Exploring anthropomorphism's role in the social interaction between individuals with ASD and social robotics

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Get out of the gutter. We had so many different ideas that didn't work. And it's okay cause all of that got us to this one end result that doesn't even have anything to do with it. But you just learn along the way and worst come to worst it's a no. But let's at least try and then fail. – Tyler the creator

Abstract

Social robots are seen as aids for improving social interaction among individuals with autism spectrum disorder. As they find it easier to understand social cues from robots than from humans. However, there are worries about the emotional attachments with increasingly lifelike robots. The cognitive system's ability to distinguish between individuals and robots may be challenged. Little is known about how this affects individuals with ASD and there remains a gap in understanding the impact of anthropomorphism on their social interactions with social robots. That is why this qualitative study investigates the impact of varying levels of anthropomorphism in social robots on the social interactions of individuals with ASD. Through semi-structured observations and retrospective interviews, 20 participants, including individuals with (n=10) and without ASD (n=10), interacted with two social robots, each varying in anthropomorphism. Findings reveal that individuals with ASD have the tendency to anthropomorphize and can distinguish between levels of anthropomorphism in social robots. Furthermore, the study suggests that the uncanny valley effect may manifest differently or be less pronounced in individuals with ASD. Both groups of participants demonstrated similar social interactions, favoring the robot with higher anthropomorphism levels. However, motivations differed significantly; individuals with ASD favored the highly anthropomorphic robot for its empathic and human-like qualities, whereas participants without ASD did not. These results underscore the importance of tailoring robot design to accommodate individual preferences, particularly emphasizing empathy, and human-like characteristics for individuals with ASD to enhance their engagement with social robots.

Keywords: Anthropomorphism, uncanny valley, social interaction, ASD

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1. Introduction

As research into human-robot interaction progresses, there is a growing interest for integrating robots into healthcare and treatment. This integration is reflected in the research on the effects of short-term robot exposure on individuals with neurocognitive illnesses. Or the study of therapeutic interventions utilizing robots to help individuals overcome some of the challenges associated with post-traumatic stress disorder (Demange et al., 2018; Labam et al., 2022). This growing interest also includes treatment approaches for neurodevelopmental diseases such as autism spectrum disorder (ASD). Since society attempts to understand and address the specific challenges individuals with ASD face in social settings, the development of robots as possible aids of social interaction provides a fascinating path for research. Especially considering the position that individuals with ASD adopt social and communicative signs more easily in robots than in humans (Amato et al., 2021; Lee & Nagae, 2021; Salhi et al., 2022).

The robots used to address the specific challenges for people with ASD in social settings are called social robots. These social robots are typically designed to be able to speak and engage with humans. They must be able to communicate and interact in a way that humans can naturally comprehend and respond to. This is why an increasing number of social robots are being designed to emulate humans. This humanization of social robotics is achieved by increasing the level of anthropomorphism of such social robots. Anthropomorphism is the attribution of human characteristics or behavior to a non-human object (Alenljung et al., 2017; Thepsoonthorn et al., 2021). However, anthropomorphizing social robots creates a variety of difficulties. Concerns have been expressed about the emotional bonds that individuals form with social robots. Due to the growing anthropomorphism in social robotics, the cognitive system may become unable to tell the difference between a human and a social robot (Asprino et al., 2022; Duffy, 2003; Funk, 2015).

Little is known about how this affects people with ASD and there remains a gap in understanding the impact of anthropomorphism on their social interactions with social robots. Presented with the notion that individuals with ASD may find it easier to engage with social robots than with humans, it is possible that the level of anthropomorphism in social robots could have a detrimental impact on their social interaction with individuals with ASD (Matarić, 2023; Lee & Nagae, 2021). As a result, the focus of this study is to answer the following research question: *How do people with ASD experience a social interaction with a social robot?*

When discussing anthropomorphism in relation to social robotics and people with ASD, the uncanny valley effect also needs to be taken into consideration. If a social robot, AI, or agent is remarkably similar to a person but still different in behavior or appearance, it can evoke negative or unsettling feelings in people. This is known as the uncanny valley effect, one of the most significant explanations for why people distinguish between humans and technology—or, more precisely, between varying degrees of anthropomorphism. Although it is clear that uncanny valley can have a negative impact on the relation between individuals and social robots, not much is known about how uncanny valley influences individuals with ASD (Alenljung et al., 2017; Destephe et al., 2015; Lobato et al., 2013).

When it comes to anthropomorphism, uncanny valley, and individuals with ASD, there is often a debate, with two opposed viewpoints. The first one suggests that individuals with ASD have a lower sense of anthropomorphism which is why the uncanny valley effect occurs less often. However, the second opposing viewpoint contends that individuals with ASD have a higher tendency to anthropomorphize non-human objects which is why the uncanny valley effect occurs more often (Ammons, 2018; Atherton & Cross, 2018; Caruana 2021; Paetzel et al., 2020). Therefore, the overall conclusion remains unclear, next to that none of these studies relate their findings to social interaction. Further research is necessary to determine whether people with ASD experience anthropomorphism and the uncanny valley effect. Additionally, there is a need to understand whether these experiences affect how individuals with ASD interact with social robots. That is why this study aims to investigate the following sub question: *Regarding anthropomorphism and the uncanny valley effect, what is the experience of people with ASD when interacting with social robots?*

There is not yet a clear consensus as to which measures are the best to examine social interaction among people with ASD. However, it is clear that at least two approaches are favored. First, the evaluation of the degree to which participants initiate social interaction and second, the frequency of which participants engage in social interaction. When combining ASD and human robot interaction theories, frequency, duration, and intensity seem to be the best approach to investigate the experience of people with ASD while interacting with a social robot. Whereas duration and intensity will represent the degree to which participants with ASD initiate social interaction (Caughlin & Basinger, 2014; McMahon et al., 2012). Therefore, the study will aim to answer the following sub question: *How do people with ASD interact (frequency, duration, intensity) with a social robot that has different levels of anthropomorphism?*

Finally, a combination of semi-structured observations and retrospective interviews were performed during this study. The combination of methods allows for an in-depth exploration of the experiences of individuals with ASD during social interactions with social robots. Both participants with and without ASD engaged in social interactions with two social robots with varying levels of anthropomorphism. These methods enable the investigation of how these interactions may be influenced by the level of anthropomorphism of the social robot and the uncanny valley effect (Argyle, 2017; Mottron and Bzdok, 2020). A semi-structured observation provides the best method when the research problem involves social interaction, while also having a deeper focus on nonverbal communication through facial expressions. However, the choice was made to conduct an additional retrospective interview because this research method is useful for gaining insights into the experience, while it also enabled participants to respond with their own words and express an opinion without being influenced by the researcher (Jorgens 1989; Latif, 2019; Shattuck 2006).

2. Review of the literature

2.1 ASD

ASD is a category of neurodevelopmental disorders that emerge at birth. The symptoms of ASD could manifest in different ways and perhaps change over time. The disorder has an impact on social interaction, learning retention, and application of skills, which may make it difficult to focus, remember, perceive, or speak. ASD is referred to as a spectrum disorder, which is a mental condition that includes a number of linked conditions, as well as singular symptoms and traits. The various elements of a spectrum are either visually similar or are believed to be caused by the same underlying cause. The idea of the spectrum allows a combination of disorders and defines a person's particular combination of traits since symptoms vary from person to person (Bölte, 2014; Ghosn, 2021; Hyman et al., 2020; Mottron and Bzdok, 2020).

ASD can be segmented into the three distinct categories. First, the most "high functioning" or mildest form of autism, level 1 ASD. People with level 1 ASD have trouble speaking clearly to others. For instance, they could be unable to read social cues and body language or to say the right thing at the right moment. A person with ASD level 1 can typically speak in full sentences and communicate, but has trouble engaging in back-and-forth conversation. Second, there is level 2 ASD, communication difficulties will be more obvious in individuals with ASD level 2 than in those with ASD level 1. Additionally, they will have a harder time shifting their attention or moving from one task to another. People with level 2 ASD have limited interests and repeat habits, which makes it challenging for them to function in social situations. Lastly, there is level 3 ASD which is displayed in difficulties in social contact and incredibly rigid behavior. People with level 3 ASD will either be nonverbal or utilize a limited number of understandable words. Both initiating social interactions and responding to others are exceedingly rare. At this stage, social interactions with others could be aberrant and limited to urgent needs (Ghosn, 2021; Mottron and Bzdok, 2020; Weitlauf et al., 2013).

Regardless of ASD level, it is evident that the most fundamental and persistent core trait of ASD is poor social interaction (Argyle, 2017; Mottron and Bzdok, 2020). The fact that social behaviors are not guided by formal or explicit norms is a basic challenge for individuals with ASD when seeking to construct rules to guide social interaction. Next to that individuals with ASD do not seem to have an innate sense of what is and is not acceptable in various contexts, nor do they appear to be able to detect that social expectations vary. However, this study only looked at people with levels 1 and 2 ASD since people with level 3 ASD have severe issues with social contact and communication, and it is essential for participants to have social interactions with social robots. There is a need to address the specific challenges that individuals with ASD face in social settings, as identifying social norms and managing social interactions are essential skills that become more important as they reach adulthood. (Cao et al., 2020; Samuels & Stansfield, 2011).

2.1 Social interaction

The best approach to assess social interactions with people with ASD is to consider the evaluation of the degree and frequency of which participants engage in social interaction. Therefore, three aspects were measured during the semi-structured observation: duration, frequency, and intensity (Caughlin & Basinger, 2014; McMahon et al., 2012). First, interaction frequency is the number of times a person interacts with someone or something else in a specific amount of time. Acquiring valuable information regarding the degree of engagement and social connection is made possible by measuring the frequency of social interaction. When examining how people with ASD interact in social situations, frequency is a commonly used metric. Social or communication problems can be indicated by atypical speech patterns, including abnormally high or low frequency. Next to that, changes in frequency indicate an individual's level of comfort or engagement during social interactions. For example, increasing speech frequency may indicate excitement or enthusiasm, whereas decreasing frequency may indicate discomfort, anxiety, or withdrawal (Baird & Norbury, 2015; Gerber et al., 2019; Jahr et al., 2007).

Second, duration measures how much time people spend engaging in social contact. Duration allows the distinction between brief contact and longer engagements by measuring interaction time, providing insights into the quality and influence of these social interactions. Longer durations often suggest deeper and more important connections, whereas shorter durations may reflect casual or shallow meetings. Social interaction duration provides a broader view by considering the total amount of time spent engaged in social interactions. This includes both verbal and nonverbal communication, as well as moments of active listening and involvement. Ultimately, duration complements frequency measurements and provides a more complete picture of social interaction and communication abilities in individuals with ASD (Caughlin & Basinger, 2014; Jahr et al., 2007; Spain et al., 2017).

Third, the relevance or emotional depth of a social interaction is referred to as intensity. Individuals with ASD's emotional response while interacting with social robots can be used to assess the intensity of the interaction. This involves studying facial expressions, body language, and expressions to determine the individual's emotional participation and expression during the interaction. Using social interaction intensity as a measure, researchers and practitioners can gain a better understanding of the effectiveness of social robotics interventions for individuals with ASD and identify factors that influence or hinder social interaction. In HRI research, measuring social interaction intensity assists in determining social robots' effectiveness in social interactions with individuals (Bolis & Schilbach, 2018; Cowen et al., 2020).

Researchers or observers use the observation method to systematically monitor and document social interactions. This involves examining the frequency and duration of social interactions, as well as communication quality, emotional expression, and engagement (also known as intensity). This allows researchers to assess the influence of emotions on individuals during social interactions. Facial expressions, voice intonation, body language, and verbal utterances indicating emotional states are all potential indicators for judging emotions. Smiling, laughing, pleasant voice tone, relaxed body posture, and displays of satisfaction are some examples of happy markers (Bolis & Schilbach, 2018; Cowen et al., 2020; Meijerink-Bosman et al., 2022).

When assessing negative and positive emotions, the following factors should be addressed. First, the frequency of the various emotions displayed throughout the contacts must be investigated. This involves tallying the number of times each emotion appears and comparing their frequency. Second, the intensity or strength with which each emotion is communicated should be considered. Some feelings may be mild or temporary, while others may be intense and persistent. Assessing the intensity of emotions offers more information about the individual's emotional experiences during interactions. Finally, there should be an emphasis on emotions that are relevant to the interaction's goals and the needs of individuals with ASD. Positive feelings, such as happiness, excitement, or comfort, indicate an effective relationship and interaction with the social robot. Whereas negative emotions, such as frustration, anger, or discomfort, can indicate disconnection or rejection with the social robot (Kafetsios & Nezlek, 2011; Meijerink-Bosman et al., 2022). In conclusion, social interaction intensity measures are crucial for assessing the social impairments commonly observed in individuals with ASD. These measures help quantify the extent and quality of social interactions, including verbal and non-verbal communication.

2.2 Social robotics

The use of social robotics in the treatment of ASD has become increasingly common over the last 20 years. Social robots have been proposed as a "bridge" to improve social communication and engagement among individuals with ASD, and the impact of social robotic treatment is regarded to be significant. In fact, individuals with autism are said to adopt social and communication signs more easily in robots than in humans. One possible explanation given is that robots, both in appearance and behavior, are predictable and non-intimidating agents (Lee & Nagae, 2021; Santos et al., 2023; Salhi et al., 2022; Syriopoulou-Delli et al., 2020). Still, most ASD patients treated with social robots have been young children. The belief is that the earlier effective ASD therapy begins, the sooner the positive effects may start, hence the focus is more on children with ASD than adults. Some people with ASD, however, learn about it later in life and do not have these opportunities while they are young. Then there is also the fact that as an adult social knowledge and proper social interaction is critical for the ability to accept and obey social acceptability standards, which is much harder for adults suffering from ASD (Argyle, 2017; Cao et al., 2020; Samuels & Stansfield, 2011). There remains a gap on adults with ASD and their interaction with social robots therefore, this study will solely include adults.

Next to that, research should investigate how anthropomorphism affects social interaction in adults with ASD, by using more lifelike stimuli. Existing research emphasizes the importance of lifelike social robots for generating more naturalistic responses and encouraging meaningful interactions among individuals with ASD. However, most studies employ images or videos of social robots to compare levels of anthropomorphism (Amato et al., 2021; Diehl et al., 2012; Lee & Nagae, 2021; Salhi et al., 2022; Schweinberger et al., 2020). To bridge this gap this study will deploy lifelike stimuli in real time during social interaction. When considering the human likeness or the varying degrees of anthropomorphism of social robotics, the following should be considered: the appearance or design of the social robot, the behavior of the social robot, and finally the personality of the social robot (Andriella et al., 2020; Mirnig et al., 2017; Song et al., 2021).

First, the design of the social robot refers to its physical appearance. Social robots with a high level of anthropomorphism closely resemble humans, with lifelike faces and body proportions. Whereas social robots with a low level of anthropomorphism have more abstract and mechanical designs. The facial expressions of social robots can be used to determine varying levels of anthropomorphism. Compared to social robots with low levels of anthropomorphism, highly anthropomorphic social robots have complex facial expressions that can convey a wide variety of emotions (Hackel et al., 2006; Kiesler & Goodrich, 2018). The design of these social robots allows for adjustments in the shape of their eyes, brows, lips, and overall facial structure. The last aspect of the design is the voice and speech of the social robot. Speech patterns, voice inflections, and the ability to express emotions through speech distinguish high and low anthropocentric social robots. As a result, the voices of highly anthropomorphic social robots have a more human-like tone, pitch, and intonation (Mirnig et al., 2017; Song et al., 2021; Vincent et al., 2015).

Second, a social robot's behavior refers to its actions, movements, and responses during social interactions. Highly anthropomorphic social robots exhibit human-like behaviors, gestures, and expressions, demonstrating an understanding of social rules and conventions. These social robots can engage in verbal exchanges, show emotions, and display social skills like empathy and turn-taking. Less anthropomorphic social robots, on the other hand, exhibit restricted or basic behaviors, prioritizing task-oriented interactions. Another behavior distinction is the elevated range of motion, fluidity, and coordination that social robots with a high degree of anthropomorphism display compared to social robots with lower levels of anthropomorphism (Elson et al., 2020; Walters et al., 2007; Wei & Zhao, 2016).

Third, a social robot's personality refers to the unique qualities, characteristics, and behaviors that define its identity and interaction style. Highly anthropomorphic social robots have personalities with preferences, and emotional states like those of humans. These social robots show warmth, humor, and empathy, allowing them to form deeper bonds with their users. Less anthropomorphic social robots have more standard or functional personalities, prioritizing efficiency, and usefulness ahead of emotional connection (Andriella et al., 2020; Chee et al., 2012; Elson et al., 2020).

Finally, it is important to assess the overall satisfaction with the social robot. The overall satisfaction of the social robot is essential when evaluating the success of human-robot interactions, and it is particularly important to individuals with ASD because it influences their engagement, emotional connection, and acceptance (Rakhymbayeva et al., 2021; Song et al., 2021). The overall satisfaction with a social robot has a direct connection to user experience and usability, which form the foundation of effective human-robot interactions. A social robot's usability contributes to an enjoyable user experience defined by engagement, emotional connection, and perceived usefulness (Elson et al., 2020; Vagnetti et al., 2024).

Since this study focuses on the social interaction between individuals with ASD and social robotics, it will enable the Furhat social robot, one of the most advanced social robots to date. Furhat's lifelike facial expressions, gestures, and vocal intonations allow for authentic interactions, which are essential for those with ASD. To begin, Furhat's adjustable design enables researchers to tailor its visual qualities to better meet the interests and demands of users. In addition, Furhat's adaptive characteristics allow programmers to modify its behavior and communication style to meet individual preferences, resulting in a more inclusive and encouraging setting for social interaction research. Finally, Furhat's customizable behavior and integration with AI technologies allow researchers to create and implement personalized interaction scenarios that target specific social skills and difficulties unique to individuals with ASD (Armstrong & Huh, 2021; Shahverdi et al., 2023).

2.3 Anthropomorphism, and the uncanny valley effect

When it comes to how anthropomorphism influences adults with ASD, researchers tend to disagree with two different views. First, there is the notion that individuals with ASD have a lowered sense of anthropomorphism. This idea is based on the theory of mind, which is the ability to attribute mental states to oneself and others. In individuals with ASD this ability is often impaired. As a result, they may have a difficult time understanding others' perspectives, empathy, and interpretation. That is why the theory of mind can have a great impact on their social interactions and overall relationships (Fletcher-Watson & McConachie, 2010; Senju, 2011). Anthropomorphism involves attributing human-like characteristics or intentions to non-human entities. Some suggest that anthropomorphism operates on the same principle as the theory of mind, but it is applied to make predictions about the behavior or intentions of other agents, such as social robots, rather than oneself or other humans. Therefore, it is proposed that individuals with ASD experience the same impairment in anthropomorphism as they do in the theory of mind, resulting in a lowered sense of anthropomorphism (Ammons, 2018; Cao et al., 2020).

Second, is the belief that individuals with ASD have a higher tendency to anthropomorphize. This is believed to be caused by social motivations and self-reported loneliness. There are three psychological characteristics that can influence an individual's tendency to anthropomorphize: social motivation, effectance motivation, and elicited knowledge. Individuals with ASD seem to be influenced by social motivation because they face challenges in social interaction. These challenges can lead to feelings of loneliness, causing them to anthropomorphize more to fulfill their social motivation needs (Atherton & Cross, 2018; Caruana, 2021; Waytz et al., 2010). It is clear both theories are connected to social interaction and motivation. However, the overall conclusion on how anthropomorphism influences social interaction among individuals with ASD remains unsettled. This study aims to give this conclusion by primarily focusing on the social interaction between individuals with ASD and social robotics while taking anthropomorphism into account.

Even though anthropomorphism and uncanny valley are related, there needs to be a clear distinction between them. The uncanny valley effect is known to have a negative or creepy effect on people, whereas anthropomorphism does not have to. Individuals can notice a high level of anthropomorphism without experiencing the uncanny valley effect. Therefore, anthropomorphism has been segmented into the following subcategories: the tendency to anthropomorphize and the ability to identify different levels of anthropomorphism (Given, 2008; Spatola et al., 2022). The uncanny valley effect manifests itself through key markers which this study will consider. First, the variation in satisfaction ratings, which can vary based on the user experience and usability. Which are said to be the primary pillars in detecting the uncanny valley phenomenon, a low ranking in user experience and usability is frequently associated with the uncanny valley effect. Second, emotional engagement and empathy are also essential because a social robot's capacity to generate real emotional reactions promotes social interaction (Song et al., 2021; Thepsoonthorn et al., 2021; Ueyama, 2015).

Regarding the uncanny valley effect the disagreement between the two sides continues. With the first viewpoint claims that due to the lowered sense of anthropomorphism among people with ASD, the cognitive system will still be able to tell the difference between a human and a social robot, which is why the uncanny valley effect does not occur (Ammons, 2018; Cao et al., 2020; Paetzel et al., 2020). If this notion is applied to this study, it might imply that the amount of anthropomorphism or the uncanny valley effect should have no influence on the social interaction. However, the second opposing viewpoint contends that individuals with ASD have a higher tendency to anthropomorphize non-human objects. This increases the chances of an error within the cognitive system, also known as the uncanny valley effect. Following this viewpoint, the suggestion can be made that the level of anthropomorphism does indeed influence the social interaction between people with ASD and social robots. In addition, there is a higher possibility that the negative effects of the uncanny valley effect influence social interaction (Atherton & Cross, 2018; Caruana, 2021; Dubois-Sage et al., 2024). As a result, this study aims to investigate the influence of the uncanny valley effect on the social interaction between individuals with ASD and social robotics.

3 Methodology

3.1 Research Design

The aim of this study was to gain insight into how individuals with ASD interact with social robotics with varying levels of anthropomorphism. Both participants with and without ASD had social interactions with two social robots, each displaying varying degrees of anthropomorphism, resulting in four distinct scenarios outlined in Table 1. All social interactions were centered around food, this subject of conversation was chosen because of its universal appeal and ease of personal engagement. Next to that, the subject encouraged natural and unplanned conversations among participants, requiring no prior knowledge (Flinkfeldt et al., 2022; Pomerantz & Fehr, 2011). Using a combination of semi-structured observations and retrospective interviews, the study attempted to address the following research question “How do people with ASD experience a social interaction with a social robot?”

Table 1

Overview of participant groups

Interaction Type	Participants with ASD	Participants without ASD
Robot-Robot	1	3
Human-Robot	2	4

Qualitative research was conducted because it provides descriptions of how individuals feel, interpret, and participate in a specific situation. A qualitative descriptive design proved to be ideal because it allows for in-depth exploration, captures rich details without imposing theories, and accommodates diverse communication styles, resulting in a comprehensive understanding of the topic (Kim et al., 2017; Rahman, 2016). The combination of methods allows for an in-depth analysis of the experiences of individuals with ASD during social interactions with social robots. For each of the social interactions illustrated in Table 1, a semi-structured observation was conducted on the frequency, duration, and intensity. The study does not only reflect on the duration, frequency, and intensity of the social interaction but also on the level of anthropomorphism of the social robot and the uncanny valley effect. Therefore, retrospective interviews right after the social interactions gave more insights about the preferences, feelings, and attitudes of the participants (Jorgens, 1989; Latif, 2019).

In summary, this study included semi-structured observations during the social interactions and retrospective interviews right after the social interactions. The observations mainly address the sub question: "*How do people with ASD interact (frequency, duration, intensity) with a social robot that has different levels of anthropomorphism*?" The retrospective interview was used to answer the second sub question: "*Regarding anthropomorphism and the uncanny valley effect, what is the experience of people with ASD when interacting with social robots*" The results of both methods have been combined to answer the main research question "*How do people with ASD experience a social interaction with a social robot?"* Lastly, the study and its measures have been given ethical approval by the board of the University of Twente.

3.2 The design and pre-testing of the social robots

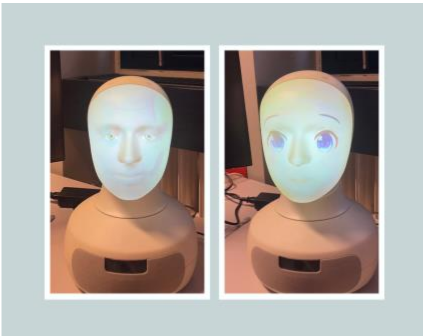
The Furhat and its platform were used to create two types of social robots. The Furhat has been designed to emulate human-like interactions with an expressive screen interface, which resembles a human face. This mask-like display can convey a wide range of emotions and expressions. It uses powerful technology, such as computer vision and linguistic processing, to detect and respond to verbal and nonverbal clues in real time (Hackel et al., 2006; Kiesler & Goodrich, 2018). The first social robot was less anthropomorphized (referred to as the robot-robot) and the second social robot was highly anthropomorphized (referred to as the human-robot). To begin with, pre-set Blocky designs reflecting high and low anthropomorphism levels were used as a starting point for the robots' development. After this, changes were made to reflect the design, behavior, and personalities of both social robots to establish a clear distinction between the level of anthropomorphism (Bartneck et al., 2008; Kiesler & Goodrich, 2018).

3.2.1 the design of the social robots

Creating the design of the social robots started at their appearance. The Blockly preset provided by Furhat were used as a foundation for the facial design. These presets are built on low vs high anthropomorphism, they still allow for personalization. That is why the researcher decided to further enhance the distinction in anthropomorphism by adjusting the design of the social robots. First, the researcher opted not to assign a gender to the robots, as it could impact user perception and subsequently influence social interactions (Forgas-Coll et al., 2022; Ghazali et al., 2020; Paetzel et al., 2020). Therefore, non-binary presets were used. Next, the researcher used the pre-set facial designs for the robot-robot and gave the pre-test participants two options shown in Figure 1 to choose from based on the following criteria: "Which of the two faces look more like a typical robot?" For the face of the robot-robot, a more realistic appearance (left) was favored over cartoon-like design (right), which participants associated with gaming aesthetics due to its anime inspiration (Hackel et al., 2006; Kiesler & Goodrich, 2018).

Figure 1

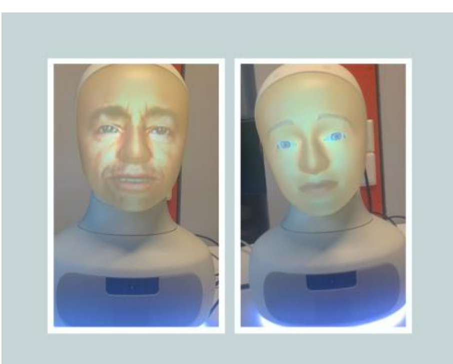
Pre-set designs of the robot-robot



For the human-robot's design, the researcher selected face designs from Furhat's FaceCore feature, which allows for the creation of more realistic and human-like faces and facial movement. Highly anthropomorphic social robots have expressive faces with adjustable features like eyes, brows, lips, and overall facial structure. That is why the human-robot underwent further modifications (Mirnig et al., 2017; Song et al., 2021; Vincent et al., 2015). Furhat's Gesture Capture Tool was used to provide the human-robot with more natural gestures and facial expressions, allowing for a more genuine interaction. The researcher then made two versions of the facial design shown in Figure 2 and had non-participants select their preferred face based on the following criteria: "Which of the two faces do you think looks more human?" For the human-robot the face on the left was considered more human-like and able to display emotions with natural facial movement. Non-participating participants stated that the face on the left looks more human because of its skin with features such as frowning or smiling lines which the other version did not have.

Figure 2

Pre-set designs of the human-robot



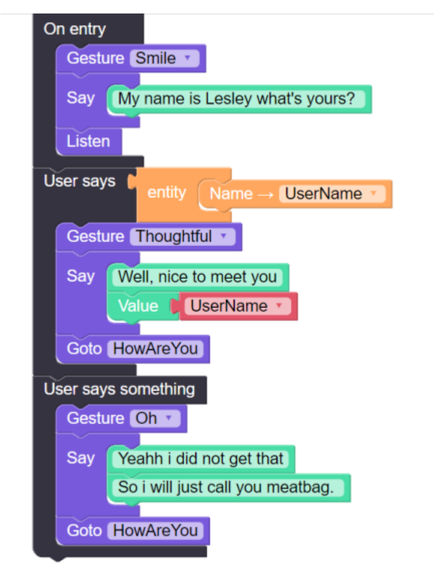
The last aspect of design is the voice and speech of the social robot. Highly anthropomorphic social robots have more human-like voices in tone, pitch, and intonation compared to low anthropomorphic ones (Elson et al., 2020; Mirnig et al., 2017). Since the researcher opted not to assign a specific gender, the robots were equipped with a non-binary voice provided by Furhat's developers. For the robot-robot the researcher opted for the standard voice included in the low anthropomorphism preset. For the human-robot the high anthropomorphic preset was used. However, the researchers added cues to create a more improved speech pattern for the human-robot. Expressions such as "hmm" and "euhh" were inserted into the script, improving the human robot's conversational abilities. Next to that, the human-robot voice was equipped with intonation and laughter. Furhat's Barge-in Beta software was utilized to prevent the human-robot from interrupting the user while speaking and to introduce pauses before responding to the user.

3.2.2 The behavior of the social robots

When it comes to behavior, highly anthropomorphic social robots demonstrate human-like behaviors, gestures, and expressions, while less anthropomorphic ones prioritize task-oriented interactions. In addition, highly anthropomorphic robots also show greater range of motion and fluidity compared to their less anthropomorphic counterparts (Elson et al., 2020; Walters et al., 2007; Wei & Zhao, 2016). For the robot-robot, the researcher used the low anthropomorphic pre-set, resulting in limited or static display of emotions. The researcher used the high anthropomorphic pre-set for the human-robot which already included facial expressions and a greater range of motion. Using Furhat's FaceCore feature allowed the human-robot to emulate specific human emotion within its facial expressions. For example, the human-robot showed smile lines when laughing. Next to that, the Blockly program was used to improve the human-robots' conversational capabilities. The human-robot was programmed to remember the surname of the user, or their preferences such as their favorite food. This enabled a greater range of user reactions, resulting in more natural and dynamic social interactions. Figure 3 displays an intent to recall and repeat a surname.

Figure 3

Illustration of intent surname



3.2.3 The personalities of the social robots

A social robot's personality determines its characteristics and interaction style, with highly anthropomorphic social robots resembling human preferences and emotions and less anthropomorphic social robots prioritizing efficiency (Andriella et al., 2020; Chee et al., 2012). To include the personalities of the social robots, a simple script was developed, including an introduction, three topics (food, hobbies/social activities, and favorite movies/series), and a conclusion, serving as the foundation for both social robots. In contrast to the robot-robot script, which included standardized questions and responses, the human-robot interaction was designed to allow more varied conversations. Depending on the user input, the human-robot offered various responses or follow-up questions. It also responded to user cues like laughter or silence. The human-robot was programmed with preferences, unlike the robot-robot. For instance, it could respond with statements like "Yeah, I really liked that movie too!" or "I understand, I wouldn't want to eat that either." Furthermore, the human-robot was programmed to acknowledge its robotic nature, as demonstrated when asked about its favorite food, responding, "I know I can't eat since I am a robot, but I would love to try pasta one day." In contrast, the robot-robot simply expressed, "I would love to try pasta one day." Lastly, the human-robot was programmed to possess a sense of humor, incorporating jokes and sarcasm into its script. For example, when it couldn't figure out the user's name, it replied, "Yeah, I didn't get that, so I'll just call you meat bag."

3.2.4 The pretesting

Both social robots underwent pre-testing for design, user experience, usability, and anthropomorphism. This was done in preparation of the study (February of 2023) using non-participating participants with (n=3) and without ASD (n=7), these non-participating participants were selected by snowball sampling and closely resemble the characteristics (age, gender, level of ASD) of the participating participants (Lee & Nagae, 2021; Naderifar et al., 2017). The social robots were pre-tested for user experience and usability because both could have an impact on the social interaction with the social robot (Rakhymbayeva et al., 2021; Paetzel et al., 2020; Song et al., 2021). Non-participants provided feedback in retrospective interviews on user experience and usability using a framework provided by the BMS lab. The user experience criteria were created to include attractiveness, clarity, efficiency, trustworthiness, engagement, and innovation. Usability criteria, on the other hand, emphasized behavioral intent, attitudes toward technology, and perceived usefulness (Fronemann et al., 2021; Koh et al., 2022). Additionally, the social robots were evaluated for anthropomorphism using the anthropomorphism questionnaire to ensure a difference in level between the robot-robot and the human-robot. This was confirmed when non-participants saw clear differences in anthropomorphism between the two versions.

Following the pre-tests, minor modifications were made to the social robots. First, the volume of both social robots' voices was increased in response to feedback from non-participants who had difficulty hearing them. Second, certain phrases and social cues in the robot-robot's script were removed. This included deleting preset facial expressions like shock or anger, as well as removing statements describing the robot's preferences or opinions, like "That sounds really delicious." Finally, the human-robot's responsiveness was improved by adding clarifying prompts when the robot failed to understand the user, such as "Can you please speak up?" I can barely hear you" or "Sorry, could you please repeat that?" After meeting basic usability and user experience standards and confirming a significant difference between the two versions through pre-testing, the social robots were ready for the social interaction.

3.2.5 The social interaction

Each social interaction had a maximum duration of 10 minutes; however, participants had the option to opt out earlier if they wanted too. When investigating social interaction between individuals with ASD and social robots, encounters with shorter durations ensure manageable participant engagement. Given that each participant engaged in two social interactions, amounting to a total timespan of 20 minutes. Using a timeframe of 10-minute effectively regulates participant fatigue, facilitates substantial data collection and analysis, and promotes consistency throughout the research process (Rakhymbayeva et al., 2021; Vagnetti et al., 2024). Initially, three conversation subjects for social interactions were chosen: food, hobbies/social activities, and favorite movies/series. These subjects served as the foundation for both social robots. However, during the initial stages of data collecting, the researcher observed significant differences in social interactions, in terms of frequency, duration, and intensity. These differences were noticeable across different conversation topics. Social interactions focusing on movies consistently lasted longer than those centered on food, and participants spoke more during discussions about hobbies than movies. However, when comparing social interactions on the same topic, the differences were not significant. This showed that the topic of conversation was the indication of the difference in social interaction (frequency, duration, intensity). As a result, the researcher chose to focus entirely on the topic of food during the social interactions, eliminating all previous interactions on other conversation topics from the study.

3.3 Measures

3.3.1 Semi-structured observation

The study's focus is on the social interaction between individuals with ASD and social robotics. Given that poor social interaction is the most fundamental of ASD, a semi-structured observation method was chosen. This approach provides a framework for observing and analyzing social interactions while allowing for some flexibility in the research process (Argyle, 2017; Mottron and Bzdok, 2020). A semi-structured observation is an effective method when the research problem involves human interaction and is observable in an everyday setting. In addition to having a deeper focus on nonverbal communication through facial expressions that would be missed if any other method, such as an interview, was used (Jorgens 1989; McKechnie 2008; Shattuck 2006).The observation was covert and non-participant, which means that participants were unaware that they were being watched and that the researcher did not take part in the social interaction.

For each social interaction, one observer made notations about duration and intensity during the social interaction. The participant was videotaped so that another observer could analyze the frequency of the social interaction as well as to secure intercoder reliability later. The duration of the social interaction was determined by timing the participants' social interactions, while the frequency was determined by tallying every time the participant spoke throughout the social interactions. Participant's emotional responses when engaging with social robots were used to determine the intensity of the social interaction. This involves examining facial expressions, body language, and emotions to evaluate the individual's personal connection and expression during the social interaction (Argyle, 2017; Bolis & Schilbach, 2018).

To evaluate the intensity of social interactions during the observations, the researcher developed a coding scheme. Positive emotions like happiness, excitement, and enjoyment tend to increase interaction intensity, resulting in more profound and significant social interactions. Negative emotions, on the other hand, may limit interaction, cause anxiety, or lead to detachment (Bolis & Schilbach, 2018; Meijerink-Bosman et al., 2022). As a result, the coding scheme was tailored to include common positive and negative emotions shown in Table 2, providing a structured approach to evaluating social interaction intensity. Facial expressions, voice intonation, body language, and verbal utterances indicating emotional states are all potential indicators for judging emotions. For each code created from an emotion, the researcher gave an example of observable target behavior (nonverbal indicators) by using existing theories on non-verbal communication. Smiling, laughing, pleasant voice tone, relaxed body posture, and displays of satisfaction are some examples of indicators for happiness (Bolis & Schilbach, 2018; Cowen et al., 2020; Given, 2008). Lastly, the researcher added codes for errors or malfunctions the social robots may encounter.

Table 2

Negative and positive emotions and errors

Negative emotions	Positive emotions	Errors
Anger	Happiness	Robot not understanding participants
Sadness	Excitement	Participant not understanding robot
Disgust	Impressed	Robot not reacting
Distress/discomfort	Contempt	
Fear		
Agitation		
Disappointment		
Frustration		

Next, the observation was semi-structured, this approach combined deductive and inductive reasoning. The observers (n=2) had the freedom to include notes on behavior they thought were noteworthy even if they differed from the initial coding scheme. To avoid bias, all observers agreed on defining and operationalizing the negative/positive emotions and their nonverbal indicators. The researcher used existing theories to define specific criteria for each emotion and provided examples of what constitutes and does not constitute as nonverbal indicators (Caughlin & Basinger, 2014; Cowen et al., 2020; Given, 2008). All observers were trained prior to the observation to ensure they could accurately identify and record the emotions and their nonverbal indicators. This was done to ensure that all observers had a consistent and clear understanding of the target behavior.

3.3.2 Retrospective interview

The study does not only reflect on the duration, frequency, and intensity of the social interaction but also on the level of anthropomorphism of the social robot and the uncanny valley effect. As a result, performing retrospective interviews immediately after the social interactions revealed more about participants' preferences, sentiments, and attitudes. This method also allowed participants to freely express their views in their own terms without being influenced by the researcher (Jorgens 1989; Latif, 2019; Shattuck 2006).The interview was semi-structured, meaning that the researcher planned the interview questions ahead of time but was able to follow relevant lines of inquiry during the interview that may have strayed from the question when it felt appropriate. In this way, no additional information would be missed. The full overview of interview questions can be found in the appendix.

The interview questions were developed by utilizing current scales on anthropomorphism, the uncanny valley effect, user experience and usability (Bartneck et al., 2008; Given, 2008; Severson & Lemm, 2015; Spatola et al., 2022; Waytz et al., 2010). Examples of questions are "*Which interaction with one of the two robots did you prefer, and can you explain why?*" and "*How satisfied were you with the way the robot treated you? Can you give it a grade from 1 to 10?*" Even though anthropomorphism and uncanny valley are related, this study separated them. This is because uncanny valley is known to have a negative or creepy effect, whereas anthropomorphism does not have to. The uncanny valley effect is about identifying between varying degrees of anthropomorphism and the negative or spooky feeling associated with this. However, the participant can notice a high level of anthropomorphism without experiencing the uncanny valley effect (Song et al., 2021; Thepsoonthorn et al., 2021).

Anthropomorphism was divided into two categories for this study: identifying varying levels of anthropomorphism and the tendency to anthropomorphize. Because earlier research failed to produce a clear conclusion, this segmentation was chosen to determine if people with ASD can distinguish different levels of anthropomorphism and if they tend to anthropomorphize at all. (Ammons, 2018; Caruana, 2021). First, the participant's tendency to anthropomorphize was investigated by rating the social robot's emotional connection, intention perception, companionship and friendship, and independent thought. Second, the emotional display, empathy and understanding, natural communication, and thought independence of the social robot as rated by participants were used to investigate the identification of various levels of anthropomorphism. Both divisions were conceptualized using the anthropomorphism scale (Given, 2008; Song et al., 2021; Spatola et al., 2022).

Lastly, the uncanny valley effect was investigated through the following segments: overall satisfaction rating, the perceiving of the social robot, the perceived emotional connection and empathy of the robot, the acceptance of the social robot by the participant. Investigating the uncanny valley effect using these segments allows for a thorough examination of participants' experiences and perceptions. First, measuring overall satisfaction ratings enables the assessment of participants' appreciation and comfort with the social robot. Furthermore, the overall satisfaction of the robot was included as this can influence the social interaction with and the overall acceptance of the social robots (Asprino et al., 2022; Rakhymbayeva et al., 2021; Song et al., 2021). Second, investigating perceived emotional connection and empathy assists in understanding the depth of participants' interactions with the social robot and whether they form genuine emotional ties. Perceived emotional connection and empathy help to determine whether participants view their interactions with the social robot to be emotionally fulfilling, as well as whether the social robot makes them feel understood and supported (Destephe et al., 2015; Lobato et al., 2013).

3.4 Procedure

The study followed a research protocol to ensure that every participant had the same interaction. The participants either signed up for the study on their own or were asked to do so by the researcher or other participants who took part in the study. After signing up, the participant set up an appointment at the BMS lab with the researcher for the social interactions. When the participant arrived, the researcher led them to the laboratory setting. The researcher gave instructions which included explaining that the interaction would be filmed. After the participant had addressed all their questions, the researcher started the video recording. The researcher then asked the participant some general questions (gender, age, occupation, and if applicable: diagnosis).

After this, each participant had two interactions, one with the robot-robot and one with the human-robot. During these social interactions, an observer performed semi-structured observations on the participant. The researcher returned to the room after the last social interaction and then conducted a retrospective interview with the participant. Finally, the researcher communicated the entire scope of the study with the participant. The participant was asked to provide informed consent, which every participant gave in the end. This included full introduction by the researcher, project details and objectives, task descriptions, data sharing and storage, and data confidentiality. After that, the researcher stopped the video recording. Lastly, the participant was asked if they had any further questions. If not, the participant was asked if they wanted to be kept up to date on the results of the study. The researcher then escorted the participant out and the study was completed. All the social interactions were collected over 6 months from January to June of 2023.

3.5 Participants

Participants were purposely selected to investigate social interaction between individuals with ASD and social robots, with participants without ASD serving as a control group. The participant groups were divided as depicted in Table 3. In line with previous work on ASD or human-robot interaction, 20 participants were selected for this study. These participants were collected by deploying snowball sampling. Meaning new participants were recruited through referrals from existing participants (Lee & Nagae, 2021; Naderifar et al., 2017).

Table 3

Participants

	Male	Female	Total
ASD	5	5	10
Without ASD	5	5	10
Total	10	10	20

To be eligible for the study, participants with ASD had to meet the following criteria: (1) a confirmed diagnosis of level 1 or 2 ASD by a qualified health professional, (2) adults aged 18 to 65, and (3) no other co-occurring disorders such as ADHD. Similarly, participants without ASD had to meet the following criteria: (1) adults aged 18 to 65 and (2) no history of ASD or co-occurring disorders. All participants were proficient in the English language and held Dutch nationality. The age range of the participants was between 25 and 32, with a mean age of 27 years old. Furthermore, the study strived for a balance between males and females with and without ASD. It has been demonstrated that it is vital to investigate the psychological consequences of social robots, particularly when it comes to their deployment in ASD treatment. However, most existing research has been conducted on males. That is why gender was also considered a control factor, as previous research has shown gender discrepancies (Modliski et al., 2022; Rattaro et al., 2020; Shefcyk, 2015).

3.6 Data analysis strategy

3.6.1 Data preparation

Each participant's data was structured into anonymized data files, which allowed the researcher to distinguish between participants while maintaining anonymity throughout the analysis process. To protect the privacy of the participants, the original video recordings were safely destroyed after the data was transcribed and compiled. Regarding the interview data, the researcher transcribed all interviews, guaranteeing accuracy and maintaining the privacy of the participants. After preparing all the anonymized data files, the researcher went through a data cleaning and verification process to verify data accuracy and consistency. Cleaning up data involved examining the observation notes for transcription errors or inconsistencies. Finally, the anonymized data files were integrated into a single dataset that was ready for analysis. By using this method of data preparation, the researcher ensured the dataset's reliability and validity while adhering to the ethical norms of informed consent, confidentiality, and participant protection.

3.6.2 Observations

During the observation, data was collected to determine the duration, frequency, and intensity of social interactions. To begin, the duration of each social interaction was determined based on the time recorded from the start to the finish of the social interaction. The observer then used the video footage to count the frequency of speech for each participant during the social interactions with the social robots. Next, to analyze the intensity of the social interaction, the researcher began deductively, examining the tallying lists of nonverbal codes provided by the observer. Second, the researcher iterated on them inductively while examining the video footage of the observations once more to confirm the significance of these events, especially concentrating on whether they occurred more frequently among participants (Caughlin & Basinger, 2014; Cowen et al., 2020; Given, 2008). The researcher uncovered key events that were not initially captured by using the notes from the observers, which increased the depth of research and ensured that all significant components of social interaction were taken into consideration.

Examples of uncovered key events were running off topic, having yes or no answers, or giving feedback. Another addition is the expressions of humor, since humor is revealed as an important feature of interactions among individuals with ASD (Argyle, 2017; Mottron and Bzdok, 2020). Expressions of humor were identified by laughing out loud and combined with codes, such as happiness and excitement. These key events were tallied as codes and the coding procedure was repeated until the researcher and other observers were unable to create any new codes, suggesting that all relevant behaviors had been coded. The researcher combined the data into a single large data file after setting up data sets for each participant, allowing for a complete study across the whole group.

During the data analysis of the social interaction intensity, the researcher focused on two key aspects: the frequency and duration of each code found in the data file. Initially, there was a strong emphasis on identifying negative and positive emotions. The researcher then focused on the duration of each code, combining this data with the frequency and duration of social interaction. This approach allows for an understanding of the patterns and dynamics of social interactions, considering both the frequency and duration of emotional reactions while interacting with social robots. Additionally, there was a specific emphasis on emotions relevant to the goals of the interaction and the unique needs of individuals with ASD, focusing primarily on positive emotions. Positive emotions are considered indicative of a successful interaction with the social robot. This approach aligns with prior research highlighting the significance of emotions and nonverbal indicators in social interactions (Kafetsios & Nezlek, 2011; Meijerink-Bosman et al., 2022).

Finally, the researcher incorporated checks for inter-observer agreement during the data analysis to guarantee reliability and consistency (Mahtani et al., 2018; Winkel et al., 2015). This entailed comparing numerous observers' observations and coding data to determine the amount of agreement in identifying and categorizing behaviors. A high level of interobserver agreement suggests a stable and dependable data analysis process. When the data analysis was finished, the researcher combined the findings to create the final narrative. The integration of data from numerous participants, the addition of additional codes based on significant occurrences, and the validation via inter-observer agreement all led to a more complete and nuanced understanding of the duration, frequency, and intensity of social interactions. The resulting narrative helped to give a coherent and well-supported description of the participants' experiences with the social robots, highlighting key patterns, trends, and emotional dynamics in the data.

3.6.3 Interviews

In the initial phase, the researcher began deductively, categorizing anthropomorphism into two subcategories: identifying varying levels of anthropomorphism and the tendency to anthropomorphize (Ammons, 2018; Caruana, 2021). The uncanny valley effect was then categorized into three categories: overall satisfaction rating, perception of the social robot, and perceived emotional connection and empathy of the robot (Song et al., 2021; Thepsoonthorn et al., 2021). Because the interview was semi-structured, the researcher was able to follow relevant lines of inquiry during the interview that may have strayed from the question when it felt appropriate (Given, 2008; Jorgens 1989; Latif, 2019; Shattuck 2006). The researcher analyzed these notes for each participant to categorize them into the existing categories by hierarchical coding. For example, instances in which participants indicated fear of the social robot were assigned to a subcategory within the perception of the robot. Similarly, remarks of user experience or usability were divided into the overall satisfaction with robots.

The final themes were divided as follows: overall satisfaction with the robot (satisfaction ratings, user experience usability), anthropomorphism (the tendency to anthropomorphize and the ability to identify different levels of anthropomorphism), and uncanny valley (satisfaction rating, the perception of the social robot, the perceived emotional connection and empathy of the robot). The researcher created individual transcripts for each participant, which were later merged into one transcript divided by theme. Finally, the researcher used the transcript to create the final narrative. To ensure that there was no bias, the researcher asked one of the observers to independently code a part of the interviews. A clear and detailed protocol allowed both observers to understand what they needed to note, reducing the likelihood of observer bias, and ensuring interrater reliability. The observer transcribed 10% of the interview data, which the researcher then compared to their own data. The researcher wrote the results when there was a minimum of 70% overlap in the transcribed data.

4 Results

4.1 The overall satisfaction with the social robots

During the retrospective interview, participants were asked to grade their satisfaction with how each robot treated them on a scale of one to ten. When analyzing the results it becomes evident that all participants were more satisfied with the treatment of the human-robot. Regardless of gender or whether the participant had ASD. Participants with ASD graded the robot-robot with an average of 5.7 and the human-robot with 8.0. Similarly, participants without ASD gave the robot-robot an average grade of 6.1 and the human-robot a grade of 7.7.

Participants found the human robot to be better because it displayed improved responsiveness and comprehension. Participants even stated that "*Because of the appearance and more responsive than the first one"* (participant 1, male with ASD) or "*Because it was easier to have a conversation with the second robot [human-robot] than with the first [robot-robot]*" (participant 2, female without ASD) when asked why they thought the human-robot treated them better. Although there are small differences in the grades given by participants with ASD compared to those without, these differences are not significant. However, it is worth mentioning that the reasoning behind favoring the human-robot varied.

Participants with ASD mentioned they preferred the human-robot due to its human qualities and its apparent ability to display emotions. The impact of ASD on participant preferences seems to be linked to their need for more human-like, engaging, and sympathetic encounters, which the human-robot offered. When asked if any of the robots had desires or thoughts of its own, participants replied with the following "*The second one* [human robot] *wants to try food even though it can't eat food*" (participant 4, male with ASD) and "*I think the second robot* [human robot] *has more thoughts of its own. It seemed better in analyzing and giving answers and making decisions based on what I said*" (participant 9, female with ASD). Participants without ASD preferred the human robot because of its improved usability and user experience rather than its ability to display human qualities. When asked which of the robots felt more human participants had answers like "*The second one [human robot], had better features the way it talked*" (participant 15, female without ASD) "*In terms of values and norms, I would say that the second robot [human robot] is more likely to have them. It seems like this robot is programmed for that and the other robot [robot robot] is not*" (participant 11, male without ASD).

4.2 Social Interaction

4.2.1 The frequency and duration of the social interaction

Overall, when it comes to the frequency and duration of the social interaction participants with ASD show similar results as the participants without ASD. To begin, participants with ASD demonstrated slightly shorter average interaction times with both robots compared to participants without ASD. However, these differences were not significantly different, implying that the two groups' overall interaction durations were comparable. The mean and standard deviations for interaction durations revealed comparable trends for robot-robot (M=8.05 minutes, SD=1.08 minutes) and human-robot (M=9.47 minutes, SD=0.41 minutes) in general.

Table 4

Average duration and frequency of social interaction for each group of participants

		ASD		Non-ASD	
		Robot-robot	Robot-human	Robot-robot	Robot-human
Duration					
	Male	7:54	9:41	8:31	9:43
	Female	8:43	9:27	8:01	9:19
	Total	8:19	9:34	8:25	9:33
Frequency					
	Male	16	22	14	22
	Female	18	20	15	21
	Total	16	21	15	21

Next, Table 4 shows that there was little variation in the frequency of social interaction between individuals with and without ASD during interactions with the robot-robot. The same goes for the human-robot. Nonetheless, it's important to note that participants, whether with ASD or without, exhibit a similar pattern regarding the frequency of social interaction between the two robots. Specifically, they tend to speak more frequently when interacting with the human-robot.

There were no significant differences in interaction duration between males and females among participants without ASD or with ASD. Gender analyses revealed that male ASD participants exhibited slightly shorter interaction durations with the robot-robot compared to female ASD participants (M = 7.54 vs. M= 8.43). It should be noted however that these differences were not significant. Furthermore, investigation into the frequency of speech during interactions revealed interesting patterns based on gender and anthropomorphism. Male participants with ASD displayed slightly higher speech frequency with the human robot than females with ASD, suggesting nuanced preferences in their communicative engagement. The following is a perfect example: In contrast, female participants with ASD exhibited a greater speech frequency during interactions with the robot-robot.

4.1.3 Intensity

It is apparent that all participants, regardless of gender or ASD status, expressed higher satisfaction with the treatment from the human-robot. Additionally, participants demonstrated a consistent pattern in the frequency and duration of social interaction between the two robots. Specifically, they tended to engage more frequently and for longer durations when interacting with the human-robot. Nevertheless, the varying degrees of social interaction intensity observed among participants with and without ASD underscored the distinct nature of emotional engagement. While both participant groups favored the human-robot, their differing levels of social interaction intensity highlighted the diverse reasons behind this preference.

To begin with, participants with ASD displayed a wider range of both negative and positive emotions during the social interactions, whereas those without ASD did not exhibit the same diversity and frequency of emotions. This disparity shows that individuals with ASD may perceive social interaction intensity differently than individuals without ASD. Next, when comparing both groups it becomes evident that participants with ASD had more positive emotions when interacting with the social robots than participants without ASD. The significant difference in intensity suggests that the quality or depth of the social interaction did vary between participants with and without ASD. With participants with ASD having a higher quality of social interaction with both social robots.

When it comes to individuals with ASD, positive emotions can indicate an effective relationship and interaction with the social robot. Whereas negative emotions can indicate disconnection or rejection with the social robot (Kafetsios & Nezlek, 2011; Meijerink-Bosman et al., 2022). If the results of all participants with ASD are compared it becomes evident that they experience more positive emotions during the social interactions with the human-robot and more negative emotions during social interactions with the robot-robot. The difference in positive and negative emotions between the two robots indicates that participants with ASD had a more effective relationship and social interaction with the human-robot.

Another indicator of social interaction intensity is the expressions of humor, since humor is revealed as an important feature of interactions among individuals with ASD (Argyle, 2017; Mottron and Bzdok, 2020). The ability of individuals with ASD to incorporate humor varied significantly, as evidenced by differences in the frequency of humor observed. Participants without ASD demonstrated humor as well, but it was less prominent and occurred less frequently. This variance in humor expression added to the overall diversity in interaction intensity. When combining the results from both the interview and observation, the study found significant differences in the intensity of social interactions with social robots between individuals with and without ASD.

4.2 Anthropomorphism

The results of the retrospective interview that individuals with ASD do in fact tend to anthropomorphize and the ability to identify different levels of anthropomorphism. However, it is highly likely that the experience of interacting with social robots varies between individuals with and without ASD in relation to anthropomorphism. Even though the tendency to anthropomorphize and the ability to identify different levels of anthropomorphism were the same for both participant groups, the reasoning behind it was different.

4.2.1. The tendency to anthropomorphize

Individuals with ASD and those without ASD identified anthropomorphism in similar ways, with both groups favoring the robot that had more human-like behaviors and emotional responses [human robot]. This is shown by participants' observations on the emotional connection with participants stating "*Because the robot [human-robot] has more emotional connection (participant 7, male with ASD)*" or "*The second one [human-robot] because it was* *better in understanding me emotionally (participant 17, without ASD)"* when asked if and why they would employ the social robot as therapist.

Moreover, participants with ASD were keener to have an emotional connection with the human-robot with participants stating that *"I would select the second robot as a therapist because I feel like the robot displays more emotional intelligence" (participants 8, male with ASD).* However, participants without ASD did not seem to have that same emotional connection. An example being *"None of the robots have free will because they are objects not living things" (participant 16, male without ASD).*

Most significantly, all participants highly preferred the human-robot to the robot-robot. This preference was confirmed by multiple observations from participants, who considered the human robot had been more engaging, responsive, and exciting to interact with. With participants stating that *"When it comes to feelings, the second robot [human-robot] was really on point. To me it showed more emotional expressions and seemed to understand and empathize with me" (participant 4, male with ASD)* or *"I preferred the second one [human robot], because of facial expressions, and in the way that it communicates more casual" (participant 5, female without ASD).*

Yet again there is a noticeable difference between the reasoning of participants with or without ASD. Participants with ASD mentioned they preferred the human-robot due to its human qualities mentioning its humor or emotional intelligence. Whereas participants without ASD preferred the human robot because of its improved usability and user experience. This also becomes evident when participants were asked about possible companionships with the social robots. Both groups underlined the fact that they would view the human-robot as a companion or even a therapist, whereas they would give the robot-robot the role of assistant; *"I would invite the second robot [human robot] to a party because it's funnier" (participant 12, female with ASD), "I would choose the first one as an assistant, because it is much more professional"(participants 20, without ASD). "I would select the second robot* [human robot] *as a friend because I feel like the robot has more social skills and is funnier" (Male participants with ASD).* Participants with ASD focused on the human qualities of the social robots while participants without ASD focused on the improved usability skills.

4.2.2. Identifying varying levels of anthropomorphism

All participants with or without ASD were able to distinguish between various levels of anthropomorphism by evaluating displays of emotions, human qualities, and user friendliness of the two robots. That is, they can identify the different levels of anthropomorphism between the two robots and grade them based on whether they have a high or low level of anthropomorphism. All participants with and without ASD consistently emphasized the importance of facial expressions, emotions, empathy, and engagement in their perception of anthropomorphism within the human-robot. With participants mentioned things like *"In terms of feeling human I would say the second one* [human robot]*, it feels more into human characteristics" (participant 11, male without ASD) or "The second robot* [human robot] *felt more human to me because of its gestures and the way it talks"(participant 1, male with ASD)* when asked which of the two robots felt more human.

However, there is a clear difference in how the participants view the human-robot and identify the difference in anthropomorphism. When asked why they thought the human-robot was better at experiencing emotions and empathy, participants without ASD had the following to say "*The second one [human-robot], because of the same reason and also facial expression (participant 3, male without ASD)" or I feel like none of them really show empathy because it was a formal conversation (participant 17, female without ASD).* Similar answers were given by participants without ASD when asked if they thought the human-robot had any consciousness or intentions. Participants stated, "*None of them, they are both still robots (participant 2, female without ASD)* " and "*I don't think either of the robots had bad intentions. However, the first robot [robot-robot] felt more robotic than intentionally good or bad (participant 11, male without ASD).*

In contrast, participants with ASD highlighted the human abilities of the human-robot in their responses whereas participants without ASD did not. With answers such as "*The second one [human-robot], because when it answers me, it feels like it is more human in understanding (participant 1, male with ASD),* "*The second robot [human-robot] seemed better. It had more facial emotions and seemed to understand my emotions better (participant 9, female with ASD)"* and "*The second robot [human-robot], it showed interest in understanding and responding to me, which makes me feel like it cares more (participant 8, male with ASD)"*

This also becomes clear when analyzing the answers given by participants about the understanding and thought process of the human-robot. When asked if any of the robots had free will or consciousness participants without ASD had the following to say "*Neither of the robots exhibited free will. They rely on pre-programmed scripts, right? (participant 5, female without ASD)"* and "*None of the robots has a consciousness, but it did feel like the second robot had more awareness (participant 11, male without ASD).* Unlike participants with ASD who stated, *"I believe the second robot [human-robot] had neutral intentions (participant 19, female with ASD)"* and "*I think the second robot has more thoughts of its own. It seems like this robot was capable of making its own discussions (participant 1, male with ASD).*

4.3 Uncanny Valley

The data collected from participants provides insights into the experiences with social robots, particularly in relation to the uncanny valley effect. First, to determine the difference in satisfaction ratings, the pre-test results of the stimuli were also considered, as these included ratings on user experience and usability. Ratings on user experience and usability with the robots ranged greatly, from high (9/10) to low (2/5). The differing satisfaction ratings and participants' assessments of their interactions with the robots show evidence of the uncanny valley effect. This also becomes clear when comparing the overall grade given by participants during the interviews. Although not focused on user experience and usability it still gives a clear insight on the difference in satisfaction between the two robots. The wide range of evaluations could reflect the participants' varying comfort levels and emotional responses to the robots' human-like characteristics. Second, participants reported that both robots felt unsettling, especially to those with ASD. With participants commenting *"I would not select any of the robots as friends because they kind of creep me out, but if I really have to, I would say the second* *robot [human robot] since it is more social" (participant 9, female with ASD)* when asked if they would select one of the robots as friends.

Third, participants, with and without ASD, generally acknowledged the challenges associated with achieving human-likeness in interactions with social robots. Although the human-robot was perceived as more engaging and responsive, indicating progress in bridging the uncanny valley, both participant groups noted that the robots lacked genuine human qualities; *"I don't believe either of the robots has desires as humans do. Instead, they are programmed to fulfill tasks and functions based on their programming (participant 2, female without ASD)"*.

This suggests that, in the context of ASD, achieving a seamless human-like interaction remains a notable challenge. Both participants expressed challenges in perceiving genuine emotions and empathy from the social robots. Despite slight improvements in authenticity observed with the human-robot, the overall struggle to convey emotions convincingly indicates that the uncanny valley effect persists in influencing the emotional engagement experienced by individuals with ASD, a good example of this phenomenon being; *"No, robots do not have free will; they are not beings (participants 6, male with ASD)*" or *"Robots do not have thoughts of their own nor feelings (participant 10, female with ASD*)".

Fourthly, when asked if the robots had real feelings the following was answered; *"None of the robots really display empathy since it is a human feeling, they only say they care but they could never really care, it is copying human behavior not having human behavior (participant 3, male without ASD)".* However, participants with ASD did ascribe intentions, with the human-robot often perceived as having better intentions. This indicates that while participants recognize the limitations of robots in terms of consciousness, they still evaluate them based on perceived motivations. Finally, in terms of role preferences, both participants generally favored the human-robot, particularly in companionship roles. However, the reluctance to invite the robots to social events or choose them as personal therapists suggests that the uncanny valley effect may still influence the acceptance of social robots in specific social contexts. With participants stating *"I actually do not want to invite any robot to a party, the way it stares, I find it scary* (participant 6, male with ASD). The lack of authentic social dynamics in both robots, as perceived by the participants, contributes to this hesitancy. Participants stated that they would not invite either robot to a party due to their lack of authentic social dynamics. Next, participants also stated that they found the robots scary, unnatural, or creepy. This suggests that the robots' behavior, though more human-like than the first one, still fell short of fully resembling human social interactions. Which is why the uncanny valley effect occurred.

5 Discussion

5.1 Main Findings and Theoretical Implications

Overall, this study proves that individuals with ASD do in fact tend to anthropomorphize and can identify different levels of anthropomorphism. Negating the statement that the amount of anthropomorphism should have no effect on the social interaction between a social robot and a person with ASD because they are unable to identify different levels of ASD (Ammons, 2018; Cao et al., 2020). The study's findings show that participants, both with and without ASD had similar social interactions with both social robots, with both groups favoring the human-robot. When comparing the social interactions, there were no significant differences in terms of the duration and frequency. However, it is worth noting that even if there were no significant differences within these aspects of the social interaction, the reasoning of participants with and without ASD differed significantly.

First, individuals with ASD indicated a longing for empathy, emotional connection, and human-like features in their social interactions, which the human-robot provided. This aligns with the notion that individuals with ASD are more inclined to anthropomorphize objects, including social robots, as a means of seeking social connection and fulfillment (Atherton & Cross, 2018; Caruana, 2021; Waytz et al., 2010). Meanwhile, participants without ASD favored the human robot for its function mentioning usability and user experience rather than its ability to emulate human characteristics. These findings highlight the need of considering individual characteristics and preferences when developing social robots. Furthermore, this study adds to prior research suggesting that altering robot design to match the specific requirements and preferences of people with ASD, such as emphasizing empathy and human-like characteristics, holds potential to improve their engagement and social interaction (Lee & Nagae, 2021; Santos et al., 2023; Salhi et al., 2022; Syriopoulou-Delli et al., 2020).

Next, this research critiques the notion that as robots approach human-like appearance, individuals with ASD may find their near-human resemblance discomforting rather than accepting (Atherton & Cross, 2018; Caruana, 2021; Dubois-Sage et al., 2024; Lobato et al., 2013). Contrary to those without ASD, individuals with ASD preferred the social robot with higher levels of anthropomorphism [human-robot] due to its empathic and human-like characteristics. This shows that the uncanny valley effect may emerge differently or be less evident in individuals with ASD due to their distinct social processing abilities. Individuals without ASD, on the other hand, felt uncomfortable with the highly anthropomorphic robot [human-robot], which is more consistent with the traditional uncanny valley hypothesis.

Therefore, this study extends on prior studies by demonstrating that the personal connection between the individual and the robot should be considered, particularly when people with ASD generate bands within that personal relation. In addition to user experience and usability, when discussing uncanny valley, it is important to examine the robot's personality as well as its display of emotion and humor. Especially in connection to people with ASD, knowing that such contributions to the social robot substantially enhance the personal interaction they have with one another, and this then determines if the uncanny valley effect occurs or not (Caruana, 2021; Dubois-Sage et al., 2024; Lobato et al., 2013).

Next, the study identified significant differences in the intensity of social interactions with social robots between those with and without ASD. The significant difference in intensity suggests that the quality or depth of the social interaction did vary between groups. The diversity in humor expression and range of emotion contributes to the overall difference of interaction intensity. Therefore, this study emphasizes the importance of considering both quantitative (frequency, duration) and qualitative (intensity, preferences) aspects of social interaction when studying the experiences of people with ASD with social robots, as well as the need for personalized approaches in designing interactive technologies for diverse user populations.

Lastly, this study aims to build a bridge between human robot interaction research and ASD research by highlighting the importance of how individual characteristics, such as ASD level and gender, influence responses to anthropomorphic technologies. In addition, this study provides a basis for stimuli design for future ASD research to build on when referring to social robots within ASD treatments. The results presented in this study extends on past research by emphasizing the link between social motivation and anthropomorphism among people with ASD (Atherton & Cross, 2018; Caruana, 2021). It investigates the use of lifelike social robotics through a combination of observations and interviews, providing valuable insights into the interactions between people with ASD and social robots with different levels of anthropomorphism. However, further research into the psychological aspects concerning the link between social motivation and anthropomorphism among people with ASD is needed. This study focused on the social interaction between people with ASD and social robotics but did not consider the underlying psychological factors. These psychological aspects may have shed additional light on why there appears to be a relationship between social motivation and anthropomorphism among people with ASD.

5.2 Practical Implications

Furthermore, there are practical implications for the design of social robots, as well as the range of anthropomorphism in social robot designs. This study showed that, even though participants with and without ASD could recognize the various levels of anthropomorphism, they still believed the robot lacked human capabilities. This belief was based on the personality of the social robot rather than design or hardware. The emphasis on the human-robot's ability to grasp emotions and demonstrate empathy highlights the significance of emotional intelligence in social robots, independent of the user's ASD status. This demonstrates that the perceived emotional intelligence of a social robot is a vital construct of its design or user experience. This study motivates designers and developers to consider the social robot’s personality within the software programming of the robot. A great example of this is the attribution of the Furhat's Barge-in Beta software used to keep the social robot from interrupting the user's speaking.

The study of anthropomorphism and the uncanny valley effect in the context of social robotics reveals fascinating differences in how people with and without ASD perceive and interact with social robots. Thus, investigating how the uncanny valley effect and anthropomorphism affect the experiences of people with ASD versus people without ASD can provide useful insights into the design and deployment of social robots for a wide range of user groups. The study also highlights the relevance of personalized design methods in accommodating varied user preferences and sensitivities. Future research should delve deeper into the mechanisms underlying these disparate responses, providing important insights for the development of socially assistive technologies that effectively help people throughout the neurodiversity spectrum. Designers and developers should focus on creating the possibility to customize the social robot’s design, behavior, and personality according to personal preferences to accommodate varying users.

5.3 Limitations

While this study sheds light on the social interactions between people with ASD and social robots, some limitations should be noted. First, the sample size in this study was small, which is quite normal for insight driven research (Kim et al., 2017; Rahman, 2016). However, seeing that the data from the observation had the most significant differences, future research into these qualitative differences could be helpful to further analyze the difference in intensity and reasoning seen among participants with and without ASD. For this a bigger sample size is needed. Using a bigger sample size as well using quantitative data allows research to say something about the finding's generalizability. In addition, the quantitative measure attached to the observations, in combination with such small groups, makes it difficult to demonstrate statistical significance.

Second, the different levels of ASD also proved to be a limitation. This study only considers levels 1 and 2 of ASD, making it difficult to say something about the overall experience of people with ASD since level 3 has not been considered. Apart from that, ASD is referred to as a spectrum disorder, which is a mental condition that includes a number of linked conditions, as well as singular symptoms and traits. In addition, the symptoms of ASD could manifest in different ways and perhaps change over time (Bölte, 2014; Ghosn, 2021; Hyman et al., 2020; Mottron and Bzdok, 2020). This is why further research should include all levels of ASD as well as consider linked neurodivergent conditions, as well as personal characteristics such as age and environment.

Third, this study included gender as a control since it has been demonstrated that gender disparities in autism and anthropomorphism research are extensively reported (Modliski et al., 2022; Rattaro et al., 2020; Shefcyk, 2015). Overall, gender analyses revealed small differences within participants with ASD. Male ASD participants exhibited slightly shorter interaction durations with the robot-robot compared to female ASD participants. Female ASD participants showed a more nuanced pattern, with increased speech frequency with the human-robot. However, these differences were not significant enough to say that the participants' gender was the reason for this. That is why further research is necessary to combat the gender disparities within ASD and human robot interaction research.

Furthermore, the study focused on short-term interactions (10 minutes) with social robots in a controlled laboratory setting, which may not accurately reflect the complex nature of real-world interactions (Vagnetti et al., 2024; Veling & McGinn, 2021). Future studies could investigate long-term interactions in naturalistic settings to better understand how social robots affect people with ASD. Longitudinal studies that examine the intensity of social interactions over time can provide important insights into the development and long-term viability of interactions between individuals with ASD and robots. This allows researchers to detect patterns, trends, and potential areas for intervention or improvement. One suggestion is employing ASD therapy settings for future study, as social robots are commonly employed in this treatment. This allows researchers to examine if the level of anthropomorphism of the social robot has an influence on the therapy itself (Amato et al., 2021; Lee & Nagae, 2021; Salhi et al., 2022).

Finally, this study attempts to build a bridge between human robot communication research and ASD research. However, future research needs input from a multidisciplinary team of ASD, human robot computer, and psychology experts to give more insights into the design and deployment of socially helpful technologies for individuals with ASD. Only then can all aspects of social robot design, social interaction, anthropomorphism, and ASD be fully explored based on their respective expertise. Overall, resolving these limitations and delving deeper into the highlighted themes could help researchers better understand the social interactions between people with ASD and social robots, guiding the creation of more effective interventions and support systems.

5.4 Conclusion

In conclusion, the social interaction between individuals with ASD and social robotics with regards to anthropomorphism and the uncanny valley effect was the focus of this study. Therefore, participants, with and without ASD, interacted with two social robots, each varying in anthropomorphism. The study included semi-structured observations and retrospective interviews to answer the main research question "*How do people with ASD experience a social interaction with a social robot*?" The main findings show that individuals with ASD do in fact tend to anthropomorphize and can identify different levels of anthropomorphism. Participants, both with and without ASD had similar social interactions, with both groups favoring the robot with the higher level of anthropomorphism. However, the reasoning of participants with and without ASD differed significantly.

Participants with ASD preferred the social robot with higher levels of anthropomorphism due to its empathic and human-like characteristics whereas participants without ASD did not. Desiring empathy, emotional connection, and human-like attributes in their social interactions, participants with ASD favored the social robot with higher levels of anthropomorphism for its empathic and human-like characteristics. This aligns with the notion that individuals with ASD are more inclined to anthropomorphize objects, including social robots, as a means of seeking social connection and fulfillment.The significant difference in social interaction intensity identified within the study suggests that the quality or depth of the social interaction did vary between groups. Therefore, this study emphasizes the importance of considering both quantitative and qualitative aspects of social interaction when studying the experiences of people with ASD with social robots, as well as the need for personalized approaches in designing interactive technologies for diverse user populations.

Furthermore, the current study shows that the uncanny valley effect may emerge differently or be less evident in individuals with ASD. Contrary to those without ASD, participants with ASD preferred the social robot with higher levels of anthropomorphism [human-robot] due to its empathic and human-like characteristics. Individuals without ASD felt uncomfortable with the highly anthropomorphic robot, which is more consistent with the traditional uncanny valley hypothesis. Therefore, this study demonstrates that the personal connection between the individual and the robot should also be considered, particularly when people with ASD generate bands within that personal relation. In addition to user experience and usability, when discussing uncanny valley, it is important to examine the robot's design, behavior, and personality.

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Appendix - Retrospective interview

Question	Reference
Which interaction with one of the two robots did you prefer, and can you explain why?	Spatola et al., 2022
How satisfied were you with the way the first robot treated you? 1/10	Spatola et al., 2022
How satisfied were you with the way the second robot treated you? 1/10	Spatola et al., 2022
Do you think both robots were able to understand and answer you properly? Which did you think did a better job at that?	Spatola et al., 2022
Which of the two robots felt more human to you, please explain.	Severson & Lemm, 2015
Which of the robots do you think is better at experiencing emotions? explain	Severson & Lemm, 2015
Which one of the two robots do you think can display more empathy? Explain why	Severson & Lemm, 2015
Do you think the first robot has good or bad intentions? Explain why?	Severson & Lemm, 2015
Which of the two robots has more thoughts of its own? Explain why you think that.	Severson & Lemm, 2015
Do you think either of the robots has a consciousness? And if so which of the robots displays a bigger sense of consciousness?	Severson & Lemm, 2015
Do you think either of the robots has desires? If so, which of the two robots do you think has more desires?	Severson & Lemm, 2015
Which of the two robots do you think has values and norms? Why?	Waytz et al., 2010

Do you think either of the robots have free will? If so, which of the robots has more sense of free will?	Waytz et al., 2010
If you could choose one of the robots, which one would you choose as a companion/friend and why?	Bartneck et al., 2008
If you could choose one of the robots, which one would you choose as an assistant and why?	Bartneck et al., 2008
Which of the robots would you invite at a party and why?	Bartneck et al., 2008
If you had to pick one of the robots as your personal therapist which one, would you pick and why?	Bartneck et al., 2008