A BELLBOY ROBOT: STUDY OF THE EFFECTS OF ROBOT BEHAVIOUR ON USER ENGAGEMENT AND COMFORT

Eduardo Rodriguez-Lizundia[a], Samuel Marcos[b], Eduardo Zalama[a,b],
Jaime Gómez-García Bermejo [a,b], Alfonso Gordaliza [c]

[a] *University of Valladolid, Instituto de las Tecnologías Avanzadas de la Producción - ITAP, Paseo del Cauce 59. 47011 Valladolid, Spain.*
[b] *Fundación Cartif, Robotics and Computer Vision Division, Parque Tecnológico de Boecillo.Boecillo, 47151 Valladolid, Spain*
[b] *University of Valladolid,Departamento de Estadística e Investigación Operativa. Paseo del Cauce 59. 47011 Valladolid, Spain.*

Abstract

This paper provides the results of various trial experiments in a hotel environment carried out using Sacarino, an interactive bellboy robot. We analysed which aspects of the robot design and behaviour are relevant in terms of user engagement and comfort when interacting with our social robot. The experiments carried out focused on the influence over the proxemics, duration and effectiveness of the interaction, taking into account three dichotomous factors related with the robot design and behaviour: robot embodiment (with/without robotic body), status of the robot (awake/asleep) and who starts communication (robot/user). Results show that users tend to maintain a personal distance when interacting with an embodied robot and that embodiment engages users in maintaining longer interactions. On the other hand, including a greeting model in a robot is useful in terms of engaging users to maintain longer interactions, and that an active-looking robot is more attractive to the participants, producing longer interactions than in the case of a passive-looking robot.

Keywords: social/service robot, HRI, proxemics

1. Introduction

Over the last few years, an increased interest for autonomous social and service robots has emerged. This imposes a challenge to provide technologies that can allow better comfort levels and better quality of life for individuals. Many of these tools aim to provide help and comfort, assisting humans by procuring quick access to information and services, helping in their jobs, or carrying out specific tasks at home. The question of interfacing and providing intuitive means of communication between man and machine is therefore one of the challenges that will enhance the uptake of technologies for everyday use.

A growing interest has recently been observed in the development of new interfaces and interaction methods to allow humans to interact with machines in a natural way. Ideally, a man-machine interface should be transparent to the user, i.e. it should allow the user to interact with the machine without requiring any cognitive effort. What is sought is that anyone can use devices in their daily lives, even people not very familiar with the technology, making both the way people communicate with devices and the way devices present their data to the user easier. Bartneck & Forlizzi (2004) defined a social robot as: "A social robot is an autonomous or semi-autonomous robot that interacts and communicates with humans by following the behavioural norms expected by the people with whom the robot is intended to interact". According to this definition, if a robot was fully human-like in appearance and behaviour, it would be reasonable to assume that other humans would respond to it socially as they would to another human and expect it to behave like a human. On the other hand, Reeves & Nass (Reeves & Nass, 1996) have shown that, regardless of the appearance, users do respond socially to technological artefacts in many of the same ways that they do with other humans. However, even though technological developments have narrowed the gap between social robots and biological organisms in terms of appearance and behaviour, it is unlikely that, in the near future, social robots could reach a level of development in which they could not be distinguished from real living systems. For that reason, it is often argued that, in the years to come, people will react socially to robots in exactly the same ways that they might react to other humans in comparable contexts.

Traditionally, within service environments, developed robots have mainly been endowed with limited functions. These robots usually exhibit a relatively small number of interaction functionalities and have often outworn their welcome after a relatively short time. Recent efforts in the improvement of robots' technical capabilities have enabled them to perform some useful functions such as simple cleaning tasks (e.g. the well-known ROOMBA vacuum cleaning robot), goods transport, or remote security monitoring. However, it is often argued that these limited tasks are selected because they actually require little in the way of human-robot interaction (HRI) (Dautenhahn et al., 2005), (Woods et al., 2007). If robots are to become truly useful in a human centred service environment, they must both be able not only to perform useful tasks, but also be socially acceptable and effective when interacting with people they share their working environment with.

The ultimate goal of a service robot is to serve people by providing information or helping for instance at home, in hospitals, hotels or industrial environments. When introducing an autonomous robot in a new environment, the working practice and usage of this new form of technology is commonly missing for non-expert users, and really hard to provide for developers. In addition, in environments such as a hotel, the potential demographics of users are likely to be heterogeneous, and the expected duration of human-robot interactions are not long enough to allow potential users to get used to the new technology.

This paper provides the results of various trial experiments in a hotel environment carried out using Sacarino, an interactive bellboy robot. The aim is for Sacarino to develop its social skills as a bellboy in a hotel; walking alongside the guests, providing information about the city and all the hotel’s services (restaurant hours, menus, etc..), as well as providing hotel-related services (calling taxis, breakfast control, bringing snacks, etc..). Sacarino is designed to stay connected to a charger in the hotel lobby when it is not doing a specific task, so it can continuously provide effective services, as well as to navigate autonomously through the hotel facilities.

Our main goal is to introduce the robot in the context of a hotel, so it is well received by users. To do so, we have conducted a series of experiments that evaluate user engagement when we vary the variables of embodiment, robot attitude (active/passive) and robot status (awake/asleep). The studied variables have been selected not only to improve the robot's reception from the hotel guests, but also to increase the robot's usefulness. One of the main aspects to consider when developing an autonomous service robot is to maximize its functionality, that is, to provide the requested services for as long as possible while maintaining the robot's capabilities. For that reason, different statuses of the robot have been analyzed, each one dealing with the pros and cons in terms of interaction, engagement and other aspects not related to HRI, but still important in robotic development (i.e. cost, energy demand).

The rest of the paper is organized as follows: Related work is reviewed in section 2. A description of our robot is presented in section 3. Experimentation design, procedure and data analysis are described in section 4. The discussion is performed in section 5. Finally, section 6 includes the conclusions and future work.

2 Related work

Prior to deploying Sacarino in a hotel environment for long periods of time, we had considered that it was of vital importance to analyze the best means of engaging new users in a practical and useful human-robot interaction. In (Dillion, 2005), user acceptance is defined as "the demonstrable willingness within a user group to employ technology for the tasks it is designed to support". To date, experimentation in user acceptance towards social and service robots has mainly been done in laboratory environments or under controlled conditions. Although simulations and modelling techniques have been common methods in Human-Robot Interaction studies (Marcos et al., 2009, 2013), nowadays it is common practice for experiments in the lab to include fully functional robots (Fiore et al., 2013). However, the environment the robot is planned to operate in adds another level of complexity, which should be taken into account when performing service robot related studies. As stated in (Sabanovic, 2006), "It is therefore necessary to evaluate human-robot interactions as socio-culturally constituted activities outside the laboratory".

Unlike other service machines, autonomous robots move around the environment as part of their normal execution. This means that they will necessarily be sharing the same space as the humans. As stated in (Harrigan et al., 2005), many fundamental social relationships for humans are reflected by, and relate to, their use of space. Therefore, robot proximity to users has been considered one aspect of great importance in describing how humans interact with robots in a real environment (KhengLee et al., 2014). The discipline in charge of studying this subcategory of non-verbal communication is called proxemics, which is the term used by the anthropologist Edward T. Hall in 1966 to describe the measurable distances between people when they interact with each other (Hall, 1996). As described by Hall, the interaction distance gives an idea of the level of intimacy between those interacting, which means, in terms of HRI, how comfortable a user feels when interacting with a robot.

Different studies have addressed how proxemics is related to participants' perceptions of the robot's social presence. Many of the findings show that there are different factors that affect human-robot proxemics. Also, (Mead et al., 2011, 2013, 2014) have concluded that other factors known to affect human-human proxemics also apply to HRI. Walters et al., have performed several experiments under different robotic configurations that establish the distance from a robot in which people are comfortable ranges from 0.4 to 0.6m (Walters et al., 2009). Their studies have shown that factors such as voice style, gender, appearance, gaze, etc. affect distancing. Those findings are highly correlated to many others, such as the ones presented by (Takayama and Pantofaru, 2009) or (Fiore et al., 2013). On the other hand, results from a recent study by Mead and Mataric (Mead and Mataric, 2014) showed that when a robot is producing gestures, comfort distance increases. Their explanation to this effect is that participants might have positioned themselves farther away from the robot to avoid physical contact.

Experiments such as the ones presented in (Fiore et al., 2013) give an idea of how proxemics and other social cues and signals affect human-robot interaction. An important conclusion of the (Fiore et al., 2013) study is that, regardless of the proxemics behaviour, participants attributed more social presence to their robot over repeated interactions. Other examples of changes in participants' perceptions across repeated or sustained interactions can be found in (Ljungblad et al., 2012). Changes in the proxemics preferences of users over time have also been addressed in (Koay et al., 2007). An explanation of this behaviour is given in (KhengLee et al., 2014): "This may be due to participants' increasing understanding of the robot's true capabilities and common behaviours with greater exposure, and as their mental model of the robot more closely resembles the real robot (capabilities) over time". However, in our particular case in a hotel scenario, long or repeated interactions are unlikely to occur, as service robots placed in public (or semi-public) scenarios are likely to maintain short-term interactions, or breaching interactions as referred to in (Weiss et al., 2008). Our research aims to address such issues as people's first time reactions in terms of proxemics and other social cues, which might only be studied in a real setting.

The ability to move gives robots a degree of usefulness that other machines lack. However, it also means that the negotiation of space is a problem that should be addressed (Pacchierotti, 2006). This is of special importance in terms of safety, but may be a drawback in terms of acceptance (Kuli´c and Croft, 2007). For example, generating loud warning sounds to avoid a possible collision with a human could be a hindrance in developing a socially acceptable robot (KhengLee et al., 2014). Taking this into account, one can conclude that sounds and verbal communication are of great importance for autonomous robots. As has been said, in our particular case of a hotel environment, breaching interactions are expected to occur, so incorporating greeting behaviour to a service robot in addition to sounds negotiating space could be crucial for user engagement. However, as stated before, a robot should exhibit appropriate social behaviour, so it is necessary to study how people react to a robot that greets them.

Several studies have addressed how users react to a robot that greets them. In (Mumm and Mutlu, 2011) they analyzed how participants vary their approaching distance to a robot while manipulating gaze behaviour and the robot's likeability (i.e., whether the robot's initial greeting message was polite or rude). Their results show that participants who disliked the robot maintained a greater physical distance from the robot than those who did not. (Bainbridge et al., 2008) studied how users react to a non-mobile physical robot that waved to the participants while an experimenter introduced it to them, and addressed that about half the subjects responded with a wave or verbal greeting. (Trovato and Zecca, 2013) found demographical differences in how Japanese and Egyptian users reacted to greetings made by what appeared to be Japanese and Egyptian non-mobile robots over a simulated teleconference. (Brandon et al., 2014) constructed an abstract greeting model based on Kendon's observations of human greetings (Kendon, 1990) and programmed it into the Nao Robot. They concluded that the greeting model improved the robot's social skills during a greeting exchange in a controlled setting as users reacted favourably towards a robot that greeted them.

The results from the above studies suggest that it would be beneficial to include greeting capabilities in an autonomous robot. However, it is not clear whether a robot should implement those capabilities in an active or passive way. In a hotel environment, a robot that tries to attract the users' attention could improve the level of engagement and the number of potential users. On the other hand, a "too enthusiastic" greeting robot that, for instance, keeps on interrupting a conversation in progress would probably decrease the level of comfort and discourage users from interacting with it.

Khan (Khan, 1998) explored the attitudes towards intelligent service robots, and concluded that intelligent service robots are conceptualized as machines that can be controlled. In (Dautenhahn et al., 2005), they indicated that a large proportion of participants were in favour of having a robot companion, but would prefer it to have a role of an assistant, appliance, or servant, while few wanted a robot companion to be a 'friend'. Similar results have later been obtained by (Céline et al., 2008), who performed a survey that involved 240 participants. These studies show that even though people prefer a robot that is useful and is endowed with certain intelligence and human interaction capabilities, robot autonomy of decision should not be too high.

(Saulnier et al., 2011) investigated how people perceived a mobile robot's attempt to attract their attention. Their results showed that people were able to interpret interruption urgency from the robot's minimal nonverbal behavioural cues. (Satake et al., 2009) observed that people usually ceased interacting with the robot when they "tested" it for a reaction, but then did not get the expected response. In terms of taking the initiative for an interaction, these results imply that a robot that greets users when it is not expected to do so could cause rejection rather than engagement.

As Sacarino is an autonomous robot, our study was focused not only on the study of better communication capabilities for user acceptance, but also on analyzing what the necessary minimum communication requirements for a service robot are in order to be able to engage new users. Being able to depict those minimum requirements will allow other aspects of great importance for an autonomous robot, such as power consumption, to be optimized.

3. Description of Sacarino

Sacarino (Zalama et al. 2013) is a humanoid robot in overall appearance and scale. It is composed of two parts: a mobile base for moving around the hotel, and an anthropomorphic body to interact with hotel guests. Sacarino's base, shown in figure 1, is controlled by four double wheels arranged in a syncrodrive configuration. The wheels move and rotate at the same time driven by two motors, one of which is responsible for the traction and the other for the turn. On top of the drive system is a platform which turns synchronously with the wheels supporting Sacarino's body, so that the social part of the robot is always facing in the direction of motion. The base is responsible for housing the control electronics and the robot navigation sensors.

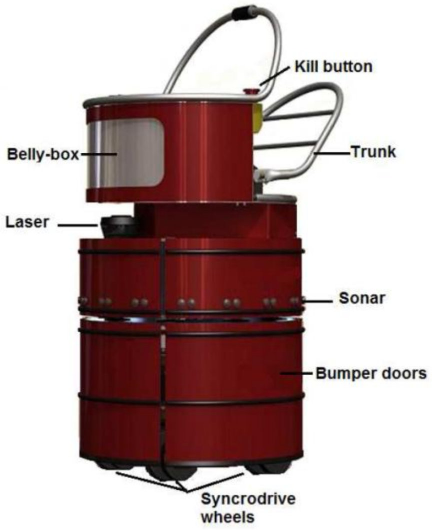

Figure 1. Sacarino's Base.

The body is in charge of the main facets of interactive social communication as it is designed in a humanoid fashion. This can be easily separated from the rest of the robot so that it can be used as an independent system. Sacarino can exhibit different social cues through its arms, head, eyes, eyelids and mouth. The body includes the following elements (see figure 2)

- Torso. The torso of the robot includes two arms with two degrees of freedom each (shoulder and elbow) which are driven by four servomotors. It also holds a touch screen in the front which provides multimedia information and permits user interaction with the robot.

- Expressive Head. The head is the component that provides more expressiveness to the system. It holds many of the interaction sensors and actuators such as camera and microphone as well as LED based eyes and mouth that endow the system with bidirectional communication capabilities. The head has two direct-coupled servomotors (providing pan and tilt movements) in order to look at the user in a natural way. The head, jointly with the voice and also the arm movement, provide the robot with different interaction channels.

- Camera and microphone. A camera is located at the top of the head. The camera also includes an array of microphones for noise filtering and voice recognition.

- Eyes. The eyes can be illuminated and the brightness adjusted by pulse width modulation. The eyelids are controlled by two servomotors for blinking and expressiveness.

- Mouth. The mouth is shaped by an array of LEDs that can set different gestures according to the emotional state of the robot, or simulate the movement of lips while the robot is speaking. Sacarino can communicate with people through the Verbio Speech Recognition and Generation System. Conversation management is performed by ALICE AIMLbot (Alice, 2014), which allows dialogues in contextually defined scopes. Communication is robot guided, and to overcome problems of bad recognition or hearing due to noise, lack of context, etc., the communication is multimodal, by voice and/or touchscreen. The robot speech is synchronously written on the screen and the user can provide information to Sacarino through voice or the touch screen.

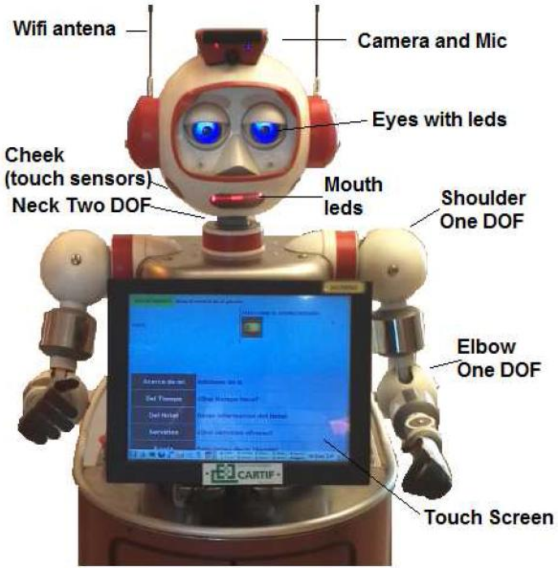

Figure 2. Sacarino’s Body.

4. Experimentation

As stated before, our goal is to analyze which aspects of the robot design and behaviour are relevant in terms of user engagement and interaction as against other aspects not related to HRI but still important in robotic development (i.e. cost, energy demand). As both groups of characteristics seem to be intrinsically conflicting, the following research questions were formulated:

1. Is embodiment relevant and important to engage users in breaching interaction?

2. Shall the robot take the initiative at the beginning of the interaction?

3. With what degree of passiveness could the robot still be able to engage new users?

The results of answering these questions would allow us to optimize our robot design. For instance, if a passive robot (a robot in a ‘sleep’ mode) is able to engage new users the same way as an active one, this would provide means for energy saving, and thus increase the autonomy of our robotic platform.

DESIGN

In order to provide answers to our three research questions, we have considered the influence of three dichotomous factors in the interaction:

1) robot embodiment (with/without robotic body)
2) status of the robot (awake/asleep)
3) who starts communication (robot/user)

The combination of these factors in the appearance and behaviour of our robot would give a total of eight different robot states, as described in table 1:

Table 1: Considered robotic states as a function of the three dichotomous factors

State Factor	1	2	3	4	5	6	7	8
Embodied	YES	YES	YES	YES	NO	NO	NO	NO
Robot is awake	YES	YES	NO	NO	YES	YES	NO	NO
Robot starts communication	YES	NO	YES	NO	YES	NO	YES	NO

However, states 3, 7 and 8 were disregarded for our study. State 3 would imply that the robot should start the communication whenever it detects the presence of a new user. In our robotic system design, when the robot is “asleep”, its arms are held in an extended static position, the head is static and held high and the eyes are open. In this state, the screen remains switched off until someone approaches. Due to the fact that when the robot detects movement in an area closer than 3 meters it changes its state to “awake”, in terms of interaction, state 3 would result in a configuration similar to the robot configuration in state 2.

On the other hand, states 7 and 8 imply the absence of the robotic body. As will be described later, the non-embodied status was evaluated by substituting the robot with a pedestal that held a conventional computer, the touchscreen, speakers and the microphone. We considered that having this type of configuration with a switched OFF screen would be of no use for engaging users in any kind of interaction.

The final 5 evaluated robotic states are summarized and renumbered in Table 2:

Table 2: The final 5 evaluated robotic states

State Factor	1	2	3	4	5
Embodied	YES	YES	YES	NO	NO
Robot is awake	YES	YES	NO	YES	YES
Robot starts communication	YES	NO	NO	YES	NO

Description of the states with the robotic body:

- First state: Sacarino is “awake”, with its arms slightly bent at the elbow, the head held high and its eyes open and switched on. The robot randomly makes gentle movements with its arms and head. The screen is on, and it shows the main menu screen. When an approach is detected, Sacarino looks in the direction of the approach and makes a greeting to incite interaction. The greeting includes sentences like: “Hello, good morning.” “Can I help you?” “Come closer and talk to me”.

- Second state: This condition aims to give Sacarino an active look, but without directly encouraging interaction. Sacarino stays “awake”. However, the robot does not make any action or gesture of greeting when someone approaches it, it just answers when someone talks to it or it is asked to provide further information through the touch screen.

- Third state: Sacarino is “asleep”, with its arms in an extended position, the head held high and the eyes open, but it does not move. In this state, the screen remains turned off until someone approaches.

Description of the states without the robotic body:

In order to evaluate the interaction with a non-embodied agent, Sacarino’s software was removed from its robotic body and placed in a conventional computer, with a touch screen, speakers and the webcam with the microphone. Everything was placed on a stand, which allows it to be at the most convenient height for handling (see figure 5). The system has the same speech ability and recognition, and touch screen interaction as before, regardless of its body. It loses its movement capacity and all similarity with the human body; however, it is able to do the same things, but without the movement.

Two states were defined in this configuration:

- Fourth state: This state is used to study whether the greeting is useful, even when it does not come from an anthropomorphic body. The configuration is the same as in the fifth state but, as in the second state, it now makes a greeting to incite interaction when someone approaches. In this state, the greeting is the same as was used in the second state.

- Fifth state: The screen remains turned on showing the main menu. It does not make any action or greeting; it just answers when someone talks to it or touches the screen.

PARTICIPANTS

A total of 169 interactions took place during the study. However, only individual interactions were considered in this study. This included interactions that occurred between a single individual and the robot, no matter if the individual was alone or accompanied by a group of people. If, in any case, more than one individual interacted directly with the robot (via voice or using the touchscreen), the whole interaction was disregarded. An interaction was considered to begin when an individual first interacted with the robot using a voice command or the touchscreen, and was considered to finish when the individual left the interaction area or deliberately said goodbye. After a finalization, repeated interactions were also disregarded.

Taking this into account, and after disregarding some cases because of incongruities in the recorded data, only 95 out of 169 interactions were considered as valid for the analysis. From those 95 interactions, 53 were held by a single user, whereas 42 were held by a single user but accompanied by more individuals. 74 were male and 21 female. The 95 participants were distributed in groups of 20 for each robot state, except the fifth state which had 15 participants after disregarding some cases because of the reasons described above.

MATERIALS

The experiment was held in the lobby of the Novotel Hotel in Valladolid. The lobby is flat and has an inverted trapezoid shape (see figure 3), approximately 20 meters long on the longest side and 8 meters on the shortest. The lateral sides were 18 meters long each. The main hotel entrance is located in the shortest side, and the foyer has no other obstacles apart from two columns and some furniture (see figure 3). The reception and an adjacent meeting area are located on the right, the dining room entrance opposite the entrance, and the elevators and stairway are on the left side of the foyer. The robot was placed close to the left central column as can be observed in Figures 4 and 5, and the five different robotic states previously described were evaluated.

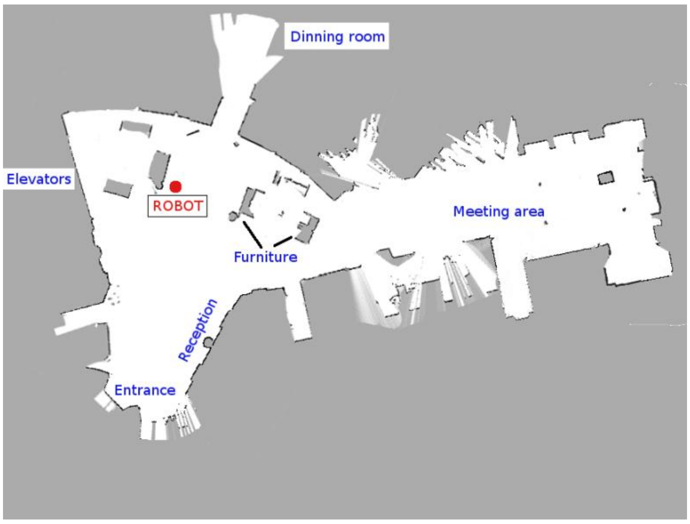

Figure 3. Annotated navigation map of the Novotel hotel foyer captured by Sacarino’s laser.

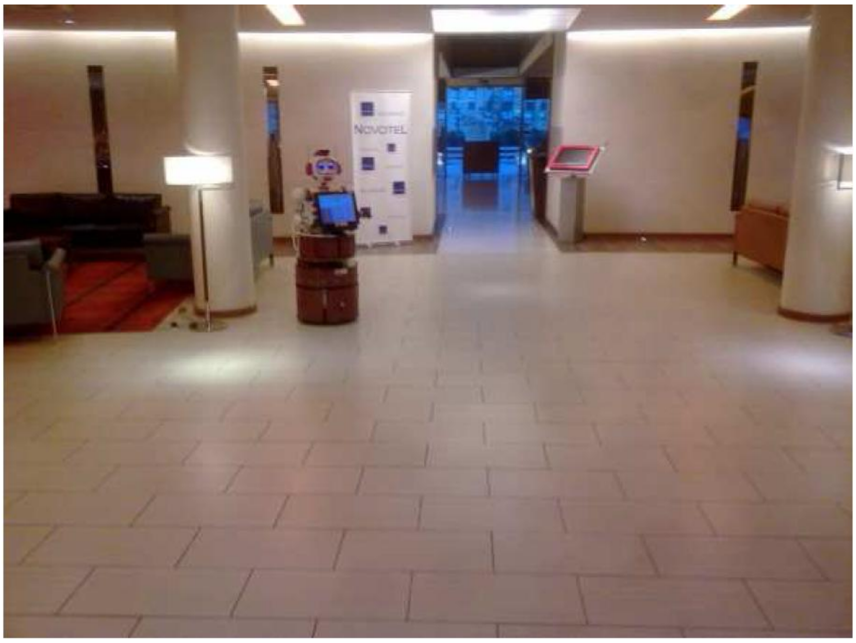

Figure 4. Set up corresponding to the first 3 states of Sacarino.

Figure 5. Set up corresponding to the last 2 states of Sacarino.

PROCEDURE

The robot was placed in the hotel lobby as can be shown in Figures 4 and 5, and each described robotic state was evaluated at a time. No indications were given to the users, as the robot is intended to operate autonomously. However, the robot screen includes an adaptive contextual menu which changes with every user interaction, and displays information, different options of commands and queries that the user can request to the robot. Figure 6 illustrates the menu that is shown in the screen of Sacarino:

Mi nombre es Sacarino. Puedes preguntarme acerca de mí, del tiempo y del hotel, o si estás confundido puedes decir ¡ayuda!.

Pulsa sobre cualquier opción o leela con voz alta y clara después de pulsar el botón del micrófono para que yo pueda escucharla. ¡Es muy fácil!

Figure 6. Screenshot of the contextual menu shown in the screen of Sacarino.

For each state, a series of interactions was recorded. Apart from distance, data were recorded by direct observation of the interaction, without the participants realizing they were being studied. The observations were made in this way in an attempt to get the most natural conditions achievable. In order to maintain the privacy of the users, no video was recorded. Instead, during the study, two researchers where strategically placed in the hotel lobby, both of them sitting in the couches placed next to where the robot was standing. Both researchers observed the interaction and accordingly filled in a tabular form which contained the following entries:

- Date, time, sample number: The date and the time when a user first interacted with the robot using a voice command or the touchscreen were recorded. The sample number is just a numbering system to keep track of the interactions.

- Age & gender: The age and gender of the users was estimated or the user was asked in cases of doubt after interaction. Age was treated as a continuous interval variable.

- Distance: The distance (in centimetres) from which the interaction was made. This was estimated using the floor tiles which included small marks. Also, the laser sensor was programmed so that, when it detected an object closer than 3 metres, it started recording the average distance of the detected object each 0.5 seconds. Data from both direct observation and laser were correlated to obtain the final distance estimation. As stated before, if more than one user approached the robot, only the one that interacted directly with the robot was considered.

- Who starts the interaction: Either Sacarino by greeting the user or the user by speech or using the touchscreen. If just an approach is made and nobody interacts, then ‘Nobody’ was recorded.

- Duration: The duration of the interaction in seconds, either in a single approach, or in several approaches within a short period of time.

- Interaction type: this variable addressed if a real interaction has taken place between the user and the robot. This variable indicates whether or not the user interacted fully with the robot, in terms of obtaining useful information from it. If a user had interacted with Sacarino either by using speech or the touchscreen and the robot had responded according to the user's demands, then the interaction type was coded as "1". On the other hand, if the user just approached to take a closer look at the robot, but there was no intention of interaction, or the user did not obtain the information he/she requested, then the variable was coded as "0".

- Observations (description): Additional information about how the interaction was carried out that might be considered relevant to the study was recorded.

No images, video sound, nor any personal information where recorded during the experiment.

DATA ANALYSIS

All analyses were performed using the software R i386 3.1.2 and STATGRAPHICS Centurion XVI 16.2.04, with the alpha level at 0.05 for statistical significance, unless otherwise stated. As shown in Figures 7 and 9, the distance and duration variables are far from being normally distributed, as they follow a very skew-symmetric pattern. For a proper analysis, we have transformed those variables into logarithmic units in order to carry out all statistical analyses that require the assumption of normality. This is the case of all two-sample Student t-tests performed. In the case of the multiple linear regression analyses performed, the logarithmic transformation allows the standard distributional requirements for the error terms in this kind of models (linearity, homoscedasticity, normality and uncorrelation) to be better accomplished. The variable age^2 was also included in the fitted regression models, in order to catch the quadratic trend observed in the scatterplots. Adding polynomial terms is a standard way (among others) to proceed when fitting linear regression models where a nonlinear trend is detected. Moreover, in this case, the fitted quadratic models allow for a nice interpretation of the different behaviours of both young and old people with respect to middle-aged people, when interacting with Sacarino.

Effects of the robotic states over proxemics

In this first analysis, we studied the effects of the different robotic states in terms of proxemics. That is, we want to determine how the different configurations of our robot affect the distance a user feels comfortable in when interacting with Sacarino.

We considered three dichotomous independent variables: embodiment, status and initiative. Age and gender were also considered as covariates, i. e., secondary variables that can affect the relationship between the dependent variable and the independent variables of primary interest. The two levels of the embodiment variable were coded as 'body' (the humanoid robot appearance as shown in figure 3) and 'no body' (the robot appearance with just a menu screen as shown in figure 4). The two levels considered for the status variable were coded as awake (as described in the first and second states) and asleep (as described in the third state).

The two levels of the initiative variable were: robot starts interaction and user starts interaction.

On the other hand, our dependent variable was the distance between the user and the robot. This distance was obtained as the median value recorded by the laser during the interaction, and was correlated with the annotations made by the two observers as described in the procedure section. The distance was expressed in centimetres.

A follow-up descriptive analysis was performed in order to better understand the relationship between the status and distance variables, and also to explore further the effects of the other two independent variables over the distance. The main observed difference was in terms of the robot status, between the awake condition (M = 56.067, SE = 6.280) and the asleep condition (M = 78.500, SE = 13.264). However, this difference is not statistically significant (p = 0.1315 for the Student t test, with the distance in logarithmic units). Results also showed a noticeable difference between the ‘body’ (M = 69.58, SE = 8.394) and ‘no body’ (M = 45.714, SE = 5.158) conditions (p = 0.1853), whereas a very small difference between ‘robot starts interaction’ (M = 67.714, SE = 12.094) and ‘user starts interaction’ (M = 56.750, SE = 5.748) was observed (p = 0.9607). Figure 7 summarizes the effects of the three independent variables over the distance.

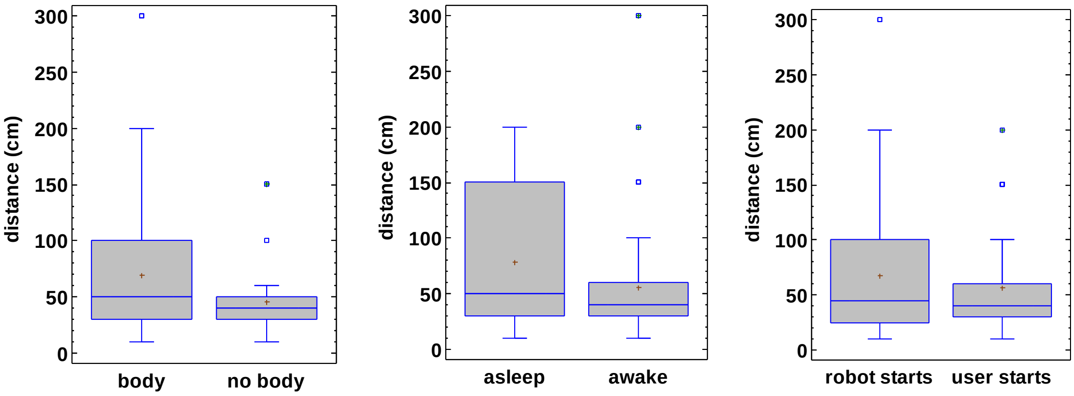

Figure 7. Two sample comparisons of the variable distance with respect to the three independent variables

A multiple linear regression model was fitted to the collected data to evaluate the overall capability of the explanatory variables (embodiment, status, initiative, age and gender) to explain the response variable distance. As mentioned before, the distance was transformed into a logarithmic scale and the explanatory variable age^2 was included to take into account the detected quadratic trend. A forward selection algorithm was used to avoid the presence of non-significant terms in the model, yielding a statistically significant model (overall significance p=0.0000, R-squared=22.43%) containing the variables: embodiment (p=0.0263), age (p=0.0001), and age^2 (p=0.0020). The contribution of the rest of the explanatory variables was not statistically significant. The fitted model is represented in Figure 8 as two parallel quadratic curves, one for embodiment=”body”, and the other one for embodiment=”no body”. Young and old people seem to feel more comfortable close to Sacarino than middle-aged people. The change of trend occurs around age=50. The estimated effect attributable to the embodiment variable is an average increase of distance of 0.3414 (in log units) when embodiment="body", independently of the age.

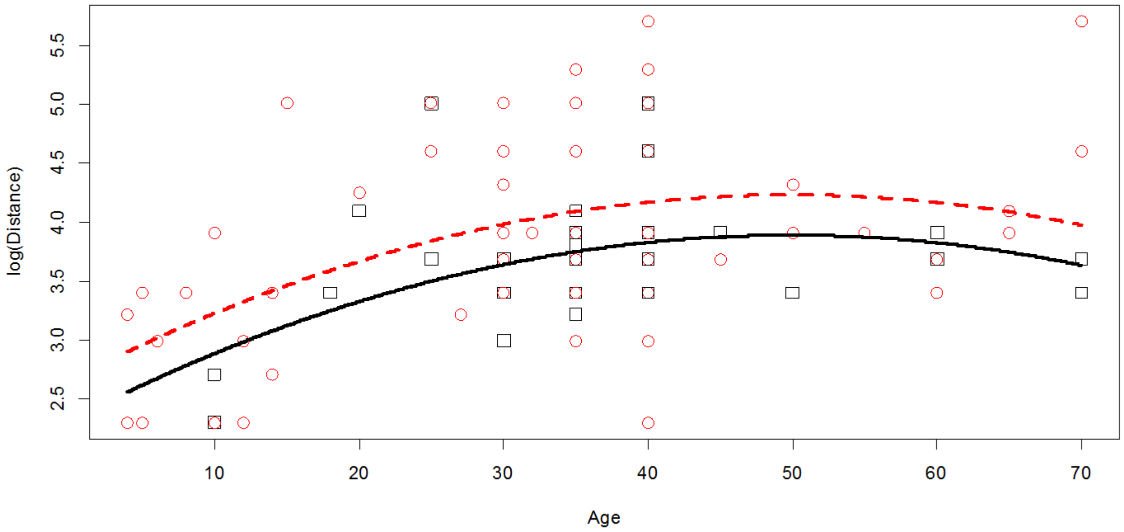

Figure 8: Plot of the fitted model for log(distance) against age, age^2 and embodiment. The dashed line and round dots (in red) correspond to embodiment="body", whereas the solid line and square dots (in black) correspond to embodiment="no body".

Effects of the robotic states over the duration of the interaction

In a second analysis, we studied the effects of the different robotic states in terms of the *duration* of the interaction held between the participants and the robot.

Again, we considered the same three dichotomous independent variables as in the proxemics study: embodiment, status and initiative; each of them coded in the same way as described before. Age and gender were also considered as covariates.

The dependent variable was the duration of the interaction with the robot. The duration of the interaction was measured in seconds. An interaction was considered to begin when an individual first interacted with the robot using a voice command or the touchscreen, and was considered to finish when the individual left the interaction area or deliberately said goodbye.

A follow-up descriptive analysis was performed in order to better understand the interaction between the three independent variables and the duration of the interaction. In terms of the robot status, there was an appreciable difference between the awake condition (M = 42.160, SE = 8.687) and the asleep condition (M = 21.750, SE = 4.417). However, this difference is not statistically significant (p = 0.1844 for the Student t test with the variables in logarithmic units). Although not statistically significant (p=0.4142), results also showed a certain difference between the 'body' (M = 43.833, SE = 10.563) and 'no body' (M = 27.629, SE = 5.183) conditions. Finally, a large and statistically significant difference (p=0.0395) was observed between the cases 'robot starts interaction' (M = 59.514, SE = 17.462) and 'user starts interaction' (M = 25.233, SE = 3.524). Figure 9 summarizes the effects of the three independent variables over interaction time.

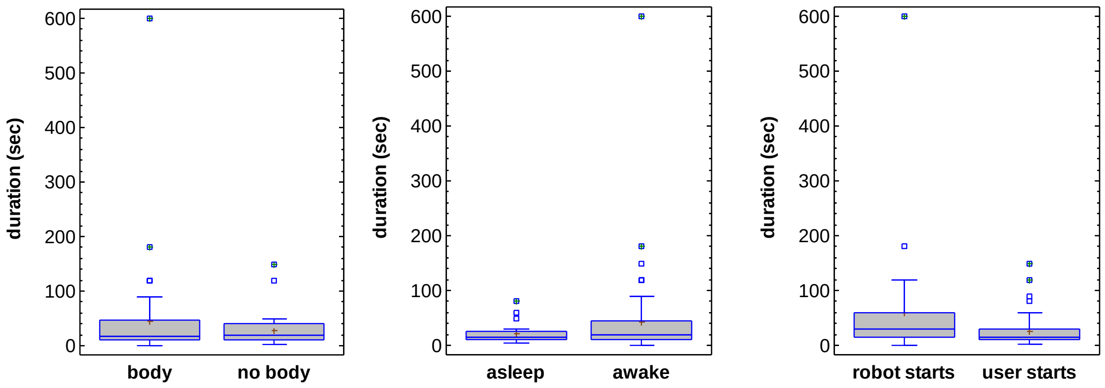

Figure 9. Two sample comparisons of the variable duration with respect to the three independent variables

As in the case of the response variable distance, a multiple linear regression model was fitted to explain the response variable duration through the explanatory variables embodiment, status, initiative, age, age^2 and gender. As mentioned before, the duration was transformed into a logarithmic scale and the explanatory variable age^2 was added to catch the quadratic trend detected. A forward selection algorithm was used to avoid the presence of non-significant terms in the model, yielding a fitted model containing the variables initiative (p=0.0412), age (p=0.0208), and age^2 (p=0.0441). The contribution of the rest of the explanatory variables was not statistically significant. Although statistically significant (overall significance p=0.0441), the amount of variability explained by the independent variables is smaller than in the case of the distance (R-squared=11.31%). The fitted model is represented in Figure 10 as two parallel quadratic curves, one for initiative="robot starts interaction" and the other one for initiative="user starts interaction". Young and old people seem to interact over longer periods with Sacarino than middle-aged people. The change of trend again occurs around age=50. The estimated effect attributable to the initiative variable is an average increase of duration of 0.4554 (in log units) when initiative="robot starts interaction", independently of the age.

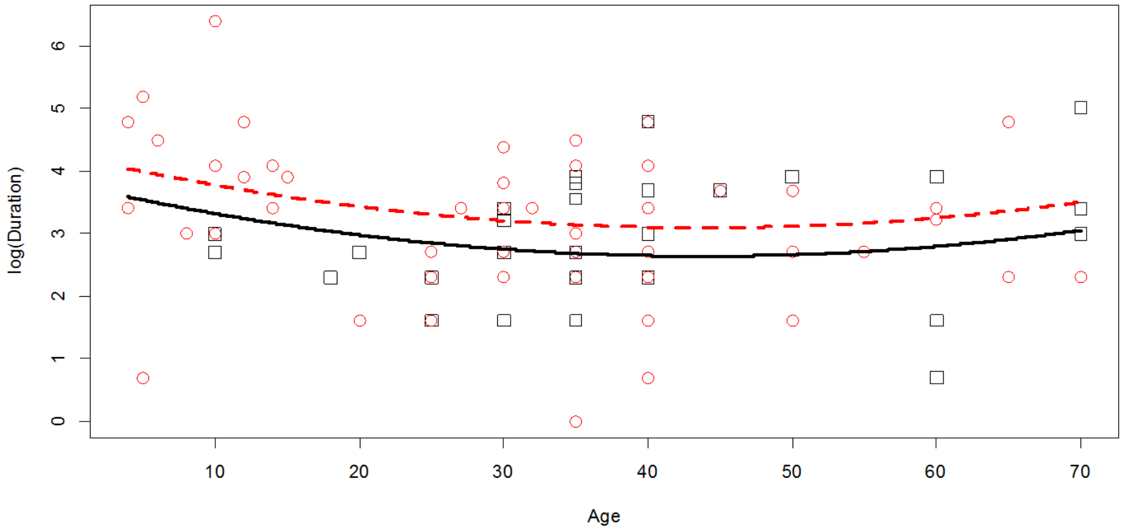

Figure 10. Plot of the fitted model for *log(duration)* against *age, age^2* and *initiative.* The dashed line and round dots (in red) correspond to initiative=”robot starts interaction”, whereas the solid line and square dots (in black) correspond to initiative=”user starts interaction”.

Effects of the robotic states over interaction type

In a third analysis, we studied the effects of the different robotic states in terms of interaction as a dichotomous variable, as already described. Figure 11 shows the results of an initial descriptive analysis using multiple bar charts, from which we can appreciate a weak and non-significant relationship in the case of embodiment (p=0.3729 for the Chi-square test of independence) and a stronger and significant relationship in the cases of status (p=0.0006) and initiative (p=0.0065). It seems that status=”awake” and initiative=”robot starts interaction” clearly favours interaction.

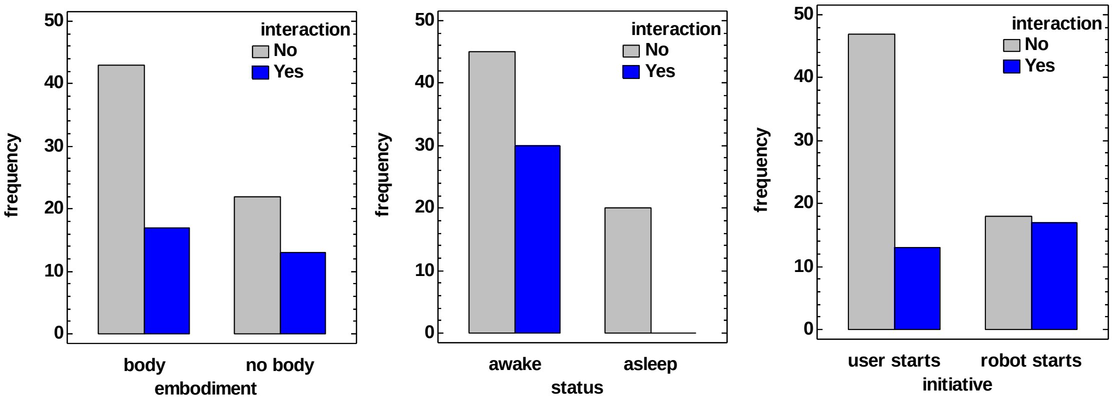

Figure 11. Multiple Bar Charts relating the response variable *interaction* with the independent variables *embodiment, status* and *initiative.*

A logistic regression model (intended for dichotomous response variables) was also fitted to the collected data to evaluate the overall capability of the set of explanatory variables embodiment, status, initiative, age, age^2 and gender, to explain the response variable interaction. The findings of this analysis are irrelevant because the resulting model (after a forward selection procedure) contains just the explanatory variable status (overall significance of the deviance p=0.0000, R-squared=14.80%), which was the most significant in the individual analysis.

Finally, the relationship between the interaction time (duration) and the distance was analyzed. Using logarithmic units for both variables, the scatterplot shows a data cloud exhibiting a decreasing linear trend. The Pearson's correlation coefficient between both variables equals -0.5000 (p=0.000 for the Student t-test, valid for the null hypothesis of a population correlation equal to zero), which indicates a moderate strength for the linear relationship. The shorter the distance, the larger the interaction time, and vice versa. This is a quite interesting relationship between both variables, since the partial correlation coefficient, having excluded the effect of the explanatory variables (embodiment, status, initiative, age, age^2 and gender), equals -0.5005 (p=0.000 for the Student t- test, valid for the null hypothesis of a population correlation equal to zero). This is a very similar value to the one obtained for the overall correlation coefficient between both variables.

5. Discussion

Parting from our research questions, we have evaluated the effects of robot embodiment, status and level of passiveness on the interaction in terms of distance, duration and effective interaction. Age and gender were also included in the analysis as covariables. Overall, the obtained results suggest a baseline in how Sacarino should be presented to users in a hotel environment, along with some fine tuning guidelines that should be taken into account. These guidelines could be relatively generalizable to other robots that share similar or analogous characteristics to the one presented in this paper.

Results from a multiple linear regression model to evaluate proxemics behaviour showed statistically significant effects for the variables embodiment and age. The contribution of the rest of the explanatory variables was not statistically significant. The effects of age and embodiment over proxemics can be observed in Figure 8. Young and old people seem to feel more comfortable close to Sacarino than middle-aged people with a change in the trend happening around age=50. The estimated effect attributable to the embodiment variable is an average increase of the interaction distance when interacting with an embodied robot, independently of the age.

As in the case of the response variable distance, a multiple linear regression model was fitted to explain the response variable duration of the interaction. The effects of age and initiative on the duration can be observed in Figure 8. Young and old people seem to interact over longer periods of time with Sacarino than middle-aged people. The change of trend again occurs around age=50. The estimated effect attributable to the initiative variable is an average increase of the duration of the interaction when the robot takes the initiative, independently of the age.

In terms of age, there is evidence that robots are more readily accepted by children, while adults have reservations about accepting robots as social entities with which to interact. In (Oosterhout, 2008), they state that children are more prone to interact with a short-sized robot. However, even though Sacarino is 1.5m tall, in many of the interactions, children are shown to have a predisposition to approaching our robot and to maintaining longer interactions. This matches other results found in the literature (Woods, 2005; Yokoyama, 2010; Walters, 2005).

Also worth noting is the increasing trend of the distance as the user's age increases until the age of 50, when it starts to decrease again. Our results for people of age >50 are different from those obtained by (Heerink, 2011). Heerink evaluated the predisposition to interact with a robot with 66 older adults, between 65 and 92 years old. His results indicated that age correlates with intention to use, and older participants are less willing to use the robot than younger ones. However, as stated in the literature, changes in robot proximity with elderly users are controversial (Camperio and Malaman 2002). Regarding elderly people, some studies in human-human proxemics have demonstrated the need for greater space, most probably due to a feeling of inadequacy; whereas other studies reveal a tendency in older people to narrow down distances because of a major need for sensorial involvement, as this increases their possibility of interaction by overcoming their declining perceptual abilities (i.e., vision/hearing).

Correlation results indicate a moderate strength for the relationship between the interaction distance and the duration of the interaction with respect to the age variable. As can be observed in Figures 8 and 10, children and older adults tend to maintain shorter interaction distances over longer interactions. However, although our results relating age match those found in the literature, these results need to be explored further, as the observed tendencies could be due to other individual differences that have not been taken into account in our study. For example, the longer interactions observed for children and older adults may be due to the available time that these two age groups have when compared with the middle-aged guests (e.g., leisure vs. business travellers). The amount of available time could, in turn, result in a decrease in the interaction distance, as longer interactions could increase the sensation of comfort, and people tend to stand closer to other people with whom they are more familiar (Hall, E. T., 1966).

Regarding the robot embodiment, results show that users tend to maintain a higher interaction distance towards an embodied agent. In the embodied case, the overall distances obtained from our experiments are consistent with human-robot proxemics literature. Obtained mean scores of the comfort distance for the embodied condition were 69.58 cm, which are slightly higher than those obtained by (Walters et al. 2009) (40 – 71 cm) or (Takayama and Pantofaru, 2009) (25-52 cm). However, as stated in (Mead and Mataric, 2014), in many of these studies, participants are explicitly told to respond to a distance or comfort cue. In our study, as in the one performed by Mead and Mataric, participants were more focused on the interaction itself, so the positioning might have been less conscious. Also, in many of the studies carried out by Walters and Takayama, the robot is not producing gestures, whereas in our study and the one by Mead and Mataric, the robot is gesturing in some of the conditions. The Mead and Mataric study reported an interaction distance of 94 cm, with a gesturing robot that had a long reach. In our case, Sacarino can reach about (25 cm) while gesturing, which could explain the increase in the comfort distance as participants might have positioned themselves to avoid physical contact.

Under the non-embodied condition (where the robot architecture is embedded in a computer and a screen) the mean distance value stays at 45.71cm. This distance could have two different explanations. On the one hand, this is a reasonable distance to interact with a computer so, regardless of the fact that in this condition speech synthesis and voice recognition capabilities were also available, users did not feel any social presence of the social agent and considered it a regular computer. On the other hand, the obtained distance is consistent with the results presented by Takayama (25-52 cm), so it could also mean that users did perceive being in the company of another social agent and stayed at a comfort distance similar to those found in the literature. To obtain a proper conclusion, these results need to be investigated further in future work.

In any case, it seems clear that embodiment affects the interacting distance, and that, in terms of the Hall distance, users tend to maintain a personal distance when interacting with our embodied robot in a hotel environment. It can be seen that this interaction distance is clearly smaller than the social distance expected in a human-human communication for interactions among acquaintances (120 – 370 cm), as the one hotel users would maintain with a human bellboy.

In terms of the duration of the interaction, embodiment engages users in maintaining longer interactions. Our results seem congruent with the ones found in the literature. For example, in (Schermerhorn and Scheutz, 2011), they show that subjects interact differently with a simulated robot than with a physically present robot, and that users tend to issue fewer commands to the simulated robot than to the embodied robot. Also, in (Bainbridge et al., 2011), they show that participants in their study had an overall more positive interaction with the physically present robot, being more likely both to fulfill an unusual request and to afford greater personal space to the robot. In terms of embodiment, it seems that our physically present version of the robot causes an increase in the users' interest, making them explore the robot's functionalities further.

Results associated with taking the initiative at the beginning of the interaction showed a small difference in terms of comfort interaction distance: *robot starts interaction* (*M* = 67.714, *SE* = 12.094) and *user starts interaction* (*M* = 56.750, *SE* = 5.748). This means that once the user has decided to interact with the robot (either taking the initiative or encouraged by the robot), the interaction runs normally in terms of proxemics. However, the small increase in the interaction distance (~10cm) observed when the robot starts the interaction may be related to the fact that our greeting model is based on both a salutation and directional gaze. As stated in (Brandon et al., 2014), the use of eye contact by having the robot's head face the person during a greeting could be highly effective in simulating social behaviour, but persistent eye contact can become uncomfortable, where the robot would appear to "stare" at the person. As (Brandon et al., 2014) suggest, this could be overcome by making use of blinking capabilities (which Sacarino actually implements as a random autonomous movement), and by occasionally staring away from the user direction.

In addition, as reported by (Fiore et al., 2013), a robot is perceived as a more social agent if it is capable of appearing to be considering implicit social rules of politeness during a shared navigation situation (i.e. giving the “right of way” when a path crossing event occurs). Extending this way of thinking to our greeting model, we could postulate that if a user perceives the robot’s greeting as a non-polite gesture (i.e. it interrupts the user, produces a sense of continuous staring), the greeting could be considered as a non-polite gesture, and the robot as a less social agent. Taking this into account, our results are consistent with the ones obtained by (Mumm and Mutlu, 2011), who showed that participants who disliked a robot in terms of attitude and gaze maintained a greater physical distance from the robot than those who did not. Although the difference in terms of distance between the greeting and non-greeting model is not significant (10cm), in terms of our robot design we should consider expanding the greeting experimentation, in order to ensure that our robot’s greeting model does not discomfort potential users.

In terms of the duration of the interaction, significant results show that a robot which takes the initiative in an interaction had a significant effect on the duration of the interactions. Descriptive statistics show a great increase in the duration of the interaction for the ‘*robot starts the interaction*‘ case, and that the duration doubles that obtained for a passive robotic state. These results match others found in the literature, such as the ones obtained by (Heerink et al., 2006), who examined the influence of the social abilities of the robotic agent iCat for elderly participants in eldercare institutions. They used two experimental conditions: one more socially communicative and a less socially communicative interface. Their results showed that the more communicative condition caused a higher communication rate among the participants.

Taking human-human communication as a reference, an expected social behaviour for a robot at the beginning of an interaction should be to greet the user, but this greeting should be performed in a way that is socially acceptable by the user. However, as extracted from the results of (Satake et al., 2009), people usually cease interacting with a robot when they “test” it for a reaction but then do not get the expected response, which implies that a robot that greets users when it is not expected to, or does so in a socially unacceptable way, could cause rejection rather than engagement. It can be observed that, in our case, the greeting model causes a great increase in users’ engagement, which leads us to conclude that our greeting model is socially well-balanced.

Although not statistically significant, differences were found between the *awake* (M = 56.067, SE = 6.280) and *asleep* (M = 78.500, SE = 14.714) conditions. It has been reported in the literature that different social cues in robots can elicit different emotional attributions. For example, in (Fiore et al., 2013), they show that it is possible to include certain social cues in a robotic design to convey certain emotional states that provide information of the intentions of a robot. In our case, the ‘awake’ condition implies a robot that is more active and aroused, and so implicitly conveys a greater sense of social presence in the user, thus inviting him/her to maintain an interaction, and promoting a closer interaction distance. On the other hand, an ‘asleep’ robot seems to be perceived as a machine that is not endowed with any social facets apart from its appearance and thus does not cause any sensation of social presence. It can be observed that the interacting distance is higher, probably because users just stopped by to take a look at the robot.

The above results are correlated with the ones obtained in terms of the duration of the interaction, and the same discussion could be applied when analyzing the data obtained for the duration of the interaction between the 'awake' and 'asleep' conditions. As results show, an 'asleep' robot seems to cause a sensation of non-activeness in the users, and thus the expectations in terms of interaction capabilities and technology usefulness created in the user seem to be lower, which leads to shorter interactions. In (Kheng Lee, 2014), they show that a-priori expectations of robots become less important over repeated interactions as the participants mental models of the robot become more like its actual capabilities. However, it can be seen that in public spaces when short, unstructured and non-repeated interactions occur, it is of special importance to elicit a sense of social presence, capabilities and usefulness in the user as early as possible.

Finally, in terms of the effectiveness of the interaction, results show that an 'awake' status and a robot which takes the initiative during the interaction clearly favours maintaining an interaction. It has to be noted, however, that apparently the embodiment does not seem to benefit maintaining a proper interaction. This effect may be due to the way the variable "interaction type" was considered, as it implies maintaining a full interaction with the robot and obtaining some kind of information from it. Although the regression model applied did not find significant results, it was observed that, on many occasions, the users who interacted with the embodied version of the robot did not pay attention to the robot's screen, where specific instructions of use were shown. As such, users tried to communicate with the robot as if it was a real human being, mainly using voice commands. It has to be taken into account that noise in open environments is a great inconvenience for voice recognition, and that users maintained a relatively long distance from the robot in order to accomplish proper voice-command recognition. For these reasons, the results in Figure 11 show the embodiment as a drawback for effective interaction.

6. Conclusions

In this work, we have investigated the effects of various configurations of our bellboy robot Sacarino in a hotel environment and under real conditions. The results of our experiments have shown that the level of a robot's presence affects social interaction with the robot in terms of proxemics, duration of the interaction and the type of interaction. We have examined physical presence, contrasting human-robot interaction with a physically present robot versus a video-displayed interface. Results have shown that although interaction distance is higher towards an embodied agent, users tend to maintain a personal distance when interacting with our embodied robot, and also, that embodiment engages users in maintaining longer interactions.

On the other hand, we have observed that including a greeting model in a robot is useful in terms of engaging users to maintain longer interactions, while our greeting model does not seem to affect the interaction distance that users feel comfortable in.

Results also show that an active-looking robot is better able to attract the attention of users, producing longer interactions than in the case of a passive-looking robot. The level of activeness clearly influences users' physical and social perception towards the robot, as they maintain a higher interaction distance when the robot is in an 'awake' state in comparison with an 'asleep' state.

Finally, based on our observations of the experiments, the fact that children are the ones who maintain a closer distance was expected, because they play with the robot, they grab it by the arms and they try to move it; in most cases without paying attention to the screen. In terms of the robot design, this implies the necessity of building a robust robotic platform in order to avoid all possible damage. However, this is a positive point of the design, as it indicates that children feel comfortable with the robot. In any case, this behaviour has to be explored further, as the lack of specific data gathered related to the type of guests (e.g., leisure vs. business travellers, nationality), could be a drawback in the explanation of the longer interactions. In any case, our annotations show that children are prone to interact with the robot, maybe because of its cartoonish appearance or maybe due to the novelty effect.

The above conclusions suggest some considerations for designers of service robots intended for open environments such as a hotel foyer. In terms of cost-saving when opposed to interaction effectiveness, developers should take into account the impact that changes in physical presence have before choosing to replace a physical robot with a virtual or video-displayed agent. Also, if looking to increase the robot's autonomy in terms of energy saving, it should be considered that a robot with an 'asleep' appearance produces less engagement in the users, and would not be able to attract as many new users as an active-looking one. In terms of behavioural design, users tend to take human-human communication as a reference, and expect the robot to greet the user at the beginning of an interaction. Our results lead us to consider the importance of including a greeting model in a robot that operates in open environments, as users perceive it as more socially present. As a final design consideration, when the robot includes multimodal interaction channels, such as voice and touchscreen, it is necessary to reconcile the closer interaction distance required by the touchscreen and the personal interaction distance required by face to face voice interaction. This can be alleviated by including large touchscreens and fonts. It has to be noted that, for this reason, Sacarino initially included a 10-inch screen which was replaced by a 17-inch.

Finally, in order to obtain the best results of effectiveness in the interaction, new ways of informing the user how to interact efficiently with the robot need to be considered. The interaction should include training, helping and feedback mechanisms in order to let the user know about the robot's capabilities and its understanding scope.

Acknowledgements

This work has been partially supported by the Ministry of Science and Innovation (grants: DPI2011-25489, DPI2014-56500 and MTM2011-28657-C02-01) and the Junta de Castilla y León (Agencia de Inversiones y Servicios, y Prog. de Apoyo a Proys. de Investigación (grant VA036U14)).

References

Aiello, J., 1987. Human Spatial Behaviour. In D. Stokols & I. Altman, eds. Handbook of environmental psychology. John Wiley & Sons, 359–504.

Alicebot. Artificial Intelligence Markup Language (AIML). http://www.alicebot.org/aiml.html

Altman, I., 1975. The Environment and Social Behavior. Brooks/Cole Publishing Company.

Bartneck, C., Forlizzi, J., 2004. A Design Centred Framework for Social Human-Robot Interaction. In Proceedings of the 13th IEEE International Workshop on Robot and Human Interactive Communication (RO-MAN 2004), Kurashiki, Okayama, Japan. pp. 591- 594.

Camperio, C. A., Malaman, M., 2002. Where to sit in a waiting room: density, age and gender effects on proxemic choices. Hum Evol 17: 175–185.

Dautenhahn, K., et al., 2005. What is a robot companion – friend, assistant or butler? In: IROS 2005, IEEE IRS/RSJ International Conference on Intelligent Robots and Systems, Edmonton, Alberta, Canada, August 2-6 2005, pp. 1488-1493.

Dillon, A., 2001. User acceptance of information technology, in Karwowski, W. (ed.). Encyclopedia of Human Factors and Ergonomics. London: Taylor and Francis.

Fiore, S. M., et al. 2013. Towards understanding social cues and signals in human-robot interaction: Effects of robot gaze and proxemics behavior. Frontiers in Psychology: Cognitive Science, 4(859), 1-15.DOI: 10.3389/fpsyg.2013.00859

Hall, E. T., 1966. The Hidden Dimension. Doubleday, NY

Heenan, B., Greenberg, S., Aghel-Manesh, S., Sharlin, E., 2014. Designing social greetings in human robot interaction. In Proceedings of the 2014 conference on Designing interactive systems (DIS '14). ACM, New York, NY, USA, 855-864.

Heerink, M., 2011. Exploring the influence of age, gender, education and computer experience on robot acceptance by older adults. ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2011 6th.

Heerink, M., Kröse, B.J.A., Wielinga, B.J., Evers, V., 2006. Studying the acceptance of a robotic agent by elderly users. In International Journal of Assistive Robotics and Mechatronics 7, (3), 2006, pp. 33-43.

Kendon, A., 1990. Conducting Interactions: Patterns of Behavior in Focused Encounters. Cambridge Univ Press.

Khan, Z., 1998. Attitudes towards intelligent service robots, Interaction and Presentation Laboratory, KTH, TRITA-NA-P9821, IPLab-154, 1998.

Kheng Lee, K., Syrdal, D. S., Mohammadreza, A-O., Walters, M.L., Dautenhahn, K., 2014. Social Roles and Baseline Proxemic Preferences for a Domestic Service Robot. International Journal of Social Robotics, DOI: 10.1007/s12369-014-0232-4.

Koay, K.L., Syrdal, D.S., Walters, M.L., Dautenhahn, K., 2007. Living with robots: Investigating the habituation effect in participants’ preferences during a longitudinal human–robot interaction study. In: The 16th IEEE international symposium on robot and human interactive communication. ROMAN 2007. pp 564–569.

Kuli´c, D., Croft, E., 2007. Pre-collision safety strategies for human–robot interaction. Auton Robots 22(2):149–164

Ljungblad, S., Kotrbova, J., Jacobsson, M., Cramer, H., Niechwiadowicz, K., 2012. Hospital robot at work: something alien or an intelligent colleague? In Proceedings of the ACM 2012 conference on computer supported cooperative work. ACM, pp 177–186.

Marcos, S., Gómez-García-Bermejo, J., Zalama, E., 2009. A realistic, virtual head for human-computer interaction. Interacting with Computers. 22 - 3, pp. 176 - 192. Elsevier.

Marcos, S., Zalama, E., Gómez-García-Bermejo, J., 2013. Dynamic Facial Emotion Recognition Oriented to HCI Applications. Interacting with Computers. online - online, pp. online - online. Elsevier,14/11/2013.

Marquardt, N., Diaz-Marino, R., Boring, S., Greenberg, S., 2011. The Proximity Toolkit: Prototyping Proxemic Interactions in Ubiquitous Computing Ecologies, Proc. ACM UIST, 315 - 326.

Mead, R., Atrash, A., and Mataric, M., 2011. Proxemic Feature Recognition for Interactive Robots. Proc Social Robotics, LNCS Volume 7072, pp. 52-61, Elsevier.

Mead, R., Atrash, A., Mataric, M., 2013. Automated Proxemic Feature Extraction and Behavior Recognition: Applications in Human-Robot Interaction. Int J Soc Robot, 5(3)May, Springer

Mead, R., Mataric, M., 2014. Perceptual Models of Human-Robot Proxemics. 14th International Symposium on Experimental Robotics (ISER 2014). Marrakech/Essaouira, Morocco.

Mumm, J., Mutlu, B., 2011. Human-Robot Proxemics: Physical and Psychological Distancing in Human-Robot Interaction. Proc ACM HRI, 331-338.

Oosterhout, T. V., Visser, A., 2008. A Visual Method for Robot Proxemics Measurements. International Conference on Human-Robot Interaction, Vol. 3, pp 61-68.

Pacchierotti, E., Christensen, H. I., Jensfelt, P., 2006. “Evaluation of passing distance for social robots,” in The 15th IEEE International Symposium on Robot and Human Interactive Communication (RO - MAN06) Hatfield, UK: September 6 –8, 2006.

Ray, C., Mondada, F., Siegwart, R., 2008. What do people expect from robots?. In: IROS 2008, IEEE IRS/RSJ International Conference on Intelligent Robots and Systems. pp 3816—3821.

Reeves, B., Nass, C., 1996. The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places. Cambridge University Press.

Sabanovic, S., Michalowski, M. P., Simmons, R., 2006. Robots in the Wild: Observing Human-Robot Social Interaction Outside the Lab. AMC proceedings 2006 Istanbul.

Satake, S., et al., 2009. How to Approach Humans? Strategies for Social Robots to Initiate Interaction. Proc ACM HRI.

Saulnier, P., Sharlin, E., Greenberg, S., 2011. Exploring Minimal Nonverbal Interruption in HRI. Proc RO-MAN, 79-86.

Schermerhorn, P., Scheutz, M., 2011. Disentangling the Effects of Robot Affect, Embodiment, and Autonomy on Human Team Members in a Mixed-Initiative Task ACHI 2011, The Fourth International Conference on Advances in Computer-Human Interactions, pp. 236-241.

Sommer, R., 1969. Personal Space: The Behavioral Basis of Design. Prentice-Hall.

Syrdal, D. S., Dautenhahn, K., Koay, K. L., Walters, M. L., Ho W. (2013). Sharing spaces, sharing lives - The impact of robot mobility on user perception of a home companion robot Social Robotics: 5th Int Conf, ICSR 2013. Springer, 10, pp. 321-330.

Takayama, L., Pantofaru, C., 2009. Influences on Proxemic Behaviors in Human Robot Interaction. IEEE Int’l Conf Intelligent Robots and Systems, 5495-5502.

Walters, M. L., Oskoei, M. A., Syrdal, D. S., Dautenhahn K., 2011. A long-term Human-Robot Proxemic study. Procs IEEE Workshop on Robot and Human Interactive Communication: RO-MAN 2011. IEEE, 6, pp. 137-142.

Walters, M., Dautenhahn, K., Boekhorst, R., Koay, K. L., Syrdal, D. S., Nehaniv, C. L., 2009. An Empirical Framework for Human-Robot Proxemics. New Frontiers in Human-Robot Interaction: Symp. AI and Simulation of Behaviour. pp. 144-149.

Walters, M., et al., 2005. Close Encounters: Spatial Distances between People and a Robot of Mechanistic Appearance. International Conference on Humanoid Robots. Vol. 5, pp 450-455.

Weiss, A., et al. A Methodological Variation for Acceptance Evaluation of Human-Robot Interaction in Public Places. Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication, Technische Universität München, Munich, Germany, August 1-3, 2008.

Wilma, A., et al., 2011. The Benefits of Interactions with Physically Present Robots over Video-Displayed Agents. International Journal of Social Robotics , Vol. 3, 1, pp 41-52.

Woods, S. N., et al., 2007. Are Robots Like People? - Relationships between Participant and Robot Personality Traits in Human-Robot Interaction. Interaction Studies, 8(3). pp. 281-305.

Woods, S., et al., 2005. Is This Robots Like Me. Links Between Human and Robot Personaliti Traits. International Conference on Humanoid Robots, 5 ,pp. 375-380.

Yokoyama, A., Hakata, M., 2010. The effect of the distance between human and robot in RAA setting. SICE Annual Conference, pp 1423-1425.

Zalama, E., et al., 2013. Sacarino, a Service Robot in a Hotel Environment (2013). Advances in Intelligent Systems and Computing, Vol.253, Springer.