive interface was developed that allows a Furhat robot to perceive touch input and has the affordance for intuitive touch interaction.
- A soft-real-time integration was developed between a Furhat robot and the touch-sensitive interface was developed.
- An appropriate reaction of a Furhat robot to attention-grabbing touches was developed.
- An interaction experiment where touching a Furhat robot is induced naturally in a social context was developed.
- An evaluation of the interaction was conducted using the Artificial Social Agent Questionnaire on the capability to influence a Furhat robot's behaviour via touch.

The rest of this thesis is structured as follows. Section 2 discusses the background and related work on the topic and the research question. To examine the research question, a study has been designed for which three pilot studies were conducted. A touch-sensitive interface has been developed, integrated, and validated to conduct the study. Section 3 describes the conducted studies and development of the touch-sensitive interface. Section 4 discusses the overall results, and Section 5 discusses future work and recommendations. This thesis is concluded by answering the research questions in Section 6.

2 Background and Related Work

The following section describes the background information needed to explore the research questions, design an interaction in which attention-grabbing touch is naturally induced, and work related to this thesis. First, human-robot interaction, in general, is discussed, followed by touch-based interaction in human-human interaction and the aspects of attention during human-human interaction. These subjects will be applied to human-robot interaction in a section about touch-based interaction in human-robot interaction, detailing how robots sense, understand and respond to touch. Lastly, different methods of evaluating a human-robot interaction are discussed.

2.1 Human-Robot Interaction

The field of understanding, designing and evaluating the use of robotic systems by humans is called Human-Robot Interaction [34, 35]. Humans naturally interact with robots similarly to how they would interact with other humans [1, 2, 3, 4, 36]. These interactions can take many forms and can involve many sensory systems. Social robots are robotic systems that can behave socially and interact with their environment, other robots, and humans [1, 2, 3, 34, 37]. One of the first social robotic systems is Kismet, created in 1998 [38]. Since then, many other social robots have been developed, both humanoid such as NAO [23], Pepper [24], and Furhat [25] and non-humanoid such as PARO [39] and AIBO [40]. These social robots are becoming more common in social situations [8], making studying HRI more relevant.

Research suggests that if there is a mismatch between a person's expectation of a robot's behaviour and the robot's actual behaviour, then this can lead to negative feelings towards the robot [11, 41]. Humans tend to anthropomorphize robots, appointing human-like characteristics, motivations, intentions and emotions [42, 43]. Therefore, robots should also allow for human-like interactions and responses. This needs to be considered when designing a HRI such as in this work. Important aspects that allow for human-like interactions and responses include the robot's reaction time, ensuring appropriate and seamless responses [37] and different modalities with which a human can interact with a robot.

2.1.1 Reaction time

Reaction time is defined as the delay between the onset of a stimulus and the initiation of the corresponding response [44]. For humans, the reaction time to a stimulus depends on the modality. For visual stimuli, the reaction time ranges between 190 ms and 240 ms [45, 46] for auditory stimuli, between 140 ms and 160 ms [45] and for tactile stimuli, between 200 ms and 400 ms [29].

In recent years, the preferred reaction times of interactive computer-based systems have also been explored. A general guideline is the 2-second rule introduced by Miller [30], which states that a computer system should respond to user input within 2 seconds to avoid user frustration. This research has extended into the field of HRI [31, 32, 44].

Shiwa et al. [32] found that the 2-second rule also applies to HRI. They evaluated the human preference for the delay in reaction time of a robot responding to an utterance. The robot reacted with a delay of 0, 1, 2 or 3 seconds. They found that participants had a slightly higher preference for a delay of 1 second than a delay of 0 seconds. The delays of 2 and 3 seconds were significantly lower evaluated.

Shiomi et al. [31] performed a similar study to investigate if the 2-second rule is also applicable to touch-based HRI. They asked participants to touch the shoulder of a humanoid robot. When touched the robot would give a spoken response. The robot's reaction was delayed by 0, 1, and 2 seconds. They found that participants slightly preferred a reaction delay of 0 seconds over a delay of 1 second and that the evaluation of the reaction delay of 2 seconds was significantly lower. Therefore, the 2-second rule also applies HRI in multiple modalities.

These studies used intervals of 1 second to determine the preference in reaction time. However, human response time to touch is more precise than 1 second. Therefore, Shiomi et al. [47] did additional research to specify the preferred reaction time. They investigated the reaction time of a robot under 1 second. They introduced delays to the robot's reaction in steps of 200 ms and asked participants to touch the shoulder of the robot. The robot would give a spoken response. They found that the preferred reaction time of a robot to touch lies around 400 ms.

These results show the importance of designing a system that supports a reaction time that human users prefer. This means that the system should respond in real-time. Generally, there are two types of real-time systems, hard real-time systems and soft real-time systems [33]. In a hard real-time system, timing is critical to ensure safe operation and, therefore, has strict timing requirements. In a soft real-time system, these timing requirements are less strict since there are limited consequences to not reacting in time.

2.1.2 Modalities of interaction

Humans interact with each other using their sensory systems [48]. To allow for human-like interaction, social robots have been given sensors to mimic human sensory systems [49, 50, 51]. Most social robots can communicate using the visual and auditory modalities. Next to this, many robots also have a way of conveying facial expressions and body language and have touch-sensing capabilities.

The visual and auditory modalities are the most developed and researched in social HRI [8, 51]. This is partly because these modalities were already used in interactions with disembodied computer systems [52]. The visual and auditory modalities of robots have different perceptive ways. Robots are equipped with stereo cameras and LiDARs to mimic the visual modality, which is supported by complex architectures, such as fully convolutional networks and transformers [53].

The tactile modality in social robots, especially in humanoid social robots, is less developed and researched [52]. Social robots often lack touch sensing capabilities, and if they have them, they can usually only detect whether a touch was made or not [54, 55]. Social touched-based HHI, on the other hand, is more complex than binary touch and is something that social robots cannot mimic as well as other sensory modalities. This can be harmful to a natural interaction because touch is an important modality in HHI [11] and with the embodiment of robots also an expected interaction modality [52].

2.2 Touched-Based Interaction in Human-Human Interaction

To design a natural touched-based HRI, it is important to understand how touched-based interaction in HHI works.

In humans, the ability to feel touch comes from the somatosensory system [11]. The somatosensory system has receptors located over the entire body, in the skin, whereas the other human sensors have their receptors more localised to specific body parts. Touch is also the first sensory system to develop [12, 56] and precedes speech as a means of communication [10] This makes it a basic and innate form of communication [10, 26, 57, 58]. Interpersonal touch can help to create and strengthen social relationships [59, 60, 61, 62], make people feel part of a group [10] and has physical benefits such as decreasing stress and blood pressure [63].

Touch interaction can be divided into functional and social touch [20]. Functional touch is related to object manipulation, for example, grabbing or moving an object. Social touch is a touch that conveys a social message, such as an emotion or intention [11, 12, 13, 17, 56, 61, 64]. During a social touch interaction, the touch initiator tries to convey a social message, and the recipient tries to decode the social message. However, the meaning of social touch can often not be inferred from the type of touch alone [11, 14, 15, 16, 17, 65, 66]. It is influenced by contextual factors such as gender, interpersonal relationship, the location of the touch and other modalities such as body language and speech characteristics. For example, a bump on the shoulder can have a positive meaning, such as ”well done”, when coming from a smiling person, but the same bump from an angry person can have a negative meaning, such as ”get out of the way”.

One of the first researchers to explore decoding the social value of touch were Jones et al. [17]. They investigated the meaning of interpersonal touch in daily interactions in a social context. They found 12 distinct categories of touch interaction: support, appreciation, inclusion, sexual interest or intent, affection, playful affection, playful aggression, compliance, attention-getting, announcing a response, greetings, and departure. For each of these touch categories, they defined its key features, prototypical events, and other characteristics, such as the social context in which the touch occurs. They found that most social touches are highly dependent on social context. For example, support, inclusion, appreciation, sexual and affection touches only occur with there is a close personal relationship between the people. There are also touch categories that are less dependent on social context. For example, attention-getting and greeting touches can occur between any gender or interpersonal relationship. However, greeting touches only occur at the beginning of an interaction, while attention-getting touches can happen all throughout the interaction.

When designing a touched-based HRI, it is important to consider the contextual factors associated with the touch category. These factors determine whether a category of touch can be decoded correctly and is perceived as natural.

2.3 Attention in Human-Human Interaction

When designing an interaction, attention is an important aspect to take into account [67]. Attention allows someone to focus on a specific part of the information available in the environment [68], for example, the person or object they are interacting with. Attention can be directed voluntarily via goal-directed cues or grabbed involuntarily via a sudden change in the environment. This direction of attention can involve different sensory modalities.

A failure to focus on specific information leads to distraction [68]. During an interaction, distraction indicates a lack of interest in the interaction [67], which can cause the other person to feel less cared for [69] and therefore harm the interaction.

2.3.1 Attention-grabbing behaviour

Attention-grabbing behaviour directs the recipient's focus to something or someone during an interaction [17, 65, 70]. When grabbing someone's attention, humans use different modalities. For example, visually by using body language and gestures such as waving, auditory by making sounds [65, 70], and tactile using attention-grabbing touches [17].

Jones et al. [17] have shown that attention-grabbing touches are highly distinctive and usually paired with the verbalization of the initiator. The prototypical event uses the hand to briefly touch a non-vulnerable body part (hands, arms, shoulders and upper back). They found that attention-grabbing touch is one of the least context-dependent touch categories. Therefore, this type of touch was chosen in this thesis to explore touch-based HRI.

2.3.2 Attentive Behaviour

Based on the behaviour of a person, it can be determined whether they are paying attention to an interaction or not [67, 71]. For example, during a storytelling interaction, where one person is the speaker, and the other person is the listener, the listener is not passive [72]. The listener expresses backchanneling behaviours to show that they are paying attention to the interaction and are engaged and affected by it [71].

Backchanneling can have many forms, such as confirmatory nodding, short verbal responses such as 'mhuh' or 'yeah', and even completing the sentences of the speaker [72]. Bavelas et al. [72] determined two distinctive types of backchanneling, generic listeners' response and specific listeners' response. Generic listeners' responses are independent of the content of the interaction and occur during the complete duration of the interaction. Specific listeners' responses are dependent on the content of the interaction and typically occur later in the interaction. Appropriate backchanneling behaviour leads to a more engaging and natural interaction, while the lack of backchanneling behaviour can negatively impact the interaction [71, 73]. Next to this, gaze also plays an important role in attentive behaviour. A lack of gaze at the other person or object indicates a lack of attention [67]. This affects the speaker since they will start over or paraphrase their sentences when a listener does not look at the expected location.

2.4 Touched-Based Interaction in Human-Robot Interaction

Silvera-Tawil et al. [11] stated that the tactile modality also plays an important role in HRI. They claim that if a robot can feel, understand and respond according to human expectations, it will lead to more meaningful HRI. While if there is a mismatch between human expectation and the robot's response, this can harm the interaction [11]. Additionally, Miyashita et al. [62] state that if a social robot had the same capabilities as a human regarding touch-based interaction, it would increase familiarity with the robot and allow for easier communication.

Since robots are anthropomorphised [43], humans expect humanoid robots to respond to touch-based interaction [11]. It is, therefore, important that a robot understands the interaction so that its response is appropriate. This means, the robot needs to be able to sense touch-based interaction accurately. The field that researches robotic applications that can detect and reason about tactile interaction is called tactile HRI [41].

2.4.1 Sensing Touch

Sensing social touch is the first step in social touch-based HRI. Robotic systems make use of touch sensors to perceive touch-based interaction. These sensors should be able to support the complexity of social touch-based HHI to allow for natural and intuitive interaction.

There are three main types of touch sensors. [41]. Sensors can be covered by a hard shell, covered or embedded in a flexible soft substrate [19, 21, 52, 58, 74] or sensors are individually placed at distinct locations [31, 59, 75]. Of these types, the soft substrate is the most common for social touch-based interaction since this type can be used to create artificial skins. The type of sensor influences the HRI. For example, McGinn et al. [76] found that humans prefer softer material over harder material and that a smooth texture for artificial skin is desirable.

Apart from different types of sensors, there are also different ways in which touch sensors function [11]. Touch sensors can function by measuring the force or pressure exerted on them. In this thesis this is measured by sensing a change of capacitance around the sensor. These types of sensors, called capacitive sensors, are commonly found in artificial skins [58, 75, 77].

Currently, most humanoid robots are limited in their perception of touch-based interactions [74]. Although some humanoid robots do have touch sensors, these are usually individual sensors that are limited in their capabilities. For example, the Nao robot and the Pepper robot have touch sensors that are individually placed on their heads and arms [54, 55]. These sensors can also only be used binary to say it is touched or not and do not support complex social touches.

2.4.2 Understanding Touch

Understanding social touch-based interaction depends on more than the type of touch alone, as described in Section 2.2. Therefore, a robot cannot understand touch-based interaction based on the sensor output alone. In complex social contexts, a robot needs to distinguish different touch categories to respond appropriately. For example, if a robot is used in therapy or as a companion for the elderly, responding appropriately to different touch interactions would be beneficial [20, 22, 78].

To understand touch-based interaction, the interaction is classified based on touch features such as intensity, duration and location [21, 79]. These features can be combined into gestures such as pats, taps, and strokes, and based on the context of the interaction, the type of touch and its social value can be extracted.

In recent years various research was done to classify and interpret different types of social touch-based interaction [20, 21, 22, 26, 27, 59, 80, 81, 82]. However, most of the research was done without considering contextual factors[27] and touch-based interaction being prompted instead of induced[21, 26]. For example, Andreasson et al. [26] investigated the possibility of transferring emotions to a NAO robot via touch, based on the HHI research by Hertsenstein [13]. Participants were instructed to touch the NAO robot to convey emotions that were prompted to them. They found that similar to touch-based HHI, conveying emotions depends on contextual factors, specifically gender and the location of the touch. This shows that understanding social touch in HRI highly depends on contextual factors similar to HHI and that these need to be considered when designing a study that involves social touch interaction. On top of this, to create a natural touch-based interaction, touch should be induced and not prompted.

2.4.3 Responding to Touch

Shiomi et al. [31] have shown that the perceived human likeness increases when the robot not only shows big obvious responses to touch but also shows subtle responses. However, due to a lack of suitable sensors on most available robotic systems, the research area of having a robotic system respond to touch is still limited.

Lehmann et al. [83] investigated the response of a Pepper and NAO robot to attention-grabbing touches. They let participants touch the hands of the robots to grab their attention, when the touch interaction was performed the robots moved their hands in different ways. They evaluated the preferred response by the participants and found that this is in line with the response of a human to attention-grabbing touch. They speculate that the participant's personality influences the preferred response.

Okuda et al. [58] have investigated the effect of robot movement and gaze responses to touch on the human impression of a robot. The researchers had participants perform specific touch interactions such as hitting, stroking and holding onto a NAO robot. The NAO responded to the interactions by speech, movement, eye colouring and gaze. They found that when the robot responds to the interaction, the impression of the robot is more positive.

Similarly to the research into understanding social touch in HRI, there is a lack of social context within this research. Next to this, the touches were invoked or prompted by the researchers and were not naturally induced. However, this research also shows that responding to a touch-based interaction positively influences the interaction. Next to this, human-like responses influence the interaction more positively.

2.5 Evaluating Human-Robot Interaction

Social robots cannot only be evaluated on their technical performance, like other computer-based systems [84]. The performance of a robot relies on the perception of the human's interaction with it [85]. Therefore, research has been done to evaluate social HRI accurately. As holds for every field of study, standardised evaluation instruments are important in HRI. They allow for comparing different social robots and their interactions.

Bartneck et al. [84] were one of the first to create a standardised measurement instrument to evaluate the human perception of a social robot. They developed the Godspeed Questionaire Series (GQS), which is a series of 5 questionnaires on the HRI constructs of automorphism, animacy, likability, perceived intelligence and perceived safety of social robots. It evaluates the human perception of these constructs on a 5-point Likert scale. The GQS became a widely used measurement instrument within the field of HRI [86]. However, there are some limitations to this questionnaire. The choice of the measured constructs was not justified by psychological models but was made to aid the current research. Next to this, the GQS only evaluates the human perception of a robot and not the interaction as a whole.

Carpinella et al. [42] investigated the shortcomings of the GQS. They found that some scale items had confounded effects, did not correspond to their underlying constructs, had endpoints that were not antonyms, and that the underlying constructs were related rather than independent. They created a more psychologically valid scale to measure human perception regarding the social constructs of robots, the Robot Social Attribute Scale (RoSAS). RoSAS evaluates the dimensions of warmth, competence and discomfort using 18 scale items. This scale is also a popular measurement instrument in HRI [86]. However, it has its limitations as well. In their paper, Carpinella et al. are unclear about which endpoints and how many rating items should be used for the scale items. Next to this, they evaluated their scale using interaction with images of robots rather than interaction with embodied robots.

Spatola et al. [87] recognised the shortcomings of the RoSAS, such as that it produces ambiguous scores when used on embodied robots. Therefore, they tried to improve RoSAS by creating a new scale, the HRI Evaluation Scale (HRIES). This scale measures four different constructs, Sociability, Animacy, Agency and Disturbance, using 16 items to be rated on a 7-point Likert scale. This improved version of the RoSAS was only suited for simple interactions, lacked endpoints for their scale items and was not widely used in HRI.

These evaluation scales only evaluate the human perception of the robot and not the human perception of the complete interaction, which is desirable for this work. However, recently, Fitrianie et al. [50] have developed the Artificial Social Agent Questionnaire (ASAQ). This questionnaire evaluates social HRIs on 19 different constructs using a 7-point Likert scale with explicitly mentioned endpoints. Two versions of the ASAQ have been developed. A short version that can be used for quick analysis and description of an interaction, and a long version that can be used for a more comprehensive evaluation of an interaction. This questionnaire is a validated standardised measurement instrument and results from research done by many researchers in the field of HRI. It has already been used to evaluate many interactions with different social robots. The results of these evaluations have been made publicly available as a representative dataset for comparison purposes. This questionnaire does not only have constructs that evaluate the human perception of the robot but also has constructs that evaluate the perception of the interaction. The questionnaire produces the 'ASA score', which is the sum of the scores of the 19 constructs. However, since the ASAQ is a relatively new measurement instrument, it is unknown what the implications of an HRI with a high or low ASA score are. Next to this, the ASAQ was validated using videos of interactions rather than real interactions. For the RoSAS, which was validated using images of robots, it turned out that this led to ambiguous scores when RoSAS was applied to interactions with embodied robots. However, Fitrianie et al. expect that, although the scores might differ between virtual and real interactions, the correlations between the items and constructs will not be affected.

3 Studies and Implementation

The work in this thesis consists out of a main study to evaluate an HRI in which attention-grabbing touches are naturally induced in a social context. However, before this main study could be conducted, four smaller studies were done. These studies aided in evaluating different aspects related to social touch-based HRI and improving the design of the main study. Next to this, materials needed to be developed to support the studies.

This section describes the conducted studies and the development of the materials. All studies were conducted at the University of Twente, using materials from the Human Media Interaction[1] research group and the Interaction Lab[2].

[1] https://www.utwente.nl/en/eemcs/hmi/

[2] https://www.utwente.nl/en/eemcs/interaction-lab/

First, a study is presented that explores the sub-questions *'Is touch a natural form of attention-grabbing behaviour in Human-Robot Interaction, and what does this look like?'* and *'What should a touch-sensitive interface look like to support attention-grabbing touch behaviours?'* In this study, the participants' behaviour was observed when they were instructed to grab the attention of a humanoid social robot. Then, the design of the main study is described.

Based on the results of the first study, a touch-sensitive interface was developed to answer the sub-question, *'How can a touch-sensitive interface be designed for a social robot that has the affordance to induce attention-grabbing touch behaviour?'* Next, the created codebase to support the robot behaviour of the main study is described to answer the sub-question *'How can a soft real-time integration between a touch-sensitive interface and a social robot be realised?'* Then, the delay of the touch-sensitive interface and codebase are determined to evaluate whether the integration is sufficient to support the preferred response times needed in HRI.

Two smaller studies were then conducted, that served as pilot studies for the main study. First, a study was conducted to check whether the procedure of the designed study. This study aimed to answer the sub-questions *How can social touch interaction be induced?* and *'What is an adequate reaction in touch-based interaction, and what does it depend on?'*, Second, a study was conducted to improve the affordance of touch during the main study. This study answers the sub-questions *'How can attention-grabbing touch be induced in context?'* and *'Which contextual factors play a role in inducing attention-grabbing touch?'* These studies also give an insight into the sub-question *'What is the importance of timing in touch-based interaction?'*

Lastly, the conduction of the main study is described. Here, the designed Human-Robot Interaction will be evaluated to answer the sub-questions *'Which social human-robot interaction constructs are influenced by a social robot reacting to attention-grabbing touch?'* and *'Which contextual factors play a role in influencing the human-robot interaction constructs?'* This study also gives an insight into the sub-question *'What is the importance of timing in touch-based interaction?'*

The studies conducted in this work were approved by the EEMCS Ethics Committee [3].

[3] https://www.utwente.nl/en/eemcs/research/ethics/

3.1 Study 1: What does attention-grabbing in HRI look like?

In HHI touching is an attention-grabbing behaviour, however, little research has been done regarding touch-based HRI in a social context. Therefore a first study was set up to investigate whether touch is considered to be a natural form of attention-grabbing behaviour in HRI as well.

The Interaction Lab has multiple humanoid robots available, which can be used for research purposes. However, none of these robots have the ability to perceive complex touch-based interaction. Next to this the Human Media Interaction research group developed a soft touch-sensitive artificial skin patch which can be used to detect complex touch-based interaction. This led to the idea to use the artificial skin patch as an interface to touch the robot. However the artificial skin patch was separate from the robot and therefore the robot itself was not directly touched. Therefore, this study also investigated whether the skin patch had enough affordance to support a suspension of disbelief that touching the skin meant touching the robot and, is therefore a suitable touch-sensitive interface for touch-based interactions.

This study aided in answering the following subquestions:

- Is touch a natural form of attention-grabbing behaviour in Human-Robot Interaction, and what does this look like?
- What should a touch-sensitive interface look like to support attention-grabbing touch behaviours?

3.1.1 Setup

This section describes the participants, materials, procedure and evaluation of the study.

3.1.1.1 Participants

Three participants were recruited from the researcher's personal network at the University of Twente. No demographic data was gathered about this group.

3.1.1.2 Materials

A Furhat robot was chosen for this study since it is a humanoid robot that can respond in a very human-like way by using facial expressions, head movements, and speech. The Furhat needed to be connected to a computer to be able to control it. This connection can be established wirelessly by connecting to a Wi-Fi network hosted on the Furhat or wired via a LAN using a router. For stability reasons, it was chosen to make a wired connection. Via USB, the soft touch-sensitive artificial skin patch was connected to the same computer as the Furhat. This way, the computer could read the values of the artificial skin patch, process them, and send appropriate instructions to the Furhat.

The artificial skin patch consists of a capacitive sensor grid embedded in silicon. The capacitive sensor is connected via a MUCA[4] multi-touch breakout board to an Arduino. The breakout board can support 21 Tx and 12 Rx electrodes, creating 252 measuring points. The top of the skin patch has a human-like skin tone.

3.1.1.3 Setting and procedure

During the study, the Furhat was situated on a table, with the artificial skin patch in front of it. This can be seen in Figure 1. The participant was seated at the table across from the Furhat. A camera was placed behind the Furhat and pointed at the participant to record the interaction. The researcher was sitting behind a computer that was also placed behind the Furhat.

The participants were instructed to grab the attention of the Furhat as if they wanted to tell it something. They were told that they could grab the robot's attention in any way they wanted. If, after some time, the participant had been unsuccessful in grabbing the robot's attention, they were told that the skin patch could be seen as an extension of the robot and then asked to try to grab its attention again.

3.1.1.4 Robot Behaviour

A schematic of the robot's behaviour can be found in Figure 2. At the start of the experiment, the Furhat looked away from the participant until the skin patch was touched. Then, the Furhat looked at the touched location, then at the participant and then looked away again until the next touch.

3.1.1.5 Evaluation

This study was evaluated qualitatively in two ways. A semi-structured interview was conducted, and, based on the video recording, behavioural patterns of the participants were analysed.

The semi-structured interview was set up to understand the behaviour of the participants, whether

[4] `https://muca.cc/`

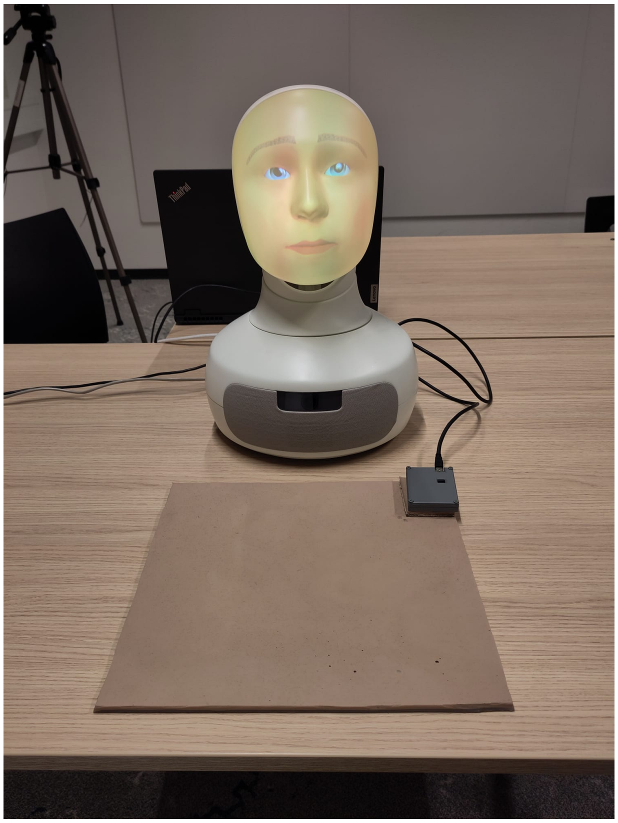


Figure 1: Setup of study 1, from the view of the participant. The Furhat is connected to the artificial skin patch and placed on a table across from the participant.

they perceived touching the robot via the skin patch as natural and whether the procedure was suitable for the participants to understand and perform the given task. The interview contained the following questions:

- What did you think of the experiment?
- Why did you try to grab the robot's attention in X way?
X = the ways the participant tried to grab attention
- Was it clear that the robot could be touched via the artificial skin patch, and why? Would moving the skin patch somewhere else make it more clear?
- Were the instructions clear?

3.1.1.6 Hypotheses

Based on the literature, it was expected that the participants use touch as a form of attention-grabbing behaviour.

It was also expected that the artificial skin patch would stand out in the setting and is, therefore, likely to be touched. When participants discover that the skin patch can be touched as an interface to touch the robot, it is expected to create a suspension of disbelief that makes the skin patch a suitable touch-sensitive interface for touched-based interaction with the robot.

3.1.2 Results

The results are presented in two-fold. First, the observed attention-grabbing behaviours are presented. Then, the results of the semi-supervised interview are presented.

3.1.2.1 Attention-grabbing behaviours

The participants shared similar behavioural patterns. They tried to wave, talk and make eye contact with the robot; these behaviours were executed separately and in combinations. Two participants also made short bursts of noise by clapping, snapping fingers and whistling.

All participants made attention-grabbing touches as time passed. They touched the robot's base and head using taps, pats, and shakes.

Two participants need to be told that the skin patch could be seen as an extension of the robot before they would touch it. One participant touched the skin patch without being told that it could be seen as an extension of the robot.

3.1.2.2 Semi-structured interview

The participants reported exhibiting their attention-grabbing behaviours because that is what they would do when trying to grab a human's attention.

Two of the three participants did not find it intuitive to touch the skin patch. They reported that it was not clear that the patch was part of the robot and that it could be used to grab the robot's attention. They reported that it would be more intuitive to touch the robot itself to grab its attention.

One participant reported that because the skin patch had a skin-like appearance and was positioned in front of the robot, it was clear it could be interacted with. However they also reported that touching the robot itself would be more intuitive.

When asked whether it would be more intuitive to touch the skin patch if the robot were partially placed on top of it, all the participants reported that they

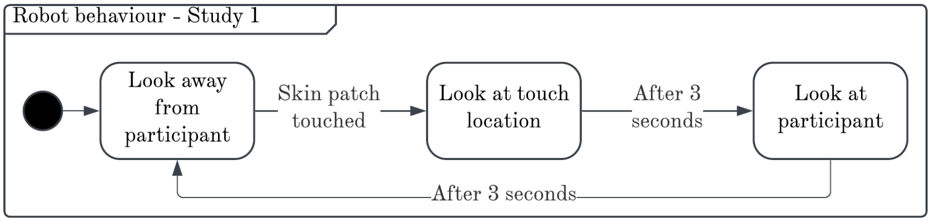


Figure 2: Study 1 - Robot behaviour.

did not think this would make a difference since the skin patch would still not be connected to the robot.

The participants reported that the instructions beforehand clear and thought the experiment was interesting but nice.

3.1.3 Discussion

The sub-question related to this study was, *'Is touch a natural form of attention-grabbing behaviour in Human-Robot Interaction, and what does this look like?'* Participants interacted with the robot as they would with humans. This aligns with what was found in the literature [1, 2, 3]. Participants did touch the robot to get its attention. However, this was not the first method they tried, given social context and task. When they touched the robot they used taps, pats and shakes on the base of the robot.

The additional question proposed was *'What should a touch-sensitive interface look like to support attention-grabbing touch behaviours?'* The artificial skin patch proved not suitable as a touch-sensitive interface, as it did not have enough affordance to create a suspension of disbelief that it was an extension of the robot. Combining this with how touch-based HRI looks like, a touch-sensitive interface should allow the robot itself to be touched in order to support intuitive touch-based interactions.

Three participants were recruited for this study, which means that the results are not statistically significant. However they do show for the main study a different direction needs to be taken with respect to the social context and task, and the way touch-based interaction can be initiated with a robot.

3.2 Main Study Design

The goal of the main study was to investigate the effect of a robot reacting to touch interaction on the human-robot interaction and to answer the main research question *'How does the adequate reaction of a social robot to induced attention-grabbing touch influence the Human-Robot Interaction?'*

Next to answering the main research question, the main study aided in answering the following sub-questions:

- Which social human-robot interaction constructs are influenced by a social robot reacting to attention-grabbing touch?
- Which contextual factors play a role in influencing the human-robot interaction constructs?
- What is the importance of timing in touch-based interaction?

This section will describe the designed methods to conduct and evaluate the main study. The execution of the main study and the results are described in Section 3.8.

3.2.1 Setup

The designed study was a within-subject design with two conditions. This section describes the participants, materials, methods, procedure and evaluation of the study.

3.2.1.1 Participants

For the experiment, 42 (17F, 25M, Mage = 24.8, MSD = 6.2) were recruited from the personal network of the researcher and the University of Twente. This was considered the most convenient way of recruiting participants.

To increase the participant pool, no gender, age or background criteria were set. The only criterion for participation was that the participant could understand English and read English out loud.

3.2.1.2 Materials and methods

For this study, a Furhat connected to a touch-sensitive interface is used. Next to the reasons for choosing the Furhat in the first study, the Furhat also has the advantage that it is only bust and does not have a full body, like the NAO or Pepper robots. This is an advantage since in the first study participants reported that touching the robot itself would be more intuitive, making a bust touch-sensitive is less complex than making a full body touch-sensitive. On top of this there is no need for a full body, since the prototypical event for attention-grabbing touch is on non-vulnerable body parts like the arms, shoulders and back. Although the Furhat does not have arms, the bust does resemble shoulders and a back.

According to the literature, attention-grabbing touch is seen as one of the more neutral types of touch, regarding factors such as gender and interpersonal relationships [17]. However, participants will make assumptions about the Furhat based on its appearance. Since touch-based interactions, in general, are influenced by contextual factors, the Furhat should have a neutral appearance such that the influence of potential contextual factors is minimised. This was accomplished by giving the Furhat the 'default' projection. Next to this, the Furhat is humanlike and has eyes and a mouth, which implies that the Furhat can see the participants and talk back to them.

Since telling a story from memory in the first study was not a context in which attention-grabbing touches were the main form of attention-grabbing behaviour, a different context was created for this study. Participants were asked to read the children's book 'The Gruffalo' [88] to the Furhat. This book contains 24 pages and was chosen for its supporting illustrations, which could encourage participants to interact with the Furhat while reading, and its easy-to-read language, which could help participants focus on interacting with the Furhat and not on the reading itself. Figure 3 shows a page of the book, showing its illustrations and easy-to-read language. By telling the participants that they had to read to the Furhat, it was implied that the Furhat could hear them.

The experiment was conducted in a laboratory setting. The participant and the Furhat were situated next to each other at a table. The Furhat was positioned at a slight angle from the participant, such that reading the book was similar to reading to another human. The Furhat was approximately at eye level with the participant and within arm's reach, to allow for a natural interaction. The book was positioned on the table in front of the participant.

Figure 4 shows an illustration of the setup. A video camera with a microphone was used to record the interaction.

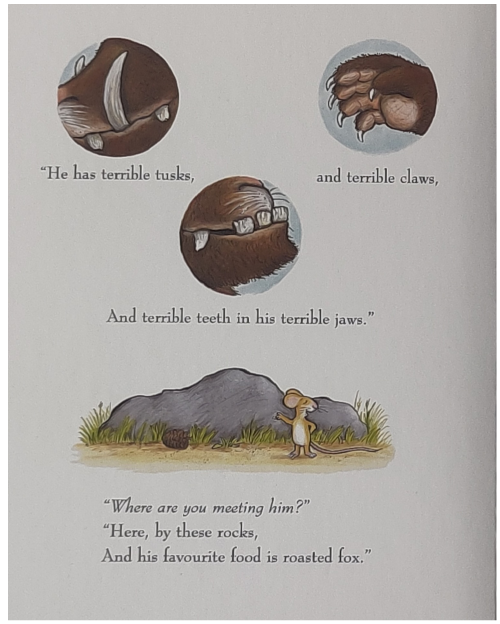


Figure 3: A page from 'The Gruffalo', showing illustrations that accompany the story and an impression of the level of English.

3.2.1.3 Conditions and robot behaviour

The participants were presented with two conditions. During each condition the participant had to read half of the book to the Furhat; the first half during the first condition, the second half during the second condition. The conditions were setup to isolate the response of the robot to touch. The order in which the participants were presented with the conditions was counterbalanced to combat order, habituation and fatigue effects.

A schematic overview of the robot's behaviour in each of the conditions can be seen in Figure 5. At the start of each condition, the Furhat would attend the book as if to read along with the participant. After 10 to 30 seconds, the Furhat loses its attention and becomes distracted. During its distracted behaviour, the robot looks around the room at three distinct locations and sometimes yawns. This is to make it obvious to the participant that the robot has lost its attention and invoke an interaction to regain its attention.

In one condition, the 'touch condition', the participant could gain the attention of the robot by performing an attention-grabbing touch, and in the other condition, the 'no-touch condition', the robot will focus its attention back on the book after 10 to 30 seconds.

It was chosen to have the robot be attentive and distracted for 10 to 30 seconds in order to combat

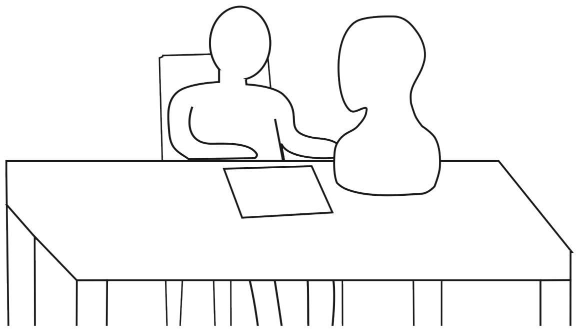


Figure 4: Illustration of the designed setup of the main study.

habituation effects that might arise when the robot focuses its attention or loses its attention after a fixed amount of time.

3.2.1.4 Procedure

The procedure consisted out of the following steps:

1. Briefing
2. Signing the informed consent form
3. Recap of the task
4. Conducting condition 1
5. Self-survey
6. Conducting condition 2
7. Self-survey
8. Interview
9. Debriefing

Prior to attending the study, participants received an information sheet with the study details. During the briefing, the participants were given a chance to read the information sheet again. The information sheet and informed consent form can be found in Appendix A and Appendix B.

During the recap of the task, the information presented in the information sheet regarding the task and procedure is repeated, to ensure that the participant understands everything correctly.

The participants were allowed to ask questions during the entirety of the study, questions related to how participants should interact with the robot were not answered prior to debriefing of the experiment.

3.2.2 Evaluation

The evaluation of the experiment was done both quantitive and qualitative. The quantitive data was gathered by having the participants fill in a self-survey questionnaire. The qualitative data was gathered by conducting a semi-structured interview and analysing the behavioural patterns of the participants.

The goal of the self-evaluation was to determine whether there was a statistically significant difference between the two conditions. On top of this, the interviews are used to assess specific statements related to the interaction conditions. Lastly, the camera recordings are used as an additional analysis to investigate how participants interact with the robot.

Statistical analysis is done on each of these evaluation methods to see if there is a statistically significant difference in the conditions.

All the statistical analyses were done using the SciPy statistics module 'scipy.stats'[5] in Python.

3.2.2.1 Self-evaluation survey

As a self-survey, the Artificial Social Agent Questionnaire (ASAQ) [50] is used. Although the ASA score itself does not have a distinct meaning. The questionnaire does evaluate the perception on the interaction as a whole and not only the perception on the robot. Since touch-based interaction is highly influenced by contextual factors, evaluating the interaction as a whole is most relevant. Next to this, combining the results of the ASAQ with the qualitative data from the interview and behavioural analysis could give meaningful insights into the ASA scores.

Table 1 shows the constructs and their shorthand notations that are used throughout this thesis. Appendix C shows all the questions presented in the ASA questionnaire. The questions in the survey were randomized for each participant to avoid semantic bias.

The results of the self-survey were statistically analysed in three main data groups: all participants, participants who touched the robot, and participants who did not touch the robot. For each of these data groups, a t-test was performed using the following sub-groups, comparing the ASA scores and the scores of the individual constructs:

- Touch condition and no-touch
- Male and female participants in the touch condition

[5]https://docs.scipy.org/doc/scipy/reference/stats.html

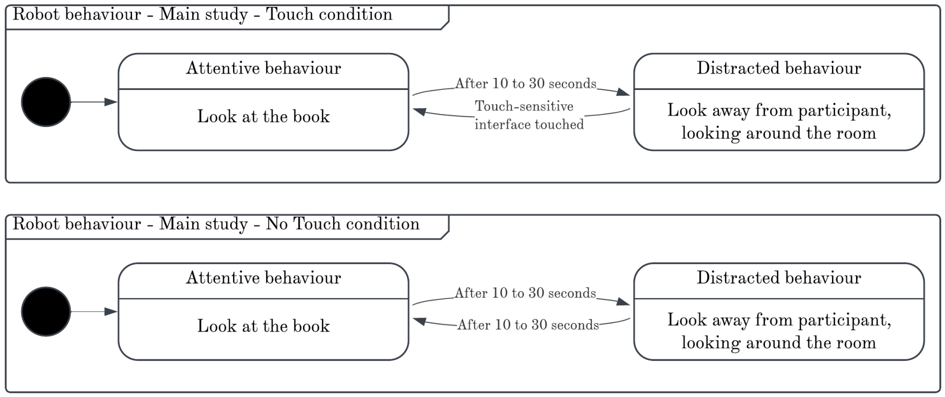


Figure 5: Schematic overview of the robot behaviour in the touch and no-touch condition.

- Male and female participants in the no-touch condition
- Male participants in the touch condition and no-touch condition
- Female participants in the touch condition and no-touch condition

3.2.2.2 Semi-structured Interview

The questions that were asked during the interview were used to gather general comments, do a manipulation check, and gain more in-depth insights into the behavioural patterns of the participants.

Four basic questions were asked during the interview.

- What did you think of the experiment?
- Did you notice a difference between the conditions?
- Was it natural for you to touch the robot?
  - If no touch behaviour happened, this question was skipped.
- Were the instructions clear?

If no touch interaction happened, the following question was asked after debriefing:

- If reading this to a human/child in the same context, would you touch them to get their attention?

The interviews were coded and combined with the data from the behavioural analysis for further analysis. This analysis is described in the next section.

3.2.2.3 Behavioural analysis

From the video recordings, the following behavioural patterns were extracted and quantified.

- Did the participant touch the robot during either condition?
- Did the participant touch the Furhat during the no-touch condition?
- What type of touches were performed during the touch condition?
- Did the participant pay attention to the Furhat while reading?
- What ways of attention-seeking behaviour did the participant use other than touch?
- How was the book positioned?
- Was there a verbal interaction in combination with the touch?
- Did the participant touch the Furhat during the touch condition?

To investigate whether contextual factors influence the experiment and the HRI constructs, the following relationships in the behavioural patterns and interview questions were analysed using a X^2 test:

- The first condition the participant was presented with and whether the participant touched the robot during the touch condition.
- The gender of the participant and whether the participant touched the robot in either of the conditions.

Construct	Short hand
Human-Like Appearance	HLA
Human-Like Behaviour	HLB
Natural Appearance	NA
Natural Behaviour	NB
Agent's Appearance Suitability	AAS
Agent's Usability	AU
Performance	PF
Agent's Likability	AL
Agent's Sociability	AS
Agent's Personality Presence	APP
User Acceptance of the Agent	UAA
Agent's Enjoyment	AE
User's Engagement	UE
User's Trust	UT
User-Agent Alliance	UAL
Agent's Attentiveness	AA
Agent's Coherence	AC
Agent's Intentionality	AI
Attitude	AT
Social Presence	SP
Interaction Impact on Self-Image	IIS
Agent's Emotional Intelligence Presence	AEI
User's Emotion Presence	UEP
User-Agent Interplay	UAI

Table 1: Overview of constructs and their shorthands of the ASA questionnaire.

- Whether the participant would touch a human in the same setting and whether the participant touched the robot in either of the conditions.
- The gender of the participant and whether the participant would touch a human in the same setting.
- The position the participants held the book and whether the participant touched the robot in either of the conditions.
- The gender the participant assigned to the robot and whether the participant touched the robot in either of the conditions.
- The gender the participant assigned to the robot relative to their own gender and whether the participant touched the robot in either of the conditions.
- The gender the participant assigned to the robot and the gender of the participant.
- The gender the participant assigned to the robot relative to their own gender and the gender of the participant.

3.2.3 Hypotheses

For the following constructs of the ASAQ a statistically significant difference was expected for the participant group that touched the robot:

- Human-Like Behaviour
  - reacting to touch is a human-like behaviour, while not reacting to touch is not.
- Natural Behaviour
  - reacting to touch is a natural behaviour, while not reacting to touch is not.
- Agent's Usability
  - Being able to influence the behaviour of the robot, could make the robot perceive more usable.
- Agent's Sociability
  - The ability of the robot to react to attention-grabbing touch, could make the robot perceive as more sociable.
- User's Engagement
  - Being able to influence the behaviour of the robot could influence the user engagement.
- User's Trust
  - Being able to influence the attention of the robot could improve the trust in the robot.
- Agent's Attentiveness
  - Reacting to touch could make the agent more attentive.
- Agent's Intentionality
  - Being able to influence the attention of the robot could improve the trust in the robot.
- Social Presence
  - Being able to react to touch could make the robot more socially present.
- User-Agent Interplay
  - Being able to influence the attention of the robot could influence the User-Agent interplay.

Next to this, no statistically significant difference was expected in either of the contextual analyses, except for the relationship between whether a participant would touch a human and whether a participant would touch the robot. It is expected that participants are more likely to touch the robot if they would touch a human in the same context as well.

3.3 Development of the touch-sensitive interface

To support the main study, a suitable touch-sensitive interface needed to be designed.

This work aided towards the sub-question: *'How can a touch-sensitive interface be designed for a Furhat that has the affordance to induce attention-grabbing touch behaviour?'*

3.3.1 Requirements

The first study showed that participants thought it would be more natural to touch the robot itself, therefore, it must allow for the Furhat itself to be touched. It must not hinder the Furhat's movement and must not obstruct the connecting ports, turning knob, internal camera, and internal speaker of the Furhat. The neck of the Furhat has three degrees of freedom and must not be blocked by the touch-sensitive interface. It must be able to connect to the electronics and could allow for the electronics to be concealed. It should conceal the capacitive grid. The shell should be produced using the facilities of the University of Twente.

3.3.2 Design process

To allow the Furhat itself to be touched, a touch-sensitive interface was created to fit around the Furhat. It was decided that only the base of the Furhat should be made touch-sensitive and not the head and face. This was based on the research by Jones et al. [17] and Silvera-Tawil et al. [11], that categorised the head of a human as a 'vulnerable body part'. Jones et al. found that touching vulnerable body parts is not prototypical for attention-grabbing touches. Therefore, the touch-sensitive interface was designed to be a shell around the Furhat's base. The finished shell can be seen in Figure 6. To make the shell touch-sensitive, it must contain a touch sensor. Since electronics that support a capacitive touch sensor were already available from the first study, a capacitive sensing grid was integrated into the shell.

To ease the manufacturing process of this shell, it was chosen to make the shell 3D printable. This is a low-cost production method for which multiple 3D printers are available at the University of Twente. Specifically, the PrusaXL 3D printer[6] of the Interaction Lab was chosen for its size and ability to easily print with multiple materials. Other advantages of 3D printing are that 3D printing allows for the creation of complex shapes and that there are a multitude of different materials available, such as conductive and flexible materials.

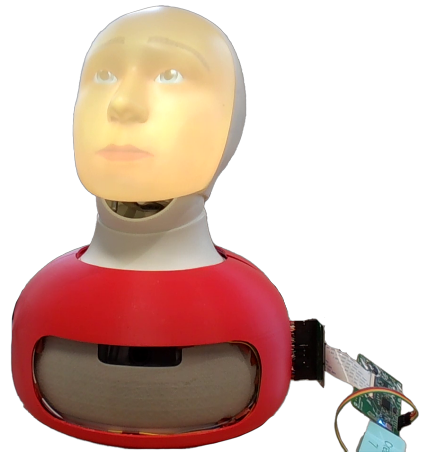


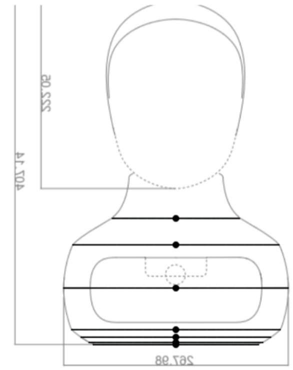
Figure 6: The finished touch-sensitive interface as shell around the Furhat.

The shell was designed using Autodesk Fusion 360[7]. Different steps of the design process are shown in Figure 7. Measurements were taken from the official technical specifications of the Furhat[8] and, as a check, compared to the measurements of the physical robot. Using these measurements, planes were created based on the different widths of the Furhat's base. These planes were sketched in Autodesk Fusion 360 and used as anchors for the Loft function to create a cylinder-like shape that fits around the base of the Furhat. Next, holes were cut out of the shell to allow access to the connecting ports, turning knob, internal camera, and internal speaker of the Furhat.

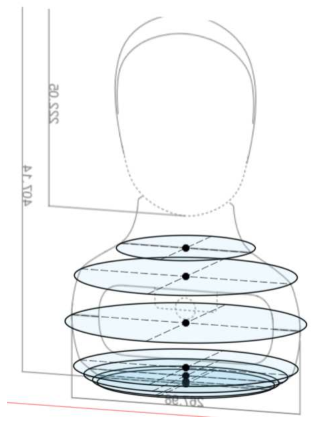
To fit on the 3D printer, the shell needed to be printed in different parts. Splitting it into two parts was sufficient for it to fit; splitting the front and the back makes the most sense for creating a capacitive sensing grid. The mechanism to connect the two parts is based on sliding the pieces together and relying on the friction of the material to hold them together. This mechanism was chosen because it was deemed easiest to implement.

Two designs were made for the integration of the

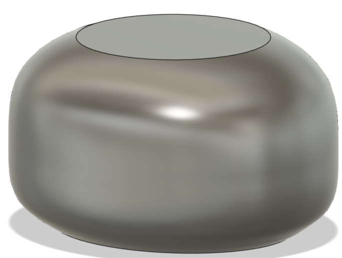
[6] https://www.prusa3d.com/en/product/original-prusa-xl-semi-assembled-5-toolhead-3d-printer/
[7] https://www.autodesk.com/products/fusion-360/
[8] https://www.furhatrobotics.com/furhat-robot



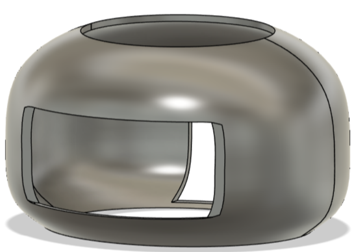
(a) The setup for the planes using the measurements of the Furhat.



(b) The planes of the Furhat to be used as anchors to create the shell.

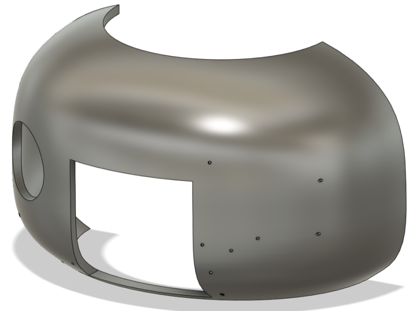


(c) The basis shape of the shell, as a result of the loft function using the planes.

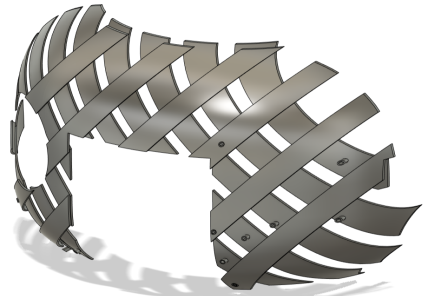


(d) Holes created to allow access to the Furhat's components.

Figure 7: The design process of the basis of the shell.



(a) The shell showing initial connector design.



(b) The conductive PLA tracks as printed within the shell.

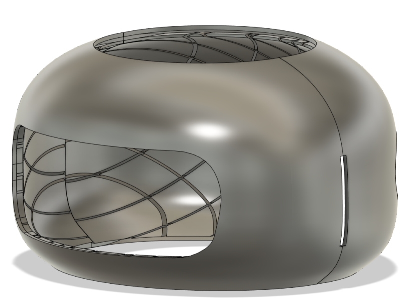
Figure 8: The first design of the capacitive sensing grid design showing of the back of the shell with tracks for conductive filament.

capacitive sensing grid. The first design used conductive PLA, which has metal particles embedded in it, to create the capacitive grid. Tracks were created inside the shell that could be printed using the conductive material. These tracks were laid diagonally inside the shell to increase the resolution of the touch-sensitive grid. The tracks were 0.8-1.4 mm apart and 2 mm thick. To be able to connect the tracks to the electronics, nozzles were created at the end of the tracks, sticking out of the shell. Figure 8 shows this version of the shell design, including the nozzles and the tracks.

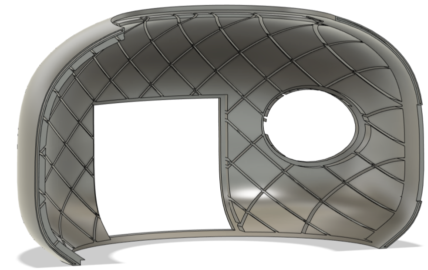
The nozzles have not yet been tested as a way of connecting the electronics because the conductive material was too difficult to print. The conductive material was too stringy, causing the different tracks to connect to each other, which resulted in a loss of resolution. Next to this, the metal particles in the filament caused the nozzle of the 3D printer to clog, causing filament grinding and under extrusion, which resulted in bad conductivity of the tracks.

Therefore, a second design of the capacitive grid integration was designed using standard insulated female-female copper jumper wires. To embed the wires, grooves were made in the shell to clamp them in, holding them in place. This was done by making a copy of the shell and offsetting it to create a double layer of the shell. Within the inner layer, grooves with a width of 1.4 mm and a depth of 7.4 mm were cut out. These grooves were diagonally similarly to the conductive PLA design. At the rims of the shell, extra grooves were created to lead the wires towards the electronics and store them away. At the connection point of the two halves, a slit is made where the wires can be connected to the electronics. Figure 9 shows this version of the shell design, including the slit where the wires can be connected to the electronics, the grooves for the wires of the capacitive grid, the connection mechanism, and the different cutouts. In both the conductive filament design as well as in the copper wire designs, there is 20 mm of space between the tracks/wires.

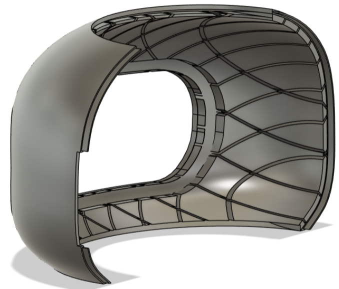
It was decided to print the shell using bright red filament, this would make it send out and increase its affordance to be used as a touch-sensitive interface.



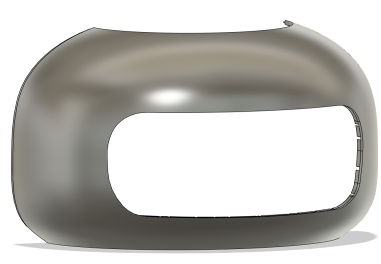
(a) The design of the full shell, showing the slit for the wires.



(b) Design of the inside of the back of the shell, showing the grooves for the wires, one half of the connection mechanism, and cutouts for the connectors and turning knob.



(c) Design of the insight of the front of the shell, showing the other half of the connection mechanism.



(d) Design of the front of the shell, showing the cutout for the internal camera and speaker.

Figure 9: The final design of the touch-sensitive shell. This design includes design two of the capacitive sensing grid, using copper wires/

3.3.2.1 Electronics and software

The electronics of the shell consist of 3 parts. A PCB consisting of the MTCH6303[9] and the Microchip MTCH652[10]. The MTCH6303 is a capacitive touch controller, supporting up to 27 Rx and 19 Tx electrodes. The MTCH652 is a boost converter that allows for a high signal-to-noise ratio. This PCB is connected to an ESP32 and communicates via the I2C protocol. To connect the wires, which serve as the electrodes, of the capacitive sensing grid to the PCB, a FPC/FFC flat cable PCB with a female-male flat cable connector is used.

In the first study, the capacitive sensing grid was supported by the MUCA multitouch breakout board. However, this supported only 12 Rx and 19 Tx electrodes, which is a much lower resolution than the MTCH6303. Since the shell is rather large, it needs a higher resolution to allow for meaningful social touch interaction. Therefore, the switch is made to the MTCH6303.

The shell can host 27 Rx wires and 19 Tx wires to support the capacitive sensing array. The wires are laid diagonally in the shell, creating a measurement point at each point the wires cross. The Rx and tx wires are separate for the front and the back to minimize the resistance in the wires. The front of the shell can host 14 Rx and 10 Tx wires, creating 140 measuring points at the cros. The back of the shell can host 13 Rx and 9 Tx wires, creating 117 measuring points. This division of wires was made because the Furhat is more likely to be touched in the front,

[9] https://www.microchip.com/en-us/product/MTCH6303
[10] https://www.microchip.com/en-us/product/mtch652

therefore it is more important for the front to have a high resolution.

The software to support the capacitive grid runs on the ESP32. Only the debug mode of the electronics components was used, as there is only a need to obtain the row measurements of the capacitive sensor.

The capacitive sensing grid outputs a value for each measuring point of the shell. The higher the value of a measuring point the closer something physically is to that measuring point on the shell.

3.3.2.2 Integration with the Furhat

The shell needed to be connected to the Furhat to be able to use the input of the shell to control the robot. This connection was made similarly to the connection of the artificial skin patch in the first study. The ESP32, to which the electronics of the shell are connected, was connected to a computer. The Furhat, in turn, had a wired connection to the same computer. A full system overview can be found in Figure 10.

3.3.3 Discussion

The shell is a touch-sensitive interface that meets all the pre-determined requirements, except for concealing the PCBs of the electronics and the EPS32. It allows the Furhat itself to be touch-sensitive using a concealed capacitive grid that can be connected to the electronics. The shell does not hinder the movements of the Furhat or the connection ports, turning knob, internal camera and internal speaker.

The electronics that were connected to the shell were visible on the outside, which could potentially have an influence on the perception of the Furhat. Ideally, there would be an encapsulation for this as well. An external box was made to fit the electronic components. However, the box was separate from the shell and hung alongside the shell. This puts extra stress on the wiring and was therefore not deemed suitable to use.

Using the wiring design instead of the conductive filament design has the advantage that it is easily producible using a 3D printer. The disadvantage is that the wires are exposed on the insides and, therefore, prone to being compressed or broken. However, the exposed wires are also easily accessible for replacement in the case of damage.

The connection of the wires to the flat cable PCB was done by soldering a female-male flat cable connector to the PCB. The male sides of the jumper wires are stuck in the female side of the connector. While this also aids in the replaceability of the wires,

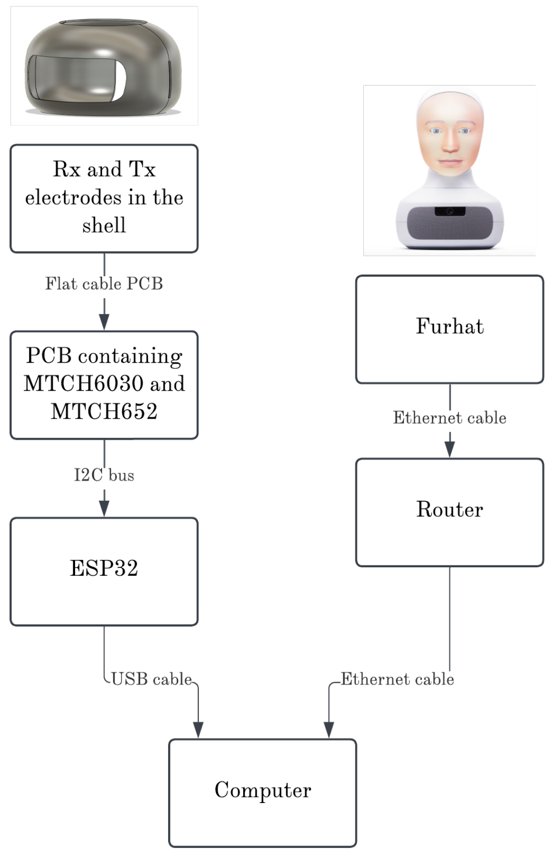


Figure 10: A schematic overview of the hardware connection.

it is also a point of weakness in the systems. The wires can easily get loose when the shell is improperly handled, breaking the connection between the wire and the PCB.

When testing the shell, it turned out that there were a few flaws in the design. One of these is the fitting of the shell. The shell was modelled based on Furhat's measurements, and a tolerance of 5 mm on the inside was added. However, this proved not to be sufficient when the first half of the shell was printed. Since the shell needed to be printed in 2 halves, the rim of the second half was extended by 7.5 mm to fit better and compensate for the less fitting front, although not perfectly yet.

Another flaw in the design is that the camera's field of view was not considered when modelling the shell. Therefore, the top section of the camera is partly blocked, as shown in Figure 11.

Lastly, the wiring in the shell, creating the capacitive grid, is clamped in place by the grooves that were made. However, at the sides where the wires meet to

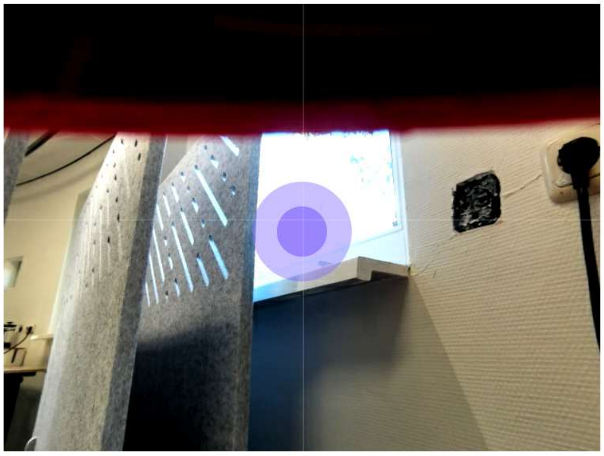


Figure 11: The view of the camera on the Furhat admin dashboard.

be directed towards the slit, it is secured using electrical tape. This is functional since it holds the wires in place but is also prone to loosening, exposing the electrical and potentially displacing wires.

3.4 Software Integration

To support the integration of the shell with the Furhat a software implementation was made. Next to this, software to support the execution of the main study was designed as well. The designed system needed to be a real-time system since in a touch-based HRI, a response is expected within 2 seconds [31] and preferred around 400 ms [47]. However there are no safety critical consequences to not reacting in time and therefore the designed system was classified as soft real-time.

This work aided towards the sub-question: *How can a soft real-time integration between a touch-sensitive interface and a Furhat be realised?*

3.4.1 Structure of the codebase

The codebase consists of two main classes implementing the two conditions of the designed experiment, two classes that control the robot behaviour, one class that monitors and interprets the output of the shell and two helper files.

Out of the box, the Furhat supports a Kotlin-based framework. However, for this research, it was chosen to use a network-based API[11] to control the robot using Python, since this made the integration of the shell easier.

[11] https://pypi.org/project/furhat-remote-api/

The two condition files, no-touch condition and touch condition are built up by threads. They both have a main thread that controls the robot's behaviour. This thread spawns a thread that runs the attentive behaviour and a thread that runs the distracted behaviour. Next to the main thread, there is also a thread which constantly monitors the shell.

The two behaviours and the monitoring are put on separate threads because they need to influence each other instantly. For example, in the touch condition, when the Furhat is distracted and the shell is touched, the Furhat needs to attend to the participant immediately. A sequential structure does not work in this case. In a sequential structure, there would be checks after each step, which induces a delay in response since a step needs to be finished before the next step can be executed. A sequential structure also introduces buffering in the shell output, which is not suitable for this application.

It was attempted to implement the threads using threading events from the standard Python library Threading[12]. However, it turned out that the completion of the execution of these events introduced a delay as well, resulting in a situation where two threads would be active at the same time. This caused undesirable behaviour. Therefore, to implement these treads Privex's Python Helpers package[13] was used. This package contains the class 'SafeLoopThread', which allows a thread to be paused and resumed instantly.

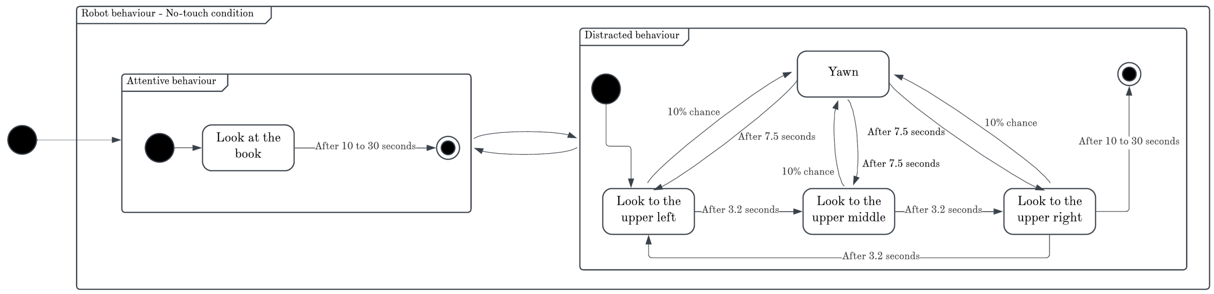
3.4.2 Implementation of the codebase

The condition files and behaviour files were implemented as described in Section 3.2.1.3. A schematic overview of the implementation of the condition classes and how they interact with other classes in the codebase can be found in Figure 12. This figure also shows a schematic overview of the implementation of the attentive and distracted behaviour classes, and the shell monitor class. When switching between the behaviour classes, the respective behaviour thread is paused and the other behaviour thread is resumed.

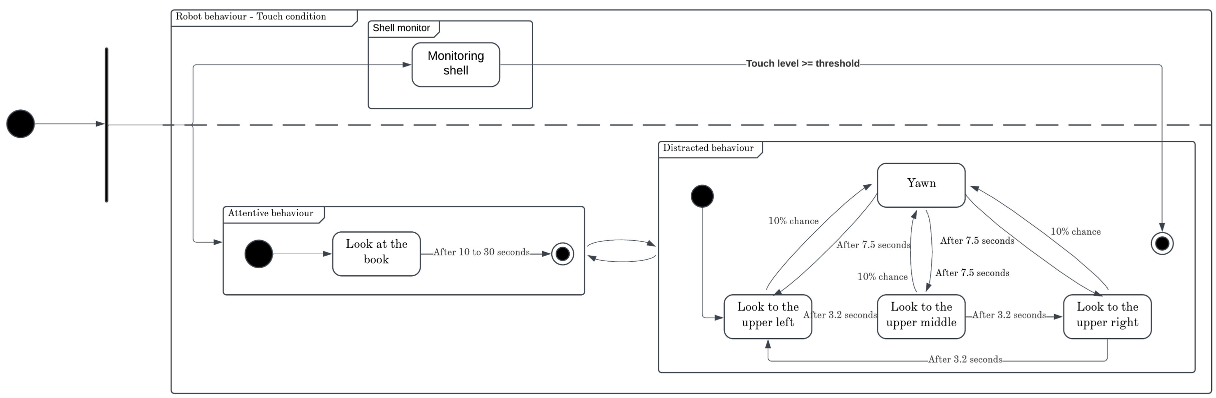
The detailed implementation of the classes and helper files can be found in Appendix D. Specifications on how of the shell monitor class determines if the shell is touched are detailed below. Next to this, the helper files are not depicted in the schematic overview and are therefore also detailed below.

[12] https://docs.python.org/3/library/threading.html

[13] https://github.com/Privex/python-helpers?tab=readme-ov-file



(a) The implementation of the no-touch condition.



(b) The implementation of the touch condition.

Figure 12: The implementations of the conditions files, also detailing the implementations of the behaviour files.

3.4.2.1 Class - Shell Monitor

This class monitors the output of the shell. It reads out the data sent by the ESP32 and creates frames of the data, with values between 0 and 255. It was chosen to clamp the data to these values to allow for a visual representation of the output of the shell. This visual representation can be seen in Figure 13.

When the data get out of sync, it re-syncs it, such that frames are read out correctly. When at least two measurement points in the frame have a value above 125, the class signals that the shell is touched. This threshold was determined empirically.

Figure 13: The visual representation of the output of the shell. It shows the shell being touched.

3.4.2.2 Helper File - Variables

The variables helper file contains all the variables that are shared between the 3 main files. These variables include the port on which the Furhat is running, thresholds, delay times and durations for certain actions, set locations to attend to and Threading Event variables.

3.4.2.3 Helper File - Gestures

The gestures helper file contains the code for the custom gestures that are being performed in the main files, such as the yawn gesture.

3.5 Study 2: Evaluation of the hardware and software delay

To assess whether the software implementation meets the timing requirements of a system that interacts was humans, as found in the literature, timing tests were performed.

This work aided towards the sub-question *'How can a soft real-time integration between a touch-sensitive interface and a Furhat be realised?'*

Three delays are measured, the delay of the shell, the delay of the reaction of Furhat and the delay of the reaction of the full system. The first two tests were carried out with only the basic necessary code, and the last test was carried out with the full codebase as used in the experiment.

3.5.1 Shell delay

The delay of the shell was measured using a microphone and a Python script. When the shell is touched, the microphone registers the sound from the impact. This was recorded in a .wav file. Simultaneously, a second .wav file is created, which has an amplitude of 0 everywhere, except for when the software registers that the shell is touched. 50 samples over 5 sessions were taken of the shell being touched. During each session, the shell was touched 10 times. This is done to counterbalance potential differences that can occur when the shell is stopped and started again. The peaks of the two .wav files are compared to determine the delay. Both .wav files are recorded simultaneously using multi-threading.

3.5.2 Furhat delay

The Furhat has multiple ways of interacting. It can talk, move its head and changing its facial expression. For this thesis, the relevant interaction modalities are head movement and facial expression. Since a head movement is a physical movement and a change in facial expression is a software-based change, it is expected that there is a difference in response time between these modalities. This is useful to measure since if the system does not meet the timing requirements, something could be changed in how the Furhat responds. Therefore, the delay of the Furhat was measured in three states of the robot. First, the delay was measured between touching the shell and the Furhat starting to change its facial expression, using the existing 'Big Smile' gesture. Second, the delay was measured between touching the shell and the Furhat starting to move, using the existing 'Nod' gesture. Last, the delay was measured between the shell being touched and the Furhat starting to move while it changes its facial expression, using the 'Wink' gesture.

To measure the delay, a video was recorded, which captures both touching the shell and the Furhat's reaction. For each of the robot gestures, 50 samples over 5 sessions were taken. During each session, the shell was touched 10 times. This is done to counterbalance potential differences that can occur when the shell is stopped and started again. Then these videos were analysed at 0.25 times speed to determine the delay with an accuracy of 10 milliseconds.

An ANOVA test was performed on the delays of the robot in the three different states. This is a useful analysis since it shows whether there actually is a statistically significant difference in the delay of the three robot states and thus it matters which gestures the robot performs.

3.5.3 Full system

The measuring of the timing of the full system was carried out synonymous with the Furhat delay test, with the difference that the full experiment code was running. There are three distinct states of the robot, during the experiment in which it could be touched:

- Looking to one side (left side or right side).
- Yawning (left side or right side).
- Switching between looking to one side (from left to right or from right to left).

At each of these moments, the delay was measured. An ANOVA test was performed to see whether there was a statistically significant difference in the delay of the three robot states. Additionally t-tests were performed for each of the robot states to see if there is a difference between grabbing the attention of the robot facing left or right. These tests are interesting to perform since it can give insight into if the reaction time of the robot differs at different moments.

To measure the delay, a video was recorded, which captures both touching the shell and the Furhat's reaction. For each of the robot states, 50 samples over 5 sessions were taken. During each session, the shell was touched 10 times. This is done to counterbalance potential differences that can occur when the shell is stopped and started again. Then these videos were analysed at 0.25 times speed to determine the delay with an accuracy of 10 milliseconds.

Compared gest.	Result t-test
Smile, Wink	t(98) = -0.14, p = .886
Smile, Nod	t(98) = -8.34, p = p $\ll$ .001
Wink, Nod	t(98) = 8.08, p = p $\ll$ .001

Table 2: Results of t-test between the delays of different gestures.

Compared state	Result t-test
Looking	t(98) = 0.04, p = .970
Switching	t(98) = 0.41, p = .684
Yawning	t(98) = -2.15, p = .034

Table 3: Results of t-test between the delays of different positioning of gestures.

Compared gesture	Result t-test
Looking, Switching comb.	t(98) = -0.92, p = .358
Switching, Yawning comb.	t(98) = 3.48, p $\ll$ .001
Looking, Yawning comb.	t(98) = 4.37, p < .001

Table 4: Results of t-test between the delays of the different states. Per state the delays of orientations were combined. For example the average delay of 'look left' was combined with the average delay of 'look right',

3.5.4 Results

An overview of the average timings in all three described scenarios can be found in Figure 14. Here it can be seen that the shell delay is shorter than the Furhat and full system delays.

3.5.4.1 Shell delay

The full results of the shell timing can be found in Appendix E.1. The average delay of the shell is 313.2 ms.

3.5.4.2 Furhat delay

The full delays of the three different gestures can be found in Appendix E.2. The Furhat delays differ per gesture, the wink gesture has an average delay of 455.6 ms, the smile gestures has an average delay of 453.65 ms and the nod gesture has a delay of 578 ms. When subtracting the average delay of the shell, the average delay of the reaction of the Furhat falls between 140 ms and 256 ms.

The results of the t-tests on the delays of the different combinations of gestures can be found in Table 2. This shows that the delays of the smile and wink gestures are not statistically different. The nod gesture is statistically different from the smile and wink gestures. The ANOVA test performed on the delays of the different gestures revealed a statistically significant difference ($F(2) = 47.85$, $p \ll .001$).

3.5.4.3 Full system delay

The full results of the three different gestures can be found in Appendix E.3. The average delays for the Look Left state and the Look Right state are 727.9 ms and 726.6 ms respectively. The average delays for the Yawn Left state and the Yawn Right state are 789.8 ms and 859.1 ms respectively. The average delays for the Middle Left state and the Middle Right state are 755.0 ms and 742.7 ms respectively. When subtracting the average delay of the Furhat, the average delay of the codebase falls between 340 ms and 400 ms.

The results of the t-tests on the delays of the different positions of gestures can be found in Table 3. This shows that there are no statistically significant differences between left and right for each of the three states. The results of the t-tests on the average delays of the different combinations of gestures can be found in Table 4. This shows that there is only a statistically significant difference between the delays of the looking state and the yawning state. The ANOVA test performed on the delays of the different states shows a statistically significant difference ($F(5) = 4.97$, $p \ll .001$)

3.5.5 Discussion

The delays of the system and the implications of this will be discussed per type of delay.

3.5.5.1 Furhat Delay

Looking at the results of the Furhat delay it is surprising that the delay of the nodding gesture is statistically significantly different from the other gestures rather than the wink gesture. The nodding gesture is only a mechanical change, while the wink gesture is both a mechanical and a software change and, therefore, is expected to have a higher delay.

An explanation could be the way the neck moves during the Wink gesture and the Nod gesture. During the Wink gesture, the head rolls, while during the Nod movement, the head tilts. The motors controlling these different mechanisms could differ in their activation speed.

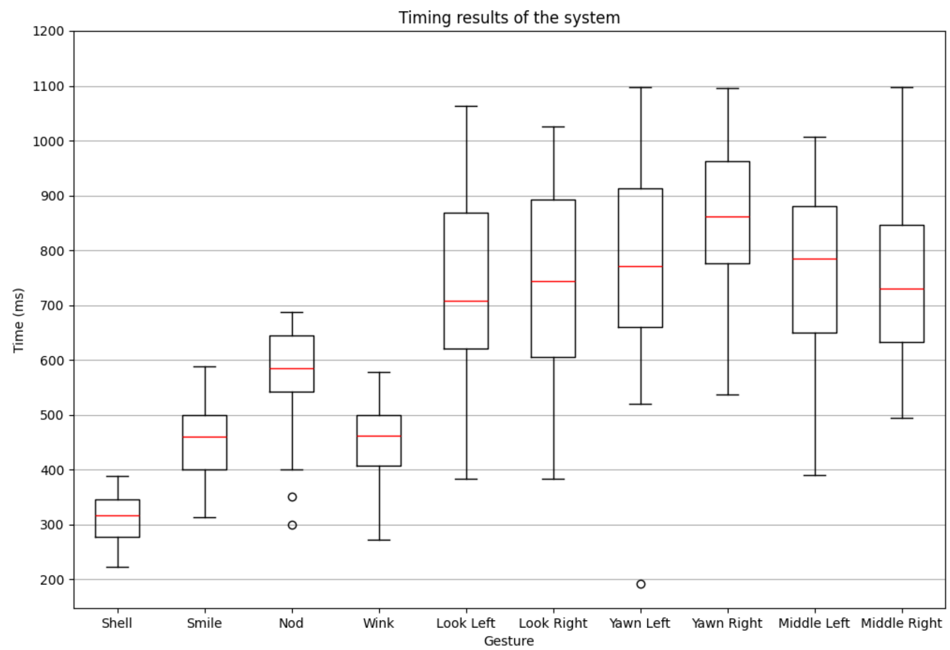


Figure 14: A boxplot depicting the results of the timing tests for all the different components of the system.

3.5.5.2 Full System Delay

The delay of the system is longer in the yawn state than in the other states. This could be due to the yawn gesture being a custom-made gesture, while the other states are inherently implemented in the Furhat. The implementation could block the reaction of the robot during the execution of the gesture, causing a longer delay. This is something to take into account during the experiment, as it might influence the interaction.

3.5.5.3 Overall delay of the system

The sub-question associated with this study was *'How can a soft real-time integration between a touch-sensitive interface and a Furhat be realised?'* As can be seen in Figure 14 the average response time of the full system lies between 700 and 850 ms depending on the state of the robot.

This delay adheres to the 2-second rule for the response time [30, 32] and is even below 1 second. However, the preferred reaction time in touch-based of around 400 ms [31] is not matched. Nevertheless this implementation can be classified as a soft real-time.

3.6 Study 3: Validation of experimental design

This study served as a pilot for the main study. The goal was to check whether the procedure of the designed experiment works as expected and to determine if the long version or short version of the ASAQ should be used. It must be noted that no statistically significant results can be derived from this study, due to its small participant pool.

This work aided towards the following sub-questions:

- How can attention-grabbing touch be induced in a social context?
- What is an adequate reaction in touch-based interaction, and what does it depend on?

3.6.1 Setup and procedure

The setup and procedure of this study was identical to the setup presented in Section 3.2.1 and Section 3.2.1.4.

Figure 15 shows the experimental setup used in this study.

For this study study four participants (3F, 1M, $M_{age} = 30.7$, $SD_{age} = 10.99$) were recruited. Three

Figure 15: Experiment setup.

participants were touchers, one participant was a non-toucher.

Two participants were presented with the touch condition as the first condition, two participants had the no-touch condition as the first condition.

To determine if the long or the short version of the ASAQ is most suited, three participants were given the long version of the ASAQ, and one person was given the short version of the ASAQ.

3.6.1.1 Evaluation

The evaluation of this study was done as described in Section 3.2.2.

Due to the small participant pool, not every analysis could be performed. The analysis of the contextual factors using the X^2 test was not done for this study. Next to this, only the toucher's data group was fully analysed; statistical analysis on the non-touchers data group and the male data group was not possible.

Statistical analysis was performed on the following data groups:

- All participants - comparing touch and no-touch condition (3F, 1M, $M_{age} = 30.75$, $SD_{age} = 10.99$)
- Touchers (2F, 1M, $M_{age} = 33.0$, $SD_{age} = 12.29$) - comparing touch and no-touch condition
- Touchers - touch condition - comparing male and female (2F, 1M, $M_{age} = 33.0$, $SD_{age} = 12.29$)
- Touchers - no-touch condition, - comparing male and female (2F, 1M, $M_{age} = 33.0$, $SD_{age} = 12.29$)
- Touchers - female participants - comparing touch and no-touch condition

Due to a bug in the questionnaire software, the results for the Agent's Personality Presence (APP) construct were not recorded. In the results, the score for this construct is set to 0.

The following question was added to the semi-structured interview, to collect feedback about the study: *'Is there anything that could be improved about the experiment?'*

3.6.1.2 Hypotheses

It was hypothesised that the participants noticed that the Furhat lost its attention after a period of time. Then the participants would touch the shell to grab its attention. Other attention-grabbing behaviours are likely to occur as well. However, it was expected that the shell would have enough affordance to be touched, since it covered the base of the robot and was printed in a bright color. Next to this, it was expected that participants like the short version of the ASA questionnaire better since it takes less time.

3.6.2 Results

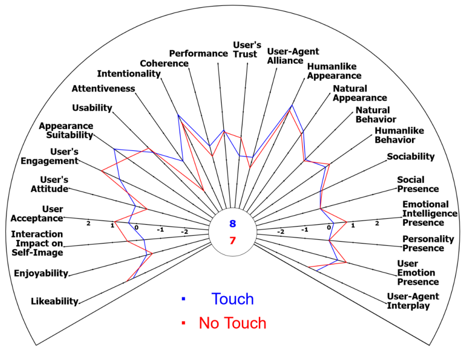
The results are presented per the evaluation method.

3.6.2.1 Statistical analysis

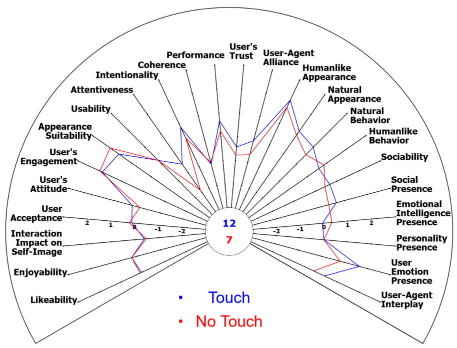
Table 5 shows descriptive statistics on the ASA scores as well as the results of the T-tests performed on the data groups. These results show that there is no statistically significant difference for any of the data groups.

The ASA scores per construct are plotted in Figure 16 for each data group. This figure also includes the ASA plots for the non-touch participant and the male participant.

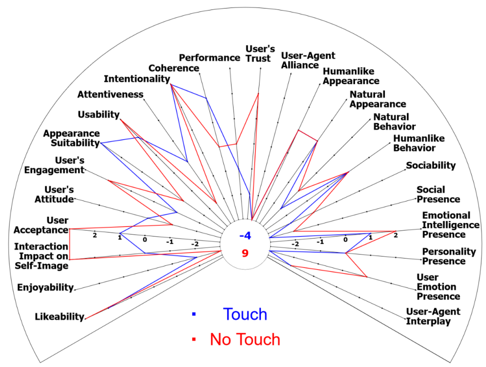
In Appendix F the complete overview can be found of the t-tests performed on each construct for each of the data groups.



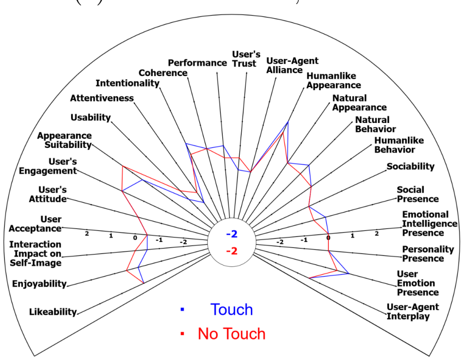
(a) All Participants - touch, no-touch.



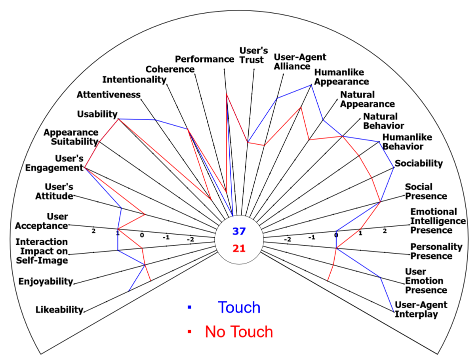
(b) Touchers - touch, no-touch.



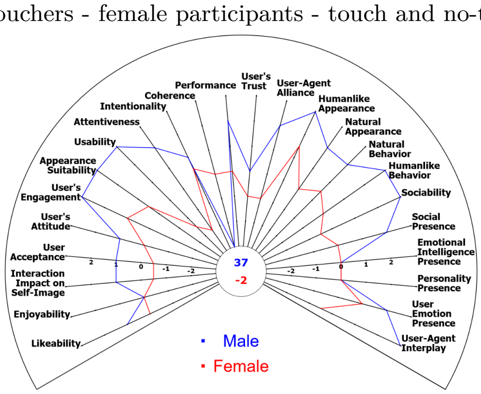
(c) Non-touchers - touch and no-touch.



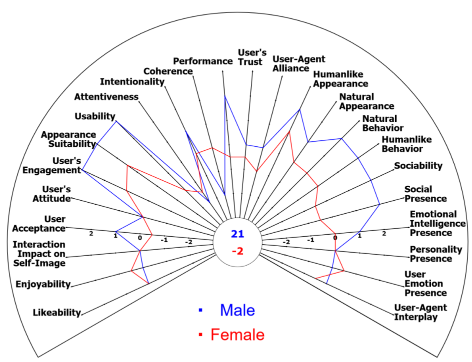
(d) Touchers - female participants - touch and no-touch.



(e) Touchers - male participants - touch and no-touch.



(f) Touchers - touch condition - female, male.



(g) Touchers - no-touch condition - female, male.

Figure 16: ASA plots for the different data groups. The plots show the score of each construct per sub-group. In the middle shows the overall ASA score for the sub-groups.

Data group	Comparison	M_{ASA}	SD_{ASA}	T-test	Sign. constructs
All participants	Touch, No-touch	T = 7.8 NT = 4.0	T = 23.0 NT = 13.1	t(3) = 0.12, p = .914	-
Touchers	Touch, No-touch	T = 11.7 NT = 6.3	T = 26.5 NT = 16.0	t (2) = 0.84, p = .490	-
	Touch - Male, Female	M = 42.0 F = -3.5	M = - F = 4.95	t(1) = 7.50, p = .084	-
	No-touch - Male, Female	M = 24.0 F = -2.5	M = - F = 6.4	t(1) = 3.40, p = 0.182	-
	Female - Touch, No-touch	T = -3.5 NT = -2.5	T = 5.0 NT = 6.4	t(1) = -1.00, p = .500	-

Table 5: Statistical test results for the overall ASA score of study 3. The table shows the mean ASA score (M_{ASA}) per data group per sub-group Touch/No-touch (T/N) or Male/Female (M/F), as well as the standard deviation of the ASA score (SD_{ASA}). The results of the t-tests per data group per sub-group are also presented, as well as which ASA constructs showed a statistically significant difference.

3.6.2.2 Interview and behavioural analysis

Based on the video footage and interview questions, the following observations were made.

- Three participants touched the Furhat on its touch-sensitive shell, one participant did not (75% touch rate).
- Three participants picked up the book while reading, and one participant left the book on the table.
- All participants sought eye contact with the robot as a form of seeking attention.
- The participants that touched the robot, touched the robot during both conditions.
- The participant that touched the robot and had the touch condition as the first condition, started immediately by touching the robot in the no-touch condition as well when it got distracted.
- The three participants that were given the long questionnaire reported it to be long, but not too long.
- Participants noticed a difference between the conditions, two participants explicitly reported noticing a difference in the touch perception of the robot.
- The participant who did not touch the robot, reported it was not explicit that touching was possible.
- The participant who did not touch the robot reported the appearance of the robot as the difference between conditions.
- The three participants that held the book in their hands while reading, reported that it was confusing when the robot was looking at the book instead of the person when in its attentive phase.
- When finding out the robot could be touched, the second time the touching happened faster.
- When the robot looked to its middle position in the distracted behaviour, two participants stopped exhibiting attention-grabbing behaviours.
- Two participants reported that they expected that the robot would react to sound and engage more when paying attention.

3.6.3 Discussion

The first sub-question associated with this study was *'How can attention-grabbing touch be induced in a social context?'* For three of the four the touch-sensitive interface had enough affordance to support touch interaction and that the social context of reading a book and the robot getting distracted can induce attention-grabbing touch behaviours. However, the non-touching participant reported that the task instructions could be changed to increase the likelihood of a touch interaction. 'Reading to the robot' did not imply that the attention should be captured as well. An adaption to the task instructions should be made to clarify that the participant should pay attention to the robot and try to grab its behaviour when it is distracted. Next to this, the non-touching participant reported that it was unclear that the robot could be touched. This should be made more explicit in the main study to ensure most participants touch the robot.

The second sub-question associated with this study was *'What is an adequate reaction in touch-based interaction, and what does it depend on?'* Three of the four participants held the book in their hands instead of having it lay down on the table as designed. This made the reaction of the robot, looking at the location of the book when attentive, confusing. As found in the literature [67], gaze plays an important role in how the interaction is perceived, a lack of gaze indicates a lack of attentiveness. The attentive behaviour of the robot should, therefore, be reconsidered. Since most participants held the book in their hands, looking at the participant when attentive would make more sense. The distracted behaviour of the robot, was too similar to the attentive behaviour when the robot looked to its middle position. This participants stop exhibiting attention-grabbing behaviours and therefore thinking the robot paid attention. This likely has to do with gaze again, since the participants behaved as if the Furhat was attentive. Removing this state from the distracted behaviour would make the distracted behaviour more clear. Two participants reported that the interaction felt a bit unnatural and that more response from the robot was expected. Currently, there is no backchanneling behaviour implemented in the robot behaviour, adding this would make the interaction feel more natural as found in the literature [72, 71, 73].

3.7 Study 4: Increasing affordance

The results of the previous study indicated that with the discussed adaptions the main study could be conducted. However, after 10 participants, it turned out that the experiment did not have enough affordance for the majority of participants to touch the robot. Thus resulting in a lack of touching participants. Therefore, the behaviour of this group of 10 participants was analysed before the conduction of the main study proceeded. This analysis helped to gain insights into the lack of affordance and how the affordance could be increased.

This study aided towards the sub-questions:

- How can attention-grabbing touch be induced in a social context?
- Which contextual factors play a role in inducing attention-grabbing touch?

3.7.1 Set up

The experiment setup was the same as described in 3.2.1. An extra task instruction was added telling the participants to ensure the Furhat understood as much of the story as possible. This instruction was added to stimulate participants to interact with the Furhat.

To make it more explicit that the robot could be touched, a brief touch by the researcher and a subsequent reaction of the robot were included in the procedure during the recap of the task. This brief touch was done before each condition.

10 participants (7F, 3M, M_{age} = 31.9, SD_{age} = 13.1) were part of this study. Two participants touched the robot, and eight participants did not touch the robot.

Five participants were presented with the touch condition first, and five participants were presented with the no-touch condition first.

3.7.2 Robot Behaviour

Based on the results of the previous study, the behaviour of the Furhat was changed. The attentive behaviour of the Furhat is changed. The Furhat now looked at the participant when being touched, and continue looking at the participant until it entered its distracted behaviour. During the distracted behaviour, looking at the location at the middle was discarded.

Participants also reported that they expected more interaction from the Furhat. Therefore, two backchanneling responses, nodding and looking surprised, were added to the attentive behaviour. The Furhat nodding was done periodically every 6 seconds based on a study by Inoue et al. [89]. The Furhat looking surprised was done based on the volume of the participant's voice. When this happens, the Furhat opens its mouth and widens its eyes, returning to its normal expression immediately afterwards. For this behaviour, a microphone monitor class is introduced in the code base. A detailed implementation can be found in Appendix D.

3.7.2.1 Class - Microphone Monitor

This class monitors the microphone of the computer that the software is run on.

It first has a calibration phase in which it records 10 seconds of the microphone and finds the mean audio level. Based on this audio level, loudness threshold is determined, which is used to trigger the looking surprised gesture while reading.

3.7.2.2 Main File - Begin Condition

During the explanation of the experiment, the robot is distracted and reacts to touch. A detailed

Aspect	Option	No.
First condition	Touch No-touch	5 5
Touched the robot		2
Touched during No-touch		1
Type of touch	Pat Tap	1 1
Fully paid attention		9
Ways of attention seeking	Making eye contact Waving Speech fluctuation Talking Exclamating Looking at camera Making a sound Showing pictures	3 3 6 4 3 1 1 1
Position book	In hand On table	9 1
Verbal Touch		2

Table 6: Quantitative overview of the analysis of the video footage for study 4. For each aspects the number of participants that expressed that behaviour was determined.

Question	Answer	No.
Thoughts on experiment	Interesting Fun/nice Confused Exciting	4 3 2 1
Fount it intuitive to touch the robot	Yes No Not asked	1 5 4
Would touch a human	No Not asked	3 7
Noticed difference between conditions	Yes, touch Yes, not correct No	2 6 2

Table 7: Quantitative overview of answers to the interview questions for participants that did not perform the startup touch.

Contextual factors	Result X^2 test
First condition, Touched dur touch cond.	$X^2(1) = 0.00$, p = 1.00
Gender, Touched (gen)	$X^2(1) = 0.03$, p = .863
Would Touch, Touched (gen)	$X^2(1) = 0.00$, p = 1.00
Book position, Touched (gen)	$X^2(1) = 0.00$, p = 1.00
Robot Gender (abs), Touched (gen)	$X^2(2) = 0.44$, p = .801
Robot Gender (abs), Gender	$X^2(2) = 1.96$, p = .376
Robot Gender (rel) Touched (gen)	$X^2(2) = 4.00$, p = .135
Robot Gender (rel) Gender	$X^2(2) = 1.96$, p = .376

Table 8: Results of the X^2 test on the contextual factors for study 4. $p < .05$ indicates that there is a dependency relationship between the factors.

implementation can be found in Appendix D.

3.7.3 Evaluation

Since the goal of this study was to analyse what caused the participants not to touch the robot and how to increase the affordance in this study, only the interview questions and the behavioural analysis were evaluated. The participants were presented with the ASAQ, but no statistical analysis was done on the results during this study.

3.7.3.1 Hypothesis

It was expected that the participants did not touch the robot because they were not aware that they could touch the robot to gain its attention.

3.7.4 Results

The results are presented per analysis.

3.7.4.1 Behavioural analysis

Table 6 shows a quantitative overview of the participant's behaviour based on the video recording.

Table 7 gives a quantitative overview of the participant's answers to the interview questions.

Table 8 shows the results of the X^2 test for the relationships between contextual factors.

3.7.4.2 Observations and interview answers

Next to the quantitative overview, some observations were made:

- Two participants compared the interaction to interacting with a child.
- Six participants reported they did not know they could touch the robot to gain its attention.
- Of these six participants two reported being uncertain if they were allowed to touch the robot.
- Two participants reported that they knew they could touch the robot but did not touch it. They reported that it did not feel natural to do so.

- One participant reported that they did not know what the Furhat was capable of.
- Six participants stopped exhibiting attention-grabbing behaviours after some period of time when they were unable to grab the robot's attention.

3.7.5 Discussion

The discussion of the results is twofold. First, the current study design, in general, is discussed, followed by discussing the associated sub-questions.

3.7.5.1 Study design

As presented in Table 7, not all participants were asked all of the questions. By design, only participants who touched the robot were asked whether it was intuitive and only participants who did not touch the robot were asked if they would touch a human in a similar situation. However, to gain more insight into the participants' behaviour, it would be interesting to hear the views of all participants on these aspects.

Based on the observations made, the additional task instruction to ensure that Furhat understood as much of the story as possible did not stimulate the participants enough the interact with the robot. Participants stopped seeking attention when they could not manage to grab the robot's attention.

As presented in Table 6, most participants hold the book in their hand instead of the table, similar to the previous pilot. On top of this, no participants reported being confused about when the robot was attentive or distracted. This was a successful change made based on the previous study.

3.7.5.2 Associated questions

The sub-questions associated with this study were *'How can attention-grabbing touch be induced in a social context?'* and *'Which contextual factors play a role in inducing attention-grabbing touch?'*

Two participants touched the Furhat (20% touch rate), which is much lower than the touch rate of the previous study. Six participants indicated that they did not know that the robot could be touched, of which two participants were uncertain if they were allowed to touch the robot. This indicates that there is a barrier for the participants to touch the robot. On top of this, of the four participants who reported that they knew they could touch the robot, only two participants touched it. This indicates that the startup touch did not prime participants enough regarding the ability of the robot to perceive touch.

From the results presented in Table 7, it became clear that touching the robot has a personal aspect. Some participants would not touch a human in the same social context, and therefore, not all participants are likely to touch the robot. This also indicates that the previous study was unluckily sampled, with most participants being likely to touch humans in the same context and, therefore, touching the robot as well. This gave the impression that the interaction had enough affordance to induce attention-grabbing touch behaviour.

As presented in Table 8, no statistically significant relationship was found between the contextual factors and touching the robot. Therefore, these contextual factors are not likely to have played a role in inducing the touching behaviour.

From these results, it can be concluded that the affordance to exhibit attention-grabbing touches can be increased by priming the participants more on the ability of the robot to perceive touch-based interaction. Next to this, the participants should be stimulated more to seek interaction with the robot.

3.8 Study 5: Effect of reaction to touch on social constructs

The following section describes conducting the main study, as described in Section 3.2, with the adaptions made based on the results of the previous studies.

3.8.1 Setup

The setup of this study was described in 3.2.1. Additional instruction was given to stimulate the participant to interact with the robot, and the participants were told to keep the Furhat's attention focused on themselves and the story.

For the experiment, 42 (17F, 25M, $M_{age} = 24.8$, $M_{SD} = 6.2$) participants were recruited.

22 participants had the touch condition as the first condition, and 20 participants had the no-touch condition as the first condition.

24 participants touched the robot, and 28 participants did not touch the robot.

3.8.2 Procedure

To prime the participants more than the robot can react to touch-based interaction, the robot's reaction to the researcher's brief touch was made more explicit. When touched, the Furhat said, 'Oh hi,' while looking at the researcher.

Next to priming participants, the barrier to touch the robot was lowered by adding a touch that the participant needed to perform to start the interaction. After a recap of the task, the Furhat entered a sleep-like behaviour, having its eyes closed and looking down. The participant was then instructed to start the interaction by touching the robot. Two new gestures were added to the gesture helper file to support this behaviour, 'neck_down' and 'wakeup'. The startup touch was added to both the touch and no-touch condition.

A schematic overview of the implementation of the final code of the touch condition class and how it interacts with other classes in the codebase can be found in Appendix G.1. A schematic overview of the implementation of the final code of the no-touch condition class and how it interacts with other classes in the codebase can be found in Appendix G.2.

3.8.3 Evaluation

The study was evaluated as described in Section 3.2.2. The ASAQ results of the ten participants of the previous study were combined with the results of this study to perform the statistical analysis. This was done to increase statistical power and could be done because for the touchers of the previous study, there was enough affordance to touch the robot, and for the non-touchers, there was not enough affordance. This was similar to the touching and non-touching participants in this study.

Six participants were excluded from the statistical analysis based on the execution of the experiment:

- Three participants where the robot would not correctly react to touch or have a touch reaction triggered without being touched.
- Three participants did not pay attention to the robot or only paid attention to the second condition.

The demographics of the data groups of the statistical analysis are as follows:

- All participants (20F, 25M, M_{age}=26.4, M_{SD} = 8.9)
- Touchers (9F, 12M, M_{age} = 26.0, M_{SD} = 8.3)
- Non-touchers (11F, 13M, M_{age} = 26.7, M_{SD} = 9.5)

The results of the interview and behavioural analysis were not combined because the experience and possibly the behaviour of the participants during the experiment were different from the previous study. In this study, the participants saw more reactions from the robot to the touch of the researcher, and they had to touch the robot themselves to start the interaction. Thus, they are priming them more to touch the robot than in the previous study.

From the behavioural analysis, three participants were excluded due to the video not being properly recorded.

3.8.4 Results

The results are presented per analysis.

3.8.4.1 Statistical analysis

Table 9 shows descriptive statistics and the t-test results on the ASA score for excluding the six participants described in the above-defined data groups.

Table 9 shows that only the touchers data group has significant results and there are statistically significant differences observed for the constructs Natural Behaviour, Agent's Appearance Suitability, Agent's Usability Performance, Agent's Sociability, User's Trust, User-Agent Alliance, Agents Attentiveness and Agent's Intentionality. For the gender comparisons Human-like behaviour is a statistically significant construct. And for the female participants User-Agent Interplay is an additional statistically significant construct.

Figure 17 shows the ASA charts for all the participants. Figure 18 shows the ASA charts for the touchers. Figure 19 shows the ASA charts for the non-touchers. In Appendix H the results of the t-tests on the individual constructs can be found, for all different data groups.

3.8.4.2 Semi structured interview and behavioural analysis

Table 10 shows the results of the X^2 test of different observed variables taken from the interview and behavioural analysis. This table shows that there are no statistically significant relationships except for the relative gender assigned to the robot and the gender of the participant.

Table 11 shows the results of the interview analysis and Table 12 shows the results of the behavioural analysis.

3.8.4.3 Observations

Next to the quantitative observations of the behaviour as described above, interesting qualitative observations were made:

Data group	Comparison	M_{ASA}	SD_{ASA}	T-test	sign. constructs
All Participants	Touch, No-touch	T = -3.9 NT = -5.9	T = 12.8 NT = 13.8	t(44) = 0.97, p = .339	NB, AEI
	Touch - Male, Female	M =-6.6 F = -0.6	M = 12.5 F = 12.4	t(43) = -1.60, p = .118	HLB, NB, UAI
	No-touch - Male, Female	M = -6.1 F = -5.7	M = 14.3 F = 13.6	t(43) = -0.09, p = .928	HLB
	Male - Touch, No-touch	T = -6.6 NT = -6.1	T = 12.6 NT = 14.3	t(24) = -0.16, p = .874	UAA
	Female - Touch, No-touch	T = -0.6 NT = -5.7	T = 12.4 NT = 13.6	t(19) = 1.85, p = .080	NB, AS, UAI
Touchers	Touch, No-touch	T = -1.0 NT = -9.5	T = 12.0 NT = 13.7	t(20) = 2.78, p = .012	NB, AAS, AU, PF, AS, UT, UAL, AA, AI
	Touch - Male, Female	M = -1.8 F = 0.1	M = 12.1 F = 12.6	t(17) = -0.34, p = .736	HLB
	No-touch - Male, Female	M = -8.2 F = -11.2	M = 15.1 F = 12.3	t(19) = 0.50, p = .626	HLB
	Male - Touch, No-touch	T = -1.8 NT = -8.2	T = 12.1 NT = 15.1	t(11) = 1.45, p = .174	AU
	Female - Touch, No-touch	T = 0.1 NT = -11.2	T = 12.6 NT = 12.3	t(8) = 2.71, p = .027	NB, AL, AS, UAI
Non-touchers	Touch, No-touch	T = -6.5 NT = -2.8	T = 13.1 NT = 13.4	t(23) -1.56, p = .132	AAS
	Touch - Male, Female	M = -11.0 F = -1.1	M = 11.8 F = 12.9	t(22) = -1.96, p = .062	HLB, NB, AL, UAA
	No-touch - Male, Female	M = -4.2 F = -1.2	M = 13.8 F = 13.5	t(22) = -0.53, p = .600	AC
	Male - Touch, No-touch	T = -11.0 NT = -4.2	T = 11.8 NT = 13.8	t(12) = -2.01, p = .059	NA, AAS, AA
	Female - Touch, No-touch	T = -1.1 NT = -1.2	T = 12.9 NT = 13.5	t(10) = -0.03, p = .977	NB

Table 9: Statistical test results for the overall ASA score, combing the results of the current study and the previous study. The table shows the mean ASA score (M_{ASA}) per data group per sub-group Touch/no-touch (T/N) or Male/Female (M/F), as well as the standard deviation of the ASA score (SD_{ASA}). The results of the t-tests per data group per sub-group are also presented, as well as which ASA constructs showed a statistically significant difference.

- Four participants reported that touching felt more like a trigger to get the robot's attention than actually getting the robot's attention.
- Twelve participants reported that they needed to get used to the interaction and the robot and felt more comfortable during the second interaction.
- Three participants only touched the robot during the no-touch condition without touching during the touch condition. For these participants, the touch condition was the first condition they were presented with.
- Twelve of the non-touching participants reported that the noticed a difference in how much the Furhat paid attention.
- Two of the non-touching participants reported that they had to put in more effort to gain the Furhat's attention in one of the conditions.
- Four participants reported not having the expectation that the robot could react to touch socially.
- Three participants reported that simultaneously reading and paying attention to the robot was difficult.
- Three participants reported that it was frustrating the robot did not respond to touch in the no-touch condition. Two participants reported it was a pity that the robot did not respond to touch in the no-touch condition.

Compared variables	Result X^2 test
First condition, Touched dur touch cond.	$X^2(1) = 0.36$, p = .546
Gender, Touched (gen)	$X^2(1) = 0.06$, p = .807
Would Touch, Touched (gen)	$X^2(2) = 5.22$, p = .074
Gender, Would Touch	$X^2(2) = 1.05$, p = .593
Book position, Touched (gen)	$X^2(2) = 3.94$, p = .139
Robot Gender (abs), Touched (gen)	$X^2(1) = 1.91$, p = .166
Robot Gender (abs), Gender	$X^2(1) = 3.01$, p = .083
Robot Gender (rel), Touched (gen)	$X^2(2) = 3.21$, p = .201
Robot Gender (rel), Gender	$X^2(2) = 19.31$, p <<0.01

Table 10: Results of the X^2 test on the contextual factors for the main study. p < .05 indicates that there is a dependency relationship between the factors.

Question	Answer	No.
Thoughts on Experiment	Interesting	7
	Fun/nice	19
	Special/Particular	8
	Other	5
Fount it intuitive to touch the robot	Yes	18
	No	24
Would touch humans in similar situation	Yes	12
	No	21
	Depends	7
Noticed difference between conditions	Yes, touching	16
	Yes, but not touching	19
	No	7

Table 11: Quantative overview of the answers to the interview questions. Th left column shows the question asked, the middle column shows the answers participants gave and the right column shows how many participants gave that answer.

- Nine of the touching participants reported that touching the Furhat often did not feel intuitive.

3.8.5 Discussion

From the results of the statistical tests only the touchers data group does have sub-groups that have a statistically significant difference in the ASA score. The results of the comparisons of the touch and no-touch condition, specifically the female participants in this group, show a statistically significant difference. This indicates that being able to influence the behaviour of the robot via touch-based interaction influences the

Aspect	Option	No.
Touched the robot		22
Touched during No Touch		24
Type of touch	Pat	11
	Tap	12
Fully paid attention		37
Ways of attention seeking	Make Eye contact	12
	Waving	8
	Speech fluctuation	8
	Talking	21
	Exclamation	14
	Make a sound	2
	Showing pictures	6
Placement of book	On table	7
	In hand	28
	In front of robot	4
Verbal Touch		16

Table 12: Quantative overview of the analysis of the video footage.

interaction, especially for female participants. When looking at the gender comparisons for the two conditions, no statistically significant difference is present. This indicates that although female participants perceive the interaction in the two conditions more different than male participants, this is not specific to one of the conditions. When looking at the results presented in Table 10, there is no statistically significant relationship between the participant's gender and whether the participant touched the robot or would touch a robot. Indicating that even though there is a statistically significant difference in females between the conditions and not in males, females are not necessarily more likely to touch.

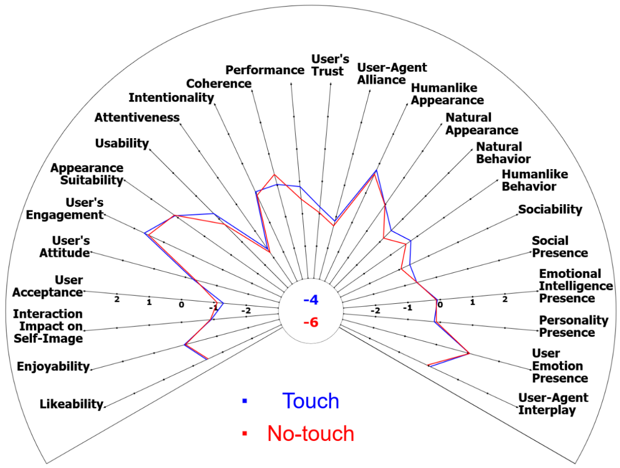
Looking at the statistically significant constructs for the touchers data group, all hypothesised constructs show a statistically significant difference, except for User's Engagement and Social Presence. Next to this human-like behaviour only has a statistically significant score when male and female participants are compared. Additionally Agent's Appearance Suitability and Performance also show a statistically significant difference. When looking at the ASA chart for the touchers data group, comparing the touch and no-touch condition as shown in Figure 18a the influence different statistically significant constructs can be evaluated. All of these constructs are rated higher by the participants in the touch condition than the no-touch condition. This means that these constructs positively influence the interaction. Therefore, the touch condition positively influenced the interaction.

User's Engagement not showing a statistically significant difference might be due to the reports of the participants that they thought touching the Furhat often was unnatural. The need to touch the Furhat often is due to its attention span of 10 to 30 seconds. This attention span is similar in the no-touch condition. There might also a connection to the participants that reported that grabbing the robots attention felt like a trigger. Having to touch the robot at a high frequency, to the extend it feels like a trigger, can make participants less engaged in the interaction and might not differ from the engagement in the no-touch condition. These aspects might also be connected to Social Presence not showing a statistically significant difference. Participants could experience the robot as not actually being socially present due to the feeling of grabbing the attention of the robot as a trigger. However, both of these constructs were rated higher by participants in the touch condition than in the no-touch condition. This indicates that there might be a difference but there were not enough participants to show this.

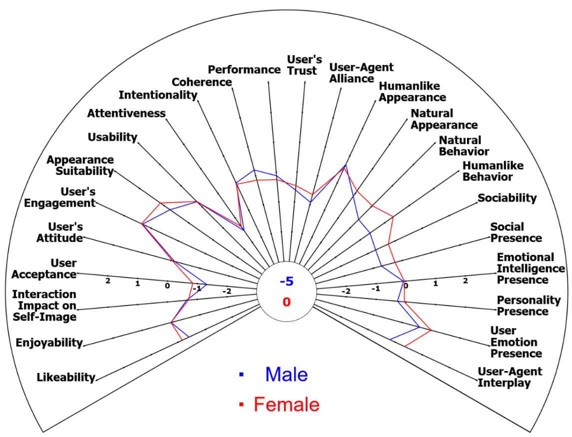
The statistically significant difference in the Performance construct could be due to the perception that the robot performs its task of paying attention to the story better when it can react to attention-grabbing touches. The statistically significant difference in Agent's Appearance Suitability is less straightforward since the appearance of the robot does not change between the two conditions. Potentially, the participants could see the robot more when it paid attention to them, and therefore, they rated the appearance differently. However, no claims can be made about this.

Participants reported that they felt more comfortable during the second interaction, this is strengthened of the observation that three participants touched the robot only in the second interaction. From this it could be expected that when participants have the touch condition as a second condition are more likely to touch the robot. However, when looking at the results presented in Table 10, it can be seen that there is no statistically significant relationship in whether the participant touched the robot and what the first condition is. This indicates that although it is expected from the reporting of the participants that they felt more comfortable during the second interaction, this made them not more likely to touch the robot. There is also no statistically significant relationship between whether the participant would touch a person to grab their attention and if they touched the robot. However, whether the participant would touch a person to grab their attention is a self-reported statistic. Some participants reported that the relationship with the person to be touched could influence the results. Most of the non-touching participants reported that they would not touch a person to grab their attention or that it depends on the relationship with this person. Although attention-grabbing touch is considered to be neutral with respect to interpersonal relationships, there does seem to be some influence of this aspect. One participant reported that they did not touch the Furhat because they did not know them. They did think that if they had more interactions, touching would be more natural. However, when looking at Table 10, whether a participant would touch a human and if they touched the robot has no statistically significant relationship with each other. The relationship between the book position and whether the person touched the robot also shows no statistically significant difference. This is indicative that the placement of the book does not influence the likelihood of touching the robot.

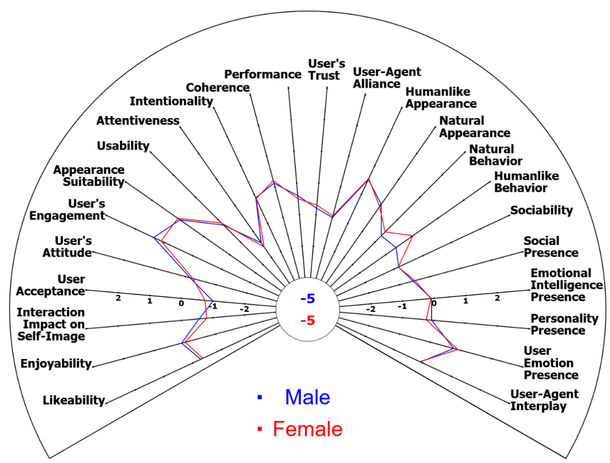
The only contextual factors that had a statistically significant relationship to each other were the participant's gender and the assigned gender relative to the participant's gender. However, no claims can be made based on these results since the assigned gender was inferred from how the participants spoke about the robot during the interview. Therefore, this result can only be used to indicate that there is a relationship between the participant's gender and how they view the gender of the robot relative to their own.



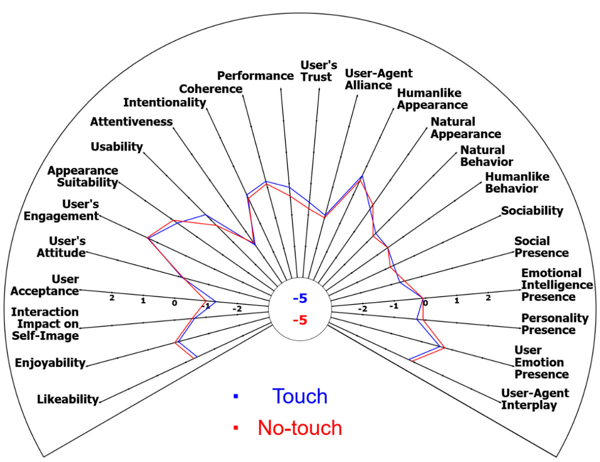
(a) Touch, no-touch.



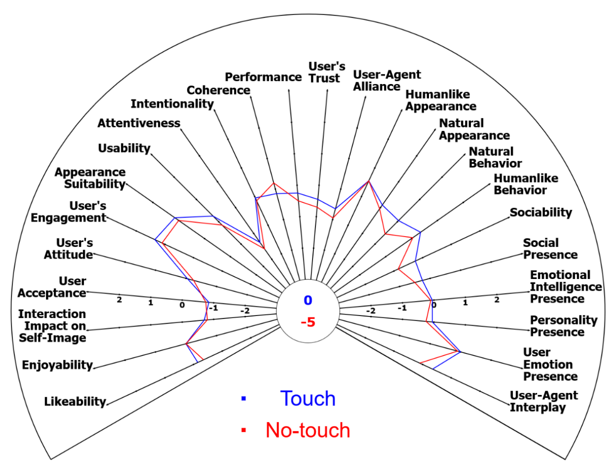
(b) Touch condition - male, female.



(c) No-touch condition - male, female.

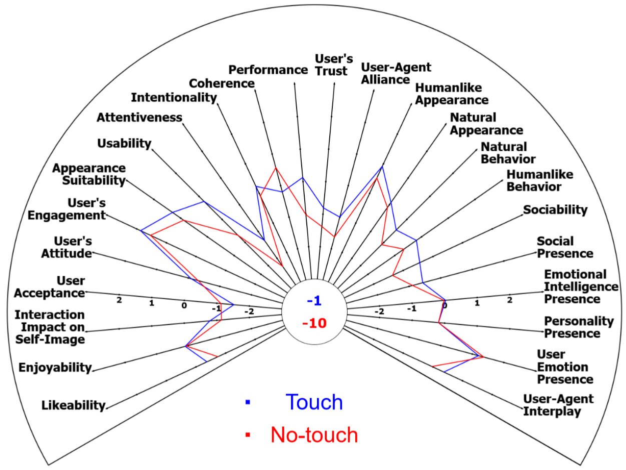


(d) Male participants - touch, no-touch.

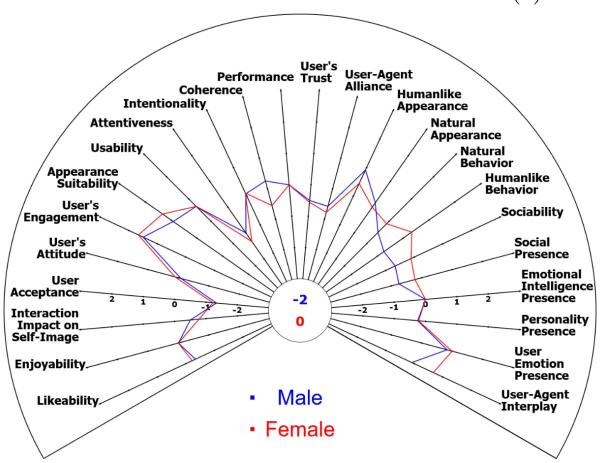


(e) Female participants - touch, no-touch.

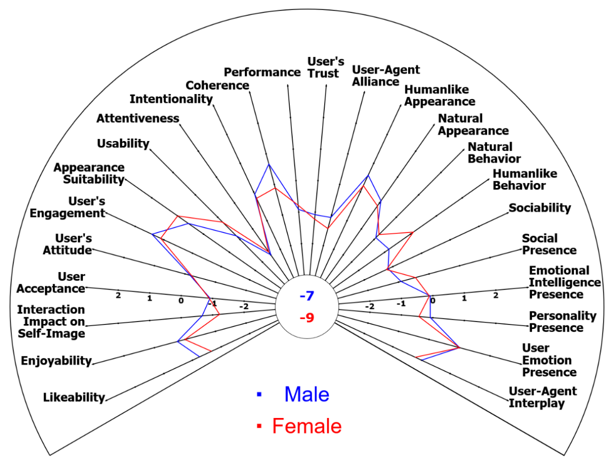
Figure 17: ASA charts for the different sub-groups of all the participants. The charts show the score of each construct per sub-group. The middle of the charts shows the overall ASA score for the compared condition.



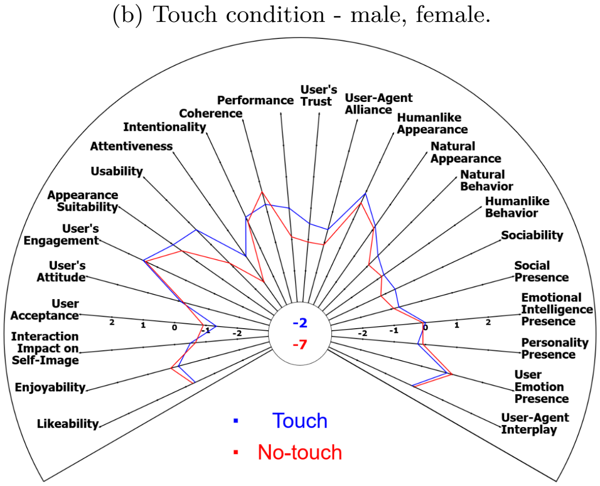
(a) Touch, no-touch.



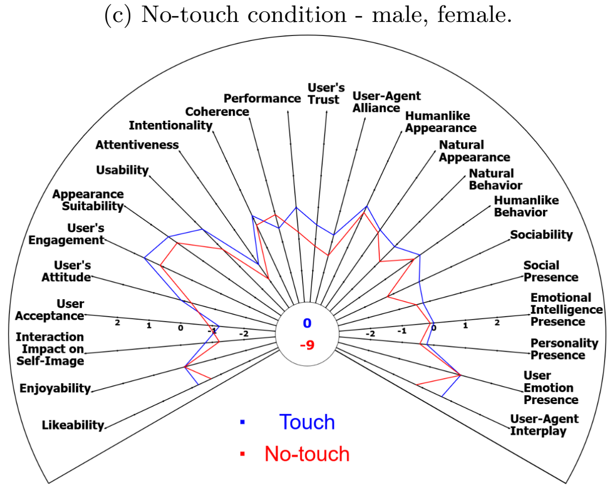
(b) Touch condition - male, female.



(c) No-touch condition - male, female.

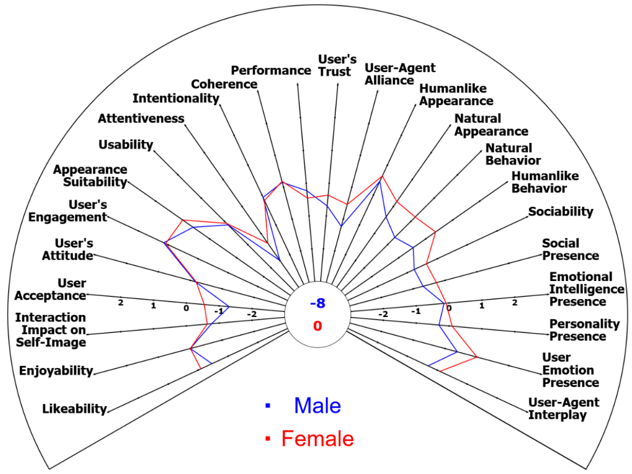


(d) Male participants - touch, no touch.

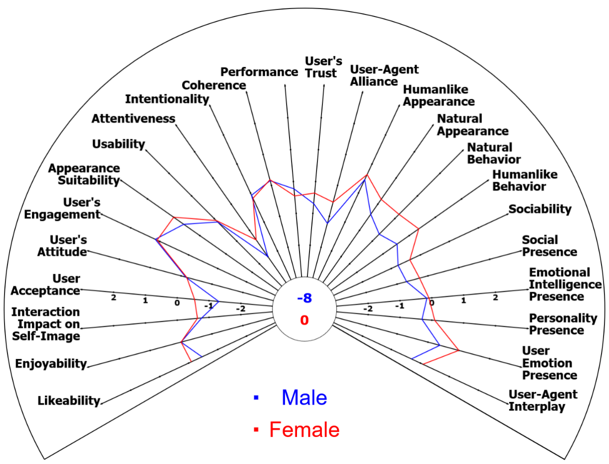


(e) Female participants - touch, no-touch.

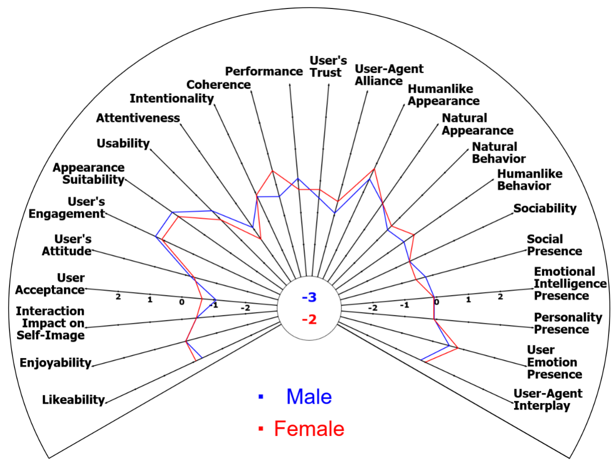
Figure 18: ASA charts for the different sub-groups of the touching participants. The charts show the score of each construct per sub-group. In the middle shows the overall ASA score for the sub-groups.



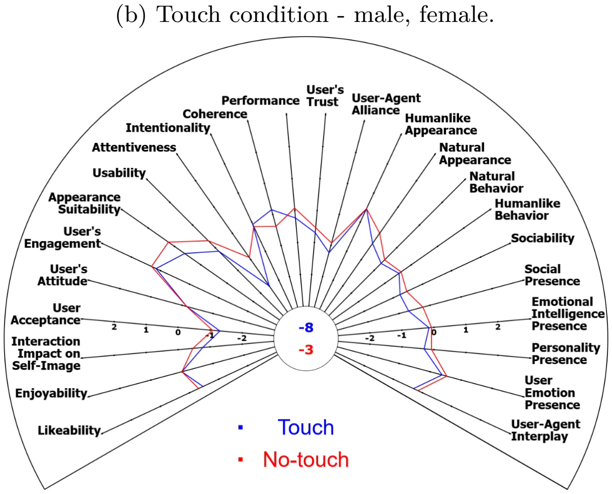
(a) Touch, no-touch.



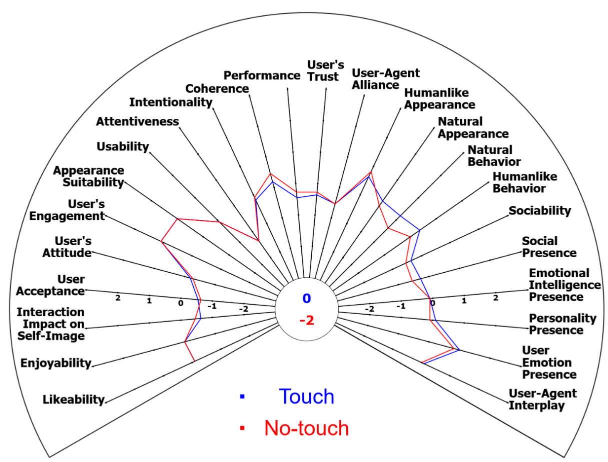
(b) Touch condition - male, female.



(c) No-touch condition - male, female.



(d) Male participants - touch, no touch.



(e) Female participants - touch, no-touch.

Figure 19: ASA charts for the different sub-groups of the non-touching participants. The charts show the score of each construct per sub-group. In the middle shows the overall ASA score for the sub-groups.

4 Discussion

The following section discusses apects of the work done in this thesis in a more broad view, tying the multiple studies together.

4.1 Design of the study

The design of main study was adapted based on two smaller studies which served as pilots. While the main study provided statistically significant results and insight in human-robot touch interactions, there are still aspects of the study design that can be discussed.

4.1.1 Task

From the results of the video footage in Table 12 it can be seen that touches and pats are both exhibited as attention-grabbing touches. However as presented in Table 7, other ways of seeking attention than touching were used by the participant as well. Most notably trying to get the attention of the robot via some form of speech interaction, either speaking full sentences or the exclamation of single words. This could be an indication that during the task of reading a book, touching as an attention-grabbing behaviour is not the most intuitive. And there that this is not a setting which induces attention grabbing touch behaviours in all participants. This is supported by Table 11 where most participants reported that it was not intuitive to touch the robot and in a similar situation most participants also would not touch a human. Next to this, participants reported that simultaneously reading, paying attention to the robot and interacting with it, was a difficult task to perform.

4.1.2 Use of the Furhat

The Furhat had the ability to perceive via the touch-sensitive shell. In this research touch interaction via the shell was binary. This way of perceiving touch interaction is similar to the NAO and Pepper robots [55, 54]. There robots are already integrated with touch sensors and therefore would have been suitable as well to explore binary touched-based interaction. However the NAO and the Pepper robots only have localised touch sensors while the Furhat's entire base was made touch sensitive allowing the participants to freely touch the robot wherever they found it most intuitive. Next to this, the shell is capable of detecting more complex touch-based interaction. As it detects a value for each of the measuring points, which indicates its proximity. On top of this the Furhat is capable of expressing more human-like reactions than the NOA or the Pepper robots, allowing for more more natural interaction.

4.1.3 Positioning of the Furhat

In the designed setup of the experiment as illustrated in Figure 4, the Furhat was situated to the left side of the participant. This choice was made arbitrarily but could have an influence on the touching behaviour of the participants. Since most participants held the book in their hands while reading, they only had one hand available to touch the Furhat. Depending on if the participant is left or right handed, the location of the Furhat could influence how intuitive and easy it is to touch the Furhat during the experiment. There this could be a factor that could influence the affordance of the context to touch the robot, which was not taken into account in the study design.

4.1.4 Participants

Most participants in this work were young adults. This introduces a bias in the results. It cannot be claimed that the results of this study are applicable to the general population. Generally young adults are more tech-savy and might be more comfortable with interacting with a robot than older adults. However, older adults might have more experience with reading a story to someone and might interact different than young adults. Another thing to notice about the population is that they are mostly recruited from the University of Twente, where usually higher educated participants are sampled than the general population.

Next to this, Brysbeart et al. [90] state that for a within-subject study with two conditions a suitable number of participants would be 52. In total 52 participants were recruited for this experiment. However not all participants touched the robot, meaning that not all participants noticed that touching the robot grabbed its attention. Therefore drawing conclusions based on all the participants would not be meaningful. For that reason the participants were divided in touching participants and non-touching participants. This left only 21 participants in the touching group from which conclusions were drawn in this study.

4.1.5 The dependent and independent variables

Personal preferences regarding touching in interaction seem to play a role. These preferences could caused that when a participant did not touch the robot and therefore the influence of touch was not measured. Likely the influence of having the attention of the robot focused on you or not was measured for the non-touching participants. However also another unknown perceived influence the participants thought to have on the behaviour of the robot could have been measured for this group. This was due to the design of the study. In the no-touch condition, the attention of the robot was directed to the participant periodically. If the participant would try something right at that moment, they might have the idea that something they did influenced the behaviour of the robot. Three participants experienced this scenario and touched the robot during the no touch condition exactly at the moment that the robot would gain back its attention. This made them think that during the no-touch condition they could also influence the robots behaviour by touching it.

The factor of measuring the influence of how much attention is being paid also plays a role in the touching participants, since the statistical analysis shows a statistically significant difference for Agent's Attentiveness in touch participants. How much this influenced the overall perception on the HRI cannot be derived from the results.

As seen in Table 11, most participants did notice a difference between the conditions. This indicates that the conditions are different enough to measure differences in constructs. However it should also be critically noted that participants could influence the behaviour of the robot in the touch condition and not in the no-touch condition. This means that next to the effect of being able to touch the robot, there is also an effect of being able to influence the behaviour of the robot. This is a confounding factor in this study and the amount of influence it has on the results is unknown.

4.1.6 Priming for touch

While attention-grabbing touch is considered one of the more neutral types of touch and described in the literature as one of the main ways in which attention is grabbed. However this might not apply directly to a robot. During the first study it was already seen that attention-grabbing touch was not the first method participants seek interaction with the robot, however after some time it does occur. By adding the task of reading to robot it was assumed that people want the listener to pay attention, it there it was assumed that this would increase likelihood of attention-grabbing touch behaviours.

The second study indicated that this might indeed be the case, however, this probably was a case of unlucky sampling since during the 10 following participants only had a touch rate of 20%. It was then decided that the participants should be primed that touching is a away in which can be interacted with the Furhat. It was expected that having the shell stand out by its colour would prime the participants to interact with it, however this was not to case. A way of priming the participant to touch the robot was then implemented. During the task recap the researcher touched the shell and the robot looked at the place of touch and the researcher, followed by the utterance 'Oh hi'. When this proved not sufficient in study 4, the participants were instructed to touch the robot to start up the experiment. While these adaptations seem to help in priming for touch interaction, it might also prime that the Furhat can talk back to them. This can also be seen in the interviews where participants reported that they did expected the Furhat to interact by for example speaking.

4.1.7 Evaluation

The interviews were used to assess why participants exhibited certain behaviours. However, during the analysis it turned out that the interview questions were not extensive enough. And that some aspects of the behaviour would have also been interesting to know something about. One of these aspects is whether someone has prior experience with interacting with social robots. Participants with prior experience might compare the interaction to an interaction with another social robot and might feel more comfortable during the interaction. Participants without prior might compare the interaction to an interaction with another human and might feel less comfortable during the interaction. Next to this, the expectation of the robot's capabilities might also be different for these two groups of people. An indication of this can be found in the participant reports. 12 of the 39 participants that were taken into account for the behavioural explicitly reported that they needed to feel comfortable and four participants explicitly reported not having the expectation that the robot could react to touch. However, no specific questions have been asked about these aspects, and therefore, no claims can be made whether these aspects influence the interaction.

Another important shortcoming is that there is no meaning attached to a certain ASA score [50]. Therefore claims can only be made about whether there is a statistically significant difference between the conditions and within data groups, but not what this difference means. The behavioural analysis and interview questions were designed to support the ASA scores, however as mentioned before they were not extensive enough to provide additional insights.

4.2 Functionality of the System

During the experiment, the shell experienced some faultiness. On the one hand the shell fired while there was no touching happening. On the other hand the shell did not fire when touching happened. This caused three of the participants to be excluded from the results.

The Furhat not always reacting correctly could have something to do with the fit of the shell. The shell fits very snugly, potentially compressing some of the wires, causing accidental firing. Adjusting the positioning of the shell did prove to help and therefore some additional testing was done before each participant to ensure correct positioning. This could also be prevented by adding a filter in the software, since the firing happened in a distinct pattern. However since this was only discovered during the experiment phase this was not added, to avoid accidentally changing the behaviour of the robot.

The shell not reacting to touch has to do with the I2C bus of the ESP32. Which has a buffer that sometimes overflows, causing it to get out of sync. If it gets out of sync it re-syncs, causing the shell to not be touch sensitive for some time. If the participant touched the shell exactly at that moment, it did not register the touch. A solution would be to build in a fail safe in the software. If the experimenter would see a touch not being registered, they could enter a command and the touch trigger would fire. However this would not be desirable since this would be using a Wizard of Oz method while the part of this research is about creating a touch-sensitive interface for a robot. By introducing a way to fire the touch trigger, the shell would not be needed for the experiment. Next to this, if the researcher would miss a touch, then the experiment would be influenced as well.

4.3 Codebase

Using the thread structure, threads can influence each other instantly, allowing for the soft real-time integration that is desired in this research. The modular structure of the code base allows for easily implementing new condition classes that use the behaviour classes or shell monitoring class. This makes the code base very flexible for future work.

Having the shared variables in a separate helper file ensures that when certain gesture durations are changed or pre-defined locations are changed. This is immediately adapted correctly in all classes, avoiding possible mistakes that can arise when changing the value of a variable that is present in multiple classes.

When the Furhat is exhibiting the yawning gesture and being touched at the same time, the yawn does not stop. The Furhat goes into its attentive behaviour and turn its attention towards the participant, but the yawning gesture is completed. This could lead to unintended behaviour, such as the participant thinking it is yawning at them when it is paying attention. This unintended behaviour could influence the interaction, however this is not explicitly analyses in this work.

5 Future Work

The future work of this study lies within improvements to the touch-sensitive shell, a more in-depth investigation of human behaviour, an expansion of the current study and improvements to the current codebase.

5.1 Conductive Filament Shell

The first version of the touch-sensitive shell was designed to 3D print tracks into the model which would serve as Rx and Tx electrodes. These tracks would have been printed using conductive filament and would have to be connected to the electronics in the same way as the wires in the current design. This is a very elegant solution and worth further research.

Two main challenges need to be tackled to realize this design. The first main challenge is the distance between the tracks. The tracks need to be close enough together that they can create an effective capacitive sensing grid, but far enough from each other that they are not connected. The conductive filament used proved to be very stringy. This causes problems if the tracks are too closely positioned together. Due to the stringiness of the material the tracks are prone to accidentally connect.

The second main challenge was that the extrusion of the conductive filament stopped halfway through the print. This can have multiple causes as well. However, two main causes were observed, namely clogging and under extrusion. The conductive filament contains metal particles to it conductive. However this makes the filament not evenly and smooth, creating clogs in the nozzle. Next to this, the metal particles can conduct the heat used for printing, introducing heat creep which can also cause clogs in the nozzle. Conducting the heat also makes the filament more prone to sticking to the inside of the nozzle, creating residual build-up, which also causes clogs.

The under-extrusion mostly seemed to be caused by filament grinding, which can be caused by a too-high print speed, too-low temperature and a wrong nozzle alignment.

Many different settings have been tried to tackle these challenges:

- Print temperature range (170 - 230, increments of 5)
- Retraction distance (0.5-2 mm, increments of 0.5)
- Retraction speed (10 mm/s - 60 mm/s, increments of 10)
- Print speed (15 mm/s-120 mm/s, increments of 15)
- z-hop (0.2-2 mm, increments of 0.4)

These challenges make the filament difficult to print with, therefore 3D printing experience is needed to solve this issue. Finding the correct settings to prevent the adverse effects of stringing and under-extrusion is something to be tackled in future work. A balance should be found for the correct temperature as the temperature cannot be too low due to under-extrusion but also not to high since otherwise clogging and heat creep occur.

5.2 Wired shell

The capacitive grid in the current design of the touch-sensitive shell is set up such that the Rx and Tx electrodes are separate for the front and the back of the shell, creating a resolution of 140 measuring points in the front and 117 measuring points in the back. This was the easiest way to set this up since no calibration needed to be done in order for the capacitive sensing grid to work. And the resolution was suitable for the application in this work. However, in the future, the resolution could be increased by spanning all the TX electrodes over the entire shell, instead of separate Tx wires for the front and back. This can be done due to the electronics creating a multiplexed capacitive sensing grid. When leaving the Rx separated over the front and the back of the shell, the capacitive sensing grid could have a resolution of up to 266 measuring points in the front and 247 measuring points in the back. Creating more measuring points would allow for a more precise sensing of touch-based interaction and, therefore, being able to perceive more complex touch-based interactions. However it should be taken into account that this could also generate more noise to the sensor.

The shell fits the Furhat quite tightly, comprising the wires if it is not placed correctly. In the next iteration of the design, more tolerances can be added to both halves of the shell. Since the second half that was printed was extended by 7.5 mm and this resulted in a tight fit, a starting point would be to increase the tolerance of the inside of both halves of the shell by 5 mm. This way, there is more space inside the shell, making it less likely for wires to be compressed.

Another improvement to be made to the current design is the way the wires are held into place. The current design allows for wires to be claimed into place, which makes the wires easily replaceable but also prone to getting loose. A solution could be to design a cover for the groves, that can be placed inside of the shell. This can be realised in a similar fashion to how the grooves were made into the shell. The shell can be copied and offset, creating an additional layer. However a mechanism should be designed to hold the extra layer into place. A simpler solution would be to use hot glue to secure the wires. This would secure the wires nicely. However, it does reduce the ease of replaceability of the wires.

The connection of the wires to the flat cable PCB is also something that should be reconsidered. A connector was soldered on to the flat cable PCB in which the wires can be placed. This allows for easy replaceability, whoever the wires are also prone to getting lose. A solution could be to solder the wires directly to the PCB, creating a stable connection between the capacitive grid and the rest of the electronics.

The blocking of the field of view (FOV) of the camera did not cause issues during the experiment, however in a second iteration of the shell it would be nice to expand the cutout around the shell to be able to use the full FOV of the camera.

5.3 Investigating effect of personality

Most participants of the main study reported that they also would not touch a human in the same situation. Their reports were mostly made by non-touching participants. A statistically significant relationship between whether a participant would touch a human and whether they touched the robot was not found. However, it would be interesting to repeat this experiment with humans. In this study, a human actor would act similarly to the robot, and participants would be reading to them and trying to keep their attention. This way a bigger claim can be made the influence of the robot itself on the likelihood of touch-based interaction and the influence of the personality of the participant.

5.4 Different types of touches, different responses

The designed experiment is quite simple since it only looks at the difference between being able to touch the robot and not being able to touch the robot. With the touch-sensitive interface in place and a better understanding of touch interaction can be gained and the step can be made to more complex interactions. Looking back at the 12 distinct touch categories, a study can be designed comparing multiple different touch categories, for example, attention-grabbing touch and supportive touch. And implementing different responses of the robot related to these different types of touch to investigate the influence of these different types of touches and different types of responses on HRI.

5.5 Extensions to the codebase

The implementation of the backchanneling behaviours is currently a not well developed part of the system. Participants reported that the timing of nodding behaviour was sometimes not in line with when the participants expected the a nod. In HHI nodding usually occurs at the end of sentences or when certain prosody changes occur [72]. However, in the codebase, nodding currently happens with a set interval. The same holds for the surprised look behaviour that happens when a change of volume is detected. This feature could also be made more sophisticated by basing this behaviour on a change in pitch or other prosody characteristics.

Currently, the microphone monitor uses the input of the computer running the software. However, the Furhat can be connected to an external microphone. This was not done in this work due to the late stage in which the feature was added. However, in future work, this is something to be considered. Using the external microphone would ease the development of speech-based interactions, since the Furhat supports basic speech processing using the external microphone.

As discussed at the main study, the yawning gesture does not stop when the shell is touched which could create unintended influences on the HRI. An improvement to this would be to stop the yawn when the participant touches the robot. However, this could lead to unnatural behaviour as well. Another improvement could be for the robot to follow up with another type of behaviour, such as embarrassment, to make the continuation of the yawning behaviour more natural.

The codebase is currently implemented in Python, using a network-based API to control the Furhat. However, out of the box, the Furhat comes with a Kotlin framework. This framework would allow a more native control of the Furhat, being able to use functionalities that are not present in the API, such as using trigger events which could limit the use of threads. Possibly solving some of the timing issues occurring now. However, it proved difficult to read out the shell using Kotlin since USB support for Kotlin is lacking. Still, it would be interesting to explore the possibilities of this framework.

To support more complex touch-based interactions, an extension of the current code should be made to determine different characteristics of the touch interaction. These characteristics could include the location, duration and intensity of the touch. But also the progression of a touch interaction over time. One additional functionality that then needs to be implemented, is passing variables between different threads. For example, when wanting to use the touch characteristics to determine the type of touch (e.g. pats and strokes), these characteristics might need to be passed to a different class that can classify them. Currently, this is not possible.

The classification of different types of touches or even different categories of touches could be done by using machine learning. As seen in the literature research is already exploring this with decent accuracy.

5.6 Evaluation of HRI

One of the main drawbacks of the evaluation of the HRI in this work is that there is no meaning attached to the ASA score. Investigating the meaning of the ASA score is ongoing research in the HRI community [50]. However, insights could be given into the ASA score by creating more extensive interview questions. The answers of the participants could then be directly related to their ASA score in order to draw more meaningful conclusions from it.

In general the evaluation of the HRI could already be improved by collecting more demographic data which can be relevant to touch-based interaction or HRI. Such as the cultural background of the participants or the experience of the participants with interaction with other social robots.

6 Conclusion

The main research question of this thesis is *'How does the adequate reaction of a social robot to induced attention-grabbing touch influence the Human-Robot Interaction?'* This question was answered by conducting the main study of this thesis which induced attention-grabbing touches in a social context. To design this study and gain more insights into the proposed question, three sub-questions needed to be answered first.

6.1 Is touch a natural form of attention-grabbing behaviour in Human-Robot Interaction, and what does this look like?

This first first sub-question was answered during a first study which observed the behaviour of participants when they were asked to grab the attention of a robot. This study showed that one of the ways the participants grabbed the robots attention was via touch-based interaction; patting, tapping and stroking the Furhat. For this study an artificial skin patch was used as a touch-sensitive interface for the robot. This skin patch was not attached to the robot making it unintuitive to use it as a touch-sensitive interface for attention-grabbing touches. This answers the additional question of this sub-question *'What should a touch-sensitive interface look like to support attention-grabbing touch behaviours?'* A touch-sensitive interface that supports attention-grabbing touches should allow for the robot itself to be touched.

6.2 How can attention-grabbing touch be induced in a social context?

This sub-question has five additional questions, starting with *'How can a touch-sensitive interface be designed for a social robot that has the affordance to induce attention-grabbing touch behaviour?'* The designed touch-sensitive interface is in the form of a shell that can encapsulate the base of a Furhat. The shell encapsulates a capacitive sensing grid and can be manufactured using 3D printing. The second additional question was *'How can a soft real-time integration between a touch-sensitive interface and a social robot be realised?'* This question is related to the additional question *'What is the importance of timing in touch-based interaction?'* An integration has been made between the shell and the Furhat using threads that can be paused and unpaused. The timing of the integration was evaluated, showing that the integration adheres to the 2-second rule, but does not comply with the preferred response time for touch interaction. In the main study participants reported that they found it more natural when the robot would react quickly to their touches. The additional questions of *'Which contextual factors play a role in inducing attention-grabbing touch?'* and *'What is an adequate reaction in touch-based interaction, and what does it depend on?'* These questions were answered by conducting two studies that served as pilot studies for the main study. The studies found that participants need to be shown that the robot can respond to touch interaction and that participants need to touch the robot itself in order to create enough affordance to induce attention-grabbing touch. Contextual factors such as the position of the book or gender of the participants did not play a role in inducing touch behaviour. Next to this it was found that an adequate reaction to touch-based interaction is for the robot to look at the participant upon being touched.

6.3 Which social human-robot interaction constructs are influenced by a social robot reacting to attention-grabbing touch?

This sub-question had the additional question *'Which contextual factors play a role in influencing the human-robot interaction constructs?'* These questions were answered by conducting the main study. This study found a statistically significant difference for the constructs of Natural Behaviour, Agents Appearance Suitability, Performance, Agent's Sociability, User's Trust, User-Agent Alliance, Agent's Attentiveness and Agent's Intentionality. These contextual factors positively contribute to the interaction. There were no contextual factors that influenced the touch interaction.

6.4 How does the adequate reaction of a social robot to induced attention-grabbing touch influence the Human-Robot Interaction?

Based on the sub-questions the main research question can now be answered. It was found that there is a statistically significant difference in being able to influence the behaviour of the robot, via touch interaction. It influences multiple social constructs and participants found it more pleasant than not being able to influence the behaviour of the robot. With the increase of social robotics in our daily lives more natural forms of interacting with these social robots are needed. Touch is one of the least researched forms of HRI. However, this thesis shows that touch can, just as with humans, be used as a form of intuitive social interaction between human and robot.

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A Appendix: Information Sheet

Information sheet Influence of Response on HRI

The research you will be participating in is for the purpose of my master thesis. The goal of this research is to investigate the influence of the response of a robot on the human perception of human-robot interaction.

For this you will be interacting with a Furhat robot, as can be seen in the image on the right. This robot is a social robot and has a realistic projection of a human face. It can move its head upwards, downwards, sideways and tilt it.

The interaction during the research will be reading a children's book to the robot out loud. You will do this twice, with different settings of the robot.

After each reading of the book you will be asked to fill in a questionnaire. After you have read to the robot twice, you will be also asked a series of questions in the form of an interview.

The complete research will be recorded on video and audio. This will be used for analysis in behavioural patterns during the interaction. Some demographic information will be collected, namely age and gender. This is used to analyse how these factors influence the results.

All of the collected data will be destroyed once the research is completed. The data will not be published or used for research other than this one. You have the right to request access to and rectification or erasure of your personal data.

You have the right to withdraw from the research at any time, without giving a reason. This can be done verbally during the executing research or afterwards by contacting the researcher by email.

This research has been approved by the Ethics Committee Information and Computer Science.

Study contact details for further information:

Sarah Onrust

s.onrust@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

03-04-2024

B Appendix: Informed Consent Form

Consent Form for Influence of Response on HRI

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated 03/04/2024 or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves interacting with the Furhat robot, filling in a survey questionnaire and a short interview. These activities will be recorded on video and audio. The recordings will be transcribed and annotated. The recordings and responses to the questionnaires and interviews will be destroyed after the study has been completed.	○	○
Use of the information in the study		
I understand that information I provide will be used for data analysis for the purpose of a master thesis.	○	○
I understand that personal information collected about me that can identify me, such as my name, gender and age, will not be shared beyond the study team.	○	○
I agree that my information can be quoted in research outputs	○	○
I agree to be audio recorded	○	○
I agree to be video recorded	○	○

Signatures

______________________ ______________________ ________

Name of participant [printed] Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ ________

Researcher name [printed] Signature Date

Study contact details for further information: Sarah Onrust s.onrust@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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C Appendix: ASA Questionnaire

- (HLA1) Furhat's appearance is human
- (HLA2) Furhat has the appearance of a human
- (HLA3) Furhat has a human-like outside
- (HLA4) Furhat's appearance makes me think of a human
- (HLB1) A human would behave like Furhat
- (HLB2) Furhat's manners are consistent with those of people
- (HLB3) Furhat's behavior makes me think of human behavior
- (HLB4) Furhat behaves like a real person
- (HLB5) Furhat has a human-like manner
- (NA1) Furhat appears like something that could exist in nature
- (NA2) Furhat has a natural physique
- (NA3) Furhat's resemblance has an organic origin
- (NA4) Furhat seems natural from its outward appearance
- (NA5) How Furhat is represented is realistic
- (NB1) Furhat is alive
- (NB2) Furhat acts naturally
- (NB3) Furhat reacts like a living organism
- (AAS1) Furhat's appearance is appropriate
- (AAS2) Furhat's physique is suitable for its role
- (AAS3) Furhat's appearance was suitable
- (AU1) Furhat is easy to use
- (AU2) Learning to work with Furhat is easy
- (AU3) Learning how to communicate with Furhat is quick
- (PF1) Furhat does its task well
- (PF2) Furhat does not hinder me
- (PF3) I am capable of succeeding with Furhat
- (AL1) Furhat's appearance is pleasing
- (AL2) I like Furhat
- (AL3) I dislike Furhat
- (AL4) Furhat is cooperative
- (AL5) I want to hang out with Furhat
- (AS1) Furhat can easily mix socially

- (AS2) It is easy to mingle with Furhat
- (AS3) Furhat interacts socially with me
- (APP1) Furhat has a distinctive character
- (APP2) Furhat is characterless
- (APP3) Furhat is an individual
- (UAA1) I will use Furhat again in the future
- (UAA2) I can see myself using Furhat in the future
- (UAA3) I oppose further interaction with Furhat
- (AE1) Furhat is boring
- (AE2) It is interesting to interact with Furhat
- (AE3) I enjoy interacting with Furhat
- (AE4) Furhat is unpleasant to deal with
- (UE1) I was concentrated during the interaction with Furhat
- (UE2) The interaction captured my attention
- (UE3) I was alert during the interaction with Furhat
- (UT1) Furhat always gives good advice
- (UT2) Furhat acts truthfully
- (UT3) I can rely on Furhat
- (UAL1) Furhat and I have a strategic alliance
- (UAL2) Collaborating with Furhat is like a joint venture
- (UAL3) Furhat joins me for mutual benefit
- (UAL4) Furhat can collaborate in a productive way
- (UAL5) Furhat and I are in sync with each other
- (UAL6) Furhat understands me
- (AA1) Furhat remains focused on me throughout the interaction
- (AA2) Furhat is attentive
- (AA3) I received Furhat's full attention throughout the interaction
- (AC1) Furhat's behavior does not make sense
- (AC2) Furhat's behavior is irrational
- (AC3) Furhat is inconsistent
- (AC4) Furhat appears confused
- (AI1) Furhat acts intentionally
- (AI2) Furhat knows what it is doing

- (AI3) Furhat has no clue of what it is doing
- (AI4) Furhat can make its own decision
- (AT1) I see the interaction with Furhat as something positive
- (AT2) I view the interaction as something favorable
- (AT3) I think negatively of the interaction with Furhat
- (SP1) Furhat has a social presence
- (SP2) Furhat is a social entity
- (SP3) I have the same social presence as Furhat
- (IIS1) My friends would recommend me to use Furhat
- (IIS2) Others would encourage me to use Furhat
- (IIS3) Furhat makes me look good
- (IIS4) People would look favorably at me because of my interaction with Furhat
- (AEI1) Furhat is emotional
- (AEI2) Furhat experiences emotions
- (AEI3) Furhat is emotionless
- (AEI4) Furhat can express its feelings
- (AEI5) Furhat cannot experience emotions
- (UEP1) Furhat's attitude influences how I feel
- (UEP2) I am influenced by Furhat's moods
- (UEP3) The emotions I feel during the interaction are caused by Furhat
- (UEP4) My interaction with Furhat gives me an emotional sensation
- (UAI1) My emotions influence the mood of the interaction
- (UAI2) Furhat reciprocates my actions
- (UAI3) Furhat's and my behaviors are in direct response to each other's behavior
- (UAI4) Furhat's and my emotions change to what we do to each other

D Appendix: Software implementation

D.1 No-touch condition

```
#!/usr/bin/env python
import random
from privex.helpers import SafeLoopThread

from variables import *
from distractedBehaviour import DistractedBehaviour
from attentiveBehaviour import AttentiveBehaviour
import shellMonitor
import micMonitor


class NoTouchCondition(SafeLoopThread):
    """
    This class controls the behaviour of Furhat during the No Touch Condition.

    Furhat is in the attentive behaviour for an amount of time and then goes to the
    distracted behaviour for an amount of time
    """
    def __init__(self, *args, default_stop=False, default_pause=False, **kwargs):
        """
        Init of the touch-condition

        Initializes the touch condition, by starting
            the distracted and attentive behaviour

        """
        # distracted behaviour is paused upon start
        self.distraction_thread = DistractedBehaviour(default_pause=True)
        self.attention_thread = AttentiveBehaviour()
        self.attend_rand = 0

        self.attention_thread.start()
        self.distraction_thread.start()
        super().__init__(*args, default_stop=default_stop,
                         default_pause=default_pause, **kwargs)

    def loop(self):
        """
        Main loop of the no touch condition - This loops until it is paused or stopped

        Carries out the attentive behaviour for a variable amount of time
        Carries out the distracted behaviour for a variable amount of time

        """
        # random duration to attend, same range as in distracted behaviour
        self.attend_rand = random.randint(10, 30)
        nodding_behaviour(self.attend_rand)
        self.attention_thread.emit_pause()      # pause the attentive behaviour
        start_attentive.clear()
```

```
        self.distraction_thread.emit_unpause()  # start the distracted behaviour
        end_distracted.wait()                   # wait on the distracted behaviour
        end_distracted.clear()
        self.distraction_thread.emit_pause()    # pause the distracted behaviour
        self.attention_thread.emit_unpause()    # start the attentive behaviour
        start_attentive.set()


def main():
    """
    Main function of the No Touch Condition

    Initialises the no touch condition thread class, starts the mic monitor
    on a thread and the shell monitor on a thread

    Waits until the startup behaviour has commenced, then starts the
    no touch condition thread and mic monitor thread
    """
    big_eyes.set()
    main_thread = NoTouchCondition()
    mic_thread = threading.Thread(target=micMonitor.main, args=(main_thread,))
    shell_thread = threading.Thread(target=shellMonitor.main)
    shell_thread.start()
    startup()
    main_thread.start()
    mic_thread.start()


if __name__ == '__main__':
    main()
```

D.2 Touch condition

```
#!/usr/bin/env python
import random
from threading import Thread
from variables import *
from privex.helpers import SafeLoopThread
from distractedBehaviour import DistractedBehaviour
from attentiveBehaviour import AttentiveBehaviour
import shellMonitor
import micMonitor


class TouchCondition(SafeLoopThread):
    """
    This class controls the behaviour of Furhat during the Touch Condition.

    """

    def __init__(self, *args, default_stop=False, default_pause=False, **kwargs):
        """
        Init of the touch-condition

        Initializes the touch condition, by starting the
            distracted and attentive behaviour

        """
        # distracted behaviour is paused upon start
        self.distraction_thread = DistractedBehaviour(touch_condition=True,
                                                      default_pause=True)
        self.attention_thread = AttentiveBehaviour(default_pause=True)

        self.attention_thread.start()
        self.distraction_thread.start()
        super().__init__(*args, default_stop=default_stop,
                         default_pause=default_pause, **kwargs)

    def loop(self):
        """
        Main loop of the touch condition - This loops until it is paused or stopped

        Carries out the attentive behaviour for a variable amount of time
        Carries out the distracted behaviour until touched

        """
        self.attention_thread.emit_unpause()  # unpause the attention behaviour
        start_attentive.set()
        # random duration to attend, same range as in distracted behaviour
        attend_rand = random.randint(10, 30)
        nodding_behaviour(attend_rand)
        self.attention_thread.emit_pause()  # pause the attend behaviour
        start_attentive.clear()
        end_distracted.clear()
        self.distraction_thread.emit_unpause()  # start the distract behaviour
```

```
        end_distracted.wait()  # wait on the distracted behaviour
        self.distraction_thread.emit_pause()  # pause the distract behaviour


def main():
    """
    Main function of the Touch Condition

    Initialises the touch condition thread class, the mic monitor on a
        thread and the shell monitor on a thread

    Waits until the startup behaviour has commenced, then starts
        the no touch condition thread and mic monitor thread
    """
    big_eyes.set()
    touch_condition = True
    main_thread = TouchCondition()
    mic_thread = Thread(target=micMonitor.main, args=(main_thread,))
    shell_thread = Thread(target=shellMonitor.main, args=(touch_condition, False,))
    shell_thread.start()
    startup()
    main_thread.start()
    mic_thread.start()


if __name__ == '__main__':
    main()
```

D.3 Attentive behaviour

```
from swagger_client import Location
from privex.helpers import SafeLoopThread

from variables import *


class AttentiveBehaviour(SafeLoopThread):
    """
    Attentive Behaviour of the Touch of the Furhat studies

    Furhat focuses on the participant and produces back channeling behaviour
    """

    def __init__(self, *args, default_stop=False, default_pause=False,
                 begin_condition_bool=False, **kwargs):
        """
        Init of the Attentive Behaviour

        :param begin_condition: bool - flags if this is the begin-condition
        """

        self.begin_condition_bool = begin_condition_bool
        super().__init__(*args, default_stop=default_stop,
                         default_pause=default_pause, **kwargs)

    def loop(self):
        """
        Attentive Behaviour  Loop - This loops until it is paused or stopped

        Makes Furhat attend a certain location and respond to loud sounds
        """
        # Check if the class is called by begin-condition or touch/no touch condition
        if not self.begin_condition_bool:
            # Check if the user is visible to The Furhat and set their location
            if len(fh.get_users()) > 0:
                userid = fh.get_users()[0]
                usr_location = userid.location
            else:  # If the user is not visible, set a pre-defined location
                usr_location = Location('-.17', '.15', '.8')

            str_loc = str(usr_location.x) + "," + str(usr_location.y) + "," + str(
                usr_location.z)  # Create a string of the location
            fh.attend(location=str_loc)  # Let The Furhat attend this location

            if loud_sound.is_set():  # Check if the participant speaks loudly
                gest.big_eyes()  # Show big eyes
                time.sleep(dur_big_eyes)  # Wait until the big eyes gesture is done
                loud_sound.clear()  # Reset the loud sound trigger
            start_attentive.set()  # The attentive behaviour is started
        else:  # In the begin-condition, look away from the instructor
            fh.attend(location=lookUpRight)
```

D.4 Distracted behaviour

```python
import random
from privex.helpers import SafeLoopThread

from variables import *


def yawn_behavior():
    """
    Controls the behaviour of the yawning gesture within a larger behaviour

    """
    # Determines if a yawn should take place
    if random.randint(1, 100) < yawn_chance:
        gest.yawn()
        time.sleep(yawn_delay)  # Wait until the yawn is completed


class DistractedBehaviour(SafeLoopThread):
    """
    Distracted Behaviour of the Touch of the Furhat studies

    Furhat is distracted from the participant and produces back channeling behaviour
    """
    def __init__(self, *args, default_stop=False, default_pause=False,
                 touch_condition=False, **kwargs):
        """
        Init of the Distracted Behaviour
        :param touch_condition: bool - flags if this is the touch condition
        """

        self.touch_condition = touch_condition
        super().__init__(*args, default_stop=default_stop,
                         default_pause=default_pause, **kwargs)

    def loop(self):
        """
        Distracted Behaviour Loop - This loops until it is paused or stopped

        Makes Furhat look around at two different locations.
        Depending on the condition, this either happens indefinitely or for a
        certain amount of cycles
        """

        if not self.touch_condition:  # Check if this is the touch condition
            # pick a random amount of times to go through the distract cycle
            dist_rand = random.randint(1, 5)
            for i in range(dist_rand):
                fh.attend(location=lookUpLeft)
                time.sleep(delay * 4)
                yawn_behavior()                    # possibility of yawning
                fh.attend(location=lookUpRight)
                time.sleep(delay * 4)
```

```
            yawn_behavior()
        end_distracted.set()
    else:  # If not it is the no touch condition
        fh.attend(location=lookUpLeft)
        time.sleep(delay * 4)
        yawn_behavior()
        fh.attend(location=lookUpRight)
        time.sleep(delay * 4)
        yawn_behavior()
```

D.5 Shell monitor

```
from time import sleep

import numpy as np
import serial
from variables import *
import cv2

NUM_ROW = 27
NUM_COL = 19

portname = "COM3"


def main(touch_condition=False, begin_condition=False):
    """
    Main function of the shellMonitor module.

    This module monitors the touch sensitive shell and reads out its frames

    Then continuously monitors the shell and triggers a Threading Event when
        a touch happens

    :return:
    """
    # connect to the serial port that has the ESP32 connected to it
    try:
        serial_conn = serial.Serial(portname, 500000)
    except:
        print('\nCant connect to port {}'.format(portname))
        exit(0)

    count = 0
    while not serial_conn.is_open:
        sleep(0.1)
        if count == 10:
            print('\nTimed out')
            exit(0)

    print('\nconnection established')
    # create a buffer to store 6 characters, to check for a Frame later
    buffer_values = ['0', '0', '0', '0', '0', '0']

    # continuously try to read out the frames while the connection is opened

    while serial_conn.is_open:
        try:
            # create a sliding window of the bytes to check when a frame starts
            bite = serial_conn.read()
            bite_char = bite.decode()
            buffer_values.pop(0)
            buffer_values.append(bite_char)
            res = ''.join(buffer_values)
```

```
            if res == "FRAME\n":  # check the buffer array if the frame has started
                sensitive.set()
                rows, cols = NUM_ROW, NUM_COL
                img = np.zeros((rows, cols))

                while True:  # continuously read out the frames
                    line = read_frame(serial_conn)
                    i = 0

                    # Create a visualisation of the touch sensitive shell
                    for r in range(NUM_ROW):
                        for c in range(NUM_COL):
                            img[r][c] = line[i]
                            i += 1
                    c = np.clip(img, 0, 255)
                    tmp = cv2.resize(c, (rows * 30, cols * 40))

                    cv2.imshow("Shell visualisation", tmp.astype(np.uint8))

                    if is_touched(c):  # check if the shell is touched
                        print("Touched")
                        if begin_condition:
                            touch.set()  # trigger for the begin-condition
                        if not begin_touch.is_set():
                            begin_touch.set()  # trigger for the startup functionality
                        elif touch_condition:
                            end_distracted.set()  # trigger for the touch condition

                    if cv2.waitKey(1) == 27:
                        break  # esc to quit
                    break

        except:
            break

    print('\nconnection lost')
    exit(0)


def read_frame(ser):
    """
    Function that reads a frame from the serial connection
    :param ser:
    :return: list [NUM_ROW*NUM_COL+1] - the read-out frame
    """
    length = NUM_ROW * NUM_COL + 1  # one byte per measurement, plus newline character
    res = ser.read(length)  # Read the whole thing
    length -= len(res)  # If the serial port was slow
    while length != 0:  # keep reading until everything is read
        line = ser.read(length)
        length -= len(line)
        res += line
    return res
```

```python
def is_touched(c):
    """
    Function that checks if there is a touch happening in the frame c
    :param c: the frame to check
    :return: bool - True if there is a touch
    """

    check = c > 125  # Threshold for touch
    return check.sum() >= 2  # At least at 2 spots the threshold should be met


if __name__ == '__main__':
    main()
```

D.6 Variables

```
import threading
from furhat import Furhat
from thesisCode.gestures import Gestures
import time

""""
Module that contains all shared imports, variables, functions, and threading events
    of the classes in the Touch of the Furhat studies
"""

fh = Furhat("192.168.0.101").furhat
# fh = Furhat("192.168.137.1").furhat
# fh = Furhat("localhost").furhat

gest = Gestures(fh)

# Variables
nod_duration = 6
dur_big_eyes = 1.5
yawn_chance = 10

loud_multiplier = 7
touch_threshold = 4

delay = .8
yawn_delay = 7.5

# Pre-set locations to look to
lookUpLeft = '10.0, 5.0, 1.0'
lookUpRight = '-10.0, 5.0, 1.0'
lookDownLeft = '10.0, -5.0, 1.0'

# lookUpMiddle = '0.0, 5.0, 1.0'

# Threading Events needed in the code
touch = threading.Event()
loud_sound = threading.Event()
sensitive = threading.Event()
big_eyes = threading.Event()
begin_touch = threading.Event()
start_attentive = threading.Event()
end_distracted = threading.Event()


def startup():
    """
    Function which produces the startup behaviour of the Furhat

    The Furhat hangs with its head down and eyes closed - as if sleeping

    Participant needs to touch the touch sensitive interface to start the study
    :return:
```

```
    """
    gest.neck_down()
    # keep Furhat's eyes closed if touch did not happen yet
    while not begin_touch.is_set():
        fh.gesture(name="CloseEyes")
        time.sleep(.3)
    fh.gesture(name="OpenEyes")
    gest.wakeup()


def nodding_behaviour(attend_rand):
    nodding = attend_rand // nod_duration
    for i in range(nodding):
        time.sleep(nod_duration / 2)
        fh.gesture(name="Nod", blocking=True)
        time.sleep(nod_duration / 2)
```

D.7 Gestures

```
from variables import *


class Gestures:
    """
    Custom-made gestures for the Touch of the Furhat behaviour studies
    """
    def __init__(self, furhat):
        self.fh = furhat

    def yawn(self):
        """
        A yawning behaviour
        """
        self.fh.gesture(body={
            "frames": [
                {
                    "time": [
                        0.5,
                    ],
                    "params": {
                        "EYE_SQUINT_LEFT": 1.0,
                        "EYE_SQUINT_RIGHT": 1.0,
                        "PHONE_N": 1.0
                    }
                },
                {
                    "time": [
                        2.0,
                    ],
                    "params": {
                        "BLINK_LEFT": 1.0,
                        "BLINK_RIGHT": 1.0,
                        "PHONE_BIGAAH": 1.0
                    }
                },
                {
                    "time": [
                        5.0,
                    ],
                    "params": {
                        "EYE_SQUINT_LEFT": 0.7,
                        "EYE_SQUINT_RIGHT": 0.7,
                        "PHONE_W": 1.0
                    }
                },
                {
                    "time": [
                        5.5,
                    ],
                    "params": {
                        "EYE_SQUINT_LEFT": 0.3,
```

```
                    "EYE_SQUINT_RIGHT": 0.3
                }
            },
            {
                "time": [
                    6.0
                ],
                "params": {
                    "reset": True
                }
            }
        ],
        "class": "furhatos.gestures.Gesture"
    })

def big_eyes(self):
    """
    A behaviour to give the furhat a surprised look
    """
    self.fh.gesture(body={
        "frames": [
            {
                "time": [
                    0.5,
                ],
                "params": {
                    "SURPRISE": 0.7,
                    # "EYE_SQUINT_RIGHT": 0.0,
                    # "PHONE_W": 1.0
                }
            },
            {
                "time": [dur_big_eyes],
                "params": {
                    "reset": True
                }
            }

        ],
        "class": "furhatos.gestures.Gesture"
    })

def neck_down(self):
    """
    Close Furhat's eyes and tilt its head down - as if sleeping
    """
    self.fh.gesture(body={
        "frames": [
            {
                "time": [
                    0.5,
                ],

                "params": {
```

```
                    "NECK_TILT": 50,
                    "BLINK_LEFT": 1.0,
                    "BLINK_RIGHT": 1.0,
                },
                "persist": True,

            },
        ],
        "class": "furhatos.gestures.Gesture"
    })

def wakeup(self):
    """
    Tilt Furhat's head up - as if to wakeup from the neck-down gesture
    :return:
    """
    self.fh.gesture(body={
        "frames": [
            {
                "time": [
                    0.5, 1.5, 2.5,
                ],
                "persist": True,
                "params": {
                    "NECK_TILT": 0,
                }
            },

        ],
        "class": "furhatos.gestures.Gesture"
    })
```

.

D.8 Mic Monitor

```
import math
import statistics
import pyaudio
import numpy as np
from variables import *


def main(parent_thread):
    """
    Main function of the micMonitor module.

    This module monitors the internal microphone of the machine it is run on

    If calibrates first for 10 seconds and then determines what would be a loud sound

    Then continuously monitors the microphone and triggers a Threading Event
    when a loud sound takes place

    :param parent_thread: Thread this module is called in
    :return:
    """
    sampling_rate = 44100
    frames = 1024            # nr of frames to read
    channel = 1

    p = pyaudio.PyAudio()
    stream = p.open(format=pyaudio.paInt16, channels=channel, rate=sampling_rate,
                    input=True, frames_per_buffer=frames)

    loud = calibrate(frames, stream)  # Calibration

    while True:  # Continuously monitor the microphone
        big_eyes.wait()  # Wait until the process is started
        data = stream.read(frames)
        data_string = np.fromstring(data, dtype=np.int16)
        mask = data_string > loud  # Check if there is a loud sound

        # If there is a loud sound and Furhat is in the attentive behaviour and
        # there is not already a loud sound, trigger the loud sound Threading Event

        if (True in mask and not parent_thread.attention_thread.should_pause
                and not loud_sound.is_set()):
            loud_sound.set()


def calibrate(chunk, stream):
    """
    Calibrate the loud sound threshold

    For 10 seconds monitor the microphone and based on that volume level,
        determine the loud sound threshold
    :param chunk:
```

```
    :param stream:
    :return: int - loud sound threshold
    """
    forms = []  # array to collect wave forms
    t_end = time.time() + 10  # duration of the calibration

    while time.time() < t_end:
        data = stream.read(chunk)
        data_string = np.fromstring(data, dtype=np.int16)

        for i in range(len(data_string)):
            forms.append(abs(data_string[i]))
    # remove silences from the collected wave forms
    without_silent = [s for s in forms if s >= 200]
    # Compute the basic loudness level
    basis_loudness = int(math.ceil(statistics.mean(without_silent) / 100.0)) * 100

    return loud_multiplier * basis_loudness


if __name__ == '__main__':
    main()
```

D.9 Begin condition

```
#!/usr/bin/env python
from privex.helpers import SafeLoopThread

from variables import *
from attentiveBehaviour import AttentiveBehaviour
import shellMonitor


class BeginCondition(SafeLoopThread):
    """
    Begin-condition of the Touch of the Furhat behaviour studies

    Allows the instructor of the study to gain Furhat's attention
    to prime the participant that touching
    makes the Furhat respond.
    """
    def __init__(self, *args, default_stop=False, default_pause=False, **kwargs):
        """
        Init of the begin-condition

        Initializes the begin-condition, by starting the attentive behaviour
        """
        self.attention_thread = AttentiveBehaviour(begin_condition_bool=True)
        self.attention_thread.start()

        super().__init__(*args, default_stop=default_stop,
                         default_pause=default_pause, **kwargs)

    def loop(self):
        """Begin Condition Loop - This loops until it is paused or stopped

        This loop waits for the touch interface to be touched, then pauses
        the attentive behaviour, looks at the touched location, then looks at
        the instructor and then says 'Oh Hi'
        """
        touch.wait()
        self.attention_thread.emit_pause()
        fh.attend(location=lookDownLeft)
        time.sleep(2)
        fh.attend(location=lookUpLeft)
        time.sleep(1)
        fh.say(text="Oh Hi!")


def main():
    """
    Main function of the begin-condition

    Starts the main thread and the shell monitor
    """
    main_thread = BeginCondition()
    main_thread.start()
```

```
    # Currently not in touch condition, but in begin-condition
    shell_thread = threading.Thread(target=shellMonitor.main, args=(False, True,))
    shell_thread.start()


if __name__ == '__main__':
    main()
```

E Appendix: Timing Tests

E.1 Shell delay

	Shell Rec (s)	Mic Rec (s)	Time (ms)
1	2.441	2.146	295
2	3.924	3.567	357
3	5.261	4.992	269
4	6.599	6.312	287
5	7.935	7.669	266
6	9.272	9.026	246
7	10.611	10.345	266
8	11.946	11.667	279
9	13.43	13.042	388
10	14.766	14.388	378
11	3.823	3.476	347
12	5.158	4.87	288
13	8.126	7.786	340
14	9.466	9.194	272
15	10.801	10.555	246
16	12.285	11.906	379
17	13.621	13.295	326
18	14.959	14.643	316
19	16.296	15.995	301
20	19.114	18.776	338
21	2.273	1.898	375
22	3.609	3.293	316
23	4.948	4.622	326
24	6.137	5.882	255
25	7.62	7.266	354
26	8.959	8.619	340
27	10.132	9.909	223
28	12.807	12.544	263
29	14.143	13.848	295
30	15.627	15.284	343
31	2.182	1.835	347
32	3.518	3.143	375
33	4.71	4.385	325
34	5.882	5.614	268
35	7.073	6.768	305
36	8.262	7.912	350
37	9.453	9.11	343
38	10.645	10.268	377
39	11.817	11.453	364
40	13.009	12.678	331
41	2.18	1.913	267
42	3.515	3.208	307
43	4.851	4.57	281
44	6.19	5.833	357
45	7.363	7.086	277
46	8.698	8.438	260
47	10.039	9.722	317
48	11.226	10.918	308
49	13.753	13.418	335
50	14.929	14.638	291

Table 13: Results of 50 measurements over 5 sessions of the shell delay.

E.2 Furhat Delay

E.2.1 Smile

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	9	59	11	51	480
2	24	41	26	17	440
3	37	90	39	24	335
4	50	70	52	9	347.5
5	2	48	4	83	587.5
6	13	84	16	19	587.5
7	25	78	27	70	480
8	37	30	39	11	452.5
9	49	67	51	43	440
10	2	47	4	76	572.5
11	9	82	11	36	385
12	21	85	23	91	515
13	35	22	37	38	540
14	47	82	49	73	477.5
15	0	94	2	79	462.5
16	13	74	15	23	372.5
17	26	39	28	9	425
18	39	61	41	5	360
19	52	67	54	68	502.5
20	6	56	8	10	385
21	6	38	8	21	457.5
22	18	59	20	64	512.5
23	31	65	33	53	470
24	43	45	45	45	500
25	55	60	56	85	312.5
26	7	40	9	0	400
27	19	44	21	43	497.5
28	33	41	35	23	455
29	47	10	48	81	427.5
30	0	33	1	81	370
31	9	72	11	72	500
32	21	44	23	63	547.5
33	33	80	35	40	400
34	45	48	47	21	432.5
35	56	98	59	21	557.5
36	8	43	10	34	477.5
37	20	48	22	34	465
38	32	2	33	93	477.5
39	44	70	46	74	510
40	57	47	58	92	362.5
41	10	80	12	44	410
42	23	11	24	83	430
43	35	23	36	75	380
44	48	34	50	32	495
45	3	29	4	88	397.5
46	14	69	16	40	427.5
47	26	48	28	46	495
48	38	27	40	31	510
49	49	86	51	38	380
50	2	18	4	9	477.5

Table 14: Results of 50 measurements over 5 sessions of the Furhat delay for the gesture Smile.

E.2.2 Nod

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	14	64	16	24	400
2	31	56	34	0	610
3	48	82	51	43	652.5
4	4	98	7	25	567.5
5	20	89	23	33	610
6	35	96	38	40	610
7	52	63	55	7	610
8	8	12	10	39	567.5
9	24	53	26	72	547.5
10	41	12	43	39	567.5
11	10	42	11	62	300
12	24	66	27	41	687.5
13	40	59	42	91	580
14	55	45	57	43	495
15	10	46	13	7	652.5
16	25	33	28	1	670
17	40	48	42	81	582.5
18	55	85	58	10	562.5
19	11	0	13	60	650
20	25	44	27	91	617.5
21	9	83	11	94	527.5
22	25	4	27	17	532.5
23	39	28	41	87	647.5
24	53	34	55	33	497.5
25	7	70	10	5	587.5
26	22	42	24	59	542.5
27	36	48	38	41	482.5
28	50	42	52	59	542.5
29	3	21	5	87	665
30	17	69	20	17	620
31	9	87	11	27	350
32	23	55	26	22	667.5
33	38	51	40	71	550
34	53	46	55	52	515
35	8	21	10	61	600
36	23	49	26	9	650
37	39	31	41	51	550
38	56	6	58	60	635
39	13	48	16	8	650
40	30	90	33	23	582.5
41	9	91	12	4	532.5
42	26	28	28	55	567.5
43	42	65	45	12	617.5
44	57	36	59	23	467.5
45	12	27	14	33	515
46	27	24	29	84	650
47	42	95	45	68	682.5
48	59	19	61	72	632.5
49	16	62	19	9	617.5
50	32	73	35	46	682.5

Table 15: Results of 50 measurements over 5 sessions of the Furhat delay for the gesture Nod.

E.2.3 Wink

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	10	18	11	67	372.5
2	22	97	24	49	380
3	37	80	39	86	515
4	51	92	53	49	392.5
5	9	14	10	33	297.5
6	22	98	24	56	395
7	37	98	39	82	460
8	53	78	55	36	395
9	7	63	9	42	447.5
10	22	40	24	41	502.5
11	13	73	15	92	547.5
12	28	46	29	98	380
13	43	34	45	0	415
14	56	36	58	21	462.5
15	9	81	11	80	497.5
16	23	2	24	11	272.5
17	36	94	38	94	500
18	50	49	52	77	570
19	4	41	6	22	452.5
20	17	1	18	77	440
21	10	77	12	58	452.5
22	23	45	24	83	345
23	35	93	37	36	357.5
24	48	80	50	42	405
25	1	67	3	63	490
26	14	35	16	2	417.5
27	26	98	29	3	512.5
28	40	9	41	95	465
29	53	77	55	63	465
30	6	21	8	35	535
31	10	85	12	91	515
32	23	53	25	8	387.5
33	35	97	37	62	412.5
34	46	73	48	98	562.5
35	57	72	59	65	482.5
36	8	29	10	26	492.5
37	19	9	21	2	482.5
38	30	8	32	29	552.5
39	42	6	44	31	562.5
40	53	47	55	78	577.5
41	11	80	13	95	537.5
42	23	68	25	68	500
43	35	85	37	85	500
44	47	58	49	30	430
45	1	46	3	32	465
46	14	77	16	56	447.5
47	28	44	30	16	430
48	41	32	43	18	465
49	54	63	56	20	392.5
50	7	73	9	51	445

Table 16: Results of 50 measurements over 5 sessions of the Furhat delay for the gesture Wink.

E.3 Full System Delay

E.3.1 Look Left

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	41	52	45	77	1062.5
2	38	27	40	75	620
3	34	94	37	7	532.5
4	6	47	9	30	707.5
5	36	57	40	47	975
6	7	4	9	52	620
7	38	56	41	39	707.5
8	35	23	38	78	887.5
9	30	49	33	38	722.5
10	1	66	5	20	885
11	30	79	33	34	637.5
12	1	40	4	97	892.5
13	31	75	34	30	637.5
14	1	33	3	63	575
15	31	43	34	23	700
16	28	81	31	36	637.5
17	59	67	61	20	382.5
18	56	74	59	55	702.5
19	19	31	21	61	575
20	50	68	53	49	702.5
21	36	3	37	97	485
22	2	53	4	19	415
23	56	86	60	19	832.5
24	29	30	32	90	900
25	59	24	61	73	622.5
26	26	56	29	89	832.5
27	1	10	3	87	692.5
28	28	15	31	20	762.5
29	25	13	27	63	625
30	56	18	59	79	902.5
31	38	91	40	94	507.5
32	8	74	12	63	972.5
33	40	5	42	83	695
34	20	48	22	89	602.5
35	51	98	54	20	555
36	24	59	28	11	880
37	55	90	58	87	742.5
38	27	3	30	81	945
39	0	57	2	61	510
40	34	29	36	89	650
41	23	58	26	86	820
42	54	90	58	18	820
43	53	99	57	27	820
44	26	4	29	32	820
45	54	54	58	18	910
46	25	86	29	14	820
47	57	91	60	82	727.5
48	29	96	32	14	545
49	26	87	30	51	910
50	28	14	31	78	910

Table 17: Results of 50 measurements over 5 sessions of the full system delay for the state look left.

E.4 Look Right

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	39	51	42	49	745
2	17	44	19	82	595
3	53	78	55	76	495
4	29	52	31	30	445
5	7	44	9	23	447.5
6	41	60	44	38	695
7	18	53	21	31	695
8	56	46	58	64	545
9	34	98	36	77	447.5
10	10	33	12	91	645
11	41	98	45	6	770
12	18	34	20	39	512.5
13	54	19	55	72	382.5
14	31	57	34	13	640
15	7	92	11	51	897.5
16	43	25	45	81	640
17	20	12	23	71	897.5
18	56	99	60	6	767.5
19	35	91	39	49	895
20	13	80	17	39	897.5
21	41	27	43	81	635
22	17	44	20	50	765
23	54	64	57	19	637.5
24	30	82	32	35	382.5
25	6	48	8	52	510
26	42	15	44	19	510
27	18	84	22	91	1017.5
28	54	51	57	56	762.5
29	30	17	32	72	637.5
30	8	39	11	44	762.5
31	46	26	49	22	740
32	22	72	26	14	855
33	58	51	62	15	910
34	34	97	38	62	912.5
35	11	21	13	26	512.5
36	49	27	53	37	1025
37	26	87	29	84	742.5
38	4	71	7	44	682.5
39	41	63	45	4	852.5
40	18	32	22	19	967.5
41	52	84	56	68	960
42	28	85	32	87	1005
43	4	95	8	71	940
44	41	52	45	6	885
45	18	37	21	68	827.5
46	54	84	58	35	877.5
47	30	20	33	22	755
48	6	17	9	8	727.5
49	44	41	48	27	965
50	20	92	22	97	512.5

Table 18: Results of 50 measurements over 5 sessions of the full system delay for the state look right.

E.4.1 Yawn Left

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	39	57	43	41	960
2	4	85	8	69	960
3	30	52	33	21	672.5
4	22	25	25	71	865
5	49	46	52	15	672.5
6	33	69	35	99	575
7	0	13	4	35	1055
8	19	65	22	72	767.5
9	51	47	54	54	767.5
10	56	96	61	19	1057.5
11	19	68	22	73	762.5
12	15	93	19	45	880
13	11	71	14	76	762.5
14	7	49	10	7	645
15	3	97	7	96	997.5
16	0	46	3	3	642.5
17	56	24	59	5	702.5
18	52	2	54	83	702.5
19	44	51	48	3	880
20	39	82	43	57	937.5
21	34	23	36	86	657.5
22	30	40	33	92	880
23	25	70	28	34	660
24	21	88	26	27	1097.5
25	18	94	21	57	657.5
26	15	11	17	75	660
27	10	41	13	5	660
28	6	59	10	98	1097.5
29	2	77	6	28	877.5
30	58	94	61	58	660
31	44	59	48	24	912.5
32	40	13	43	26	782.5
33	36	45	38	54	522.5
34	32	26	35	13	717.5
35	28	58	32	49	977.5
36	23	86	27	78	980
37	18	63	22	28	912.5
38	16	78	18	86	520
39	12	58	16	75	1042.5
40	8	38	10	47	522.5
41	38	72	41	30	645
42	33	71	37	7	840
43	30	51	32	83	580
44	26	53	27	30	192.5
45	22	29	25	91	905
46	19	9	23	22	1032.5
47	15	11	17	70	647.5
48	11	14	14	75	902.5
49	6	64	9	74	775
50	3	18	6	80	905

Table 19: Results of 50 measurements over 5 sessions of the full system delay for the state yawn left.

E.4.2 Yawn Right

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	55	5	58	57	880
2	50	47	53	60	782.5
3	46	82	51	10	1070
4	42	21	46	16	987.5
5	38	68	42	64	990
6	34	96	37	60	660
7	30	83	33	54	677.5
8	27	14	31	50	1090
9	15	42	18	50	770
10	19	4	22	17	782.5
11	53	82	57	48	915
12	49	15	53	2	967.5
13	44	91	48	14	807.5
14	40	89	43	90	752.5
15	37	94	41	17	807.5
16	31	98	35	85	967.5
17	26	73	30	18	862.5
18	22	49	25	72	807.5
19	18	47	20	62	537.5
20	11	7	14	51	860
21	2	90	6	44	885
22	58	83	61	26	607.5
23	57	41	60	72	827.5
24	49	57	52	89	830
25	46	83	50	14	827.5
26	42	53	45	63	775
27	41	46	44	99	882.5
28	36	72	39	37	662.5
29	33	53	37	51	995
30	29	68	33	88	1050
31	50	53	53	90	842.5
32	0	30	4	68	1095
33	56	3	59	68	912.5
34	52	18	54	71	632.5
35	48	61	52	26	912.5
36	43	59	47	53	985
37	40	36	43	72	840
38	36	51	39	60	772.5
39	32	38	35	19	702.5
40	24	96	28	61	912.5
41	52	65	56	43	945
42	49	62	53	32	925
43	44	43	47	77	835
44	41	90	45	75	962.5
45	37	57	40	39	705
46	32	36	36	17	952.5
47	28	65	33	1	1090
48	25	60	29	44	960
49	21	26	23	83	642.5
50	18	2	22	6	1010

Table 20: Results of 50 measurements over 5 sessions of the full system delay for the state yawn right.

E.4.3 Switching Left

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	48	69	51	85	790
2	19	4	22	21	792.5
3	19	75	23	55	950
4	52	0	54	53	632.5
5	52	71	56	51	950
6	24	33	27	50	792.5
7	55	32	58	48	790
8	26	94	30	10	790
9	42	27	45	43	790
10	13	26	17	5	947.5
11	36	48	39	60	780
12	6	70	8	79	522.5
13	35	89	39	54	912.5
14	7	16	9	76	650
15	38	43	41	55	780
16	8	65	10	74	522.5
17	31	52	34	12	650
18	2	27	5	39	780
19	32	49	35	10	652.5
20	2	72	5	33	652.5
21	38	15	40	77	655
22	8	47	12	13	915
23	42	55	44	64	522.5
24	14	96	18	62	915
25	46	32	49	46	785
26	18	21	20	82	652.5
27	49	57	52	18	652.5
28	20	93	23	2	522.5
29	53	34	54	90	390
30	24	70	26	79	522.5
31	34	54	38	31	942.5
32	4	7	6	58	627.5
33	34	85	37	99	785
34	6	89	10	3	785
35	38	92	41	44	630
36	11	59	15	36	942.5
37	43	0	45	51	627.5
38	16	29	19	43	785
39	47	7	50	48	852.5
40	15	34	19	11	942.5
41	38	71	42	23	880
42	9	39	11	90	627.5
43	39	6	42	58	880
44	9	73	11	74	502.5
45	38	90	41	91	752.5
46	9	7	12	8	752.5
47	40	24	44	27	1007.5
48	10	92	14	44	880
49	41	59	45	62	1007.5
50	41	43	44	95	880

Table 21: Results of 50 measurements over 5 sessions of the full system delay for the state switching left.

E.4.4 Switching Right

	Touch (s)	Touch (ms)	Face Move (s)	Face move (ms)	Time (ms)
1	48	95	51	15	550
2	40	10	43	24	785
3	23	97	27	42	862.5
4	16	69	18	89	550
5	7	53	10	67	785
6	59	62	62	13	627.5
7	52	34	56	11	942.5
8	45	6	48	83	942.5
9	35	90	39	4	785
10	27	36	30	19	707.5
11	35	15	38	54	847.5
12	25	74	29	13	847.5
13	19	20	23	11	977.5
14	4	29	8	20	977.5
15	55	92	58	79	717.5
16	38	67	41	54	717.5
17	31	34	35	26	980
18	15	91	18	52	652.5
19	6	76	9	89	782.5
20	58	40	61	52	780
21	50	15	52	22	517.5
22	42	88	45	99	777.5
23	25	77	28	36	647.5
24	17	48	20	6	645
25	9	70	14	9	1097.5
26	54	66	56	98	580
27	46	62	48	94	580
28	22	76	25	35	647.5
29	14	72	16	79	517.5
30	6	43	9	79	840
31	15	39	19	41	1005
32	6	28	9	96	920
33	50	5	53	40	837.5
34	27	39	30	74	837.5
35	19	28	21	62	585
36	2	72	6	6	835
37	55	27	58	95	920
38	47	16	50	17	752.5
39	39	5	41	39	585
40	30	93	33	61	670
41	48	79	51	43	660
42	40	88	42	86	495
43	33	63	36	60	742.5
44	25	72	28	3	577.5
45	2	32	5	95	907.5
46	45	52	48	16	660
47	37	61	40	25	660
48	29	37	31	68	577.5
49	13	55	15	86	577.5
50	6	96	9	60	660

Table 22: Results of 50 measurements over 5 sessions of the full system delay for the state switching right.

F Appendix: Results study 3

Data Group	HLA	HLB	NA	NB
All Participants	t(3) = 1.73, p = .182	t(3) = 1.73, p = .182	t(3) = 1.00, p = .391	t(3) = 0.00, p = .000
Touchers	t(2) = 2.00, p = .184	t(2) = 1.00, p = .423	t(2) = 1.00, p = .423	t(2) = 1.00, p = .423
Touch Condtion	t(1) = 1.73, p = .333	t(1) = inf, p = .000	t(1) = inf, p = .000	t(1) = 1.73, p = .333
No-touch Condition	t(1) = 0.58, p = .667	t(1) = inf, p = .000	t(1) = inf, p = .000	t(1) = inf, p = .000
Female	t(1) = 1.00, p = .500	t(1) = nan, p = nan	t(1) = nan, p = nan	t(1) = 1.00, p = .500

Table 23: Results of t-tests performed on individual constructs, for each data group

Data Group	AAS	AU	PF	AL
All Participants	t(3) = 0.42, p = .703	t(3) = -1.73, p = .182	t(3) = 0.00, p = .000	t(3) = 0.00, p = .000
Touchers	t(2) = -2.00, p = .184	t(2) = -1.00, p = .423	t(2) = 1.00, p = .423	t(2) = 1.00, p = .423
Touch Condtion	t(1) = 2.89, p = .212	t(1) = 1.73, p = .333	t(1) = 1.15, p = .454	t(1) = inf, p = .000
No-touch Condition	t(1) = 1.73, p = .333	t(1) = 2.31, p = .260	t(1) = 2.89, p = .212	t(1) = nan, p = nan
Female	t(1) = -inf, p = .000	t(1) = -1.00, p = .500	t(1) = 1.00, p = .500	t(1) = nan, p = nan

Table 24: Results of t-tests performed on individual constructs, for each data group

Data Group	AS	APP	UAA	AE
All Participants	t(3) = 0.00, p = .000	t(3) = nan, p = nan	t(3) = -1.00, p = .391	t(3) = 0.00, p = .000
Touchers	t(2) = 1.00, p = .423	t(2) = nan, p = nan	t(2) = nan, p = nan	t(2) = -1.00, p = .423
Touch Condtion	t(1) = 4.04, p = .154	t(1) = nan, p = nan	t(1) = 1.73, p = .333	t(1) = nan, p = nan
No-touch Condition	t(1) = 2.89, p = .212	t(1) = nan, p = nan	t(1) = 1.73, p = .333	t(1) = -0.58, p = .667
Female	t(1) = nan, p = nan	t(1) = nan, p = nan	t(1) = nan, p = nan	t(1) = -1.00, p = .500

Table 25: Results of t-tests performed on individual constructs, for each data group

Data Group	UE	UT	UAL	AA
All Participants	t(3) = -0.88, p = .444	t(3) = -1.32, p = .278	t(3) = 1.00, p = .391	t(3) = 1.13, p = .342
Touchers	t(2) = 0.00, p = .000	t(2) = -1.00, p = .423	t(2) = 1.00, p = .423	t(2) = 0.65, p = .580
Touch Condtion	t(1) = 1.15, p = .454	t(1) = inf, p = .000	t(1) = 1.73, p = .333	t(1) = 2.31, p = .260
No-touch Condition	t(1) = inf, p = .000	t(1) = 0.58, p = .667	t(1) = 0.58, p = .667	t(1) = -0.19, p = .879
Female	t(1) = 0.00, p = .000	t(1) = -1.00, p = .500	t(1) = nan, p = nan	t(1) = -1.00, p = .500

Table 26: Results of t-tests performed on individual constructs, for each data group

Data Group	AC	AI	AT	SP
All Participants	t(3) = 0.40, p = .718	t(3) = 1.00, p = .391	t(3) = 1.73, p = .182	t(3) = 0.00, p = .000
Touchers	t(2) = -1.00, p = .423	t(2) = 1.00, p = .423	t(2) = 1.00, p = .423	t(2) = 1.00, p = .423
Touch Condtion	t(1) = -inf, p = .000	t(1) = 0.58, p = .667	t(1) = inf, p = .000	t(1) = inf, p = .000
No-touch Condition	t(1) = -inf, p = .000	t(1) = inf, p = .000	t(1) = nan, p = nan	t(1) = 2.89, p = .212
Female	t(1) = nan, p = nan	t(1) = 1.00, p = .500	t(1) = nan, p = nan	t(1) = 1.00, p = .500

Table 27: Results of t-tests performed on individual constructs, for each data group

Data Group	IIS	AEI	UEP	UAI
All Participants	t(3) = -0.88, p = .444	t(3) = -1.73, p = .182	t(3) = -0.19, p = .861	t(3) = 1.00, p = .391
Touchers	t(2) = 0.00, p = .000	t(2) = -1.00, p = .423	t(2) = 1.73, p = .225	t(2) = 1.00, p = .423
Touch Condtion	t(1) = 1.73, p = .333	t(1) = nan, p = nan	t(1) = 0.58, p = .667	t(1) = 4.04, p = .154
No-touch Condition	t(1) = nan, p = nan	t(1) = inf, p = .000	t(1) = -0.58, p = .667	t(1) = 0.58, p = .667
Female	t(1) = -1.00, p = .500	t(1) = nan, p = nan	t(1) = 1.00, p = .500	t(1) = nan, p = nan

Table 28: Results of t-tests performed on individual constructs, for each data group

G Appendix: Schematic representation of the final code

G.1 Touch condition

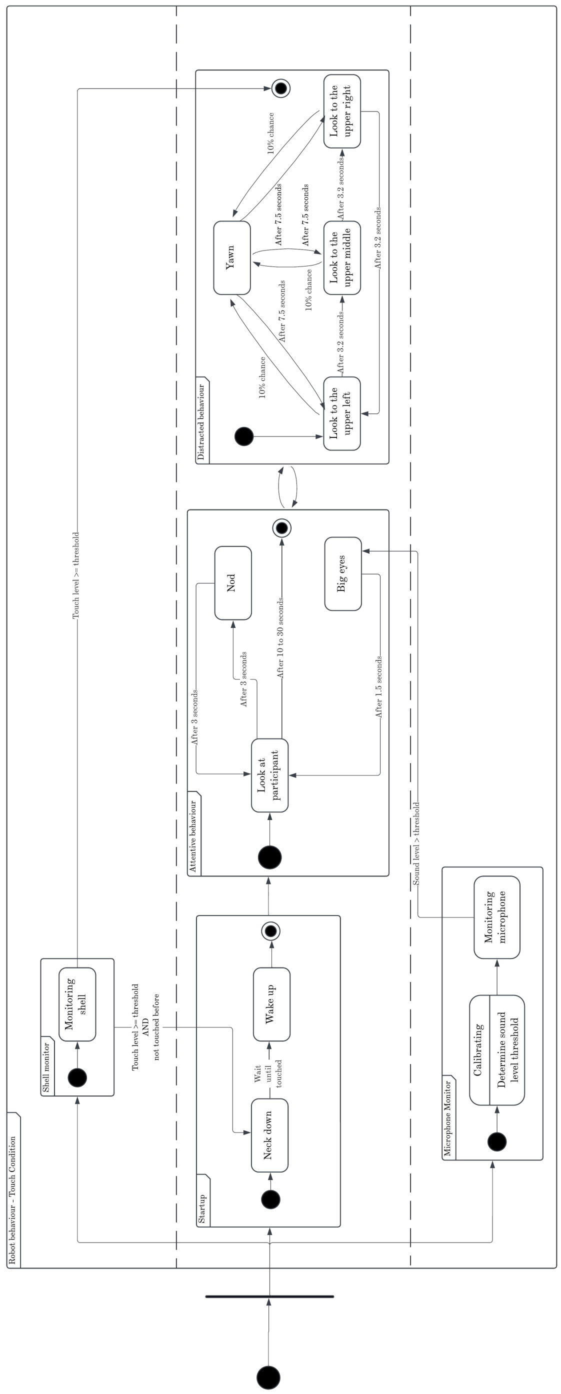

Figure 20: Schematic representation of the final code used to execute the touch condition. The interaction between the different classes in this condition is shown.

G.2 No-touch condition

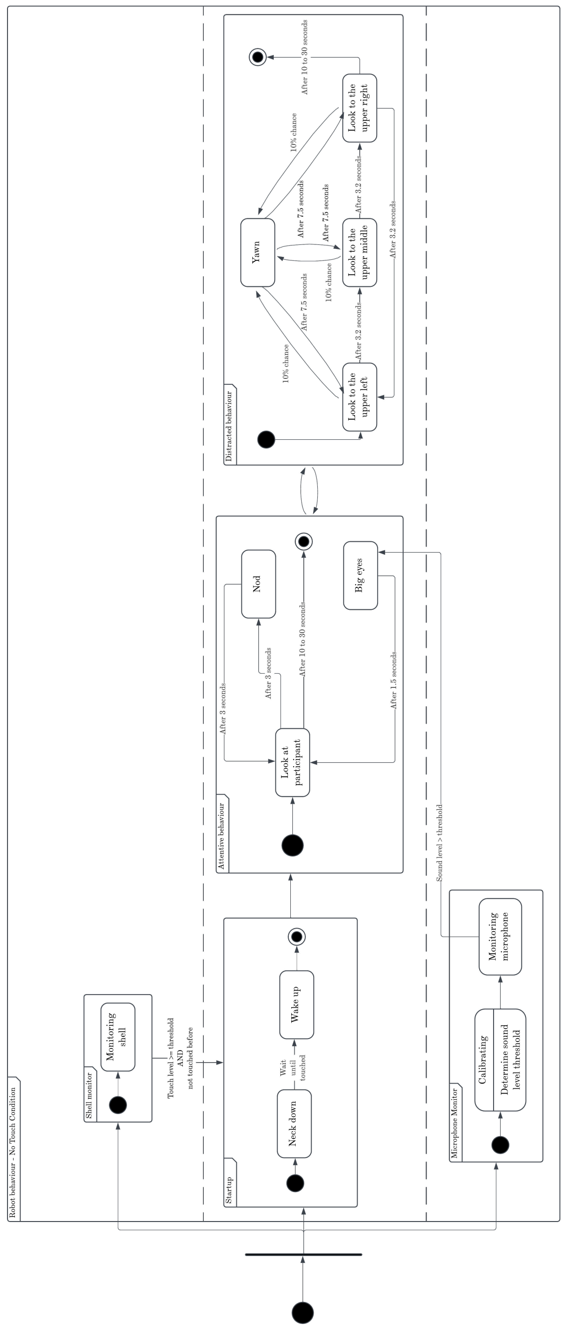

Figure 21: Schematic representation of the final code used to execute the no-touch condition. The interaction between the different classes in this condition is shown.

H Appendix: Results main experiment

Data Group	Comparison	HLA	HLB	NA
All Participants	Touch, No-touch	t(42) = 0.21, p = .838	t(43) = 0.68, p = .499	t(43) = -0.18, p = .855
	Touch - Male, Female	t(43) = 0.46, p = .649	t(43) = -3.76, p = .001	t(43) = -0.87, p = .388
	No-touch Male, Female	t(43) = -0.09, p = .929	t(43) = -2.34, p = .024	t(43) = 0.32, p = .751
	Male - Touch, No-touch	t(24) = 1.16, p = .256	t(24) = 0.00, p = .000	t(24) = -1.07, p = .294
	Female - Touch, No-touch	t(18) = -0.90, p = .380	t(19) = 1.55, p = .137	t(19) = 0.77, p = .453
Touchers	Touch, No-touch	t(20) = 1.37, p = .186	t(20) = 0.62 p = .545	t(20) = 0.49 p = .629
	Touch - Male, Female	t(19) = 1.29, p = .213	t(19) = -2.66, p = .016	t(19) = 0.45, p = .661
	No-touch Male, Female	t(19) = 0.67, p = .512	t(19) = -2.17, p = .043	t(19) = 0.36, p = .720
	Male - Touch, No-touch	t(11) = 1.48, p = .166	t(11) = 0.27, p = .795	t(11) = 0.32, p = .754
	Female - Touch, No-touch	t(8) = 0.55, p = .594	t(8) = 0.61, p = .559	t(8) = 0.36, p = .729
Non-touchers	Touch, No-touch	t(23) = -0.57, p = .575	t(23) = 0.77, p = .450	t(22) = -0.83, p = .418
	Touch - Male, Female	t(22) = -0.41, p = .685	t(22) = -2.55, p = .018	t(22) = -1.69, p = .105
	No-touch Male, Female	t(22) = -0.85, p = .402	t(22) = -1.07, p = .298	t(22) = 0.00, p = .000
	Male - Touch, No-touch	t(12) = 0.00, p = .000	t(12) = -0.32, p = .753	t(12) = -2.74, p = .018
	Female - Touch, No-touch	t(10) = -0.69, p = .506	t(10) = 1.79, p = .104	t(10) = 0.69, p = .506

Table 29: Results of t-tests performed on individual constructs, for each data group

Data Group	Comparison	NB	AAS	AU
All Participants	Touch, No-touch	t(43) = 2.2, p = .033	t(43) = 0.00, p = .000	t(43) = 2.05, p = .047
	Touch - Male, Female	t(43) = -2.40, p = .021	t(43) = -1.33, p = .191	t(43) = -0.03, p = .979
	No-touch Male, Female	t(43)= -0.55, p = .587	t(43) = -0.26, p = .793	t(43) = -0.22, p = .830
	Male - Touch, No-touch	t(24) = 0.57, p = .574	t(24) = -0.94, p = .356	t(24) = 1.42, p = .168
	Female - Touch, No-touch	t(19) = 3.56, p = .002	t(19) = 1.0, p = .330	t(19) = 1.29, p = .214
Touchers	Touch, No-touch	t(20) = 2.23 p = .038	t(20) = 2.32, p = .031	t(20) = 3.34 p = .003
	Touch - Male, Female	t(19) = -0.96, p = .347	t(19) = -0.86, p = .400	t(19) = 0.00, p = .000
	No-touch Male, Female	t(19) = -0.28, p = .784	t(19) = -0.74, p = .468	t(19) = -0.99, p = .335
	Male - Touch, No-touch	t(11) = 1.16, p = .269	t(11) = 1.48, p = .166	t(11) = 2.91, p = .014
	Female - Touch, No-touch	t(8) = 2.31, p = .050	t(8) = 2.0, p = .081	t(8) = 1.65, p = .137
Non-touchers	Touch, No-touch	t(23) = 1.0, p = .328	t(23) = -2.14, p = .043	t(23) = -1.24, p = .228
	Touch - Male, Female	t(22) = -2.33, p = .029	t(22) = -1.07, p = .298	t(22) = -0.13, p = .898
	No-touch Male, Female	t(22) = -0.45, p = .657	t(22) = 0.82, p = .419	t(22) = 0.74, p = .465
	Male - Touch, No-touch	t(12) = -0.69, p = .502	t(12) = -3.41, p = .005	t(12) = -1.90, p = .082
	Female - Touch, No-touch	t(10) = 2.63, p = .025	t(10) = 0.00, p = .000	t(10) = 0.00, p = .000

Table 30: Results of t-tests performed on individual constructs, for each data group

Data Group	Comparison	PF	AL	AS
All Participants	Touch, No-touch	t(43) = 1.43, p = .16	t(43) = 0.27, p = .785	t(43) = 1.52, p = .135
	Touch - Male, Female	t(43) = 0.53, p = .597	t(43) = -1.87, p = .068	t(43) = -1.79, p = .080
	No-touch Male, Female	t(43) = 0.32, p = .751	t(43) = 0.39, p = .700	t(43) = 0.03, p = .977
	Male - Touch, No-touch	t(24) = 1.10, p = .283	t(23) = -1.70, p = .103	t(24) = 0.45, p = .657
	Female - Touch, No-touch	t(18) = 0.42, p = .682	t(19) = 1.71, p = .104	t(19) = 2.18, p = .042
Touchers	Touch, No-touch	t(20) = 2.90 p = .009	t(20) = 1.14 p = .267	(20) = 2.41, p = .025
	Touch - Male, Female	t(19) = 0.00, p = .000	t(19) = -0.53, p = .599	t(19) = -1.49, p = .152
	No-touch Male, Female	t(19) = -0.30, p = .765	t(19) = 2.0, p = .060	t(19) = 0.11, p = .914
	Male - Touch, No-touch	t(11) = 2.20, p = .05	t(11) = -0.56, p = .586	t(11) = 1.11, p = .293
	Female - Touch, No-touch	t(8) = 1.79, p = .111	t(8) = 2.53, p = 0.035	t(8) = 2.63, p = 0.030
Non-touchers	Touch, No-touch	t(23) = -1.37, p = .185	t(23) = -0.81, p = .426	t(23) = -0.20, p = .846
	Touch - Male, Female	t(22) = 0.71, p = .485	t(22) = -2.09, p = .049	t(22) = -1.07, p = .296
	No-touch Male, Female	t(22) = 0.92, p = .370	t(22) = -0.80, p = .434	t(22) = 0.02, p = .988
	Male - Touch, No-touch	t(12) = -1.48, p = .165	t(12) = -1.00, p = .337	t(12) = -0.82, p = .427
	Female - Touch, No-touch	t(10) = -0.56, p = .588	t(9) = -1.00, p = .343	t(10) = 0.56, p = .588

Table 31: Results of t-tests performed on individual constructs, for each data group

Data Group	Comparison	APP	UAA	AE
All Participants	Touch, No-touch	t(42) = 0.42, p = .675	t(43) = -1.88, p = .067	t(41) = -0.81, p = .421
	Touch - Male, Female	t(43) = -1.19, p = .242	t(43) = -1.71, p = .094	t(43) = 0.00, p = .000
	No-touch Male, Female	t(43) = 0.84, p = .406	t(43) = -0.97, p = .338	t(43) = 1.02, p = .314
	Male - Touch, No-touch	t(23) = -0.70, p = .491	t(24) = -2.14, p = .0429	t(22) = -1.00, p = .328
	Female - Touch, No-touch	t(19) = 1.07, p = .297	t(19) = -0.52, p = .606	t(17) = nan, p = nan
Touchers	Touch, No-touch	t(20) = 0.00 p=0.00	t(20) = -2.02, p = .057	t(20) = -1.83, p = .083
	Touch - Male, Female	t(19) = -0.14, p = .890	t(19) = -0.24, p = .810	t(19) = nan, p = nan
	No-touch Male, Female	t(19) = 1.07, p = .298	t(19) = -0.07, p = .949	t(19) = 1.65, p = .116
	Male - Touch, No-touch	t(11) = -0.80, p = .438	t(11) = -1.82, p = .096	t(11) = -1.91, p = .082
	Female - Touch, No-touch	t(8) = 0.61, p = .559	t(8) = -1.0, p = .347	t(8) = nan, p = nan
Non-touchers	Touch, No-touch	t(22) = 0.81, p = .426	t(23) = -0.57, p = .575	t(21) = 0.57, p = .576
	Touch - Male, Female	t(22) = -1.23, p = .230	t(22) = -2.38, p = .0267	t(22) = 0.00, p = .000
	No-touch Male, Female	t(22) = 0.06, p = .955	t(22) = -1.37, p = .183	t(22) = 0.00, p = .000
	Male - Touch, No-touch	t(12) = -0.90, p = .387	t(12) = -1.15, p = .273	t(12) = 0.00, p = .000
	Female - Touch, No-touch	t(10) = 1.00, p = .341	t(10) = 0.43, p = .676	t(10) = 0.00, p = .000

Table 32: Results of t-tests performed on individual constructs, for each data group

Data Group	Comparison	UE	UT	UAL
All Participants	Touch, No-touch	t(43) = 0.15, p = .884	t(43) = 1.32, p = .193	t(43) = 1.04, p = .302
	Touch - Male, Female	t(43) = -0.13, p = .898	t(43) = -0.61, p = .545	t(43) = -0.98, p = .333
	No-touch Male, Female	t(43) = 0.86, p = .394	t(43) = -0.36, p = .718	t(43) = -0.16, p = .874
	Male - Touch, No-touch	t(23) = -1.00, p = .328	t(24) = 0.96, p = .346	t(24) = 0.36, p = .723
	Female - Touch, No-touch	t(19) = 0.93, p = .367	t(19) = 1.10, p = .287	t(19) = 1.55, p = .137
Touchers	Touch, No-touch	t(20) = 1.14 p = .267	t(20) = 2.91, p = 0.008	t(20) = 2.25, p = .036
	Touch - Male, Female	t(19) = -0.50, p = .625	t(19) = 0.16, p = .872	t(19) = 0.47, p = .641
	No-touch Male, Female	t(19) = 0.76, p = .457	t(19) = 0.32, p = .753	t(19) = 0.78, p = .447
	Male - Touch, No-touch	t(11) = 0.43, p = .674	t(11) = 2.03, p = .067	t(11) = 1.32, p = .214
	Female - Touch, No-touch	t(8) = 1.05, p = .325	t(8) = 2.00, p = .081	t(8) = 2.00, p = .081
Non-touchers	Touch, No-touch	t(23) = -0.39, p = .704	t(23) = -0.65, p = .524	t(23) = -1.16, p = .257
	Touch - Male, Female	t(22) = 0.20, p = .841	t(22) = -0.90, p = .376	t(22) = -1.90, p = .070
	No-touch Male, Female	t(22) = 0.47, p = .642	t(22) = -0.90, p = .378	t(22) = -0.93, p = .363
	Male - Touch, No-touch	t(12) = -0.43, p = .673	t(12) = -0.56, p = .584	t(12) = -1.48, p = .165
	Female - Touch, No-touch	t(10) = 0.00, p = .000	t(10) = -0.32, p = .756	t(10) = 0.00, p = .000

Table 33: Results of t-tests performed on individual constructs, for each data group

Data Group	Comparison	AA	AC	AI
All Participants	Touch, No-touch	t(42) = 0.6, p = .555	t(42) = -1.14, p = .263	t(43) = 1.27, p = .21
	Touch - Male, Female	t(43) = -0.60, p = .554	t(43) = 1.34, p = .187	t(43) = 0.37, p = .717
	No-touch Male, Female	t(43) = 0.45, p = .656	t(43) = -0.28, p = .783	t(43) = 0.24, p = .808
	Male - Touch, No-touch	t(24) = -0.20, p = .840	t(23) = -0.18, p = .857	t(24) = 1.36, p = .185
	Female - Touch, No-touch	t(19) = 0.82, p = .425	t(19) = -1.58, p = .130	t(19) = 0.81, p = .428
Touchers	Touch, No-touch	t(20) = 2.79, p = .011	t(20) = -1.57, p = .131	t(20) = 2.50, p = .021
	Touch - Male, Female	t(19) = 0.88, p = .390	t(19) = 1.96, p = .065	t(19) = -0.13, p = .900
	No-touch Male, Female	t(19) = -0.31, p = .763	t(19) = 1.95, p = .066	t(19) = 0.65, p = .524
	Male - Touch, No-touch	t(11) = 2.17, p = .053	t(11) = -1.10, p = .295	t(10) = 1.49, p = .167
	Female - Touch, No-touch	t(8) = 1.89, p = .095	t(8) = -1.08, p = .312	t(8) = 2.00, p = .081
Non-touchers	Touch, No-touch	t(23) = -1.62, p = .120	t(22) = 0.25, p = .803	t(23) = 0.00, p = .000
	Touch - Male, Female	t(22) = -1.69, p = .105	t(22) = -0.09, p = .931	t(22) = 0.56, p = .580
	No-touch Male, Female	t(22) = 0.80, p = .431	t(22) = -2.42, p = .024	t(22) = -0.45, p = .659
	Male - Touch, No-touch	t(12) = -2.21, p = .0470	t(12) = 1.85, p = .089	t(12) = 0.56, p = .584
	Female - Touch, No-touch	t(10) = 0.00, p = .000	t(10) = -1.15, p = .277	t(9) = -1.50, p = .168

Table 34: Results of t-tests performed on individual constructs, for each data group

Data Group	Comparison	AT	SP	IIS
All Participants	Touch, No-touch	t(41) = 1.53, p = .133	t(42) = -0.17, p = .864	t(42) = 0.5, p = .618
	Touch - Male, Female	t(43) = -0.45, p = .655	t(43) = -1.98, p = .054	t(43) = 0.21, p = .837
	No-touch Male, Female	t(43) = 0.59, p = .558	t(43) = -0.19, p = .853	t(43) = 0.69, p = .492
	Male - Touch, No-touch	t(23) = 0.81, p = .426	t(24) = -0.89, p = .382	t(23) = 0.30, p = .770
	Female - Touch, No-touch	t(18) = 1.37, p = .187	t(19) = 1.23, p = .234	t(19) = 0.40, p = .694
Touchers	Touch, No-touch	t(19) = 1.75, p = .096	t(20) = 0.94, p = .358	t(20) = 1.10, p = .284
	Touch - Male, Female	t(19) = -0.69, p = .500	t(19) = -1.52, p = .145	t(19) = 0.53, p = .600
	No-touch Male, Female	t(19) = 0.24, p = .813	t(19) = -1.07, p = .299	t(19) = 1.12, p = .278
	Male - Touch, No-touch	t(11) = 0.43, p = .674	t(11) = 0.69, p = .504	t(11) = 0.62, p = .551
	Female - Touch, No-touch	t(8) = 1.41, p = .195	t(8) = 0.61, p = .559	t(8) = 0.88, p = .403
Non-touchers	Touch, No-touch	t(23) = 0.00, p = .000	t(22) = -0.68, p = .503	t(22) = -1.37, p = .186
	Touch - Male, Female	t(22) = 0.18, p = .862	t(22) = -1.24, p = .227	t(22) = -0.42, p = .675
	No-touch Male, Female	t(22) = 0.56, p = .580	t(22) = 0.69, p = .496	t(22) = -0.01, p = .988
	Male - Touch, No-touch	t(12) = 0.00, p = .000	t(12) = -1.90, p = .082	t(11) = -1.00, p = .339
	Female - Touch, No-touch	t(10) = 1.0, p = .341	t(10) = 1.15, p = .277	t(10) = -1.00, p = .341

Table 35: Results of t-tests performed on individual constructs, for each data group

Data Group	Comparison	AEI	UEP	UAI
All Participants	Touch, No-touch	t(39) = 2.08, p = .044	t(42) = -0.15, p = .878	t(43) = 0.61, p = .543
	Touch - Male, Female	t(43) = -0.39, p = .697	t(43) = -1.29, p = .204	t(43) = -2.11, p = .041
	No-touch Male, Female	t(43) = 0.18, p = .855	t(43) = -0.39, p = .700	t(43) = 0.06, p = .950
	Male - Touch, No-touch	t(22) = 1.00, p = .328	t(23) = -0.68, p = .503	t(24) = -0.59, p = .559
	Female - Touch, No-touch	t(18) = 1.46, p = .163	t(19) = 0.42, p = .681	t(19) = 2.13, p = .046
Touchers	Touch, No-touch	t(20) = 1.00, p = .329	t(20) = -0.36, p = .724	t(20) = 1.32, p = .201
	Touch - Male, Female	t(19) = nan, p = nan	t(19) = -0.53, p = .602	t(19) = -1.8, p = .087
	No-touch Male, Female	t(19) = 0.14, p = .890	t(19) = 0.00, p = .000	t(19) = 0.45, p = .656
	Male - Touch, No-touch	t(11) = 0.56, p = .586	t(11) = -0.52, p = .615	t(11) = -0.27, p = .795
	Female - Touch, No-touch	t(8) = 1.00, p = .347	t(8) = 0.00, p = .000	t(8) = 2.53, p = .035
Non-touchers	Touch, No-touch	t(21) = -1.82, p = .083	t(23) = 0.00, p = .000	t(23) = -0.24, p = .814
	Touch - Male, Female	t(22) = -0.45, p = .659	t(22) = -1.19, p = .247	t(22) = -1.23, p = .230
	No-touch Male, Female	t(22) = 0.12, p = .907	t(22) = -0.53, p = .603	t(22) = -0.36, p = .721
	Male - Touch, No-touch	t(11) = -1.48, p = .166	t(12) = -0.81, p = .436	t(12) = -0.56, p = .584
	Female - Touch, No-touch	t(8) = nan, p = nan	t(10) = 0.80, p = .441	t(10) = 0.43, p = .676

Table 36: Results of t-tests performed on individual constructs, for each data group