BACHELORTHESIS

ROBOVACS IN THE DOMESTIC ENVIRONMENT:

MEASURING PHYSIOLOGY TO IDENTIFY EMOTIONS UNDERLYING REAL-WORLD HUMAN-ROBOT INTERACTION

Simone Einhoff

0173681

BEHAVIOURAL SCIENCES

DEPARTMENT COGNITIVE PSYCHOLOGY AND ERGONOMICS

EXAMINATION COMMITTEE

1st Dr. M.L. Noordzij

2nd Dr. M. Schmettow

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Samenvatting

De afgelopen jaren werd steeds meer aandacht geschonken aan de ontwikkeling van persoonlijke service robots. Buiten de ontwikkeling van technologische aspecten, moet aandacht worden besteed aan een op een mens gefocust oogpunt, welk zich richt op de interactie tussen mens en robot (Dautenhahn, 2007). Derhalve wordt in deze studie, in de context van Human-Robot Interaction (HRI), onderzocht wat de emotionele respons is van gebruikers op stofzuigende robots (robovacs), door fysiologische (EDA), kwantitatieve en kwalitatieve metingen toe te passen. Het onderzoek bevat de observatie van twee verschillende robovacs in de woonkamers van de participanten (n=16). De fysiologische respons was hoger tijdens interactie met de robovacs dan toen geen interactie plaats vond. In plaats van een significant verschil in emotionele reactie tussen de twee robovacs, kon een significant verschil in geslacht vast worden gesteld. Hoewel het aantal botsingen verschilde tussen de robovacs kan geen relatie tussen de botsingen en de fysiologische respons worden geconstateerd. Samsung's stofzuigende robot, Navibot, werd over het algemeen positiever geëvalueerd werd dan iRobot's Roomba. Deze studie levert eerste experimentele inzichten zodat toekomstig onderzoek zich zou moeten richten op een langdurig veld onderzoek, waar de individuele reacties van de gebruiker nader onderzocht kunnen worden.

Abstract

During the last decade the development of personal service robots has been thriving. In addition to the technical requirements, attention has to be paid to the human-centered viewpoint, which concentrates on the interaction between humans and robots (Dautenhahn, 2007). Accordingly, within the context of Human-Robot Interaction (HRI) this study investigates user's emotional response toward vacuum robots (robovacs) by employing physiological (EDA), quantitative and qualitative measurements. The study included observing two distinct robovacs in the living rooms of the participants (n=16). The results indicated a higher physiological reaction during robot interaction than during non-activity. Instead of finding a significant difference in EDA reaction toward the robovacs, a significant gender difference was found. Though the amount of collisions differed significantly, no relation between collisions and arousal could be established. In general Samsung vacuum cleaner, Navibot, received a more positive evaluation than iRobot's Roomba. As this study is a means to indicate first experimental insights, future research could conduct a longitudinal field-study where the individual reactions toward the robovacs could be investigated in more detail.

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Introduction

It can be assumed that a lot of people somewhere along the way have wished for a cleaning help that gets work done without much effort. The technological industry has reacted to this desire and as a start created vacuum robots (robovacs) that assist with the cleaning process. Though personal service robots, for example robovacs, are not yet as fully established as industrial robots, they are supposed to emerge quickly (Waarsing, Nuttin & van Brussel, 2001; IFR Statistical Department, 2010; Hendriks, Meerbeek, Boess, Pauws & Sonneveld, 2010). In 1996, Joanne Pranksy entitled the development of service robots "the most exciting and promising robot evolution" (p.4). According to Pranksy (1996), achieving mass distribution of service robots requires more descriptions, information and definitions about service robots. In the meantime several researchers have addressed her demand and studied the field of service robotics and the directly linked Human-Robot Interaction (HRI). HRI comprises the study of the collaboration and interplay between robots and humans (Kosuge & Hirata, 2004) and has been a field of study since the end of the 20th century (Goodrich & Schultz, 2007). Against the background that HRI is a discipline with many facets, Dautenhahn (2007) generated a model that captures three concepts of HRI research approaches (see figure 1). The scope of this study falls within the human-centered view, where the focus lies on how humans react to the appearance and behavior of a robot with the intention to develop a user-satisfying robot design. In particular, the International Federation of Robotics (IFR) states that additional research and development within the domain of personal service robots is needed before acceptation in households is reached (IFR Statistical Department, 2010).

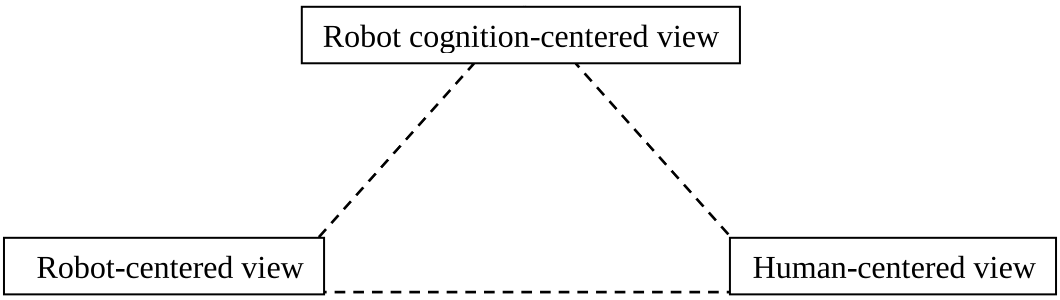

Figure 1. Different conceptual viewpoints on HRI.

Relating to that, in human environments personal service robots assist, help or support humans with fulfilling tasks (Waarsing, Nuttin & van Brussel, 2001; Kosuge & Hirata, 2004). Inevitably, the contact with for example robovacs leads to interaction which has been found to have various impacts on users (Forlizzi & DiSalvo, 2006; Hendriks et al., 2010). Whenever interacting with a product, users establish their own product-experience, which is composed of the attribution of meaning, an aesthetic reception and an emotional response toward the product (Desmet & Hekkert, 2007). For example, research on consumer product-experience showed that users have different emotional responses toward various telephone models (Desmet, Overbeeke & Tax, 2001). This finding might also apply to different products, such as robovacs. Since emotional responses vary from one individual to the other they notably influence the user experience of the human-product interaction. Therefore it is relevant to further investigate the emotional reaction toward service robots, and in this study specifically toward robovacs. An emotional response can be composed of an expressive, a behavioral, a subjective and a physiological reaction (Desmet, 2005). Research about robovacs has commonly focused on observations or surveys, which concentrated on the subjective and expressive aspects of an emotional response (Forlizzi & DiSalvo, 2006; Sung, Grinter, Christensen & Guo, 2008; Riek, Rabinowitch, Chakrabarti & Robinson, 2009). However, an advantage of investigating physiological reactions is that the underlying non-reactive emotions can be captured during interaction and in addition to that such investigations can provide precise data of every second of the interaction (Picard, 2010).

Consequently, this study investigates the emotional reaction of users during interaction with two robovacs in the home environment of the participants. In order to capture the emotional reaction the main focus lies on the physiological measurement. Additionally and with relation to the framework of triangulation, expressive behavior and the users' attitude will be studied as well. This study is a means to provide initial experimental insights into the physiological reaction toward robovacs.

As HRI and in particular the domain of personal service robots are a relatively new and intricate field of study it is important to gain a deeper understanding of these topics, focusing on the human-centered view. Hence, in the following sections the existing literature on HRI and about the characteristics of service robots will be reviewed while occasionally referring to the object of this study. The review sketches robovacs within the dimension of HRI before delving into the details of this study, the results, the discussion and the conclusion with guidelines for robovac developers.

Theoretical Background

General Review of Human-Robot Interaction (HRI)

HRI is "the interdisciplinary study of how humans interact with robots, and how best to design and implement robot systems capable of accomplishing interactive tasks in human environments" (Feil-Seifer & Matarić, 2009). HRI is a cross-disciplinary area which brings together Psychology, Human-Computer Interaction (HCI), Cognitive Science and Robot-and-Computer Science (Burke, Murphy, Rogers, Lumelsky & Scholtz, 2004). Kiesler and Hinds (2004) indicated that the two disciplines HRI and HCI are closely intertwined which allows research from HCI as a basis for studies in HRI. Social interaction, for instance, illustrates the similarities between HRI and HCI. An HCI research indicated that humans tend to react to a social interface on a computer on a human-based approach, that is, similarly to other humans (Reeves & Nass, 1996). In HRI, the research with the robot Kismet also showed that humans react to Kismet's expressive cues which facilitate social interaction (Breazeal, 2002, 2003). Computer interfaces and robots are both intended to assist humans. Though, in contrast to a computer interface, the robot has a physical embodiment and freely moves around in the environment in order to help the user. The assistance can therefore occur in different settings and manners, depending on the kind of robot that is used.

Commercial robots can be divided into three categories: industrial robots, professional service robots and personal service robots (Thrun, 2004). The market for industrial robots and professional service robots has been thriving (IFR Statistical Department, 2009) and professional service robots, such as rescue robots or medical robots, are widely known. Yet service robots in personal settings have not found so much market demand (IFR Statistical Department, 2009). Though, their market tendency to increase has been captured by the IFR (IFR Statistical Department, 2010) as well as by other researchers (Severinson-Eklundh, Green & Hüttenrauch, 2003; Burke et al., 2004; Sung, Guo, Grinter & Christensen, 2007). Most common in the personal sector are domestic and entertainment robots, former including robots that vacuum (e.g. Roomba, www.IRobot.com) or assist with lawn-mowing (e.g. Robomow, www.robomow.com). Entertainment robots assist with educating or training (e.g. e-puck, www.e-puck.org; Scribbler, www.parallax.com), include toy robots (e.g. AIBO, http://support.sony-europe.com/aibo/) or provide companionship and therapeutic support (e.g. Paro, www.parorobots.com). These distinct robot applications contain different properties, features and capabilities that have an impact on the interaction between human and robot.

The investigation of two distinct robovacs in the home environment and therefore in close contact with the user is central to this study. In this context HRI literature indicated the following attributes that are relevant during the interaction between human and robot as well as for the comparison of the two robots in this study: autonomy, physical space that is shared with a human, communication capabilities and appearance (Thrun 2004; Minato, Shimada, Ishiguro & Itakura, 2004; Goodrich & Schultz, 2007). Other attributes that have been mentioned in that literature are less relevant for this study, like teamwork or training robot and human, since robovacs have limited ability to participate in sharing a task with a human, for example, building a car in team work. Furthermore, humans are not supposed to need training to operate the robot and neither is a vacuum robot able and expected to learn for example the humans' emotions. The four attributes of HRI that do play a role in this study will be amplified in the next paragraph.

Autonomy. Thrun (2004, p.10) states that "possibly the biggest difference between robots and other physical devices - such as household appliances - is autonomy". Autonomy of an object is its ability to function independently (Steinfeld et al., 2006). The right level of autonomy, that is needed to accomplish a task successfully, leads to beneficial and productive interaction between humans and robots (Goodrich & Schultz, 2007). It can be argued that, provided the autonomy level and task requirements match, the more autonomous a robot is the more time the operator has at hand (Crandall, Goodrich, Olsen & Nielsen, 2005). For example, a high level of autonomy might be desirable in a situation when it is too dangerous for a human to enter the grounds, such as during the inspection of the reactor buildings after the earthquake in Fukushima (Normile, 2011). Logically, the less autonomous a robot, the more interaction between human and robot takes place. The interaction varies, depending on the independent character of the robot and how well that matches the tasks requirements and humans' expectations (Yanco, Drury & Scholtz, 2004). The robovacs of this study are likely to need assistance once in a while which makes them less autonomous. Therefore observation can point to how people react to having to provide assistance and how they perceive the level of autonomy.

Physical space. It has been stated that "from the human-robot interaction perspective, a very important characteristic of these new target domains [service robotics] is that service robots share physical spaces with people" (Thrun, 2004, p. 14). The earlier mentioned autonomy of a robot determines the distance between human and robot that can be maintained until the robot needs assistance (Yanco et al., 2004). Goodrich and Scholtz (2007) introduce two kinds of interaction. Remote interaction appears when human and robot are not co-located, thus they might be separated spatially or temporarily (e.g. space robots). Proximity interaction occurs when they are co-located, that means in the same room (e.g. vacuuming robot). It can be assumed that as soon as robots need monitoring of their task, the interaction needs to be closer. A study with autistic children indicated that close interaction with a humanoid robot mediated and facilitated interaction with another human being (Robins et al., 2005). In comparison with digital agents, who are physically unreachable, interaction with co-located robots also resulted in a more positive attitude (Pavers, Kiesler, Fussel & Torrey, 2007). On the contrary Kidd and Breazeal (2004) stated that a robot has a greater social impact and is more enjoyable than an on-screen agent, but that this difference is not due to proximity to the user but to the robot's physical embodiment. With respect to this study it shall be examined whether people are willing to reduce the distance between themselves and the robovac.

Communication. Another important factor in HRI are the communication capabilities of a robot and how they vary between robot applications. Goodrich and Schultz (2007) state that the communication between a human and a robot takes place via sight, hearing and touch. In robotics the communication spectrum ranges from facial expressions (e.g. Kismet, Breazeal, 2001, 2003), natural language (Perzanowksi, Schultz, Adams, Marsh & Bugajska, 2001), speech recognition (e.g. Cero, Severinson-Eklundh et al., 2003), physical interaction and visual- and touch displays (e.g. Roomba) to non-speech audio (e.g. airplane warning systems). For example, in the context of speech researchers discovered that speech recognition of the robot facilitates interaction (van Breemen, Crucq, Kröse, Nuttin, Porta & Demeester, 2003). Few communication problems are likely to appear by simple touch commands, thus by direct manipulation. As commanding the robovacs is based on touch commands, the interaction between a user and a robovac might yield insights into how and when communication takes place.

Appearance. The last attribute that influences the way how people interact with robots is appearance. For instance, a study about the level of anthropomorphism (degree of human-likeness) in robots indicated that the more human-like a robot is the more empathy is displayed by the users (Riek et al., 2009). In contrast to that, a humanoid robot study showed that autistic children preferred interacting with a plain robot appearance above a robot with human features (Robins, Dautenhahn, te Boekhorst & Billard, 2004). The matching hypothesis further elaborates that "robot appearance and social behavior should match the seriousness of the task and situation" (Goetz, Kiesler & Powers, 2003, p.55). The match of these factors affects how people review and perceive robots. In the context of this study appearance aspects like color, movement or form will supposedly play a larger role than in the humanoid studies that investigated anthropomorphic appearance. This study also intends to shed some light on the evaluation of the different appearance of the robovacs.

With reference to the previous aspects it becomes apparent that the influences of the attributes are shaped by the tasks and performance that have to be done and can therefore differ, depending on the robot application. The robot applications used in this study belong to the domain of personal service robots. The next paragraph will review literature on this topic, also relating to the four attributes, and will review studies that specifically concentrated on robovacs.

Characteristics of Personal Service Robots and Robovacs in Particular

Considering the fact that robots enter the homes of humans and engage in interaction calls for more information about how they affect the lives of the users and how the interaction takes place. In literature most descriptions of service robots are oriented toward the same direction. Here, service robots are defined as devices that directly assist human beings in executing tasks or services in their home environment. This definition is mostly in line with Kawamura, Pack, Bishay and Iskarous (1996), Hillman (2003) and Bartneck and Forlizzi (2004). Thus, the most desirable purpose of service robots is that they take over tasks humans do not like to do or are unable to do on their own, which saves time and improves the quality of people's lives.

The direct contact with humans raises some design issues and questions about robot capabilities and characteristics. Wösch, Neubauer, Wichert & Kemény (2004) declare that first human safety should be guaranteed. In addition to that, issues like reliability, cost, appearance and user-interface should be considered (Kawamura, 1996). Furthermore, household robots should be robust, reliable and flexible to cope with unforeseeable events (Lindström, Orebäck & Christensen, 2000). These requirements support the assumption that it is essential to facilitate interaction between humans and robot, especially because most users are not trained nor do they have much technical experience (Bartneck & Forlizzi, 2004).

With reference to the previous section, four attributes affect the interaction between humans and a personal service robot. Relating to the attribute of *autonomy*, when focused on the attitude of users toward an intelligent service robot, users preferred a robot that only did what it was programmed to do, instead of a robot that moves independently through the home (Kahn, 1998). The fact that a service robot should only have as much autonomy as its purpose requires has been explained elsewhere (Kawamura et al., 1996). The autonomy of a robovac can be characterized as semi-autonomous, as it is supposed to operate independently in the dynamic home environment but at the same time the user has to intervene and help the robot at certain points, for example, when it gets stuck or stops due to blockage. In relation to the attribute of *physical space*, a study about how people imagined their future robot indicated that 70% of the participants preferred a robot as a companion instead of a butler and 96,4% wanted him to do household tasks (Dautenhahn, Woods, Kaouri, Walters, Koay & Werry, 2005). Vacuum robots possess an interface to receive touch commands and frequently produce sounds, which relates to the attribute of *communication*. An interview with Roomba users revealed that the sound signals were used as an indicator for personality (Sung et al., 2007). Though, it is questionable whether the sound is evidence enough to be interpreted as the robovacs personality instead of its current and technical state. Relating to *appearance* a study of an assistant robot in a controlled laboratory setting showed that a playful appearance was evaluated with a more positive personality than the serious robot (Goetz & Kiesler, 2002). Surprisingly, the level of cooperation was lower with the playful and more positively rated robot. A study for developing a domestic robot interface indicated that people increasingly enjoy the interaction if the robot, in this case Lino, has an appealing appearance and is able to communicate its emotional state (van Breemen et al., 2003). Another study concluded that "people anthropomorphize robot vacuum cleaners and (…) attribute personality characteristics" (Hendriks et al., 2010, p. 194). When traits like being calm, working efficiently and systematically, being cooperative and following a routine were incorporated in a robot prototype users recognized the intended personality which enhanced user experience. The above described findings suggest a user preference for a co-located robot, which is to a certain extent independent and assists with household tasks, like a robovac.

A few home studies of the vacuum robot Roomba reveal insights into its characteristics, its usage and its impact on the household. Hendriks et al. (2010) state that vacuum robots will be the leading robots to share domestic and close personal working space with humans. Field research showed that the robovac Roomba changed the cleaning patterns of the whole family and affected individual cleaning habits (Forlizzi & DiSalvo, 2006; Sung et al., 2007). Additionally, they found higher levels of satisfaction and facilitation of interaction with Roomba when human features, like personality, gender or names, were attributed to it or when users engaged in non-cleaning activities in contrast to simply using it as a cleaning device (Sung et al. 2008; Hendriks et al., 2010). The home studies also showed that the home environment is marked by a lot of obstacles, difficult for a vacuum robot to dodge. For that reason many users modified Roomba's cleaning area to facilitate the cleaning process (Forlizzi & DiSalvo, 2006). This behavior is referred to as *roombarization*, which describes the act of moving furniture or making any other physical adjustments in the home in order to facilitate Roomba's operation (Sung et al., 2008). Presumably, users make these modifications due to the fact that colliding with their own furniture is an unwanted feature, as seen in the study of Forlizzi and DiSalvo (2006). Relating to that, it has been proposed that human safety, and probably that of furniture as well, must be guaranteed in HRI (Kulić & Croft, 2007b). For many people home vacuum robots are an unfamiliar technology that requires reducing the lack of information about the functioning of the robots in order to establish a proper HRI (Hendriks et al. 2010). Besides unfamiliarity, other aspects might trigger a cognitive and emotional response in the user. Accordingly, beyond studying the robot's impact on cleaning activities and social behavior, this study is to investigate in which ways emotion and perception are affected. The concept of emotion and investigating emotion in HRI will be elaborated on in the next section.

The preceding literature review gives many insights into HRI and the interaction with personal service robots. Though Dautenhahn (2007) already tried to simplify the field of HRI, it becomes apparent that even the human-centered view on robotics consists of various fragments. With respect to the current study it is relevant that the home studies reveal that robovacs affect cleaning activities and the way people interact with it. Furthermore, the four attributes previously described are expected to play a role in the evaluation, perception and interaction with the robovacs.

The Concept of Emotion and Emotion and EDA in HRI

In 1981, Kleinginna and Kleinginna reviewed 92 definitions of emotion in order to shed some light on the many understandings that exist. Their undertaking illustrates that it is complicated to grasp the whole concept of emotion. In order to establish a basis for understanding emotion in this study, a general review about emotion will precede a review of emotion in HRI. To begin with, Kleinginna and Kleinginna (1981) came up with the following comprehensive definition:

> *"Emotion is a complex set of interactions among subjective and objective factors, mediated by neural hormonal systems, which can (a) give rise to affective experiences such as feelings of arousal, pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals, labeling processes; (c) activate widespread physiological adjustments to the arousing conditions; and (d) lead to behavior that is often, but not always, expressive, goal directed, and adaptive." (p. 355)*

Other authors agree that emotions are composed of physiological processes, observable behaviors and the notion of a cognitive and experiential aspect (Izard, 1977;

Picard, 1997; Ackerman, Abe & Izard, 1998). Theories of emotion differ in whether cognition or physiology is its origin. For a review of the existing theories of emotion, see Oatley, Keltner and Jenkins (2006). From the preceding descriptions it becomes clear that measures of emotions need to concentrate on more than one aspect. Accordingly, this study applies triangulation with the main focus on physiology. Additionally, due to the observational character of this study, aspects of cognition and expressive behavior will also be taken into account.

The concept of emotion. The concept of emotion includes the relation between external stimuli and internal processes such as thinking and feeling (Kagan, 1984) and usually results in an expressive behavioral reaction toward a stimulus (Breazeal, 2003). An emotional reaction response toward a stimulus, such as an incident in the environment, is signaled by activity or arousal in the autonomic nervous system (ANS) (Oatley et al., 2006). In particular, the sympathetic branch of the ANS is responding to emotions and other body reactions which can be indicated by physiological measurements, for example heart rate, blood pressure, electrodermal activity (EDA) or pupil dilation (Picard, 1997). When studying the interaction between humans and technology, physiological changes have been proposed as a widely used method to assess the stress level and the level of arousal (Picard, Vyzas & Healey, 2001; Mandryk & Inkpen, 2004). Several researchers pointed out that studying physiological activity is contributing to study humans' affective responses in HRI (Kulić & Croft, 2007; Rani, Sarkar & Smith, 2003).

Within physiology EDA, which is the measure of skin conductance, has been indicated as a reliable measure of the activity of the sympathetic nervous system (SNS) and as a suitable measurement to examine the interaction between humans and robots and its relation to a person's level of arousal (Picard, 1997; Damasio, 1998; Oatley et al., 2006). Having a certain emotion leads the body to react with less moisture emission. Thus, more moisture results in an increased skin conductance which enables the electricity to flow faster. Hence, the intensity of an emotional reaction can be detected by whether the skin conductance is increasing or decreasing. EDA enables the researcher to gain objective data on reactions of the SNS that are related to experiences and reactions toward, for example, a technological device. Additionally, measuring EDA provides insights into the body reactions that are not expressive and unconscious to the human. Receiving measurements of the activity every second allows detailed comparison of the expressive and non-reactive emotional reactions of humans. The type and the perceived intensity of an emotion may differ among individuals, as might their interpretation of an experienced event (Izard, 1977). Accordingly, it cannot be determined after measuring only physiology whether the reaction to the stimuli is positive or negative but it requires additional measures.

Emotion and EDA in HRI. Not only do emotions play an important role in interaction with other human-beings but also during contact with objects. Lee, Kim, Yoon, Yoon & Kwon (2005) declare that humans exhibit emotions during interaction with inanimate devices like cars or stuffed animals. An ethnographic study of Roomba indicated that once Roomba had entered a household, family members and household members establish a social and therefore emotional relation with their Roomba (Forlizzi & DiSalvo, 2006).

In studies of HRI and HCI, several physiological measurements reveal insights into the affective responses of users. In studies with the therapeutic robot Paro, physiological measures revealed less stress after the introduction of the robot (Wada & Shibata, 2007). An experiment that tested the emotional reaction toward different movie films discovered a relationship between EDA and the level of frustration (Lisetti & Nazos, 2004). When respondents were frustrated their EDA increased. Picard (1997, p.162) additionally notes that EDA "tends to increase when a person is startled or experiences anxiety (…)". In a controlled laboratory setting, Kulić and Croft (2007) studied the physiological response of humans during observation of a table-top assistive lab robot's motions. In addition to several questions they measured EMG signal, heart rate and EDA, to estimate the level of arousal. They stated that fast robot motions resulted in high arousal. Furthermore, a novel or unexpected stimulus can cause arousal in the ANS, as found in pattern response experiments (Berlyne, Craw, Salapatek & Lewis, 1963; Dawson, Schell & Filion, 1990). Consequently, a new technological device in the household might trigger arousal. An HCI study examined technological advancement in video games. The technologically more advanced, thus newer versions of a video game increase EDA arousal in contrast to the older versions of the same video game (Ivory & Kalyanaraman, 2007). More specifically, the authors conclude that "(…) technological advancement in video games increased player's sense of presence, feelings for involvement, and arousal but did not significantly affect aggressive thoughts or feelings" (Ivory & Kalyanaraman, 2007, p. 547). Accordingly, the difference in technical advancement of the two robovacs used in this study, which becomes evident by a difference in, for example, brushes, sensors, obstacle avoidance mechanisms or velocity, is assumed to have an influence on the emotional response. In an ethnographic home study "Roomba was described by individuals and families in functional, aesthetic, symbolic, social and *emotional* [italics added] terms" (Forlizzi, 2007, p. 134), whereas the conventional handheld vacuum device used in that ethnography was only described in functional and symbolic terms. Therefore it can be assumed that service robots elicit an emotional response. Furthermore, it has been recommended that robots should avoid collisions with obstacles and humans (Butler & Agah, 2001; van Breemen et al., 2003). If the level of comfort is affected by collisions, collisions also may have an influence on the emotional reaction and thus the level of arousal (Butler & Agah, 2001). The obstacle avoidance mechanism seems to be a highly valued technical feature in vacuum robots. Hence, studying the physiological reaction will elucidate the impact of the robot's collisions with obstacles on the emotional response.

Present Research

In order to contribute to the field of HRI this study investigates the physiological reaction of users during interaction with two robovacs. To date, literature has not focused on user's body response toward a robovac in order to establish users' emotional reaction. Referring to the assumption that interaction with objects elicits arousal, as it was described in the previous sections, it is expected that the interaction with a robovac will result in higher physiological activity than during moments of rest (H1). Due to the fact that one robovac is technically less advanced than the other robot used in this study, it is expected that the less advanced robovac will elicit more arousal (Ivory & Kalyanaraman, 2007) (H2). In this study technological advancement is defined as having a better obstacle avoidance mechanism, cleaning more efficiently and working autonomously. An additional aspect that supports the assumption that the less advanced robot will evoke more emotional response stems from the fact that a higher collision rate might result in higher user frustration, which is related to an increase in EDA (Lisetti & Nazos, 2004). However, as literature has not yet focused on the physiological effect of colliding with or demolishing personal belongings, the assumptions made about the origin of arousal are based on common sense. But with this assumption in mind, a relation between the amount of collisions and the level of arousal is expected. (H3).

H1: Arousal is higher during interaction with robovacs than during baseline.

H2: Arousal is higher during interaction with the less advanced robovac (Roomba) than with the technologically more advanced robovac (Navibot).

H3: There is a relation between collisions and arousal.

In addition to measuring physiology, the attitude toward and interaction with the robovacs shall be investigated and, in this context, it will also be analyzed how the distinguishing features of the two robovacs of this study are evaluated, perceived and liked. Among other things, they differ in appearance (e.g. blue vs. silver), operation (e.g. touch display vs.

buttons) and technological advancement (e.g. two sensors and a visionary mapping system vs. one sensor in the bump). Though one robot appears to be more advanced (Navibot), the other one (Roomba) has been studied intensively, enjoys more popularity on the internet (245.000 vs. 1.020.000 Google results), has been produced by a corporation that calls itself " a leader in delivering robotic technology based solutions" and is very successful in the robot market (iRobot, 2011). Personal communication with Philips, another producer for electronic devices, confirmed that Roomba holds an estimated market chair of 95%. After viewing these arguments, the question that remains is which robot will be evaluated more positively? Due to the lack of earlier EDA research on robovacs, this study can be a means to give first experimental impulses.

Method

Participants

The 16 participants of this study were acquaintances or family members of the researcher. Table 1 gives an overview of the demographics and distribution during the experiment. Having different nationalities, age and gender serves the purpose of a diverse sample. The participants ranged in age from 18 to 91 years. They further ranged in technical affection which was detected by one question in the questionnaire. 75% judged themselves to be very or a little technically affected, 25% found themselves neutral or not very affected and no one ticked the box of not being technically at all. It was the first experience with a robovac for all participants. The participants were contacted by phone and received a small reward for their participation after the experiment.

Table 1

Amount of and details of the participants and their distribution over the two orders.

Group	Robot order	Gender Male	 Female	Nationality Dutch	 German	Age in years
1	Navibot Roomba	6	2	3	5	*M* = 48,5
2	Roomba Navibot	1	7	2	6	*M* = 48,5

Instruments and Measurements

Figure 2 illustrates the two robovacs (independent variable) used in this study: the Roomba 555 from iRobot and the Navibot SR8855 from Samsung. For more information about Roomba see Jones (2006), Tribelhorn & Dodds (2007) or www.irobot.com. For

Navibot see the official homepage of Samsung, www.samsung.com. The three dependent variables and their measurement will be described next.

Figure 2. Illustration of the two robovacs: Roomba (left) and Navibot (right).

Emotion. The arousal response is measured with EDA. The EDA measurements were gained by the *Q-Sensor* from the firm *Affectiva* (www.affectiva.com). The Q-Sensor is a small, wearable device that includes two small electrodes which measure the EDA in microsiemens (μS). Using a wearable measuring device is an unobtrusive method and facilitates gaining natural results. Research from the Massachusetts Institute of Technology [MIT] showed that this sensor is a reliable and valid measure of EDA during daily activity (Poh, Swenson & Picard, 2010). The researchers indicate that their device has a higher measurement error at lower resistance values. After testing several EDA values, they found a mean sensitivity of the device at 0.01 ± 0.01 μS. On top of the sensor there is a button that can be pressed in order to mark certain events that seem to be important and which will later be marked as a water drop in the output of the Q-Sensor data.

Evaluation and perception of the robovacs. In order to assess the evaluation and perception of the robovacs, the participants had to fill out three self-designed questionnaires during the experiment, which are attached in appendix I. The first questionnaire included demographical questions, questions about their expectations of the first robot and how they value different aspects of the cleaning process. The possibility that some of the participants are unfamiliar with robovacs initiated the idea of examining their expectations before and after the first contact. They were asked about their values during the cleaning process to gain knowledge about which functions a robovac should possess and what needs to be developed. The second questionnaire asked again which expectations the respondents had of the following robot and which aspects they appreciated during the cleaning process. The second and third questionnaires are a means to assess the users' evaluation of the robots. They are divided into three scales. The first scale focuses on how participants perceived the robot to gain their general opinion. The second explores the emotions the participants felt during the interaction in order to link their cognitive evaluation to the results of the physiological measure. The third scale concerns the functionality of the robot and explores the cleaning abilities of the robovacs in more detail. Semantic differential scale, a 5-likert scale and open questions are employed in the questionnaires. In both questionnaires one open question was asked to give the three top likes and bottom dislikes about each robot and when and why they pressed the button on the Q-Sensor. The third questionnaire ended with three open questions about the intention of buying a domestic robot and whether the participants had any general remarks. After the fifth participant the questionnaire was optimized by adding these last open questions to the third questionnaire.

Expressive behavior during interaction. To put the EDA results and the results gained from the questionnaires in perspective, the exhibited behavior of the participants and the robots was observed. The two interaction phases were taped on video for later analysis. A Panasonic digital camera (NV-GS400EG) was used.

Design

The design of this study was a 2x2 mixed design with as the within subjects factor the two robovacs, Navibot and Roomba. Each participant observed both robots, but the order (between subjects variable) was counterbalanced over participants. The participants were divided evenly over the two orders (Navibot-Roomba or Roomba-Navibot). The division into the two groups occurred rotationally and the approach of the participants occurred according to their schedule. The dependent variables were the evaluation and perception of the robovacs (measured with questionnaires), emotion (measured with EDA) and the exhibited behavior during interaction (video).

Procedure

At the beginning each participant received an explanation of the purpose of the study, the procedures and signed an informed consent. The observation took place in the living rooms of the participants and was intended to resemble a product introduction to give the participants the impression that the robot belonged to them. Before the experiment could start, the Q-Sensor was placed on the wrist of the participants for an adjustment period of ten minutes. It was not possible to get standardized measures of additional five minutes of rest as it was undesirable to delay the experiment any further. People had a filled schedule and as the study was carried out with other household members the intrusion of the family life was kept to a minimum. After the adjustment period the participants started with filling in the first questionnaire. Then, the participants received the first robot to observe. Afterwards, the second questionnaire was given, followed by the observation of the second robot, which had been kept out of sight until then. After the observation the third questionnaire was administered. Finally, the Q-Sensor was removed.

The following procedure was handled during the interaction with both robots. First, the participants were instructed to unpack the robot, to plug in the charging station and to place the robovac onto the station. In order to make the experiment less complex and doable for all levels of experience and age, the virtual barriers and the remote control were removed from the packaging. The participants were free to read the guidelines. However, after the fifth respondent adjustments were made as they programmed the robot and studied the guidelines intensively for more than five minutes. Hence, for simplicity and due to the fact that the observation had already lasted 60 minutes, the main instructions were explained. The instructions included an explanation of the start/stop button and how they could make it move back to the docking station at the end of the observation. They were instructed to observe the robot and engage with it as if it was their own for the next ten minutes. Toward the end they were told to direct the robot to the charging station. The intended ten minute duration of interaction differed between participants as the robots requested dissimilar time to get back to the docking station.

Data Acquisition and Analysis

The EDA data were gained by an 8Hz sampling rate. The baseline measurement is computed from the 160 seconds one minute before the exposure to the first robot, the 160 seconds one minute before the second robot and the 160 seconds one minute after the second robot, resulting in a mean of eight minutes. These intervals fall within filling in the questionnaires. The mean EDA measures were the last eight minutes of each robot interaction, until the robot connected with its docking station. The total mean of arousal, which was used in order to compare the baseline and the EDA activity during HRI (H1), comprises the mean of both robovac interactions. The EDA reaction was computed by deducting the baseline from the mean measures to indicate the pure reaction of the participants. Transcripts of the video observations were made, including the count of collisions (counted in seconds), remarks and other incidents during the interaction in order to place the results of the questionnaire and the EDA measures in perspective.

A Shapiro-Wilk test tested the distribution of the EDA data and the questionnaire. The results of the tests can be found in appendix II. The EDA data were normally distributed. The means of the questionnaire scales were also normally distributed but the items, with some exceptions, were not normally distributed. In order to use consistent measures non-parametric methods were used. A Wilcoxon test was used to compare related means and a significance criterion of $p < .05$ was employed for all analyses. The reliability of the questionnaire scales was tested by a Cronbach's Alpha measurement. As the normality assumption was not violated, linear regression analyses were employed to test whether the independent variable affects the dependent variables. Given that there is no previous research that includes two robovacs, the variables order and gender were added to the model as control variables, next to the main independent variable robot. A stepwise method was used to specify the best fitting model and the dependencies between the variables. One female participant (case 9) was excluded from the analysis as the Q-Sensors' wristband did not fit around her arm which resulted in failed measurements as the electrodes had no skin contact.

Results

Physiological Analysis

H1: More arousal during robot interaction than during non-activity. The Wilcoxon test was employed to compare the baseline and the total mean of arousal (mean of both robovacs). The comparison showed that participants had a significantly higher EDA during interaction than during non-activity (p = .04, z = -2.1, Baseline M = .62, SEM = .14, Interaction M = .78, SEM = .19). The difference is displayed in figure 3. The finding implies that, on average, the interaction with a robovac was more arousing than during the times when no robovac was present.

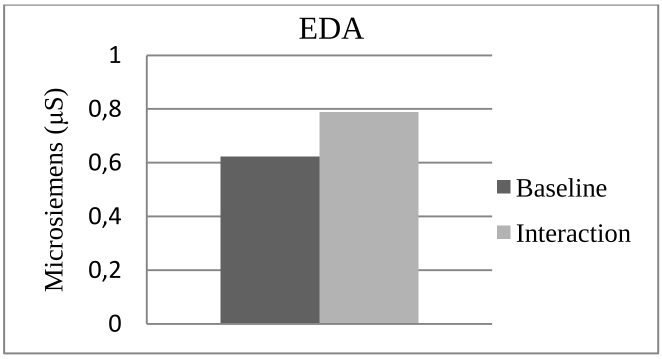

Figure 3. Mean measures of the EDA during interaction and during non-activity (baseline).

H2: More arousal during Roomba interaction than during Navibot interaction. In order to test this hypothesis a Wilcoxon test was applied. The comparison of the mean reactions of the EDA measurements during the interactions did not indicate that Roomba significantly elicits higher arousal than Navibot (*p*= .49, *z*= -.68, Navibot *M*=.19, *SEM*= .09, Roomba *M*= .12, *SEM*= .10). However, it can be stated that, on average, Navibot elicited a higher EDA reaction. Figure 4 first of all indicates that the EDA reaction varied individually and across the robots. In particular, not all participants had higher arousal during interaction in comparison with the baseline. When comparing participant 1 with participant 10 it becomes obvious that their reactions differ remarkably. In line with the result of the first hypothesis, participant one displayed more arousal during both robovac interactions. In contrast to that, participant number 10 had an EDA reaction below the baseline, which indicates that that participant found the robot interaction less arousing than filling in the questionnaire. Respondents 4, 13 and 14, for instance, had a stronger reaction toward one robovac and a reaction below the baseline toward the other one, which shows that they did not find that interaction not arousing at all.

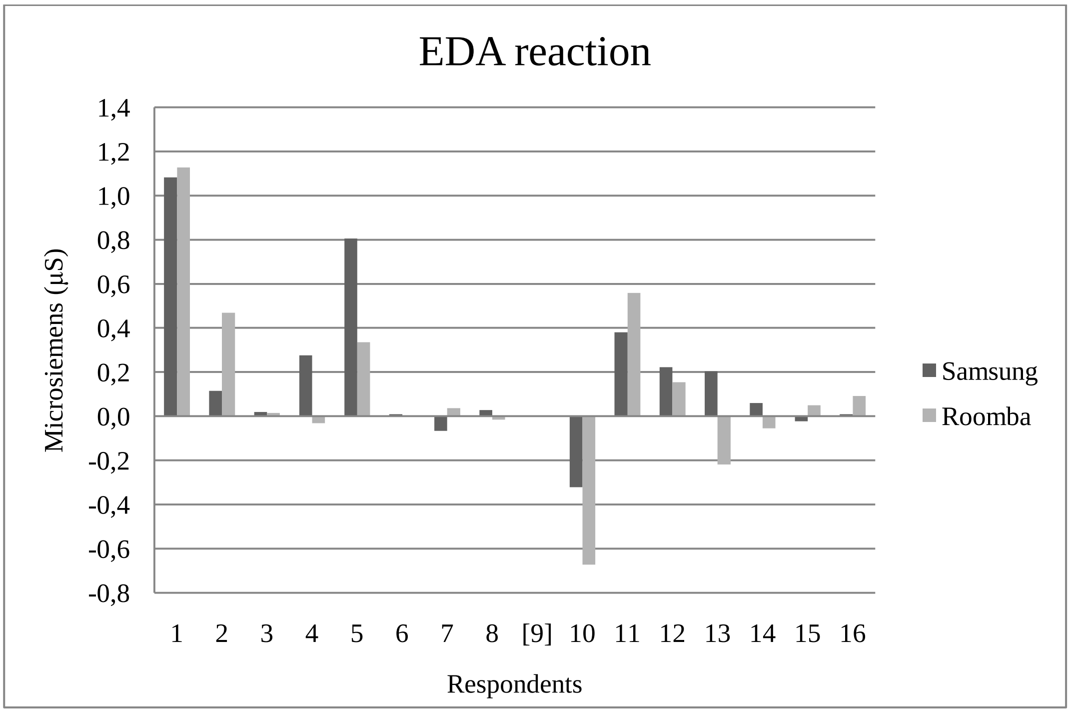

Figure 4. EDA reaction of each respondent per robot, set off against the baseline (value= 0).

Employing linear regression to further investigate the EDA reaction. Merely comparing the reaction toward the two robovacs disregards other potentially relevant factors. The study also contained other independent variables that could predict the EDA reaction toward the robovacs. As these were not considered when the hypotheses were formulated, stepwise linear regression was employed with the variable robot and the control variables order and gender (see table 2 for the results). The variables robot and order were not significant and were excluded from the model. The best fitting model for the mean measurement of the EDA includes gender as the independent variable. The gender variable contributes 17% to the variation in EDA which leaves the possibility that other factors explain the variation in EDA. The comparison of the gender indicated that, on average, men (M = .32, SEM = .11) had a higher reaction than women (M = .01, SEM = .06). Although robot is not significantly predicting the EDA, figure 5 highlights the reaction differences between men and women across the two robots. It can be seen that Navibot elicited higher arousal for both genders.

Table 2

Mean EDA reaction and the independent factors

Model	R^2	t-value	Sig.	df
Gender	.17	2.48	.02	29
Robot		-.49	.62	
Order		-.74	.47	

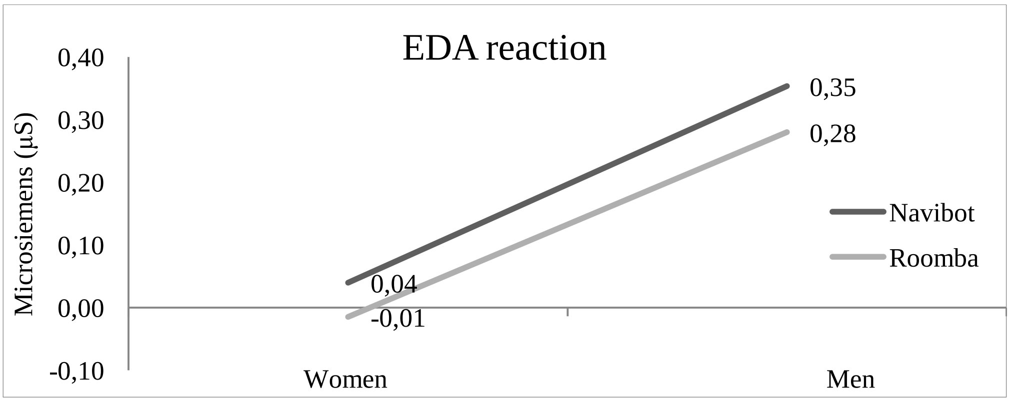

Figure 5. Mean EDA reactions of the genders across the two robots.

Investigation of the gender difference. As the gender difference was an unanticipated but interesting result, this effect was investigated in more detail. Table 3 shows the distribution of the variables technical affection, education and age, which were obtained by one question respectively. The variables were correlated with gender. The results showed that none of the variables were significantly related to gender: age (r = -.016, N = 15, p = .56), education (r = .39, N = 15, p = .16), technical affection (r = -.397, N= 15, p = .14). Thus, none of the data that was gathered and tested in this study can explain the gender effect. Though, there is a tendency that men rate themselves higher on technical affection than women and that they are higher educated than the women of this study.

Table 3

Distribution of the demographical variables technical affection, education and age.

Technical affection	Male	Female	Education	Male	Female
To a great extent	3	2	Training	1	5
Somewhat	4	3	College	3	1
Neutral	0	2	University	3	2
Very little	0	1			
Not at all	0	0	Mean age in years	45	52

H3: Relation between collisions and arousal. Comparing the amount of collisions of the two robovacs indicated a significant difference (p = .001, z = -3.41, Navibot M = 25.07, SEM = 6.62, Roomba M = 91.2, SEM = 9.15). As figure 6 shows, Roomba had more collisions than Navibot. However, a relationship between the total amount of collisions, during the last 8 minutes of interaction, and the mean reaction of arousal could not be established (r = .06, N = 15, p = .84).

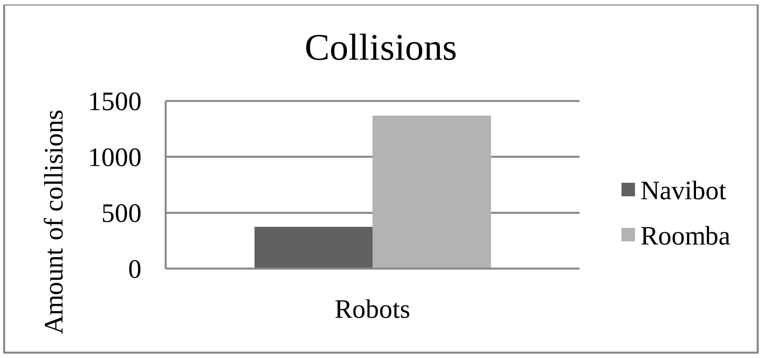

Figure 6. Total amount of collisions of Navibot and Roomba contrasted with each other.

Quantitative and Qualitative Analysis of HRI and the Evaluation of the Robovacs

Reliability of the questionnaire. The perception scale consisted of 12 items and has a Cronbach's Alpha (α) of .72. Within literature a value of Cronbach's Alpha that is lower than 0.7 indicates a less reliable scale and values between 0.7 and 0.8 indicate a highly reliable scale (Field, 2009, p.675-681). The emotion scale consisted of 10 items (α = .86), the functionality scale had 24 items (α = .69), the expectation scale consisted of 10 items (α = .54) and the value scale had 11 items (α = .79). In order to generally view the valence of the evaluation of the two robots the perception, emotion and functionality scales were analyzed together. This will be the evaluation questionnaire referred to in the next section. A more specific analysis of the three scales will follow after discussing the evaluation questionnaire.

General and detailed evaluation of the robovacs after observation. In order to assess the general evaluation of the robovacs, linear regression was employed with the evaluation questionnaire. An overview of the results can be found in table 4. The tested stepwise model included the robot, order and gender as independent variables. The Order and gender had no significant influence on the evaluation of the robots. As expected, the robot variable is significantly predicting the evaluation and contributes 17% to the variation of the model. So it appears that participants had a different attitude toward the robots. As the robot variable is only contributing 17% to the explanation of the evaluation, other factors might be of importance to the model.

Table 4

Linear regression analysis of the evaluation questionnaire

Model	R^2	*t*-value	Sig.	df
Robot	.17	-2.46	.02	31
Order		.35	.73	
Gender		-.27	.79	

To further investigate the differences between the robots, mean scores of the general evaluation of the two robovacs were assessed. High values indicate a positive evaluation. As figure 7 displays, Navibot, (*M* = 3.29, *SEM* = .12) was, on average, more positively evaluated than Roomba (*M* = 2.89, *SEM* = .12).

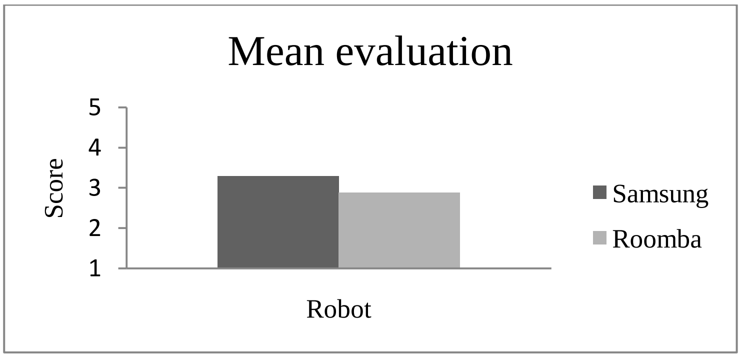

Figure 7. Mean evaluation of the two robots.

In order to specify the valence differences between the robovacs the Wilcoxon test was administered. The scale comparison indicated significant differences in the perception (p = 0.001, z = -3.33), the emotion of the participants (p = 0.035, z = -2.10) and the perceived functionality (p = 0.003, z = -2.95). Table 5 displays the significant differences between the robovacs for each scale. As it can be seen Navibot was perceived as more controlled, more intelligent, funnier, handier and quieter than Roomba. In relation to the emotions that the participants felt after the interaction with Navibot, participants were significantly happier, more pleased and less irritated. Concerning the functionality, Navibot was rated as having the nicer appearance, which is related to the attribute of appearance. Navibot was furthermore rated as technologically more advanced and people minded less when it collided with obstacles which can be related to the attribute of autonomy. Participants also minded less when Navibot got stuck and rated its velocity back to the docking station as fast enough. Finally, Navibot scored higher on fulfilling the expectations and greater satisfaction. The comparison showed that Roomba did not score significantly higher than Navibot on any item, which lays emphasis on the fact that Navibot was generally judged more positively. The analysis of the other items, that showed no significant difference, is included in appendix III.

Table 5

Details of evaluation differences from the three subscales

Perception of the robot

Item		Controlled	Intelligent	Funny	Handy	Quiet
	z-value	-3.10	-2.68	-2.75	-3.03	-2.15
	p-value.	0.002	0.007	0.006	0.002	0.03
Navibot	*Mean*	3.44	3.19	3.19	3.38	3.25
	SEM	.29	.29	.28	.28	.23
Roomba	*Mean*	2.06	2.25	2.37	2.31	2.50
	SEM	.25	.25	.22	.27	.24

Emotion of the participants after interaction

Item		Happy	Pleased	Not irritated
	z-value	-2.11	-3.14	-2.49
	p-value.	.04	.002	.01
Navibot	*Mean*	3.62	3.63	4
	SEM	.16	.24	.27
Roomba	*Mean*	3.12	2.50	3.06
	SEM	.16	.24	.29

Perceived functionality of the robovacs

Item	Aesthetic Appearance	Technological advancement	Not minding collisions	Fast enough (back to station)	Fulfilling expectations	Satisfied
z-value	-2.23	-2.33	-2.89	-2.02	-2.12	-2.11
p-value.	.03	.02	.004	.04	.03	.04
Navibot						
Mean	3.85	3.54	3.36	3.56	3.00	2.81
SEM	.22	.24	.27	.35	.24	.32
Roomba						
Mean	3.08	2.69	2.56	2.38	2.19	2.37
SEM	.27	.31	.29	.38	.28	.29

Expectancy of the robovacs and values during cleaning process. The expectancy and value scale were both administered before and after the operation of the first robovac, in order to indicate whether the interaction with the robovac has an influence. Although the mean expectancy of the robovacs did not differ significantly before and after the observation (p = .07, z = -1.8). It can be stated that before the first robot interaction participants expected significantly less collisions (M = 3.25, SEM = .28) than after the first observation (M= 4.19, SEM= .25). In other words, initially participants had the positive expectancy of few collisions, which was immediately disappointed after the first observation. The two measurements of what participants value during cleaning did not vary significantly (p = .218, z = -1.23), indicating that participants consistently value the aspects they find important during the cleaning process and that in this study the observation had no effect. Altogether they find the following aspects in descending order very and a bit important: reliance on the robovac (M = 4.56, SEM = .13), autonomy of the robovac (M = 4.5, SEM = .12), thoroughness with cleaning (M = 4.41, SEM = .15), cleaning itself (M = 4.28, SEM= .12), silence during cleaning (M = 3.88, SEM = .17), not getting stuck under furniture or anywhere else (M = 3.81, SEM = .20). The other aspects were of neutral value: finishing quickly (M = 3.37, SEM = .89), velocity (M = 3.22, SEM = .21), colliding with objects (M = 2.97, SEM = .24), communicating with the robovac (M = 2.94, SEM = .29) and if the robovac would stop vacuum (M = 2.91, SEM = .28). Viewing these aspects against the background of the four attributes, it can be said that autonomy plays a more important role than communication.

Open questions and video analysis with user comments. The participants were asked to mention their top three likes and bottom three dislikes about each robovac after observation. From the possible 192 reactions, a total of 93 likes and dislikes were listed. The Pearson's chi-square test was used to examine the association between the likes and dislikes between the two robovacs. The analysis of the likes and dislikes (see table 6) revealed that there is a significant difference between the evaluation of the robovacs, X^2 (1, N = 93) = 3.89, p = .049. Participants noted more dislikes about Roomba and more likes about Navibot. One striking difference that emerged from this comparison is that Navibot was liked for its systematical working patterns and its intelligence, whereas Roomba was described as chaotic and having uncontrolled patterns. Furthermore, Navibot's appearance was also favored over Roomba's, which is in line with the results from the comparison of the functionality questionnaire scale. This notion also supports the idea that appearance is an attribute that users think about in the context of evaluation. One aspect where Roomba leads in contrast to Navibot is its ease of use. Furthermore, when viewing the listed aspects, it can be noticed that participants did not agree on the velocity of the robovacs. Both robots received likes and dislikes on this aspect. However, when viewing the amount of comments on speed it can be stated that Navibot was evaluated more unfavorably than Roomba. This finding is not in line with the outcome of the functionality scale. But with this sort of question it has to be kept in mind that participants optionally reported what stroke them, which might emphasize the importance of the answers.

By the means of video analysis several comments during observation were captured. The cleaning inefficiency of Roomba has been commented with "there is still some dirt there, he needs to go back there" and "he doesn't need to clean the same corner again". Roomba was further described to be "a bit aimless" when it constantly collided with furniture in a forceful manner. However, Roomba also received the comment to be "a funny thing". Participants reported on Navibot that "some areas are being neglected" and that "he has been there but needs to go back" as dirt has not been picked up, indicating its cleaning inefficiency. On the other hand its appearance was commented with "looks slightly more modern". Two respondents commented that "he is not bumping as much as the other one (Roomba)", which relates to Navibot's systematic way of working. One participant purposefully put dirt in the way and was surprised that "[Oh] he is truly sucking things up". Someone else approved that "It is a small agile thing". Before the start of the experiment seven participants reported to possibly buy a domestic service robot. After the experiment all the participants that had earlier considered a purchase, changed their mind to not wanting to buy a service robot at all.

Table 6

Likes and dislikes listed by the participants for the two robovacs

Attitude	Navibot	Roomba
Liked	Systematically working, intelligent (7)* Aesthetic appearance (4) Back to the docking station (3) Ease of use (3) Actually cleaning (2) Suction power (1) Tunes (1) Sensitive sensors (1) New device (1) Speed (1) Less collisions (1) **25**	Ease of use (less buttons) (5) Vacuumed (2) Speed (2) Moves clumsy over obstacles (1) Seems to learn (1) Tunes (1) Autonomous (1) Back to the docking station (1) New device (1) Funny appearance (1) **16**
Disliked	Inefficiently cleaning (oversees dirt, does not reach all edges & corners) (7) Slow (back to docking station & moving around)(5) Sounds & Volume (4) Stuck on standard lamp, carpet edges (2) Collides with chair legs (2) On-button illogically placed (1) **21**	Inefficiently cleaning- (same spots, only one route, does not reach all edges & corners) (8) Uncontrolled patterns (chaotic) (8) Volume (4) Collisions (3) Slow speed (Maneuvering out of an corner, back to docking station) (3) No learning effect (1) Radius too small (1) Unaesthetic appearance (1) Eats up wires (1) Giving directions is impossible (1) **31**

Note. *= Amount of people that mentioned this point. The bold numbers indicate the total amount of comments in each category.

At the end of the third questionnaire participants had the possibility to write down general reactions and further remarks about the robovacs and the interaction. The answers can be divided into three categories and can be found in table 7. The evaluation of the questionnaire scales indicated that none of the robovacs received a very bad evaluation. However, in this optional remark section remarkably more negative evaluation points were mentioned in contrast to the few positive things mentioned here. This gives reason to believe that the participants had not expected these points and were consequently negatively surprised. More participants had the same opinion about factors that would influence their purchase decision. Four participants agree that a satisfying cleaning result is important, which is in line with what they value the most during cleaning. Furthermore they wish for controlled and goal-oriented movements and for a correct price-performance ratio. In conversation with the researcher it became obvious that the added value of robovacs in comparison with conventional vacuum cleaners is very important to the participants.

Table 7

Remarks about robovacs in general at the end of the observations

Influencing purchase decision	Ability to clean efficiently (4)* Ability to clean controlled and goal-oriented (3) Price performance ratio (3) Autonomy of the robot (1) Time saving in contrast to conventional cleaning devices (1) Power consumption in contrast to conventional cleaning devices (1) Ease of use (1) Ability to clean silently (1)	**15**
Positive evaluation of the robovacs	Good manufacturing (2) Pleasant appearance (1) Silent (1)	**4**
Negative evaluation of the robovacs	Useful for people that are unable to use hand operated devices and are immobile (2) Toy, not useful (housewife) (1) Corners still need to be cleaned by hand (1) Noisy (1) Own vacuum cleaner faster and more efficient (1) Handy to use on larger area, with little furniture (1) Aimless (1) Inefficient (1) Takes too long (1) Not reliable (1)	**11**

Note. *= Amount of people that mentioned this point. The bold numbers indicate the total amount of comments in each category.

Usability of the robovacs. Several aspects concerning the usability of the robovacs were standing out during the observation with all participants. Both robots had problems moving around obstacles, especially chair legs. The Navibot was a lot better in detecting obstacles, except for obstacles that were very slender. This fact can be proved by Navibot's lower amount of collisions. Furthermore, Navibot lacks immediate feedback after the start/stop button was pressed. It takes three seconds before it starts moving. That seemed too long for the participants as they pressed the start/stop button again, which resulted in no action at all. The third try mostly resulted in Navibot's first movement. Only two participants immediately found the on-button of Navibot on the first try and without help. From the eight participants receiving Navibot first, five also searched Roomba for the on-button on the bottom of the robot. Although Roomba claims to have a dirt-detection, the blue light indicating the dirt, only appeared during one interaction.

Interaction between robovacs and the participants. Eight participants engaged with the robovac by moving furniture to create a wider space for the robot to move around. Twelve participants helped Roomba to either come in contact with the docking station or to free it. Four participants took action to help Navibot. These reactions indicate that people are willing to interact with the robovacs and to reduce their physical distance to them. In relation to the attribute of communication it can be stated that during the observation most participants were noticeably positively amused by the sounds the robovacs were making after one had pushed a button or when it moved over its own docking station. When Roomba reached a certain spot one participant seemed to stimulate it, saying "Yes, that's where he has to be".

Usability and Comfort of the Q-Sensor

After approximately one hour of wearing, the Q-Sensor left pressure marks of the two electrodes on the wrist of the participants. The wristband was not long enough to adjust the sensor on thicker arms. Some participants showed interest in the workings of the sensor but generally paid little attention to it. This is enough evidence to assume that the Q-Sensor was indeed an unobtrusive way to measure EDA. The fact that the adjustment to the body temperature takes ten to fifteen minutes makes the Q-Sensor less suitable for experimenting on many participants during a short period of time. Although all participants were explicitly told that they could use the button to indicate specific and remarkable events, only nine participants made use of it. Figure 8 illustrates Q-Sensor data from participant number one (top) in comparison with the data from the eighth participant (bottom). The graphs show the EDA in microsiemens (μS) on the right axis and display a period of 42 minutes. The scale ranges to 3,4μS for participant one and to 0,4μS for participant eight, which indicates the differences in individual responses. Participant one pressed the button on the Q-Sensor, indicated by the water drop, which, in this case, indicates arousal increases. The graph of participant eight illustrates a slow increase in EDA. With reference to figure 5, participant one had a very strong reaction toward both robovacs, whereas the reaction of the eighth participant toward Roomba was below the baseline and the reaction toward Navibot just above. In line with this finding, the lower graph shows a slightly higher reaction during the Navibot interaction than during Roomba interaction. Further analysis of the individuals and their button usage was omitted as the button response was low and its relation to the actual EDA increase is variable and can be biased by other factors or thoughts of the participants. See appendix IV for additional sensor data that highlight the individual differences.

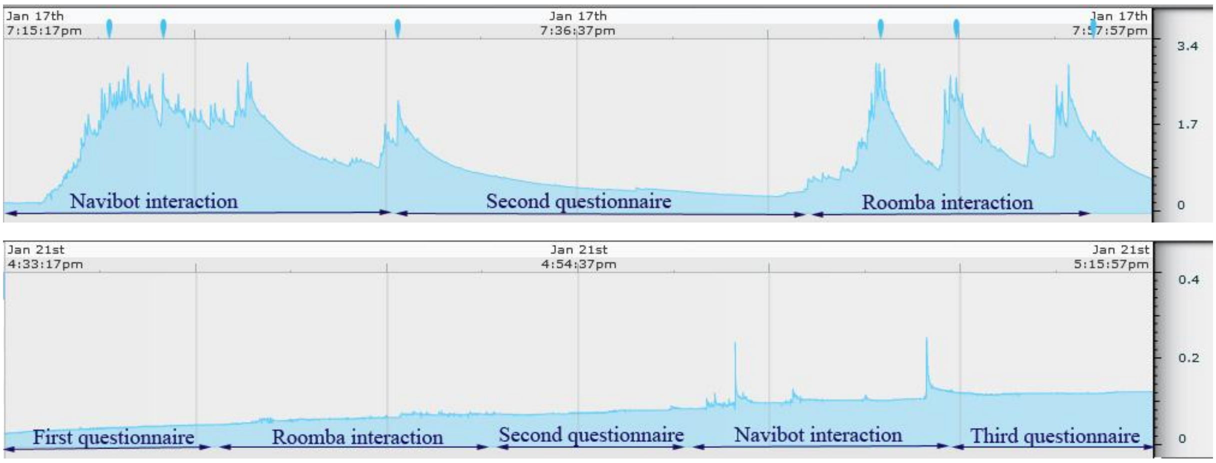

Figure 8. Output of the Q-sensor data from participant number one (top) and number eight (bottom).

Discussion

Within the context of HRI and with a human-centered viewpoint, the interaction between two domestic robots and humans were highlighted by a study that took place in the homes of the participants. The purpose of this study was to detect users' emotional response toward the robovacs by employing physiological, quantitative and qualitative measurements.

Physiological Measurements

With reference to the physiological response it was expected that the arousal response would be higher during interaction with a robovac than during moments of rest. Due to employing distinct robovacs in this study it was suggested that there would be a difference in level of arousal toward them. As both robots are likely to collide with objects it was expected that there would be a relationship between the amount of collisions and the level of arousal. Previously to the study, positive aspects for both robots could be found. Accordingly, the positive or negative qualitative evaluation of the robots was an open question.

The results of the physiological measurement showed that, on average, users had higher arousal during robot interaction than during moments of rest. This finding is in line with earlier research that indicated that interaction with objects elicit emotional responses

(Desmet et al., 2001; Lee et al., 2005). As none of the participants had previous experience with domestic robots, it could be argued that the higher arousal is due to the novel and unfamiliar character of the robovacs (Berlyne et al., 1963; Dawson et al., 1990). A different explanation for the difference in arousal might be that fast robot motions elicit higher arousal (Kulić & Croft, 2007b). Although the two robovacs of this study do differ in velocity, there was no significant difference of the levels of arousal between the robots. Therefore it can be assumed that the level of velocity is not the determining factor but possibly the fact that they are moving. Further research should focus on which factors are responsible for the increase of arousal.

The second hypothesis concentrated on the difference in EDA reaction between the two robovacs, Roomba and Navibot. Results did not indicate a difference in EDA between the two robots but showed that men had a significantly higher physiological reaction than women. Surprisingly, an effect of the two robovacs on the EDA could not be established. As the quantitative evaluation revealed a significant difference in perception of the technological advancement ($p = .02$, $z = -2.33$) and other aspects, the similarity of the robovacs cannot serve as a possible explanation. A different explanation might be that the intensity of reaction might be attenuated by the fact that both robots are evenly new to the participants. The most convincing explanation might be that the robovacs evoke the same level of arousal but carry different valences. As the questionnaire indicated, Navibot was evaluated more positively than Roomba, which suggests the possibility that Navibot evoked a positive EDA reaction and Roomba a negative one, but to the same extent. Future research could study valence physiologically by corrugators muscle EMG as proposed by Kulić and Croft (2007a). In the course of the experiment it appeared logical to not only view the mean reaction but also different moments in time. Therefore the first thirty seconds of interaction were investigated, as being confronted with a stimulus can elicit an automatic and unconscious emotional response (Öhman & Soares, 1994). Additionally, three time intervals of the interaction were explored, as the reaction toward the robots might have changed in the course of the observation. However, these analyses also revealed a gender effect but not an effect of the robots (see appendix V).

One possible explanation that was analyzed to explain the gender effect was that the male participants of this study rated themselves higher on technological affection than women. If thinking in typical stereotypes, men might be more intrigued by a technological device. It could be argued that their arousal has a negative valence, because technologically interested people might soon recognize flaws and be frustrated more easily. However, as the general evaluation of the robots was positive, it can be assumed that their emotional reaction must have had a positive valence. The correlation analysis, however, could neither reveal a significant relation between gender and technical affection, nor a relation with education and age, which were the other possible factors tested in order to explain the gender effect. As this experimental study was conducted with relatively few participants it is suggested that a study with a larger sample should focus on the factor of technical affection in more detail. Additional factors that could explain the gender difference but could not be examined in this study are for example the division of the cleaning duty and whether men view robovacs as a technological toy and women as a cleaning device. From a biological point of view it could be argued that men innately have a higher EDA than women. However, research about the physiological responds toward various film scenes indicated a similar EDA change in men and women (Kring & Gordong, 1998).

The assumption that the amount of collisions is related to the level of arousal could not be confirmed. Apparently, the aspects of safety and damaging furniture do not play a large role in eliciting a physiological reaction, which is a surprising result as the participants seemed very affected and sometimes even angry when the robovac collided with vases, furniture or lamp stands. A later analysis of the relation between the robots and their amount of collisions did not indicate a significant relationship either (Navibot, r= -.007, p= .98, N= 15; Roomba, r= .03, p= .92, N= 15). Moreover, the results showed that Samsung's Navibot had significantly less collisions than Roomba, which was much appreciated by the participants.

Quantitative and Qualitative Measures

The questionnaires indicated that Navibot was generally viewed more positively than Roomba. Despite the significant difference, both robots were evaluated relatively neutral. This effect does not support the finding that people rather see the advantages than the disadvantages when evaluating new technology (Scopelliti, Guiliani & Fornara, 2005). In fact, the optional remarks about the usability and evaluation of robovacs in general turned out to be more negative than the individual robot evaluation. The negative feedback is consistent with the fact that in the end, none of the participants was interested in buying a robovac.

With respect to the evaluation of the robovacs, it can be stated that Navibot's perceived higher intelligence can be ascribed to its systematic movement patterns, which several people liked, as they reported. Furthermore, participants were more satisfied after the interaction with Navibot, which also might go hand in hand with its systematic cleaning patterns. This is an important finding, as satisfaction is influencing the purchase intention of users (LaBarbera & Mazursky, 1983). A frequently mentioned advantage of Roomba is its ease of use. Though the scales revealed that Navibot's speed is more satisfying, the open questions showed that both robovacs are perceived as slow but also indicated the tendency that Roomba moves faster. This could explain the fact that Navibot's collisions were more tolerated and that it was perceived less irritating than Roomba. Being perceived as slow might evoke the idea that it does not clean efficiently. The velocity of the cleaning process and the robovacs was not rated as important as the cleaning efficiency by the participants. However, this stands in contrast to the fact that both robovacs were disliked for their slowness. For that reason, it can be assumed that people do prefer a fast robovac that cleans efficiently. According to the purpose of a vacuum cleaner, the participants rated the cleaning efficiency as very important and compared the robovacs to conventional cleaning products and their advantages. They concluded that both robots lack thoroughness and the ability to get to all places. In contrast to the finding of Sung et al. (2007) none of this study's participants would recommend the robovacs to friends or acquaintances. These contradictory findings might be due to the fact that they conducted a longitudinal study where users had built up an intimate relationship with Roomba.

Though this study primarily focused on the physiological reaction, its experimental component is likewise relevant. The observation revealed that people actively engaged by moving furniture or trying to change the robovacs direction, denoted as roombarization. Furthermore, they experimented with it by purposefully putting dirt in front of it or trying to counter its movement with their feet. These findings are in line with previous field research of Roomba (Forlizzi & DiSalvo, 2006). During the interaction participants informed the researcher immediately that "he (Navibot) is a great thing" or "more controlled than the other one (Roomba), right?". This confirms the assumption that robovacs are a topic of conversations between humans which enhances their social interaction (Sung et al., 2007).

The introduction alluded to four attributes that were presumably relevant to this study. Firstly, the autonomy of the robovac was of major importance for the participants. However, no difference in perceived autonomy could be established. As the participants supervised the robot during this study, it cannot be confirmed whether the level of autonomy matched the task requirements of the robot and therefore led to a productive interaction (Goodrich & Schultz, 2007). However, in this scenario participants were willing to assist the robovacs, if necessary, though they generally would prefer a robot that works independently and they can rely on. Secondly, the aspect of autonomy goes hand in hand with the aspect of physical space. As participants were asked to observe the robots, a very close interaction took place. Participants were not afraid to make contact with the robot and engage with it. Third, the communication capabilities of the robovacs were limited to physical interaction and producing sounds. The touch display of Navibot was the only source of communication problems, as it did not provide immediate feedback. Apart from that, the tunes both robots made to indicate their status were positively perceived by the participants and presumably facilitated the interaction. Fourth, participants repeatedly attested Navibot an aesthetic appearance, which is one of the factors that contribute to its positive evaluation. Consequently, appearance of robots does play an important role and might therefore be a determining factor in the purchase decision. Future research could concentrate on which aspects of appearance are crucial.

Improvements

This study was the first of its kind in the field of domestic robotics. Accordingly, there are several aspects that could be improved in the future and should be considered when viewing the results. Due to the extensiveness of this study, including two nationalities and conducting the experiment in the homes of volunteering participants, relatively few participants were involved. A larger sample could make the results more representative and might disclose stronger reactions.

Though intended, participants presumably did not have the feeling that they own the robot. This might have had an influence on the EDA reaction and the evaluation of the robots. The quantitative measures revealed a neutral and objective evaluation of the robovacs in contrast to the more negative and subjective evaluation in the open questions, where participants considered the personal benefit of a robovac. One participant mentioned that if she had bought one of the vacuuming robots, she would have been quite irritated, as the robots did not work as she had expected and felt that her money would be lost. It is supposed that the emotional commitment to an object is influenced by the investment one has made (van Lange et al, 1997). Therefore, it can be argued that the feeling of ownership, the amount of money that was spent and the time spent on interaction might influence the way people reacted toward the robots.

Though the primary focus of this study was placed on physiology, it is recommended to use pre-tested and validated questionnaires in the future instead of the personally developed questionnaires used in this study. In order to identify the emotional response toward robovacs the Product Emotion Measurement Instrument (PrEmo) (Desmet, 2005) or Emocards

(Desmet, Overbeeke & Tax, 2001) could be used. The PAD scale, used in the study of Algarwal and Meyer (2009), could facilitate the identification of the general emotional state of participants. Measuring the perception of robots could be enhanced by the questionnaire scales proposed by Bartneck, Kulić, Croft & Zoghbi (2009).

The baseline was generated while participants were filling in the questionnaires which gives reason to assume that, although the experiment was conducted in their familiar environment and with a familiar person, participants might have a distinct baseline outside an experimental situation. The EDA measurements indicated that some participants had a higher emotional reaction during the baseline than during robot interaction (see figure 4). Hence, those people became more aroused by filling in the questionnaire, than by the robovacs. It would be desirable that the baseline would be conducted during a pure phase of rest.

Implications

The gender effect found in this study suggests that the target group for robovacs should not only be housewives, but also the male family members. Women even appeared to be more critical with the robovacs by comparing them to their own skills and in relation to conventional vacuum cleaners. One female respondent mentioned that it is not a cleaning device but a toy, which might be the perfect trigger for men to participate in the cleaning process. The study of Forlizzi and DiSalvo (2006) also showed that males introduced the robovac to the homes, took lead in its first usage and showed excitement about this new technological device. A big advantage reported by a lot of participants was Roomba’s ease of use. Though the docking station came in two parts, people operating the robot seemed to manage Roomba’s buttons better than Navibot’s touch display. Moreover, as collisions were consciously viewed negatively but had no relation to the body response, the collisions might be one of the reasons why people do not intend to buy a robovac in the future. In addition to the design aspect mentioned earlier, improvements in the sensor technology need to be made. Furthermore, reasons for the cleaning inefficiency are that the brushes of Navibot do not reach the edges of furniture or corners or that Roomba has very uncontrolled cleaning pattern which seems to make it miss parts of the room.

Future Research

The results of this study reveal new aspects for further analysis. First of all, future research should investigate why the robovacs did not cause an effect on EDA during HRI. Future research could also further investigate the unexpected gender effect by, for example, studying the physiological response of men and women during interaction with a different technical product. Furthermore, future analysis needs to focus on the individual EDA responses and connect those responses to the incidents during the interaction. Additionally, research should take the personality of the individual into account as the EDA reaction differs tremendously between the individuals. Apart from including more participants and participants who have had previous experience with robovacs, it is suggested to conduct a longitudinal study that measures physiology. A long-term study in the home of the participants can lea d to several improvements. Even more real-life data can be obtained as the Q-Sensor is an unobtrusive device that can easily be used for long-term studies. Studying the interaction on several days increases the validity of the study. Furthermore, the robovacs could be operated in their true natural task scenario which implies working independently without constant supervision and which in turn allows the user to do different things. A longitudinal study could also investigate whether there is a novelty effect in EDA reaction and whether it wears off or whether it increases as the emotional reaction with the robovac is strengthened.

Conclusion and Guidelines

Concerning the questions that guided this study it can be concluded that, with the limited sample size in mind, the interaction with robovacs is physiologically more arousing than during no interaction. In particular, the physiological response revealed that interaction with the robovacs evoked, on average, higher reaction in men than in women. As this study could not draw definite conclusions about why the robovacs did not cause a difference in arousal future research is needed. Though both robots frequently collided with obstacles and participants mentioned they disliked the collisions, a relationship between arousal and collision could not be established. Although the evaluation of the robovacs revealed that the Navibot from Samsung received significantly more positive reactions on several attributes than iRobots' Roomba, the participants generally had a neutral attitude toward both. However, the optional annotations that were made about the usability and general evaluation of robovacs revealed a more negative attitude. Hence, the participants of this study were not very fond of the robovacs, which is also indicated by the fact that, except for one, none of the participants would actually want to purchase a robovac.

The attribute of autonomy was a desired feature of the robovacs, but its importance might become more relevant during a natural task scenario. Respondents participated in close interaction with the robovacs and showed no restraint to help the robovacs. Appearance was a noticeably important attribute during evaluation and comparison of both robovacs. The interaction with the robovacs initiated the participants to talk about them with the researcher. The tunes of the robovacs were much appreciated and the displays or buttons, as the other communication ability, only caused a slight disadvantage for Navibot concerning its ease of use.

In addition to obtaining the anticipated results, the study also accumulated findings that can be used as guidelines for further development of vacuum robots. As for every other consumer product its ease of use and its efficiency is crucial. Observations during this study indicated that even the basic commands and functions need to be as easy as possible. Robovacs should support a ready-to-use design instead of, for instance, placing an on-button on the bottom of the robovac or delivering the docking station in two parts. Furthermore, immediate feedback, in terms of sound signals, would facilitate interaction after entering a command. The fact that the participants highly appreciated the tunes encourages further development of human-robot communication, by for example designing an individually adjustable welcoming message. It has been indicated that the use of human-like features, like speaking, and other social competences can facilitate interaction (Duffy, 2003; Severinson-Eklundh et al., 2003). However, in the realm of vacuum robots it has to be sorted out carefully to what extent social capabilities are beneficial. In order to convince future consumers to purchase a vacuum robot, its strong points should be highlighted, beginning with the obvious that using a robovac enables the users to spend their time on something else. Next, the main purpose of a vacuum robot, namely its cleaning efficiency, needs further improvement. Extended brushes could minimize the striking fact that both robovacs were unable to clean edges and in the corners and an improvement in the sensor technology would minimize the amount of the disadvantageous collisions. More systematic cleaning patterns would convey controllability, intelligence, trust and reliability. These are favorable aspects a robovac should be associated with, as otherwise consumers will rather revert to their old conventional cleaning devices. Last but not least the price performance ratio weighs in the consumer's purchase decision.

Finally, this study contributes to the development of robovacs and further research on domestic service robots. It is the first of its kind to present insights into the physiological reaction in combination with investigating the attitudes of users during real-world HRI.

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Appendixes

Appendix I. Questionnaires 1, 2, 3

Questionnaire 1.

Fragebogen 1 *Testperson:*

Persönliche Angaben

Wie alt sind Sie?___________________

Was ist ihre Nationaltät? ___________________

Geschlecht? männlich ☐ weiblich ☐

Welche Ausbildung haben sie absolviert/absolvieren sie?______________________________
Ausbildung ☐ Fachhochschule ☐ Universität ☐
Was sind Sie von Beruf? _____________________________________

Inwiefern würden Sie sich als technisch begabt/interessiert bezeichnen?
1 (sehr) 2(ein bisschen) 3 (neutral) 4 (nicht so sehr) 5 (überhaupt nicht)

Haben Sie sich über staubsaugende Roboter informiert? Ja ☐ Nein ☐
Falls „Ja“, was haben sie herausgefunden?____

Haben Sie früher schon einmal einen Service Robot benutzt? (bv: stofzuigende robot, grasmaaier, …)
Ja ☐ Nein ☐
Falls "Ja", was für einen? ____

Würden sie einen Roboter für den Haushalt kaufen wollen? Ja ☐Nein ☐ Vielleicht ☐

Wenn Sie "vielleicht" angekreuzt haben, wovon ist der Kauf abhängig?__________________

____

Was erwarten Sie von dem Roboter?

stimme komplett zu (1), stimme zu (2), neutral (3), stimme nicht zu (4), stimme überhaupt nicht zu (5)

Erwarten Sie, dass der Robter viel Lärm macht?	1	2	3	4	5
Denken Sie, dass der Roboter schnell arbeitet?	1	2	3	4	5
Erwarten Sie, dass der Roboter Dreck übersieht?	1	2	3	4	5
Erwarten Sie, dass der Roboter mit Ihnen kommuniziert?	1	2	3	4	5
Denken Sie, dass der Roboter unkoordiniert ist?	1	2	3	4	5
Erwarten sie, dass er langsam ist?	1	2	3	4	5
Denken sie, dass der Roboter gegen Gegenstände stößt?	1	2	3	4	5

Finden Sie, dass der Roboter intelligent sein muss?	1	2	3	4	5
Erwarten Sie, dass Sie ihm helfen müssen?	1	2	3	4	5
Denken Sie, dass Sie sich auf die Putzqualitäten des Roboters verlassen können?	1	2	3	4	5

Was schätzen sie? (Im Allgemeinen und bei einem staubsaugendem Roboter)

Sehr (1)-ein bisschen (2) neutral (3) weniger (4) gar nicht (5)

Wie wichtig finden Sie saubermachen?	1	2	3	4	5
Wie wichtig finden Sie es, dass es beim Saubermachen still ist?	1	2	3	4	5
Ist es Ihnen wichtig, dass Sie sich auf die Putzqualitäten des Roboters verlassen können?	1	2	3	4	5
Wie wichtig ist Ihnen die Geschwindigkeit für einen staubsaugenden Roboter beim Saubermachen?	1	2	3	4	5
Finden Sie Kommunikation mit dem Roboter wichtig?	1	2	3	4	5
Wie wichtig ist es Ihnen um schnell fertig zu sein beim Saubermachen?	1	2	3	4	5
Wie wichtig finden Sie Selbstständigkeit bei einem Robot?	1	2	3	4	5
Wie wichtig ist ihnen Gründlichkeit beim Saubermachen?	1	2	3	4	5
Wie schlimm würden Sie es finden, wenn er gegen etwas anstoßen würde?	1	2	3	4	5
Fänden Sie es schlimm, wenn er stehen bleiben würde?	1	2	3	4	5
Wäre es ein Problem für SIe, wenn er unter den Möbeln oder irgendwo anders fest sitzen bleiben würde?	1	2	3	4	5

Questionnaire 2.

Fragebogen 2 *Roboter:* *Testperson:*

Wie haben Sie den Roboter wahrgenommen?

(kreuzen Sie an, was am ehesten zutrifft)

ruhig	•	•	•	•	•	aktiv
chaotisch	•	•	•	•	•	Kontrolliert
langsam	•	•	•	•	•	schnell
dumm	•	•	•	•	•	intelligent
süß	•	•	•	•	•	gemein
persönlich	•	•	•	•	•	unpersönlich
klein	•	•	•	•	•	groß
witzig	•	•	•	•	•	böse
unbeholfen	•	•	•	•	•	geschickt
flott	•	•	•	•	•	träge
zielgerichtet	•	•	•	•	•	unkoodiniert
laut	•	•	•	•	•	leise

Wie fühlten Sie sich während der Beobachtungsphase?

(kreuzen Sie an, was am ehesten zutrifft)

böse	•	•	•	•	•	glücklich
frustriert	•	•	•	•	•	befriedigt
zufrieden	•	•	•	•	•	unzufrieden
verärgert	•	•	•	•	•	nicht verärgert
ängstlich	•	•	•	•	•	mutig
hilflos	•	•	•	•	•	selbstständig
aktiv	•	•	•	•	•	passiv
wütend	•	•	•	•	•	fröhlich
positiv	•	•	•	•	•	negativ
genervt		•	•	•	•	nicht genervt

Allgemeine Fragen zur Beobachtung

trifft komplett zu (1), trifft zu (2), neutral(3), trifft nicht zu (4), trifft überhaupt nicht zu (5)

Wollten Sie dem Roboter gerne helfen?	1	2	3	4	5

Sollte er schneller arbeiten?	1	2	3	4	5
Würden Sie nochmal alles nachputzen?	1	2	3	4	5
Fanden Sie es schlimm, als er gegen Gegenstände gestoßen ist?	1	2	3	4	5
Finden Sie das Putzresultat zufriedenstellend?	1	2	3	4	5
Hatten Sie Angst während des Saubermachens?	1	2	3	4	5
Haben Sie sich auf die Putzfähigkeiten des Roboter verlassen?	1	2	3	4	5
Fanden Sie den Roboter zu laut?	1	2	3	4	5

Fragen über den Roboter

Sehr (1)-ein bisschen (2) neutral (3) weniger (4) gar nicht (5)

Ich fand ihn äußerlich schön	1	2	3	4	5
Er machte einen schlauen Eindruck auf mich	1	2	3	4	5
Ich habe wahrgenommen das er Sensoren hat	1	2	3	4	5
Die Sensoren könnten noch besser wahrnehmen	1	2	3	4	5
In wieweit fanden Sie ihn technisch fortgeschritten?	1	2	3	4	5

Wie haben sie die folgenden Ereignisse wahrgenommen?

stimmt absolut (1), stimmt (2), neutral (3), stimmt nicht (4), stimmt absolut nicht (5)

Die Kollisionen fand ich nervig	1	2	3	4	5
n.z. ☐					
Es machte mir etwas aus, dass er feststecken blieb	1	2	3	4	5
n.z. ☐					
Ich fand es toll, dass er sich so gedreht hat	1	2	3	4	5
n.z. ☐					
Es dauerte mir zu lange, als er zur Aufladestation zurückfuhr	1	2	3	4	5
n.z. ☐					
Als er einfach stehenblieb, habe ich mich geärgert	1	2	3	4	5
n.z. ☐					

Haben Sie die Gebrauchsanleitung gelesen? Ja ☐ Nein ☐

Falls “Ja”, worüber haben Sie Informationen bekommen können?

Sensoren ☐

Schnellheit ☐

An- und Ausmachen ☐

Erster Gebrauch ☐

Aufladen ☐

anders: ____

Ich möchte nun gerne wissen, welche Sachen Ihnen während der Beobachtung positiv oder negativ aufgefallen sind.
(denken Sie zB an Benutzerfreundlichkeit, Äußerlichkeiten, Bewegung, Lärm, etc.)

Fand ich nicht so toll	Fand ich am tollsten
1.	1.
2.	2.
3.	3.

Sie hatten die Möglichkeit einen Knopf auf dem Sensor zu drücken, sofern Ihnen etwas Besonderes auffällt. Für den Fall, dass Sie den Knopf benutzt haben:
In welchen Situationen haben Sie den Knopf gedrückt? Und **warum?**

Was denken Sie jetzt von Robotern, die staubsaugen?

trifft absolut zu1), trifft zu (2), neutral(3), trifft nicht zu (4), trifft überhaupt nicht zu (5)

Er macht alles, was ich erwartet hab	1	2	3	4	5
Ich bin zufrieden mit seiner Arbeit	1	2	3	4	5
Ich würde diesen Roboter nicht kaufen	1	2	3	4	5
Es macht Spaß ihn zu benutzen	1	2	3	4	5
Ich würde den Roboter Freunden empfehlen	1	2	3	4	5
Er ist nur auf größeren Flächen gut zu benutzen?	1	2	3	4	5

Da Sie nun wissen, was ein staubsaugender Roboter alles tun kann, möchte ich gerne wissen, was Sie vom zweiten Roboter erwarten.

Was erwarten Sie von dem Roboter?

stimme komplett zu (1), stimme zu (2), neutral (3), stimme nicht zu (4), stimme überhaupt nicht zu (5)

Erwarten Sie, dass der Robter viel Lärm macht?	1	2	3	4	5
Denken Sie, dass der Roboter schnell arbeitet?	1	2	3	4	5
Erwarten Sie, dass der Roboter Dreck übersieht?	1	2	3	4	5
Erwarten Sie, dass der Roboter mit Ihnen kommuniziert?	1	2	3	4	5
Denken Sie, dass der Roboter unkoordiniert ist?	1	2	3	4	5
Erwarten sie, dass er langsam ist?	1	2	3	4	5
Denken sie, dass der Roboter gegen Gegenstände stößt?	1	2	3	4	5
Finden Sie, dass der Roboter intelligent sein muss?	1	2	3	4	5
Erwarten Sie, dass Sie ihm helfen müssen?	1	2	3	4	5
Denken Sie, dass Sie sich auf die Putzqualitäten des Roboters verlassen können?	1	2	3	4	5

Was schätzen sie? (Im Allgemeinen und bei einem staubsaugendem Roboter

Sehr (1)-ein bisschen (2) neutral (3) weniger (4) gar nicht (5)

Wie wichtig finden Sie saubermachen?	1	2	3	4	5
Wie wichtig finden Sie es, dass es beim Saubermachen still ist?	1	2	3	4	5
Ist es Ihnen wichtig, dass Sie sich auf die Putzqualitäten des Roboters verlassen können?	1	2	3	4	5
Wie wichtig ist Ihnen die Geschwindigkeit für einen staubsaugenden Roboter beim Saubermachen?	1	2	3	4	5
Finden Sie Kommunikation mit dem Roboter wichtig?	1	2	3	4	5
Wie wichtig ist es Ihnen beim Saubermachen schnell fertig zu sein?	1	2	3	4	5
Wie wichtig finden Sie Selbstständigkeit bei einem Robot?	1	2	3	4	5
Wie wichtig ist ihnen Gründlichkeit beim Saubermachen?	1	2	3	4	5
Wie schlimm würden Sie es finden, wenn er gegen etwas anstoßen würde?	1	2	3	4	5
Fänden Sie es schlimm, wenn er stehen bleiben würde?	1	2	3	4	5
Wäre es ein Problem für sie, wenn er unter den Möbeln oder irgendwo anders fest sitzen bleiben würde?	1	2	3	4	5

Questionnaire 3.

Fragebogen 3 *Roboter:* *Testperson:*

Wie haben Sie den Roboter wahrgenommen?

(kreuzen Sie an, was am ehesten zutrifft)

ruhig	•	•	•	•	•	aktiv
chaotisch	•	•	•	•	•	Kontrolliert
langsam	•	•	•	•	•	schnell
dumm	•	•	•	•	•	intelligent
süß	•	•	•	•	•	gemein
persönlich	•	•	•	•	•	unpersönlich
klein	•	•	•	•	•	groß
witzig	•	•	•	•	•	böse
unbeholfen	•	•	•	•	•	geschickt
flott	•	•	•	•	•	träge
zielgerichtet	•	•	•	•	•	unkoodiniert
laut	•	•	•	•	•	leise

Wie haben Sie sich während der Beobachtungsphase gefühlt?

(kreuzen Sie an, was am ehesten zutrifft)

böse	•	•	•	•	•	glücklich
frustriert	•	•	•	•	•	befriedigt
zufrieden	•	•	•	•	•	unzufrieden
verärgert	•	•	•	•	•	nicht verärgert
ängstlich	•	•	•	•	•	mutig
hilflos	•	•	•	•	•	selbstständig
aktiv	•	•	•	•	•	passiv
wütend	•	•	•	•	•	fröhlich
positiv	•	•	•	•	•	negativ
genervt		•	•	•	•	nicht genervt

Allgemeine Fragen zur Beobachtung

trifft komplett zu (1), trifft zu (2), neutral(3), trifft nicht zu (4), trifft überhaupt nicht zu (5)

Wollten Sie dem Roboter gerne helfen?	1	2	3	4	5

Sollte er schneller arbeiten?	1	2	3	4	5
Würden Sie nochmal alles nachputzen?	1	2	3	4	5
Fanden Sie es schlimm, als er gegen Gegenstände gestoßen ist?	1	2	3	4	5
Finden Sie das Putzresultat zufriedenstellend?	1	2	3	4	5
Hatten Sie Angst während des Saubermachens?	1	2	3	4	5
Haben Sie sich auf die Putzfähigkeiten des Roboter verlassen?	1	2	3	4	5

Fragen über den Roboter

Sehr (1)-ein bisschen (2) neutral (3) weniger (4) gar nicht (5)

Ich fand ihn äußerlich schön	1	2	3	4	5
Er machte einen schlauen Eindruck auf mich	1	2	3	4	5
Ich habe wahrgenommen das er Sensoren hat	1	2	3	4	5
Die Sensoren könnten noch besser wahrnehmen	1	2	3	4	5
In wieweit fanden Sie ihn technisch fortgeschritten?	1	2	3	4	5

Wie haben sie die folgenden Ereignisse wahrgenommen?

stimmt absolut (1), stimmt (2), neutral (3), stimmt nicht (4), stimmt absolut nicht (5)

Die Kollisionen fand ich nervig	1	2	3	4	5	n.z. ☐
Es machte mir etwas aus, dass er feststecken blieb	1	2	3	4	5	n.z. ☐
Ich fand es toll, dass er sich so gedreht hat	1	2	3	4	5	n.z. ☐
Es dauerte mir zu lange, als er zur Aufladestation zurückfuhr	1	2	3	4	5	n.z. ☐
Als er einfach stehenblieb, habe ich mich geärgert	1	2	3	4	5	n.z. ☐

Haben Sie die Gebrauchsanleitung gelesen? Ja ☐ Nein ☐

Falls “Ja”, worüber haben Sie Informationen bekommen können?

Sensoren ☐

Schnellheit ☐

An- und Ausmachen ☐

Erster Gebrauch ☐

Aufladen ☐

anders: ______________________________

Ich möchte nun gerne wissen, welche Sachen Ihnen während der Beobachtung positiv oder negativ aufgefallen sind.

(denken Sie zB an Benutzerfreundlichkeit, Äußerlichkeiten, Bewegung, Lärm, etc.)

Fand ich nicht so toll	Fand ich am tollsten
1.	1.
2.	2.
3.	3.

Was denken Sie jetzt von Robotern, die staubsaugen?

trifft absolut zu1), trifft zu (2), neutral(3), trifft nicht zu (4), trifft überhaupt nicht zu (5)

Er macht alles, was ich erwartet hab	1	2	3	4	5
Ich bin zufrieden mit seiner Arbeit	1	2	3	4	5
Ich würde diesen Roboter nicht kaufen	1	2	3	4	5
Es macht Spaß ihn zu benutzen	1	2	3	4	5
Ich würde den Roboter Freunden empfehlen	1	2	3	4	5
Er ist nur auf größeren Flächen gut zu benutzen	1	2	3	4	5

Sie hatten die Möglichkeit einen Knopf auf dem Sensor zu drücken, sofern Ihnen etwas Besonderes auffällt. Für den Fall, dass Sie den Knopf benutzt haben:
In welchen Situationen haben Sie den Knopf gedrückt? Und **warum? Oder warum nicht?**

Würden Sie jetzt einen staubsaugenden Robot kaufen wollen? Ja ☐ Nein ☐ Vielleicht ☐
Wovon ist Ihre Entscheidung abhängig? ____

____

Haben Sie weitere Anmerkungen über die Roboter?

____

____

Appendix II. Tests of normality

Tests of normality, with robot as the factor variable.

Shapiro Wilk test for the mean of the scales.

Scale	Robot	df	*p-value*
Perception	Navibot	16	.66
	Roomba	16	.96
Emotion	Navibot	16	.73
	Roomba	16	.43
Functionality	Navibot	16	.95
	Roomba	16	.95
Evaluation (perception,	Navibot	16	.67
emotion & functionality)	Roomba	16	.62
Expectation	Navibot	16	.24
	Roomba	16	.95
Value	Navibot	16	.53
	Roomba	16	.05

Shapiro Wilk test for each item of each scale.

<u>Perception of the robot</u>

Item	Robot	df	*p-value*
Active	Navibot	16	.004
	Roomba	16	.005
Controlled	Navibot	16	.021
	Roomba	16	.012
Fast	Navibot	16	.002
	Roomba	16	.06
Intelligent	Navibot	16	.031
	Roomba	16	.045
Sweet	Navibot	16	.001
	Roomba	16	.002
Personal	Navibot	16	.09
	Roomba	16	.005
Large	Navibot	16	.003
	Roomba	16	.014
Funny	Navibot	16	.269
	Roomba	16	.027
Handy	Navibot	16	.069
	Roomba	16	.026
Agile	Navibot	16	.002
	Roomba	16	.041
Goal-directed	Navibot	16	.014
	Roomba	16	.007
Quiet	Navibot	16	.032
	Roomba	16	.037

Emotion of the participants during interaction

Item	Robot	df	*p-value*
Happy	Navibot	16	.001
	Roomba	16	.001
Pleased	Navibot	16	.065
	Roomba	16	.037
Satisfied	Navibot	16	.037
	Roomba	16	.029
Well-tempered	Navibot	11	.017
	Roomba	11	.301
Unfearful	Navibot	16	.001
	Roomba	16	.002
Autonomous	Navibot	16	.017
	Roomba	16	.018
ActivePassive	Navibot	16	.088
	Roomba	16	.046
Cheerful	Navibot	16	.002
	Roomba	16	.002
Positive	Navibot	16	.005
	Roomba	16	.003
Not irritated	Navibot	16	.004
	Roomba	16	.003

Perceived functionality of the robovacs

Item	Robot	df	*p-value*
No need for assistance (1)	Navibot	16	.108
	Roomba	16	.021
Fast enough (2)	Navibot	16	.027
	Roomba	16	.021
No need to clean up after it (3)	Navibot	16	.039
	Roomba	16	.083
Did not mind collisions (4)	Navibot	16	.043
	Roomba	16	.218
Satisfactory cleaning result (5)	Navibot	16	.021
	Roomba	16	.022
Unfearful during cleaning (6)	Navibot	16	.000
	Roomba	16	.006
Reliance on the cleaning abilities (7)	Navibot	16	.007
	Roomba	16	.050
Quiet (8)	Navibot	16	.255
	Roomba	16	.031
Aesthetic appearance (9)	Navibot	13	.010
	Roomba	13	.024
Intelligent (10)	Navibot	13	.317
	Roomba	13	.139

Recognized its sensors (11)	Navibot	13	.010
	Roomba	13	.082
Sensors do not need improvement (12)	Navibot	11	.095
	Roomba	11	.000
Technological advancement (13)	Navibot	13	.025
	Roomba	13	.059
Not minding collisions (14)	Navibot	14	.096
	Roomba	16	.021
Not minding getting stuck (15)	Navibot	12	.126
	Roomba	14	.004
Liking its turning around (16)	Navibot	15	.049
	Roomba	15	.048
Fast enough (back to station) (17)	Navibot	16	.013
	Roomba	16	.007
Did not mind when it stopped (18)	Navibot	10	.198
	Roomba	11	.127
Fulfilling expectations (19)	Navibot	16	.015
	Roomba	16	.011
Satisfied (20)	Navibot	16	.138
	Roomba	16	.018
Would purchase it (21)	Navibot	16	.006
	Roomba	16	.000
Fun to use (22)	Navibot	16	.021
	Roomba	16	.095
Would recommend it (23)	Navibot	16	.009
	Roomba	15	.002
Better to use on large surface (24)	Navibot	11	.093
	Roomba	11	.255

Shapiro Wilk test for the EDA reaction.

<u>Mean reaction</u>

Item	Gender	df	*p-value*
Navibot reaction	Female	8	.61
	Male	7	.13
Roomba reaction	Female	8	.08
	Male	7	.35

Appendix III. Detailed Comparison of the Robovacs

The Wilcoxon test was conducted for the detailed comparison of the robovacs. The tables below show the items were no significant difference between the two robovacs could be established.

Perception of the robot

Item		Active	Fast	Sweet	Personal	Large	Agile	Goal-directed
	z-value	-1.41	-1.03	-.63	-.36	-.35	-.51	-1.61
	p-value	.16	.31	.53	.72	.73	.61	.11
Navibot	*Mean*	3.50	3.44	3.00	3.06	2.69	3.06	3.25
	SEM	.29	.29	.24	.34	.18	.213	.28
Roomb	*Mean*	3.94	3.50	2.81	2.94	2.8	3.19	2.44
	SEM	.30	.26	.16	.41	1.94	.23	.38

Emotion of the participants after interaction

Item		Satisfied	Well-tempered	Unfearful	Autonomous	Active	Cheerful	Positive
	z-value	-.18	-1.65	-1.67	-1.03	-1.77	-1.93	-.11
	p-value	.86	.09	.09	.31	.08	.05	.92
Navibot	*Mean*	2.81	4.09	3.69	3.50	3.06	3.75	3.06
	SEM	.29	.25	.15	.20	.36	.17	.28
Roomba	*Mean*	2.94	3.36	3.38	3.25	3.69	3.31	3.06
	SEM	.31	.41	.20	.28	.29	.18	.29

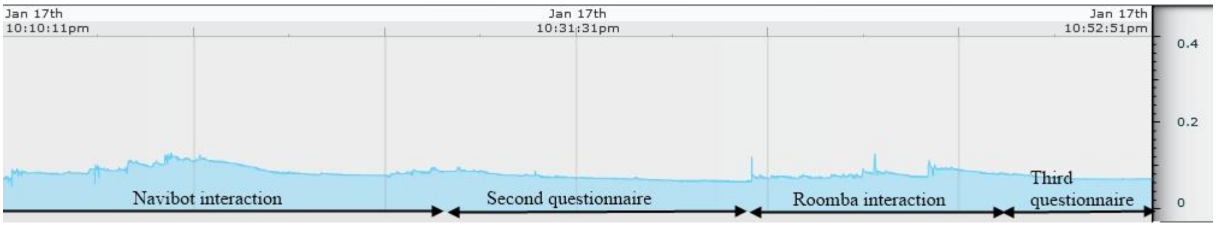
Perceived functionality of the robovacs

Item			Navibot		Roomba	
	z-value	*p-value*	*Mean*	*SEM*	*Mean*	*SEM*
No need for assistance	-1.87	.06	3.12	.32	2.25	.32
Fast enough	-.29	.77	3.38	.22	3.31	.27
No need to clean up after it	-.09	.14	2.62	.27	2.62	.33
Did not mind collisions	-1.47	.14	3.73	.32	3.31	.29
Satisfactory cleaning result	-.91	.37	2.88	.26	2.69	.29
Unfearful during cleaning	-1.07	.29	4.19	.37	3.94	.31
Reliance on the cleaning abilities	-.21	.83	3.00	.26	2.94	.32

Item	*z-value*	*p-value*	Navibot *Mean*	*SEM*	Roomba *Mean*	*SEM*
Quiet	-.99	.32	3.25	.28	2.81	,33
Intelligent	-1.89	.06	3.00	.37	2.54	.27
Recognized its sensors	-1.63	.53	3.85	.34	3.69	.35
Sensor need no improvement	-1.93	.05	2.09	.29	1.36	.20
Accepting when it got stuck	-1.73	.08	3.08	.42	2.29	.19
Liked its turning around	-1.73	.08	3.67	.21	3.20	.24
Did not mind when it stopped	-.14	.89	3.60	.43	3.55	.28
Satisfied	-2.11	.04	2.81	.32	2.37	.29
Would purchase it	-.57	.57	2.62	.41	2.19	.38
Fun to use	-1.22	.22	3.31	.27	3.00	.34
Would recommend it	-1.86	.06	2.19	.29	1.73	.25
Better to use on large surface	-.96	.34	2.55	.34	2.91	.37

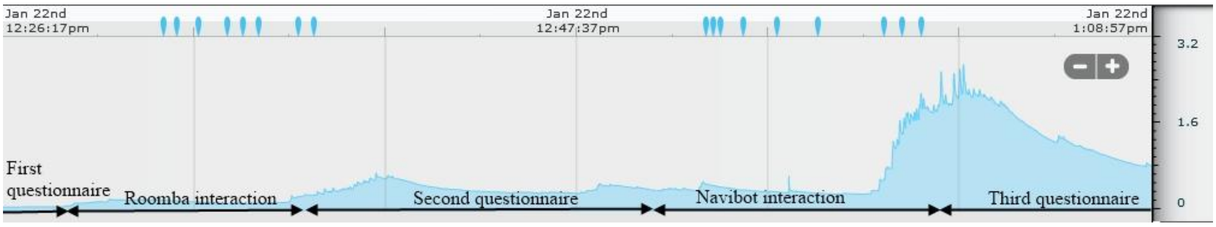
Appendix IV. Q-Sensor data.

Five graphs of the Q-Sensor data illustrate the individual differences in EDA and button response. The blue graph indicates the EDA in microsiemens (µS). The µS values are displayed on the scale on the right hand sight of the graphs.

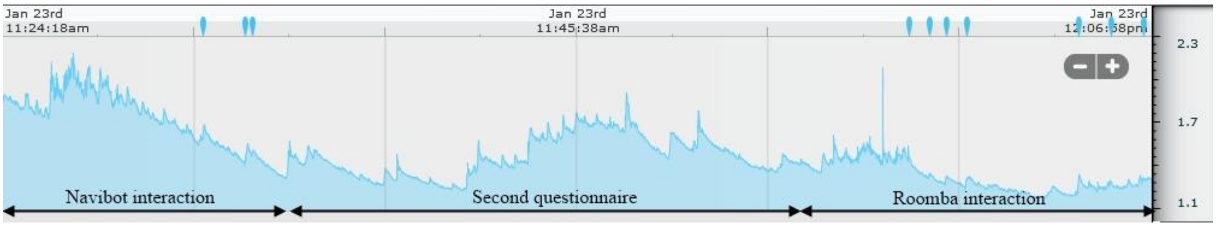


Participant 3

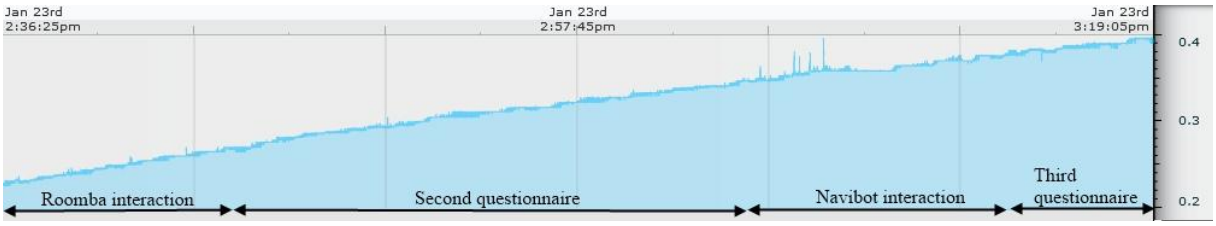
Participant 5



Participant 10



Participant 13



Participant 14

Appendix V. Linear regression of EDA reaction across different moments of time.

Table A *Average EDA reaction during the first 30 seconds of interaction with the robots*

Model	R^2	*t-value*	*Sig.*	*df*	*M*	*SEM*
Gender	.19	2.59	.02	29		
Men					.43	.18
Women					-.04	.06
Robot		-.22	.83			
Order		-.79	.44			

Table B *Average EDA reaction of the first interval of interaction with the robots*

Model	R^2	*t-value*	*Sig.*	*df*	*M*	*SEM*
Gender	.19	2.57	.02	29		
Men					.23	.09
Women					-.09	.06
Robot		-.17	.87			
Order		-.77	.45			

Table C *Average EDA reaction of the second interval during robot interaction*

Model	R^2	*t-value*	*Sig.*	*df*	*M*	*SEM*
Gender	.18	2.49	.02	29		
Men					.32	.13
Women					-03	.06
Robot		-.72	.48			
Order		-.76	.46			

Table D *Average EDA reaction of the third interval during robot interaction*

Model	R^2	*t-value*	*Sig.*	*df*	*M*	*SEM*
Gender	.14	2.13	.04	29		
Men					.28	.10
Women					.03	.06
Robot		-.52	,.61			
Order		-.73	.47			