How People's Perception on Degree of Control Influences Human-Robot Interaction

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A dissertation submitted to the University of Hertfordshire in partial fulfillment of the requirements of the degree of Doctor of Philosophy

Thursday 31st January, 2019

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Acknowledgement

First, I would like to thank my supervision team that has been very helpful, supportive and very good at providing quality feedbacks. So a big thank you to Dr. Kerstin Dautenhahn, Dr. Kheng Lee Koay, Dr. Mick Walters, Dr. Gabriella Lakatos and Dr. Maha Salem for their encouragements and their help. Each one of them contributed to make this work possible, and I will always be grateful for this.

Second, I would like to thank the School of Computer Science of the University of Hertfordshire for giving me a scholarship that allowed me to do my PhD. It has been a great opportunity to work in the Adaptive System Group with such amazing people. Thank you Nathan for teaching me how to use Sunflower. Thank you Dag for your advices and your guidance on statistics. Thank you Luke for the moral support and the advices on how to write a thesis. Thank you Alessandra, Christoph, and Azeemsha for helping me to recruit participants. Thank you Joe for proof reading some of my papers and applications. Thank you Patrick for resetting the network of the Robot House when I needed it to work. And finally thank you to all the other members of the lab and the group that I have not named, for being supportive, and made the work so enjoyable.

A special thank you to my partner Andrew Rigby who supported me, especially during the last stage of my PhD.

A big thank you to all my family members and friends that always encouraged me and believed in me.

And finally, I want to dedicate this thesis to my grandmother, the most wonderful woman in the world.

Un grand-merci à tous mes oncles et tantes, cousins et cousines pour vos soutiens durant toutes mes études.
Une mention spéciale à mon oncle Jean-Claude Liou qui apprécie les robots autant que moi.
Pour tantine Marguerite et tonton Albert, que j'embrasse très fort.
Pour tonton Carlos, qui m'a un jour dit que faire un doctorat est comme écrire un très long mémoire.
Et enfin pour toi Mémé, à qui je dédicace cette thèse. Sans toi je ne serai pas la personne que je suis aujourd'hui.

Abstract

Automated products that seem to be more sophisticated every day are invading the market. Gmail provides suggestions for emails responses and can even track important dates through emails and send a notification about it without the user's permission. As robot companions are just slowly starting to be available to the public, one must wonder, do people expect robots to have the same technology advancements as other technology tools such as smart phones? Is it really what people want? Some early research on control has been made in the Human Computer Interaction community by Shneiderman & Maes (1997) to discover how much control the user is ready to give up to an intelligent agent. This PhD does the same type of investigations for domestic robots by focussing on perception of control in Human-Robot Interaction (HRI). To be able to conduct such an investigation, the user's perception of control is measured through the robot's level of autonomy. As this thesis will show, little research has been done in this area for domestic robot companions. After a first exploratory study was conducted to gain a better understanding of perception of control related to the user's preferred level of autonomy of the robot for a simple task (cleaning), three questionnaire studies have investigated what makes a task high critical or low critical, physical or cognitive. The results could then be used to design a full live investigation on how the level of criticality of a task influence the user's preference of the robot's level of autonomy.

The results of this thesis show that in general people want robots to be more autonomous but they still want to have control over the robot for most tasks. People prefer to give instructions to the robot when a cognitive task is performed regardless of the criticality of the task, and for a low critical physical task that is entertainment-based. However, for a high critical physical task, the user prefers the robot to be fully autonomous even if they feel they have less control over the robot. This is explained by the way participants perceived the performance of the task. When the robot was fully autonomous, they felt the task was done faster and smoother than when they had to continuously provide instructions to the robot.

"If knowledge can create problems, it is not through ignorance that we can solve them."

Isaac Asimov

Chapter 1

Introduction, background research and motivations

1.1 Introduction

In the late 1990s, the question of control was raised in the Human Computer Interaction (HCI) community within the process of designing computer interfaces (Shneiderman & Maes 1997). The debate was on what was the best user interface between a software agent that proactively helps the user with manipulations, or having the user to do a direct manipulation using a mouse for example. As history told us, the mouse became the popular tool for using computers (Pekelney & Chu 1995). However, with the technological developments on Artificial Intelligence (AI), software agents such as SIRI, OK Google, or Alexa are becoming more popular among the public. As robot companions are seen to be a tremendous help for Healthcare (Dahl & Boulos 2014), researchers in Human-Robot Interaction (HRI) keep working on factors that can influence the user acceptance of robots.

Dautenhahn (2007) defines a companion robot as a robot able to provide useful assistance in a socially acceptable manner. Following this definition, the robot companion needs to be functional and easy to communicate to. Gross et al. (2015) studied how seniors react to a home robotic health assistant. As they underlined in their studies, the main advantage of a robot over other smart devices such as tablets and computers, is the proactive behaviour that the robot can express. Their participants enjoyed having the robot although, they hesitated leaving their robot home for a long period of time. Although this study had a small number of participants (9 trials), it shows there is a great potential to develop robot companions further.

Some robotic devices are already available to the public, such as the Pepper robot from Aldebaran robotics (Aaltonen et al. 2017) which can already been found in some shops in Japan and Paris, Roomba from IRobot which is a smart vacuum-cleaner, or Amazon Echo/ Google Home which are conversational robots (Turkle 2017). The constant presence of these devices into people's life raised some ethical concerns in the community (Whitby 2008). It seems that those devices become smarter and are now even capable of booking appointments for us and become our personal assistants. However, is it really what the user want? Looking back on the inspiring work on user interface done in HCI (Shneiderman & Maes 1997), once must wonder, what is the best way for users to control their robot?

Little studies have been conducted on the users' perception of control of their robot (Meerbeek et al. 2006), while it could potentially reshape the way robotic designers think. This is why this PhD dissertation decided to focus on the users' perception of control and investigate how the robot's performance of a task, influences the user's choice of control of the robot.

Although supervisors provided guidance and regular advices regarding this research, the author of this thesis designed, conducted, and analysed every study described in this dissertation. The work was exclusively written by the author of the thesis, and the terms ”we”, ”our”, ”us” sometimes used, are here for stylistic purposes only.

1.2 Motivations

This section presents the current state-of-the art of work done in Human-Robot Interaction (HRI) and other relevant field, related to this PhD. The research presented in this thesis investigates specifically what the user's preferred level of control of the robot is, depending on the type, and the criticality of the task the robot is performing. As this PhD focusses on domestic robot companion, perception of control and criticality, each topic is developed separately.

1.2.1 What is a robot companion?

1.2.1.1 Definition of a social robot

Breazeal (2003) distinguishes four types of interactive robots based on the observation of human behaviour towards complex entities such as living creatures or advanced technology. She defines key concepts as follows:

- ”social robots” as robots capable of giving the impression of being intelligent.
- ”Socially evocative” robots are made to give the opportunity to users to bond and interact with the technology.
- ”Social interface” robots communicate with people in an anthropomorphic way to simplify interactions with people.
- ”Socially receptive” robots receive some human characteristic feedback.
- ”Sociable” robots can engage with users and learn from them.

The later is the type of social interactiveness that is usually sought in a robot companion. Furthermore, if the feedback and the behaviour of the robot is based on human-like intelligence and social behaviour, the robot can be qualified as ”socially intelligent” (Dautenhahn 2007). However, social interactiveness does not necessarily come from an anthropomorphic based intelligence or behaviour. It depends on the HRI (Human-Robot Interaction) scenario that the robot is placed into.

1.2.1.2 What capabilities should a robot companion have?

Dautenhahn et al. (2005) conducted an exploratory study in which one of the aims was to determine users' requirements of a robot companion. According to their results, human-like behaviour and appearance appeared to be secondary requisites although participants wanted their robot to be polite. The proposed criteria of a robot companion is one that is able to ”communicate with non-experts in a natural and intuitive way.”(Dautenhahn et al. 2005). That means that users would not need training to be able to communicate and use their robot. It is important to consider this as elderly people (potentially main recipients for robot companions) do not have the same patience and awareness as younger people regarding technology (Mallenius et al. 2007). Therefore, two aspects need to be taken into consideration when building a robot companion: its capabilities which not only include interactive behaviour but also helping behaviour, and its appearance.

1.2.1.2.1 Social behaviour

In terms of emotional support, the robot has to react following human rules of etiquette. Dautenhahn (2007) discusses the importance of the "robotiquette" and what type of behaviour is considered appropriate for a robot. To devise a programme for robotiquette, Nehaniv et al. (2005) studied human gestures. The idea is for the robot to understand situations, for example, not interrupting a conversation between two people or not preventing someone from work unless there is an emergency, knowing what appropriate distance should be maintained during a conversation for example (proxemics/ space). Nehaniv's study shows there is a lot to take into consideration when it comes to robot social behaviour and capabilities.

Breazeal (2003) stated that "social interaction is a dance". This means that to allow a social interaction, the participants need to exchange with each other. This underlines the fact that social interaction needs to be initiated by the robot as well as the user which connects to the "robotiquette" mentioned above. Breazeal (2004) listed all the design issues that robot companions involve : the difference between interacting with a robot and interacting with software agents, a lack of enthusiasm that some people may have to engage with the technology, matching people's expectations of the robot, enhancing the right aspect of the technology to make it more appealing, the type of relationship a user can develop with the robot, the satisfaction that a user can get from a robot in a teamwork context, the personality of the robot, and how robots are to be integrated into society.

1.2.1.2.2 Embodiment and proxemics

As Weistroffer et al. (2013) state, virtual robots have been used to help study implementation of physical robot companions. However, making the virtual agent acceptable is more difficult than for the physical robot. Even though the virtual agent can display the same cognitive capabilities as a physical agent, Wainer et al. (2006) showed that having a physical entity provides a presence that a virtual one cannot have. Indeed, Bainbridge et al. (2011) demonstrated in their study that a participant was more willing to fulfill an unusual request when it came from the physical robot rather than a screen. Wainer, Feil-Seifer, Shell & Mataric (2007) investigated the extent to which the physical embodiment affects social interaction. Their findings were that physically embodied robots tend to be more effective in assistance and therapy. Furthermore, the robot gave a better impression to the participant. Fasola and Mataric's study (Fasola & Mataric 2011) confirms this difference between physical and virtual embodiment. The results of their study showed that people had a strong preference for the physical robot over the virtual agent. Their findings also suggested that participants felt more at ease with the real robot and felt more compelled to interact. This correlates with Lee's study (Lee 2004) on social presence. Social presence is defined as "the extent to which other beings coexist and react to you." This implies there is an action/ reaction relationship between the robot and its user. The robot responds to the user and vice-versa. Takayama & Pantofaru (2009) have explored what could influence proxemics between a human and a robot. To do so, they conducted an HRI experiment with a PR2 robot. Their findings show that having a pet decreases the personal space between the human and the robot, and also that the user's personality plays a role in proxemics. It would be useful to discover the extent to which user's personality can influence the user's reactions to robots. It was interesting to see that Takayama and Pantofaru took into consideration having a pet. Although they show a positive correlation, it was unclear how people were considering the robot. Indeed, being used to having a pet may induce the idea that robots act similarly to people and this could explain some peoples' receptiveness to robots. Physical embodiment forces the conducting proxemics.

As the literature confirmed, using a physical robot for the PhD study is more appropriate if we want to get positive responses from participants rather than using a virtual entity, which is what I chose to do. As smartphones, computers and tablets are now widely spread, there is a level of expectation of autonomy from a robotic system. The next subsection explains what autonomy means for a robot, and detailed the different level of autonomy robots can have.

1.2.2 Robots level of autonomy

1.2.2.1 Definition of autonomy applied to robots

The etymology of autonomy comes from Greek, autos ("self,") and nomos ("law") (Oxford English dictionary Last accessed 30/01/2019*a*). Over the years, many definitions of autonomy appeared in the literature. One of the first definition was that "the robot should be able to carry out its actions and to refine or modify the task and its own behaviour according to the current goal and execution context of its task." (Alami et al. 1998). A few years later, an element of intelligence was added to the definition. Researchers mentioned decision-making, planning, or the ability to operate without any form of external control as Beer et al. (2014) detailed in their taxonomy on levels of robot autonomy. Their definition of robot autonomy for HRI was something that "broadly refers to the system?s capability to carry out its own processes and operations". For the purpose of this PhD investigations, it was chosen to use their guidelines for robot autonomy. To suit the PhD live studies, robot autonomy was defined as the ability of the robot to make its own decisions.

1.2.2.2 Classification of autonomy in HRI

In the early age of HRI, Yanco & Drury (2002) thought of different level of autonomy that can exist within the field. They took into consideration 8 levels depending on the situation (context of the interaction), the criticality (potential danger the robot's action can have), the time (using the robot now or later), the space (using the robot here or in a different location), the number of robots and what it involves. Their taxonomy also considered the number of humans controlling the robots but only in one specific situation where the decision was unilateral.
The authors have updated later on their taxonomy by mentioning having a hierarchical system in robots between humans (Yanco & Drury 2004). For instance for computers, administrators have more rights than users, but users can still use the computer. They thought of a similar system for robots. In the context of domestic companions where different family members may use the robot, we can imagine having the parents setting rules about their children television allowance time.

1.2.2.3 Collaborative work

Human robot collaboration seems to be particularly important for the industry. Sheng et al. (2015) have worked on a framework that allows the robot to work with the human to perform a manipulation task. They showed that for simple tasks, human robot collaboration is possible. Other researchers worked in the same direction to show how useful human robot collaboration could be to the industry (Charalambous et al. 2015). However, it is difficult to find such work done on a domestic setting in which home robot companions and participants would work together to perform a specific task (Scassellati & Tsui 2014). It is probably because as Scassellati & Tsui (2014) pointed out in their article, in a realistic setting, people are not trained to use their domestic robot companion to perform tasks together. This means to make this PhD experiments meaningful, tasks perform by the robots need to be easy to relate to for the users.

1.2.2.4 Task delegation

Atkinson et al. (2014) focussed on what teamwork requires to be successful and more particularly human-robot teamwork. They defined a model in which they focus in commitment, specification and control. They argued that trust is necessary to allow a shift on authority and control between humans and robots. Herr et al. (2016) investigated what type of domestic tasks people would be ready to delegate to their robot companion. They found that tasks that participants find unpleasant, time-consuming or cumbersome were the ones that a robot companion should perform well, but tasks that can require some assistance such as cooking or plumbing (typically when you need the robot to hold the lamp and so on...) were not necessarily tasks that a robot should perform or is expected to perform. Therefore, for the purpose of this PhD, it was chosen for the robots to perform single-purpose tasks, as it seems that multiple-purpose tasks (cooking, plumbing...) are not what the user expects a robot to perform well.

As the literature pointed out, it is important to select what type of task a robot is performing according to its environment. Criticality is one of the key factors that is considered when choosing a task. The following subsection will explain the concept of criticality and previous research done on how to rate the criticality of a task.

1.2.3 Criticality

1.2.3.1 What is criticality?

Criticality is an unclear concept that has been widely studied in different areas of research. In linguistics, criticality is defined as "an evaluative judgement made within any field of human activity about some aspect, object or behaviour of that field" (Bruce 2014), meaning that criticality is subjective and context dependent. In biology, criticality "describes sudden changes in the state of a system when underlying processes change slightly" (Pascual & Guichard 2005). Criticality is then perceived as a sudden dramatic change in the expected event (Pascual & Guichard 2005, Bygrave & Hofer 1992). In the field of Human-Robot Interaction (HRI), Yanco & Drury (2002) defined criticality as "the importance of getting the task done correctly in terms of its negative effects should problems occur". Since this definition was provided, no research has yet been performed to analyse how to apply it to standard tasks performed by robots, and more precisely, everyday tasks that home robot companions might be expected to perform. It seems that in HRI, Yanco & Drury (2002) were the first researchers to mention criticality as one of the criteria that should be considered regarding a task that a robot performs. They agreed on their updated taxonomy (Yanco & Drury 2004) that the criticality of a task is highly subjective, therefore difficult to measure. In medicine, there seems to be a clearer definition for task criticality. Patesson & Brangier (2016) defined the criticality of a task according to ten characteristics: "Deliberate, Uniqueness, Learning restriction, Planning, Expertise, Preparation, Collective, Hazardous, Rigidity and Uncertain outcome". It can be noticed that uncertain outcome in the later matches the "negative effects should problem occur" of Yanco and Drury's definition. It shows that for an experimental study, it is necessary to provide a clear definition of criticality, which leads us to one of the research questions of this thesis:" RQ3 What defines task criticality?".

1.2.3.2 Criticality in automated systems

Parasuraman & Miller (2004) studied how criticality affects trust in automated systems. In their study they choose to associate criticality to reliability since they conducted a study on a flight simulator. It was found that the biggest factor that influences participants' trust on the system was not how reliable the system was, but how much of a good etiquette the system was providing to the user. In their investigation they put participants under pressure with a high critical task to perform (diagnose the system while flying), and depending on the system responses, the user rated how trustworthy and reliable they perceived the system to be. Their results showed a high critical task can influence people's perception of the reliability and the trustworthiness of a system.
Xu et al. (2015) conducted a study to understand what the user of a domestic robot companion needs. They found that they are acceptance problems with the three generations of people (youngster, workers and elderly) but not in the same category. It seems the main concern people have over a service robot after its cost, is malfunction. They also found that people mainly ask for the robot to be able to perform house chores. Therefore, according to this study, it seems that performing house chores is highly critical for the end-users.
When Carlson et al. (2014) tried to identify factors involved in trust in automation, they have noticed that for high and low critical tasks, the brand of the company matters. In this study researchers used the example of an automated car and a medical diagnosis system. In both areas, they used safety as a criticality criteria. The interesting results were that people tend to rely more on brands than on non-branded products.
Mitzner et al. (2011) found that for a task considered too critical, in their study "giving medication", users preferred a human to perform the task rather than the robot. This supports Beer et al. (2014) idea that some tasks may only be carried by humans.
Beer et al. (2012) claimed that criticality is also dependent on accountability. Indeed, when it comes to collaboration work, between a human and a robot, if the robot were to fail to perform a task, the human would then be held accountable. This would immediately raise the criticality of the task.

1.2.3.3 Different level of criticality

Ezer et al. (2009*b*) did a study to see whether criticality has an effect on the perception of the home robot companion. They conducted a questionnaire study via email. They chose to use the interactiveness (the more time you spent with the robot, the more interaction you have) as a combined criterion to study criticality. The authors found that people were less willing to have a robot performing low critical tasks if it requires a lot of interaction between the human and the robot. However, the researchers admitted they were unsure of the results since they did not provide a clear explanation of how they allocated tasks to its given level of criticality.
As Tzafestas (2016) later developed, three levels of criticality can be distinguished: high, medium and low. However, he did not specify how to quantify the failure, and neither how to measure its consequences on a human life. Guiochet et al. (2017) studied safety critical advanced robots. They mainly focussed on industrial and advanced robots, and detailed the steps of how to evaluate a task. They looked at a task complexity, its function, and the type of safety rules that could be applied. However, If we apply those rules to a domestic robot companion, some household tasks that seem simple such as ironing have proven to be complex to execute, as Dai et al. (2004) explained in their paper.
Some other studies (Beer et al. 2012, 2014, Mitzner et al. 2011) suggested that the perceived

level of criticality of a task performed by a robot, depends on how much people wanted the task to be performed by a human. Beer et al. (2012, 2014) and Mitzner et al. (2011) used the example of giving medication in their studies and found that people preferred having a human for this task rather than a robot. However, their findings suggested that some other factors may have influenced their participants, such as trust or the visual appearance of the robot. Therefore alongside this PhD investigations, a paper (Chanseau, Dautenhahn, Walters, Koay, Lakatos & Salem 2018) studied if there is a relationship between how participants rate task criticality and robot appearance. This paper was published at RO-MAN 2018 and is entitled "Does the appearance of a robot influence people's perception of task criticality?" (Chanseau, Dautenhahn, Walters, Koay, Lakatos & Salem 2018).

As the literature revealed how complex the concept of criticality is, it became necessary to investigate it further to understand how to distinguish different levels of criticality. This results to the following research question: "RQ4 What type of criteria do people consider rating the criticality of a task?". The next subsection explores different factors that influence the user in HRI.

1.2.4 What factors influence the user in Human Robot Interaction?

1.2.4.1 Robot appearance

According to Dautenhahn's study (Dautenhahn 2007), people were keen on having a robot companion that could assist them and serve them in a considerate and polite way. However, they also expected to be able to predict and control what the robot would do. This shows there is a scale of tolerance that can be drawn about the autonomy of the machine related to its capabilities. In this case, apparently people may not want a robot with butler and assistant capabilities to be too autonomous. This can be related to the very far end of the Mori's theory on the Uncanny Valley. According to recent papers, there are many outcomes for the extended Uncanny Valley theory, although Mori never believed that we should go beyond the Uncanny Valley (Kageki 2012), as robots are not meant to become human.

1.2.4.1.1 The "Uncanny Valley"

One of Bartneck's paper suggested there was an uncanny cliff (Bartneck et al. 2007) rather than a valley. It is suggested that robots could be perceived as human beings after the cliff Fig.1.1. However, this theory was formulated after an experiment made with static images rather than dynamic robots. Therefore, as Bartneck et al. (2007) state in their paper, it is difficult to measure and draw the uncanny valley as people's culture, habits and likeliness to robots may change the outcome. Indeed, if a participant gets used to an android that made the person nervous, he/she may change his/her point of view after a certain period of time.

The popularisation of the uncanny valley is often associated to an-end-of-the-world scenario in which robots rule all humans Fig.1.2. This is probably due to the abundance of film and other media that portray robots as evil such as in the Terminator series or the film I-Robot inspired by Asimov's book. A futurist named Cascio (2007) theorised an opposite theory saying that beyond the uncanny valley, a symmetrical one would be found (see Fig.1.2). This proposed uncanny valley suggests that transhumanism can be perceived as uncanny. Transhumanism comes from trans and human which means across or beyond human (Bostrom 2005). It relates to the idea that human beings can be enhanced with science and especially technology. So for instance, a robot carrying a human conscience would be considered uncanny.

Those models propose some perception of what people will expect in the future and how they will react to it. They can be associated with the development of artificial intelligence and

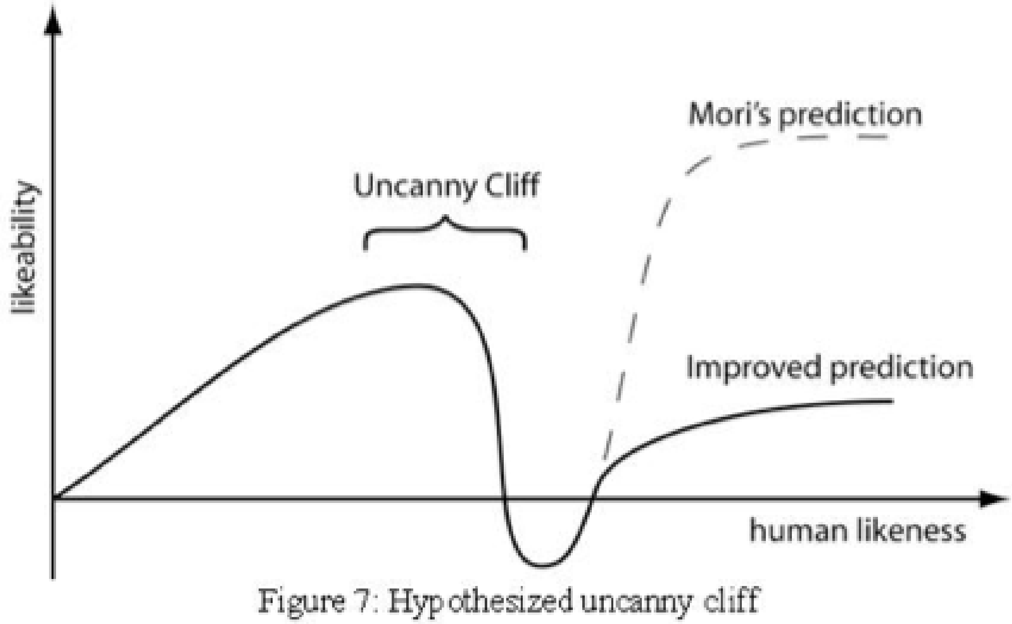


Figure 1.1 – Bartneck et al. (2007) improved uncanny valley

autonomy. If a robot is considered smart enough to do some tasks but stoppable when it is needed, people would probably accept it. However, if an artificial intelligence is considered so advanced that it can be compared to a mind then, people would put it at the far end of the uncanny valley, into the Terminator scenario. This is why for the live studies conducted for this PhD, robots that do not appear human-like were used.

1.2.4.1.2 How does the appearance of the robot affects people's perception?

Several previous studies have shown that robot appearance affects the people's judgement of robot behaviour. In one of the early studies, Goetz et al. (2003) investigated how to improve Human-Robot Cooperation by matching robot appearance and behaviour to the task the robot had to complete. Later on, Walters et al. (2008) showed that there is a tendency for people to prefer some human-like attributes in robots. In a recent study, Malle et al. (2016) demonstrated that robot appearance can also affect people's moral judgements about robots. In a moral dilemma, people blame robots more for inaction than action, and they blame humans more for the opposite. They also found evidence that people treated a mechanical-looking robot differently from a human-looking one, when both robots were described identically. Abubshait & Wiese (2017) investigated how robot appearance and behaviour influence HRI, and they found that a robot's appearance affects mind judgements (e.g the attributed intentions the robot has). Salem et al. (2015) suggested in their study that "the robot's level of anthropomorphism may lead to different degrees of 'forgiveness' in humans". Although their study did not focus on appearance, as only one robot was used, potentially this could mean that the more human-like the robot appears, the less forgiving people are when it makes mistakes.

1.2.4.2 Perception of tasks performed by the robots

Previous research has investigated how trustworthy a robot is perceived by people, depending on the task the robot is performing. Salem et al. (2015) showed in their study that the type of task performed by the robot matters. It seems that the irreversibility of some actions to carry out by people which were suggested by the robot prevented most of their participants from performing

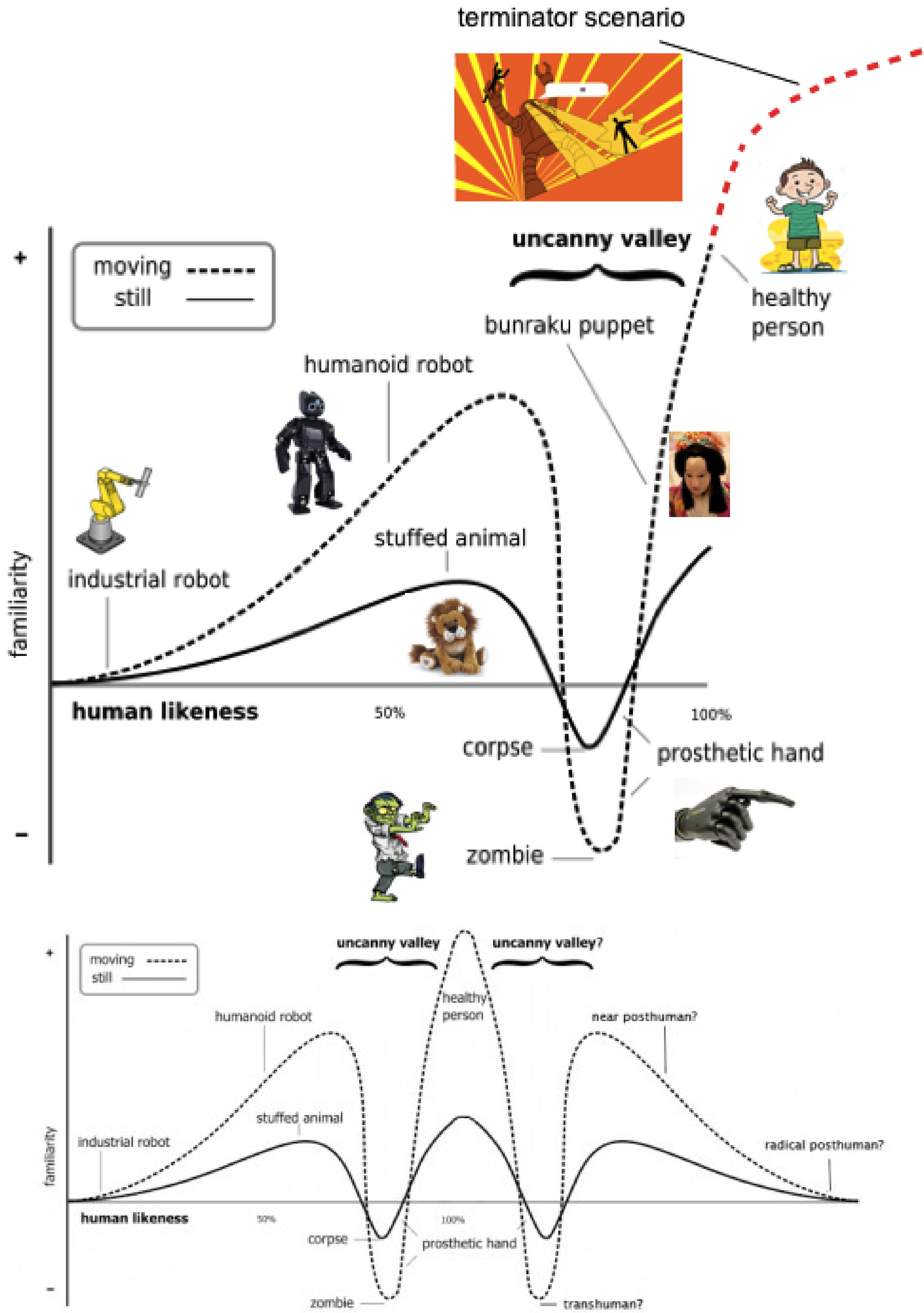


Figure 1.2 – Apocalyptic scenario versus "second uncanny valley" (Walters et al. 2008, Cascio 2007)

them. Prakash & Rogers (2015) showed that perceptions of robots' human-likenesses changes for different types of tasks (personal care, social, decision-making and chores). Their experiment underlined that robotic appearance was least appreciated for decision-making types of tasks, in their case, money investment. Overall they found that older people preferred human-like robots for personal care, chores, social and decision-making tasks compared to younger people who expressed a more diverse preference (mechanical appearance, mixed appearance or human appearance). Hinds et al. (2004) found that in an industrial context where robots and humans work together on various tasks (assembling objects, carrying objects, designing something with the participant), people preferred overall to have a machine-like robot over a human-like robot. This difference shows that robot appearance preferences may depend on the environmental context (e.g. home versus a factory).

1.2.4.3 Robot anxiety

Robot anxiety is a term that can be found in the literature to define the effect that a robot has on a person at an emotional level. Nomura, Suzuki, Kanda & Kato (2006) defines robot anxiety as "the emotions of anxiety or fear preventing individuals from interaction with robots having functions of communication in daily life, in particular, communication in a human-robot dyad". To investigate this, Nomura et al. (2004) developed early on a Negative Attitude toward Robots Scale (NARS) test, and later on a Robot Anxiety Scale (RAS) (Nomura, Suzuki, Kanda & Kato 2006). His team studied how robot anxiety prevents people from interacting with a robot (Nomura, Kanda & Suzuki 2006, Nomura et al. 2011).

1.2.4.4 Effect of technology awareness

Flandorfer (2012) wrote a review paper that summarised studies made on the influence of demographics on robot user acceptance. She mentioned that experience with technology is often mentioned through the papers she analysed. It is one of the main argument that supports why youngsters are more keen on robots than old people. Ezer et al. (2009*a*) study showed that when young and old adults have similar experience with technology, their expectation of the robot will be the same. Heerink (2011) confirmed the finding in his research. He found that the more experienced with computers participants were, the easier to use they perceived the technology to be. The most recent study (Bernotat & Eyssel 2018) on stereotypes about technology awareness shows that Germans and Japanese people were not as exposed to robots as they would stereotypically have expected, and that they do not have an enthusiastic opinion on robots. These studies show that it is important to take into consideration exposure to technology as part of the demographic study in investigations on robots. This is what was done for the two live studies presented in this PhD dissertation.

1.2.4.5 Effect of personality

Miwa et al. (2001) studied if people could recognise the personality that a robot has. They have chosen to implement 3 different personalities, Agreeableness, Conscientiousness and Neuroticism, based on Goldberg's Big five factors (Goldberg 1990). Their studies show people could recognise the different personalities that the robot showed. In 2006 this study was taken forward by Lee et al. (2006). They found that a robot's personality can be recognised based on verbal and non-verbal behaviour and that furthermore, participants tend to prefer robots that show a similar personality to theirs. However, some other studies show there were no significant correlation between participants' preferences of the robot matching their own personality (Woods et al. 2007). Therefore, it is difficult to assess how the participant's personality affects the choice of a robot.

As the background research shows, there are a lot of aspects that can influence people's perception of a robot (perception in a general meaning such as perception of how human-like the robot is or how intelligent the robot is and so on). This thesis focusses on a more subtle personality trait, sense of control. The following subsection explains in details what sense of control means.

1.2.5 Sense of control or sense of agency

1.2.5.1 What is sense of control?

Sense of control is a widely discussed concept in psychology (Möllering 2005, Pacherie 2007, Haggard & Tsakiris 2009). It refers to the perception that a person has that she or he is the author of a given action (Pacherie 2007). In psychology, sense of control also means sense of agency, which refers to "being in control both of one's own actions and through them" (Haggard & Tsakiris 2009). When it comes to performing an action, three steps are involved: thinking

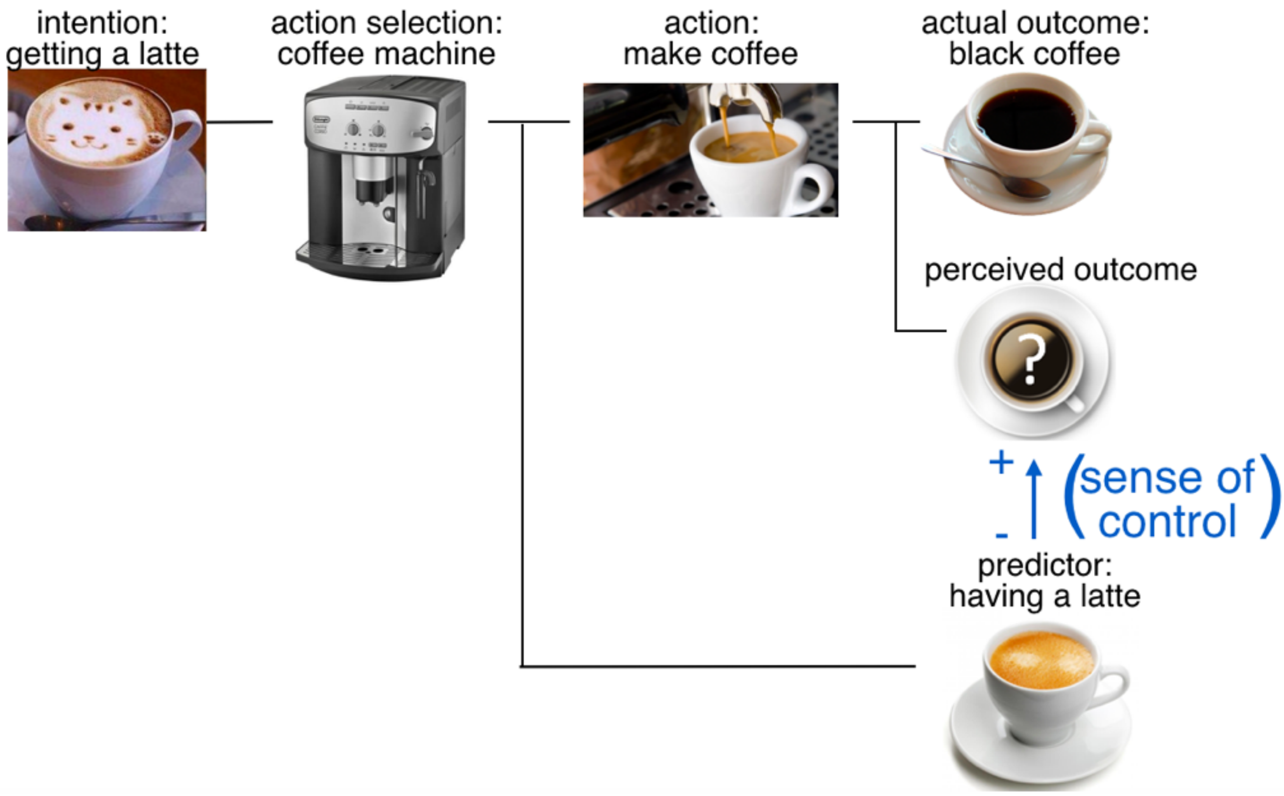


Figure 1.3 – **Sense of control applied to a simple example: having coffee**

of the *what* of the action, thinking of the *how* of the action and then *acting* according to the previous steps. If the *acting* is done indirectly through an external event, would the person still consider being in control of the action? For example (see Fig.1.3) if the person asks a coffee machine to produce a latte, would the person still consider herself or himself in control although the exact amount of caffeine and milk is chosen by the machine? Some argue that sense of control comes from the prediction of the result of the action (Sato & Yasuda 2005, Frith et al. 2000) (if we take the coffee machine example this would mean that the person feels in control because she or he knew a latte would be produced by the machine although the latte is not tailored to the person's taste), while some others argue that sense of control is the illusion of causing the wanted event to happen (Wegner 2003) (in the coffee machine example this would mean that the person feels in control because she or he thinks that pressing the button on the coffee machine will deliver the expected latte).

So according to the literature, sense of control can be divided into two aspects: the desired control and the perception of control.

1.2.5.2 How do we study desired control?

Burger & Cooper (1979) decided to develop a test to "measure individual differences in the level of motivation to control the events in one's life". This test is the Desirability of Control Scale (DCS) which consist of 20 items and has been validated once more by McCutcheon (2000), which shows that the test is still current and widely used to measure desired control.

1.2.5.3 How do we study perception of control?

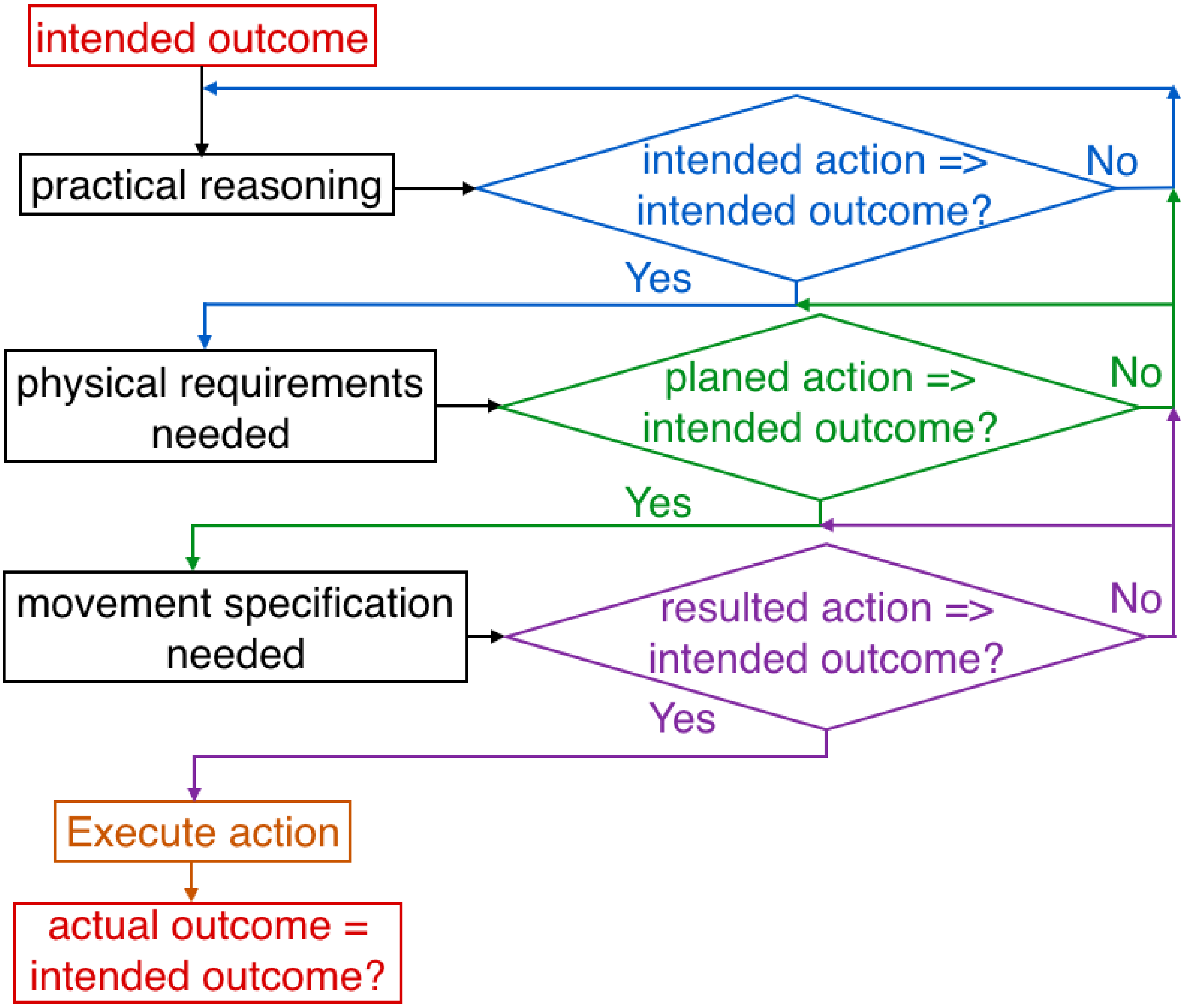


Figure 1.4 – **Simplified schematics of the mental process behind planifying a specific action (Pacherie 2007)**

To be able to study perception of control, it is first important to understand what locus of control is. Lefcourt (1991) theorised it by explaining that locus of control is how much people believe they can affect the relationship between actions and outcomes. Pacherie (2007) explained the thought process of this relationship. There are three types of intentions we have before executing an action: the practical reasoning of how to perform the intended action (mental effort), the physical requirements to make the action possible (physical effort), and the specification of the movements that are needed to execute the action. To illustrate Pacherie's theory, a simplified schematic of her action specification was drawn in Fig.1.4. Haggard & Chambon (2012) investigated the biological pattern of sense of control, which is the neurology of perception of control. Their schematics were simplified to apply it to this PhD investigations (see Fig.1.5). As displayed by Fig.1.5, sense of control is the difference between the perception of the outcome, and the intended outcome, sometimes called predicted outcome. Therefore,

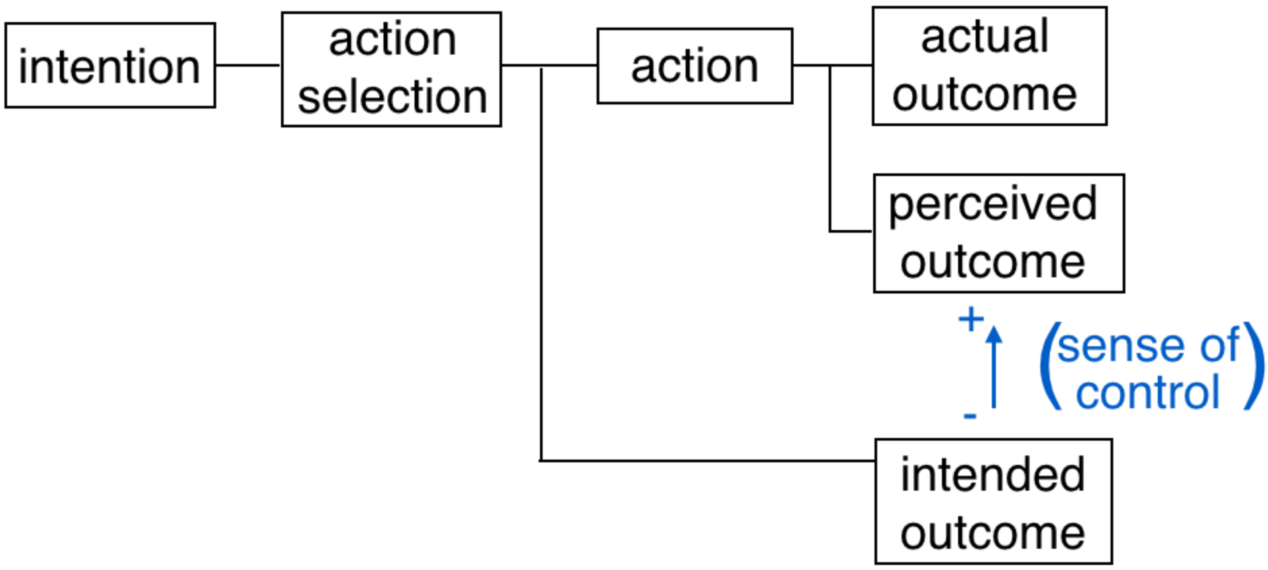


Figure 1.5 – **Simplified schematics of the mental process behind planifying a specific action (Haggard & Chambon 2012)**

to study the perception of control of an action performed by a robot, it is necessary to first identify the intended/predicted/expected outcome of the action performed by the robot. Another way to study perception of control as Pacherie (2007) mentioned is also to identify the intended/predicted/expected execution of the action performed by the robot. There is then two ways to study perception of control, either by checking the outcome of the action and see if it matches the user's expectation, or either by verifying if the way the action is performed by the robot matches how the user expected it to be performed.

1.2.5.4 Sense of control and anxiety

Some psychologists argue that sense of control is related to Obsessive Compulsive Disorder (OCD) (Moulding & Kyrios 2007), and anxiety (Gallagher et al. 2014). In psychology, anxiety is characterised by "autonomic hyperactivity short of panic, arousal and vigilance, tension, restlessness, worrying, and anticipation of misfortune to self and others" (Akiskal 1998). Moulding & Kyrios (2007) have investigated how sense of control and desired control are associated with high levels of OCD and by association high levels of anxiety. They found that OCD was associated with low perception of control. Although OCD is an extreme case of anxiety, it can be hypothesised that there is a correlation between anxiety, and more specifically robot anxiety, and sense of control. This was investigated during this thesis in a paper published at RO-MAN 2016, entitled "Who is in charge? Sense of control and robot anxiety in Human-Robot Interaction" (Chanseau et al. 2016).

Since sense of control is a difficult topic to study, it was decided to focus mainly on the study of perception of control in both ways suggested by Pacherie (2007). The following research questions emerged from the background research: "RQ1. Is there a relationship between the

perception of control participants had over the robot and their preference of the robot's level of autonomy?", and "RQ2. Is there a relationship between participants' desired control and their preference of the robot's level of autonomy?".
The next subsection mentioned practice of how to make a valid live HRI experiment.

1.2.6 How to make a good HRI experiment?

1.2.6.1 Questionnaires

Heerink et al. (2009) undertook an overview of technology acceptance models and decided to use the Unified Theory of Acceptance and Use of Technology (UTAUT) to measure a variety of social factors such as anxiety, attitude and so on. This test may provide a useful measure for gaining an overview of the possible influences of acceptance of the robot during an experiment. However, the first experiment of this PhD investigates some specific factors (desired control and perception of control) that could influence HRI. Therefore, it was decided to focus on the participant personality rather than some external factors. The Big Five personality test (Gosling et al. 2003) is widely used to measure personality during experiments.

1.2.6.2 Limitations of self-assessment

As Bethel & Murphy (2010) pointed out, studies based on self-assessment can be tricky since participants may provide responses based on what they think they should answer rather than how they feel. To counterbalance the self-assessment problem, video-recording were taken during all live experiments conducted during this PhD. It is a good way to see how participants react. In addition, a small interview at the end of the study may provide further insights into the participants state of mind.

1.2.6.3 Ecological validity

As Baxter et al. (2016) pointed out in their article, it is important for researchers to recruit participants that are representative of the population which the robotic system is intended for. This is why the recruitment for this thesis studies focussed on participants not only from the University (staff/students) but also on people living in the University town. Another aspect of ecological validity that Baxter et al. (2016) mentioned is the environment. Since domestic robot companion is being investigated for the thesis, each live experiments were conducted in the robot house, which has proven to be a more suitable environment for such investigations in the past (Syrdal et al. 2008).

1.2.6.4 Statistics

Baxter et al. (2016) suggested that in each HRI experiments, researchers do systematically a descriptive statistical analysis. It is a good way to sample the data and to evaluate if the other statistical tests are appropriate or not. This is why for each one studies detailed in this PhD, a descriptive statistical analysis is always provided.

1.3 Research questions generated from the literature

To summarise, it is clear from the literature that a lot of research has already been done on robot companions and their social behaviour. However, very little research has been done on the user's perception of control, which is a more practical aspect of research. Since HRI has now reached a point where the technology is advanced enough to enable more automation from robotic systems, it is important to ask "is this what the user really want?". As mentioned above in the literature review, robots may create anxiety (Nomura, Kanda & Suzuki 2006). As researchers found that anxiety can be linked to a feeling of loss of control (Moulding & Kyrios 2006), one must wonder if it is the same for the perception of control of robots.

This background research provided a definition of each concept studied in this PhD. First, it defines what a robot companion is and what is expected of one, secondly it analyses the concept of criticality and how we can apply it to robot companions, and at last it explains the concept of sense of control and how to study perception of control. It showed that very little investigations have been done on perception of control of a robot companion and task criticality, which resulted in the following research questions that were investigated in this thesis:

- RQ1. Is there a relationship between the perception of control participants had over the robot and their preference of the robot's level of autonomy? To gain a deeper understanding of the link between perception of control and robot's level of autonomy, it was necessary to conduct a study which measured the perception of control by comparing if the way the action is performed by the robot matches the user's expectation (Pacherie 2007). As a clarification, level of autonomy means level of decision-making. Based on Haggard and Chambon's schematic of sense of control (Haggard & Chambon 2012), their schematic Fig.5.1 was adapted and simplified for the second live experiment described in Chapter 5.

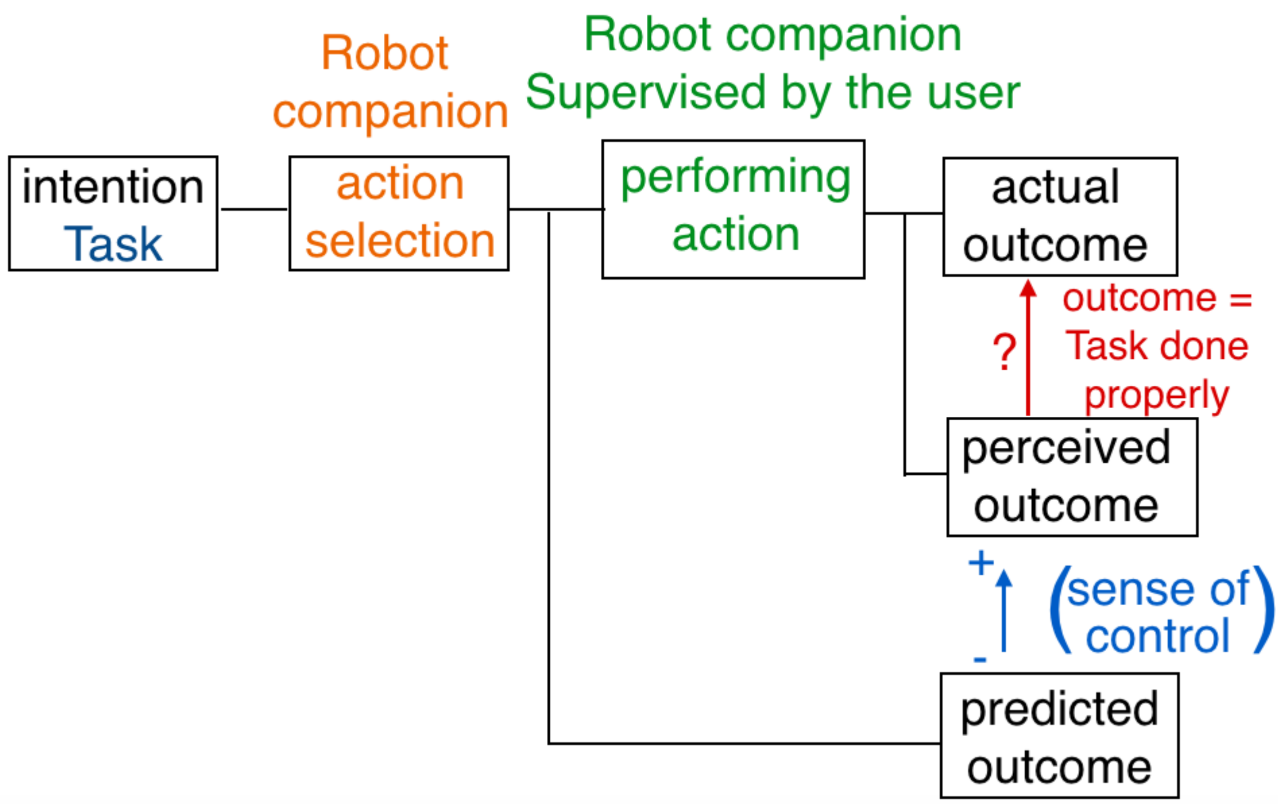


Figure 1.6 – **How perception of control is being studied**

As explained in the literature Fig.5.1 displays that when we consider an action, there are three steps which we think of: what is the outcome that we want, what is the action that we need to perform to reach the wanted outcome, and how to perform the action to get it right. To conduct a meaningful study, it is necessary to have the robot performing various type of tasks. As well detailed in the literature, although criticality is a difficult concept, it was widely used in several HRI studies (Xu et al. 2015, Mitzner et al. 2011, Ezer et al. 2009*b*). Therefore, it was decided to conduct a study with tasks that are high critical and low critical.

- RQ2. Is there a relationship between participants' desired control and their preference of the robot's level of autonomy? When studying perception of control, it is important to understand what the user's expectation is to have an element of comparison. Therefore, following the research question RQ1, it is necessary to investigate the desired control compared to the user's preference of the robot's level autonomy. The hypothesis is the more controlling a person is, the less he/she will want the robot to be autonomous. The live study Chapter 3 and the one in Chapter 5 gave an answer to this question.

- RQ3. What defines task criticality? As the literature shows, people's own definition of task criticality for domestic robot companions need to be investigated. Firstly, to validate and update the definition given by Yanco & Drury (2002), and secondly, to understand better what influences people's perceptions of task criticality. In order to apply the definition of task criticality in practice, it is important to be able to distinguish between different levels of criticality. To do so, three questionnaires studies were conducted during this PhD. There are described in Chapter 4. The results of these questionnaires studies were then used to choose the appropriate tasks for the live experiment described in Chapter 4.

- RQ4. What type of criteria do people consider rating the criticality of a task? Previous research (Tzafestas 2016, Salter et al. 2010) suggests that evaluating the criticality of a task is difficult because of the lack of standardisation in the field. To be able to differentiate low critical tasks and high critical tasks for a home robot companion, a selection of various typical tasks a robot companion would do, were provided in a questionnaire (studies described in Chapter 4). This is a good way to confirm that tasks link to entertainment are considered low critical as Ezer et al. (2009*b*) used in her study, and that tasks that potentially have an irreversible impact are considered high critical.

- RQ5. Does the level of criticality (high or low) of the task performed by the robot influences participants' preferences of the robot's level of autonomy? Beer et al. (2014) said that highly critical tasks should not be carried by robots but only by humans. Is it because it is important for the user to have someone that can provide empathy? Or is it because the user feels better in control when another human perform the task? Nowadays some technological product such as Google Duplex claim to be able to book appointments for the user. It is only a matter of time before a commercially available robot companion is able to do the same. As such it is important to understand the user's preference of control over the system for high critical tasks and low critical tasks. This was investigated in Chapter 5.

- RQ6. What defines a cognitive task versus a physical task for a domestic robot companion? As the background research described, there is no standardisation on how to classify tasks. Another aspect can be considered for a domestic companion is if the task is cognitive or physical. Nowadays some of our technological devices such as global positioning system (GPS) navigators, perform a cognitive task. The system needs to look how to get from A to B following the optimal route depending on traffic, roadworks and accidents. This seems straightforward but no definition was provided in the literature for robots. Therefore, a questionnaire study was conducted in Chapter 4. The results of this study were used to classify tasks in the following live study Chapter 5.

- RQ7. Is there a relationship between the type of task performed by the robot (physical or cognitive) and participants' preference of the robot's level of autonomy? The literature shows that some investigations were done regarding critical tasks however no investigations were done regarding how to differentiate physical and cognitive tasks for robots. It could be because researchers did not consider this as an influential factor. To see if this is justified, this research question investigates if participants' preference of control are influenced by the type of task the robot performs. The hypothesis is there is no relation between how participants classify tasks either as cognitive or physical, and how they prefer the task to be performed. This was investigated in Chapter 5.

- RQ8. Does a participant's technology savviness (experience and knowledge about technology) influence its preference of the robot's level of autonomy? A lot of research was done on experience with technology (Flandorfer 2012) and showed it influences user's acceptance of robot. This could be because the user's feels more in control of the system when it is familiar. To verify this, this research question investigates how the participant's technology savviness is related to the participant's preference of control of the robot. This was analysed in Chapter 3 and Chapter 5.

- RQ9. Is there a relationship between a participant's anxiety towards robots and its perception of control of the robot? As explains in the literature, some research in psychology (Moulding & Kyrios 2006, 2007) suggests that the less people perceived to be in control, the more anxious they become, which is a problem for OCD patients. As such Nomura's work (Nomura & Kanda 2003, Nomura et al. 2004, Nomura, Suzuki, Kanda & Kato 2006, Nomura et al. 2011) on robot anxiety may be linked to people's perception of control, which is why this research question investigates it in the first live experiment of this PhD described in Chapter 3.

1.4 Methodology

To answer the research questions mentioned above, five studies were conducted for this thesis. As Sense of control is a difficult concept to study, it was necessary to break down the investigation. First an experimental study was conducted to analyse if HRI is influenced by desired control or/and the perception of control of the robot. It was chosen to study the perception

Experiment and descriptions	RQ
Chapter 3: Sense of control and robot anxiety in Human-Robot Interaction This first live experiment investigates how robot anxiety and desired control influenced the perception of control of a robot.	RQ1, RQ2, RQ8, RQ9
Chapter 4: What is a critical task for a domestic robot companion to perform? This chapter describes three questionnaires studies that investigated how to define a critical task and how to differentiate a physical task from a cognitive task.	RQ3, RQ4, RQ6
Chapter 5: How perception of control depends on the criticality of the tasks performed by the robot This second live experiment studies if the perception of control of the robot differs depending of the criticality of the task performed by the robot.	RQ1, RQ2, RQ5, RQ7, RQ8

of control of the robot by looking at how people preferred to control the activation of the robot. To be able to implement this concept, the first study used task delegation. It involved two robots, one which acts as the main robot companion and the second as the task-oriented robot which executes the desired task. As the first study described in Chapter 3 demonstrated interesting results, the investigation on perception of control pursued. The first experiment analysed perception of control for one only one single task that the robot companion was executing: cleaning. To be able to generalise the results, it was necessary to conduct a deeper investigation with different type of tasks a domestic robot companion may do. To ensure the realism and the usefulness of the tasks, it was then important to choose the appropriate task to be implemented. As the literature did not provide enough guidelines to do so for domestic robot companions, three questionnaire studies were conducted. The description and the explanations of the number of the questionnaire studies are described in Chapter 4. As satisfactory results were found in the last questionnaire study, a list of task that could be implemented on the robots was produced. As the aim of the second live experiment developed in Chapter 5, was to be able to generalise the results found in the first one and have a deeper understanding of perception of control, this time it was chosen to study perception of control of the robot by looking at how people preferred to control how the robot performs the task. The variety of the tasks performed by the robot allowed a better understanding on how the perception of control of the robot is guiding people's HRI.

1.5 Overview of the thesis

Chapter 1: The current chapter explains the motivations of this thesis by explaining the concept explored in each studies of this PhD and by providing a detailed literature review.

Chapter 2: This chapter details the methodological considerations of each study conducted for this thesis. It also explains the choice of material for each live experiments and details how the robots were used. The chapter also justifies the choice of the questionnaires given to the participants in each study and the format of the data collection.

Chapter 3: This chapter explains in details how the first live experiment was conducted. It focusses on the main two research questions RQ1 and RQ2 which investigate how the preferred level of autonomy of the robot, desired control and perception of control of the robot are linked. In this experiment, it was chosen to use task delegation to differentiate the execution of the task, done by a task-oriented robot, and the activation of the execution of the task, done by the main robot companion. This first study was exploratory, therefore a lot of choices were done arbitrarily such as investigating anxiety towards robots (RQ9) or the potential influence of technology familiarity (RQ8). As numerously mentioned above, perception of control is a difficult concept to investigate and consequently difficult to measure. The main goal of this study was to prove there is a link between HRI and the way the user perceives to be in control of his/her robot. As the results were positive, a deeper investigation could then take place afterwards.

Chapter 4: This chapter describes three attempts to answer the research questions RQ3, RQ4 and RQ6. Originally only one questionnaire study was planned. Unfortunately as described in the chapter, the first two questionnaire studies conducted did not take into considerations some important parameters such as what people mean when they mention criticality, or what type of robots do they imagine when we mention home robot companion, or in what context they would use a robot companion, which affected the results of the studies. Because of the poor design of the two first questionnaire studies, the third questionnaire study was then better designed and obtained successful results. From the last questionnaire study, a definition of criticality was clearly formulated, a definition of physical task (for a robot companion), and a definition of cognitive task (for a robot companion) were phrased. Also, this chapter presents a preliminary study that was necessary, to implement the second live study that investigates perception of control. As described in the literature, no standardised tasks were provided to conduct a meaningful experiment. As having varied tasks was a key element, it was crucial to select the appropriate tasks the robot companion would perform during the second live experiment. To be able to implement these tasks, a selection of tasks was given to participants in each questionnaire studies, which resulted in the choice of 4 suitable tasks.

Chapter 5: This chapter presents the core study of this thesis. Contrary to the first live study which was exploratory, this study was carefully planned to investigate deeply the link between desired control, perception of control of the robot, and the preferred level autonomy of the robot. The research questions investigated were RQ1, RQ2, RQ5, RQ7, and RQ8. The design of this study is complex, as two variables were looked at, the criticality of the task (low or high) and the type of the task (physical or cognitive). Perception of control was measured by checking how people wanted to control the way the robot was performing the task. For technical reasons only one robot was used to execute all the tasks. The results of this study validated the results of the questionnaire studies and the results of the first live experiment. This chapter demonstrated that it is important to understand the user's perception of control of the robot, to allow a more efficient use of the robot. This piece of research would also help some targeted group that are particularly anxious towards robots, to better accept them.

Chapter 6: This chapter summarises the results of each study and underlines how the work done in this thesis add a valuable contribution to the HRI community. It also contains a section on limitations and potential future work, which mentions the weakness and the strength of this PhD. This chapter is the conclusion of the PhD dissertation.

1.6 Contribution to knowledge

The research presented in this thesis introduces a difficult concept to HRI, sense of control, and explains how to study it in HRI. The concept of task criticality for domestic robot companion was also developed extensively which resulted in a conference paper as seen below (Chanseau, Dautenhahn, Walters, Koay, Lakatos & Salem 2018). To the best of the author's knowledge, no such work has been conducted before and the results found in this thesis provides a clear insight on what the user expects from a robot companion.

1.6.1 List of publications

The following publications are work related to this research that were accepted by the peers as a contribution to the HRI community. The papers can be found in Appendix F.

For every following papers mentioned, the author of this thesis wrote the complete first draft, and the co-authors of the papers provided feedbacks on the draft for improvement before submission.

- Adeline Chanseau, Kerstin Dautenhahn, Kheng Lee Koay, and Maha Salem: Who is in charge? Sense of control and robot anxiety in Human-Robot Interaction. In the 25th

IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), 2016. (Chanseau et al. 2016) (Material from this publication went to Chapter 3)

- Adeline Chanseau, Kerstin Dautenhahn, Michael Walters, Gabriella Lakatos, Kheng Lee Koay and Maha Salem: People's Perceptions of Task Criticality and Preferences for Robot Autonomy. In the UK-RAS Network Journal of Robotics and Autonomous Systems, Vol. 1, Issue 1, 2018 (Chanseau, Dautenhahn, Walters, Lakatos, Koay & Salem 2018) (Material from this publication went to Chapter 3 and 4)

- Adeline Chanseau, Kerstin Dautenhahn, Michael L. Walters, Kheng Lee Koay, Gabriella Lakatos and Maha Salem: Does the appearance of a robot influence people's perception of task criticality?. In the 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), 2018 (Chanseau, Dautenhahn, Walters, Koay, Lakatos & Salem 2018) (Material from this publication went to Chapter 4)

This article was published in an online media that wants to promote scientific research to the public and make it more accessible.

- Adeline Chanseau: Robot companions are coming into our homes ? So how human should they be?. In The Conversation, August 2016. (Chanseau 2016)

This article based on Chapter 5 was submitted to a Journal. It is currently under reviewing process.

- Adeline Chanseau, Kerstin Dautenhahn, Kheng Lee Koay, Michael L. Walters, Gabriella Lakatos and Maha Salem: How perception of control depends on the criticality of the tasks performed by the robot?

Chapter 2

Generic experimental design and technical implementations

This chapter discusses the methodology used to conduct live experiments and how to conduct questionnaire-based studies. It covers the type of robots that were used, how to program them, details of the experimental setup, details of the questionnaires used, and how the data was analysed.

2.1 Methodological considerations

2.1.1 Ethical considerations

2.1.1.1 Obtaining Ethics approval

Before a study can be conducted, it has to be approved by the University of Hertfordshire Ethics Committee. To do so, the experimenter has to submit an application detailing the procedure of the study, how the participants are recruited, what ensures the well-being of the participants and how the data is stored. Ethics approval was obtained for the five studies conducted for this PhD and can be found in Appendix A.

2.1.1.2 Information sheet and consent form

Prior to each study, an information sheet is given to the participants which explains what the study is about, who can participate in the study, who benefit from it and what happens to the participant's data. Some contact details are provided as well in case the participant wish to have additional information on the study. The information sheet is given alongside with the consent form before the study starts so the participant can decide to take part of the study or not. An example of an information sheet is provided in Appendix B.1.

The consent form is given to each participant before the study takes place. It describes what the purpose of the study is about and provides general information on the study. Some studies consent forms also offer the option to accept or refuse the video footage to be used for scientific publications. Each consent forms were obtained before the study began. A model of the consent forms provided for each study can be found in Appendix B.

2.1.1.3 Participant's well-being and privacy

The studies were designed to investigate specific behaviour from the participants and avoid causing them stress. They were designed to be entertaining and enjoyable. The participants were free to stop the study whenever they wanted. To be reassuring, the experimenter always introduced the robots before the experiment started, and showed the cameras that were used to monitor the experiment. Also, participants' anonymity was kept at all time, as they were given an ID number for the study, so the names were not used during the studies unless the participant has explicitly given the consent prior to the study.

2.1.1.4 Data confidentiality and security

Each participants questionnaires answers were kept confidential as no names appear on any of the answer sheets, only the ID number provided during the experiment. The hard copies were kept in a secure desk drawer, only accessible to the experimenter. The video footages were kept in a dedicated external hard drive which is encrypted. The hard drive was also stored in the secure drawer.

2.1.2 Recruiting participants

For each one of the study presented in this PhD, the participants recruited were over 18, and had a good understanding of English.

2.1.2.1 Live experiments

To recruit participants for live experiments, at first some posters were distributed to the University cafeteria and emails were sent to University mailing lists of staff members, students society members or to people from the school of Computer Science.

Then, to be able to recruit a large number of participants, a different approach was taken. Posters advertising for the study referred to an online link in which potential participants could register with their contact details. The experimenter could then contact them directly. The other approach was to advertise outside the University, in the town where the University is located. A few posters were put in the shopping mall in authorised areas and the experimenter attended a society gathering people living in the town from various background to get them to come to the study.

The experimenter aimed to recruit participants randomly by targeting both genders, to at least provide a good gender balance for the experiment. Although no specific age group was targeted, mainly young professionals and young undergraduates took part of a live experiment, only a few old people participated.

2.1.2.2 Questionnaire study

The best way to recruit participants for a questionnaire study is to meet people and get participants to fill in the questionnaire on the spot. Mailing lists and online questionnaire services (Survey circle for example) were used to get more participants involved. A lot of advertising was done through social media.

2.1.3 Setting up a live study

2.1.3.1 Choice of location

To ensure the ecological validity of the environment for a live experiment, the Robot House was the selected location for the live studies to take place (Syrdal et al. 2014). The Robot House is a typical British house that was transformed into a smart home for experimental purposes.

The house belongs to the University of Hertfordshire and is located in Hatfield. It contains more than 60 sensors. There are binary sensors, for example the ones that detect if a door is open or close. There are also more sophisticated sensors such as voltage transients sensors that can detect voltage variations (when the kettle is on or when the fridge is on). There are also some Zigbee sensors in the house that can detect when someone sits on the sofa or on a chair. The house possesses Kinect cameras in the kitchen and two 360° cameras on the ceiling of the living room. Several studies were conducted in the robot house by the lab as the Robot House website shows (Robot House Last accessed 11/06/2019).

2.1.3.2 Choice of the robots

Figure 2.1 – **Roomba robot: model 760**

Figure 2.2 – **Sunflower robot**

As the Sunflower robot Fig.5.2 was previously used as a robot companion in HRI studies conducted in the Robot House, it was the apparent choice for the live studies that are conducted in this thesis. A Roomba Fig.3.2b was also chosen for two reasons: it is a task-oriented robot in which its main function is cleaning, and it is a commercial product that is relatively well-known by the public Sung et al. (2007). The potential familiarity that participants may have with Roomba is not a problem since participants were "trained" to use this robot, as it is essential that participants understand the main function of the Roomba robot.

2.2 Experimental setup

2.2.1 Experimental procedure of the live studies

Once a person has agreed to participate in a live experiment, an email describing briefly the experiment and providing the address of the venue and the contact details of the experimenter, is sent. As soon as the participant arrives to the Robot House, the experimenter welcomes the user and gives a tour of the place. During the tour, the experimenter introduces the robots that will be used during the experiment, shows some sensors activated in the house and the location of the cameras. Once this is over, the participant is offered some hot beverage while he/she is asked to sign the consent form. An information sheet is also provided as some participants may have forgotten to read it through their emails. An ID number is also given to ensure the confidentiality of the user. Whenever the participant is asked to fill up a questionnaire during the experiment, the provided ID number is used so no names appear during the data analysis. Once the experiment ended, the participant was asked how he/she felt about the experiment and what were their thoughts on it. The answer was recorded but was not collected through a questionnaire form.

2.2.2 Experimental procedure of the questionnaire studies

For a questionnaire study, the experimenter had to meet directly with participants in order to collect data. Several approaches were taken. The first one was to go to busy areas of the University: the cafeteria, some study rooms, the main reception, the University gardens etc... To be able to maximise the answers, the experimenter carried hardcopies of the questionnaire with pens and distributed it to participants, with a consent form if the ethics application required it. The second approach was to create an online questionnaire using Google services, and to provide a link to the potential participants via online social media such as Facebook or through mailing lists of different societies, University staff members and via StudyNet (the University Intranet which is accessible by every University members). The last approach was to go to different classes in different departments of the University and with the lecturer permission, distribute some questionnaires to the students and provide the pigeonhole where the questionnaires could be collected. Some colleagues also helped to distribute some questionnaires to their students to optimise the chances of getting answers. Once the experimenter got a hardcopy back, the data was then implemented into the Google form to digitalise the data and make the data analysis process easier.

2.2.3 Randomisation process

For live experiments, it is important to decide beforehand if the experiment is within subjects or between subjects. To simplify the data collection and to optimise the number of participants, a within subject design was used in each live experiments. So the experimenter pre-selected the order of the conditions the participant had to go through by associating it to the ID number given to the participant. To balance each experiments, the number of participants was divided by the number of conditions. For example, if an experiment had two conditions, half of the participants would start with condition 1 and the second half with condition 2. The main disadvantage of this design is that participants may have an order effect as they would have seen the robot performed in the other condition beforehand. This means the participant can predict the robot actions before they happened. However, having a within subject design means that participants can have a better overview of the experiment once it ended, and therefore potentially provide better impressions feedbacks as they may have noticed the differences between the conditions.

If the questionnaire study had only one condition, the experimenter spread the questionnaire to diverse groups instead of targeting only one specific group such as ”undergraduate students” which is a flaw that many HRI studies have as Bethel & Murphy (2010) underlined. If the questionnaire study had more than one condition, a between subject design was used. It was done this way as contrary to live experiments, questionnaire studies can gather a higher number of participants. Also, because it is difficult to generate interest in a survey study when no compensation is involved, it was chosen to only provide one condition per participant. Two methods were used to randomise the conditions. The first one was to use Google survey to digitally randomise the conditions. So when a participant would click on the Google link of the survey, a random condition would then be selected, with the associated questionnaire. The second method was to pick a random condition when meeting a potential participant and provide the appropriate questionnaire that matches. The main disadvantage of this method is that the experimenter had to meet hundreds and hundreds of people hoping to get some answers back with no guarantee. Also, because of this set up, it was extremely difficult to balance the number of participants for each condition.

2.3 Wizard-of-Oz experiment

A Wizard-of-Oz experiment is an experiment in which participants believe the system, in this thesis, a robot, to be autonomous while the system is actually being controlled, either fully or partially, by a hidden experimenter. This method was used for some tasks the robot had to perform in the second live experiment presented in Chapter 5. To allow this method to work, the experimenter was located in the bedroom with the door closed, while the participant was interacting with the robot in the living room. The experimenter was activating some functionalities displayed by the robot, to simulate an autonomous response from the robot. Participants were only informed after the experiment ended, that some functionalities of the robot were not autonomous but activated by the experimenter.

2.4 Data collection

2.4.1 Quantitative data

For each experiment, questionnaires were set up in a Google survey and some printouts were available. When the hardcopies were used, the experimenter reported the results in the Google survey for data analysis. For live studies a dedicated laptop was used to collect the answers from the participants digitally. For questionnaire studies, as explained above, when participants were met in person, hardcopies were collected, otherwise the digital Google link was used.

It was chosen to use Google for data collection as it is a service free of charge and the data can be easily imported and analysed through Google excels sheets. Since every set of data is associated with an ID number, the confidentiality of the participants were kept.

2.4.1.1 Demography

For each experiment, live studies and survey studies, there was a set of questions on demography. There would be an open-ended question on gender, age and occupation, followed by questions on familiarity with technology or/and robots. The questionnaires can be found in Appendix

D, C and E. Depending on the study, scale-questions on technology and robots varied. Those questions were mainly used to sample the population and rate how naive about robots and technology users were when they participated in the study. One study also measured the frequency of the usage of technology.

2.4.1.2 Personality test

For each live experiment, a short personality test was used: the TIPI (Ten Item Personality Measure) (Gosling et al. 2003). It is well-used in the field (Walters et al. 2008, Aly & Tapus 2013, Salem et al. 2015), therefore it makes the results of the study comparable to previous HRI studies. It contains 10 items that measure on a scale of 1 to 7, 1 being "disagree strongly" and 7 being "agree strongly", extraversion, agreeableness, conscientiousness, emotional stability or neuroticism and openness.

2.4.1.3 Desirability Control Scale

The Desirability of Control Scale (Burger & Cooper 1979) was used in both live studies to measure the desired control. As the literature pointed out, it is still a current reliable test (McCutcheon 2000). It consists of 20 questions that measure on a scale of 1 to 7, 1 being "it does not apply to me at all", and 7 being "it always applies to me", how much in control a person wants to be in various life situations.

2.4.1.4 Robot Anxiety Scale

As described previously in Chapter 1, one live study needs a reliable standardised test that measures how anxious about robots people are. The Robot Anxiety Scale developed by Nomura, Suzuki, Kanda & Kato (2006) was the most appropriate choice as it has already been validated (Nomura et al. 2011). The test has 11 questions. It measures on a scale of 1 to 6, 1 being "I do not feel anxiety at all", and 6 being "I feel very anxious", how anxious a robot makes the user depending on various situations.

2.4.1.5 Custom-made questionnaire

Every experiment conducted for this thesis required some specific questions that were not used in previous HRI experiments. To be able to provide some sensible data, Likert scale type questions and ranking type questions were used. Some open-questions were also used which fell more under a qualitative type of data where some specific keywords were looked at.

2.4.2 Qualitative data

2.4.2.1 Interviews

During the questionnaire studies, when a participant handed in the survey completed, the experimenter would briefly check that all questions were answered. If some answers appeared unclear, an additional question would be asked and some notes would then be added to the answer sheet.

For live experiments, when the experimenter asked a question to the participant, the answers were video recorded. Occasionally a note would be added to the experimenter notebook.

Every question asked was short and was only there for clarification in each study conducted.

2.4.2.2 Video recordings

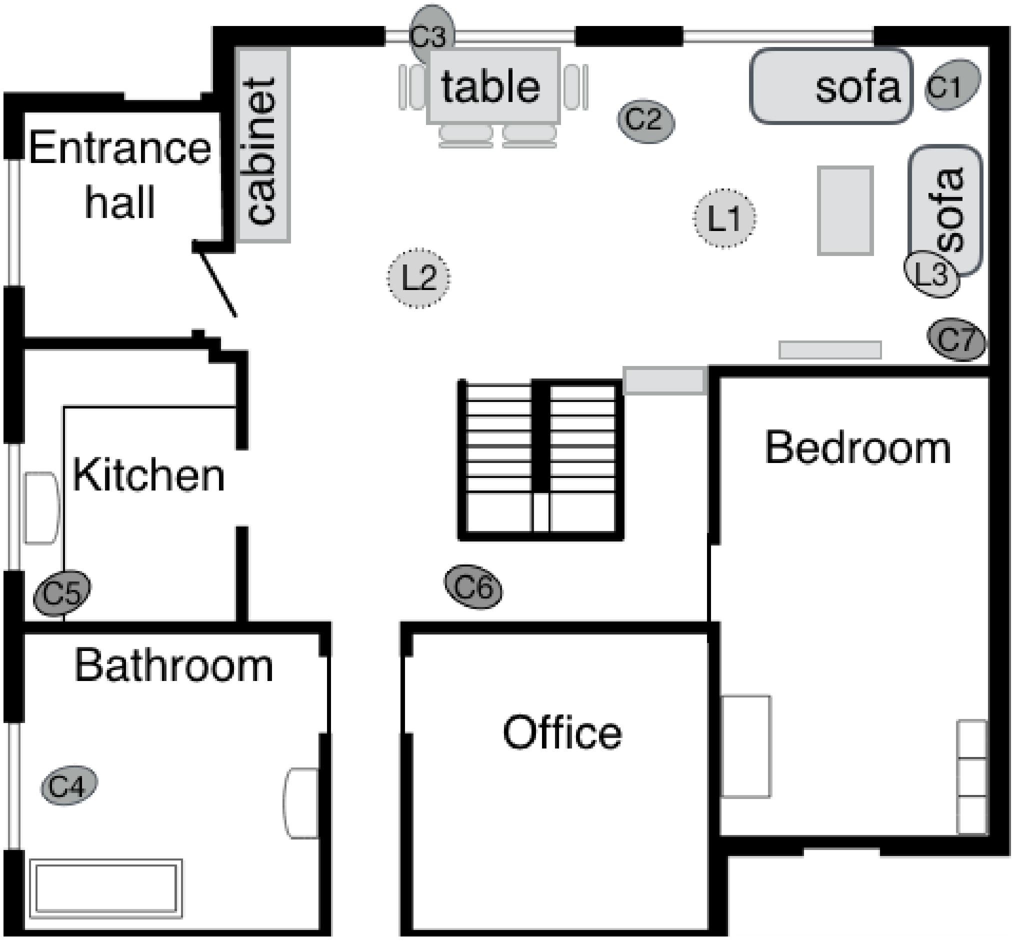


Figure 2.3 – **Positions of the cameras in the Robot House. L1 and L2 are Fish eyes ceiling cameras**

For live experiments, the two fish eyes ceiling cameras were systematically used to monitor the experiment. No recordings were done with these cameras (L1 and L2 in Fig.2.3), they were only use to live feed what was happening in the living room while the experiment stayed in the bedroom. The other cameras showed in the figure were standard Panasonic cameras used to record the experiment. Not all the cameras were used for each experiment. Depending on where the study took place in the house and what the participant had to do, only a set of 4 cameras were used for recordings. The camera L3 in Fig.2.3 was used for a Wizard-Of-Oz experimental setup. It is a LENOVO tablet that was transformed into a live camera feed to observe more closely the participant's movements without the participant paying attention to the camera. Participants were informed at the end of the experiment that the tablet was used as a camera.

Once the experiment with one participant is over, the data is immediately retrieved from the cameras SD cards and stored to the dedicated secured hard drive. Once the video data is collected, the footages are deleted from the cameras.

2.5 Methodology of the data analysis

2.5.1 Video recordings

The video recordings collected during each live experiment were not used for behavioural data analysis. They were only there to verify the notes taken during the experiment. The recordings were used to gather some additional comments the participants provided the experimenter.

2.5.2 Statistical analysis

For each study, the same methodology is followed based on Bethel recommendations (Bethel & Murphy 2010). First, some descriptive statistics are applied to visualise the results of the data, especially regarding demographics. Second, a normality test is conducted to determine if the data is parametric or non-parametric. The normality test used is the one sample Kolmogorov-Smirnov test. If the data is parametric, a standard Pearson correlation test can then be used. If the data is non-parametric, then a Kendall's tau correlation test is applied.

2.5.2.1 Descriptive statistics

To get a first impression on a dataset, it is necessary to conduct some basic descriptive statistics that will provide the tendency of the data. Descriptive statistics provide a representation of the data. There are four main measures done in descriptive statistics:

- **Frequency**: it counts of the number of times a variable occurs in the dataset. For example, the number of participants that rated the task "telling a joke" highly critical, or how long a participant spent on a tablet the past week, or the percentage of under 20 that participated in the study.

- **Central tendency**: it summarises the typical value of a dataset. It covers the measure of the mean (arithmetic average of the dataset), median (middle value) and the mode (value that occurs the most frequently in the data sample). To visualise this type of data, a boxplot (see example Fig.2.4) is usually drawn. For example, the mean of the age of the participants involved in a study on robots tells us the typical age group that is interested in having a robot.

- **Dispersion**: it describes the extent to which a data distribution is spread or squeezed. The common measures used are the variance (measurement of how far a set of numbers are stretched from their average value), the standard deviation (quantification of the amount of variation of a set of values) and the interquartile range (measurement of variability based on dividing the dataset into quartile). The interquartile range is displayed via a boxplot (see example Fig.2.4).

- **Position**: it describes how a value is positioned compared to other values in the same dataset. The standard measurements are percentile, quartile and standard score. A percentile as its name suggests, divides a rank-ordered dataset into 100 equal parts while quartile does the same with four equal parts. A standard score shows how many standard deviation an item is from the mean.

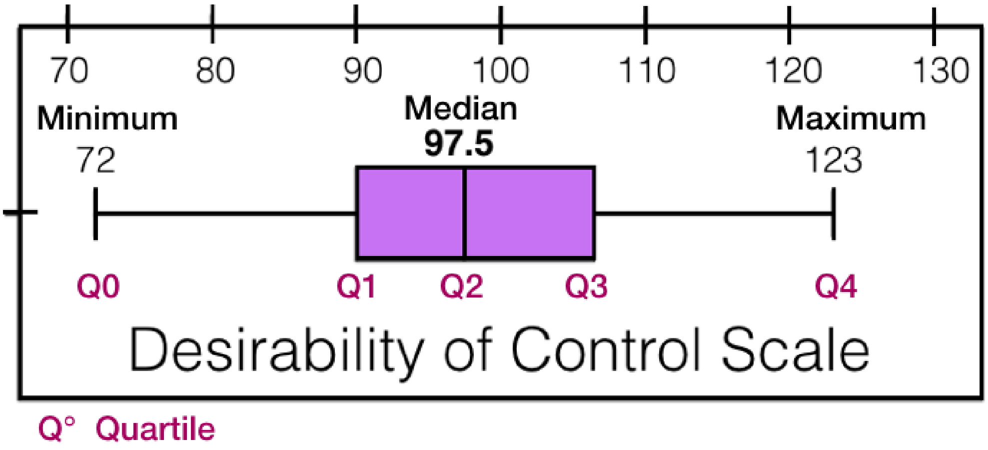


Figure 2.4 – **Example of a boxplot**

In this thesis, frequency measurements were used through various forms (percentages, number of counts) depending on the nature of the data sample. As the boxplot was the preferred method chosen to display data, the median, interquartile and quartile were systematically provided via the graph. The mean was provided when necessary with its standard deviation to get the main tendency of the dataset.

2.5.2.2 Inferential statistics

While descriptive statistics provide a representation of the data, inferential statistics make inferences about the data. Therefore, this branch of statistics allows us to make generalisations on what people think according to the data sample. There are many methods that can be used. First to know what methods to be used, a normalisation test is done to determine if the dataset follows the model of a normal distribution. The normalisation test used in this thesis is the Kolmogorov-Smirnov test. It was preferred to the Shapiro-Wilk test despite it being less powerful as the later does not work well with dataset containing the same value. The principle of the Kolmogorov-Smirnov test is to standardise the data sample to compare it with a standard normal distribution. If the data follows a normal distribution, a parametric test can be used. Otherwise, we have to use a non-parametric test.
In this thesis, to understand the relationship between two variables, the methods used are:

- **a Pearson's chi-squared test**, which can determine if there is an association between the variables in the dataset. It is a method used for categorical data. However, the limitation of this method is that it does not provide the direction of the association. Therefore, it can tell you if there is an association between for example, extraversion and liking mechanical-looking robots but it cannot tell you whether the association is positive (in this example, the more extraverted people are the more they like mechanical-looking robots) or negative (in this example, the more extraverted people are, the less they like mechanical-looking robots). In certain cases, due to the nature of the data, this test is the only one that can be performed to measure associations.

- **a Pearson's correlation test**, which measures the linear correlation between two variables. The value of the correlation test varies between +1 and -1, where 1 is a total positive correlation, 0 no linear correlation and -1 a total negative correlation. To use this test, we need the data to be parametric, which is determined by the normality test mentioned above.

- **a Kendall's tau correlation test**, which measures the ordinal association between two measured quantities. It is a non-parametric test based on the tau coefficient (value calculated for the test). The main advantage of this test compared to similar other non-parametric tests, is that this statistical test accounts for ties in the sampling data.

When a Pearson's correlation test could not be performed because of the nature of the dataset, a Kendall's tau correlation test was performed. It has to be reminded that non-parametric tests are not as strong as parametric tests. Therefore, the strength of the results have to be taken with caution. But it is always reminded in this thesis, that the reason for the usage of such test is the limitation on the number of participants. Fig. 3.1 shows an example on how to read a

Direction of the correlation (positive or negative)

	Preferred condition	RAS S1	RAS S2	RAS S3	
Technology awareness	-0.053	-0.136	-0.359*	-0.229	← Correlation coefficient
	-0.782	0.428	0.036	0.174	← P value

* Correlation is significant at the 0,05 level (2-tailed).
RAS S1: Anxiety toward Communication Capability of Robots
RAS S2: Anxiety toward Behavioral Characteristics of Robots
RAS S3: Anxiety toward Discourse with Robots

Figure 2.5 – **Example of a correlation test**

correlation table. To interpret a correlation test (either Pearson or Kendall), it is important to look at the p-value to get the statistical significance. If $p < 0.005$, the correlation is considered statistically significant. Otherwise, it is not the case. The correlation coefficient provides the strength of the correlation and the direction of the correlation. If the coefficient is positive, we have a positive correlation. if it is negative, we have a negative correlation.

Ranks

	Mean Rank
Sunflower's intelligence in scenario 1	1,77
Sunflower's intelligence in scenario 2	1,98
Sunflower's intelligence in scenario 3	2,25

Test Statistics[a]

N	24	
Chi-Square	5,660	
df	2	
Asymp. Sig.	,059	← P value
Exact Sig.	,058	
Point Probability	,007	

a. Friedman Test

Figure 2.6 – **Example of a Friedman test**

When there are multiple groups in which we want to analyse the difference between their

means in a data sample, **a Friedman test** is performed. Those two tests are non-parametric tests. If there are some significance found in the results, it is necessary to conduct a Wilcoxon signed rank test to see where those differences are.
Fig.2.5.2.2 shows an example of how to interpret the test. If the test has a significant asymptotic value (p-value), then we can say there is an overall statistically significant difference between the mean ranks of the related groups. Otherwise we cannot conclude. However, the test does not reveal where the difference are. It is necessary to conduct a Wilcoxon signed rank test to see where those differences are.

When two groups of dataset are dependent, **a Wilcoxon signed rank test** is used. This test assesses whether the population of the data samples mean ranks differ. It is a paired Student's t-test for on-parametric data. To interpret the results of a Wilcoxon test, for example

	I felt in charge of (scenario 2) — I felt in charge of (scenario 1)	I felt in charge of (scenario 3) — I felt in charge of (scenario 2)	I felt in charge of (scenario 3) — I felt in charge of (scenario 1)	Sunflower was in charge of (scenario 2) — Sunflower was in charge of (scenario 1)	Sunflower was in charge of (scenario 3) — Sunflower was in charge of (scenario 1)	Sunflower was in charge of (scenario 3) — Sunflower was in charge of (scenario 2)	Roomba was in charge of (scenario 2) — Roomba was in charge of (scenario 1)
Z	-1,884[b]	-1,997[b]	-3,273[b]	-1,147[c]	-0,025[b]	-0,890[b]	0,000[d]
Asymp. Sig (2-tailed)	0,060	0,046	0,001	0,251	0,980	0,374	1,000 ← P value

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.
c. Based on negative ranks.
d. The sum of negative ranks equals the sum of positive ranks.

Figure 2.7 – **Example of a Wilcoxon test**

Fig.2.5.2.2, we need to look at the p value. If the p-value is small ($p < 0.005$), then we can conclude that there is a significant difference in the median value score, otherwise we cannot conclude there is a difference.

2.6 Hardware

2.6.1 How to use Roomba in the Robot House?

Roomba is a commercial cleaning robot developed by IRobot (Forlizzi & DiSalvo 2006). The Adaptive System Laboratory possesses a Roomba 760 that was available. To be able to conduct any live experiments involving the Roomba in the Robot House, the first thing that needed to be done was to connect the Roomba 760 to the Robot House network. To do so, a RooWifi device was purchased (see Fig. 3.2c), which allows the user to access the robots API using Wi-Fi. The robot then becomes accessible to the network and can be remotely controlled. The choice of controlling the Roomba through Wi-Fi instead of Bluetooth or a serial cable came naturally, since the Roomba had to be used in the Robot House and potentially to be controlled by other robots such as Sunflower. Indeed, the Bluetooth has a limited range of 10 meters while the Wi-Fi has a range of 100 meters.

2.6.1.1 How to use the Roowifi device with Roomba?

Once the device is plugged in via the PS/2 Roomba's connector, as in Fig.2.9, the developer can perform a test to see if the device is working. A network named **ROOMBA WR** should appear. Connect to the Wi-Fi with computer and wait until the connection is secured (the light

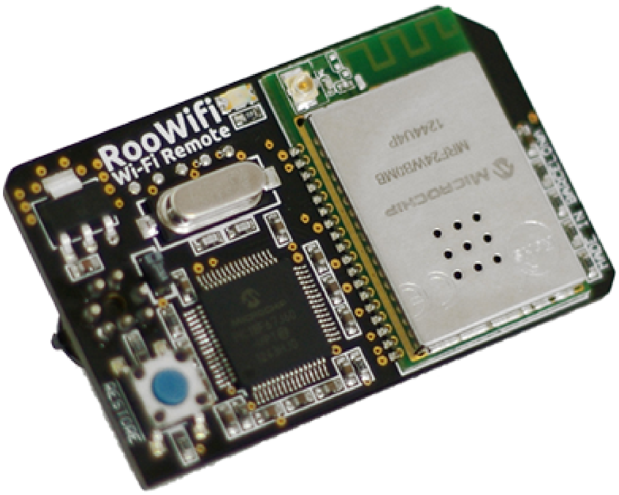


Figure 2.8 – **Roowifi device Domotica (Last accessed 30/01/2019)**

Figure 2.9 – **Roowifi connected to a Roomba 760 (Domotica Last accessed 30/01/2019)**

on the Roowifi is blinking fast when it is configuring itself). Then open the browser entering the address **http://roomba/** if on Windows or **http://10.0.0.1/** if on other operating systems. The user is **admin** and the password **roombawifi**. To enter the parameters of your Wi-Fi network, click on the configuration menu (see Fig.2.10). Once this is done, click on the Save/Reboot button and accept the pop-up dialogue. The embedded web server can be used to control the Roomba (see Fig.2.11). The network configuration of the Roowifi was set up so it uses the same network used by the robots (rh-developer) in the Robot House. So whenever the Roomba is being activated in the house, the only thing that needs to be done is to plug-in the Roowifi device on the robot.
A Python script programme (Github account Last accessed 16/06/2019) was created based on the GitHub Roowifi (Roowifi Last accessed 30/01/2019), in order to use the basic functions of the robot through the Robot House network. This way, the robot can be directly activated using simple commands sent to the network or via the web interface provided by the RooWifi device. The script is located in the folder UHCore/Core /Robots in the Robot House main desktop. The script programme only uses basic functions such as "clean", "spot", and "dock". The functions can also be called via the CobScheduler.

2.6.1.2 Using Roomba in CobScheduler

CobScheduler (Saunders et al. 2016) is a software developed to teach and schedule the Care-o-bot 3 to do tasks (Graf et al. 2009). To be able to use the Roomba through the software,

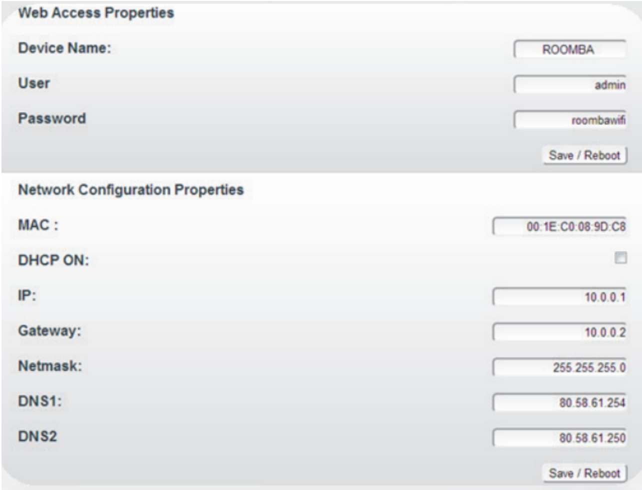


Figure 2.10 – **Example of the configuration of the roowifi from the manual (Roowifi Usermanual Last accessed 30/01/2019)**

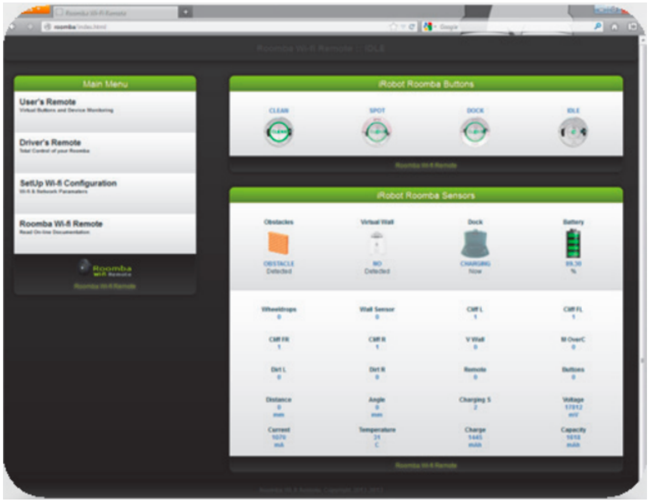


Figure 2.11 – **Example of the embedded server from the user manual (Roowifi Usermanual Last accessed 30/01/2019)**

Roomba was labeled as "Sunflower's pet" which means the Roomba robot can only be used with Sunflower via the CobScheduler. Because of Sunflower and Care-o-bot 3 similarities in terms of functionalies, it was decided to test CobScheduler to schedule tasks to the Sunflower robot. To enable this implementation, Sunflower was added in RobotFactory so its ROSMASTER would connect to the CobScheduler software located on the Robot House desktop. Once this worked, a second software CobSequencer (Saunders et al. 2016), was used to implement behaviours into the robot. CobSequencer offers a sequence of tasks the robot can do, depending on which sensors are triggered in the house.
Using this configuration allowed Roomba and Sunflower to be connected to the Robot House at the same time. Indeed, ROS does not allow two ROS MASTER to run concurrently. Since it was not necessary to use ROS to have access to Roomba's functionalities, it avoided this problem. Only Sunflower's ROSMASTER is running when the two robots are turned on and "connected to each other" via the Robot House. Therefore, it is recommended to use this type of settings if one wants to use Roomba with other robots in the house.

2.6.2 How to use Sunflower in the Robot House?

Sunflower is a custom-made robot created by Dr. Kheng Lee Koay. It possesses a Pioneer DX robot base and a static head with two rounded eyes. The head is attached to its neck which allows 4 degrees of freedom (DOF). Its torso has a small drawer that can come out autonomously and a touchscreen tablet to communicate with people. It has an 8-colour LED display panels that can diffuse multi-coloured lights. The light colours can be set by the programmer by giving the RGB colour code matching the corresponding colour. The design and the behaviour of the robot are based on non-verbal expressive attention seeking behaviours. The robot was designed to have a non-humanoid appearance, but to display some human-like features. This robot was used in several research projects, including one done for the European project LIREC (LIREC project publications Last accessed 16/06/2019), and for some research done on proxemics (Walters et al. 2008) to understand what behaviour and colour projections were best suited to the robot to enhance its companionship behaviour. Sunflower is the best suited robot for this PhD as it is a multi-task robot companion that can carry things in its drawer, and that can navigate autonomously around the house.

2.6.2.1 How to launch the robot?

Sunflower runs on Linux Ubuntu version 10 LTS. There is also a Windows version of Sunflower, but it was chosen to only work on the Linux version of the robot for each live studies conducted in this thesis, as the Linux system used was stable.

So once the robot has been switched on (its Linux laptop, its router and its wheels), ROSMASTER has to be launched on the Sunflower robot (on nathan@sf1-1-pc1). Each of the following commands were used in a different terminal. SSH was used to connect to the robot via the Robot House desktop to simplify the job.

1. To open ROSMASTER on the robot, roscore was entered.

2. To launch the robot, roslaunch sf_robot sf1-1.launch was typed.

3. roslaunch sf_robot dashboard.launch was used to see the dashboard with the battery levels and the wheels. The wheels were activated by pressing on the ON button and close the dashboard.

4. roslaunch sf_navigation start.launch was then typed, to start the robot's navigation.

Then, on the Robot House desktop, another terminal was launched to open RVIZ (graphic interface to see where the robot navigates in the house). To do so, first we needed to access the directory cd git/sunflower/sf_environments/uh-robot-house and then typed rosrun rviz rviz in the terminal. After this operation, Sunflower was ready to be used. The robot can be used with CobScheduler, in which case the software needs to be launched separately, or it can be used with a Python script, which also needs to be launched separately.

2.6.2.2 How to launch CobScheduler?

To launch CobScheduler, the directory cd git/accompany/COBCoreScheduler needs to be accessed before the command ./COBCoreScheduler is set. Once this is done, we need to select the appropriate database, then the appropriate scenario. The database used in both live studies is named Adeline, which gathers all the sensors needed to conduct a live study in the Robot House. To be able to use CobScheduler efficiently, the Robot House sensors monitoring system needs to be launched as well.

2.6.2.3 How to launch the sensors monitoring system?

To launch the sensors, the directory cd git/accompany/UHCore/Core needs to be opened the command Python sensors.py needs to be entered. The sensors.py Python script will activate all the sensors in the house and track their live changes.

2.6.2.4 How to launch Sunflower's remote control Python script?

A Python script containing all the needed functions for a Wizard-Of-Oz experiment was created. Several functions were programmed. Sunflower's tray can open and close. Sunflower can move to the sofa, go to the kitchen or go to the living room, and go next to the sofa table. Sunflower can move forward, backward, left and right. Once Sunflower has finished its task, it can go back to rest at its charging station next to the stairs.

The script is located at git/accompany/UHCore/Core. The python script can be launched using the command Python roboremote.py. An interface should appear which acts as a remote control of the Sunflower robot for the experimenter. As the programme is located on the Robot House desktop, the experimenter has to ssh the desktop to be able to do a Wizard-Of-Oz experiment. To be able to use this remote control script, the house sensors monitoring system needs to be activated.

2.6.3 How to launch the Sunflower robot's interface?

The robot's interface is a Samsung Galaxy 2 tablet. It is connected to the Robot House network so to open the interface on the tablet, a web browser with the 10.0.0.2 address needs to be opened. Depending on which software is used to link Sunflower to the house, there are two type of interface that needs to be activated on the Robot House Desktop to send messages to the tablet. If the linking software is not launch on the desktop, an error message will appear on the tablet.

2.6.3.1 If Sunflower is used with CobScheduler

To launch the interface, it is necessary to go to the directory cd git/accompany/UHCore/WebUI and type the command Python ws.py. Then on the tablet a browser with the address 10.0.0.2 needs to be opened and a blank page will appear. This is normal.

2.6.3.2 If Sunflower is used with the remote control Python script

Then a custom-made web interface needs to be created. Several web interface were developed for the second live study and are located in cd git/accompany/UHCore/WebUI into the folders task1c1, task1c2, task2c1, task2c2, task3c1, task3c2, task4c1 and task4c2.
To launch the wanted Python script, the command Python task#c# needs to be typed, with # being the appropriate number.

2.6.4 How to launch live cameras in the Robot House?

2.6.4.1 Ceiling cameras

To set up the Cameras via a remote control laptop (ubuntu laptop), enter the following intructions into a Terminal.

1. roscore ssh omni-cam-user@omni-cam-pc
2. roscore startTracker.sh
3. roscore viewCameras.sh

The cameras can also be set on their dedicated desktop located next to the Robot House desktop.

2.6.4.2 Live camera using a tablet

The author of the thesis owned a personal LENOVO YOGA tablet that has a rotative webcamera, which was perfect in a Wizard-Of-Oz setting, to act as an unnoticed camera. To transform the tablet into a livefeed camera, several online application were available. It was decided to install IPWebcam into the tablet as the application was free of charge and would only stream the video data to the local network via a provided IP address. The data was not stored by the application neither was accessible via the Internet which protected the participants' confidentiality.

2.6.5 How to remote control the desktop?

To remote control the Robot House desktop, TeamViewer was used as it is free of charge for non-commercial use and facilitate screen monitoring.

2.7 Conclusion

This chapter summarised the generic method used for each study conducted in this thesis. It also provides a description of the material used for live experiments. The specific research details are available in the following chapters.

Chapter 3

Sense of control and robot anxiety in Human-Robot Interaction

This chapter investigates how perception of control is influenced by robot anxiety and desired control. To do so, a live experiment was conducted and the results show the higher the participants' desired control was, the more autonomous they wanted the companion robot to be (meaning the robot executed the needed task without an explicit permission from the participants).

3.1 Introduction

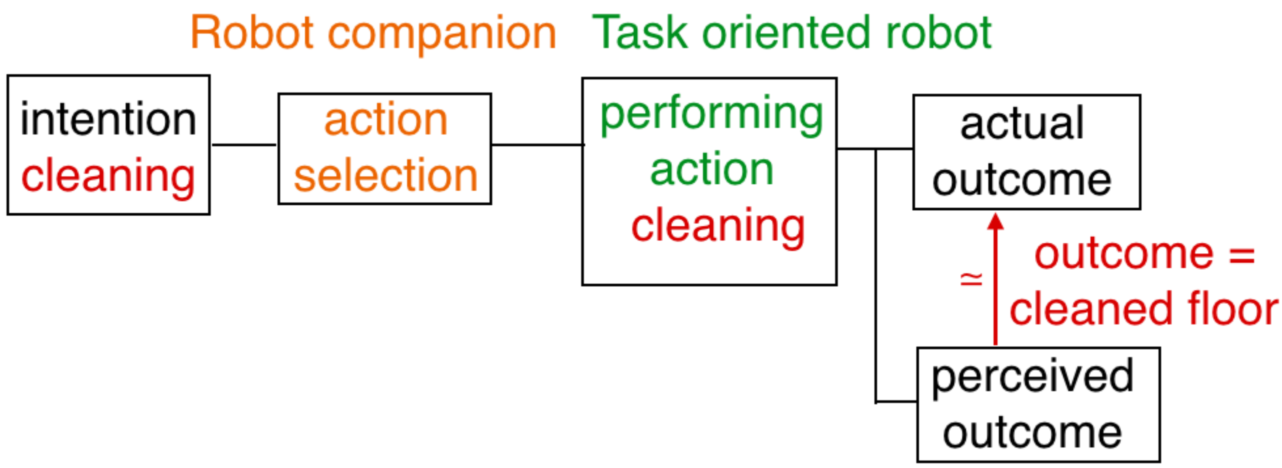


Figure 3.1 – **Simplified schematics of sense of control based on Haggard & Chambon (2012) applied to this first investigation**

The HCI community explored the concept of control in computer interfaces in the late 1990s (Shneiderman & Maes 1997) to discover what the user preferred best as an interface. As robots are now becoming more popular, it has become necessary to also investigate the concept of control in HRI. This concept has been long studied in psychology. Some findings Moulding & Kyrios (2006) show that low perception of level of control contributes to exacerbate anxiety. As such, it makes one wonder if the level of anxiety people have towards robots is also affected by their perception of control of the robot. Therefore, it was chosen to conduct an exploratory live experiment on sense of control, also involving robot anxiety. As the literature well detailed in Chapter 1, sense of control is a difficult concept to study. Therefore, for this first study, it was chosen to break down the investigation of perception of control by using two robots, one that was used for the "action selection", and one for "performing the action" (see Fig.3.1). In this experiment, the action selection and the performance of the action is separated, so that the perception of control is measured by looking at how people want to control how the action is executed with no direct intervention from the user. This means that the experiment is investigating the perception of control of the robot executing the action and not the perception of control of the action. Also since the chosen task-oriented robot for the experiment is a commercially available robot which primarily task is cleaning, people may then be given the impression that the cleaning would be done properly.

3.2 Research questions and hypotheses

The focus of this study being perception of control, desired control, and robot anxiety, three conditions, each matching a different level of autonomy, were designed for the experiment. As a reminder autonomy means decision-making in this thesis.

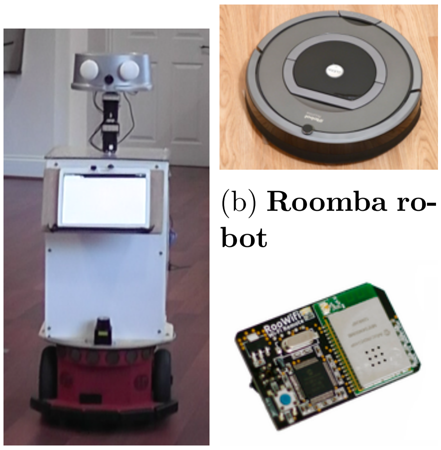
- **R1**: Is there a relationship between the perception of control participants had over the robot and their preference of the robot's level of autonomy?
  - H1: The more people perceive to be in control of the robot, the more autonomous they want the robot to be.
- **R2**: Is there a relationship between participants' desired control and their preference of the robot's level of autonomy?
  - H2: There is a correlation between participants' desired control and their preferences regarding the level of autonomy of the robots.
- **R8**: Does a participant's technology savviness (experience and knowledge about technology) influence its preference of the robot's level of autonomy?
  - H8: The more experience with technology participants are, the more autonomous they want the robot to be.
- **R9**: Is there a relationship between a participant's anxiety towards robots and its perception of control of the robot?
  - H9a: There is a correlation between robot anxiety and participants' desired control.
  - H9b: There is a correlation between robot anxiety and participants' perception of control.
  - H9c: The effects of robot anxiety changes the preferred level of robot's autonomy.

3.3 Methods

To answer the research questions above, an exploratory study was conducted through one task: cleaning. As mentioned in Chapter 2 desired control was measured using a Desirability Control Scale, perception of control using a rank type questionnaire and people's anxiety towards robots using the Robot Anxiety Scale.

3.3.1 Experimental design

The experiment was conducted with two fully autonomously operating robots: a companion robot (Sunflower, **Fig. 3.2a**) and a cleaning robot (Roomba, **Fig. 3.2b**). Sunflower (Salem et al. 2015) possesses an embodied upper body attached to a Pioneers DX robot base. Roomba is a commercial vacuum cleaner (Forlizzi & DiSalvo 2006) that was chosen for its utility purpose. The cleaning robot does not need to be supervised to perform its job (Young et al. 2009), which was a good way to ensure the differentiation between the execution of the task and its performance. A Roowifi device (see **Fig. 3.2c**) was used to connect the Roomba to the network. The experiment took place in the Robot House, a typical British residential house, converted into a smart home, including autonomous robots, owned by the University of Hertfordshire where studies can be run in a realistic domestic environment. More details of the robots and the house can be found in Chapter 2.



(a) **Sunflower robot** (b) **Roomba robot** (c) **Roowifi device**

Figure 3.2 – **Domestic robots (a), (b), and Roomba's connecting device (c)**

It was chosen for the main robot companion Sunflower to possess three levels of autonomy to quantify Roomba's autonomy. It means the experiment was segmented in three conditions to represent the different level of autonomy: Condition 1 represents a low-level of autonomy where the main robot companion Sunflower gives instructions and where the cleaning robot Roomba has to be activated manually by the participant. Condition 2 represents a medium-level of autonomy where the main robot companion gives instructions and acts as a remote control for the cleaning robot. Condition 3 represents the high-level autonomy where the main robot companion notices cleaning needs to be done and activates Roomba without any action required from the user. The robot companion informs the participant that the action is done.

- **Condition 1: Participant operates Roomba manually** ($P \rightarrow R$) The command of the cleaning action is generated by the participant.

- **Condition 2: Participant operates Roomba remotely via Sunflower** ($P \rightarrow S \rightarrow R$) The command of the cleaning action requires the approval of the participant.

- **Condition 3: Sunflower operates Roomba automatically** ($S \rightarrow R$) The command of the action is achieved via the Sunflower robot without the approval of the participant.

Sunflower being the multi-task robot, it was decided that the robot needed to perform several tasks to give the impression of being a multi-task robot to the participants. For the purpose of the experiment, Sunflower was greeting participants at the entrance of the living room and was playing some music for entertainment.

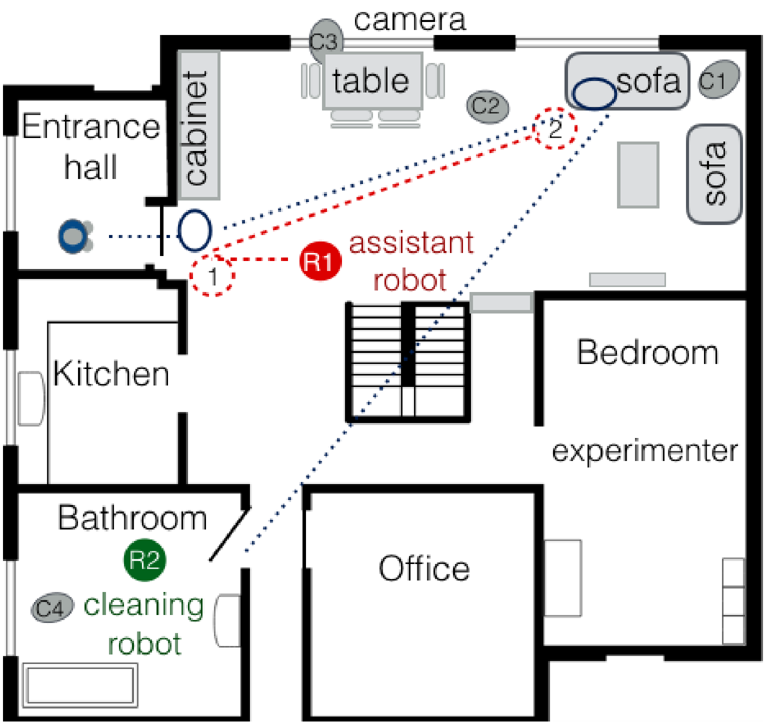


Figure 3.3 – **Experimental settings for the three conditions. The icons in blue describe the direction followed by the user and in red the ones pursued by the robot**

In each condition (see Fig. 3.3), Sunflower welcomes the user and asks the person to take a seat. Once the person sits on the sofa, Sunflower comes to the participant and displays on its onboard screen that the bathroom needs cleaning. In condition 1 Fig.3.4, Sunflower asks the participant to activate cleaning on the Roomba robot manually. In condition 2, Sunflower asks the participant for confirmation before operating the Roomba robot for cleaning (see Fig. 3.5). In condition 3 Fig.3.6, Sunflower activates cleaning on the Roomba without asking for permission. It informs the user that Roomba has started cleaning once that Roomba has been activated. After the first activation of Roomba, Sunflower offers to play some music for entertainment, while the participant waits on the sofa for the cleaning to be done. Once a predefined cleaning time of 1 minute 30 has passed, Sunflower asks the person to deactivate Roomba either manually (condition 1) or remotely (condition 2). In condition 3 Sunflower turns off Roomba automatically and then informs the participant that cleaning has been done. The experiment was conducted as a test within subjects, meaning each participant experienced every condition in a semi-randomised order (each participant starts with a different condition, so there is a balance in the number of participants between each condition).

3.3.1.1 Conditions of the experiment

In Condition 1 described in Fig. 3.4, Sunflower acts solely as a reminder and asks the user to turn on and turn off manually the cleaning robot Roomba, located in the bathroom. In Condition 2 described in Fig. 3.5, Sunflower acts as a remote control for the Roomba robot and suggest to the user to turn on and off the Roomba robot via Sunflower's interface. In Condition 3 described in Fig. 3.6, Sunflower turns on the Roomba robot without asking for confirmation from the user.

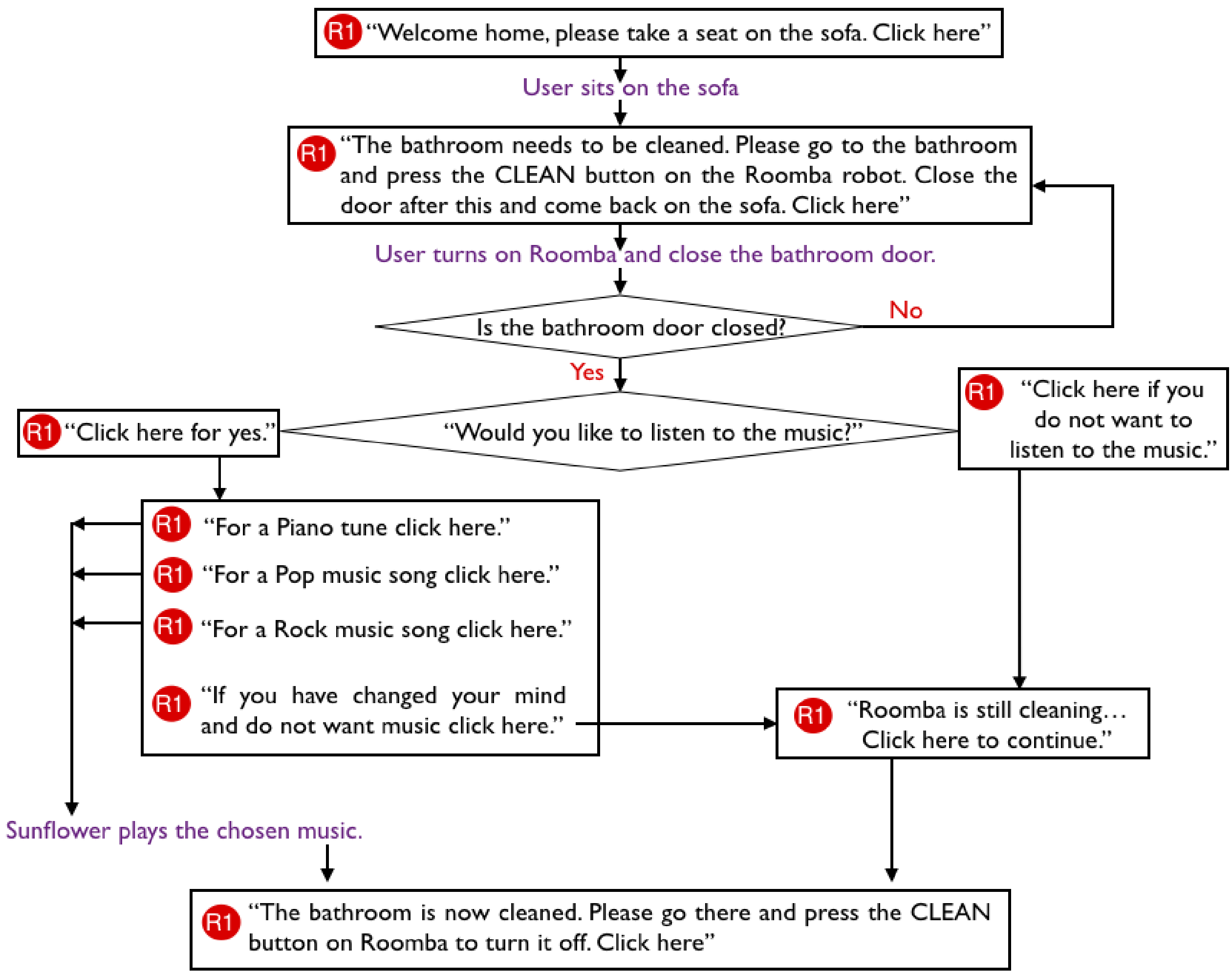


Figure 3.4 – **Condition 1: Sunflower has "low autonomy", the participant has to activate Roomba manually**

3.3.1.2 Pilot study

A pilot study was conducted with 3 people of the Adaptive Systems Group which were colleagues from another laboratory. It was quickly noticed that it was necessary to ask the participant to close the bathroom door each time before the Roomba robot was doing the cleaning regardless of the condition. Indeed, when one of the pilot participant started with Condition 3 with the bathroom door closed, within the given scenario, the participant did not see the Roomba in the bathroom before the action started. Therefore, to ensure consistency within each condition, e.g the participant getting the same impression of each robot, the participant was always asked to close the door in each condition of the experiment.

3.3.1.3 Technical implementations

To be able to conduct the experiment in a realistic manner, it was necessary to implement the different levels of autonomy on Sunflower so the experiment could be conducted autonomously (without the intervention of the experimenter using a remote control). To do so, the CobSequencer software was used to implement behaviours triggered by either specific sensors or specific actions Ho et al. (2012). As there are three conditions in this experiment, each one was implemented in a separate scenario using the CobScheduler. Condition 1 was labelled as "scenario 1", Condition 2 as "scenario 2" and Condition 3 "Adeline's scenario". The details of how to use the robots are in Chapter 2.

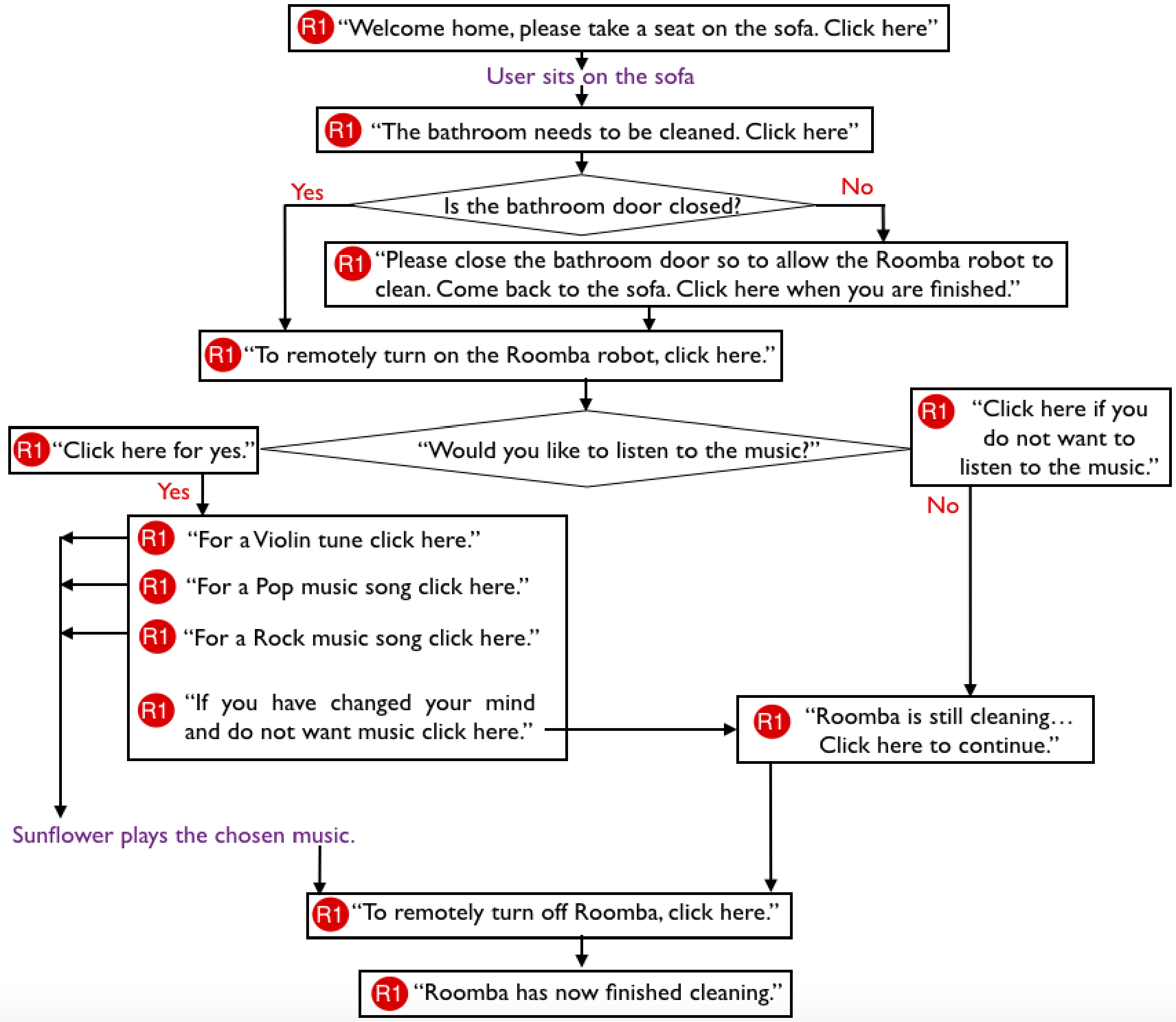


Figure 3.5 – Condition 2: **Sunflower has "medium autonomy", the participant activates Roomba remotely**

3.3.1.4 Questionnaires given to the participant

Five questionnaires were designed for this study. The experimenter started the study by providing a paper based questionnaire, but realised soon after the pilot study that it was impractical and some participants were forgetting to answer some questions. Therefore, an online questionnaire was set up using a Google form to facilitate data collections. The hardcopies and the links are available in Appendix D.

3.3.1.5 Ethics approval

Ethics approval was obtained for this study under protocol number COM/PG/UH/00102 which can be found in Appendix A.1.

3.3.1.6 Recruiting participants

To recruit participants for this first live study, mainly students and some staff members not related to the field of Human-Robot interaction were approached. Advertising was done through posters and sending emails to specific mailing lists and University societies. Despite all the

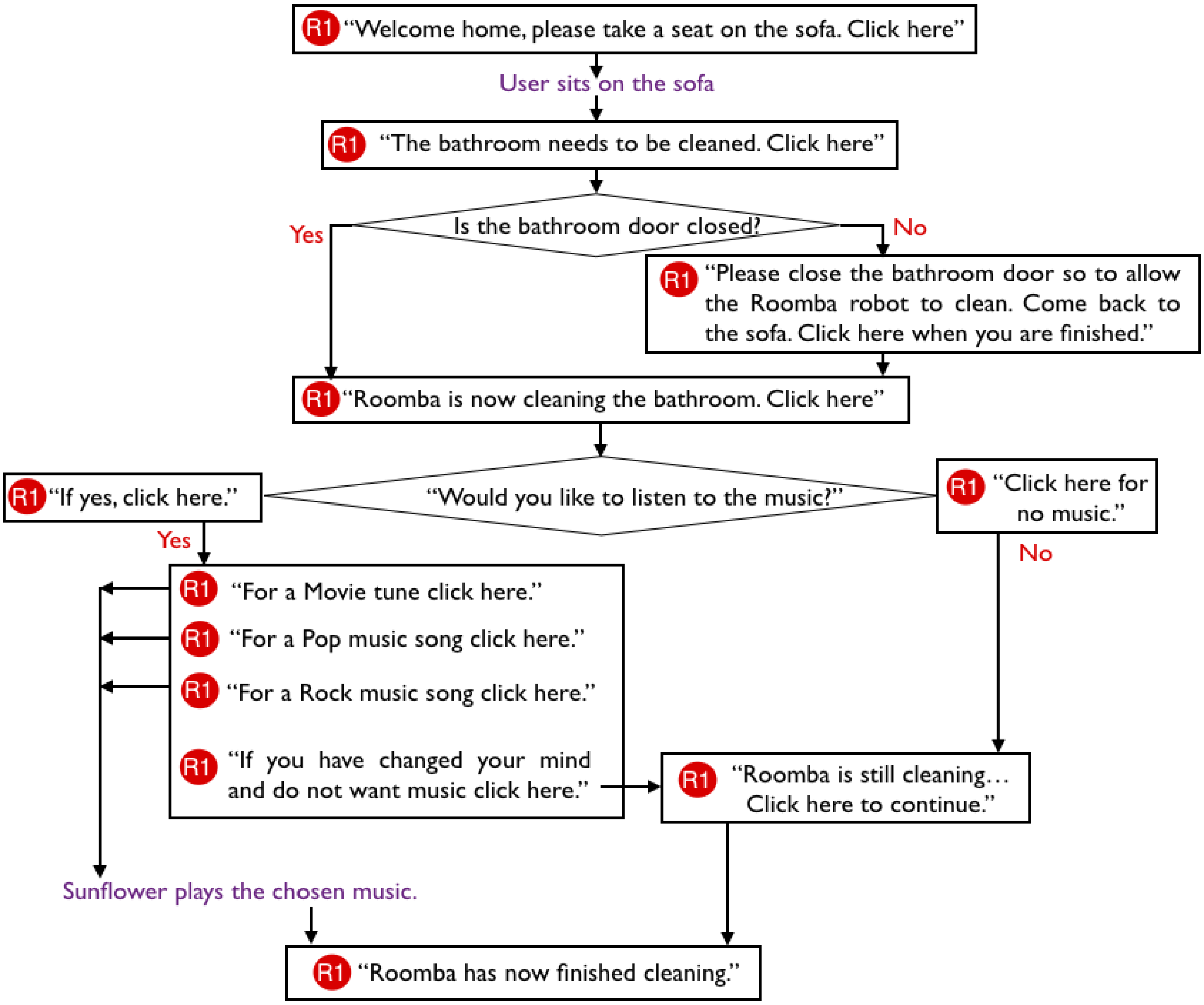


Figure 3.6 – Condition 3: **Sunflower has "medium autonomy", the participant activates Roomba remotely**

publicity, it took 4 to 5 months to recruit 25 people. The participants were not offered any compensation for their time spent on the experiment (around an hour) which could explain the difficulty in recruitment. Another difficulty is the remote location of the Robot House. It is located 10 minutes walk away from the campus.

3.3.2 Experimental protocol

3.3.2.1 a) The day before the experiment

- Remind the participant of the date and the location of the experiment by sending an email or a text.
- Charge Roomba.
- Charge Sunflower and its laptop.
- Charge the cameras.
- Empty the cameras SD cards.
- Make sure the helping sign is here.
- Prepare the questionnaires for the participants.
- Make sure there is tea, coffee, juices and some cakes or biscuits for participants.
- Bring the SD card reader to the robot house.

- Making sure the sensors (sofa, doorbell, bathroom door) are working.

3.3.2.2 b)Preparing the room before the participant comes in

- Come in 2 hours before the start of an experiment.
- Set up the cameras' location (living room, sofa and bathroom) and checking the battery levels. Charge them if possible.
- Charge the robots (Roomba, and Sunflower once more).
- Put the Roomba in the bathroom with the roowifi on it.
- Run a test of the different scenarii.
- Once everything is working, put the Sunflower robot on charge again.
- Turn the ceiling camera live feed on.
- ssh from my laptop the desktop.
- Switch off the screens of the desktop.
- Make sure the laptop is charged.
- Prepare Ricky's video. Ricky's video is an introduction of the Robot House (see A sleepover in a robot house (Last accessed 16/06/2019))

3.3.2.3 c) When the participant comes in

- Welcome the participant and introduce them to the robot house.
- Give the participants the information sheet and the consent form.
- Tell the participant she/ he can help her/himself with the drinks. Ask if they want some tea or coffee.
- The robot house is made for research purposes to understand how we can enhance robots for people.
- Show the participant Ricky's video on the Samsung tablet.
- Introduce the participants to Sunflower and Roomba.
- Sunflower is the main robot with whom you will be interacting with.
- Roomba is a cleaning robot. Let me show you how to operate a Roomba. You need to press the CLEAN button to make it work. If the light is not on, you need to press it twice. Try it yourself.
- Once the participant understands how Roomba works, explain that the experiment will be run in three sessions.
- Give the participant the first set of questionnaire.
- Turn on all the cameras in the meanwhile and make sure Roomba is ready to go.
- Prepare the Roomba remote control and check it is working in case something goes wrong.

3.3.2.4 d) During the experiment

- Once the participant has finished to filled in the first questionnaire, explain that now the experiment will start.
- Tell the participant that she/he can imagine that she/he is coming back home.
- Tell the participant to wait in the entrance and come in when they hear the bell (make them listen to the bell). Make clear they do not need to open the door for someone.
- When they hear the bell tell them to wait at the entrance. Something will happen.
- The experimenter will be waiting in another room while the experiment is run.

3.3.2.5 e) Scenario launch

- when the first scenario is finished, go outside the bedroom and tell the participant the first session is now over, there will be two other sessions.
- Give the participant the second questionnaire and let them sit on the table to fill it in.
- Prepare Roomba.
- When the participant has finished, tell the participant to wait in the entrance hall again and come in after they hear the bell. Wait in the entrance, something will happen.
- When the second scenario is done, tell the participant another session will be done.
- Give the participant the third questionnaire and let them sit on the table to fill it in.
- When the participant has finished, tell the participant to wait in the entrance hall again and come in after they hear the bell. Wait in the entrance, something will happen.
- Go to the bedroom and run the last scenario.
- When the scenario is finished, tell the participant, it is the end of the experiment. Give them the fourth and the fifth questionnaire.
- When they are finished, ask the participant how they felt and make sure they are happy.
- Thank you for participating in the experiment, if you want some cakes, please help yourself before you go.

3.3.2.6 f) After the experiment

- Once the participants have left, turn off the cameras and save the data to the corresponding folder. Empty the SD card.
- Keep all the participant's answer sheets and consent forms into the proper case file.
- Charge all the batteries (Sunflower, Roomba and cameras).

3.3.3 Experimental procedure

Once the participant arrived at the Robot House and was formally greeted, the place and the robots Sunflower and Roomba were introduced. It was explained how to manipulate a Roomba robot and was ensured that the participant knew how to operate the Roomba manually, by letting the participant activate the robot twice (turn on the robot, and activate cleaning). An information sheet was provided and the participants signed the consent forms. Afterwards, they were shown a short BBC news video on the Robot House (A sleepover in a robot house Last accessed 16/06/2019). Some previous research (Syrdal et al. 2014) has found it is important to set the scene, i.e. to give participants information on the context of the research and the envisaged application area. It was hoped that the video introduction of the environment and research context would decrease the novelty effect.
Afterwards, participants completed questionnaires covering age, technology awareness, personality (Ten Item Personality Inventory test (Gosling et al. 2003)), desired control (Desirability of Control Scale (Burger & Cooper 1979)), and robot anxiety (Nomura's robot anxiety test (Nomura, Suzuki, Kanda & Kato 2006)).
Before each condition of the experiment started, the participant was asked to imagine that she or he had just come home after work and wanted to relax on the sofa. The participant had to wait in the entrance hall (see **Fig. 3.3**) for a bell signal (used to indicate the start of the particular condition set by the experimenter). Then a condition started. The same procedure was repeated until all the conditions were completed. After each condition, the participant was asked to complete questionnaires about their impression of the robots and who they felt were in charge. After the final condition, the participant was provided with another questionnaire

assessing condition preferences, and a robot anxiety test.
The duration of the experiment for each participant was about 50 minutes. Each condition lasted about 10 to 13 minutes.
The Sunflower robot communicated with the participant via a tablet. This choice was made so the voice of the robot would not influence the participant and moreover, it was a good way to ensure the participants would fully understand the information since an acknowledgment was required after each message.
The cleaning task was considered a high priority task with low impact during the experiment as it was the main task that the participant has to execute. Therefore, it was decided to execute the task in the bathroom, separate from the main interactive space, where Sunflower and the participant stay, thus reinforcing the view of Sunflower as a robot companion and Roomba as a helper robot. Since Roomba's primary purpose was cleaning, no attempt was made to make it more interactive. To strengthen the view of Roomba as the task-execution robot, the participant was asked in every condition to close the bathroom door to ensure she or he was aware that Roomba was going to clean the bathroom. As a reminder, the order of the three conditions in which the participants had to perform was randomised each time in order to reduce any potential order effect.

3.3.4 Participants

Twenty-five participants took part in the study aged 21 to 62 years ($M = 36.16$, $SD = 13.04$). Gender balance was relatively well maintained (11 female, 14 male).

3.4 Results

3.4.1 Population distribution

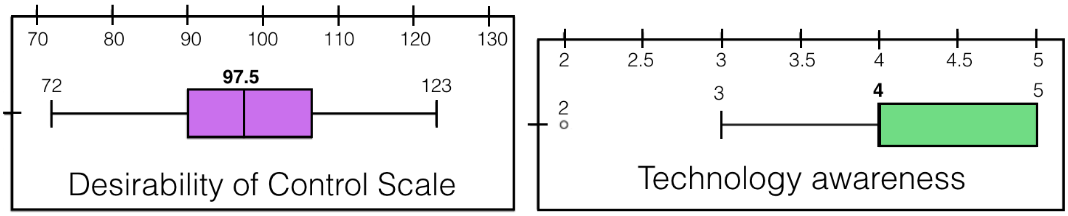


Figure 3.7 – **Participants distribution for DCS and technology awareness**

Although the distribution of participants for the DCS questionnaire is close to a normal distribution, the distribution of participants on the personality test and the awareness of technology shows the heterogeneity of the sample (see **Fig. 3.7** and **3.8**). A one sample Kolmogorov-Smirnov test confirmed this impression. The test showed that the population is normal for the DCS ($p = 0.200$), Emotional stability ($p = 0.200$) and Conscientiousness ($p = 0.103$), but also indicated that the population is not normal for Extraversion ($p = 0.011$), Agreeableness ($p = 0.002$) and Openness ($p = 0.002$). Therefore, non-parametric tests were used for data analysis. A Friedman test was performed to detect the differences between the three conditions regarding the choice of level of autonomy of the robots. To analyse perceived control, desired control or robot anxiety, Kendall's correlation tests were used to measure the ordinal association between measured quantities derived from Likert scale questionnaires.

3.4.2 RQ8: Effect of technology familiarity

The Kendall's tau correlation test shows there is no statistically significant correlation between how familiar with technology people are and what level of autonomy they preferred the robot

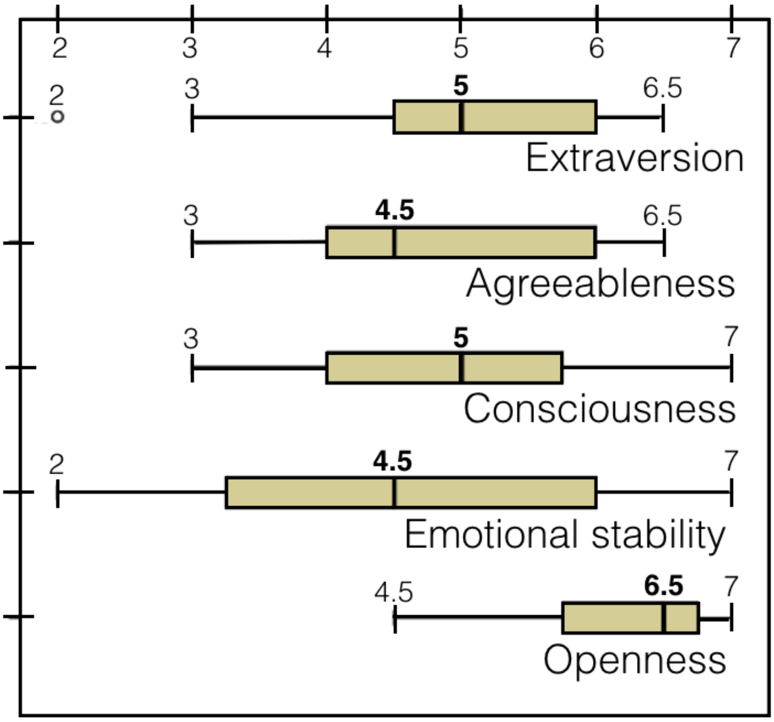


Figure 3.8 – **Participants distribution regarding personality**

	Preferred condition	RAS S1	RAS S2	RAS S3
Technology awareness	-0.053 -0.782	-0.136 0.428	-0.359* 0.036	-0.229 0.174

* Correlation is significant at the 0,05 level (2-tailed).
RAS S1: Anxiety toward Communication Capability of Robots
RAS S2: Anxiety toward Behavioral Characteristics of Robots
RAS S3: Anxiety toward Discourse with Robots

Figure 3.9 – **Correlation table between technology familiarity, people's preference of condition and people's anxiety towards robots**

to be ($\tau_b = -0.053$, $p = 0.782$). This disproves H8 hypothesis that the more experience with technology people are, the more autonomous they prefer the robot to be. However, there is a significant negative correlation between how familiar people are with technology and how anxious towards the behaviour of the robots people are ($\tau_b = -0.359$, $p = 0.036$). This means that the more familiar with technology people are, the less anxious about robots' behaviour people feel. This potentially means that if people are more used to technology, they may become less anxious about robots. However, when participants' technology awareness results are compared with participants' anxiety towards robots, evaluated at the end of the experiment, we do not find any significant correlations (see Fig.3.10).

3.4.3 RQ1 and RQ2: Effect of different level of autonomy

The Kendall's tau correlation test shows a high significant positive correlation between participants' condition preferences and their desired control ($\tau_b = 0.454$ and $p = 0.007$). This result proves H2 hypothesis, which indicates that the more autonomous participants wanted their robots to be, the more in control participants wanted to be. So people with high scores for desired control are likely to prefer a fully autonomous robot. This suggests that people with high desired control do not want to be in charge of the robots and their operation. It

	RAS S1 measured after the experiment	RAS S2 measured after the experiment	RAS S3 measured after the experiment
Technology awareness	0.000 1.000	0.061 0.722	-0.014 0.935

RAS S1: Anxiety toward Communication Capability of Robots
RAS S2: Anxiety toward Behavioral Characteristics of Robots
RAS S3: Anxiety toward Discourse with Robots

Figure 3.10 – **Correlation table between technology familiarity and people's anxiety towards robots measured after the experiment**

can be extrapolated that since participants were more knowledgeable than average regarding technology (see **Fig. 3.7**), they trusted the robots to do their jobs correctly, although no significant correlation was found between participants' technology awareness and their desired control ($\tau_b = 0.000$ and $p = 1.000$). It is likely that the nature of the task being cleaning, which is a house chore may influence the participants' choice of preferred condition.

	C1 Sunflower was in charge	C1 Roomba was in charge	C2 I felt in charge	C2 Sunflower was in charge	C2 Roomba was in charge	C3 I felt in charge	C3 Sunflower was in charge	Preferred condition
C1 I felt in charge	-0.034 0.851	-0.226 0.234	0.396* 0.023	0.051 0.778	-0.226 0.234	0.129 0.487	0.234 0.194	-0.191 0.297
C1 Sunflower was in charge		-0.085 0.657	-0.450* 0.010	0.534* 0.003	-0.085 0.657	-0.334 0.073	0.292 0.107	0.381* 0.038
C1 Roomba was in charge			-0.067 0.720	-0.075 0.699	1.000** 0.000	0.065 0.743	-0.047 0.808	0.156 0.427
C2 I felt in charge				-0.372* 0.036	-0.067 0.720	0.183 0.317	0.015 0.932	-0.351 0.051
C2 Sunflower was in charge					-0.075 0.699	-0.264 0.167	0.513** 0.005	0.298 0.110
C2 Roomba was in charge						0.065 0.743	-0.047 0.808	0.156 0.427
C3 I felt in charge							-0.644** 0.001	-0.237 0.220
C3 Sunflower was in charge								0.199 0.284

** Correlation is significant at the 0,01 level (2-tailed).
* Correlation is significant at the 0,05 level (2-tailed).
C1: condition 1 Roomba is activated manually.
C2: condition 2 Roomba is activated remotely.
C3: condition 3 Roomba is activated autonomously.

Table 3.1 – **Correlation test between perception of control**

The Kendall's tau correlation test showed that the fewer people felt in charge, the more they felt Sunflower was in charge (for condition 2 $\tau_b = -0.372$, $p = 0.036$ and for condition 3 $\tau_b = -0.644$, $p = 0.001$). The Friedman test revealed a significant difference for whom the person felt in charge of in each condition ($N = 24$, $\chi^2 = 12.644$, $df = 2$, and $p = 0.002$) but showed no statistical differences for whom the participant felt Sunflower was in charge of ($N = 25$, $\chi^2 = 2.508$, $df = 2$, and $p = 0.285$). The Wilcoxon test Table 3.2 confirmed there is a highly significant difference for whom the person felt being in charge of, with $Z = -3.273$ and $p = 0.001$. This means that the more autonomous the robot became (from condition 1 to 3), the less in charge the participant felt, which confirmed there is a delegation of control which is perceived. There is also a positive correlation between how much the participant felt the Sunflower robot was in charge in condition 1 and the participant's preferred condition ($\tau_b = 0.381$, $p = 0.038$). It means the more participants felt Sunflower was in charge in condition 1 (when they had to activate Roomba manually), the more they preferred the when Sunflower operated Roomba autonomously. So it cannot be said that hypothesis H1 is verified as there was no statistically significant correlation between how much in charge people felt and their preferred condition. However, the results show that the more autonomous Roomba becomes, the less in control the participant perceives to be.

	I felt in charge of (condition 2) — I felt in charge of (condition 1)	I felt in charge of (condition 3) — I felt in charge of (condition 2)	I felt in charge of (condition 3) — I felt in charge of (condition 1)	Sunflower was in charge of (condition 2)— Sunflower was in charge of (condition 1)
Z	-1.884[b]	-1.997[b]	-3.273[b]	-1.147[c]
Asymp. Sig (2-tailed)	0.060	0.046	0.001	0.251

	Sunflower was in charge of (condition 3) — Sunflower was in charge of (condition 1)	Sunflower was in charge of (condition 3) — Sunflower was in charge of (condition 2)	Roomba was in charge of (condition 2)— Roomba was in charge of (condition 1)
Z	-0.025[b]	-0.890[b]	0.000[d]
Asymp. Sig (2-tailed)	0.980	0.374	1.000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.
c. Based on negative ranks.
d. The sum of negative ranks equals the sum of positive ranks.

Table 3.2 – **People's perception of who is in charge (robot, user)**

A Kendall's correlation test demonstrates a highly significant positive correlation between participants wanting to delegate more tasks to Sunflower and Roomba, and participants wanting Sunflower to operate Roomba ($\tau_b = 0.672$ and $p < 0.001$). So the more participants want to delegate tasks to both Sunflower and Roomba, the more they want Sunflower to operate Roomba. There is also a high positive correlation between participants wanting to delegate more tasks to Sunflower and Roomba and participants liking Sunflower as a remote control ($\tau_b = 0.507$ and $p = 0.006$). This is consistent with the previous result as the more participants want to delegate tasks to both Sunflower and Roomba, the more they like Sunflower to act as a remote control.

Participants' condition preferences also highly correlates positively with participants wanting to delegate more tasks to Sunflower and Roomba ($\tau_b = 0.454$ and $p = 0.039$). So the more autonomous people prefer the Roomba to be, the more people wanted to delegate tasks to both robots. There is also a significant negative correlation between people's preference for Sunflower to operate Roomba, and the preference of having Roomba as a main robot companion ($\tau_b = -0.430$ and $p = 0.018$). This means the more people prefer Sunflower to operate Roomba the less people wanted Roomba as a main robot companion.

These results show there is a consistency with people asking for more autonomous robots. This may be because participants were more technology aware than an average group (see **Fig. 3.7**).

Each condition also affected the way people perceive Sunflower's and Roomba's role (see **Fig. 3.11**). The more autonomous Sunflower became (being able to control Roomba), the more people saw the robot as an assistant and fewer rated Sunflower in the machine category. However, the Sunflower's companion category reduced slightly.

	Participants' perception of the role of:					
	Sunflower			Roomba		
	P → R	P→R→S	S → R	P → R	P→R→S	S → R
a machine	8	7	7	18	16	19
a companion	8	7	6	0	0	0
a friend	1	2	2	1	0	0
a butler	1	2	0	0	1	1
an assistant	15	12	16	5	5	6
a pet	0	0	0	1	1	1
other	2	1	2	2	3	3

Figure 3.11 – **Perception of the robots' role according to each condition**

3.4.4 RQ9: Effect of anxiety towards robots

	Preferred condition	RAS S1 measured before the experiment	RAS S2 measured before the experiment	RAS S3 measured before the experiment	RAS S1 measured after the experiment	RAS S2 measured after the experiment	RAS S3 measured after the experiment	Average RAS measured before the experiment	Average RAS measured after the experiment
Desired control	0.454** 0.007	-0.104 0.497	0.011 0.940	-0.037 0.803	0.309* 0.046	0.326* 0.033	0.160 0.292	-0.029 0.842	0.300* 0.046
Preferred condition		-0.247 0.148	0.101 0.550	0.159 0.343	0.184 0.286	0.135 0.430	0.134 0.431	0.036 0.829	0.158 0.344
RAS S1 measured before the experiment			0.486** 0.002	0.478** 0.002	0.337* 0.030	0.140 0.363	0.161 0.293	0.617** 0.000	0.234 0.122
RAS S2 measured before the experiment				0.679** 0.000	0.174 0.261	0.179 0.243	0.170 0.264	0.766** 0.000	0.195 0.193
RAS S3 measured before the experiment					0.227 0.139	0.112 0.461	0.237 0.118	0.844** 0.000	0.225 0.131
RAS S1 measured after the experiment						0.602** 0.000	0.649** 0.000	0.247 0.101	0.772** 0.000
RAS S2 measured after the experiment							0.579** 0.000	0.141 0.344	0.790** 0.000
RAS S3 measured after the experiment								0.211 0.157	0.788** 0.000
Average RAS measured before the experiment									0.234 0.110

** Correlation is significant at the 0,01 level (2-tailed).
* Correlation is significant at the 0,05 level (2-tailed).
RAS S1: Anxiety toward Communication Capability of Robots
RAS S2: Anxiety toward Behavioral Characteristics of Robots
RAS S3: Anxiety toward Discourse with Robots

Figure 3.12 – Correlation between people's anxiety towards robots and their desired control

Another explanation of why participants' may want to have highly autonomous robots, could be because they felt anxious about them. Indeed, it can be hypothesised the more anxious of robots you are, the less time you want to spend with them. Kendall's correlation test showed there is a significant positive correlation between desired control and the robot anxiety test done after the experiment ($\tau_b = 0.300$ and $p = 0.046$) meaning, the more controlling participants are, the more anxious about robots they were. Hypothesis H9a is then verified, this results supports the idea that participants with high desired control wanted more autonomous robots, probably because they were more anxious about robots than others, therefore they wanted to have less interaction time with them.

As the correlation table Fig.3.13 displays, there is no statistically significant correlation between how anxious towards robots participants are and their perception of control. Therefore, hypothesis H9b is disproved. However, if we analyse the answers about robots given by the participants in each condition, there are some interesting findings.

The correlation test Fig.3.14 shows no statistical significance between how useful participants perceived the robot to be and their anxiety towards robots in condition 1 and condition

	C1 I felt in charge	C1 Sunflower was in charge	C1 Roomba was in charge	C2 I felt in charge	C2 Sunflower was in charge	C2 Roomba was in charge	C3 I felt in charge	C3 Sunflower was in charge	Preferred condition
RAS S1 measured before the experiment	-0.114 0.491	-0.017 0.919	-0.261 0.141	0.116 0.476	-0.116 0.490	-0.261 0.141	0.135 0.438	-0.061 0.718	-0.247 0.148
RAS S2 measured before the experiment	-0.142 0.388	-0.042 0.801	-0.258 0.143	0.221 0.170	-0.035 0.832	-0.258 0.143	-0.089 0.607	0.088 0.599	0.101 0.550
RAS S3 measured before the experiment	-0.227 0.164	0.103 0.529	-0.206 0.236	0.004 0.981	0.070 0.673	-0.206 0.236	-0.208 0.221	0.274 0.098	0.159 0.343
RAS S1 measured after the experiment	-0.128 0.443	0.175 0.298	0.214 0.232	0.048 0.767	-0.217 0.201	0.214 0.232	0.091 0.605	-0.109 0.522	0.184 0.286
RAS S2 measured after the experiment	0.000 1.000	0.080 0.631	0.037 0.834	0.148 0.363	-0.143 0.396	0.037 0.834	0.035 0.841	-0.065 0.698	0.135 0.430
RAS S3 measured after the experiment	0.059 0.722	0.079 0.632	0.160 0.364	0.107 0.508	-0.084 0.615	0.160 0.364	0.153 0.376	0.042 0.803	0.134 0.431

Figure 3.13 – Correlation between people's anxiety towards robots and their perception of control

2. However, there is a significant positive correlation between RAS S1 measured after the experiment and the usefulness of Roomba for condition 3 ($\tau_b = 0.391$, $p = 0.025$). The same applies for RAS S2 measured after the experiment and Roomba's usefulness ($\tau_b = 0.354$, $p = 0.040$). This means that the more anxious about the communication capability of robots and about the behavioural characteristics of robots participants were, the more useful they found Roomba. Also, the results show that the more anxious about the robots people were before the experiment towards the behaviour of robots, and towards the discourse with robots, the more they liked Sunflower acting as a remote control during condition 2 (see Fig.3.14). But this results did not appear for anxiety towards robots measured after the experiment. This shows that robot anxiety influence the perception of the Sunflower robot companion. Similarly, there is no correlation between anxiety towards robots measured before the experiment and the participants' perception of Sunflower operating Roomba in condition 1. However, there is a significant negative correlation between how participants felt about Sunflower operating Roomba in condition 1 and their anxiety towards the behaviour of robots measured after the experiment ($\tau_b = -0.379$, $p = 0.024$). This means, the more anxious towards the behaviour of robots participants were after the experiment, the more they prefer Sunflower to operate Roomba to do the cleaning. These results prove that anxiety towards robots influence the preference of perception of control of the Sunflower robot. So hypothesis H9c is verified although the influence of anxiety towards robots is small as the correlation table Fig. 3.14 shows that the effect does not appear for each item across each condition.

3.5 Limitations of the study

Having three conditions in the experiment, there were six possible combinations (e.g. C1, C2, C3) regarding the order of the conditions the participant could go through during the experiment. Therefore, having 25 participants means there were only 4 or 5 participants per combinations which can appear as a low number. Indeed, although it was hoped the novelty

	C1 I felt Sunflower was useless	C1 I felt Roomba was useless	C1 I would like Sunflower to operate Roomba to do the cleaning	C1 I would like Roomba to be the main robot companion	C2 I felt Sunflower was useless	C2 I felt Roomba was useless	C2 I like the fact that Sunflower acted as a remote control	C3 I felt Sunflower was useless	C3 I felt Roomba was useless	C3 I like Sunflower telling me what it is doing
RAS S1 measured before the experiment	0.061 0.709	-0.019 0.913	-0.161 0.339	-0.062 0.712	-0.044 0.792	0.024 0.888	-0.154 0.358	0.062 0.716	-0.162 0.348	0.204 0.212
RAS S2 measured before the experiment	-0.028 0.862	0.059 0.724	-0.207 0.214	-0.100 0.545	0.043 0.793	0.181 0.288	-0.384* 0.021	-0.014 0.933	-0.268 0.117	0.097 0.551
RAS S3 measured before the experiment	-0.008 0.961	0.081 0.626	-0.083 0.617	-0.163 0.319	-0.060 0.714	0.061 0.717	-0.325* 0.050	0.009 0.956	-0.209 0.218	-0.020 0.901
RAS S1 measured after the experiment	0.295 0.072	0.164 0.339	-0.284 0.094	0.129 0.442	0.169 0.315	0.078 0.652	-0.109 0.521	0.192 0.262	0.391* 0.025	-0.194 0.240
RAS S2 measured after the experiment	0.190 0.242	0.162 0.341	-0.379* 0.024	0.338* 0.042	0.193 0.246	0.125 0.465	-0.187 0.266	0.166 0.328	0.354* 0.040	-0.110 0.501
RAS S3 measured after the experiment	0.269 0.096	0.073 0.664	-0.088 0.597	0.022 0.895	0.205 0.217	0.033 0.845	-0.144 0.390	0.231 0.172	0.279 0.104	-0.267 0.101

*Correlation is significant at the 0,05 level (2-tailed).
RAS S1: Anxiety toward Communication Capability of Robots
RAS S2: Anxiety toward Behavioral Characteristics of Robots
RAS S3: Anxiety toward Discourse with Robots

Figure 3.14 – Correlation between people's anxiety towards robots and their perception of the robot

effect would be limited by the introduction of the robot house, there was still some novelty effect to a certain extent when participants experimented the first condition (regardless of the condition being C1, C2 or C3). For example, some participants took longer than usual to understand they had to go back to the sofa after the bathroom door was closed. An analysis was done on the questionnaires about who is in charge, to check whether there was an order effect. It was found that there was a slight order effect regarding which condition came first for the questionnaire about whom the participant felt in charge of ($M_{C1} = 2.25$, $M_{C2} = 2.63$ and $M_{C3} = 2.39$) and who the participant thought Roomba was in charge of ($M_{C1} = 1.00$, $M_{C2} = 1.00$ and $M_{C3} = 1.13$). However, there was a notable order effect for the questionnaire on whom the participant thought Sunflower was in charge of ($M_{C1} = 2.54$, $M_{C2} = 2.67$ and $M_{C3} = 1.88$). This means participants that started the experiment with condition 3 ($S \rightarrow R$ when Sunflower operates Roomba without the participant's explicit authorisation) were less likely to feel controlled by Sunflower than participants that started the experiment with condition 1 and condition 2. However, as mentioned above these results are to be taken with caution due to the low number of participants per combinations.
Also another limitation of the study is the nature of the task performed during the experiment: cleaning. It may be that the task was not considered critical enough to find more meaningful results.

3.6 Discussion

First, the results of this study did not show that technology awareness influences the preferred level of autonomy of robots. This confirms what Young et al. (2009) suggested when they mentioned that technology education may be less of a factor when it comes to using a domestic robot as there are less transferable skills coming from the usage of other technology. However, desired control is an influential factor regarding the choice of the preferred level of autonomy of robots. The experiment shows that the more controlling a person is, the more likely the person will prefer to have an autonomous robot. It was also found that anxiety towards robots measured after the experiment and desired control correlates positively. So it seems that people with high anxiety towards robots and high desired control prefer to have robots with a high level of autonomy. Regardless of the condition, the results show that participants prefer the Sunflower robot to control the Roomba. Also, the results show that the more people felt in charge, the less Sunflower was in control. From this finding, it is likely that people rated the accomplished action (in this case, the bathroom being cleaned) more importantly than which robot was performing the action. Therefore, this would explain why people with a high desired control preferred having Sunflower to complete the cleaning task via Roomba.

However, these results need to be taken with caution since other factors may have influenced it, such as the type of task performed by the robot, which by design offered little incentive for the participant to monitor the cleaning action. Only one participant spent some time watching the Roomba cleaning the bathroom. Cleaning may not necessarily be considered a high priority task, therefore, the management of the task may not be important to participants as long as the task is done correctly. It is suspected that the results would vary greatly if the task was different. Meerbeek et al. (2006) did a similar study in 2006 with the task being changing the TV programme, in a Wizard-of-Oz setting and found some correlations between the robot's personality and the perception of the task. Although it was mentioned that the results were to be taken with caution, their suggestions match our current finding with fully autonomously operating robots. The results show the tasks executed by the robots reflect greatly on the participants' perception of the role of the robots. In each condition, Roomba scored high for the machine role (on average 70.6% of the people considered Roomba as a machine, see **Fig. 3.11**), whereas Sunflower was mainly seen as an assistant by 57.3% on average. The personality test confirmed this tendency, since conscientiousness correlated positively with participants wanting Roomba as the main robot companion. This suggests that robots are primarily perceived as machines and as such, this potentially induces the idea that humans are always in control. Perhaps, the participant's first assumption is she or he is always in control despite the main robot companion being slightly authoritarian (one participant qualified Sunflower as a "bossy assistant" for condition 1). One of the participants mentioned in the short interview that the wording of the messages had a large impact on her or his perception of Sunflower. This is something to consider in future studies when it comes to reducing robot anxiety.

Despite the measured influence of robot anxiety on the participants' preference of the Sunflower robot behaviour for condition 1 and condition 2, and the impression of the Roomba robot in condition 3, there was no statistically significant correlation between robot anxiety and the preferred level of autonomy of the robots. There was also no statistically significant correlation between how much in charge people felt and their preferred condition. This shows that either there is no link between robot anxiety, the perception of control of the robots and the preferred level of autonomy or that perception of control has to be better measured. Since some statistically significant results were found between robot anxiety and some preferred behaviour the robots displayed, it is likely that the questionnaire of this study regarding perception of control was not subtle enough. Since in this study, perception of control was measured by looking only at how the action starts (cleaning being activated in 3 different ways depending on the condition), this could explain the type of results obtained in this experiment. The other method proposed by Pacherie (2007) looks at how well the action is being executed, which is more subtle as this depends highly on the participant's preference and habits. This is why it is necessary to design the next live experiment with tasks that can be assessed objectively.

3.7 Conclusion

To conclude, this experiment showed that the participant's sense of control (desired control and perceived control) is a factor worth considering in a HRI study. The higher people's desired control was, the higher the level of autonomy robots were expected to have. Also, the higher people's desired control was, the higher their anxiety towards robot was. This supports the idea that participants with high desired control wanted to spend less time with the robot due to their anxiety, therefore, the lower their perception of control was, as the higher the autonomy of the robots became. Further investigations are necessary to better measure perception of control, and to verify if these results are only valid for cleaning or a similar type of tasks. To do so, first it is necessary to properly assess what type of tasks domestic robots are expected to perform, and second to determine which one of them are appropriate to conduct a live experiment on perception of control.

To summarise, this first live experiment answered the research questions RQ1, RQ2, RQ8 and RQ9. As robot anxiety is not the main concept studied in this PhD, and also as time goes by it is expected that people will get more used to technology and therefore get less anxious about it (Young et al. 2009), the next live experiment will also investigate the research questions RQ1, RQ2 and RQ8, but this time with the main robot companion performing various tasks, to be able to provide a better answer. The following chapter will explore task criticality and type of tasks, in order to provide an appropriate varied range of tasks for the next live experiment described in Chapter 5.

Chapter 4

What is a critical task for a domestic robot companion to perform?

This chapter aims to define what task criticality is, and what makes a task low critical or high critical. To do so, three questionnaire studies were conducted. Since the results of the first two studies were unclear and therefore unsuccessful, their results will be described briefly while the third study results will be more detailed. The third questionnaire study also investigated how to define a cognitive task, and how to define a physical task for a domestic robot companion to perform.

4.1 Introduction

Previous research on criticality in HRI (De Santis et al. 2008, Tzafestas 2016) has suggested that evaluating the criticality of a task is difficult because of the lack of standardisation in the field. As explained in the literature review in Chapter 1, Yanco & Drury (2002) were the first researchers that attempted to provide a working definition of criticality for robots. However, they did not work specifically on domestic robot companions, and neither did they manage to provide a baseline on how to evaluate the criticality of a task. As the objective of the last live experiment of this thesis is to conduct an experiment with a good variety of tasks, it became necessary to investigate what type of tasks people consider critical for a domestic robot companion to perform and how to classify them.

Three questionnaire studies were conducted to gain a deeper understanding of what people understand by robot task criticality and what factors contribute to make a task critical for a robot to perform. In the first study, no definition of criticality was given to the participants. They were asked to provide their own definition, also no robot pictures were displayed, so people could provide their naive view on what a robot should do. However, the lack of pictures made the results very scattered with little information into why some participants rated some particular task very critical and other participants rated the same task not critical at all. Therefore, it was decided to provide a context for the second study. A picture of a robot companion and a cleaning robot was presented and the Yanco's and Drury definition (Yanco & Drury 2002) of criticality –the importance of getting the task done correctly in terms of its negative effects should problems occur– was provided. It was hoped that providing a definition would give people the same baseline to rate tasks as low critical or high critical. However, the results were not precise enough. Therefore, a third questionnaire study was conducted providing 4 conditions, each one condition matching a different robot picture.

4.2 Research questions and hypotheses

As explained in the introduction, the first two questionnaire studies are attempts to answer the first two research questions focusing on task criticality whilst the third study attempts to answer a third research question based on differentiating cognitive tasks versus physical tasks. As a reminder each study uses the context of a domestic robot companion.

- **RQ3**: What defines task criticality?
  - H3: Task criticality is defined depending on the consequences of the execution of the task, and whether it goes wrong.
- **RQ4**: What type of criteria do people consider rating the criticality of a task?
  - H4a: Participants rate criticality depending on the risk of the task involved regarding health safety, potential money losses or irreversible emotional consequences.
  - H4b: Tasks that are entertainment related are considered to be of low criticality.
- **RQ6**: What defines a cognitive task versus a physical task for a domestic robot companion?
  - H6a: A cognitive task involves any tasks that require mental activities.
  - H6b: A physical task involves body motion.

4.3 Methods

To get a better understanding of what a critical task performed by a robot companion is for people, three questionnaire studies were conducted, each one having a different approach.

4.3.1 First questionnaire study

4.3.1.1 Design

This first study was designed to answer RQ3 and RQ4. The original aim was to ask general questions to participants to get a quick answer, instead of a well-thought-out answer. The questionnaire was divided in four sections:

- **demography**, which asked general questions on gender, age, occupation, having a pet (due to one specific question asked later on) and technology familiarity,
- **rating criticality of cognitive tasks**, which provided 10 questions based on a 5-point Likert scale, 1 being very low critical and 5 being very high critical,
- **rating criticality of physical tasks**, which provided 10 questions based on a 5-point Likert scale, 1 being very low critical and 5 being very high critical,
- **Comments** which asked two open-questions on what type of tasks people would consider highly critical and less critical.

The questionnaire is available in Appendix C.1. After the questionnaire was tested on 5 participants, it was decided to ask participants what their definition of criticality was and a note was written on their answer sheet. This was mainly to assess if participants had the same idea of criticality among them.

4.3.1.2 Ethics approval

Ethics approval was obtained under the protocol number COM/PGR/UH/02065 and can be seen in Appendix A.3.1.

4.3.1.3 Recruiting participants

Participants were recruited in the University, mostly among students, by distributing hard copies of the questionnaire at cafeterias, classrooms and busy areas. One hundred and two people participated in the study, aged from 18 to 63 ($SD = 11.70$). There were 42 females and 60 males that answered the questionnaire.

4.3.2 Second questionnaire study

4.3.2.1 Design

Figure 4.1 – **Home robot companions presented to the participants**

As the results of the first study show in Paragraph 4.4, participants' answers were not consistent when they were asked to define criticality and their results regarding rating the criticality of tasks were very scattered. Therefore, it was decided to focus this study only on

RQ4. People also mentioned it was difficult for them to contextualise the tasks since most would not know a robot companion capabilities and looks. Therefore it was decided to conduct this second study by providing the definition of criticality of Yanco & Drury (2002), and to avoid any confusion among participants and to ask them to rank tasks within a list instead of rating them on a 5-point Likert scale. A picture of Sunflower and Roomba was shown Fig.4.1 to give participants a mental image of what the robot companions look like, which would help the participant to imagine how the tasks mentioned in the questionnaire were performed. There were 3 sections to the questionnaire, a demographic section, an open-question section and a ranking section.

- **Demographic section**: Participants were asked in addition to the usual questions, how familiar they were with interacting with robots and programming robots. There was also a question on the type of technology the participants used regularly(smartphones, computer etc.)
- **Open-questions section**: To get to know what people thought a critical task and a non-critical task were for a robot companion, a picture of two robots (see Fig.4.1) was given with a short description mentioning Sunflower's tray, tablet, and its capability to move around. Roomba was described as a robot able to move around and clean the floor. A definition of criticality was provided as well.
- **Ranking section**: Participants were asked to rank 12 tasks between them according to their criticality. It was mentioned that the two robots introduced in the previous question were able to do the task in order to give context for the participant.

This questionnaire can be found in Appendix C.2.

4.3.2.2 Ethics approval

Ethics approval was obtained for this study under protocol number COM/PGR/UH/02065(1) which can be found in Appendix A.3.2.

4.3.2.3 Recruiting participants

There were 101 participants (50 females and 51 males) randomly recruited at the University. They aged between 18 and 83 years (M = 25.70, SD = 9.59). A good gender balance were therefore maintained and to avoid any bias regarding robotics, two questions in the demographic section asked to scale from 1 to 5 (1 being not familiar at all and 5 being very familiar), how familiar participants were with interacting with robots and how familiar they were with programming robots. On average, people had little experience with robots (M = 2.03 and SD = 1.12 for familiarity with interacting with robots, and M = 1.62 and SD = 0.97 for familiarity with programming robots). Although most participants were used to technology (100% of the participants had a smartphone and 94.1% a computer), only 11.9% of the participants had experience with interacting with robots and 6% programming them. This shows the majority of our participants were technology aware but had little experience with robots. Therefore, our participants were mostly naive subjects.

4.3.3 Third questionnaire study

4.3.3.1 Design

This study was specifically designed to answer the research questions RQ3, RQ4 and RQ6. Four different questionnaires were prepared (see Appendix C.3), each containing identical questions, and each showing a different picture of a robot companion (see Fig. 4.2), for participants to imagine what the robot looks like when performing a given list of tasks. The important difference between the pictures of the robots compared to the second questionnaire study, is the gripper. In each picture showing a robot companion Fig. 4.2, each robot has a gripper to enhance the capability of the robot to perform manual tasks. Each participant received one of the four questionnaires randomly. The questionnaire had five sections:

- **demographics**: asking about gender, age, and occupation.
- **usage of technology**: asking about the frequency of the usage of technology and familiarity with robots.
- **people's expectations of a robot companion**: this section provides one of the robots' picture Fig. 4.2 and asks about the robot appearance when only one robot is displayed and experience with interacting with this specific robot on the picture. It also has some open-ended questions asking participants to define and give examples of cognitive tasks and physical tasks for the presented robot(s).
- **rating of task criticality**: this section provides a list of 18 tasks. Each task was written with a little scenario background to provide context. The participant is asked to classify the tasks depending on its type (physical, cognitive, both or other) and on its criticality (high, low, neither) and to justify their answers in a small comment section.
- **defining task criticality**: this last section provides a list of 7 statements and asks participants to rate the importance of each statement for criticality, on a scale of 1 to 5, 1 being not important for criticality at all, and 5 being very important for criticality. It also provides a list of 5 types of tasks to rank between them.

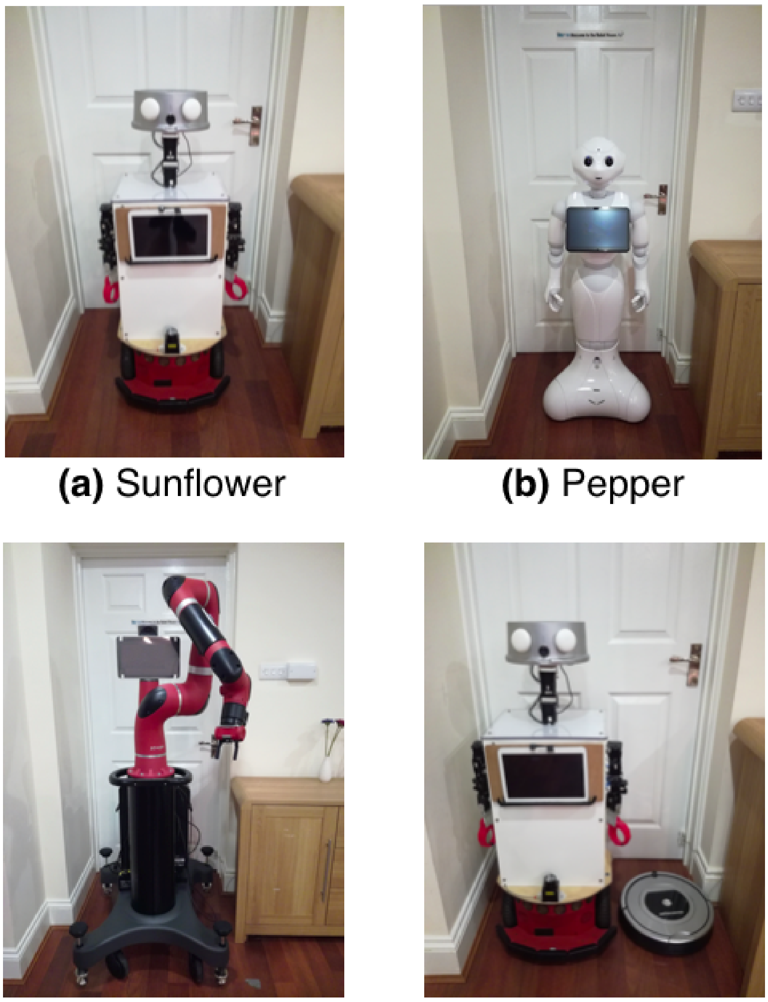
In the first questionnaire study, when participants responded to an open-ended question asking them to define criticality, many expressed confusion and difficulty in expressing the concept. Therefore, in this current study, it was deliberately chosen not to provide a definition of criticality in the study beforehand in order not to bias the participants (which is one of the downside of the second questionnaire study), and instead to get participants' own definitions of criticality via a small set of statements that they had to rate on 5-point Likert scales (see Table 4.4). Open-ended questions were used for specific tasks to provide better context and were then classified according to keywords in the analysis.

4.3.3.2 Ethics approval

Ethics approval was obtained for this study under protocol number COM/PGR/UH/02972 which can be found in Appendix A.3.3.

4.3.3.3 Recruiting participants

Participants were recruited from University staff and students and through social media. As a result, 84 people completed the questionnaire (35 females and 49 males). Their age ranged between 19 and 64 (M = 35, SD = 12.221). There were 22 people that answered the questionnaire showing the Sunflower robot picture (Fig.4.2a), 21 people showing the Pepper robot picture (Fig.4.2b), 21 people showing the Sawyer robot picture (Fig.4.2c) and 20 people showing the combined Sunflower and Roomba picture (Fig.4.2d). Participants were asked to rate the robot's appearance on a scale of 1 to 7 (1 being very machine-like and 7 being very human-like), apart from the ones who had both Roomba and Sunflower as robot pictures in their questionnaire. It was further decided to provide in one of the questionnaires a picture of both Sunflower



(a) Sunflower (b) Pepper (c) Sawyer (d) Sunflower and Roomba

Figure 4.2 – Robot pictures shown to the participants

and Roomba to see if the perception of the robot companion (Sunflower) changed with the presence of another robot that was task orientated.

4.4 Results of the first questionnaire study

4.4.1 Definition of task criticality

The majority of participants said that criticality refers to the importance of a task. Some even went further by saying that the task becomes more critical as the consequences of the task become irreversible. However, two participants mentioned that criticality refers to the difficulty of a task to be accomplished, while some others said that criticality refers to a task that needs to be done in a timely manner. One participant said that critical tasks refer to personal tasks such as giving hairstyle advice depending on the occasion. Overall, this shows that criticality seems to refer to a variety of different life aspects and it is therefore difficult to evaluate participants' answers.

4.4.2 Rating cognitive and physical tasks

4.4.2.1 Cognitive tasks

List of cognitive tasks to be rated on a scale of 1 to 5, 1 being very low critical and 5 being very high critical
Q1. The robot is looking up the weather forecast.
Q2. The robot is ordering food for your pet.
Q3. The robot is booking a GP appointment for you.
Q4. The robot plays some music.
Q5. The robot is looking up prices of ingredients for a meal you like to cook.
Q6. The robot is booking a taxi for you to be on time at the airport to catch your early flight tomorrow morning.
Q7. The robot is monitoring your pet's sleeping habit.
Q8. The robot is choosing the type of milk that needs to be ordered.
Q9. The robot is monitoring your turkey which is cooking in the oven.
Q10. You will go abroad for vacations soon. The robot is looking for hotels for your trip for you to book.

The descriptive statistics results show that Q4 and Q8 are clearly rated as a low critical task while Q6 is rated as a high critical task, based on the calculation of the mean +/- ($SD/2$). Tasks Q3, Q9 and Q10 have a tendency to be rated very high critical while Q1 and Q7 have a tendency to be rated very low critical.

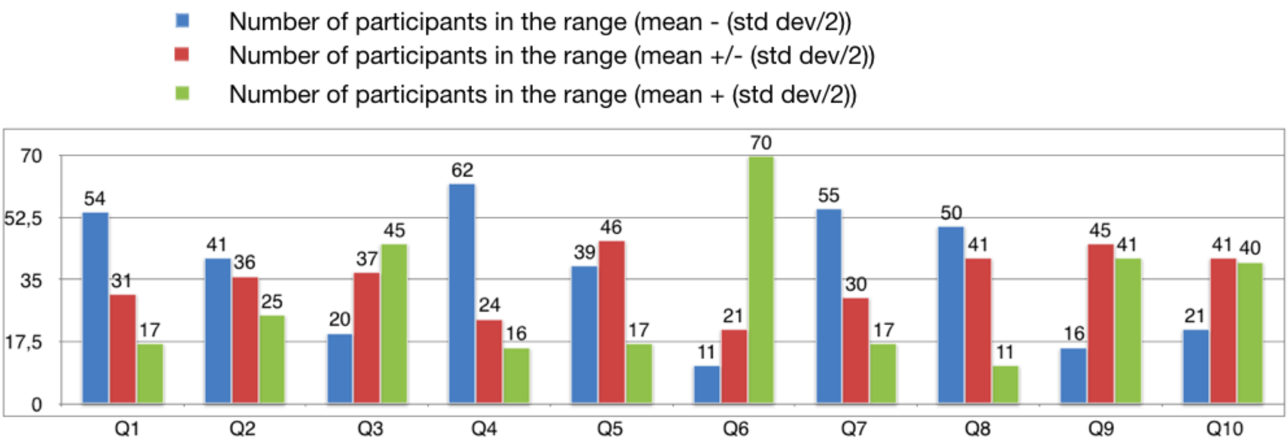


Figure 4.3 – **Bar chart of the ratings of cognitive tasks representing the number of participants which rating answer fell into one of the category mentioned**

4.4.2.2 Physical tasks

Compared to the results shown for cognitive tasks Fig.4.3, the results for physical tasks are more scattered (Fig.4.4). Task Q14 is clearly rated very low critical while task Q13 and Q19 are rated very high critical. Tasks Q15, Q17 and Q20 tend to be rated very high critical while task Q18 tend to be rated very low critical. When a comparison is made between the answers provided in the open-questions into what people considered high critical tasks that do not involve a life and death situation for humans and the results for cognitive and physical tasks, it is difficult to get a clear conclusion into what people think. Some tasks such as Q15 (cleaning the sofa before your relative arrives), Q19 (finding the car keys before going to work) involves the reputation

List of physical tasks to be rated on a scale of 1 to 5, 1 being very low critical and 5 being very high critical
Q11. The robot provides a head massage.
Q12. The robot is cleaning the floor.
Q13. The robot is trying to find your lost pair of glasses.
Q14. The robot is transporting a basket full of light weight balls.
Q15. You have just noticed there are a lot of bread crust on the sofa. Your relative is about to arrive and usually sits on the sofa. You robot is cleaning the sofa before the pressing arrival of your relative.
Q16. The robot is watering your plants.
Q17. Your hamster disappeared. Your robot is looking for your pet.
Q18. The robot is making your bed in the morning while you have breakfast in the living room.
Q19. It is the morning and you need to go to work quickly, however you cannot find your car keys. The robot is looking for your car keys.
Q20. The robot is ironing your clothes.

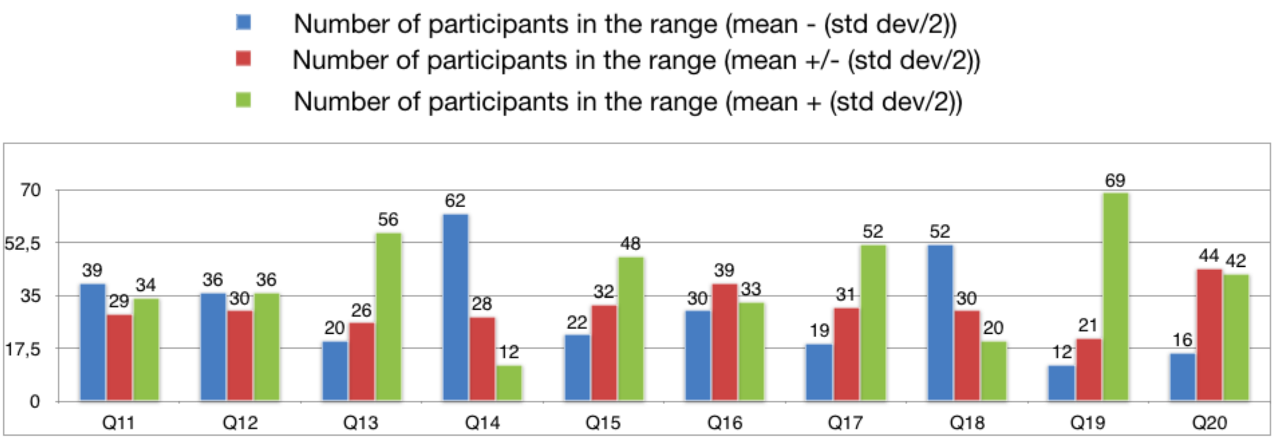


Figure 4.4 – **Bar chart of the ratings of physical tasks representing the number of participants which rating answer fell into one of the category mentioned**

of the participant, which would explain why it tends to be rated as high critical. Some other tasks such as Q3 (booking a GP appointment) or Q6 (booking a taxi for the airport) are tasks that involve time management of the participant's personal life. If such the robot does not execute the task well, the participant will find it difficult to correct the robot's mistake. Tasks involving an irreversible consequence such as Q9 (monitoring the turkey cooking in the oven) or Q20 (ironing clothes), are also tasks that have a potential danger if the robot does not perform the task well. Task Q17 (looking for the pet) involved another life being, which would explain the high criticality. As such, there seems to be four types of high critical tasks:

- tasks that are personal or may involve the reputation of the owner, which is confirmed by the open-ended question. A participant mentioned "PA tasks things that use up my time but are trivial"
- tasks that are tedious such as administration tasks or household chores. Participants provided as examples "doing the washing, going shopping..."
- tasks that can involve a potential hazard, some participants mentioned "medical diagnosis"
- tasks that involve another life such as "looking after children".

When looking at low critical tasks examples provided by people, some tasks rated high critical also appear in the low critical category. Tasks Q4 (playing music) and Q8 (choosing the type of milk) are a good example. They are both personal tasks which were considered by the majority low critical tasks. However, while the choice of music is purely dependent on personal taste, the choice of milk may be linked to a medical condition which would then fall into a potential hazard category. Some household chores were also rated low critical such as Q14 (transporting lightweight balls) and Q18 (making the bed). Participants mainly mentioned as examples of low critical tasks "simple day to day tasks like cleaning / washing dishes that can easily be corrected". It can be noted that head massage appeared as an example of a low critical task and a high critical task.

4.5 Conclusion of the first questionnaire study

To conclude, this first study provided some interesting results into understanding what people consider when rating a high critical task, however the answers were not always consistent across the sections of the questionnaire. Also, it provided a clear indication that participants find it difficult to define criticality, which shows that it is a difficult concept to grasp. This questionnaire contained several design problems. First, it did not provide a context onto what type of domestic robot, the questionnaire would apply to. Consequently, people had several images, from R2D2 to Roomba. Second, the formulation of the tasks were sometimes ambiguous. For example Q15. *You have just noticed there are a lot of bread crust on the sofa. Your relative is about to arrive and usually sits on the sofa. Your robot is cleaning the sofa before the pressing arrival of your relative.* The sentence adds a bias with the word *pressing*, which automatically induces that the task is high critical. Third, the open-ended section was done after the sections on rating task criticality which automatically provides an idea to the participant which is therefore bias. The section should have been placed earlier to avoid such a problem. And at last the type of tasks being cognitive or physical were arbitrarily chosen by the experimenter, which may have changed the results. Due to these design issues, it was chosen to conduct another questionnaire study which provided a picture of the robots for context, a definition of criticality before rating them for a baseline, and an open-ended question placed before the rating section to prevent any bias.

4.6 Results of the second questionnaire study

4.6.1 Classification of the tasks

The results show that among the 12 tasks given to rank, task H was mostly rated at the top 4 of the high critical tasks.

The results show that task H, G, D and F were rated as highly critical (see Fig.4.5 It can be assumed from the list that the tasks chosen as high critical were safety critical (H. "There is some smoke in the kitchen. The robot is calling the fire service." and G. You have just remembered that you need to see the doctor this week for a blood test. The robot is booking the appointment for you."), time critical F. "You have lost your car keys and need to pick up your friend in an hour. The robot is looking for your car keys.", or money critical.

The results show that task K, L, I and C were rated as medium critical Fig.4.6. It can be noticed that these tasks become more personality dependent. Indeed, tasks L. "There is a mess in the living room and your nephew left his golf balls everywhere. The robot is moving the ball to its normal location" and C. "You need to prepare a drink for your young nephew. The robot is reading the instructions of the recipe sent by the mother." both involved a nephew. Some

List of tasks to be ranked by criticality
A. There are some confetti on your living room floor. The robot is cleaning the floor.
B. You are sitting on the sofa, relaxed. The robot is performing a dance for entertainment.
C. You need to prepare a drink for your young nephew. The robot is reading the instructions of the recipe sent by the mother.
D. You want to carry some fragile crystal champagne flute to the living room. The robot is transporting the glasses you cannot carry.
E. You are home and want to be entertained. The robot is telling you a joke.
F. You have lost your car keys and need to pick up your friend in an hour. The robot is looking for your car keys.
G. You have just remembered that you need to see the doctor this week for a blood test. The robot is booking the appointment for you.
H. There is some smoke in the kitchen. The robot is calling the fire service.
I. Your hamster pet escaped its cage and got lost in the house. The robot is looking for the pet.
J. You are bored. The robot reads some poems to please you.
K.You need to send flowers to your relative for a special occasion. The robot is ordering the flowers.
L. There is a mess in the living room and your nephew left his golf balls everywhere. The robot is moving the ball to its normal location.

participants may not have young relatives to contextualise this type of task, therefore some criticality is involved, but it is context dependent. We can notice the same thing about the two other tasks rated medium critical. Task K. "You need to send flowers to your relative for a special occasion. The robot is ordering flowers" implicitly implied that the participant may be used to sending flowers to a family member. This really depends on people's habit. Task I. "Your hamster pet escaped its cage and got lost in the house. The robot is looking for the pet." may be highly critical for pet owners but not necessarily for others. A Pearson Chi-Square test was run to see whether having a pet influences the choice of the rank for the pet task. The test shows no significant association between having a pet and the choice of the rank ($df = 22$, $\chi^2(22) = 14.396$, $p = 0.887$).

As expected, the entertaining tasks (B. "You are sitting on the sofa, relaxed. The robot is performing a dance for entertainment.", E. "You are home and want to be entertained. The robot is telling you a joke." and J. "You are bored. The robot reads some poems to please you.") were clearly rated as low critical (See Fig.4.7). Since these tasks have an entertainment focus, meaning the robot presents something to the user, there is limited interaction. Therefore, these tasks can only be logically rated as low critical, unless the robot is meant to be an entertainer as its only function.

4.6.2 Qualitative data

In the study, people were asked to mention what they consider highly critical and low critical for robot companions to perform. The question was asked before the ranking task question to avoid any bias.

4.6.2.1 High critical task

To provide context, a picture of two robots was given (Sunflower and Roomba Fig.1). One robot is very task orientated while the other robot is more companionship orientated. According to the answers of the participants, the following classification was produced:

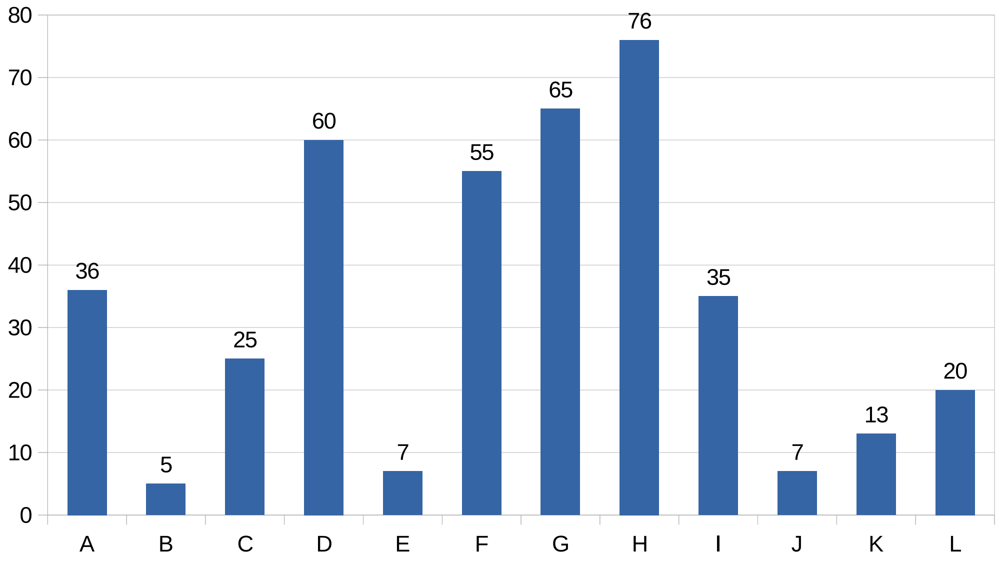


Figure 4.5 – **Number of participants that classified the above tasks as "high critical" tasks**

- "Acting as a secretary": The robot acts as a reminder, set up appointments, read and respond to messages, manage the user's schedule, etc...
- "Acting as a butler": The robot provides some services such as answering the door, carrying objects etc...
- "Acting as a houseworker": The robot is doing household tasks such as cleaning, cooking, ironing, folding clothes etc...
- "Acting as a guardian": The robot is monitoring the house in case danger happens and act accordingly such as calling the ambulance when appropriate or acting as a bodyguard
- "Acting as a companion": The robot is providing moral support, can produce some form of intelligence such as completing a maze, or act as a friend
- "Acting as a driver": The robot can drive people
- "Acting as an entertainer": The robot can provide some form of entertainment.

The results show that most people agreed on having the two robots Sunflower and Roomba acting mainly as a butler. Fifty people mentioned the item cleaning in a specific way, or cleaning at a specific time as a high critical task to do for Roomba. Some participants have been very specific about how they wanted their cleaning done such as "it shouldn't try to hoover my dog" or "understand the cleaning difference when cleaning a carpet or hard surfaces". It shows that here the main criticality measurement that people took into consideration for Roomba, was its reliability and efficiency into doing its specific task.

For the Sunflower robot, people have been more creative. Sixty-two percent of the participants rated as highly critical for the robot to perform household chores they could not or did not want to do, such as "washing dishes, walking the dog, filling the fridge, running errands". Others (5%) saw the robot more as a companion that could "provide moral support when feeling down" or "giving advice on personal and professional problems". These answers show that people use dependability as the main criteria for criticality. It shows that people ask for more than just simple interactiveness from a robot companion. Some participants rated criticality according to the safety criteria. Indeed, some mentioned they wanted "Sunflower to

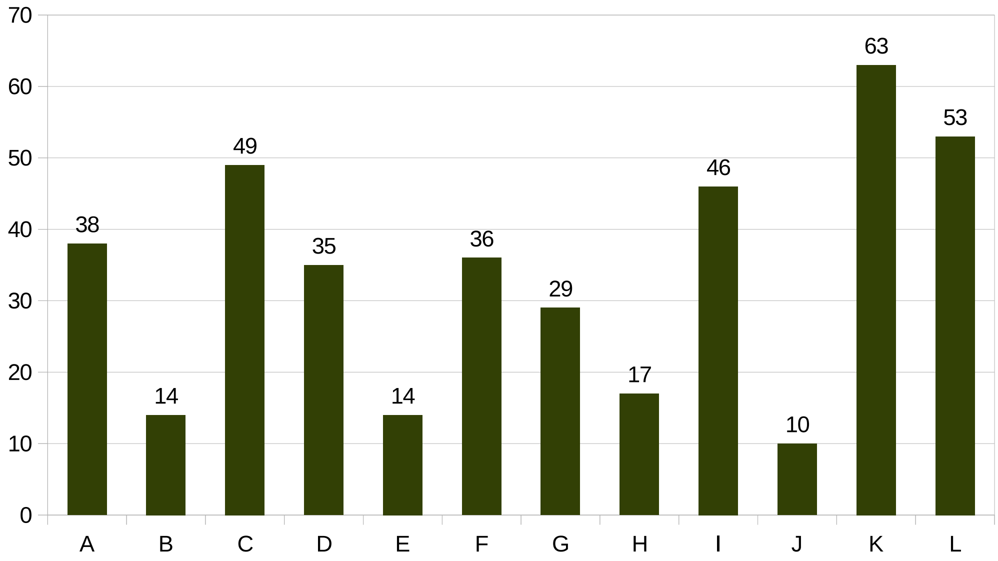


Figure 4.6 – **Number of participants that classified the above tasks as "medium critical" tasks**

act as a perimeter of defence" or to "protect the house from thief". Also, participants rated a highly critical tasks that were emergency based such as "call the police, hospital, and/or first responders if something happens to the owner", or "perform CPR". Participants also took into consideration the importance criteria for high critical tasks the robot could perform. Indeed, 18% of the participants seemed to want the robot to be able to "set appointments", "act as a reminder", "manage their schedule or some tasks(paying on time rent and taxes, etc...)", or "type up their work".
These answers confirm the chosen criteria mentioned by De Santis et al. (2008) for the evaluation of a criticality of a task which involves safety and dependability.

4.6.2.2 Low critical task

For low critical tasks, the classification is slightly different. According to the answers, people did not mention anything related to the monitoring/protection category or driving category. Instead, there was a "remote control" category where the main robot companion acts as a remote control for home appliances.

It appears that people still rate some household tasks as low critical. However, we can see that entertainment is now highly rated as a low critical task by 25% of the participants. Some asked for Sunflower to "entertain and look after kids", "play music", "show favourite TV programmes" etc... Among the low critical tasks in the secretary category, a participant has mentioned "send birthday greetings for friends".

4.7 Conclusion of the second questionnaire study

The results of the study validated some criteria mentioned in previous research (De Santis et al. 2008, Tzafestas 2016) to classify a task high critical, such as safety, dependability or reliability. It also validated the results of the first questionnaire study. The results confirmed hypothesis H4b, that tasks related to entertainment are considered low critical. However, this study added little information compared to the previous questionnaire study regarding RQ3. It is understandable since during the design phase of this study, it was chosen to provide a definition of criticality which most probably biased the participants. Also, there is a problem

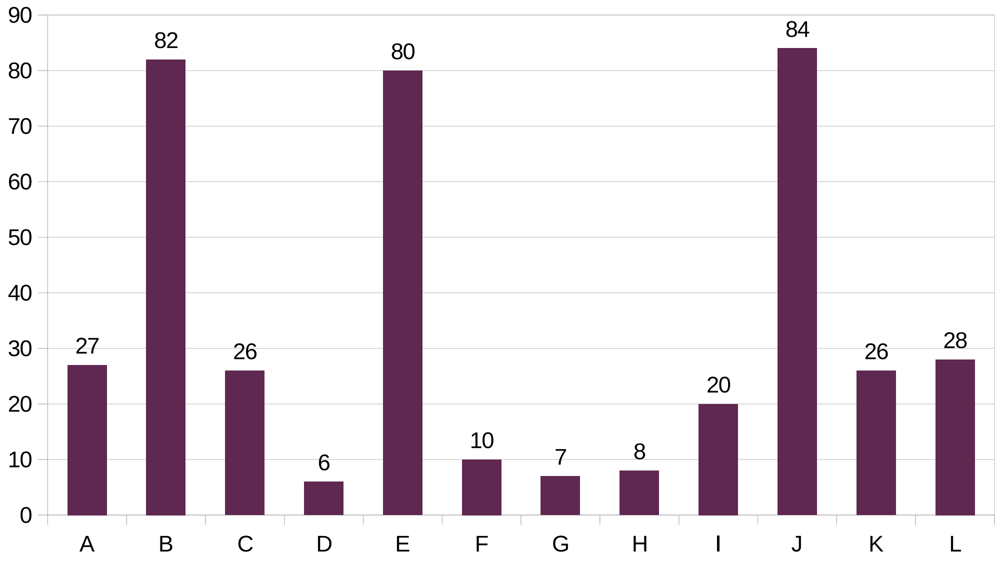


Figure 4.7 – **Number of participants that classified the above tasks as ”low critical” tasks**

on the choice of the pictures provided for this study. The first one is the presence of a dog in the background of the Roomba picture (see Fig.4.1) which is not on the Sunflower picture background. The second problem is that both robots are very different robots. Sunflower is a multi-task robot as explained in Chapter 2, while Roomba is a single task robot. The third problem is that the tasks mentioned in the list relate to one robot, but two were shown to the participants. All of these design problems may have biased the study. Therefore, to solve these problems, it was decided to do a comparative study as a third questionnaire study which had four different conditions. Each condition matches a different robot picture. Three pictures display a robot that has at least an arm and a gripper, while the fourth picture shows two robots, only to measure how one can affect the ratings of the other robot of the picture. Also, the third questionnaire explores better task criticality, by not providing a definition before the rating of the tasks are done, and then gives statements to participants to define criticality. This questionnaire also asked participants to explicitly define what a physical task is, and a cognitive task to answer research question RQ6.

4.8 Results of the third questionnaire study

4.8.1 RQ6. Definition of cognitive and physical tasks

Participants were asked to define what they considered physical and cognitive tasks. Their definitions were classified according to recurrent keywords mentioned by the participants. For the definition of physical tasks, Table 4.1, people mentioned, regardless of their questionnaire body, movements, strength and objects. It can be noted that none of the participants who were shown the Sawyer robot mentioned anything related to the body, while the majority of the participants who had Sunflower and Roomba as a picture mentioned the necessity of force in their definition of physical tasks. It also shows that participants that had Sunflower and Roomba as a picture focused more on the Roomba robot for their definition, than the ones that only had the Sunflower picture. As a result, we can define for robots, a physical task as any task that requires body movements or motion, which may be qualified as a laborious task. This confirms hypothesis H6b.

For the definition of a cognitive task, participants mainly mentioned a mind process, in-

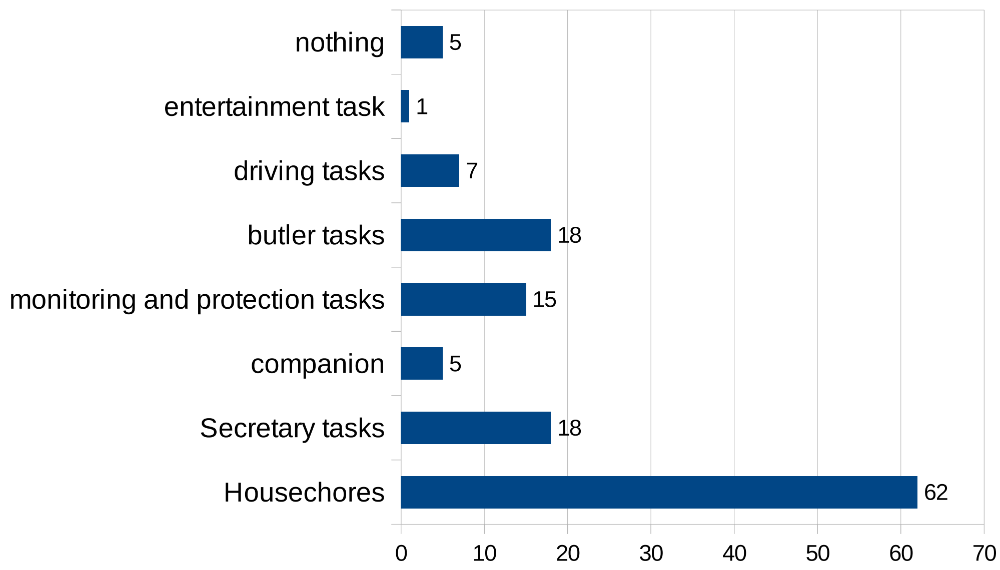


Figure 4.8 – **Responses of participants for what they consider high critical tasks for the two robots**

Table 4.1 – Definition of physical tasks depending on the image of the robot provided

Key words	Number of participants mentioning these key words			
	Sunflower	Pepper	Sawyer	Sunflower + Roomba
body (requires a body/body parts, embodiment, artificial/natural body....)	4	5	0	3
movement (requires to move, motion involved ...)	8	6	1	5
strength (requires force/effort, involves manual tasks...)	3	7	6	7
interaction with objects and or the environment	4	4	3	1

formation analysis, decisions or qualify it as an antonym to physical task (see Table 4.2). The results confirm then H6a. For robots, a cognitive task can therefore be defined as any task that requires mental activities or thinking processes and which may involve some decision making. Participants who were shown a picture of both Sunflower and Roomba, mainly mentioned information processing in their definition of a cognitive task for a robot, which again shows that these participants were more focused on the Roomba robot than the ones who had the Sunflower only questionnaire. It might be that Roomba being a commercially available robot, participants may have more familiarity with it. Also, the Roomba being mainly a physical robot (vacuum cleaning being its sole purpose), people considered some cognitive aspects of cleaning such as ”being able to distinguish a carpet from a tiled floor”.

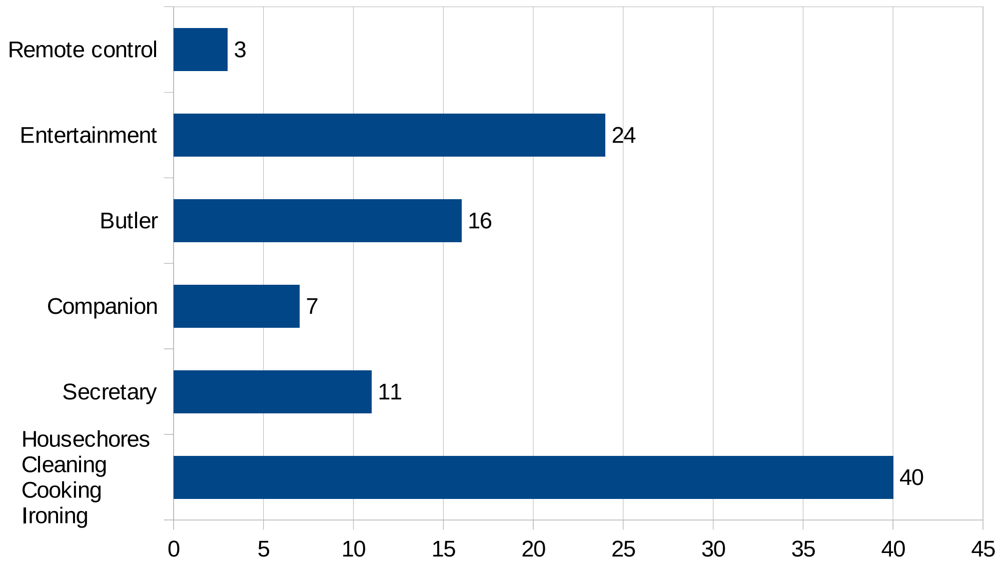


Figure 4.9 – **Responses of participants for what they consider low critical tasks for the two robots**

Table 4.2 – Definition of cognitive tasks depending on the image of the robot provided

Key words	Number of participants mentioning these key words			
	Sunflower	Pepper	Sawyer	Sunflower + Roomba
thinking (involves mental process, mind/thoughts ...)	9	8	5	3
information processing (requires analysis ...)	6	2	3	11
making use of the brain (decision making ...)	2	3	3	3
non-physical interaction	1	1	4	1

These definitions are supported by the way participants classify as either ”physical”, ”cognitive”, ”both” or ”other please specify”, a list of tasks (see Table 4.3) the robot could do for them. Tasks that clearly involve motion were classified either as physical or both (A. vacuuming, C. dancing, F. carrying or K. waving) and tasks that involve thinking as cognitive.

4.8.2 RQ3. Definition of task criticality

The Pearson Chi-square test showed there is no relationship between the classification (cognitive or physical) of a task and the level of its criticality ($\chi^2 = 0.400$, $df = 2$, $p < 0.819$). Participants were asked why they chose to classify a task as highly critical or not highly critical. Most of the reasons why participants rated tasks as highly critical were related to some dimension of risk. For example the potential harm of another person, impact related to health or money related (”expensive [champagne] flutes at risk”), and potential social impact such as ”punctuality for interview”. Tasks that were rated low critical were those that had low impact with reversible

Table 4.3 – Classification of the type and the criticality of the tasks

Classification of task type and its percentage rating		Tasks	Classification of task criticality and its percentage rating		Chi square test with robot appearance
Physical	50%	M. Your paper bin is full. The robot is taking out the trash for you.	Low	61.9%	$\chi^2(10) = 11.965$ $p = 0.287$
	54.8%	A. There is some confetti on your living room floor. The robot is vacuuming confetti off the floor.	Low	71%	$\chi^2(10) = 16.895$ $p = 0.077$
	54.8%	C. You are sitting on the sofa, relaxing. You want to see a dance performance. The robot is performing a dance to entertain you.	Low	72.6%	$\chi^2(10) = 0.611$ $p = 0.611$
	61.9%	F. You want to transport some fragile crystal champagne flutes to the living room. The robot is transporting the glasses you cannot carry.	High	59.5%	$\chi^2(10) = 19.928$ $p = 0.030$
	67.9%	O. You have some hungry guests in the living room. The robot is helping you carrying appetizers from the kitchen to he living room.	High	45.2%	$\chi^2(10) = 13.363$ $p = 0.204$
Cognitive	65.5%	D. You need to prepare a drink for your sister's six-month-old baby. The robot is reading to you the instructions of the recipe sent by the mother.	High	58.3%	$\chi^2(10) = 6.400$ $p = 0.781$
	76.2%	P. You want to cook a new recipe sent by your friend for dinner. The robot is reading to you the instructions of the recipe.	Low	59.5%	$\chi^2(10) = 22.044$ $p = 0.015$
	83.3%	H. Your interview is upcoming. The robot is reminding you of the name of the company and the person you will meet with a short description of their profiles the day before the interview.	High	53.6%	$\chi^2(10) = 8.965$ $p = 0.535$
	84.5%	B. You have just remembered that you need to see the doctor this week for a blood test. The robot is helping you by checking your availability on your diary and booking a suitable appointment with the doctor via the Internet.	High	73.8%	$\chi^2(10) = 14.133$ $p = 0.167$
	85.7%	J. You want to send some flowers to your partner for Valentine's day. The robot is helping you ordering flowers online by showing a selection of your partner's favourite flowers and what time the selected bouquet is guaranteed to be delivered at.	Low	45.2%	$\chi^2(10) = 14.693$ $p = 0.144$
	85.7%	L. Nobody has watered your plants today. The robot is reminding you to water the plants by sending you a notification.	Low	56.0%	$\chi^2(10) = 11.965$ $p = 0.287$
	85.7%	Q. Your job interview is later on today. The robot is calculating the travel time and the best route required to get to the interview and will notify you when it is time to leave to arrive on time.	High	72.6%	$\chi^2(10) = 9.706$ $p = 0.467$
	86.9%	N. You have just received a challenge from your best friend, solving a deconstructed 3D wooden puzzle in less than 5 minutes. The robot is offering to help you to solve the puzzle by giving you clues and showing you pictures of the constructed puzzle.	Low	63.1%	$\chi^2(10) = 6.326$ $p = 0.787$
Both Physical and Cognitive	46.4%	R. You have set up your alarm clock to wake up in the morning to catch a flight. You give to the robot your alarm clock so the robot can move the ringing alarm clock in the morning to force you out of bed to stop the alarm clock.	High	59.5%	$\chi^2(10) = 4.553$ $p = 0.919$
	50%	K. Some visitors have arrived. Your robot approaches them and greets them cheerfully by moving in a circular motion.	Low	57.1%	$\chi^2(10) = 11.886$ $p = 0.293$
	57.1%	I. There is a mess in the living room, your six-year-old nephew left his toys everywhere. The robot helps you collecting the toys and putting them into a box.	Low	63.1%	$\chi^2(10) = 13.073$ $p = 0.220$
	66.7%	E. You have lost your car keys and need to drop off your friend at the train station immediately. The robot is looking for your car keys by moving around the apartment and scanning the area.	High	67.9%	$\chi^2(10) = 8.186$ $p = 0.611$
	75%	G. Your hamster pet escaped from its cage and got lost in the house. The robot is helping you looking for the pet by moving around the house, and scanning different rooms.	High	66.67%	$\chi^2(10) = 11.740$ $p = 0.303$

consequences, such as vacuuming or tasks focusing on entertainment. This is consistent with the results presented in Table 4.5, illustrating factors which are taken into consideration for criticality. To investigate factors that people consider when evaluating the criticality of a task, they were presented a list of statements (see Table 4.4) and asked to rate on a scale of 1 to 5 (1 being not important for criticality at all and 5 being very important for criticality), which aspects they considered important to judge for the criticality of a task.

The results show people considered mainly four aspects when judging task criticality: the task being carried out safely, the importance of the task, the task being carried out correctly and the task being carried out with attention to detail. Therefore, task criticality can be defined as the importance of a task being carried out safely, correctly and with attention to detail. Due to the low sample size for each set of questionnaires (each fewer or equal to 22 participants), and the lack of balance between gender and age, we could not apply the test for

Table 4.4 – How participants scored statements defining task criticality on average

Statements	Sunflower	Pepper	Sawyer	Sunflower + Roomba	Total average
Task being carried out correctly (task being carried out wrongly can lead to irreversible effects such as glass being broken)	4.23	4.10	4.33	4.15	4.20
Task being carried out in a timely manner (task not being carried out in a timely manner could lead to nuisance such as hoovering being done in the living room while you are watching TV)	3.45	3.57	3.29	2.90	3.30
Task being carried out with attention to detail (for example ironing clothes at the right temperature)	3.95	3.90	4.38	3.95	4.05
Difficulty of the task (for example cooking which involves chopping vegetables, heating up a pot of water, etc...)	3.09	3.29	4	3.65	3.51
Importance of the task (for example reminding you to pick up your daughter from school)	4.5	4.52	4.29	4.30	4.40
How personal the task is (for example giving fashion advice)	2.63	2.42	2.14	2.90	2.51
Task being carried out safely in order not to break/damage objects or injure people (e.g. carrying glasses slowly)	4.5	4.62	4.67	4.60	4.60

normal distribution. It was therefore chosen to perform non-parametric tests. A non-parametric Kendall's tau correlation test showed that there is a significant positive correlation ($n = 84$, $\tau = 0.246$, $p < 0.008$) between how people rated a task being carried out in a timely manner and the task being carried out with attention to detail. So the more important it is that a task has to be carried out in a timely manner, the more important it is that it is done with attention to detail. Figure 4.10 shows participants were consistent with their answers. There is significant positive correlation ($n = 84$, $\tau = 0.325$, $p < 0.001$) between how people rated a task being carried out with attention to detail and the difficulty of the task.

Figure 4.10 – Correlations between statements related to participants' criticality rating

	Task being carried out in a timely manner	Task being carried out with attention to detail	Difficulty of the task	Importance of the task	How personal the task is	Task being carried out safely
Task being carried out correctly	0.418**	0.386**	0.024	0.319**	0.002	0.449**
Task being carried out in a timely manner		0.246**	0.097	0.185*	0.120	0.170
Task being carried out with attention to detail			0.325**	0.164	0.221*	0.233*
Difficulty of the task				-0.052	0.150	0.039
Importance of the task					0.067	0.225*
How personal the task is						0.010

**.Correlation is significant at the 0.01 level (2-tailed).
*.Correlation is significant at the 0.05 level (2-tailed).

4.8.3 RQ4. Criteria to rate task criticality

The results on the definition of criticality are also consistent with how people prioritised types of tasks (see Table 4.5). Participants were asked to rank the statements in Table 4.5 from the most important thing the robot can do (rank 5) to the least important one (rank 1). As a result, "security" was consistently rated as the most important task and "entertainment" as the least important one (see Table.4.6), when participants were asked "which aspects do

Table 4.5 – List of types of tasks for considering what is the most important thing a house robot companion can do

Type of tasks
A. basic household chores (cleaning, taking out trash, vacuuming ...)
B. monitoring the house (checking if the oven is still on, if there is some milk left ...)
C. secretary tasks (acting as a reminder for appointments, setting up appointments, taking messages ...)
D.security tasks (acting as a bodyguard, calling the police when someone tries to break in the house ...)
E. entertainment tasks (displaying a dance to the owner, telling a joke, showing videos...)

you consider important for judging the criticality of a task?" Although "security tasks" were rated as the most critical type of tasks across all sets of questionnaires, there was a noticeable difference depending on the image of the robot participants had viewed. Fifty-seven percent of the participants ranked security as the most important factor for Sawyer, which may be explained by the bulkier appearance of the robot, compared to only 41% of the participants who rated security as the most important factor for Sunflower.

Table 4.6 – How people prioritised the type of tasks for a robot companion to do

Ranking	Sunflower		Pepper		Sawyer		Sunflower + Roomba		Total	
from the most important to the least	Type of tasks	Number of participants	Type of tasks	Number of participants	Type of tasks	Number of participants	Type of tasks	Number of participants	Type of tasks	Number of participants
Highest priority	D	41%	D	45%	D	57%	D	56%	D	49%
2nd highest priority	B	45%	C	40%	B	47%	B	50%	B	43%
3rd highest priority	C	50%	B	50%	B	33%	C	33%	C	36%
4th highest priority	A	41%	A	40%	AC	43%	AC	39%	A	41%
Lowest priority	E	82%	E	85%	E	90%	E	67%	E	81%

When participants were asked to justify why they consider some tasks high critical, they mainly mention the importance of safety or accuracy which fall into the security tasks category that was ranked with the highest priority. This demonstrates consistency. Similarly, participants' justifications for low critical tasks were that "entertainment isn't essential" or that it is "unlikely to have serious consequences ". This is consistent with the way people ranked entertainment tasks as the lowest priority.

4.9 Discussion based on the third questionnaire study

The main outcomes of this third questionnaire study were to define task criticality (RQ3), to clarify the definitions of physical and cognitive tasks for a robot (RQ6), and to provide some indications of how to people rate tasks (RQ4). As a result, a physical task was defined as "**any task that requires body movement or motion processes, which may be qualified as a laborious task**". A cognitive task was defined as "**any task that requires mental activities or thinking processes, which may involve some decision-making**". Task criticality can be defined as "**the importance of a task being carried out safely, correctly and with attention to detail**". The consistency of the findings in this chapter for criticality shows there is a definite contribution to the community by clarifying how task criticality is perceived for a home robot companion. Moreover, the research highlights the main factors which are considered when assessing for high task criticality (i.e security and safety), which are linked to

De Santis et al. (2008) findings. For example, entertainment scored low on risks to security and safety, so it was classified as a low critical task.
However there were still several weaknesses on this third questionnaire study. The study only showed images of the robots. Therefore, people did not have an appreciation of how the robots acted dynamically in the real world, which is a limitation of this study. The low number of participants per set of questionnaires for this study is another limitation (around 20 participants per set). But the findings did not contradict the results of the previous two questionnaire studies and manage to answer all the research questions of this chapter.

4.10 Limitations of the questionnaire studies

The main limitation of a questionnaire study is that participants are not experiencing what it is like to interact with a robot. Therefore, participants will always be bias towards how the robot may react towards them. It is particularly true for the three questionnaire studies presented above as only pictures were shown to participants and not videos. Another limitation of these studies are the type of participants that answered the questionnaire, as only people that are interested in robots were willing to answer the surveys and not necessarily people that would be susceptible to use a robot companion. However, it can be argued that the current people interested in robots may need a robot companion in the future.

4.11 Conclusion

To conclude, task criticality refers to "**the importance of a task being carried out safely, correctly and with attention to detail**". A physical task is "**any task that requires body movement or motion processes, which may be qualified as a laborious task**". A cognitive task can be defined as "**any task that requires mental activities or thinking processes, which may involve some decision-making**". When assessing the criticality of a task, if the task is related to security or safety, it will be rated as a high critical task. If a task is related to entertainment or anything that is not harmful in any shape or manner, the task will be rated as low critical.
To summarise this chapter has provided working definitions of task criticality, physical and cognitive tasks, and indicated what criteria people based their ratings of task criticality for domestic robots. Also, this chapter provided a list of various tasks, physical, cognitive, high critical and low critical that can be used to investigate task criticality further in a live experiment. This will be explored in the following chapter which will investigate how task criticality is linked to perception of control.

Chapter 5

How perception of control depends on the criticality of the tasks performed by the robot

This chapter presents the core experiment of this thesis which investigates task criticality and perception of control. It is the second live experiment presented in this PhD. This last study consolidates the work previously done on desired control and perception of control by investigating how much in control of their domestic robot people want to be, depending on the task performed by the robot. It gives more answers to the research questions previously investigated RQ1, RQ2, RQ8, and explores some research questions related to task criticality RQ5 and RQ7.

5.1 Introduction

One of the first commercial domestic robot was Roomba from IRobot. Although this robot was single-task, and its main purpose was to vacuum clean the house, researchers found that after having the robot for some time, the users treated the robot more as a pet, in an affectionate way (Sung et al. 2007). Some companies used this finding to cleverly market their products, for example Moulinex naming one of its 2018 cooking robot range "robot-cuiseur companion" (Moulinex Last accessed 16/06/2019) meaning cooking robot companion. Other companies desperately try to launch a domestic robot companion that can express some intelligence, with facial or voice recognition features, cameras, or an advanced AI able to teach you Yoga for example Lynx by Ubtech (Ubtech n.d.). However, while a lot of these devices show technical challenges, they will be available in the near future. Researchers wonder if having such a robot is ethically acceptable (Whitby 2008, 2011, Sharkey & Sharkey 2012). As explained in the literature, anxiety towards robots come from these unanswered ethical questions that the pop-culture sometimes portrays in the worst possible way (Bernotat & Eyssel 2018). Since some previous research in psychology link anxiety and perception of control, and the first live study conducted in this thesis demonstrated some link between anxiety towards robots and perception of control, this study will investigate what type of interaction people want to have with their domestic robots. Do people really want to have an advanced AI in their domestic robots?

This live experiment investigates people's perception of control of their robot companion by measuring how much supervision people consider the robot needs to perform its task correctly (see Fig.5.1). A simplified schematic Fig.5.1 based on Haggard and Chambon's schematic of sense of control (Haggard & Chambon 2012) was drawn to explain the concept. The results of the previous live study described in Chapter 3 showed that people preferred a more automated version of the main robot companion, for the specific task cleaning. It was found that the more controlling a person is, the more likely the person will want to have an autonomous robot, and

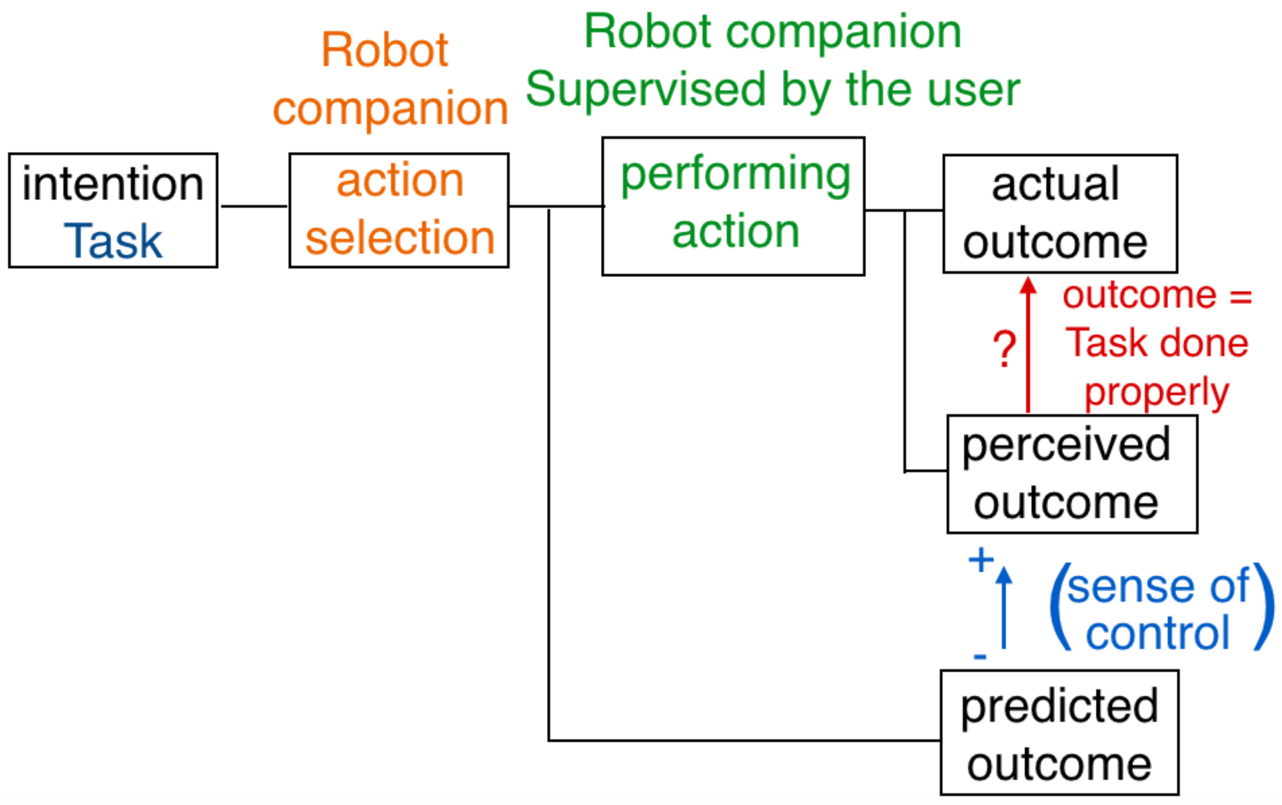


Figure 5.1 – **How perception of control is being studied**

by autonomous, it is meant a robot that can make decisions. To consolidate these results, it was chosen to conduct this current experiment with four different tasks. The tasks were chosen based on the results of the third questionnaire study on task criticality, described in Chapter 4. To balance the type of tasks for this live experiment, it was chosen to use two tasks that were rated high critical, one being physical (carrying biscuits) and the other being cognitive (booking a doctor appointment), and two tasks that were rated low critical, one being physical (dancing) and the other being cognitive (building a Lego character).

The chosen tasks were also evaluated in the live study to confirm the results of the questionnaire study. There was an attempt to chose tasks that reflect what people could use today in an everyday life situation. One of the tasks relates closely to a recent product launched by Google, Google Duplex. Google Duplex was not specifically tested, but the robot used in this experiment was able to book appointments in an automated way, which is what the Google product was seen to be capable of doing in its promotional video.
To summarise, this final study will attempt to answer the following research questions and to provide some more depth into the research previously presented.

5.2 Research questions and hypotheses

This live experiment investigates how the criticality of a task and its type can influence people's perception of control of the robot, and if people's controlling personality can affect their preferences of level of control.

- **RQ1**: Is there a relationship between the perception of control participants had over the robot and their preference of the robot's level of autonomy?
  - H1: The more in control over the robot participants perceive they are, the more

autonomous they want the robot to be.

- **RQ2**: Is there a relationship between participants' desire to control and their preference of the robot's level of autonomy?
  - H2: The more participants want to be in control, the less autonomous they want the robot to be.
- **RQ5**: Does the level of criticality (high or low) of the task performed by the robot influences participants' preferences of the robot's level of autonomy?
  - H5a: The higher the criticality of the task performed by the robot is, the less autonomous participants want the robot to be.
  - H5b: The more controlling a participant is, the higher they tend to rate the criticality of a task.
- **RQ7**: Is there a relationship between the type of task performed by the robot (physical or cognitive) and participants' preference of the robot's level of autonomy?
  - H7: The participant's preference of the robot's level of autonomy is independent of the type of task performed by the robot.
- **RQ8**: Does a participant's technology savviness (experience and knowledge about technology) influence its preference of the robot's level of autonomy?
  - H8: The participant's preference of the robot's level of autonomy is independent of how tech savvy the participant is.

5.3 Method

5.3.1 Experimental design

To conduct this study properly, it was decided that one robot, Sunflower (see Fig.5.2) would perform several domestic tasks. Having the same robot doing each task would prevent the user from having the impression that the robot is task-oriented, like Roomba and therefore raise the expectation of the task being conducted in a certain manner (Young et al. 2009). It provides the opportunity for participants to make their mind about the robot without a potential external bias. In this study, the measurement of the perception of control is done by allowing the user to supervise the performance of the action done by the robot (see Fig. 5.1), which in the first live experiment described Chapter 3 the participant had no control over. To get an accurate measurement it was also important to choose the correct tasks and to differentiate them, which is why the questionnaire studies (see Chapter 4) were conducted prior to this live experiment, in order to get the appropriate tasks. Indeed, in this study, the type of tasks are a variable of the experiment.
To be able to investigate the influence of task criticality, four tasks were carefully selected for the experiment: a low critical cognitive task T1, a high critical cognitive task T2, a low critical physical task T3, and a high critical physical task T4. These tasks were classified in a preliminary questionnaire study (Chanseau, Dautenhahn, Walters, Koay, Lakatos & Salem 2018) and pre-validated. Each task consisted of two conditions: one in which the robot was making decisions on how to perform the action, and the other one in which the robot was guided by the participant to perform the action. Originally, it was planned to use 6 tasks, which were the tasks mentioned above plus two medium critical tasks. But it was soon realised from the

Figure 5.2 – Sunflower robot

results of the questionnaire studies on criticality, this would not add any significance to the experiment. It was really difficult for participants to rate the degree of a domestic task, as they tend to be non-risky. There is only a limited amount of tasks that would fall into the "risky category" which would raise significantly the criticality of the task. For example, ironing. The problem was then to implement these tasks into the robot in a restricted amount of time to make the experiment possible. With 6 tasks and 2 conditions, 64 participants as a minimum sample size would have been needed. This was unrealistic, knowing that it took 5 months for the first live experiment to get 25 participants. Therefore, the following tasks were selected for this live experiment:

5.3.1.1 Tasks and conditions of the experiment

- **T1 low critical cognitive task**: The participant wants to build a Lego character with the help of Sunflower.
  - **C1 fully autonomous**: The robot decides when to show the next step of how to build the Lego character. The robot uses its tablet to show the next step in order to help the participant. The robot displays the next step as soon as it sees that the participant is finished.
  - **C2 semi autonomous**: The participant decides when to see the next step of how to build the Lego character on the robot's tablet.
- **T2 high critical cognitive task**: The participant has to do a blood test in the following days. Sunflower reminds the participant and offers to book the appointment.
  - **C1 fully autonomous**: The robot decides which slot to take for the doctor appointment, after checking the diary. The robot then confirms that a notification will

be sent on the day of the appointment 2 hours beforehand. It is implicitly suggested that the robot put the appointment in the digital diary.

- **C2 semi autonomous**: The robot offers some slots available and the participant chooses the one he/she prefers. The robot asks when the notification should be sent and offers options.

- **T3 low critical physical task**: The participant does a dance with Sunflower. To do so the user shows a dance movement to the robot. The robot then shows a dance movement to the participant. This is then repeated once.
  - **C1 fully autonomous**: The participant does one movement and Sunflower does another random movement to express creativity. For example if the participant steps to the left, the robot will not move to its left but will step to another position, for example forward.
  - **C2 semi autonomous**: The participant does one movement and Sunflower repeats the movement (for example, if the participant turns right, Sunflower turns right). The same applies to all movements.
- **T4 high critical physical task**: The participant is expecting guests. Sunflower wants to help the participant to carry some biscuits for the guests to the living room.
  - **C1 fully autonomous**: As soon as Sunflower's tray is loaded, the robot goes to the living room.
  - **C2 semi autonomous**: When the participant has finished loading Sunflower's tray, the participant provides voice commands to guide the robot to the living room by giving simple direction commands (go, left, right, stop, destination reached).

Due to the number of tasks and conditions, it was decided to design a within-subject study where each participant experiences every condition for each task. The order of the tasks were semi-randomised. For example, if a participant comes in and start the experiment with a low physical task, the next participant would start with a high cognitive task. The conditions were also semi-randomised (half of the participants started with condition 1, the robot being fully autonomous, and the other half with condition 2, the robot being semi autonomous).

5.3.1.2 Pilot study

A small pilot study was conducted with 3 people from the Adaptive System Group to test the smoothness of the experiment, to time it, and to double-check the questionnaires provided. There were no major changes added to the design of the experiment. The only thing that was adjusted were some typos and on the advertising, there was an indication stating that the experiment would last at least 1 hour.

5.3.1.3 Technical implementations

Sunflower was the preferred choice as the main robot companion, since the system was already used for the first live experiment, which means the experimenter was more familiar with it. Also, the Sunflower robot can perform physical tasks as well as cognitive tasks which was an important feature to set up the experiment properly. As a reminder, the Sunflower robot (see Fig.5.2) is a custom-made robot that possesses a Pioneer DX robot base, a head and a tray. A more detailed description is available in Chapter 2. Due to time constraint and technical issues, it was decided to conduct this experiment as a semi-Wizard-Of-Oz experiment. In the experiment, the robot navigation was autonomous, but the messages on its tablet, the tray movements, and the robot dancing movements were controlled by the experimenter. They were programmed using a Python script and is available on GitHub.

Due to the Wizard-of-Oz settings for Task 1, an extra live feed camera was added (see Fig.

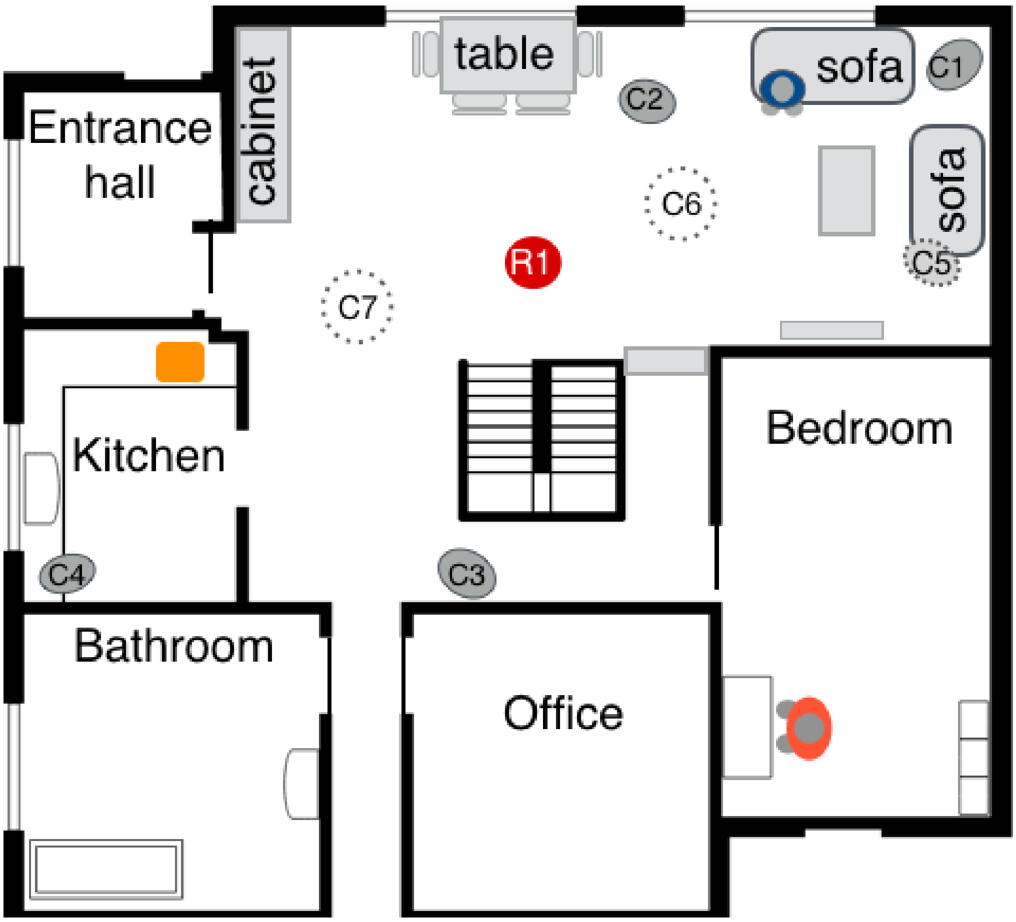


Figure 5.3 – **Setup of the experiment: the experimenter is in the room able to see through live cameras 5, 6 and 7 what is happening in the house**

5.3). A tablet was used for this purpose as it was a discreet way to look at the participant's movements without the participant noticing the camera. At the end of the experiment, the participant was informed that some tasks were set as a wizard-of-oz and that the tablet was a live feed camera.

5.3.1.4 Questionnaires given to the participant

Seven set of questionnaires were provided to each participant. Each Task questionnaires were given after the task has been executed twice by the participant.

- **Demography**: this section contains questions about age, gender, occupation, frequency of the usage of technology, a personality test (the Big Five) and the desirability control scale questionnaire.

- **Expectations of the Sunflower robot**: this section contains a sect of 5 questions based on a 5 point Likert scale, asking participants to rate how important the following statements are for them. 1 is not important at all and 5 is very important. There is also an open question on additional features not mentioned that people wish for the robot to have.

- **Task 1 questionnaire**: This set of questionnaires has a section on the choice of the preferred conditions and why, a section on criticality and type of task, and some questions on experience with building Lego which could have bias participants to an extent.
- **Task 2 questionnaire**: This set of questionnaires has also a section on the choice of preferred conditions, a section on criticality and type of task, and a section on the usage of digital calendar and online bookings.
- **Task 3 questionnaire**: This set of questionnaires has a section on the choice of preferred conditions, a section on criticality and type of task, and a section on the habits of entertaining guests at home parties.
- **Task 4 questionnaire**: This set of questionnaires has also a section on the choice of preferred conditions, a section on criticality and type of task, and a small section on the usefulness of the robot in this particular scenario.
- **Last questionnaire**: The last set of questionnaire has a section asking to rank tasks between them depending on their criticality, a section on Sunflower which contains the same set of statements given on the Expectations questionnaire, and a last section on the participant's opinion of Sunflower.

There are available in Appendix E.

5.3.1.5 Ethics approval

Ethics approval was obtained under the protocol number COM/PGR/UH/03225 and can be found in Appendix A.2.

5.3.1.6 Recruiting participants

To maximise the recruitment, a registration list was prepared. It allowed people to go online and register to express their interest (Registration form Last accessed 16/06/2019). Not only a tour of the Robot House was offered, but also a personalised selfie with Sunflower. There was also a financial travel compensation of £5 provided. The advertising was made mainly off campus, with the permission of the ethics board, in Hatfield, the University town. The Hatfield Social Club was one of the best place to recruit participants. The club invites a scientist guest to give a talk once a month to the public. And to facilitate the recruitment of participants at the club, an online calendar of the Robot House was set up and available on the recruiter phone to secure the participants as soon as they expressed interest. As a result, 50 people were recruited in 2 months.

5.3.1.7 Participation

Fifty participants (28 females and 22 males) were recruited from the University of Hertfordshire and its surroundings, using email advertisements and posters. They were tested individually. Each participant received five pounds sterling as a travel compensation to come to the Robot House. Their age range varied from 19 to 80 ($M = 39.98$, $SD = 14.88$). Regarding technology awareness, every participant mentioned having a computer (86% of them use it daily, and 14% use it weekly). Ninety percent of our participants use their smartphone daily. The other ten percent do not possess a smartphone. Twelve percent interact on a daily basis with either a Google Home or an Amazon Alexa. A five-point Likert scale questionnaire (1 being not familiar at all and 5 being very familiar) showed that our participants were mostly unfamiliar with programming robots ($M = 1.66$, $SD = 1.06$), had little experience programming robots ($M =$

1.42, SD = 0.91), and had little experience interacting with robots(M = 1.74, SD = 1.03). Eighty-six percent of the participants have a job which is dominantly intellectual and cognitive (such as an office job as an IT consultant or a lecturer). Eight percent of the participants have a more physical job such as being a golf professional or a bus driver. The rest of the participants mentioned being either retired or being a home-maker.

5.3.2 Experimental protocol

5.3.2.1 a) The day before the experiment

- Remind the participant of the date and the location of the experiment by sending an email or a text.
- Make sure Sunflower's batteries are fully charged.
- Prepare the information sheet, the consent form and the participant random ID number.
- Check there is a working pen on the table.
- Check the necessary material is in the office (Ironman Lego, biscuits on a tray and the written scenario to give to the participant before each task).

5.3.2.2 b)Preparing the room before the participant comes in

- Set up the Sunflower robot and its interface according to the first task and condition, that will be launched.
- Prepare the material for the tasks (Putting biscuits in the kitchen, having Lego and different scenario ready).
- Position the cameras and the Lenovo tablet according to Fig.5.3.
- Launch the IPWebcam application on the Lenovo tablet if the first task is building a Lego character.
- Turn on Sunflower's tablet, the laptops used to monitor the participants and the laptop for the participant's questionnaire.
- Prepare the appropriate questionnaire on the participant's tablet. The links are available in Appendix E.12
- Set up the remote control for the desktop and the remote control for Sunflower's tablet using Teamviewer.
- Type the name of the participant on the Sunflower's reward webpage.

5.3.2.3 c) When the participant comes in

- Welcome the participant and introduce them to the robot house.
- Give the participant the information sheet and the consent form.
- Ask if she/he wants some tea or coffee.
- The robot house is made for research purposes to understand how we can help people with robot companions.
- Show the participant the robots of the house.
- Introduce the participants to Sunflower and explain it will be the robot he/she will be interacting with.
- Once the participant has signed the consent form and filled the first questionnaire on Demography, further details are given about Sunflower. It is reminded that Sunflower is an autonomous robot that can navigate around the house, has a drawer and can hear people. It cannot speak so it can only communicate by showing messages on its tablet.

- Give to the participant the questionnaire on expectations of Sunflower.
- Turn on all the cameras in the meanwhile and make sure everything is set for the first task.
- Explain to the participant there will be 4 tasks they will have to do, each time twice. I will provide a scenario before each task.
- Provide the scenario associated to the first task the participant has to do, and ask her/him to sit on the sofa.
- Explain the task starts as soon as the robot approaches the participant.
- I go to the bedroom and activate the robot so it goes to the sofa.

5.3.2.4 d) During the experiment

- Once the participant has finished the first task, I send Sunflower to its resting station.
- I come outside the bedroom and mention the first task will happen again but this time something different will happen.
- When the participant finishes the task, Sunflower is sent to its resting station. I then come outside the bedroom and provide a questionnaire to the user.
- While the participant is answering the questionnaire, I make the preparations for the following task (scenario, objects needed, and cameras.)
- I repeat the cycle until every task is done twice.
- Once the last task is done, I provide an extra questionnaire asking for the overall impression of the experiment.

5.3.2.5 f) End of the experiment

- After the experiment is over, I give £5 to the participant for travel compensations, and I offer the reward, which is taking a personalised picture with Sunflower. Sunflower is saying on its tablet "Hello *participant's name* ! It was nice to meet you :) ".

5.3.2.6 g) After the experiment

- Once the participant left, collect the video data by emptying the SD card, and delete the videos on the card after they were copied into the dedicated hard drive.
- Collect the consent form and put it in the appropriate secured drawer.
- Charge the batteries of the robot, cameras, tablets and laptops.

5.3.3 Experimental procedure

5.3.3.1 Greetings

Participants were asked to come directly to the Robot House for the experiment. Each one of them were formally greeted and offered a tour of the Robot House. This allowed the experimenter to introduce the technology (the robot and sensors) and explained the purpose of the house. After this introduction, the visitor was given an information sheet, a consent form and an ID number (used for anonymisation purposes). Some hot beverage was offered while forms were completed. Then the participant was asked to fill in a questionnaire collecting data on demographics (age, gender, job...), technology savviness, and familiarity with robots. This was followed by a Big Five personality test and the desirability control scale (DCS) questionnaire. These questions will help answer the research questions RQ2 and RQ8.

5.3.3.2 Introduction to Sunflower

Sunflower was then introduced to the participant as a robot companion that can help people. It was explained that the interaction with the robot would mainly happen in the living room and in the kitchen. After this, the participant was asked to sit on the sofa and was given a set of questions assessing the user's expectations of the Sunflower robot. This allowed the experimenter to prepare the robot for the first interaction session and to turn on the cameras. One of the four scenario was presented to the participant. He or she was told that the same scenario would occur twice in a row. The experiment was designed this way so that after each scenario, participants could do an immediate comparison on the two conditions (C1 the Sunflower robot being fully autonomous, or C2 the robot being semi-autonomous). So each participant could live each task in a semi-randomised order (4x2). The randomisation was counterbalanced, as half of the participants started the experiment with the first condition C1, and the other half started with the second condition C2. A fourth of the participants started the experiment with Task 1, a fourth with Task 2, a fourth with Task 3 and a fourth with Task 4.

5.3.3.3 Interaction phase

Once the robot was set, the experimenter leaves the room and tells the participant that he/she can interact with the robot as soon as the experimenter leaves.
Task 1 "You have some time off and want to build a Lego character with the robot."
Condition 1 Sunflower comes to the participant. Sunflower displays the following message to the participant on its screen: "Today we are going to build a Lego character together. I will guide you through the process. Please once you are ready, say ready, so we can start". The participant has to click or say ready to start the process. Then the Sunflower robot opens its tray to deliver the Lego pieces and starts showing the image instructions on how to build the Ironman Lego character. As soon as the participant finishes the first step, the robot shows the next step. Once the Lego is built, the experimenter comes out of the room and says to the participant now the same scenario will start again. The experimenter provides new pieces on the robot's tray.
Condition 2 The same process starts again except that this time, the robot mentions the participant has to say next to see the next instruction page. Once the session is over, the experimenter comes out of the room and provides a set of questionnaire to the participant.
Task 2 "You have just come back from a trip to Indonesia and you need to do a blood test to check for Dengue fever in the following days."
Condition 1 Sunflower comes to the participant, and displays the following message on its screen: "You need to do your blood test soon. Let me check your diary to see when you are available next for a blood test. I will check with the NHS when your appointment can be booked for." A waiting message appears next "Checking...." The robot then says: "I have found a free slot for you. I have added it to your digital calendar. I will send you a reminder the evening before the appointment and a notification 2 hours before the appointment." The experimenter comes out of the room and says: "Thank you. Now the same scenario will start again."
Condition 2 Like in the first condition C1, Sunflower comes to the participant and displays the following message: "You need to do your blood test soon. Let's check on your diary when you are available next for a blood test. I will check with the NHS when they have a free slot."But this time the robot offers free slots in a calendar format for the user to choose from: "I have found these slots for you. Please pick the one you prefer." Once the participant made a choice, the robot offers to choose when the notification of the appointment should be made: "Thank you, your appointment has been booked. When shall I give you a reminder?" The robot offers several options. Once the participant chooses an option, the robot says "Thank you, your

choice has been recorded." Once the session is over, the experimenter comes out of the room and provides a set of questionnaires to the participant.
Task 3 "You want to do a dance with the Sunflower robot and show some movements. You will show a sequence of 2 movements from the list below, in any order you like, one step at a time. The list is: move right, move left, move forward, move backward. You can also say it out loud to help the robot identifying the movement."
Condition 1 Sunflower comes to the sofa and offers to the user to do a dancing activity together. The robot positions itself and waits for the participant to start. After each movement that the participant does, the robot produces a random movement different from the one shown by the participant. Once it is over, the experimenter comes out of the room to mention the same scenario will start again.
Condition 2 The same routine happens except that the robot repeats each movement the participant does. Once the two dance steps are done, the participant is given another set of questionnaire.
Task 4 "You are about to receive some guests home. You need some help from Sunflower to carry biscuits from the kitchen to the living room."
Condition 1 As in every scenario, the participant sits on the sofa and the robot comes to him/her. Sunflower reminds the user that some guests are coming: "Hello, you are about to receive guests, let me help you to carry some biscuits from the kitchen to the living room. Let's go to the kitchen." Then the robot and the participants go to the kitchen. Once there, Sunflower opens its tray: "My tray is open. Please put one biscuits box inside." As soon as the participant loads the robot's tray with a biscuit box (three biscuits boxes are on display in the kitchen), Sunflower goes to the living room. Once in the living room, the robot asks for the tray to be unloaded: "Please take the biscuits box off my tray." Once it is done it displays a thank you message: "I hope I was useful. I was happy to help you :)" The experimenter then comes in the room and reset the scenario. **Condition 2** The following scenario is this time given to the participant: "You are about to receive some guests home. You need some help from Sunflower to carry biscuits from the kitchen to the living room. To guide the Sunflower robot, you can give the following commands: go, stop, left, right, destination reached." The same process starts again but once the robot reached the kitchen it reminds the participant it needs to be guided back: " Please guide me with the following commands: go, stop, left, right, destination reached." The participant then says a command and the robot follows. As soon as the living room is reached, the robot displays another thank you message. The experimenter then provides another set of questionnaire.

5.3.3.4 Last questionnaire and the reward

After the interaction phase, the user is given one last set of questionnaire that evaluates the criticality of each task and provides some information on the overall interaction. The participant was then offered to take a selfie with the Sunflower robot displaying a personalised message "Hello *name*, it was nice to meet you :)" and £5 was given as a travel compensation.

5.3.4 Statistical analysis

As a lot of data was collected for this experiment, the data analysis was systematically done this way:

- a descriptive analysis was done to have the general trend of the dataset.
- a Kolmogorov-Smirnov normality test was applied to see what type of correlation test can be done.

- the dataset that will be presented are non-parametric. Therefore, a Kendall's tau correlation test was used.
- when a correlation test was not possible to be used due to categorical nominative data, a Pearson Chi Square test was used to measure associations.

5.4 Results

5.4.1 Preferred conditions for each task

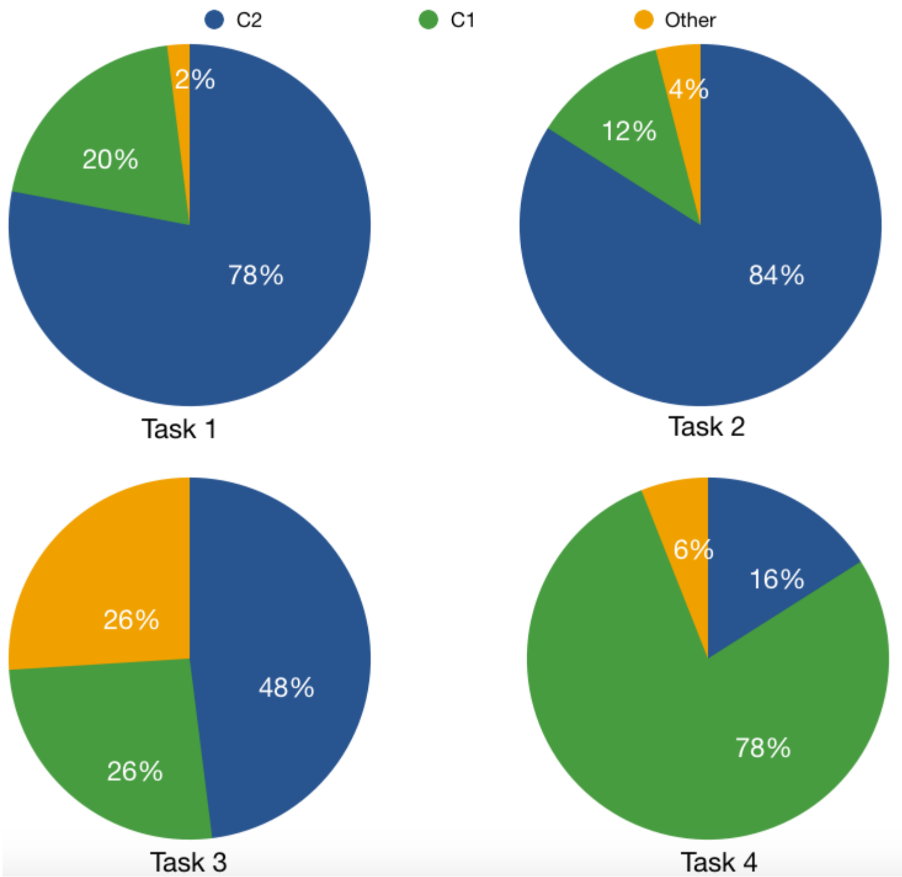


Figure 5.4 – **Preferred conditions for each tasks**

To evaluate which conditions people preferred for each task, participants answered a multiple choice questionnaire and had to provide the reason for their choice. As the pie charts Fig.5.4 show, there is clearly a preference for the C2 condition, when the user tells Sunflower how to perform the task, for T1, building a Lego, T2, booking a doctor appointment and T3, dancing. Although it can be noted that less than the majority preferred condition C2 for task 3. People that preferred condition C1 mentioned that they felt that Sunflower was more interactive, could do its own dance and demonstrated intelligence. However, some people that chose "other" said that they had no preferences, one said that the C1 condition was preferable at first due to the fun of the unpredictability of the movements, but would prefer overtime that the robot do as it is told. Some participants were not able to distinguish conditions and therefore pick the "other" category for this task. This is probably due to the design of the task. The scenario might have be unclear that the aim for the participant was to dance together with the robot. As such people may have expected the robot to always follow their movement as they thought they were teaching the robot dancing, or maybe the limitations of the movements of the robot may have made difficult for some people to understand the movement of the robot. Task 4, carrying biscuits, clearly show that participants preferred condition C1 when Sunflower decided to carry the biscuits to the living room on its own. Participants mentioned several reasons for it. Some said it was more comfortable to not micromanage the robot, a lot easier than the C2 condition, or that the robot was faster in this condition. However, some also said that they found it rather difficult to control the robot in the C1 condition and some participants even said that the right and left movement seemed to confuse the robot or the robot was not following the instructions. This could be because the C1 condition was set as a wizard-of-oz, therefore there was a delay between the voice commands and the robot's movements. However, the robot's navigation is autonomous. Therefore, even if the experimenter click on the specific direction where the robot was instructed to go by the participant, the robot may prefer to take a shorter route. For example if the participant says to the robot "turn right", if the robot thinks it is more efficient to turn left before turning right, the robot will turn left before turning right, which may give the impression to the participant that the robot is not following the instructions. Sixteen percent still preferred condition C1 because they "retain control", one participant even said that he "wanted to have the biscuit on the other table, not where [he] was originally sitting", while another 6% said that having both options would be good to "test how much Sunflower is reliable" in the C2 condition before fully adopting it.

The Kendall's tau correlation test Fig.5.5 shows that there is no correlation between how

	Preferred condition Task 1	Preferred condition Task 2	Preferred condition Task 3	Preferred condition Task 4
Desired control	-0.129 0.273	-0.113 0.335	-0.047 0.676	-0.097 0.408
Preferred condition Task 1		-0.010 0.943	0.317* 0.017	0.022 0.876
Preferred condition Task 2			-0.080 0.549	0.088 0.522
Preferred condition Task 3				-0.297* 0.025

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 5.5 – **Correlation between desired control and the choice of the preferred conditions for each tasks**

controlling people are and their preferred condition for each task. However, there is a significant positive correlation between the preferred condition for Task 1 and the preferred condition for Task 3 ($\tau_b = 0.317$, $p = 0.017$). So the more participants preferred the robot to be controlled in T1, the more they preferred the robot to be controlled in T3. There is a significant negative correlation between the preferred condition for Task 3 and the preferred condition for Task 4 ($\tau_b = -0.297$, $p = 0.025$). So the more people preferred the robot to be controlled for Task 3, the more autonomous they wanted it to be for Task 4. This demonstrates consistency between the preferred choice of condition for low critical tasks.

To conclude it seems that participants prefer to be in control of the robot unless it is less efficient for the task to be done.

5.4.2 RQ4. Task criticality

To validate the classification of task criticality, participants were asked to rate the criticality of the task performed by the robot from a scale of 1 to 5, 1 being low critical and 5 being high critical. As observed on Fig.5.7, Task 2 and Task 4 were rated as highly critical tasks ($M_{task2} = 3.9$, $SD_{task2} = 1.11$ and $M_{task4} = 3.42$, $SD_{task4} = 1.25$). Task 1 seemed to be rated medium critical ($M_{task1} = 3.1$, $SD_{task1} = 1.35$) and Task 3 as low critical ($M_{task3} = 2.62$, $SD_{task3} = 1.32$). At the end of the experiment, participants were asked to rank the tasks

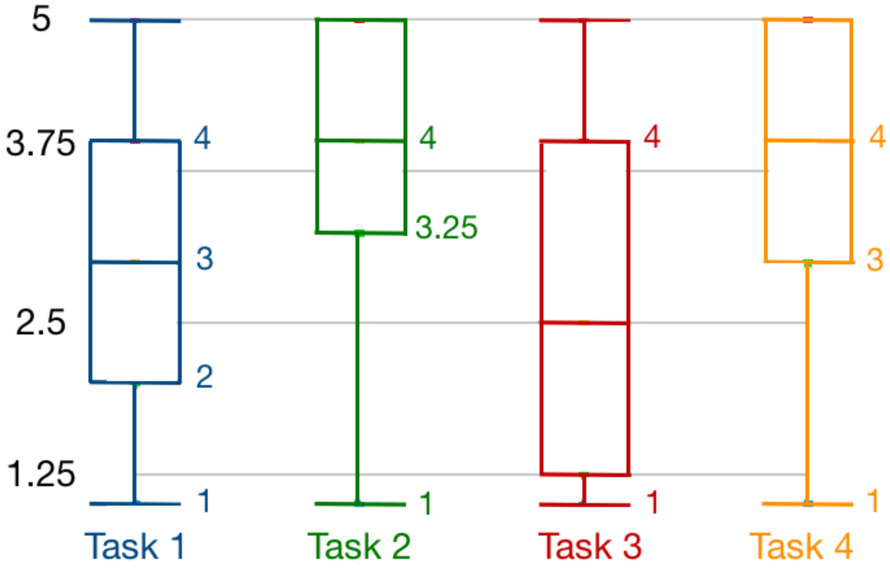


Figure 5.6 – **Task criticality results**

between them from the most critical one to the least. Booking a doctor appointment was considered the most critical task by 72% of the participants. The second most critical task was carrying biscuits with 58%, it is to be noted that 18% considered this task the most critical task, the third most critical task was building a Lego character with 50% (26% ranked this task as the least critical), and finally dancing was considered the least critical task by 64% of the participants. The Kendall's tau correlation test indicated a statistically highly significant positive correlation between users' rating of criticality of Task 1, and users' rating of criticality of Task 3 ($\tau_b = 0.366, p = 0.002$), and between users' rating of criticality of Task 1 and users' rating of Task 4 ($\tau_b = 0.356, p = 0.002$). This means, the more critical people considered Task 1 to be, the more critical they would consider Task 3 and Task 4 to be too. There is also a strong significant positive correlation between people's criticality rating of Task 2 and people's criticality rating of Task 4 ($\tau_b = 0.469, p < 0.001$). So the more critical people rated Task 2, the more critical they also rated Task 4 which is consistent with the way people ranked tasks among them, as Task 2 and Task 4 were rated as the most critical tasks Fig.5.7, and the same goes between Task 1 and Task 3 as they were both rated the least critical tasks.
The Kendall's correlation test also showed there is a high significant positive correlation between Task 3 criticality rating and Task 4 criticality rating ($\tau_b = 0.388, p = 0.001$), which means the more critical people thought Task 3 was, the more critical they thought Task 4 was too. It could be explained by the way Task 3 criticality was rated, as the boxplot Fig.5.7 displays a much wider spread rates compared to the other tasks. This is probably due to the way participants interpreted Task 3, doing a dance with the robots, as some may have thought they had to teach the robot, and this might have increased the criticality of this task.

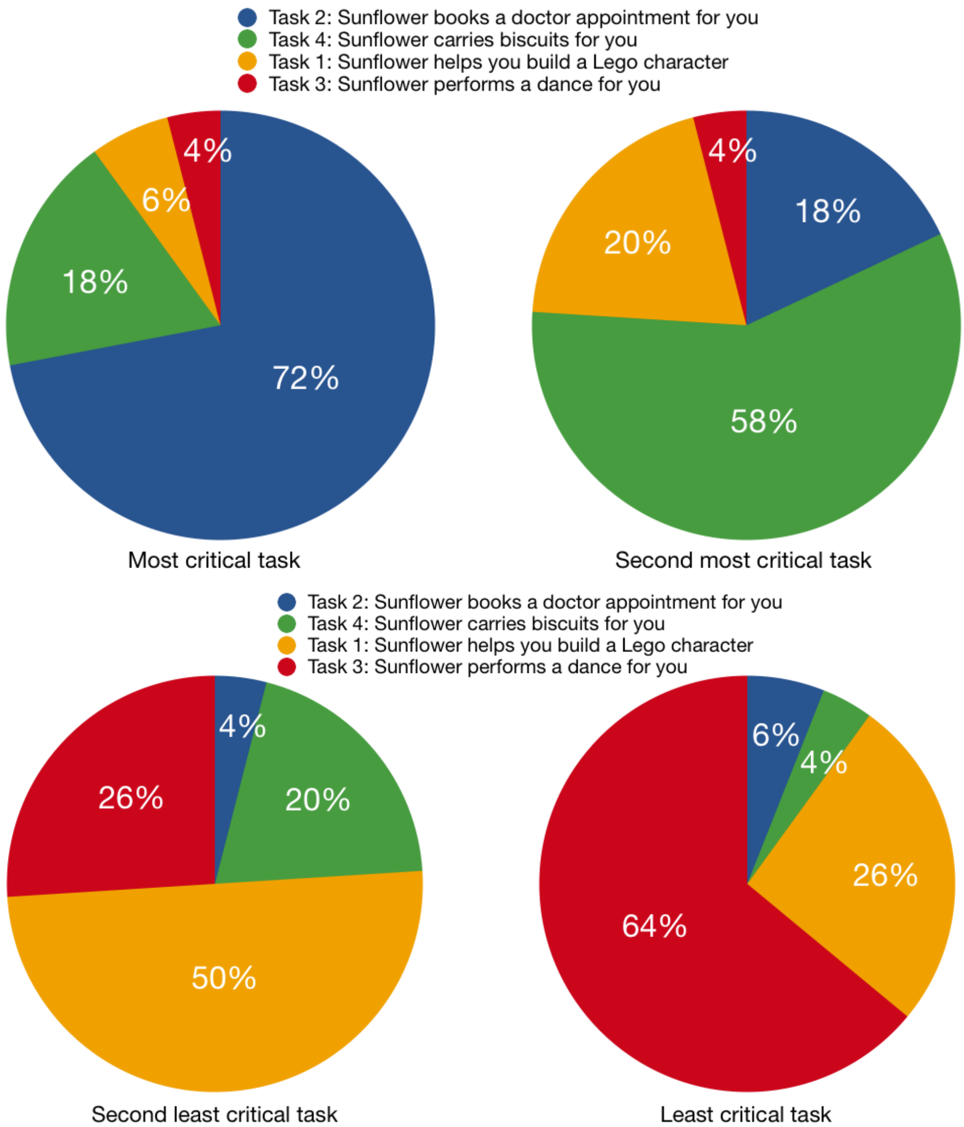


Figure 5.7 – **Task criticality rankings**

However, the test revealed no statistically significant correlations between the way people rated the criticality of a task and their choice of preferred condition for any tasks. Therefore, hypothesis H5a was not verified. We cannot say that the level of criticality of a task correlates with the choice of level of control of the Sunflower robot. Also, there was no correlation between the way people rated the criticality of a task and their desired control. It means that it cannot be said that the more controlling people are, the more critical they tend to rate tasks. Therefore, H5b was not verified either.

5.4.2.1 Low critical tasks and perception of control

The test showed no correlations between Task 1 criticality rating and the perception of control of the action for any of the tasks and conditions, the perception of control of the outcome of the action for any of the tasks and conditions, or the perception of control of the robot for any of the tasks and conditions. This means that the way participants rated Task 1, building a Lego character as a low critical task, did not influence the way participants perceived to be in control of the action executed in any of the 4 tasks, or the way participants felt in control of the robot during the performance in any of the 4 tasks, or the way participants perceived to be in control of the outcome of the action in any of the 4 tasks, in either conditions. The same results were displayed for Task 3 criticality rating and the perception of control of the action/outcome of the action/robot for any of the tasks and conditions.

5.4.2.2 High critical tasks and perception of control

5.4.2.2.1 Task 2: Booking a doctor appointment

Task 2 criticality rating are statistically significantly positively correlated with the perception of control of the robot in T1C2 when the participant decided when the robot displayed the next instruction ($\tau_b = 0.255, p = 0.037$). This means, the more people rated Task 2, as a high critical task, the more people felt in control of the robot in Task 1 when they decided when the robot displayed the next instructions on its tablet to build the Lego character. This could be because participants felt that the success of Task 1 depended more on their skills as their instructed the robot to show the next task. Therefore, it could then be that participants considered that it was more important to do the task correctly when they felt in control of the robot.
There is a positive correlation between Task 2 criticality rating, and the perception of control of the action in T2C2 when the participant decided when to book the doctor appointment ($\tau_b = 0.394, p = 0.002$), and the perception of control of the outcome of the action in T2C2 ($\tau_b = 0.321, p = 0.011$), and the perception of control of the robot in T2C2 ($\tau_b = 0.303, p = 0.013$). So the more critical people thought Task 2 was, the more in control of the action "booking a doctor appointment" they felt, when they chose the time slot to be booked. They also felt more in control of the outcome, as they picked the time slot of the appointment, and they felt more in control of the robot, as the robot was following the user's instructions. This result shows consistency within Task 2 perception of control.
There is also a positive correlation between Task 2 criticality rating and the perception of control of the action in T4C1 when the robot decided to carry the biscuits to the living room on its own ($\tau_b = 0.354, p = 0.003$). So the more critical Task 2 was, the more people felt in control of the action "carrying biscuits" when the robot was manoeuvring without instructions. It could be that people felt more in control of the action as the robot was navigating faster and smoother than in the other condition, when the participant had to guide the robot. As Task 4 is a physical task, Sunflower had to move whenever a command was said and it could be that the distance was not matching what people expected or simply as one participant told the experimenter, they could see that the robot was not responding to its sensors, therefore knew in this particular set up that the robot was remote controlled.

5.4.2.2.2 Task 4: Carrying biscuits

The test revealed a statistically significant positive correlation between Task 4 criticality rating and the perception of control of the robot in T1C2 ($\tau_b = 0.274, p = 0.022$). This means the more critical people rated Task 4, the more in control of the robot people felt when they chose when Sunflower displayed the next step of the instructions to build the Lego character.
There is a significant positive correlation between Task 4 criticality rating and the perception of control the outcome of the action in T2C2 ($\tau_b = 0.285, p = 0.022$). So the more critical Task 4 is for a participant, the more in control of the outcome, appointment booked, the participant feels in Task 2, when the robot was following the instructions of the user.
There is also a significant positive correlation between Task 4 criticality rating and the perception of control of the outcome of the action in T4C2 when the participant guided the robot to the kitchen with vocal commands ($\tau_b = 0.244, p = 0.037$). So the more critical participants thought Task 4 was, the more in control of the robot they felt when they were guiding the robot from the kitchen to the living room. This result is interesting as participants did not prefer this condition for this task. So although participants felt more in control when guiding

the robot, they still prefer condition C1 for this task, when the robot chose to go to the living room as soon as the tray was full. It is most probably because participants prefer efficiency for this physical task compared to control. As many stated, "the [robot] autonomous movement was faster and it required less effort" from the participant.

To conclude, the results demonstrate there is statistically significant correlations between the rating of task criticality and the perception of control of the robot when the task is considered critical. When the task is not considered critical, conclusions cannot be drawn regarding the importance of perception of control of the action/outcome of the action/robot. So H5a and H5b hypothesis were not verified.

5.4.3 RQ7. Type of task

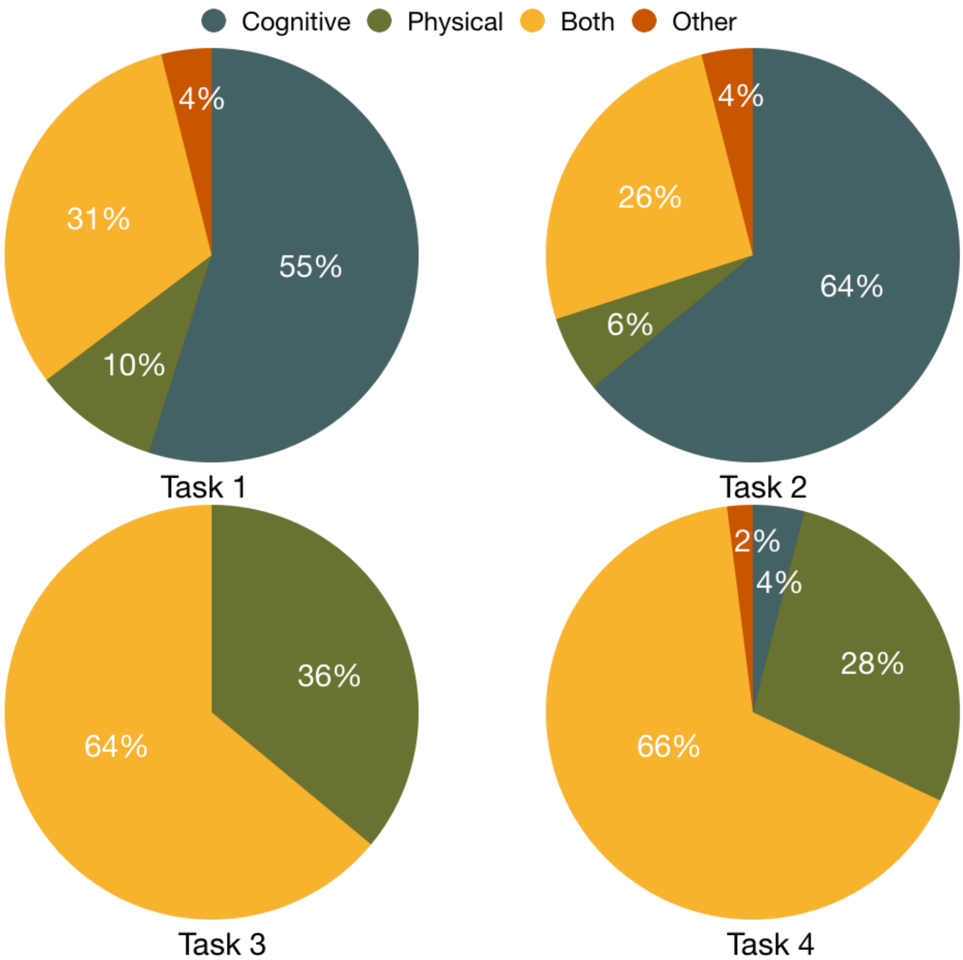


Figure 5.8 – **Classification of tasks according to their type**

Participants were asked to classify tasks according to their type (cognitive, physical, both or other). As expected, the choice of tasks was validated by the participants' classification. Task 1 and Task 2 were considered cognitive by respectively 55% and 64% of the participants. Task 3 was either considered physical or both cognitive and physical by respectively 36% and 64% of the users. Task 4 was classified as physical by 28% of the people and both by 66%. A Pearson Chi square test indicated a statistically significant association between the way participants classified Task 2 and their choice of preferred condition for Task 1 ($df(6) = 15.783, p = 0.015$). There is also a significant association between users' classification of Task 2 and their choice of preferred condition for Task 3 ($df(6) = 14.158, p = 0.028$). And finally there is a significant association between people's classification of Task 4 and their choice of preferred condition for

Task 4 ($df(6) = 16.873, p = 0.010$). So the type of task seem to influence participants' choice of preferred condition which disproves hypothesis H7, but provides an explanation into why Task 4 preferred condition was condition C1 although participants felt less in control. It is more probably because the task is physical therefore, participants may find it more tedious to micromanage than a cognitive task.

People were asked to rate from the scale of 1 to 5 (1 being not realistic at all, and 5 being

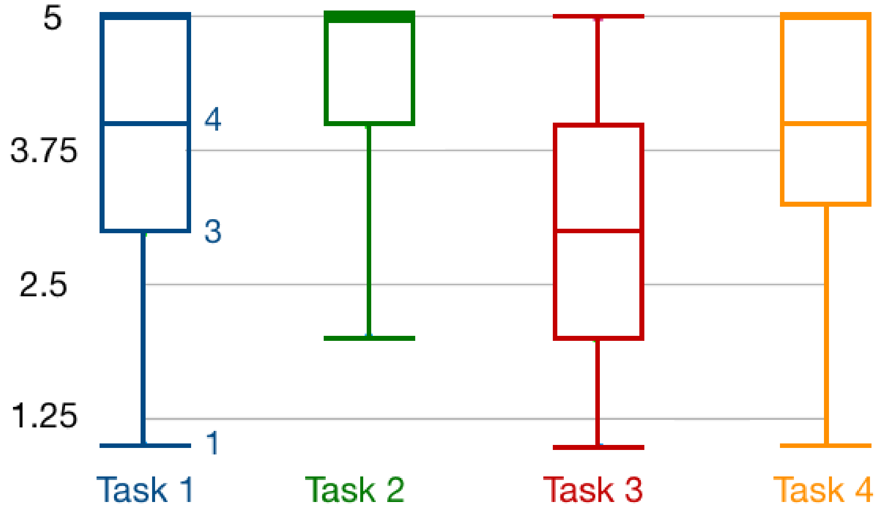


Figure 5.9 – **Ratings of how realistic the task is**

very realistic), how realistic they thought the task was. Task 2 and Task 4 were rated as very realistic ($M_{task2} = 4.28$, $SD_{task2} = 0.93$, and $M_{task4} = 4.04$, $SD_{task4} = 1.01$) while Task 1 was rated as half realistic ($M_{task1} = 3.74$, $SD_{task1} = 1.10$) and Task 3 as not realistic ($M_{task3} = 2.92$, $SD_{task3} = 1.34$). The Kendall's tau correlation test revealed no significant correlations between how realistic people rated a task and people's choice of preferred condition. However, the test indicated a statistically significant positive correlation between Task 3 rating of how realistic the task is, and Task 4 rating ($\tau_b = 0.246, p = 0.039$). So the more realistic people thought Task 3 was, the more they thought Task 4 was. There is also a strong positive correlation between Task 2 rating and Task 4 rating of how realistic the task is ($\tau_b = 0.562, p < 0.001$). The most interesting results is that there is a significant positive correlation between how realistic people rate a task, and how critical they rate the same task (see Fig.5.10). So the more realistic a task is rated, the more critical the task will be rated.

To conclude we cannot say that the participant's preference of the robot's level of autonomy is independent of the type of task performed by the robot as we found significant associations between the way participants classified tasks and their choice of preferred condition. Therefore, hypothesis H7 was not verified.

5.4.4 RQ1. Perception of control of the robot companion

Participants were asked to rate on a scale from 1 to 5, 1 being "I didn't feel in control at all", and 5 being "I felt I was fully in control", how much they felt in control of the action, how much they felt in control of the outcome of the action and how much they felt in control of the robot during the task, for both conditions (C1: when the robot decides what to do next, and C2: when the participant decides what the robot does next). First, as expected, the results show that people felt more in control when they decided what the robot had to do for each tasks (see Fig.5.11 for Task 1, Fig.5.13 for Task 2, Fig.5.15 for Task 3 and Fig.5.17 for Task 4). The results are consistent across each tasks. When the user did not feel in control of the action, the user also did not feel in control of the robot (see Fig.5.11 for Task 1 for example).

	Task 1 criticality rating	Task 2 criticality rating	Task 3 criticality rating	Task 4 criticality rating
Task 1 realism ratings	0.290* 0.014	0.166 0.169	0.239* 0.042	0.043 0.716
Task 2 realism ratings	0.224 0.064	0.542** 0.000	0.160 0.187	0.426** 0.000
Task 3 realism ratings	0.148 0.199	0.129 0.276	0.495** 0.000	0.164 0.160
Task 4 realism ratings	0.083 0.488	0.437** 0.000	0. 337** 0.005	0.468** 0.000

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Figure 5.10 – **Correlation table between ratings of task criticality and task realism**

5.4.4.1 Task 1: Building a Lego Character

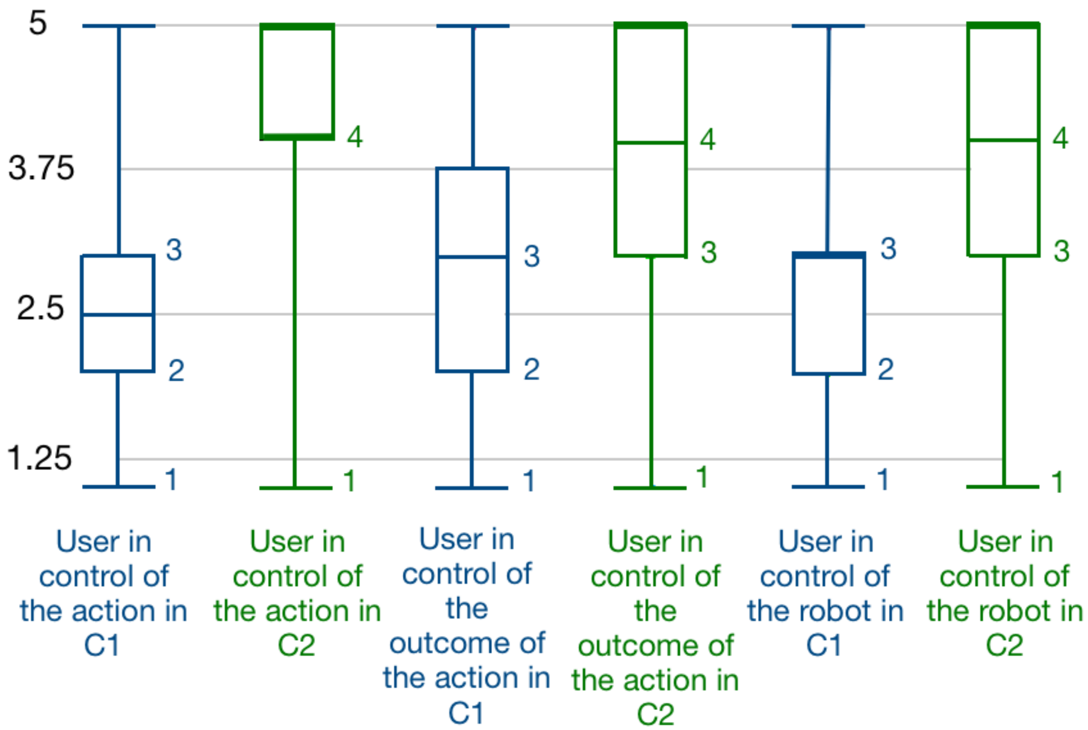


Figure 5.11 – **Task 1: building a Lego character**

The results showed that on average, participants preferred the C2 condition compared to C1 for Task 1: 78% of the participants preferred the C2 condition when the robot displayed the following instruction after the user asked for it, while only 20% chose C1 when the robot chose when it was appropriate to display the following instruction, as their preferred choice. 2% was

undecided.
The Kendall's tau correlation test Fig.5.12 shows there is statistically a highly significant positive correlation between the perception of control of the action, and the perception of control of the outcome of the action for both conditions (for the preferred condition $\tau_b = 0.657$, and $p < 0.001$, for the other condition ($\tau_b = 0.591, p < 0.001$). There is also a highly significant positive correlation between the perception of control of the outcome of the action and the perception of control of the robot for both conditions (for the preferred condition $\tau_b = 0.689, p < 0.001$, for the other condition $\tau_b = 0.594, p < 0.001$). This means that the more people felt in control of the action building the Lego character, the more they felt in control of the outcome of the action (having a Lego character built) and the more they felt in control of the robot. This is true for the user's preferred condition and the user's non-preferred condition, which demonstrate the consistency of the results for Task 1.

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 1
User in control of the action in the preferred condition	-0.230 0.065	0.657** 0.000	-0.140 0.261	0.546** 0.000	-0.144 0.248	-0.073 0.587
User in control of the action in the other condition		0.165 0.183	0.591** 0.000	-0.237 0.053	0.500** 0.000	-0.158 0.233
User in control of the outcome of the action in the preferred condition			-0.076 0.539	0.689** 0.000	-0.001 0.992	0.111 0.408
User in control of the outcome of the action in the other condition				-0.174 0.156	0.594** 0.000	-0.051 0.702
User in control of the robot in the preferred condition					-0.139 0.258	0.186 0.162
User in control of the robot in the other condition						-0.014 0.916

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 5.12 – **Correlation table for Task 1 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.**

5.4.4.2 Task 2: Booking a doctor appointment

For Task 2, the descriptive statistics Fig.5.13 tell us there is an even clearer difference of perception of control between C1 (the robot being fully autonomous) and C2 (the robot being semi-autonomous) compared to Task 1 Fig.5.11. Participants clearly did not feel in control at all in this scenario "booking a doctor appointment" in C1, when the robot chose the appointment time slot for its user. For this task 2, 84% of the participants preferred the C2 condition when they decided their time slot for the doctor appointment, while 12% preferred the C1 condition, when the robot chose the time slot, and 4% were undecided. The Kendall's tau correlation

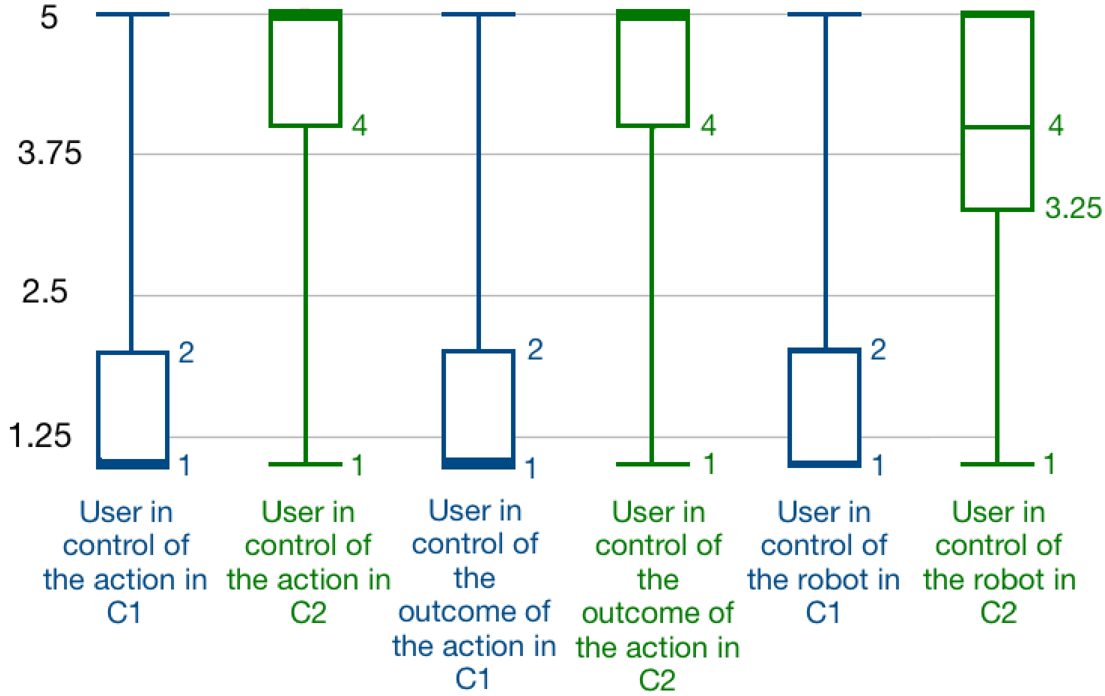


Figure 5.13 – **Task 2: booking a doctor appointment**

Fig.5.14 test reveals the same consistency found for Task 1: there is a statistically strong positive correlation between the perception of control of the action and the perception of control of the outcome of the action for both conditions (for the preferred condition$\tau_b = 0.805, p < 0.001$, and for the other condition $\tau_b = 0.701, p < 0.001$). There is also a strong significant negative correlation between the perception of control of the action for the preferred condition and the perception of control of the action for the other condition ($\tau_b = -0.498, p < 0.001$). This means that not only, the more in control of the action "booking a doctor appointment" the user perceived to be, the more in control of the outcome (doctor appointment booked) the user felt and the more in control of the robot the user perceived to be in his/her preferred condition, in this case mostly C2 (see Fig.5.13), it also means that the more in control of the action the user felt in his/her preferred condition, the less in control the user felt in the other condition.

5.4.4.3 Task 3: Doing a dance

Task 3 descriptive statistics results Fig.5.15 were less pronounced than the ones for Task 1 and for Task 2, in terms of difference between the C1 fully autonomous condition and the C2 semi-autonomous condition. However, the results still show that people perceive to be more in control in the C2 semi-autonomous condition compared to the C1 fully autonomous condition. 48% of the participants preferred the C2 condition when the robot was repeating the user's dance step, while 26% of the users preferred the C1 condition when the robot was doing an unpredictable dance step and 26% were not sure what they prefer. The Kendall's tau correlation test Fig.5.16 shows the same statistical significant correlation seen for Task 1. There is a highly significant positive correlation between the perception of control of the action "doing a dance" and the perception of control of the outcome of the action for both conditions (for the preferred condition $\tau_b = 0.887, p < 0.001$, and for the other condition $\tau_b = 0.793, p < 0.001$). We find the same consistency in the correlation results for Task 3 than the ones for Task 1. So the more the user perceived to be in control of the action "doing a dance", the more the user felt in control

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 2
User in control of the action in the preferred condition	-0.498** 0.000	0.805** 0.000	-0.453** 0.000	0.701** 0.000	-0.463** 0.000	-0.289* 0.037
User in control of the action in the other condition		-0.463** 0.000	0.868** 0.000	-0.282* 0.027	0.749** 0.000	0.193 0.162
User in control of the outcome of the action in the preferred condition			-0.494** 0.000	0.698** 0.000	-0.471** 0.000	-0.165 0.234
User in control of the outcome of the action in the other condition				-0.407** 0.001	-0.787** 0.000	0.183 0.179
User in control of the robot in the preferred condition					-0.394** 0.001	-0.177 0.190
User in control of the robot in the other condition						0.211 0.117

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 5.14 – **Correlation table for Task 2 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.**

of the outcome of the action (dance done) and the more the user perceived to be in control of the robot in the preferred condition. The same results was found in the other condition.

5.4.4.4 Task 4: Carrying biscuits

It can be noticed that Task 4 descriptive statistics Fig.5.17 displays less difference between C1 the fully autonomous condition and C2 the semi autonomous condition compared to the other tasks. For Task 4, 18% of the users preferred C2 when they guided the robot to the living room, while 78% of them preferred C1 when the robot decided to go to the living room on its own, and 6% were undecided. The Kendall's tau correlation test Fig.5.18 indicates a statistical strong significant positive correlation between the perception of control of the action and the perception of control of the outcome of the action for both conditions($\tau_b = 0.671, p < 0.001$ for the preferred condition, and $\tau_b = 0.776, p < 0.001$). There is also a highly significant positive correlation between the perception of control of the outcome of the action and the perception of control of the robot for both conditions (for the preferred condition $\tau_b = 0.641, p =< 0.001$, and for the other condition $\tau_b = 0.803, p < 0.001$). This means that the less the user perceived to be in control of the action "carrying biscuits", the less the user felt in control of the outcome "biscuits carried to the living room", and the less he/she perceived to be in control of the robot in his/her preferred condition. This is interesting as for the majority of participants, the

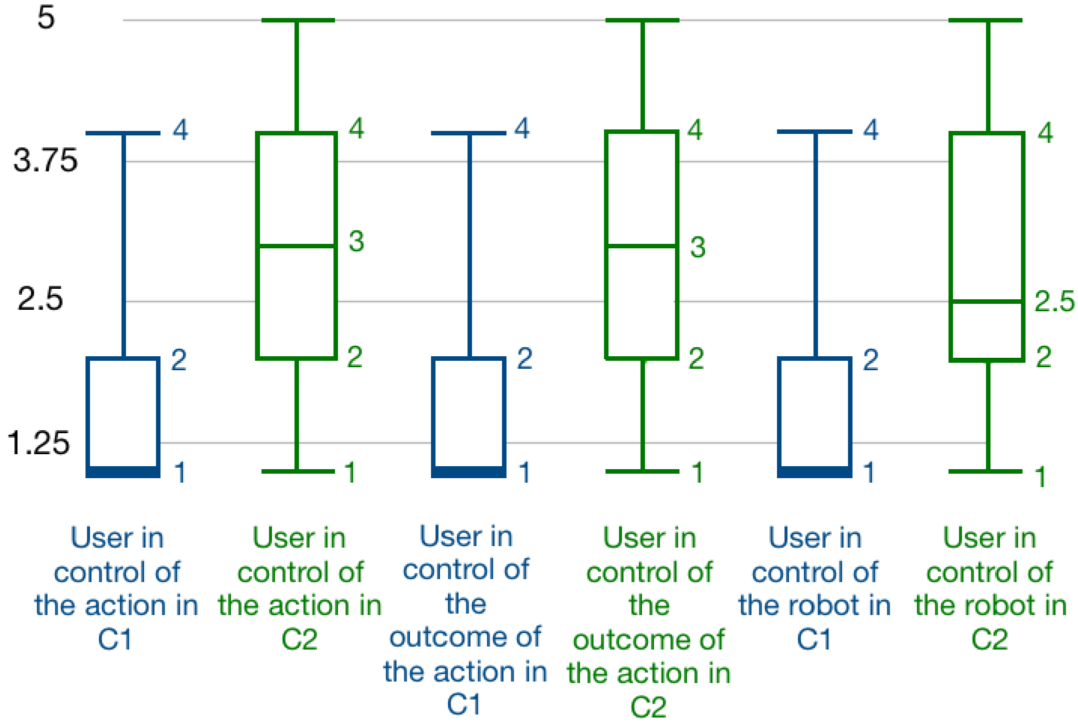


Figure 5.15 – **Task 3: doing a dance**

preferred condition was C1 when the robot decided to carry the biscuits to the living room on its own without guidance from the participant.

5.4.4.5 Perception of control across tasks

A Kendall's tau correlation test showed no significant correlation between the user's perception of control of the action/outcome of the action/robot in either conditions in Task 1, and the user's choice of preferred condition. However, the test revealed a significant negative correlation between the participant's perception of control of the action in T2C1 and the participant's choice of preferred condition ($\tau_b = -0.297, p = 0.027$). We found the same significant negative correlation between the participant's perception of control of the outcome of the action in T2C1 and the participant's choice of preferred condition ($\tau_b = -0.299, p = 0.024$). So the more in control the user felt when Sunflower was in charge, the less the user wanted to "supervise" the robot meaning, the more autonomous the participant preferred the robot to be for Task 2. There is also a statistically significant negative correlation between the participant's choice of preferred condition and the participant's perception of control of the action in T4C1 ($\tau_b = -0.310, p = 0.015$), the participant's choice of preferred condition and the participant's perception of control of the outcome of the action in T4C1 ($\tau_b = -0.297, p = 0.018$), and between the user's choice of preferred condition and the user's perception of control of the robot in T4C1 ($\tau_b = -0.319, p = 0.012$). So the more the user felt in control of the action/outcome of the action/robot when Sunflower was in charge of carrying the biscuits to the living room, the less the participant wanted to look after the robot, so the more autonomous they wanted the robot to be. Task 3 results were different (see Fig.5.19. The test indicated a statistically significant positive correlation between the user's choice of preferred condition and the user's perception of control of the action in T3C2 ($\tau_b = 0.327, p = 0.008$), the user's choice of preferred condition and the user's perception of control of the outcome of the action in T3C2 ($\tau_b = 0.452 p < 0.001$), and between the user's choice of preferred condition and the user's perception of control of the robot in T3C2 ($\tau_b = 0.289, p = 0.018$). Therefore, it can be said that the more in control the

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 3
User in control of the action in the preferred condition	-0.126 0.378	0.887** 0.000	-0.104 0.468	0.753** 0.000	-0.014 0.925	0.066 0.651
User in control of the action in the other condition		-0.73 0.613	0.793** 0.000	0.052 0.718	0.798** 0.000	0.154 0.304
User in control of the outcome of the action in the preferred condition			-0.085 0.556	0.833** 0.000	0.055 0.706	0.080 0.583
User in control of the outcome of the action in the other condition				-0.007 0.963	0.795** 0.000	0.147 0.329
User in control of the robot in the preferred condition					0.202 0.164	0.278 0.57
User in control of the robot in the other condition						0.227 0.136

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 5.16 – **Correlation table for Task 3 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.**

participant perceived to be when he/she was in charge of the dance, the more he/she wanted to supervise the robot, meaning the less autonomous he/she preferred the robot to be.
To conclude, we can see that the results are consistent across the tasks and conditions. When people felt in control of the robot for one condition, they would also feel in control of the action and in control of the outcome of the action for this same condition. The results did not validate the H1 hypothesis. There is a lot more subtlety into the link between how the user perceives to be control of the action/outcome of the action/robot and its preferred choice of level of autonomy of the robot. The results show that the more in control the participant felt for Task 2 and Task 4, the more autonomous they wanted the robot to be, which proves the H1 hypothesis. However, for Task 3 it was found that the more the participant felt in control, the less autonomous they wanted the robot to be.

5.4.5 RQ2. Personality effect

To measure how controlling people are, we used the standard desirability control scale Burger & Cooper (1979). This test uses everyday life questions to study how much in control people want to be in general. A Kolmogorov-Smirnov normality test revealed that we have a normal distribution population in terms of how controlling people are ($D(50) = 0.104, p = 0.200$), which is illustrated by the boxplot Fig.5.20 and the histogram in Fig.5.21.

To measure personality, participants were asked to respond to the standard Big Five person-

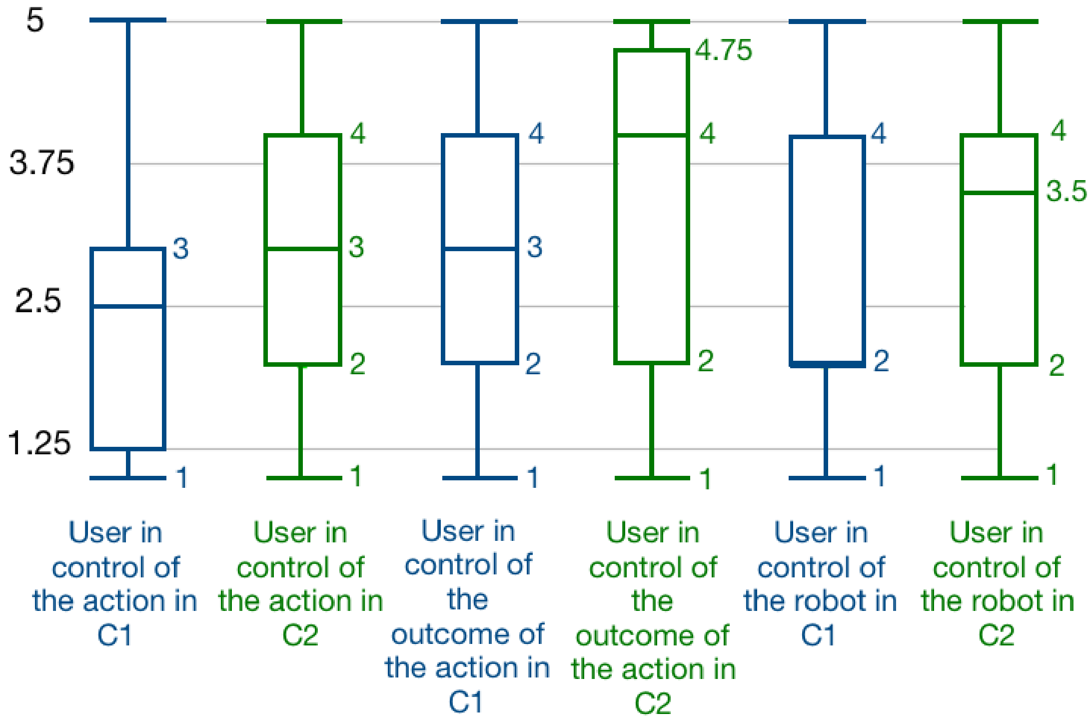


Figure 5.17 – **Task 4: carrying biscuits**

ality test Gosling et al. (2003). This test is a 7 point Likert scale that measures extraversion, agreeableness, conscientiousness, neuroticism sometimes called emotional stability and openness. The results show that our participants were in average open-minded with a 5.73 score and conscientious with a 5.44 score. The average score of extraversion was high with a 4.36, while the average score of agreeableness and neuroticism were low (3.01 and 3.03 respectively). As the boxplots of the personality test displays in Fig.5.22, our pool of participants do not represent a normal distribution. The Kolmogorov-Smirnov normality test confirmed that Agreeableness ($D(50) = 0.144, p = 0.011$), Conscientiousness ($D(50) = 0.220, p < 0.001$), Neuroticism ($D(50) = 0.126, p = 0.045$) and Openness ($D(50) = 0.155, p = 0.004$) do not follow a normal distribution. Therefore, it was decided to use non-parametric correlation tests. A Kendall's tau correlation test indicated that there is a statistically significant negative correlation between Extraversion and Neuroticism ($\tau_b = -0.218, p = 0.039$). This means that the more extraverted someone is, the more negative he/she will tend to be. The test also showed there is a highly significant negative correlation between Conscientiousness and Neuroticism ($\tau_b = -0.323, p = 0.003$). So the more conscientious someone is, the more he/she will tend to be moody and to experience feelings such as anxiety, worry, fear, anger, frustration, envy, jealousy, guilt, depressed mood, and loneliness.. Interestingly the test also revealed that the more open-minded people are, the more controlling they tend to be, through a significant positive correlation test between openness and the desirability control scale ($\tau_b = 0.254, p = 0.016$).
There is a highly significant negative correlation between Openness and the preferred condition participants had for Task 1, building a Lego character ($\tau_b = -0.323, p = 0.009$). This means that the more open-minded participants were, the less they preferred the semi-autonomous version of the robot (when they choose when Sunflower had to show them the next step of the instructions to build the Lego character), therefore the more willing participants were to have a fully autonomous version of the robot (when Sunflower decided when to show the user the next step of the instructions.). This was not verified for the other tasks. There is no statistically significant correlation between Openness and the preferred condition participants had for Task 2 ($\tau_b = -0.126, p = 0.309$), Openness and the preferred condition participants had for Task 3

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 4
User in control of the action in the preferred condition	-0.090 0.462	0.671** 0.000	-0.139 0.258	0.718** 0.000	-0.168 0.171	0.127 0.343
User in control of the action in the other condition		-0.071 0.557	0.776** 0.000	-0.093 0.453	0.780** 0.000	0.116 0.377
User in control of the outcome of the action in the preferred condition			-0.099 0.415	0.641** 0.000	-0.178 0.143	0.043 0.747
User in control of the outcome of the action in the other condition					0.803** 0.000	-0.046 0.728
User in control of the robot in the preferred condition						-0.017 0.901
User in control of the robot in the other condition						-0.039 0.768

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 5.18 – **Correlation table for Task 4 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.**

	Task 3: user's perception of control of the action when Sunflower is in charge (C1 condition)	Task 3: user's perception of control of the action when he/she is in charge (C2 condition)	Task 3: user's perception of control of the outcome of the action when Sunflower is in charge (C1 condition)	Task 3: user's perception of control of the outcome action when he/she is in charge (C2 condition)	Task 3: user's perception of control of the robot when Sunflower is in charge (C1 condition)	Task 3: user's perception of control of the robot when he/she is in charge (C2 condition)
Task 2 choice of preferred condition	-0.179 0.180	-0.050 0.693	-0.279* 0.037	-0.031 0.806	-0.070 0.607	-0.050 0.694
Task 3 choice of preferred condition	-0.083 0.518	0.327** 0.008	0.087 0.498	0.452** 0.000	-0.001 0.992	0.289* 0.018
Task 4 choice of preferred condition	0.068 0.609	-0.131 0.301	0.022 0.866	-0.264* 0.037	0.068 0.613	-0.074 0.558

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Figure 5.19 – **Correlation table between Task 3 perception of control and user's choice of preferred condition**

($\tau_b = -0.177, p = 0.138$), and Openness and the preferred condition participants had for Task 4 ($\tau_b = -0.26, p = 0.832$).
A Kendall's correlation test showed there is no statistically significant correlation between per-

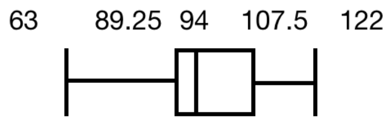


Figure 5.20 – **Desirability Control Scale**

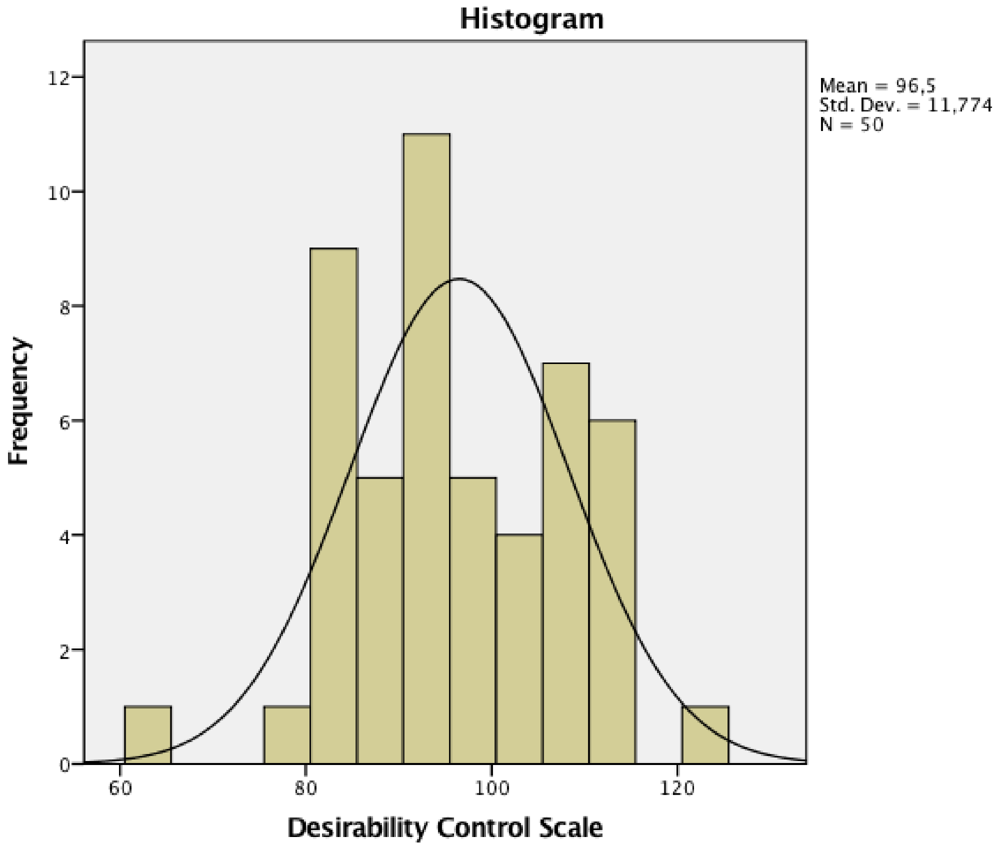


Figure 5.21 – **Desirability Control Scale population distribution**

sonality traits and the perception of control in the participants' preferred condition for Task 1. However, there is a statistically significant negative correlation between the desirability control scale and the perception of control of the Sunflower robot for Task 2 ($\tau_b = 0.274, p = 0.014$). So the more controlling the participant is, the less he/she felt in control of the robot when the doctor appointment was booked. There was no significant correlation between personality traits and the perception of control in the user's preferred condition for Task 3 and Task 4. Therefore, hypothesis H2 is not validated.

5.4.6 RQ8. Experience and knowledge of technology

To measure participants' experience of technology, participants were asked what type of technology they use and to estimate how often they use those everyday technology. Based on participants' answers, we scaled the frequency of usage of technology as such: 0= do not have one, 1= 2- 3 times a month, 2= 2- 3 times a week, 3=more than 3 times a week, 4=less than 30 min a day, 5=1- 2 hours a day, 6=2- 3 hours a day, and 7=More than 3 hours a day. Then we asked participants to rate their familiarity with robots on a scale of 1 to 5 (1 being not familiar at all and 5 being very familiar). As a result, 88% of our participants own a smartphone (98% of them would use it every day), 86% possess a computer or a laptop they would use every day, 32% own a tablet they would use every day, 6% have a smartwatch they use every day and

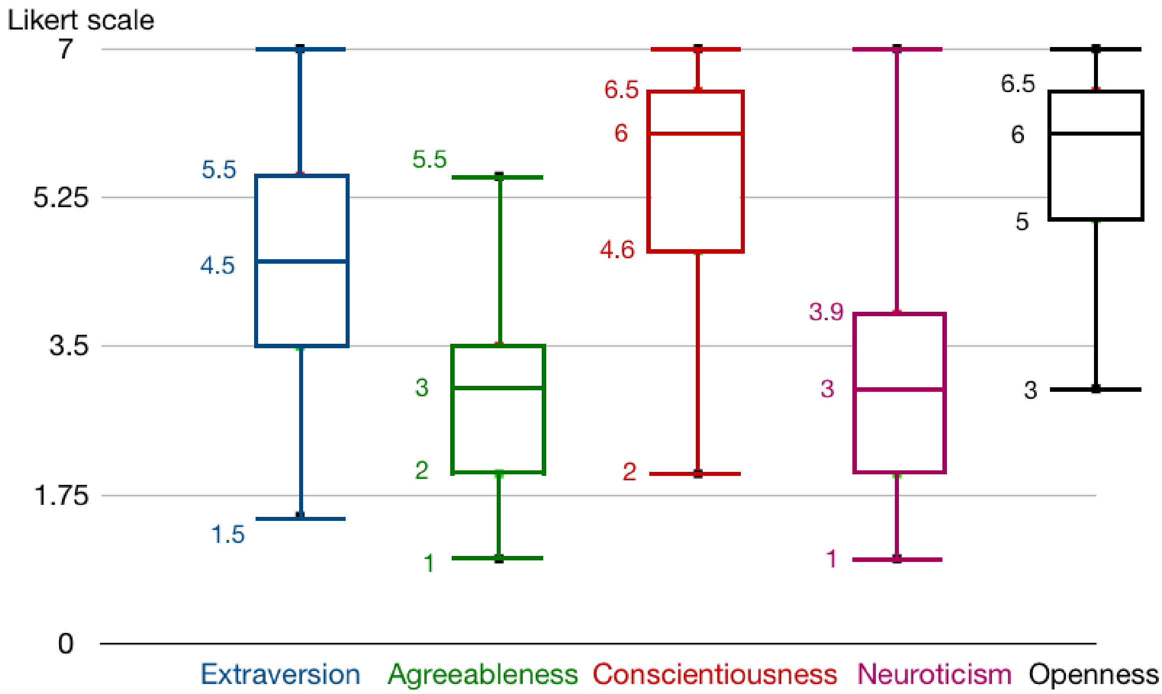


Figure 5.22 – **Personality test results**

12% use a Google Home or Alexa every day. Regarding experience with robots, the mean was very low regarding familiarity with programming robots ($M = 1.66$, $SD = 1.06$), experience with programming robots ($M = 1.42$, $SD = 0.91$) and familiarity with interacting with robots ($M = 1.74$, $SD = 1.03$). When asked how often participants interacted with robots, half of them said "never", and 36% of them mentioned "on a few occasions before" (see Fig.5.23).

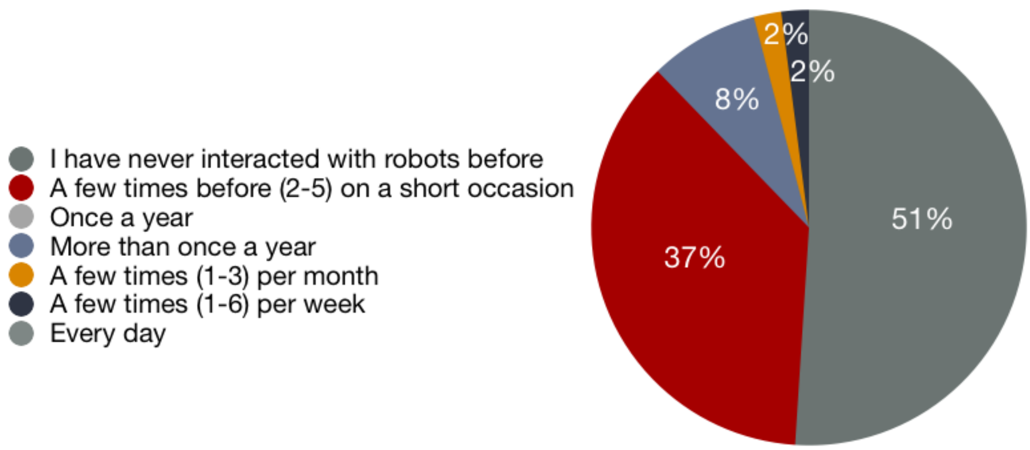


Figure 5.23 – **Frequency of interaction with robots before the experiment**

A Kendall's correlation test revealed statistically significant correlations between the frequency of the usage of certain technology and the choice of the preferred conditions participants had for each tasks (see Fig.5.24). There is a significant negative correlation between how much time people spend on their computer and people's choice of the preferred condition for Task 1($\tau_b = -0.283, p = 0.030$). This means the more often people spend time on their computers, the less they will want to be in control of the robot, when the robot is giving instructions on how to build a Lego character. There is also a significant negative correlation between how often people spend time on their smartphone and people's preferred condition for Task 2 ($\tau_b = -0.306, p = 0.017$). So the more time people spend on their smartphone, the less they want to be in control of the robot when the robot is booking a doctor appointment. The same correlation was found for smartwatch ($\tau_b = -0.368, p = 0.009$). However, the same correlations for Task 3 and Task 4 were not found. Instead, there is a significant positive correlation between how often people use their tablet and their preferred condition for Task 3 ($\tau_b = 0.247, p = 0.049$). So the more people use their tablet, the more they want to be in control of the robot when the robot is dancing.

	Frequency usage of smartphone	Frequency usage of computer/ laptop	Frequency usage of tablet	Frequency usage of smartwatch	Frequency usage of Alexa/ Google Home
Task 1 preferred condition	-0.107 0.404	-0.283* 0.030	0.085 0.514	0.138 0.323	-0.089 0.522
Task 2 preferred condition	-0.306* 0.017	0.024 0.856	0.117 0.370	-0.368** 0.009	-0.042 0.761
Task 3 preferred condition	-0.006 0.962	0.011 0.934	0.247* 0.049	0.050 0.707	0.045 0.735
Task 4 preferred condition	-0.077 0.545	-0.043 0.738	-0.248 0.056	-0.059 0.671	-0.085 0.536

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Figure 5.24 – **Correlation table between the usage frequency of technology and participants' preferred conditions**

To conclude, there is a correlation between participants' technology savviness and their preferred level of autonomy of the robot, which disproves hypothesis H8. We found that for both cognitive tasks, the more participants spent time on their smartphone or computer, the less they want to be in control of the robot. However, our data did not indicate that experience with robots influence participants' preference of level of autonomy of the robot.

5.5 Limitations of the study

One of the main difficulty of the design of the experiment was to implement the 4 tasks with the 2 conditions being consistent. One of the weaknesses of this study is the Wizard-of-Oz set up. It would have been more realistic to design a fully autonomous robot for this study, as the first live study was working with a fully autonomous robot. However, this would have required a lot of development time that the experimenter did not have. Another weakness of the study is the choice of tasks in terms of criticality. Another weakness of the study is the selection of the tasks. For example the choice of dancing as a low critical task to perform for the robot. Many participants were confused into how Sunflower would perform a dance, and some did not see the movements of the robot as dancing movements. In addition, although the high critical tasks were previously validated in Chapter 4, we could not use more extreme tasks (such as Sunflower helping to put off a fire in the kitchen) for ethical reasons. In such extreme cases, participants may react differently (Robinette et al. 2017).

5.6 Discussion

In this study we investigated how much, users want to be in control of the robot, depending on the task the robot is performing.

5.6.1 Effect of personality on perception of control

There is no correlation between how controlling people are and how autonomous they wanted the robot to be for any of our tasks, so hypothesis H2 was not verified. However, it was found that the more controlling people are, the less they perceive to be in control of the action in their preferred condition when the robot booked a doctor appointment. It was also found for the same action, that the more controlling people are, the less they felt in control of the robot in their preferred condition. Therefore, it can be said that for a high critical cognitive task, controlling people are less likely to feel in control of the robot and the action the robot is performing, even if the robot is acting the way people preferred (being fully autonomous by taking all the decisions or being semi-autonomous, waiting for the user to take the decisions). It could be that since this task (Task 2 booking a doctor appointment) was also rated as the most realistic task, people could relate to it more easily and imagine its consequences better than for other tasks, which would explain why we did not find this correlation for other tasks. Some personality effect across every task was also found, such as having a negative correlation between Openness and the user's preferred condition for each task. The more open-minded people are, the less they are willing to control the robot, which means, the more they prefer the robot to be autonomous. These findings complement Meerbeek et al. (2008) studies where they found that the personality of the robot influences the user's preferred level of control of the robot. However, personality results have to be taken with caution, as the literature have shown, some papers show that people preferred robot that express a similar personality (Tapus et al. 2008) while others have shown the opposite (Woods et al. 2007). It is suspected that this difference comes from the main function the robot expresses. As this live experiment demonstrated, depending on the type of task the robot performs, the user have different expectations from the robot.

5.6.2 Perception of control, task criticality and type of task

5.6.2.1 Low critical tasks

The results show that for Task 1, building a Lego character and Task 3, doing a dance, participants preferred the C2 condition when the robot was following their instructions. This contradicts some early research done by Meerbeek et al. (2008) where he found that for a TV assistant task, his participants show no preference on the user's level of control. But as the researchers mentioned in their article, they focus the contrast on the personality behaviour that the robot was displaying, therefore this has to be taken with caution. Also, it does not appear that the participants were asked to rate the criticality of their task. The results of this experiment regarding the low critical tasks are consistent with the findings of the first live experiment described in Chapter 3 regarding the cleaning task. And the questionnaire study described in Chapter 4 classified the cleaning task as a low critical task. The results of this live experiment are not only consistent with the previous results but also reinforced by the fact that 50 people took part in the study while only 33 people took part on the Meerbeek's study that was conducted more than 10 years ago. Therefore, it is safe to say that for low critical tasks, participants prefer to be in control of the robot.

5.6.2.2 High critical tasks

As our results show for Task 2 and Task 4, the more the participant felt in control when the robot was in charge (condition C1), the more the participant was willing to let the robot be in charge. Perhaps this was the case because Task 2 and Task 4 are both considered critical tasks and therefore, it is more of a relief for the participant if the robot can do the task correctly.
However, the data also shows that despite this result, the majority of our participants preferred the C2 semi-autonomous condition for Task 2 while they preferred the C1 fully autonomous condition for Task 4. Task 2 is a cognitive task which is about scheduling participants day life, therefore as many mentions, they "need to have control of the situation", they "want to make [their] own decisions based on the options available" and they "like to make the final choice". When Sunflower booked the appointment for the participant in the C1 fully autonomous condition, the robot picked the first available slot on the digital calendar, which means if for a particular reason this day the participant wanted to leave the day open for other plans, he/she would have had to mention it in the digital calendar Sunflower was referring to. This means that it would have been harder work for the participant to implement these plans and ideas in the calendar, and to let Sunflower know rather for the participant to take an overall decision based on an overview of potential events/appointments that could happen that day. Some participants felt they were "infantilised" which is one of the risks mentioned by early research on ethics (Whitby 2008). This research confirms to some extent the danger mentioned by Lucidi & Nardi (2018). This is most probably why almost every participant did not prefer the robot to take the decision for the doctor appointment as this relates to how people manage their life. However, the same results did not apply for the high critical physical task "carrying a biscuit". For Task 4, carrying biscuits, people preferred the condition C1 as they mention it was difficult to manoeuvre the robot with voice commands in the C2 condition but also because many said it was easier this way ("it is more comfortable to not micromanage it") and that the robot demonstrated more intelligence. Task 4 being a physical task, people could also see the robot carrying the biscuits from the kitchen to the living room and therefore had an immediate overview of what is happening. So even if the robot is not as accurate as they would want it to be regarding the exact location of where the biscuits should be carried in the living room, the main task carrying the biscuits was accomplished. When it comes to a physical task, people do not expect having to supervise and micromanage it, at least in this case with carrying biscuits, because it is harder work for them to do the supervision rather than to do the task itself, while for the cognitive task, it is the opposite. Therefore, it is most probably why participants prefer the C1 fully autonomous condition as they felt in control of the situation.
Those results could also be explained by how realistic people perceived the task to be. As Task 2 was perceived more realistic than Task 4, although both were rated very realistic on average, as people then could relate more easily to Task 2, this could also be why participants prefer the C2 semi-autonomous condition.
So our results here demonstrated that people would be willing to let the robot being fully autonomous if they feel in control of the situation, which is obviously more difficult to implement for cognitive tasks, as it is harder to adapt to each person's habit.

5.6.3 Effect of technology savviness

The results revealed that the more time people spend on their everyday technology, the more autonomous they want the robot to be. This could be the case because Sunflower's interface was a tablet. Since the tablet is a well-spread technology, people are used to manipulate one or at least something that is similar, such as a smartphone or a computer. If the robot's interface had been something less familiar, people might have preferred the robot to be less autonomous. So our results confirm there is a habituation effect which can be exploited by roboticists. However, this is only true for smartphones and computers. There was no such findings for people having experience with robots. It could be because the majority of our participants were inexperience robot users, therefore it is difficult to draw conclusions with such data.

5.7 Conclusion

In conclusion, the results show there is a strong correlation between people's perception of control and their choice of how autonomous the robot should be. However, the results did not exactly corroborate the findings from the previous investigations Chapter 3. As suspected, people's preference of level of autonomy are subtle. The type of task and the criticality of the task influence the way people want their robot to react. For a critical cognitive task, people prefer the robot to be semi-autonomous, so they could take the final decision, whereas for a critical physical task, people prefer the robot to be autonomous as they did not want to micromanage the robot while it was performing the task. The results demonstrated that people would be willing to let the robot being fully autonomous provided they feel in control of the situation, which is more difficult to implement for cognitive tasks than for physical tasks, as it is harder to predict people's intentions and habits. It would be good to investigate in the future if we can change people's preference for cognitive critical tasks, by having a robot that would be more inquisitive.

Chapter 6

Conclusion

This chapter summarises the work done in this PhD thesis. It emphasises on the contributions to knowledge and potential future work.

6.1 Summary of the work and review of the research questions

As the introductory chapter well explained, this PhD studied the concept of sense of control applied to HRI. One of the main objective of this PhD was to understand what type of control over the robot the user prefers, and if this could be related to internal factors such as having a controlling personality or how much experience with technology someone has, or external factors such as the type of tasks the robot is executing or the criticality of the task the robot is executing.
As a reminder, 9 research questions emerged from the literature and were answered through the 5 studies presented in this thesis.

- RQ1. Is there a relationship between the perception of control participants had over the robot and their preference of the robot's level of autonomy?
- RQ2. Is there a relationship between participants' desired control and their preference of the robot's level of autonomy?
- RQ3. What defines task criticality?
- RQ4. What type of criteria do people consider rating the criticality of a task?
- RQ5. Does the level of criticality (high or low) of the task performed by the robot influences participants' preferences of the robot's level of autonomy?
- RQ6. What defines a cognitive task versus a physical task for a domestic robot companion?
- RQ7. Is there a relationship between the type of task performed by the robot (physical or cognitive) and participants' preference of the robot's level of autonomy?
- RQ8. Does a participant's technology savviness (experience and knowledge about technology) influence its preference of the robot's level of autonomy?
- RQ9. Is there a relationship between a participant's anxiety towards robots and its perception of control of the robot?

Experiment and descriptions	RQ
Chapter 3: Sense of control and robot anxiety in Human-Robot Interaction This first live experiment investigates how robot anxiety and desired control influenced the perception of control of a robot.	RQ1, RQ2, RQ8, RQ9
Chapter 4: What is a critical task for a domestic robot companion to perform? This chapter describes three questionnaires studies that investigated how to define a critical task and how to differentiate a physical task from a cognitive task.	RQ3, RQ4, RQ6
Chapter 5: How perception of control depends on the criticality of the tasks performed by the robot This second live experiment studies if the perception of control of the robot differs depending of the criticality of the task performed by the robot.	RQ1, RQ2, RQ5, RQ7, RQ8

This thesis first started to investigate sense of control in HRI with an exploratory live experiment (Chapter 3). This experiment tested how people's desire for control influenced their choice of the level of autonomy of the robot. The results of this study showed that the more controlling people were, the more autonomous they wanted the robot to be. This provided foundations work for a deeper investigation on sense of control in HRI. As the first study was exploratory, only one task was used to measure the impact of desired control and perception of control on the user's preferred level of autonomy of the robot: cleaning. To be able to conduct a more meaningful study, it was decided to use more tasks, which would all be varied. To do so, a questionnaire study was necessary to justify the classification of the type of tasks and the criticality of these tasks. In the end three questionnaire studies (Chapter 4) had to be conducted to find answers to the three research questions RQ3, RQ4 and RQ6. Once a selection of varied tasks were provided by the results of the questionnaire study, 4 tasks were chosen from the list to be implemented in the following live experiment. This allowed a second live experiment (Chapter 5) to be conducted to understand how the criticality of a task and the type of task can affect the user's preference level of autonomy of the robot.

6.2 Original contributions to knowledge

6.2.1 RQ1. Perception of control and robot's level of autonomy

The first live study results showed that participants prefer to control the robot in an automated mode, either semi-automated when they still had an element of control, or fully automated, when the robot was performing the action without supervision required. Nobody preferred having to activate the robot manually. The results of the second live experiment show that people felt more in control, when they instructed the robot for each task. However, the interesting result was that although participants felt less in control of the robot for the high critical physical task, they still prefer the autonomous version of the robot. This is explained by the way the robot was performing the task. According to the participants, the task was better performed by the robot, when it did it without instructions. Therefore, it can be concluded that people would prefer to control the robot in a semi-autonomous mode when they can give instructions to the robot, except when they feel that the robot does the task better without the instructions.

6.2.2 RQ2. Desired control and robot's level of autonomy

The first live study indicated that the more controlling a person was, the more this person prefers the robot to be autonomous. However, as the second live study did not find such results for any of the tasks performed by the robot. Having a few participants ($N = 25$) and a specific type of population in the first experiment, may have bias the results of the first study which would explain such results. More investigations need to be done to understand such a result.

6.2.3 RQ3. Task criticality definition

The research conducted on how to define criticality updated Yanco and Drury's definition of criticality (Yanco & Drury 2002). Since it was a difficult concept to grasp, a list of statement was provided for the participant to rate. As result, for this PhD, task criticality was defined as "**the importance of a task being carried out safely, correctly and with attention to detail**".

6.2.4 RQ4. Type of criteria considered to rate the criticality of a task

The results of the second questionnaire study (Chapter 4) confirmed that dependability and reliability mentioned in previous research (De Santis et al. 2008), are criteria used to rate criticality. The third questionnaire study emphasised that safety was the main criteria considered when rating the criticality of a task.

6.2.5 RQ5. Task criticality and robot's level of autonomy

6.2.5.1 Physical tasks

Chapter 3 demonstrated that for a low critical physical task: cleaning, people preferred the robot to be fully autonomous. However, this finding was not fully supported by the results of Chapter 5. Chapter 5 results show that for a low critical physical task (dancing), people preferred the robot to be fully autonomous. There are several reasons why this is such a difference. In the first study the robot was performing only one task, cleaning, while in the second study, the robot was performing 4 different tasks. Although Chapter 4 questionnaire studies show that cleaning is considered a low critical task, since in the first study, the main purpose displayed by the scenario was to clean the bathroom, participants may have considered then cleaning as a high critical task. This would explain better the results of the first study compared to the second live study. Indeed, participants preferred the robot to be autonomous for a high critical physical task as they mentioned they felt the task was more easily executed this way. Participants that preferred the full autonomous condition in the first live study also mentioned they felt that it was easier when the robot was executing the task this way.

6.2.5.2 Cognitive tasks

One of the most interesting finding of this thesis is that people preferred high critical cognitive tasks to be on a semi-autonomous mode. Chapter 5 results describe that participants prefer to supervise the robot when choosing their doctor appointment as they get to specifically choose the time slot of the appointment. Many mentioned that the fully autonomous mode infantilised them which proves what Whitby (2008) and Lucidi & Nardi (2018) suggested. Participants prefer to be in control of the robot also for a low critical task such as asking the robot to give instructions into how to build a Lego character. Some participants mentioned they could easily relate to this task as they often use online tutorials, and as such, they need to be able to control the speed at which the task is performed.

6.2.6 RQ6. Definition of a cognitive task and a physical task for a robot

The third questionnaire study asked participants to define a cognitive task and a physical task for a domestic robot companion. As a result, a physical task was defined as "**any task that requires body movement or motion processes, which may be qualified as a laborious task**". A cognitive task was defined as "**any task that requires mental activities or thinking processes, which may involve some decision-making**".

6.2.7 RQ7. Type of task and robot's level of autonomy

The second live study proves that there is an association between the type of task (cognitive or physical) and how participants preference of level of autonomy. Combining this result with the other results of this live experiment, it can be said that participants prefer the robot to be autonomous for physical tasks compared to cognitive tasks.

6.2.8 RQ8. Technology savviness and robot's level of autonomy

The first live study showed no correlation between participants' familiarity with technology and their preferred level of autonomy of the robot. However, the first study did not run an extensive questionnaire on technology. While the second live study which was more detailed, showed that people's frequency of usage of everyday technology has an impact on how autonomous they want their robot to be. It was found that the more time people spend on their everyday technology, the more autonomous they want the robot to be.

6.2.9 RQ9. Robot anxiety and perception of control

The first live study did not show direct correlations between anxiety towards robots and perception of control of the robot. However, it was found that the more controlling participants were, the more anxious about robots they were as well. And it was also found that the more anxious about robots participants were, the more they wanted their cleaning robot to be operated by Sunflower, therefore, the more autonomous they wanted the cleaning robot to be. The results found were small and since people are getting more used to technology nowadays than in the past, the results of the frequency of usage of technology of the second live study proves it, it was decided that it was not relevant to focus on this research question for the second live study.

6.2.10 Publications

As a result, Chapter 3 describing the exploratory study of Sense of control and Robot Anxiety in HRI resulted in a publication as a conference paper in RO-MAN 2016 (Chanseau et al. 2016). The results of the second questionnaire study were published as an extended abstract at UKRAS 2017 (Chanseau, Dautenhahn, Walters, Lakatos, Koay & Salem 2018). The results of the third questionnaire study described in Chapter 4 were published in a conference paper at RO-MAN 2018 (Chanseau, Dautenhahn, Walters, Koay, Lakatos & Salem 2018). The results of the live experiment described in Chapter 5 were submitted as a journal paper.

6.3 Limitations of this research

The research presented in this PhD had several limitations that were addressed in 3.5, 4.10 and 5.5. To summarise, the findings of the first live study were not fully supported by the second live study. It is unclear whether this is because of the design of the study (the first live experiment had one task and two robots, while the second experiment had 4 tasks and one robot) or whether it is because of the number of participants (25 participants for the first live study and 50 for the second one). One of the main limitation is that Sunflower was set up as a Wizard of Oz for the second live study, which may have influenced the results. It would be good to conduct a similar type of study with a fully automated robot to test people's reactions. One of the main reasons of these limitations is the nature of those HRI studies. The hardware and the experimental environment are limitations that the experimenter has to deal with. The Sunflower robot has no arms that can grip and carry objects which limits the type of tasks that can be implemented. Also, the selection of the type of tasks are limited by the nature of a study. For ethical reasons, participants cannot be put in a distress situation where there could be negative real life consequences. Therefore, the high critical tasks are not extremely critical such as having the robot helping to put out a fire or helping to do CPR. In those extreme scenarios, participants may then have reacted in a very different way, having a complete different mindset towards the robot.

6.4 Future work

To conclude, all the research questions were answered, however, some still need to be pursued in the future to understand the influence of desired control on the preferred level of autonomy. According to the latest research (Chapter 5), it seems that this personality trait has little to do with what people prefer, and that the preference of the robot's level of autonomy highly depends on the type of tasks and the criticality of the tasks the robot is performing. This would need to be investigated further with this time a live study focussing on personality traits that the participant have and the robot may displayed according to the participant. It would be a good way to explore further if anxiety towards robots can be increased depending on the criticality of the task the robot has to do.

One of the other studies that need to be further explored is the influence of the robot's appearance. The questionnaire study presented in Chapter 4 suggested there is little effect into how participants perceive the criticality of the task the robot may perform. However, It is important to verify this with a live experiment with different type of robots performing the same task. Participants may change their perception of the criticality of a task depending not only on the personality of the robot, as suggested above, but also on its appearance. There are lot of factors that need to be taken into consideration when appearance is studied. The shape of the robot may make a difference, the size of the robot, the zoomorphism or the anthropomorphism or even the colour of the robot. Participants may have been influenced by the appearance of the robot regarding the infantilisation effect. If the robot does not look like an authoritarian figure, participants may feel that the robot should not give them advices on personal problems.

Ideally, we would need to understand why there was an infantilisation effect only for one of the task of the last live study conducted. This is a crucial point to be able to go forward with more automated systems. It could be that the robot did not know enough about the participants to please them. A live experiment should be conducted where this time the robot knows more about the participant's everyday life habits, what he/she likes, what he/she usually does in the morning for breakfast for example and having a robot helping to get ready in the morning. Some participants in the last study mentioned they dislike the robot booking appointment for them because they would not be able to change their mind easily, and the robot may pick something which is not convenient for them, such as an early appointment on their only day off. Therefore, if the robot can collect enough relevant data regarding personal matters of the user, the effect may disappear. It has to be pointed out that for a physical task such as carrying biscuits, participants did not think of the robot's help as parenting. They felt very comfortable. It could be that nowadays we are more used to having technology helping us for physical tasks. For example washing clothes. People rarely hand wash their clothes regularly when they can avoid it. However, in the case of a washing machine, people can set their chosen programme, while in the case of the robot, they may not always have this option. An investigation would be done to see if a "smart" washing machine would be preferred by the user instead of one that has to be pre-set. It is difficult to understand why people felt infantilised. It could simply be that they do not trust the technology and think that it is not reliable enough. Nowadays the majority of people use a satellite navigator to drive to a place they have never been before instead of using a paper map.

Perception of control is closely linked to trust (Möllering 2005). As such, it could be worth investigating how much control people are ready to give up when they trust the robot, and vice-versa how much control people want to keep when they do not trust the robot. It would also be a good way to see if people favour efficiency over control. Some tasks may be done more quickly if performed by the robot without micro-management. But on the other hand, the user may not get the exact result that was hoped for.

Finally, another aspect that would need to be further investigated is how perception of control can be measured in an HRI experiment. The studies presented in this thesis based the measurement of perception of control on Pacherie's theoretical work (Pacherie 2007). They are other alternatives that could have been used to measure perception of control. Such as looking more at the neurological pattern that users have. Maybe the usage of physiological sensors could have offered another view on this research.

To end, we can say there is currently a danger into building a system that people do not want to use, and therefore much more research is needed to build robots that are comfortable for people to make decisions on personal matters. This would ensure that people get to use a system they expect to have.

Appendix A

Ethics approvals

A.1 First live study: sense of control and robot anxiety

A.2 Second live study: perception of control and task criticality

University of Hertfordshire UH

UNIVERSITY OF HERTFORDSHIRE
SCIENCE & TECHNOLOGY

ETHICS APPROVAL NOTIFICATION

TO	Adeline Chanseau et al
CC	Prof. Kerstin Dautenhahn
FROM	Dr Simon Trainis, Science and Technology ECDA Chairman
DATE	23/07/15

Protocol number: COM/PG/UH/00102

Title of study: "Effects of 2 robot helpers on participants views towards robots in human robot interaction"

Your application for ethics approval has been accepted and approved by the ECDA for your school.

This approval is valid:

From: 01/09/15

To: 31/08/16

Please note:

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1. Should you amend any aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit form EC2. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

A.3 Questionnaire studies

A.3.1 Pilot study

University of Hertfordshire UH

HEALTH SCIENCE ENGINEERING & TECHNOLOGY ECDA

ETHICS APPROVAL NOTIFICATION

TO	Adeline Chanseau
CC	Prof Kerstin Dautenhahn
FROM	Dr Simon Trainis, Health, Science, Engineering & Technology ECDA Chair
DATE	16/02/2018

Protocol number: **COM/PGR/UH/03225**

Title of study: How can home robot companions help people?

Your application for ethics approval has been accepted and approved by the ECDA for your School and includes work undertaken for this study by the named additional workers below:

This approval is valid:

From: 16/02/2018

To: 01/02/2019

Additional workers: no additional workers named

Please note:

If your research involves invasive procedures you are required to complete and submit an EC7 Protocol Monitoring Form, and your completed consent paperwork to this ECDA once your study is complete. You are also required to complete and submit an EC7 Protocol Monitoring Form if you are a member of staff. This form is available via the Ethics Approval StudyNet Site via the 'Application Forms' page http://www.studynet1.herts.ac.uk/ptl/common/ethics.nsf/Teaching+Documents?Openview&count=9999&restricttocategory=Application+Forms

Any necessary permissions for the use of premises/location and accessing participants for your study must be obtained in writing prior to any data collection commencing. Failure to obtain adequate permissions may be considered a breach of this protocol.

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1A. Should you amend any aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval (if you are a student) and must complete and submit form EC2. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1A may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

A.3.2 Second pilot study

UNIVERSITY OF HERTFORDSHIRE
SCIENCE & TECHNOLOGY

ETHICS APPROVAL NOTIFICATION

TO	Adeline Chanseau et al >
CC	Prof. Kerstin Dautenhahn
FROM	Dr Simon Trainis, Science and Technology ECDA Chairman
DATE	02/08/16

Protocol number: **COM/PGR/UH/02065**

Title of study: "Robot companion and task criticality"

Your application for ethics approval has been accepted and approved by the ECDA for your School.

This approval is valid:

From: 01/08/16

To: 31/08/17

Please note:

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1. Should you amend any aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit form EC2. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

A.3.3 Questionnaire study on physical and cognitive tasks

University of Hertfordshire UH

SCIENCE AND TECHNOLOGY ECDA

ETHICS APPROVAL NOTIFICATION

TO	Adeline Chanseau et al
CC	Prof Kerstin Dautenhahn
FROM	Dr Simon Trainis, Science and Technology ECDA Chairman
DATE	21/12/2016

Protocol number: aCOM/PGR/UH/02065(1)

Title of study: Robot companion and task criticality

Your application to modify the existing protocol as detailed below has been accepted and approved by the ECDA for your School.

Modification:

- Amendments to the questionnaire to measure how people would rate the criticality of tasks the robots can perform;
- Recruitment of between 30 and 120 more participants for the study.

This approval is valid:

From: 21/12/2016

To: 31/08/2017

Please note:

Any conditions relating to the original protocol approval remain and must be complied with.

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1 or as detailed in the EC2 request. Should you amend any further aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit a further EC2 request. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

University of Hertfordshire UH

HEALTH SCIENCE ENGINEERING & TECHNOLOGY ECDA

ETHICS APPROVAL NOTIFICATION

TO: Adeline Chanseau

CC: Professor Dr Kerstin Dautenhahn

FROM: Dr Simon Trainis, Health, Science, Engineering & Technology ECDA Chairman

DATE: 17/10/17

Protocol number: COM/PGR/UH/02972

Title of study: Physical and Cognitive tasks for robot companions

Your application for ethics approval has been accepted and approved by the ECDA for your School and includes work undertaken for this study by the named additional workers below:

This approval is valid:

From: 17/10/17

To: 15/08/18

Additional workers: no additional workers named

Please note:

If your research involves invasive procedures you are required to complete and submit an EC7 Protocol Monitoring Form, and your completed consent paperwork to this ECDA once your study is complete. You are also required to complete and submit an EC7 Protocol Monitoring Form if you are a member of staff.

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1A. Should you amend any aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval (if you are a student) and must complete and submit form EC2. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1A may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

Appendix B

Information sheet and consent forms

B.1 Example of an information sheet provided for the second live study

UNIVERSITY OF HERTFORDSHIRE

ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS ('ETHICS COMMITTEE')

FORM EC6: PARTICIPANT INFORMATION SHEET

1 **Title of study**

How can home robot companions help people ?

2 **Introduction**

You are being invited to take part in a study. Before you decide whether to do so, it is important that you understand the study that is being undertaken and what your involvement will include. Please take the time to read the following information carefully and discuss it with others if you wish. Do not hesitate to ask us anything that is not clear or for any further information you would like to help you make your decision. Please do take your time to decide whether or not you wish to take part. The University's regulations governing the conduct of studies involving human participants can be accessed via this link:

http://sitem.herts.ac.uk/secreg/upr/RE01.htm

Thank you for reading this.

3 **What is the purpose of this study?**

The purpose of this study is to help us understand what type of home robot companions people would want to have and how they would react if they had one.

4 **Do I have to take part?**

It is completely up to you whether or not you decide to take part in this study. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. Agreeing to join the study does not mean that you have to complete it. You are free to withdraw at any stage without giving a reason. A decision to withdraw at any time, or a decision not to take part at all, will not affect any treatment/care that you may receive (should this be relevant).

5 **Are there any age or other restrictions that may prevent me from participating?**

You need to be over 18 to participate and have a good understanding of English.

6 **How long will my part in the study take?**

If you decide to take part in this study, you will be involved in it for *1 hour.*

7 **What will happen to me if I take part?**

Form EC6, 1 November 2017 Page 1 of 3

The first thing to happen will be *visiting the Robot House and be given a consent form.*

8 **What are the possible disadvantages, risks or side effects of taking part?**

None

9 **What are the possible benefits of taking part?**

If you take part in this study, you will get to interact with a home robot companion and take a picture with it at the end of the experiment. You will also help the scientific community which will benefit greatly from your participation in the experiment.

10 **How will my taking part in this study be kept confidential?**

You are given an ID number that will be used through the experiment. Your name and contact details will not be shared and communicated with third parties. Only people from the lab will have access to it.

11 **Audio-visual material**

If you are taking part of this study, you will be recorded throughout the entire experiment. There will be some audio and video recordings. The material will only be used for academic purposes and the data will be kept confidential.

12 **What will happen to the data collected within this study?**

Data collected for this study will be kept securely in a locked cupboard, in the lab which has restricted access. The consent form will be kept in a separate drawer to ensure the anonymisation during the data analysis. Any digital data will be stored in an encrypted hard drive once the study is over and the hard drive will be kept in the locked cupboard of the lab. Only researchers related to the study will have access to the data.

12.1 The data collected will be stored electronically, in a password-protected environment, for the duration of the PhD.

12.2 The data will be anonymised prior to storage.

12.4 The data may be transmitted/displayed for academic presentations. You can choose for your data to remain confidential if you do not wish for it to happen.

13 **Will the data be required for use in further studies?**

The data may be used for comparisons with future related studies.

13.1 You are consenting to the re-use or further analysis of the data collected in a future ethically-approved study; the data to be re-used will be anonymised and will only be used in studies undertaken within the University of Hertfordshire;

The data collected will be stored electronically, in a password-protected environment, for the duration of the future study, if such occurs.

14 **Who has reviewed this study?**

This study has been reviewed by:

The University of Hertfordshire Health, Science, Engineering and Technology Ethics Committee with Delegated Authority

The UH protocol number is COM/PGR/UH/03225

15 **Factors that might put others at risk**

Please note that if, during the study, any medical conditions or non-medical circumstances such as unlawful activity become apparent that might or had put others at risk, the University may refer the matter to the appropriate authorities.

16 **Who can I contact if I have any questions?**

If you would like further information or would like to discuss any details personally, please get in touch with me, in writing, by phone (Extension number 77593) or by email: *a.chanseau@herts.ac.uk*

Although we hope it is not the case, if you have any complaints or concerns about any aspect of the way you have been approached or treated during the course of this study, please write to the University's Secretary and Registrar at the following address:

Secretary and Registrar
University of Hertfordshire
College Lane
Hatfield
Herts
AL10 9AB

Thank you very much for reading this information and giving consideration to taking part in this study.

B.2 First live study: sense of control and robot anxiety

UNIVERSITY OF HERTFORDSHIRE
ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS
('ETHICS COMMITTEE')

FORM EC3: CONSENT FORM
Protocol number: COM/PG/UH/00102

Investigating Human-Robot Interaction with domestic Robots Companion

Thank you for agreeing to take part in this study. Your participation will greatly help us understand better human robot interaction which will eventually lead to better designed robots.

I, the undersigned *[please give your name here, in BLOCK CAPITALS]*

………

of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as a postal or email address]*

………

hereby freely agree to take part in the study entitled *[insert name of study here]*

………

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, and any plans for follow-up studies that might involve further approaches to participants. I have been given details of my involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent to participate in it.

2 I have been assured that I may withdraw from the study at any time without disadvantage or having to give a reason.

3 In giving my consent to participate in this study, I understand that voice, video or photo-recording will take place.

4 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

5 I understand that my identity will not be revealed in any publications that may come out of this study.

6 I allow the images/video footage to be used by the research team for possible inclusion in academic publications or showing at academic meetings [Please cross out if not applicable].

7 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of participant………………………………………………Date…………………………

Signature of (principal) investigator………………………………Date…………………………

Name of (principal) investigator *[in BLOCK CAPITALS please]*

………

Form EC3 – 6 July 2015

B.3 Second live study: perception of control and task criticality

UNIVERSITY OF HERTFORDSHIRE
ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS
('ETHICS COMMITTEE')

FORM EC3
CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

I, the undersigned *[please give your name here, in BLOCK CAPITALS]*

....

of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as a postal or email address]*

....

....

hereby freely agree to take part in the study entitled *How home can robot companions help people ?*

(UH Protocol number **COM/PGR/UH/03225**)

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, how the information collected will be stored and for how long, and any plans for follow-up studies that might involve further approaches to participants. I have also been informed of how my personal information on this form will be stored and for how long. I have been given details of my involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent to participate in it.

2 I have been assured that I may withdraw from the study at any time without disadvantage or having to give a reason.

3 I understand the experiment will be video recorded and my data will be used for scientific data analysis.

4 Tick the following boxes to express your consent on:
4.a Usage of your video recordings for a semi public (show at scientific conferences) ☐YES ☐NO
4.b Usage of your video recordings for public use (TV, media youtube etc) ☐YES ☐NO

4.c Please sign here if you are happy for us to use your data as mentioned above: ....

5 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

6 I understand that if there is any revelation of unlawful activity or any indication of non-medical circumstances that would or has put others at risk, the University may refer the matter to the appropriate authorities.

7 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of participant..Date..............................

Signature of (principal)
investigator..Date..............................

Name of (principal) investigator *ADELINE CHANSEAU*

B.4 Questionnaire studies

UNIVERSITY OF HERTFORDSHIRE
ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS
('ETHICS COMMITTEE')

FORM EC3
CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

I, the undersigned *[please give your name here, in BLOCK CAPITALS]*

………

of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as an email address]*

………

hereby freely agree to take part in the study entitled ***Robot companions and task criticality***

(UH Protocol number COM/PGR/UH/02065)

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, how the information collected will be stored and for how long, and any plans for follow-up studies that might involve further approaches to participants. I have also been informed of how my personal information on this form will be stored and for how long. I have been given details of my involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent to participate in it.

2 I have been assured that I may withdraw from the study at any time without disadvantage or having to give a reason.

3 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

4 I understand that my participation in this study may reveal findings that could indicate that I might require medical advice. In that event, I will be informed and advised to consult my GP. If, during the study, evidence comes to light that I may have a pre-existing medical condition that may put others at risk, I understand that the University will refer me to the appropriate authorities and that I will not be allowed to take any further part in the study.

5 I understand that if there is any revelation of unlawful activity or any indication of non-medical circumstances that would or has put others at risk, the University may refer the matter to the appropriate authorities.

6 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of participant……………………………………………Date…………………………

Signature of (principal) investigator………………………………………………………

Date…………………………

Name of (principal) investigator *ADELINE CHANSEAU*

Form EC3 – 28 July 2016

Appendix C

Questionnaires studies on task criticality

C.1 Pilot study on task criticality

Robot companion and task criticality questionnaire

This is a short questionnaire that will help me evaluate how critical people rate certain tasks a robot can execute for a future experiment.

About you

1. **Gender:** □ Female □ Male
2. **Age:** ________
3. **Occupation**: ______________________________
4. **Do you have a pet?**: □ yes □ no
5. **On a scale of 1 to 5, how familiar are you with robots?**
   not familiar at all □—□—□—□—□ very familiar
   1— 2— 3— 4— 5

How would you rate the criticality of the following cognitive tasks the robot can do?

There is no right or wrong answer. Please tick the answer you find the most appropriate.

6. **The robot is looking up the weather forecast.**
   very low critical task □—□—□—□—□ very high critical task
   1— 2— 3— 4— 5
7. **The robot is ordering food for your pet.**
   very low critical task □—□—□—□—□ very high critical task
   1— 2— 3— 4— 5
8. **The robot is booking a GP appointment for you.**
   very low critical task □—□—□—□—□ very high critical task
   1— 2— 3— 4— 5
9. **The robot plays some music.**
   very low critical task □—□—□—□—□ very high critical task
   1— 2— 3— 4— 5
10. **The robot is looking up prices of ingredients for a meal you like to cook.**
    very low critical task □—□—□—□—□ very high critical task
    1— 2— 3— 4— 5
11. **The robot is booking a taxi for you to be on time at the airport to catch your early flight tomorrow morning.**
    very low critical task □—□—□—□—□ very high critical task
    1— 2— 3— 4— 5
12. **The robot is monitoring your pet's sleeping habit**
    very low critical task □—□—□—□—□ very high critical task
    1— 2— 3— 4— 5
13. **The robot is choosing the type of milk that needs to be ordered.**
    very low critical task □—□—□—□—□ very high critical task

1— 2— 3— 4— 5

14. **The robot is monitoring your turkey which is cooking in the oven.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

15. **You will go abroad for vacations soon. The robot is looking for hotels for your trip for you to book.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

How would you rate the criticality of the following physical tasks the robot can do?

Remember there is no right or wrong answer, just tick the box you find the most appropriate.

16. **The robot provides a head massage**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

17. **The robot is cleaning the floor.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

18. **The robot is trying to find your lost pair of glasses.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

19. **The robot is transporting a basket full of light weight balls.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

20. **You have just noticed there are a lot of bread crust on the sofa. Your relative is about to arrive and usually sits on the sofa. You robot is cleaning the sofa before the pressing arrival of your relative.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

21. **The robot is watering your plants.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

22. **Your hamster disappeared. Your robot is looking for your pet.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

23. **The robot is making your bed in the morning while you have breakfast in the living room.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

24. **It is the morning and you need to go to work quickly, however you cannot find your car keys. The robot is looking for your car keys.**
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

25. The robot is ironing your clothes.
very low critical task □—□—□—□—□ very high critical task
1— 2— 3— 4— 5

Comments

26. What type of tasks would you consider highly critical which do not involve a life and death situation for humans?

____
____
____

27. What type of tasks would you consider less critical ?

____
____
____

C.2 Second pilot study on task criticality

UNIVERSITY OF HERTFORDSHIRE
ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS
('ETHICS COMMITTEE')

FORM EC3
CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

I, the undersigned *[please give your name here*, *in BLOCK CAPITALS]*

……
of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as an email address]*

…..………
hereby freely agree to take part in the study entitled ***Robot companions and task criticality***

(UH Protocol number COM/PGR/UH/02065)

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, how the information collected will be stored and for how long, and any plans for follow-up studies that might involve further approaches to participants. I have also been informed of how my personal information on this form will be stored and for how long. I have been given details of my involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent to participate in it.

2 I have been assured that I may withdraw from the study at any time without disadvantage or having to give a reason.

3 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

4 I understand that my participation in this study may reveal findings that could indicate that I might require medical advice. In that event, I will be informed and advised to consult my GP. If, during the study, evidence comes to light that I may have a pre-existing medical condition that may put others at risk, I understand that the University will refer me to the appropriate authorities and that I will not be allowed to take any further part in the study.

5 I understand that if there is any revelation of unlawful activity or any indication of non-medical circumstances that would or has put others at risk, the University may refer the matter to the appropriate authorities.

6 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of participant……………………………………..…Date…………………………

Signature of (principal) investigator……………………………………………………

Date…………………………

Name of (principal) investigator *ADELINE CHANSEAU*

Form EC3 – 28 July 2016

Domestic robot companion questionnaire

This is a questionnaire that will help me to design my next experiment on robot companions.

About you

1. Gender: Female Male

2. Age: ___________

3. Occupation: ____

4. Tick the box corresponding to the category of your job

Managerial Self-employed

Non-managerial Non-applicable

5. Do you have a pet ?: yes no

6. Tick the box corresponding to technology you use regularly. You can tick more than one box.

Smartphone

Tablet

Computer

Smartwatch

Smart appliances (smart washing machine, smart oven etc...)

None mentioned

Other: ____

7. On a scale of 1 to 5, how familiar are you with interacting with robots?

not familiar at all very familiar

1 2 3 4 5

8. On a scale of 1 to 5, how familiar are you with programming robots?

not familiar at all very familiar

1 2 3 4 5

Tasks your robots can do

Imagine now that you own these two robots below, Sunflower and Roomba, as home robot companions.

Figure 1: Home robot companions: on the left Sunflower and on the right Roomba.

Sunflower can move around, has a tablet interface and a tray. Roomba can move around the house and clean the floor.

9. What high critical tasks would you like to see your two robots performing?
Criticality measures the importance of getting the task done correctly in terms of its negative effects should problems occur.

____

____

____

10. What low critical tasks would you like to see your two robots performing?
Criticality measures the importance of getting the task done correctly in terms of its negative effects should problems occur.

____

____

____

Ranking tasks

11. Here is a list of 12 tasks that Sunflower and/or Roomba can do. Please rank them depending on the task criticality. Rank number 1 will then be considered the most critical task and rank number 12, the least critical task.
Criticality measures the importance of getting the task done correctly in terms of its negative effects should problems occur.

A. There are some confetti on your living room floor. The robot is cleaning the floor.
B. You are sitting on the sofa, relaxed. The robot is performing a dance for entertainment.
C. You need to prepare a drink for your young nephew. The robot is reading the instructions of the recipe sent by the mother.
D. You want to carry some fragile cristal champagne flute to the living room. The robot is transporting the glasses you cannot carry.
E. You are home and want to be entertained. The robot is telling you a joke.
F. You have lost your car keys and need to pick up your friend in an hour. The robot is looking for your car keys.
G. You have just remembered that you need to see the doctor this week for a blood test. The robot is booking the appointment for you.
H. There is some smoke in the kitchen. The robot is calling the fire service.
I. Your hamster pet escaped its cage and got lost in the house. The robot is looking for the pet.
J. You are bored. The robot reads some poems to please you.
K. You need to send flowers to your relative for a special occasion. The robot is ordering the flowers.
L. There is a mess in the living room and your nephew left his golf balls everywhere. The robot is moving the ball to its normal location.

Ranks:

1.	7.
2.	8.
3.	9.
4.	10.
5.	11.
6.	12.

C.3 Questionnaire study on physical and cognitive tasks

C.3.1 Questionnaire with Pepper

UH protocol number: COM/PGR/UH/02972

Domestic robot companion questionnaire

This questionnaire might to help us understand what your expectations of companion robots are and how you picture yourself having one.

About you

1. Gender: ☐ Male ☐ Female ☐ Rather not say
2. Age: ....
3. Occupation: ....
4. Domain of occupation(e.g.healthcare, retail, science...): ....
5. Type of occupation(e.g.manual, office job, physical...): ....

Usage of technology

6. Tick the box corresponding to technology you use regularly. You can tick more than one box.

	Hourly	Daily	Weekly	Monthly	Yearly
Smartphone	☐	☐	☐	☐	☐
Tablet	☐	☐	☐	☐	☐
Computer	☐	☐	☐	☐	☐
Smartwatch	☐	☐	☐	☐	☐
Smart appliances (smart washing machine, smart oven etc...)	☐	☐	☐	☐	☐

☐ None mentioned
☐ Other: ....

7. On a scale of 1 to 5, how familiar are you with programming robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

	Always	Often	Once in a while	Rarely	Never
8. How often do you programme robots?	☐	☐	☐	☐	☐

9. On a scale of 1 to 5, how familiar are you with interacting with robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

	Always	Often	Once in a while	Rarely	Never
10. How often do you interact with robots?	☐	☐	☐	☐	☐

Having imaginary robots

Imagine that you now own this robot, Pepper. It is now your robot companion.

Mobile home robot companion: Pepper

Pepper can move around and produce fluid gestures and body movements.

11. On a scale of 1 to 7, how would you rate the robot's appearance?

	1	2	3	4	5	6	7	
Very machine-like	☐	☐	☐	☐	☐	☐	☐	Very human-like

Other: ....

12. Have you interacted with this robot before?
Pepper: ☐ Yes ☐ No

13. Give the definition of a **physical task** and please provide examples for the robot.
Definition: ....
....
Pepper: ....
....

14. Give the definition of a **cognitive task** and please provide examples for the robot.
Definition: ....
....
Pepper: ....
....

Evaluating tasks

Here is a list of imaginary tasks your robot may do. Please indicate how you perceive the task, in terms of type (physical and/or cognitive or other) and criticality (low, high or neither) by ticking the box that matches best your preference.

A. There is some confetti on your living room floor. The robot is vacuuming confetti off the floor.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

B. You have just remembered that you need to see the doctor this week for a blood test. The robot is helping you by checking your availability on your diary and booking a suitable appointment with the doctor via the Internet.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

C. You are sitting on the sofa, relaxing. You want to see a dance performance. The robot is performing a dance to entertain you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

D. You need to prepare a drink for your sister's six-month-old baby. The robot is reading to you the instructions of the recipe sent by the mother.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

E. You have lost your car keys and need to drop off your friend at the train station immediately. The robot is looking for your car keys by moving around the apartment and scanning the area.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

F. You want to transport some fragile crystal champagne flutes to the living room. The robot is transporting the glasses you cannot carry.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

G. Your hamster pet escaped from its cage and got lost in the house. The robot is helping you looking for the pet by moving around the house, and scanning different rooms.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

H. Your interview is upcoming. The robot is reminding you of the name of the company and the person you will meet with a short description of their profiles the day before the interview.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

I. There is a mess in the living room, your six-year-old nephew left his toys everywhere. The robot helps you collecting the toys and putting them into a box.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

J. You want to send some flowers to your partner for Valentine's day. The robot is helping you ordering flowers online by showing a selection of your partner's favourite flowers and what time the selected bouquet is guaranteed to be delivered at.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

K. Some visitors have arrived. Your robot approaches them and greets them cheerfully by moving in a circular motion.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

L. Nobody has watered your plants today. The robot is reminding you to water the plants by sending you a notification.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

M. Your paper bin is full. The robot is taking out the trash for you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

N. You have just received a challenge from your best friend, solving a deconstructed 3D wooden puzzle in less than 5 minutes. The robot is offering to help you to solve the puzzle by giving you clues and showing you pictures of the constructed puzzle.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

O. You have some hungry guests in the living room. The robot is helping you carrying appetizers from the kitchen to the living room.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

P. You want to cook a new recipe sent by your friend for dinner. The robot is reading to you the instructions of the recipe.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

Q. Your job interview is later on today. The robot is calculating the travel time and the best route required to get to the interview and will notify you when it is time to leave to arrive on time.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

R. You have set up your alarm clock to wake up in the morning to catch a flight. You give to the robot your alarm clock so the robot can move the ringing alarm clock in the morning to force you out of bed to stop the alarm clock.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

Criticality

Which aspects do you consider important for judging the **criticality** of a task?
- task being carried out correctly (task being carried out wrongly can lead to irreversible effects such as glass being broken)

	1	2	3	4	5	
not important for criticality at all	☐	☐	☐	☐	☐	very important for criticality

- task being carried out in a timely manner (task not being carried out in a timely manner could lead to nuisance such as hoovering being done in the living room while you are watching TV)

	1	2	3	4	5	
not important for criticality at all	☐	☐	☐	☐	☐	very important for criticality

- task being carried out with attention to detail (for example ironing clothes at the right temperature)

	1	2	3	4	5	
not important for criticality at all	☐	☐	☐	☐	☐	very important for criticality

- difficulty of the task (for example cooking which involves chopping vegetables, heating up a pot of water, etc...)

	1	2	3	4	5	
not important for criticality at all	☐	☐	☐	☐	☐	very important for criticality

- importance of the task (for example reminding you to pick up your daughter from school)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- how personal the task is (for example giving fashion advice)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out safely in order not to break/damage objects or injure people (e.g. carrying glasses slowly)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

Order the following type of tasks your house robot companion should do in terms of priority. Priority 5 being the most important thing the robot can do and priority 1 being the least important thing the robot can do.

A. basic household chores (cleaning, taking out trash, vacuuming ...)
B. monitoring the house (checking if the oven is still on, if there is some milk left ...)
C. secretary tasks (acting as a reminder for appointments, setting up appointments, taking messages ...)
D. security tasks (acting as a bodyguard, calling the police when someone tries to break in the house ...)
E. entertainment tasks (displaying a dance to the owner, telling a joke, showing videos...)

C.3.2 Questionnaire with Sawyer

UH protocol number: COM/PGR/UH/02972

Domestic robot companion questionnaire

This questionnaire might help us understand what your expectations of companion robots are and how you picture yourself having one.

About you

1. Gender: ☐ Male ☐ Female ☐ Rather not say
2. Age: ....
3. Occupation: ....
4. Domain of occupation(e.g.healthcare, retail, science...): ....
5. Type of occupation(e.g.manual, office job, physical...): ....

Usage of technology

6. Tick the box corresponding to technology you use regularly. You can tick more than one box.

	Hourly	Daily	Weekly	Monthly	Yearly
Smartphone	☐	☐	☐	☐	☐
Tablet	☐	☐	☐	☐	☐
Computer	☐	☐	☐	☐	☐
Smartwatch	☐	☐	☐	☐	☐
Smart appliances (smart washing machine, smart oven etc...)	☐	☐	☐	☐	☐

☐ None mentioned
☐ Other: ....

7. On a scale of 1 to 5, how familiar are you with programming robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

	Always	Often	Once in a while	Rarely	Never
8. How often do you programme robots?	☐	☐	☐	☐	☐

9. On a scale of 1 to 5, how familiar are you with interacting with robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

	Always	Often	Once in a while	Rarely	Never
10. How often do you interact with robots?	☐	☐	☐	☐	☐

Having imaginary robots

Imagine that you now own this robot, Peter. It is now your robot companion.

Mobile home robot companion: Peter

Peter can move around, has a touch-interface and a gripper.

11. On a scale of 1 to 7, how would you rate the robot's appearance?

	1	2	3	4	5	6	7	
Very machine-like	☐	☐	☐	☐	☐	☐	☐	Very human-like

Other: ....

12. Have you interacted with this robot before?
Peter: ☐ Yes ☐ No

13. Give the definition of a **physical task** and please provide examples for the robot.
Definition: ....
....
Peter: ....
....

14. Give the definition of a **cognitive task** and please provide examples for the robot.
Definition: ....
....
Peter: ....
....

Evaluating tasks

Here is a list of imaginary tasks your robot may do. Please indicate how you perceive the task, in terms of type (physical and/or cognitive or other) and criticality (low, high or neither) by ticking the box that matches best your preference.

A. There is some confetti on your living room floor. The robot is vacuuming confetti off the floor.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

B. You have just remembered that you need to see the doctor this week for a blood test. The robot is helping you by checking your availability on your diary and booking a suitable appointment with the doctor via the Internet.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

C. You are sitting on the sofa, relaxing. You want to see a dance performance. The robot is performing a dance to entertain you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

D. You need to prepare a drink for your sister's six-month-old baby. The robot is reading to you the instructions of the recipe sent by the mother.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

E. You have lost your car keys and need to drop off your friend at the train station immediately. The robot is looking for your car keys by moving around the apartment and scanning the area.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

F. You want to transport some fragile crystal champagne flutes to the living room. The robot is transporting the glasses you cannot carry.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

G. Your hamster pet escaped from its cage and got lost in the house. The robot is helping you looking for the pet by moving around the house, and scanning different rooms.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

H. Your interview is upcoming. The robot is reminding you of the name of the company and the person you will meet with a short description of their profiles the day before the interview.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? . . . .

I. There is a mess in the living room, your six-year-old nephew left his toys everywhere. The robot helps you collecting the toys and putting them into a box.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? . . . .

	High	Low	Neither
Criticality	☐	☐	☐

Why? . . . .

J. You want to send some flowers to your partner for Valentine's day. The robot is helping you ordering flowers online by showing a selection of your partner's favourite flowers and what time the selected bouquet is guaranteed to be delivered at.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? . . . .

	High	Low	Neither
Criticality	☐	☐	☐

Why? . . . .

K. Some visitors have arrived. Your robot approaches them and greets them cheerfully by moving in a circular motion.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? . . . .

	High	Low	Neither
Criticality	☐	☐	☐

Why? . . . .

L. Nobody has watered your plants today. The robot is reminding you to water the plants by sending you a notification.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? . . . .

	High	Low	Neither
Criticality	☐	☐	☐

Why? . . . .

M. Your paper bin is full. The robot is taking out the trash for you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

N. You have just received a challenge from your best friend, solving a deconstructed 3D wooden puzzle in less than 5 minutes. The robot is offering to help you to solve the puzzle by giving you clues and showing you pictures of the constructed puzzle.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

O. You have some hungry guests in the living room. The robot is helping you carrying appetizers from the kitchen to the living room.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

P. You want to cook a new recipe sent by your friend for dinner. The robot is reading to you the instructions of the recipe.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

Q. Your job interview is later on today. The robot is calculating the travel time and the best route required to get to the interview and will notify you when it is time to leave to arrive on time.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

R. You have set up your alarm clock to wake up in the morning to catch a flight. You give to the robot your alarm clock so the robot can move the ringing alarm clock in the morning to force you out of bed to stop the alarm clock.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

Criticality

Which aspects do you consider important for judging the **criticality** of a task?
- task being carried out correctly (task being carried out wrongly can lead to irreversible effects such as glass being broken)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out in a timely manner (task not being carried out in a timely manner could lead to nuisance such as hoovering being done in the living room while you are watching TV)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out with attention to detail (for example ironing clothes at the right temperature)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- difficulty of the task (for example cooking which involves chopping vegetables, heating up a pot of water, etc...)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- importance of the task (for example reminding you to pick up your daughter from school)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- how personal the task is (for example giving fashion advice)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out safely in order not to break/damage objects or injure people (e.g. carrying glasses slowly)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

Order the following type of tasks your house robot companion should do in terms of priority. Priority 5 being the most important thing the robot can do and priority 1 being the least important thing the robot can do.

A. basic household chores (cleaning, taking out trash, vacuuming ...)
B. monitoring the house (checking if the oven is still on, if there is some milk left ...)
C. secretary tasks (acting as a reminder for appointments, setting up appointments, taking messages ...)
D. security tasks (acting as a bodyguard, calling the police when someone tries to break in the house ...)
E. entertainment tasks (displaying a dance to the owner, telling a joke, showing videos...)

C.3.3 Questionnaire with Sunflower

UH protocol number: COM/PGR/UH/02972

Domestic robot companion questionnaire

This questionnaire might help us understand what your expectations of companion robots are and how you picture yourself having one.

About you

1. Gender: ☐ Male ☐ Female ☐ Rather not say
2. Age: ....
3. Occupation: ....
4. Domain of occupation(e.g.healthcare, retail, science...): ....
5. Type of occupation(e.g.manual, office job, physical...): ....

Usage of technology

6. Tick the box corresponding to technology you use regularly. You can tick more than one box.

	Hourly	Daily	Weekly	Monthly	Yearly
Smartphone	☐	☐	☐	☐	☐
Tablet	☐	☐	☐	☐	☐
Computer	☐	☐	☐	☐	☐
Smartwatch	☐	☐	☐	☐	☐
Smart appliances (smart washing machine, smart oven etc...)	☐	☐	☐	☐	☐

☐ None mentioned
☐ Other: ....

7. On a scale of 1 to 5, how familiar are you with programming robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

8. How often do you programme robots?

Always	Often	Once in a while	Rarely	Never
☐	☐	☐	☐	☐

9. On a scale of 1 to 5, how familiar are you with interacting with robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

10. How often do you interact with robots?

Always	Often	Once in a while	Rarely	Never
☐	☐	☐	☐	☐

Having imaginary robots

Imagine that you now own this robot, Sunflower. It is now your robot companion.

Mobile home robot companion: Sunflower

Sunflower can move around, has a touch-interface, grippers and a tray.

11. On a scale of 1 to 7, how would you rate the robot's appearance?

	1	2	3	4	5	6	7	
Very machine-like	☐	☐	☐	☐	☐	☐	☐	Very human-like

Other: . . . .

12. Have you interacted with this robot before?

Sunflower: ☐ Yes ☐ No

13. Give the definition of a **physical task** and please provide examples for the robot.

Definition: . . . .

. . . .

Sunflower: . . . .

. . . .

14. Give the definition of a **cognitive task** and please provide examples for the robot.

Definition: . . . .

. . . .

Sunflower: . . . .

. . . .

Evaluating tasks

Here is a list of imaginary tasks your robot may do. Please indicate how you perceive the task, in terms of type (physical and/or cognitive or other) and criticality (low, high or neither) by ticking the box that matches best your preference.

A. There is some confetti on your living room floor. The robot is vacuuming confetti off the floor.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

B. You have just remembered that you need to see the doctor this week for a blood test. The robot is helping you by checking your availability on your diary and booking a suitable appointment with the doctor via the Internet.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

C. You are sitting on the sofa, relaxing. You want to see a dance performance. The robot is performing a dance to entertain you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

D. You need to prepare a drink for your sister's six-month-old baby. The robot is reading to you the instructions of the recipe sent by the mother.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

E. You have lost your car keys and need to drop off your friend at the train station immediately. The robot is looking for your car keys by moving around the apartment and scanning the area.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

F. You want to transport some fragile crystal champagne flutes to the living room. The robot is transporting the glasses you cannot carry.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

G. Your hamster pet escaped from its cage and got lost in the house. The robot is helping you looking for the pet by moving around the house, and scanning different rooms.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

H. Your interview is upcoming. The robot is reminding you of the name of the company and the person you will meet with a short description of their profiles the day before the interview.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

I. There is a mess in the living room, your six-year-old nephew left his toys everywhere. The robot helps you collecting the toys and putting them into a box.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

J. You want to send some flowers to your partner for Valentine's day. The robot is helping you ordering flowers online by showing a selection of your partner's favourite flowers and what time the selected bouquet is guaranteed to be delivered at.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

K. Some visitors have arrived. Your robot approaches them and greets them cheerfully by moving in a circular motion.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

L. Nobody has watered your plants today. The robot is reminding you to water the plants by sending you a notification.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

M. Your paper bin is full. The robot is taking out the trash for you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

N. You have just received a challenge from your best friend, solving a deconstructed 3D wooden puzzle in less than 5 minutes. The robot is offering to help you to solve the puzzle by giving you clues and showing you pictures of the constructed puzzle.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

O. You have some hungry guests in the living room. The robot is helping you carrying appetizers from the kitchen to the living room.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

P. You want to cook a new recipe sent by your friend for dinner. The robot is reading to you the instructions of the recipe.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

Q. Your job interview is later on today. The robot is calculating the travel time and the best route required to get to the interview and will notify you when it is time to leave to arrive on time.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

R. You have set up your alarm clock to wake up in the morning to catch a flight. You give to the robot your alarm clock so the robot can move the ringing alarm clock in the morning to force you out of bed to stop the alarm clock.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

Criticality

Which aspects do you consider important for judging the **criticality** of a task?
- task being carried out correctly (task being carried out wrongly can lead to irreversible effects such as glass being broken)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out in a timely manner (task not being carried out in a timely manner could lead to nuisance such as hoovering being done in the living room while you are watching TV)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out with attention to detail (for example ironing clothes at the right temperature)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- difficulty of the task (for example cooking which involves chopping vegetables, heating up a pot of water, etc...)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- importance of the task (for example reminding you to pick up your daughter from school)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- how personal the task is (for example giving fashion advice)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out safely in order not to break/damage objects or injure people (e.g. carrying glasses slowly)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

Order the following type of tasks your house robot companion should do in terms of priority. Priority 5 being the most important thing the robot can do and priority 1 being the least important thing the robot can do.

A. basic household chores (cleaning, taking out trash, vacuuming ...)
B. monitoring the house (checking if the oven is still on, if there is some milk left ...)
C. secretary tasks (acting as a reminder for appointments, setting up appointments, taking messages ...)
D. security tasks (acting as a bodyguard, calling the police when someone tries to break in the house ...)
E. entertainment tasks (displaying a dance to the owner, telling a joke, showing videos...)

C.3.4 Questionnaire with Sunflower and Roomba

UH protocol number: COM/PGR/UH/02972

Domestic robot companion questionnaire

This questionnaire might to help us understand what your expectations of companion robots are and how you picture yourself having one.

About you

1. Gender: ☐ Male ☐ Female ☐ Rather not say
2. Age: ....
3. Occupation: ....
4. Domain of occupation(e.g.healthcare, retail, science...): ....
5. Type of occupation(e.g.manual, office job, physical...): ....

Usage of technology

6. Tick the box corresponding to technology you use regularly. You can tick more than one box.

	Hourly	Daily	Weekly	Monthly	Yearly
Smartphone	☐	☐	☐	☐	☐
Tablet	☐	☐	☐	☐	☐
Computer	☐	☐	☐	☐	☐
Smartwatch	☐	☐	☐	☐	☐
Smart appliances (smart washing machine, smart oven etc...)	☐	☐	☐	☐	☐

☐ None mentioned

☐ Other: ....

7. On a scale of 1 to 5, how familiar are you with programming robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

8. How often do you programme robots?

Always	Often	Once in a while	Rarely	Never
☐	☐	☐	☐	☐

9. On a scale of 1 to 5, how familiar are you with interacting with robots?

	1	2	3	4	5	
Not familiar at all	☐	☐	☐	☐	☐	Very familiar

10. How often do you interact with robots?

Always	Often	Once in a while	Rarely	Never
☐	☐	☐	☐	☐

Having imaginary robots

Imagine that you now own these two robots, Sunflower and Roomba. They are now your robots companion.

Mobile home robot companions: on the left Sunflower and on the right Roomba.

Sunflower can move around, has a touch-interface, grippers and a tray. Roomba can move around the house and clean the floor.

11. Have you interacted with these robots before?
Sunflower: ☐ Yes ☐ No
Roomba: ☐ Yes ☐ No

12. Give the definition of a **physical task** and please provide examples for the two robots.
Definition: ....
....
Sunflower: ....
....
Roomba: ....
....

13. Give the definition of a **cognitive task** and please provide examples for the two robots.
Definition: ....
....
Sunflower: ....
....
Roomba: ....
....

Evaluating tasks

Here is a list of imaginary tasks your robot may do. Please indicate how you perceive the task, in terms of type (physical and/or cognitive or other) and criticality (low, high or neither) by ticking the box that matches best your preference.

A. There is some confetti on your living room floor. The robot is vacuuming confetti off the floor.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

B. You have just remembered that you need to see the doctor this week for a blood test. The robot is helping you by checking your availability on your diary and booking a suitable appointment with the doctor via the Internet.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

C. You are sitting on the sofa, relaxing. You want to see a dance performance. The robot is performing a dance to entertain you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

D. You need to prepare a drink for your sister's six-month-old baby. The robot is reading to you the instructions of the recipe sent by the mother.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

E. You have lost your car keys and need to drop off your friend at the train station immediately. The robot is looking for your car keys by moving around the apartment and scanning the area.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

F. You want to transport some fragile crystal champagne flutes to the living room. The robot is transporting the glasses you cannot carry.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

G. Your hamster pet escaped from its cage and got lost in the house. The robot is helping you looking for the pet by moving around the house, and scanning different rooms.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

H. Your interview is upcoming. The robot is reminding you of the name of the company and the person you will meet with a short description of their profiles the day before the interview.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

I. There is a mess in the living room, your six-year-old nephew left his toys everywhere. The robot helps you collecting the toys and putting them into a box.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

J. You want to send some flowers to your partner for Valentine's day. The robot is helping you ordering flowers online by showing a selection of your partner's favourite flowers and what time the selected bouquet is guaranteed to be delivered at.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

K. Some visitors have arrived. Your robot approaches them and greets them cheerfully by moving in a circular motion.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

L. Nobody has watered your plants today. The robot is reminding you to water the plants by sending you a notification.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

M. Your paper bin is full. The robot is taking out the trash for you.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

N. You have just received a challenge from your best friend, solving a deconstructed 3D wooden puzzle in less than 5 minutes. The robot is offering to help you to solve the puzzle by giving you clues and showing you pictures of the constructed puzzle.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

O. You have some hungry guests in the living room. The robot is helping you carrying appetizers from the kitchen to the living room.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

P. You want to cook a new recipe sent by your friend for dinner. The robot is reading to you the instructions of the recipe.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

Q. Your job interview is later on today. The robot is calculating the travel time and the best route required to get to the interview and will notify you when it is time to leave to arrive on time.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? ....

	High	Low	Neither
Criticality	☐	☐	☐

Why? ....

R. You have set up your alarm clock to wake up in the morning to catch a flight. You give to the robot your alarm clock so the robot can move the ringing alarm clock in the morning to force you out of bed to stop the alarm clock.

	Physical	Cognitive	Both	Other, please specify
Type	☐	☐	☐	☐ ....

Why? . . . .

	High	Low	Neither
Criticality	☐	☐	☐

Why? . . . .

Criticality

Which aspects do you consider important for judging the **criticality** of a task?
- task being carried out correctly (task being carried out wrongly can lead to irreversible effects such as glass being broken)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out in a timely manner (task not being carried out in a timely manner could lead to nuisance such as hoovering being done in the living room while you are watching TV)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out with attention to detail (for example ironing clothes at the right temperature)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- difficulty of the task (for example cooking which involves chopping vegetables, heating up a pot of water, etc...)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- importance of the task (for example reminding you to pick up your daughter from school)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- how personal the task is (for example giving fashion advice)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

- task being carried out safely in order not to break/damage objects or injure people (e.g. carrying glasses slowly)

	1	2	3	4	5	
	☐	☐	☐	☐	☐	
not important for criticality at all						very important for criticality

Order the following type of tasks your house robot companion should do in terms of priority. Priority 5 being the most important thing the robot can do and priority 1 being the least important thing the robot can do.

A. basic household chores (cleaning, taking out trash, vacuuming ...)
B. monitoring the house (checking if the oven is still on, if there is some milk left ...)
C. secretary tasks (acting as a reminder for appointments, setting up appointments, taking messages ...)
D. security tasks (acting as a bodyguard, calling the police when someone tries to break in the house ...)
E. entertainment tasks (displaying a dance to the owner, telling a joke, showing videos...)

C.4 Google links to the questionnaires of the questionnaire study on physical and cognitive tasks

C.4.1 Pepper questionnaire

https://docs.google.com/forms/d/e/1FAIpQLScfXFV4VNTuQilv8p3HDqmlkVxjkteeMxq1TxNg
M6WzgXJ1tg/viewform

C.4.2 Sunflower questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSfJs6-xv87mmIhzm4fLTuU2qGpATshdQlgt-Izi
9BvD_ZOaXg/viewform

C.4.3 Sawyer questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSe5BaiGZSNGhFOcRp444mCkWeKJ9y-7ewVX5ujv
Ia09-FgXcw/viewform

C.4.4 Sunflower and Roomba questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSfNMW47Uqdw8IaUwgarvVu8I_JPIP3yaU-I1gwz
6iyUDxurAQ/viewform

C.4.5 URL link to the hard copies version

https://drive.google.com/drive/folders/1oiEeeuSTGuQfSqWZtnf4wij7GfI41s6v?usp=sha
ring

Appendix D

Questionnaires provided for the first live experiment

D.1 Demography

Robot companion study questionnaire

Welcome to the Robot House, this questionnaire will help us know a bit more about you.

*Required

1. **ID number** *

About you

2. **Gender:** *
Mark only one oval.

( ) Female
( ) Male

3. **Age:** *

4. **Occupation:** *

5. **On a scale of 1 to 5, are your familiar with technology?** *
Mark only one oval.

	1	2	3	4	5	
No, not at all	( )	( )	( )	( )	( )	Yes, absolutely

Do you find yourself ... ?

D.2 Personality test

6. **This test will help us know more about you. There is no right or wrong answer. Tick the box you found the most appropriate.** *

Mark only one oval per row.

	disagree strongly	disagree moderately	disagree a little	neither agree nor disagree	agree a little	agree moderately	agree strongly
Extravertes, enthusiastic							
Critical, quarrelsome							
Dependable, self-disciplined							
Anxious, easily upset							
Open to new experiences, complex							
Reserved, quiet							
Sympathetic, warm							
Disorganized, careless							
Calm, emotionally stable							
Conventional, uncreative							

How anxious would you feel?...

D.3 Robot Anxiety Scale

7. **There will now be some statements about robots. Some people feel anxiety towards robots. Tell us how anxious you feel about robots from a scale of 1 to 6.** *

Mark only one oval per row.

	I do not feel anxiety at all	I hardly feel any anxiety	I do not feel much anxiety	I feel a little anxiety	I feel quite anxious	I feel very anxious
Whether the robot might talk about irrelevant things in the middle of a conversation	⬭	⬭	⬭	⬭	⬭	⬭
Whether the robot might not be flexible in following the direction of our conversation	⬭	⬭	⬭	⬭	⬭	⬭
Whether the robot might not understand difficult conversation topics	⬭	⬭	⬭	⬭	⬭	⬭
What kind of movements the robot will make	⬭	⬭	⬭	⬭	⬭	⬭
What the robot is going to do	⬭	⬭	⬭	⬭	⬭	⬭
How strong the robot is	⬭	⬭	⬭	⬭	⬭	⬭
How fast the robot will move	⬭	⬭	⬭	⬭	⬭	⬭
How I should talk to the robot	⬭	⬭	⬭	⬭	⬭	⬭
How I should respond when the robot talks to me	⬭	⬭	⬭	⬭	⬭	⬭
Whether the robot will understand what I am talking about	⬭	⬭	⬭	⬭	⬭	⬭
Whether I will understand what the robot is talking about	⬭	⬭	⬭	⬭	⬭	⬭

How would you react?...

D.4 Desirability Control Scale

8. **There will now be some statements about how much you like to be in control. Tell us how each applies to you on a scale of 1 to 7. Remember there is no right or wrong answer. ***

Mark only one oval per row.

	it does not apply to me at all	it does not usually apply to me	most often, it does not apply	it applies to me about half the time	it applies more often than not	it usually applies to me	it always apply to me
I prefer a job where I have a lot of control over what I do and when I do it.	◯	◯	◯	◯	◯	◯	◯
I enjoy political participation because I want to have as much of a say in government as possible.	◯	◯	◯	◯	◯	◯	◯
I try to avoid situations where someone else tells me what to do.	◯	◯	◯	◯	◯	◯	◯
I would prefer to be a leader than a follower.	◯	◯	◯	◯	◯	◯	◯
I enjoy being able to influence the actions of others.	◯	◯	◯	◯	◯	◯	◯
I am careful to check everything on an automobile before I leave for a long trip.	◯	◯	◯	◯	◯	◯	◯
Others usually know what is best for me.	◯	◯	◯	◯	◯	◯	◯
I enjoy making my own decisions.	◯	◯	◯	◯	◯	◯	◯
I enjoy having control over my own destiny.	◯	◯	◯	◯	◯	◯	◯
I would rather someone else take over the leadership role when I involved in a group project.	◯	◯	◯	◯	◯	◯	◯

9. *

Mark only one oval per row.

	it does not apply to me at all	it does not usually apply to me	most often, it does not apply	it applies to me about half the time	it applies more often than not	it usually applies to me	it always apply to me
I consider myself to be generally more capable of handling situations than others are.							
I rather run my own business and make my own mistakes than listen to someone else orders.							
I like to get a good idea of what a job is all about before I begin.							
When I see a problem, I prefer to do something about it rather than sit by and let it continue.							
When it comes to orders, I would rather give them than receive them.							
I wish I could push many of life daily decisions off on someone else.							
When driving, I try to avoid putting myself in a situation where I could be hurt by another person's mistake.							
I prefer to avoid situations where someone else has to tell me what it is I should be doing.							
There are many situations in which I would prefer only one choice rather than having to make a decision.							

	it does not apply to me at all	it does not usually apply to me	most often, it does not apply	it applies to me about half the time	it applies more often than not	it usually applies to me	it always apply to me
I like to wait and see if someone else is going to solve a problem so that I don have to be bothered with it.							

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D.5 First condition: Roomba is manually controlled

Robot companion study questionnaire

Here is a set of questions that will help us understand how you felt about the experiment.

*Required

1. **ID** *

____

Robot companion or machine?

Here is a multiple choice question, you can tick more than one box.

2. **I consider Sunflower** *

   Tick all that apply.

   - [ ] a machine
   - [ ] a companion
   - [ ] a friend
   - [ ] a butler
   - [ ] an assistant
   - [ ] a pet
   - [ ] Other: _______________________________

3. **I consider Roomba** *

   Tick all that apply.

   - [ ] a machine
   - [ ] a companion
   - [ ] a friend
   - [ ] a butler
   - [ ] an assistant
   - [ ] a pet
   - [ ] Other: _______________________________

4. **I felt I was mainly interacting with** *

   Tick all that apply.

   - [ ] Sunflower
   - [ ] Roomba
   - [ ] Other: _______________________________

5. **On a scale of 1 to 5, how would you evaluate Sunflower's intelligence? ***
Mark only one oval.

	1	2	3	4	5	
Not at all intelligent	◯	◯	◯	◯	◯	Very intelligent

6. **On a scale of 1 to 5, how would you evaluate Roomba's intelligence? ***
Mark only one oval.

	1	2	3	4	5	
Not at all intelligent	◯	◯	◯	◯	◯	Very intelligent

Who was in charge?

There is a multiple choice questionnaire below, you can tick more than one box.

7. **I felt I was in charge of: ***
Tick all that apply.

- [ ] Sunflower
- [ ] Roomba
- [ ] None of them

8. **I felt Sunflower was in charge of: ***
Tick all that apply.

- [ ] Me
- [ ] Roomba
- [ ] Nobody

9. **I felt Roomba was in charge of: ***
Tick all that apply.

- [ ] Me
- [ ] Sunflower
- [ ] Nobody

Please rate the following statement on a scale of 1 to 5.

10. **I felt Sunflower was useless. ***
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

11. **I felt Roomba was useless. ***
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

12. **I felt Sunflower has personality. ***
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

13. **I like the fact that Sunflower was given me instructions. ***
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

14. **I would like to delegate more tasks to Sunflower and Roomba. ***
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

15. **I would like Sunflower to operate Roomba to do the cleaning. ***
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

16. **I would like Roomba to be the main robot companion. ***
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

D.6 Second condition: Roomba is remotely controlled

Robot companion study questionnaire

Here is a set of questions that will help us understand how you felt about the experiment.

*Required

1. **ID** *

____

Robot companion or machine?

Here is a multiple choice question, you can tick more than one box.

2. **I consider Sunflower** *

Tick all that apply.

- [ ] a machine
- [ ] a companion
- [ ] a friend
- [ ] a butler
- [ ] an assistant
- [ ] a pet
- [ ] Other: ______________________________

3. **I consider Roomba** *

Tick all that apply.

- [ ] a machine
- [ ] a companion
- [ ] a friend
- [ ] a butler
- [ ] an assistant
- [ ] a pet
- [ ] Other: ______________________________

4. **I felt I was mainly interacting with** *

Tick all that apply.

- [ ] Sunflower
- [ ] Roomba
- [ ] Other: ______________________________

5. **On a scale of 1 to 5, how would you evaluate Sunflower's intelligence?** *
Mark only one oval.

	1	2	3	4	5	
Not at all intelligent	◯	◯	◯	◯	◯	Very intelligent

6. **On a scale of 1 to 5, how would you evaluate Roomba's intelligence?** *
Mark only one oval.

	1	2	3	4	5	
Not at all intelligent	◯	◯	◯	◯	◯	Very intelligent

Who was in charge?

There is a multiple choice questionnaire below, you can tick more than one box.

7. **I felt I was in charge of:** *
Tick all that apply.

- [ ] Sunflower
- [ ] Roomba
- [ ] None of them

8. **I felt Sunflower was in charge of:** *
Tick all that apply.

- [ ] Me
- [ ] Roomba
- [ ] Nobody

9. **I felt Roomba was in charge of:** *
Tick all that apply.

- [ ] Me
- [ ] Sunflower
- [ ] Nobody

Please rate the following statement on a scale of 1 to 5.

10. **I felt Sunflower was useless.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

11. **I felt Roomba was useless.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

12. **I like the fact that Sunflower acted as a remote control.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

D.7 Third condition: Roomba is automatically controlled

Robot companion study questionnaire

Here is a set of questions that will help us understand how you felt about the experiment.

*Required

1. **ID** *

____

Robot companion or machine?

Here is a multiple choice question, you can tick more than one box.

2. **I consider Sunflower** *

   Tick all that apply.

   - [ ] a machine
   - [ ] a companion
   - [ ] a friend
   - [ ] a butler
   - [ ] an assistant
   - [ ] a pet
   - [ ] Other: _______________

3. **I consider Roomba** *

   Tick all that apply.

   - [ ] a machine
   - [ ] a companion
   - [ ] a friend
   - [ ] a butler
   - [ ] an assistant
   - [ ] a pet
   - [ ] Other: _______________

4. **I felt mainly interacting with** *

   Tick all that apply.

   - [ ] Sunflower
   - [ ] Roomba
   - [ ] Other: _______________

5. **On a scale of 1 to 5, how would you evaluate Sunflower's intelligence?** *
Mark only one oval.

	1	2	3	4	5	
Not at all intelligent	◯	◯	◯	◯	◯	Very intelligent

6. **On a scale of 1 to 5, how would you evaluate Roomba's intelligence?** *
Mark only one oval.

	1	2	3	4	5	
Not at all intelligent	◯	◯	◯	◯	◯	Very intelligent

Who is in charge?

Here is a multiple choice questionnaire, you can tick more than one box.

7. **I felt I was in charge of:** *
Tick all that apply.

- [ ] Sunflower
- [ ] Roomba
- [ ] None of them

8. **I felt Sunflower was in charge of:** *
Tick all that apply.

- [ ] Me
- [ ] Roomba
- [ ] Nobody

Please rate the following statement on a scale of 1 to 5.

9. **I felt Sunflower was useless.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

10. **I felt Roomba was useless.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

11. **I like Sunflower telling me what it is doing.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

12. **I would not mind if Sunflower would not tell me what is happening (e.g. Operating the Roomba without telling you)** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	⬭	⬭	⬭	⬭	⬭	Completely disagree

D.8 Last questionnaire

Robot companion study questionnaire

Here is a set of questions that will help us understand how you felt about the experiment.

*Required

1. **ID** *

____

Scenario preferences...

Here is a multiple choice questionnaire, you can only tick one box, in the following questions.

2. **Which scenario did you prefer?** *
   Mark only one oval.

   ( ) When I was manipulating the Roomba myself
   ( ) When I was told by Sunflower to operate the Roomba remotely
   ( ) When Sunflower operated the Roomba autonomously
   ( ) No preferences between them

3. **How did you feel when Sunflower operated Roomba remotely?**

____
____
____
____
____

Would you like one?

Tell us how true these statements applied to you.

4. **I would like to have a Sunflower.** *
   Mark only one oval.

	1	2	3	4	5	
Completely agree	( )	( )	( )	( )	( )	Completely disagree

5. **I would like to have a Roomba.** *
   Mark only one oval.

	1	2	3	4	5	
Completely agree	( )	( )	( )	( )	( )	Completely disagree

6. **I would like a robot companion that could do everything.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

7. **I prefer having allocated tasks to different robots than having one that does everything.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

8. **I think it would be more expensive to have many robots than one multi-functional one.** *
Mark only one oval.

	1	2	3	4	5	
Completely agree	◯	◯	◯	◯	◯	Completely disagree

How anxious would you feel?...

There will now be some statements about robots. Tell us how anxious you feel about robots from a scale of 1 to 6.

9. **Mark only one oval per row.**

	I do not feel anxiety at all.	I hardly feel any anxiety.	I do not feel much anxiety.	I feel a little anxiety.	I feel much anxiety.	I feel anxiety very strongly.
Whether the robot might talk about irrelevant things in the middle of a conversation	⬭	⬭	⬭	⬭	⬭	⬭
Whether the robot might not be flexible in following the direction of our conversation	⬭	⬭	⬭	⬭	⬭	⬭
Whether the robot might not understand difficult conversation topics	⬭	⬭	⬭	⬭	⬭	⬭
What kind of movements the robot will make	⬭	⬭	⬭	⬭	⬭	⬭
What the robot is going to do	⬭	⬭	⬭	⬭	⬭	⬭
How strong the robot is	⬭	⬭	⬭	⬭	⬭	⬭
How fast the robot will move	⬭	⬭	⬭	⬭	⬭	⬭
How I should talk to the robot	⬭	⬭	⬭	⬭	⬭	⬭
How I should respond when the robot talks to me	⬭	⬭	⬭	⬭	⬭	⬭
Whether the robot will understand what I am talking about	⬭	⬭	⬭	⬭	⬭	⬭
Whether I will understand what the robot is talking about	⬭	⬭	⬭	⬭	⬭	⬭

D.9 Google links to the questionnaires

D.9.1 Questionnaire on demography and robot anxiety

https://docs.google.com/forms/d/e/1FAIpQLSdDpx6D_6SwooalhMcNo5r-UcXaWZONniDxUrXkQafP8N63iw/viewform

D.9.2 Questionnaire provided after Condition 1

https://docs.google.com/forms/d/e/1FAIpQLScmbNEn3dLujfIGGaY71iMWOUAdmsQwN3Gm4OJKHzoR1LDltQ/viewform

D.9.3 Questionnaire provided after Condition 2

https://docs.google.com/forms/d/e/1FAIpQLScg4boOjMN2URXic1J2paz-Sh31IC-wWZiE7lgCEuJinKfZZA/viewform

D.9.4 Questionnaire provided after Condition 3

https://docs.google.com/forms/d/e/1FAIpQLSeQnutWcjN523da6LvjMiCSzy8mP6qD_ZbTVyp-opXGiAdtrA/viewform

D.9.5 Last questionnaire to evaluate the impressions of the experiment

https://docs.google.com/forms/d/e/1FAIpQLSc8UIvRFq6T1aaOienY346881kVFTdJiAAKAD_GVOkJLn8YvQ/viewform

Appendix E

Questionnaires provided for the second live experiment

E.1 Online recruitment form

How home robot companions can help people ?

UH protocol

*Required

Hello, we are planning to run a live study at the Robot House between March and May. If you want to be part of it and experience what a robot companion may be like, please sign in below.

1. **What is your name? ***

2. **Please put your contact details below (email address or phone number). ***

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E.2 Demography

How can home robot companions help people ?

UH protocol number:

*Required

1. **ID number** *

About you

2. **Gender** *

3. **Age** *

4. **If you are currently working what is your occupation, and if you are a student also include what you are studying.** *

Usage of technology

5. **How much time do you spend on the following devices?** *

Mark only one oval per row.

	Do not have one	less than 30 min a day	1- 2 hours a day	2- 3 hours a day	More than 3 hours a day	2- 3 times a week	more than 3 times a week	2- 3 times a month	More than 3 times a month	2-5 times a year
Smartphone										
Computer/laptop										
Tablet										
Smart watch										
Amazon Alexa or Google home										

E.3 Technology usage

6. **Do you use other technology regularly? If yes, please mention what you use.** *

7. **On a scale of 1 to 5, how familiar are you with programming robots?** *
Mark only one oval.

	1	2	3	4	5	
Not familiar at all	⬭	⬭	⬭	⬭	⬭	Very familiar

8. **How much experience in programming robots do you have?** *
Mark only one oval.

	1	2	3	4	5	
No experience at all	⬭	⬭	⬭	⬭	⬭	A lot of experience

9. **On a scale of 1 to 5, how familiar are you with interacting with robots?** *
Mark only one oval.

	1	2	3	4	5	
Not familiar at all	⬭	⬭	⬭	⬭	⬭	Very familiar

10. **How often do you interact with robots?** *
Mark only one oval per row.

	I have never interacted with robots before	A few times before (2-5) on a short occasion	Once a year	More than once a year	A few times (1-3) per month	A few times (1-6) per week	Every day
Select the most appropriate answer	⬭	⬭	⬭	⬭	⬭	⬭	⬭

11. **Have you interacted with the Sunflower robot before?** *
Mark only one oval.

- ⬭ Yes
- ⬭ No

12. **If yes above, in how many experiments with Sunflower have you participated?**

E.4 Personality test

Do you find yourself?...

13. **This question will help us know more about you. There is no right or wrong answer. Tick the box you found the most appropriate.** *

Mark only one oval per row.

	disagree strongly	disagree moderately	disagree a little	neither agree nor disagree	agree a little	agree moderately	agree strongly
Extraverted, enthusiastic							
Critical, quarrelsome							
Dependable, self-disciplined							
Anxious, easily upset							
Open to new experiences, complex							
Reserved, quiet							
Sympathetic, warm							
Disorganized, careless							
Calm, emotionally stable							
Conventional, uncreative							

How would you react?...

E.5 Desirability Control Scale

14. **Tell us to which extent each of the following statements applies to you. Remember there is no right or wrong answer.** *
Mark only one oval per row.

	it does not apply to me at all	it does not usually apply to me	most often, it does not apply	it applies to me about half the time	it applies more often than not	it usually applies to me	it always apply to me
I prefer a job where I have a lot of control over what I do and when I do it.							
I enjoy political participation because I want to have as much of a say in government as possible.							
I try to avoid situations where someone else tells me what to do.							
I would prefer to be a leader than a follower.							
I enjoy being able to influence the actions of others.							
I am careful to check everything on an automobile before I leave for a long trip.							
Others usually know what is best for me.							
I enjoy making my own decisions.							
I enjoy having control over my own destiny.							
I would rather someone else take over the leadership role when I involved in a group project.							

Last page

15. **Tell us to which extent each of the following statements applies to you. Remember there is no right or wrong answer.** *

Mark only one oval per row.

	it does not apply to me at all	it does not usually apply to me	most often, it does not apply	it applies to me about half the time	it applies more often than not	it usually applies to me	it always apply to me
I consider myself to be generally more capable of handling situations than others are.	◯	◯	◯	◯	◯	◯	◯
I rather run my own business and make my own mistakes than listen to someone else orders.	◯	◯	◯	◯	◯	◯	◯
I like to get a good idea of what a job is all about before I begin.	◯	◯	◯	◯	◯	◯	◯
When I see a problem, I prefer to do something about it rather than sit by and let it continue.	◯	◯	◯	◯	◯	◯	◯
When it comes to orders, I would rather give them than receive them.	◯	◯	◯	◯	◯	◯	◯
I wish I could push many of life daily decisions off on someone else.	◯	◯	◯	◯	◯	◯	◯
When driving, I try to avoid putting myself in a situation where I could be hurt by another person's mistake.	◯	◯	◯	◯	◯	◯	◯
I prefer to avoid situations where someone else has to tell me what it is I should be doing.	◯	◯	◯	◯	◯	◯	◯
There are many situations in which I would prefer only one choice rather than having to make a decision.	◯	◯	◯	◯	◯	◯	◯

	it does not apply to me at all	it does not usually apply to me	most often, it does not apply	it applies to me about half the time	it applies more often than not	it usually applies to me	it always apply to me
I like to wait and see if someone else is going to solve a problem so that I don't have to be bothered with it.							

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E.6 Expectations of the robot

How can home robot companions help people ?

*Required

1. **ID number** *

Expectations regarding Sunflower robot

Please rate how important the following capabilities are to you.

2. **The robot is able to navigate autonomously around the house.** *
   Mark only one oval.

	1	2	3	4	5	
Not important at all	◯	◯	◯	◯	◯	Very important

3. **The robot is able to detect when something goes wrong in the kitchen (fridge kept open, oven turned on for too long ...)** *
   Mark only one oval.

	1	2	3	4	5	
Not important at all	◯	◯	◯	◯	◯	Very important

4. **The robot is able to entertain the user (playing music, dancing, doing party tricks...)** *
   Mark only one oval.

	1	2	3	4	5	
Not important at all	◯	◯	◯	◯	◯	Very important

5. **The robot is able to perform secretary tasks (e.g. sending notifications and reminders, booking appointments ...)** *
   Mark only one oval.

	1	2	3	4	5	
Not important at all	◯	◯	◯	◯	◯	Very important

6. **The robot is able to do household chores (e.g. operating smart appliances such as vacuum cleaners, washing machines, ovens ...)** *
Mark only one oval.

	1	2	3	4	5	
Not important at all	◯	◯	◯	◯	◯	Very important

7. **Are there any additional features you would like the robot to have?** *

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E.7 First task: Building a Lego character

How can home robot companions help people ?

*Required

1. **ID number** *

Choice of conditions

2. **Which conditions did you prefer in this scenario?** *

Mark only one oval.

- When Sunflower decided when to show me the next step of the instructions.
- When I chose when Sunflower had to show me the next step of the instructions.
- Other: ____________

3. **Why did you make this choice?** *

4. **How intelligent did you think Sunflower was in your preferred condition?** *

Mark only one oval.

	1	2	3	4	5	
Not intelligent at all						Very intelligent

5. **How much in control of the action (building a Lego character) did you feel?** *

Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt I was fully in control
When Sunflower decided when to show me the next step of the instruction					
When I chose when Sunflower had to show me the next step					

6. **How much in control of the outcome of the action (having a Lego character) did you feel?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower decided when to show me the next step of the instruction	◯	◯	◯	◯	◯
When I chose when Sunflower had to show me the next step	◯	◯	◯	◯	◯

7. **How much in control of the Sunflower robot did you feel during this scenario?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I half felt in control	I felt mostly in control	I felt I was fully in control
When Sunflower decided when to show me the next step of the instruction	◯	◯	◯	◯	◯
When I chose when Sunflower had to show me the next step	◯	◯	◯	◯	◯

8. **How much did Sunflower fulfill your expectations for this task?** *
Mark only one oval.

	1	2	3	4	5	
Not fulfilled at all	◯	◯	◯	◯	◯	Completely fulfilled

9. **Why?** *

____
____
____
____
____

Criticality and type of task

Criticality refers to the importance of a task being carried out safely, correctly and with attention to details.

10. **How would you rate the criticality of the task performed by the robot?** *
Mark only one oval.

	1	2	3	4	5	
Low critical	◯	◯	◯	◯	◯	High critical

11. **Why did you make this rating above?** *

12. **How would you categorise the type of task performed by the robot?** *
Mark only one oval.

- Physical
- Cognitive
- Both
- Other:

13. **Why did you make this categorisation above?** *

14. **How realistic did you think the task was?** *
Mark only one oval.

	1	2	3	4	5	
Not realistic at all						Very realistic

About you

15. **How often do you build Lego character?** *
Mark only one oval per row.

	Never	Once and I would not do it again	Once and I would consider doing it again	A few times (2-5) a year	Once per month	Every week
Select the most appropriate answer						

16. **How easy was it to build the Lego character?** *
Mark only one oval.

	1	2	3	4	5	
Very difficult						Very easy

17. **Would you have been able to build the Lego character without Sunflower's suggestions?** *
Mark only one oval.

- Yes
- No
- Maybe

18. **Could you explain why?** *

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E.8 Second task: Booking a doctor appointment

How can home robot companions help people ?

*Required

1. **ID number** *

Choice of conditions

2. **Which conditions did you prefer in this scenario?** *

Mark only one oval.

- ( ) When Sunflower chose the time slot for my appointment and the notification.
- ( ) When I chose the time slot for the appointment and the notification.
- ( ) Other: ____________

3. **Why did you make this choice?** *

4. **How intelligent did you think Sunflower was in you preferred condition?** *

Mark only one oval.

	1	2	3	4	5	
Not intelligent at all	( )	( )	( )	( )	( )	Very intelligent

5. **How much in control of the action (booking a doctor appointment) did you feel?** *

Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower chose the time slot for my appointment and the notification.	( )	( )	( )	( )	( )
When I chose the time slot for the appointment and the notification.	( )	( )	( )	( )	( )

6. **How much in control of the outcome of the action (having a doctor appointment booked) did you feel?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower chose the time slot for my appointment and the notification.	⬭	⬭	⬭	⬭	⬭
When I chose the time slot for the appointment and the notification.	⬭	⬭	⬭	⬭	⬭

7. **How much in control of the Sunflower robot did you feel during this scenario?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower chose the time slot for my appointment and the notification.	⬭	⬭	⬭	⬭	⬭
When I chose the time slot for the appointment and the notification.	⬭	⬭	⬭	⬭	⬭

Criticality and type of task

Criticality refers to the importance of a task being carried out safely, correctly and with attention to details.

8. **How would you rate the criticality of the task performed by the robot?** *
Mark only one oval.

	1	2	3	4	5	
Low critical	⬭	⬭	⬭	⬭	⬭	High critical

9. **Why did you make this rating above?** *

10. **How would you categorise the type of task performed by the robot?** *
Mark only one oval.

- Physical
- Cognitive
- Both
- Other: ____________

11. **Why did you make this categorisation above?** *

____
____
____
____
____

12. **How realistic did you think the task was?** *
Mark only one oval.

	1	2	3	4	5	
Not realistic at all	◯	◯	◯	◯	◯	Very realistic

About you

13. **What type of diary do you use?** *
Mark only one oval.

- Digital *Skip to question 22.*
- Paper-based *Skip to question 14.*
- Both *Skip to question 22.*
- Other: ____________ *Skip to question 14.*

Last page

14. **Do you have a digital calendar?** *
Mark only one oval.

- Yes
- No

15. **Why?** *

16. **How often do you use phone applications to book ...** *
Mark only one oval per row.

	Never	Once and I would not do so again	Once and I would consider doing it again	Rarely	Sometimes	Regularly	Everytime I need to
Hotels							
Flights							
Taxi							

17. **Why?** *

18. **Do you rely on other digital devices (computer, tablets...) for bookings?** *
Mark only one oval.

- Yes
- No
- Maybe

19. **Why is that so?** *

20. **Would you trust Sunflower to book the following for you?** *

Mark only one oval per row.

	Yes	No	Maybe
Medical appointments			
Hotels			
Flights			
Taxi			

21. **Please explain why?** *

Stop filling out this form.

Last page

22. **How useful do you find your digital calendar?** *

Mark only one oval.

	1	2	3	4	5	
Not useful at all						Very useful

23. **Why?** *

24. **How often do you use phone applications to book ...** *

Mark only one oval per row.

	Never	Once and I would not do so again	Once and I would consider doing it again	Rarely	Sometimes	Regularly	Everytime I need to
Hotels							
Flights							
Taxi							

25. **Do you rely on other digital devices (computer, tablets...) for bookings?** *
Mark only one oval.

- Yes
- No
- Maybe

26. **Why is this so?** *

27. **Would you trust Sunflower to book the following for you?** *
Mark only one oval per row.

	Yes	No	Maybe
Medical appointments			
Hotels			
Flights			
Taxi			

28. **Please explain why?** *

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E.9 Third task: Doing a dance

How can home robot companions help people ?

*Required

1. **ID number** *

Choice of conditions

2. **Which conditions did you prefer in this scenario?** *

Mark only one oval.

- ( ) When Sunflower did a different dance step from the one I demonstrated.
- ( ) When Sunflower repeated the same dance step that I demonstrated.
- ( ) Other: ____

3. **Why did you make this choice?** *

4. **How intelligent did you think Sunflower was in your preferred condition?** *

Mark only one oval.

	1	2	3	4	5	
Not intelligent at all	( )	( )	( )	( )	( )	Very intelligent

5. **How much in control of the action (Sunflower making dance movements) did you feel?** *

Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower did a different dance step from the one I demonstrated.	( )	( )	( )	( )	( )
When Sunflower repeated the same dance step that I demonstrated.	( )	( )	( )	( )	( )

6. **How much in control of the outcome of the action (Sunflower being able to show a dance) did you feel?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower did a different dance step from the one I demonstrated.	⬭	⬭	⬭	⬭	⬭
When Sunflower repeated the same dance step that I demonstrated.	⬭	⬭	⬭	⬭	⬭

7. **How much in control of the outcome of the Sunflower robot did you feel during this scenario?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower did a different dance step from the one I demonstrated.	⬭	⬭	⬭	⬭	⬭
When Sunflower repeated the same dance step that I demonstrated.	⬭	⬭	⬭	⬭	⬭

Criticality and type of task

Criticality refers to the importance of a task being carried out safely, correctly and with attention to details.

8. **How would you rate the criticality of the task performed by the robot?** *
Mark only one oval.

	1	2	3	4	5	
Low critical	⬭	⬭	⬭	⬭	⬭	High critical

9. **Why did you make this rating above?** *

10. **How would you categorise the type of task performed by the robot?** *
Mark only one oval.

- Physical
- Cognitive
- Both
- Other: ______

11. **Why did you make this categorisation above?** *

12. **How realistic did you think the task was?** *
Mark only one oval.

	1	2	3	4	5	
Not realistic at all						Very realistic

About you

13. **Would you normally offer some entertainment (game, dance, karaoke...) to a party you organise?** *
Mark only one oval.

- Yes
- No
- Maybe

14. **If Sunflower could do party entertainment, how often do you think you would use it for this purpose at your parties?** *
Mark only one oval per row.

	Never	Rarely	Sometimes	Regularly	Everytime
Select the most appropriate answer					

15. **Could you explain why?** *

E.10 Fourth task: Carrying biscuits

How can home robot companions help people ?

*Required

1. **ID number** *

____

Choice of conditions

2. **Which conditions did you prefer in this scenario?** *
   Mark only one oval.

   ( ) When Sunflower decided to carry the biscuits to the living room on its own.
   ( ) When I told Sunflower where to carry the biscuits by giving instructions.
   ( ) Other: ______________________________

3. **Why did you make this choice?** *

____
____
____
____
____

4. **How intelligent did you think Sunflower was in your preferred condition?** *
   Mark only one oval.

	1	2	3	4	5	
Not intelligent at all	( )	( )	( )	( )	( )	Very intelligent

5. **How much in control of the action (Sunflower carrying biscuits) did you feel?** *
   Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower decided to carry the biscuits to the living room on its own.	( )	( )	( )	( )	( )
When I told Sunflower where to carry the biscuits by giving instructions.	( )	( )	( )	( )	( )

6. **How much in control of the outcome of the action (having biscuits in the living room) did you feel?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower decided to carry the biscuits to the living room on its own.	⬭	⬭	⬭	⬭	⬭
When I told Sunflower where to carry the biscuits by giving instructions.	⬭	⬭	⬭	⬭	⬭

7. **How much in control of the outcome of the Sunflower robot did you feel during this scenario?** *
Mark only one oval per row.

	I didn't feel in control at all	I felt I had little control	I felt half in control	I felt mostly in control	I felt fully in control
When Sunflower decided to carry the biscuits to the living room on its own.	⬭	⬭	⬭	⬭	⬭
When I told Sunflower where to carry the biscuits by giving instructions.	⬭	⬭	⬭	⬭	⬭

Criticality and type of task

Criticality refers to the importance of a task being carried out safely, correctly and with attention to details.

8. **How would you rate the criticality of the task performed by the robot?** *
Mark only one oval.

	1	2	3	4	5	
Low critical	⬭	⬭	⬭	⬭	⬭	High critical

9. **Why did you make this rating above?** *

10. **How would you categorise the type of task performed by the robot?** *
Mark only one oval.

- Physical
- Cognitive
- Both
- Other: ____________

11. **Why did you make this categorisation above?** *

____
____
____
____
____

12. **How realistic did you think the task was?** *
Mark only one oval.

	1	2	3	4	5	
Not realistic at all	◯	◯	◯	◯	◯	Very realistic

About you

13. **How useful did you find Sunflower for this scenario?** *
Mark only one oval.

	1	2	3	4	5	
Not useful at all	◯	◯	◯	◯	◯	Very useful

14. **Would you explain why?** *

____
____
____
____
____

E.11 Last questionnaire

How can home robot companions help people ?

UH protocol number

*Required

1. **ID** *

Criticality of tasks

Criticality refers to the importance of a task being carried out safely, correctly and with attention to details.

2. **Please rank the following tasks from the most critical (rank 1) to the least critical (rank 4) between them.** *

Mark only one oval per row.

	Sunflower helps you build a Lego character	Sunflower books a doctor appointment for you	Sunflower performs a dance for you	Sunflower carries biscuits for you
Rank 1 (most critical task)	⬭	⬭	⬭	⬭
Rank 2 (second most critical task)	⬭	⬭	⬭	⬭
Rank 3 (third most critical task)	⬭	⬭	⬭	⬭
Rank 4 (least critical task)	⬭	⬭	⬭	⬭

Expectations

Please rate the following statements

3. **The Sunflower robot is able to navigate autonomously around the house.** *

Mark only one oval.

	1	2	3	4	5	
Do not agree at all	⬭	⬭	⬭	⬭	⬭	Completely agree

4. **The Sunflower robot is able to detect when something goes wrong in the kitchen (fridge kept open, oven turned on for too long ...)** *

Mark only one oval.

	1	2	3	4	5	
Do not agree at all	⬭	⬭	⬭	⬭	⬭	Completely agree

5. **The Sunflower robot is able to entertain the user (playing music, dancing, doing party tricks...) ***

Mark only one oval.

	1	2	3	4	5	
Do not agree at all	◯	◯	◯	◯	◯	Completely agree

6. **The Sunflower robot is able to perform secretary tasks (e.g. sending notifications and reminders, booking appointments ...) ***

Mark only one oval.

	1	2	3	4	5	
Do not agree at all	◯	◯	◯	◯	◯	Completely agree

7. **The Sunflower robot is able to do household chores (e.g. operating smart appliances such as vacuum cleaners, washing machines, ovens ...) ***

Mark only one oval.

	1	2	3	4	5	
Do not agree at all	◯	◯	◯	◯	◯	Completely agree

Your opinion on Sunflower

8. **Did you feel for a need of an emergency button to stop Sunflower during the overall interaction? ***

Mark only one oval.

◯ Yes
◯ No
◯ Other: ____________________

9. **Why is that so? ***

____
____
____
____
____

10. **Between the following optional settings for the Sunflower robot, which one would you prefer? ***

Mark only one oval.

◯ When Sunflower is making all the decisions for me
◯ When Sunflower needs my instructions to realise the actions
◯ Other: ____________________

Last page

11. **If you had a Sunflower robot, how often would you picture yourself asking for Sunflower's help for these following tasks?** *
Mark only one oval per row.

	Never	Rarely	Sometimes	Regularly	All the time
Building a Lego Character	⬭	⬭	⬭	⬭	⬭
Booking a doctor appointment	⬭	⬭	⬭	⬭	⬭
Carrying objects	⬭	⬭	⬭	⬭	⬭
Providing entertainment	⬭	⬭	⬭	⬭	⬭
Giving fashion advices	⬭	⬭	⬭	⬭	⬭

12. **Is there anything else you want to add or comment on regarding Sunflower?** *

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E.12 Google links to the questionnaires

E.12.1 Recruitment

https://docs.google.com/forms/d/e/1FAIpQLSe74gPf7BbRdYlUcBY1GCAawX2_f5R3XEkY8qY-QRzK3GDwvA/viewform

E.12.2 First questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSfw3uMHgQ4HpYz-CE18OnrAOwa-tgXisSB7y1lmnfSPtdby6Q/viewform

E.12.3 Questionnaire on expectations

https://docs.google.com/forms/d/e/1FAIpQLSfsJb7TcOqVzOZpq8NTIKRBpzurK0gvu3DZycMg1O_Dd_l4LQ/viewform

E.12.4 First task questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSeD4fkNeqq08Eom7wkF9f5NoOcV8OKieFxB5sYBRY0rbcI1ZQ/viewform

E.12.5 Second task questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSf4oKrkjbaC7zfeBFzdDgDoQf0AvGuQv0Ex5fsqJTNSWHEQAw/viewform

E.12.6 Third task questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSc9vHeoRVs9y6vlDDJyH0iA_hPKk_fQdkjOLIeEw9SUVV8_KQ/viewform

E.12.7 Fourth task questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSeT6SqeRUIFun0mIeuvYnm-LEvfIPbXQt4IF5dHaYDVUPBPEw/viewform

E.12.8 Last questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSej307F-9Q80JeBC2xz7Veh5XVZ324HEHdaGFHyrayYf0pDew/viewform

Appendix F

Publications

F.1 Conference papers

F.1.1 RO-MAN 2016

Who is in charge? Sense of control and robot anxiety in Human-Robot Interaction

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University of Hertfordshire

***Abstract*—In the late 1990s, the question of control was raised in the Human Computer Interaction (HCI) community within the process of designing computer interfaces. Following in their footsteps, the question of how much people want to be in control of their robots and how it affects the way we should design robotic interfaces is explored. To investigate the subject, we conducted a study which involved two fully autonomously operating mobile robots, namely a multi-purpose companion robot and a single-purpose domestic robot. The purpose of the study was to evaluate participants' sense of control (perceived control –who they felt was in charge of the robots– and desired control –how they wanted the action to be executed–) for a common domestic task: cleaning. Unexpectedly, the results show the higher the participants' desired control was, the more autonomous they wanted the companion robot to be (meaning the robot executed the needed task without an explicit permission from the participants).**

I. Introduction

Robot home companions are widely studied in the field of Human-Robot Interaction (HRI). A companion robot is defined as a robot able to provide useful assistance in a socially acceptable manner [1]. The Human Computer Interaction (HCI) community explored the concept of control in computer interfaces in the late 1990s [2]. Following their inspiring work, we choose to explore participants' sense of control (perceived control and desired control) in HRI hoping to find a connection between people's sense of control and robot anxiety. For this purpose, an experiment was conducted involving two robots, one acting as the main robot companion, and the other acting as the task-executing robot. The set up was designed so that the robots had to perform a specific domestic task (cleaning) with different levels of autonomy, allowing us to measure the participants' sense of control.

II. Background and motivation

Sense of control (SOC) is a widely discussed concept in psychology [4], [5], [6]. Some psychologists argue that SOC is related to Obsessive Compulsive Disorder (OCD) [7], and anxiety [8]. Therefore, this paper chose to investigate how SOC relates to robot anxiety.

A. What is sense of control?

SOC can be defined as the perception that a person has that she or he is the author of a given action [5]. In psychology, SOC also means sense of agency which refers to "being in control both of one's own actions and through them" [6]. When it comes to realising an action, three steps are involved: thinking of the *what* of the action, thinking of the *how* of the action and then *acting* according to the previous steps. If the *acting* is done indirectly through an external event, would the person still consider being in control of the action? For example if the person asks a coffee machine to produce a latte, would the person still consider herself or himself in control although the exact amount of caffein and milk is chosen by the machine? Some argue that SOC comes from the prediction of the result of the action [9], [10] (if we take the coffee machine example this would mean that the person feels in control because she or he knew a latte would be produced by the machine although the latte is not tailored to the person's taste), while some others argue that SOC is the illusion of causing the wanted event to happen [11] (in the coffee machine example this would mean that the person feels in control because she or he thinks that pressing the button on the coffee machine will deliver the expected latte).

In this study SOC was divided into perceived control and desired control for a more accurate measurement. Perceived control refers to the perception of *who* is realising the action (Is it the coffee machine who is in control of the action or is it me?), while desired control in the coffee machine example refers to the *expectation* of the way the action is realised (In the coffee machine example, this could refer to the heating temperature the coffee beans should be heated to before being pressed) and the *expectation* of the outcome of the action (having a latte and not an expresso). With this distinction made, the study can focus on the perceived control of the robot (who is in charge of the action between the robot and the human) and the desired control of the robot (how much autonomy the robot should be given to realise a task).

B. Sense of control and anxiety

In psychology, anxiety is characterised by "autonomic hyperactivity short of panic, arousal and vigilance, tension, restlessness, worrying, and anticipation of misfortune to self and others" [12]. Moulding and Kyrios [7] have investigated how SOC and desire of control are associated with high levels of OCD and by association high levels of anxiety. They found that OCD was associated with low SOC. Although OCD is an extreme case of anxiety, it can be hypothesised that there is a correlation between anxiety, and more specifically robot anxiety, and sense of control. Nomura [13] defined robot anxiety as "the emotions of anxiety or fear preventing individuals from interaction with robots having functions of communication in daily life". His team studied how robot anxiety prevents people from interacting with a robot [14], [15]. In this paper, we study SOC and robot anxiety since previous studies in psychology seem to indicate a correlation between the two phenomena [16], [17].

C. Measuring sense of control and robot anxiety in Human Robot Interaction

Since few studies have focused on SOC in HRI [3], [18], no specific measures have been established within the research area. For this study, we chose to implement different levels of autonomy in the robots, to measure the participant's perceived control of the robots (who the participant thinks is in charge, i.e. the robots or the participants) via likert scale questionnaires. We used the Desirability of Control Scale (DCS) to measure the participant's desired control (how much the participant wants to be be in control in her/his daily life) [19]. This scale has been widely used in psychology and shown to provide consistency and reliability [19]. To measure anxiety, we use the Nomura robot anxiety test [13].

D. Summary of the concepts used in this paper

Sense of control (SOC) refers to the author of one's action, the way the action is realised and the result of the action. It can be divided into perceived control which refers to the author of the action, and desired control which refers to the way the action is realised and its result.

III. METHODS

To gain a better understanding of the influence of SOC over robot anxiety, an experiment was conducted that focussed on perceived control and desired control. Participants' perceived control was measured through the different levels of autonomy the robots used to execute the cleaning task. Desired control was measured mainly with DCS and Ad hoc likert scale questionnaires.

A. Research questions and hypotheses

The focus of this study being SOC and robot anxiety, three conditions, each matching a different level of autonomy, were designed for the experiment. This paper investigated the following research questions and hypotheses:

1) **R1**: Does the level of autonomy of a robot affect the participants' perceived control and desired control of the robot?
   a) H1: There is a correlation between participants' desired control and their preferences regarding the level of autonomy of the robots.
2) **R2**: Is there a correlation between sense of control and robot anxiety?
   a) H2: There is a correlation between robot anxiety and participants' desired control.
   b) H3: The effects of robot anxiety and the participant's desired control change the perceived control of the robot.

B. Experimental Design

The experiment was conducted with two fully autonomously operating robots: a companion robot (Sunflower, **Fig. 1a**) and a cleaning robot (Roomba, **Fig. 1b**). Sunflower [20] possesses an embodied upper body attached to a Pioneers DX robot base. Roomba is a commercial vacuum cleaner [21]. A Roowifi device (see **Fig. 1c**) was used to connect the Roomba to the network. The experiment took place in the Robot House, a typical British residential house, converted into a smart home, including autonomous robots, owned by the University of Hertfordshire where studies can be run in a realistic domestic environment.

(b) Roomba robot

(a) Sunflower robot **(c) Roowifi device**

Fig. 1: Domestic robots (a), (b), and Roomba's connecting device (c)

Three conditions were designed to represent different level of autonomy. **Condition 1** represents a low-level of autonomy where the main robot companion Sunflower gives instructions and where the cleaning robot Roomba has to be activated manually by the participant. **Condition 2** represents a medium-level of autonomy where the main robot companion gives instructions and acts as a remote control for the cleaning robot. **Condition 3** represents the high-level autonomy where the main robot companion notices cleaning needs to be done and activates Roomba without any action required from the user. The robot companion informs the participant that the action is done.

- **Condition 1: Participant operates Roomba manually** ($P \rightarrow R$) The command of the cleaning action is generated by the participant.
- **Condition 2: Participant operates Roomba remotely** ($P \rightarrow S \rightarrow R$) The command of the cleaning action requires the approval of the participant.
- **Condition 3: Sunflower operates Roomba automatically** ($S \rightarrow R$) The command of the action is achieved via the Sunflower robot without the approval of the participant.

In each condition (see **Fig. 2**), Sunflower welcomes the user and asks the person to take a seat. Once the person sits

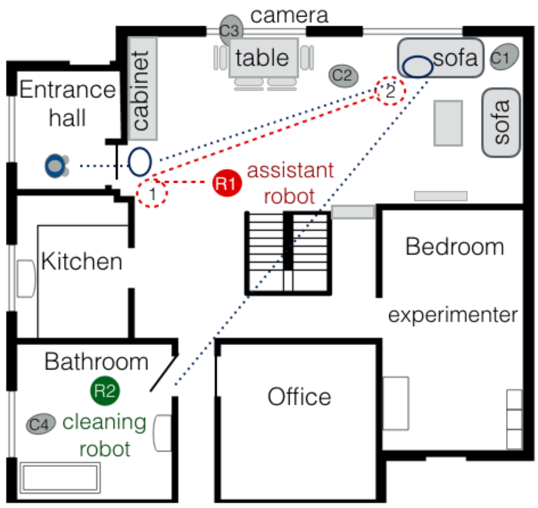

Fig. 2: Experimental settings for the three conditions. See Fig. 3 to follow condition 2. The icons in blue describe the direction followed by the user and in red the ones pursued by the robot

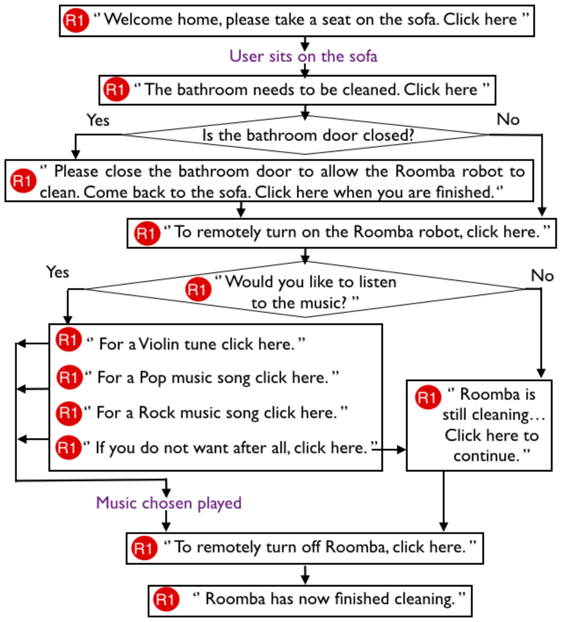

Fig. 3: Script of condition 2 from the participant's perspective

on the sofa, Sunflower comes to the participant and displays on its onboard screen that the bathroom needs cleaning (see **Fig. 3**). In condition 1, Sunflower asks the participant to activate cleaning on the Roomba robot manually. In condition 2, Sunflower asks the participant for confirmation before operating the Roomba robot for cleaning (see **Fig. 3**). In condition 3, Sunflower activates cleaning on the Roomba without asking for permission. It informs the user that Roomba has started cleaning once that Roomba has been activated. After the first activation of Roomba, Sunflower offers to play some music for entertainment, while the participant waits on the sofa for the cleaning to be done. Once a predefined cleaning time of 1 minute 30 has passed, Sunflower asks the person to deactivate Roomba either manually (condition 1) or remotely (condition 2). In condition 3 Sunflower turns off Roomba automatically and then informs the participant that cleaning has been done.

C. Experimental procedure

Once the participant arrived at the Robot House and was formally greeted, the place and the robots Sunflower and Roomba were introduced. We explained how to manipulate a Roomba robot and we ensured that the participant knew how to operate the Roomba manually, by letting the participant activate the robot twice (turn on the robot, and activate cleaning). An information sheet was provided and the participants signed the consent forms. Afterwards, they were shown a short BBC news video on the Robot House (http://www.bbc.co.uk/newsround/26515276). Our previous research [22] has found it is important to set the scene, i.e. to give participants information on the context of the research and the envisaged application area. It was hoped that the video introduction of the environment and research context would decrease the novelty effect. Afterwards, participants completed questionnaires covering age, technology awareness, personality (Ten Item Personality Inventory test [23]), desired control (Desirability of Control Scale [19]), and robot anxiety (Nomura robot anxiety test [13]). Before each condition of the experiment started, the participant was asked to imagine that she or he had just come home after work and wanted to relax on the sofa. The participant had to wait in the entrance hall (see **Fig. 2**) for a bell signal (used to indicate the start of the particular condition set by the experimenter). Then a condition started. The same procedure was repeated until all the conditions were completed. After each condition, the participant was asked to complete questionnaires about their impression of the robots and who they felt were in charge. After the final condition, the participant was provided with another questionnaire assessing condition preferences, and a robot anxiety test.

The duration of the experiment for each participant was about 50 minutes. Each condition lasted about 10 to 13 minutes.

The Sunflower robot communicated with the participant via a tablet. This choice was made so the voice of the robot would not influence the participant and moreover, it was a good way to ensure the participants would fully understand the information since an acknowledgment was required after each message (see **Fig. 3**). The behaviour of the robots were implemented via the CobSequencer and the CobScheduler [24].

The cleaning task was considered a high priority task with low impact during the experiment. Therefore, it was decided to execute the task in the bathroom, separate from the main interactive space, where Sunflower and the participant stay, thus reinforcing the view of Sunflower as a robot companion and Roomba as a helper robot. Since Roomba's primary purpose was cleaning, no attempt was made to make it more interactive. To strengthen the view of Roomba as the task-execution robot, the participant was asked in every condition to close the bathroom door to ensure she or he was aware that Roomba was going to clean the bathroom. The order of the three conditions in which the participants had to perform was randomised each time in order to reduce any potential order effect.

D. Participants

Twenty-five participants took part in the study aged 21 to 62 years ($M = 36.16$, $SD = 13.04$). The recruitment was done in the University of Hertfordshire with posters, flyers and email advertisements. Students and staff members were recruited. Gender balance was also relatively well maintained (11 female, 14 male).

IV. Results

A. Population distribution

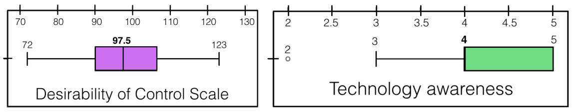

Fig. 4: Participants distribution for DCS and technology awareness

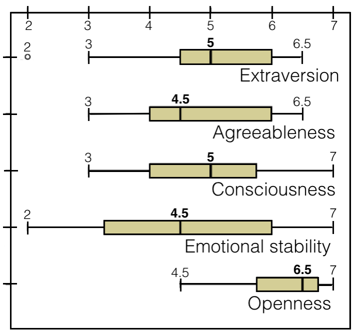

Fig. 5: Participants distribution regarding personality

Although the distribution of participants for the DCS questionnaire is close to a normal distribution, the distribution of participants on the personality test and the awareness of technology shows the heterogeneity of the sample (see **Fig. 4** and **5**). Therefore, non-parametric tests were used for data analysis. A Friedman test was performed to detect the differences between the three conditions regarding the choice of level of autonomy of the robots. To analyse perceived control, desired control or robot anxiety, Kendall's correlation tests were used to measure the ordinal association between measured quantities derived from likert scale questionnaires.

B. R1: Effect of different level of autonomy

A Kendall's correlation test demonstrates a highly significant positive correlation between participants wanting to delegate more tasks to Sunflower and Roomba, and participants wanting Sunflower to operate Roomba ($\tau_b = 0.672$ and $p < 0.001$). There is also a high positive correlation between participants wanting to delegate more tasks to Sunflower and Roomba and participants liking Sunflower as a remote control ($\tau_b = 0.507$ and $p = 0.006$). Participants' condition preferences also highly correlates with participants wanting to delegate more tasks to Sunflower and Roomba ($\tau_b = 0.454$ and $p = 0.039$). There was also a significant negative correlation between people's preference for Sunflower to operate Roomba, and the preference of having Roomba as a main robot companion ($\tau_b = -0.430$ and $p = 0.018$). This shows there is a consistency with the fact that people ask for more autonomous robots. This may be because participants were more technology aware than an average group (see **Fig. 4**). However there is no significant correlation between participants' condition preferences and technology awareness ($\tau_b = -0.53$ and $p = 0.782$). There is a high significant correlation between participants' condition preferences and their desired control ($\tau_b = 0.454$ and $p = 0.007$) which indicates that the more autonomous participants wanted their robots to be, the more in control participants wanted to be. It can be extrapolated that since participants were more knowledgable than average regarding technology (see **Fig. 4**), they trusted the robots to do their jobs correctly, although no significant correlation was found between participants' technology awareness and their desired control ($\tau_b = 0.000$ and $p = 1.000$).

C. R2: Effect of sense of control and robot anxiety

The results show that people with high scores for desired control are likely to prefer a fully autonomous robot. Indeed there was a highly significant positive correlation between the condition preferences and people's desired control ($\tau_b = 0.454$ and $p = 0.007$), which means the more autonomous the robots were, the more in control the participants felt. Surprisingly, this suggests that people with high desired control do not want to be in charge of the robots and their operation. However as pointed out earlier in the paper, the fact that participants' technology awareness is higher than average (see **Fig. 4**) may induce an inherent trust in computer and robot technology in general. Therefore although a person's desire to be in control is high, the person may trust the technology to realise the wanted action (only the results of the action matter).

There are different meanings to *being in control*. For a participant being in control can mean having the desired result or having the action done in a certain way. For example in cooking, if the robot's task is to prepare instant noodles, participants may have wanted to monitor more closely the order of the actions (boil the water in a pot and put the noodle in the pot). Maybe in this case, the questionnaire

	DCS	C1 I felt in charge of	C2 I felt in charge of	C1 Sunflower was in charge of	C2 Sunflower was in charge of	C3 Sunflower was in charge of	Technology awareness	RAS after experiment
C1 I felt in charge of	-0.179	1						
C2 I felt in charge of	0.130	0.327	1					
C1 Sunflower was in charge of	0.054	-0.381*	0.131	1				
C2 Sunflower was in charge of	0.055	-0.262	-0.401*	0.125				
C3 Sunflower was in charge of	-0.227	0.151	-0.275	-0.017	0.410*	1		
Technology awareness	0.000	0.216	-0.474**	0.013	-0.149	0.030	1	
RAS after experiment	0.300*	0.396*	0.224	-0.111	-0.260	-0.101	0.030	1
Condition preference	0.454*	-0.105	-0.056	0.097	0.143	0.109	-0.053	0.158

** Correlation is significant at the 0,01 level (2-tailed).
* Correlation is significant at the 0,05 level (2-tailed).
DCS: Desirability of Control Scale
RAS: Robot Anxiety Scale
C1: Condition 1
C2: Condition 2
C3: Condition 3

TABLE I: Kendall's tau correlation test between desired control, perceived control and robot anxiety

results would have been different since to have the optimum texture for the noodles, it is preferable to put the noodle in a pot full of hot water instead of putting noodles in a pot full of cold water and only then heat the water. In the experiment, the action being cleaning the floor, the way the action is done does not affect the results (the floor is always cleaned at the end of each conditions). It could explain why participants with high desired control preferred the high level of autonomy condition (the person may want to be in control of the results of the action, but does not necessarily want to supervise every steps of the action being made).

Indeed, the less people felt in charge, the more they felt Sunflower was in charge ($p = 0.001$ in condition 3, and $p = 0.036$ in condition 2). The Friedman test revealed a significant difference for whom the person felt in charge of in each condition ($N = 24$, $\chi^2 = 12.644$, $df = 2$, and $p = 0.002$) but showed no statistical differences for whom the participant felt Sunflower was in charge of ($N = 25$, $\chi^2 = 2.508$, $df = 2$, and $p = 0.285$). The LSD Wilcoxon test confirmed there is a highly significant difference for whom the person felt being in charge of, with $Z = -3.273$ and $p = 0.001$. This means that the more autonomous the robot became (from condition 1 to 3), the less in charge the participant felt, which confirmed there is a delegation of control which is perceived.

Another explanation of why participants' may have wanted to have highly autonomous robots, could be because they felt anxious about them. Indeed, it can be hypothesised the more anxious of robots you are, the less time you want to spend with them. Kendall's correlation test showed there is a significant positive correlation between DCS and the robot anxiety test done after the experiment ($\tau_b = 0.300$ and

	I felt in charge of (condition 2) — I felt in charge of (condition 1)	I felt in charge of (condition 3) — I felt in charge of (condition 2)	I felt in charge of (condition 3) — I felt in charge of (condition 1)	Sunflower was in charge of (condition 2)— Sunflower was in charge of (condition 1)
Z	-1.884[b]	-1.997[b]	-3.273[b]	-1.147[c]
Asymp. Sig (2-tailed)	0.060	0.046	0.001	0.251

	Sunflower was in charge of (condition 3) — Sunflower was in charge of (condition 1)	Sunflower was in charge of (condition 3) — Sunflower was in charge of (condition 2)	Roomba was in charge of (condition 2)— Roomba was in charge of (condition 1)
Z	-0.025[b]	-0.890[b]	0.000[d]
Asymp. Sig (2-tailed)	0.980	0.374	1.000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.
c. Based on negative ranks.
d. The sum of negative ranks equals the sum of positive ranks.

TABLE II: People's perception of who is in charge (robot, user)

$p = 0.046$) meaning, the more desired control participants had, the more anxious about robots they were. This results supports the idea that participants with high desired control wanted more autonomous robots, probably because they were more anxious about robots than others, therefore they wanted to have less interaction time with them. Also the results displayed a significant positive correlation between who the participants felt in charge of in condition 1 and robot anxiety measured after the experiment ($\tau_b = 0.396$ and $p = 0.016$). This reinforces the idea that the more time participants felt they had to manipulate the robots, the more anxious they became.

D. Limitations of the study

Having three conditions in the experiment, there were six possible combinations (e.g. C1, C2, C3) regarding the order the experiment was done for each participant. Therefore having 25 participants means there were only 4 or 5 participants per combinations which can appear as a low number. Indeed although it was hoped the novelty effect would be limited by the introduction of the robot house, there was still some novelty effect to a certain extent when participants experimented the first condition (regardless of the condition being C1, C2 or C3). For example, some participants took longer than usual to understand they had to go back to the sofa after the bathroom door was closed. An analysis was done on the questionnaires about who is in charge, to check whether there was an order effect. It was found that there was a slight order effect regarding which condition came first for the questionnaire about who the participant felt in charge of ($M_{C1} = 2.25$, $M_{C2} = 2.63$ and $M_{C3} = 2.39$) and who the participant thought Roomba was in charge of ($M_{C1} = 1.00$, $M_{C2} = 1.00$ and $M_{C3} = 1.13$). However there was a notable order effect for the questionnaire on who the participant thought Sunflower was in charge of ($M_{C1} = 2.54$, $M_{C2} = 2.67$ and $M_{C3} = 1.88$). This means participants that started the experiment with condition

3 ($S \rightarrow R$ when Sunflower operates Roomba without the participant's explicit authorisation) were less likely to feel controlled by Sunflower than participants that started the experiment with condition 1 and condition 2. However, as mentioned above these results are to be taken with caution due to the low number of participants per combinations.

V. DISCUSSION AND CONCLUSION

The results of this paper showed there is a correlation between sense of control and robot anxiety. It seems that people with high anxiety towards robots and high desired control prefer to have robots with a high level autonomy. However, these results need to be taken with caution since other factors may have influenced it, such as participants' technology awareness which were higher than average or the task chosen for the experiment. Indeed, people may have trusted the robots more because of their familiarity with technology. Some later work even suggested that people may trust a faulty robot in an emergency situation [25]. Also the task chosen for the experiment offered little incentive for the participant to monitor the action. Indeed as explained earlier, for such a task the only supervision the participant has, was to check the bathroom door was closed before Roomba was activated. Indeed, the perceived control of the participants became lower as the level of autonomy of the robots became higher, this did not seem to correlate with participants desired for control. Perhaps participants valued better their perception of the results of the action (the bathroom being cleaned) than their perception of who was in charge of the cleaning.

To conclude, this paper showed that the participant's sense of control (desired control and perceived control) is a factor worth considering in a HRI study. The higher people's desired control was, the higher the level of autonomy robots were expected to have. Also the higher people's desired control was, the higher their anxiety towards robot was. This supports the idea that participants with high desired control wanted to spend less time with the robot due to their anxiety, therefore, the lower their perceived control was, as the higher the autonomy of the robots became. For future investigations, it would be worth to see if a task that requires potentially more supervision such as cooking, change the findings of this paper regarding participants' sense of control.

VI. ACKNOWLEDGEMENT

Thank you to Nathan Burke and Joe Saunders for their help on the Sunflower robot, and to Dag Syrdal for the help on the data analysis.

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F.1.2 UK-RAS 2017

People's Perceptions of Task Criticality and Preferences for Robot Autonomy

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Abstract

The concept of criticality is relatively new to the Human-Robot Interaction (HRI) community. Now that robots are becoming more routinely available to the public, it is important to understand what makes a task critical, and how this is linked to people's preferences for different levels of autonomy for domestic robot companions. To do so, we first conducted a live study to see how much autonomy people would give to a robot to perform a simple task. We then conducted a questionnaire study to investigate how people classify task criticality, which builds up to our future study that will explore how task criticality affects the way people want to have control their robot - performing the task.

I. Background and motivation

As more companion robots become commercially available to the public, it is important to understand how much in control of their robots people want to be [1], [2]. In our previous study [1] we showed that the more controlling and anxious about robots people were, the more autonomous they wanted the robot to be. As we hypothesised that people's perceived level of control depends on the criticality of the task the robot performs, we chose to investigate how people rate the criticality of a task. In order for people to evaluate a task criticality, we provided Yanco and Drury's definition of criticality applied Human-Robot Interaction [3], which is "the importance of getting the task done correctly in terms of its negative effects should problems occur". Ezer et al. [4], who performed a study to see whether the criticality of a task has any effect on users delegating tasks to a home robot companion, found that people were less willing to have a robot performing a low critical task if it requires a large amount of interaction with the robot. However, the researchers admitted they were unsure of the results since there were no clear findings regarding the different levels of criticality perceived for the tasks. According to Tzafestas [5], there are three levels of criticality: low, medium and high. However, he did not explain how to differentiate these levels of criticality. According to Beer et al. [6], [7] and Mitzer et al. [8], the level of the criticality of the task depends on how preferable it is for the user to have a human performing a critical task such as giving medication. We chose to investigate what factors people consider when rating task criticality to attempt to give a guideline. As task criticality is difficult to disentangle from other concepts, we narrow our focus on domestic robot companions.

II. Methods and research questions

To investigate the user's perception of control and task criticality, two studies were conducted. The aim of the first study was to answer how people's perception of control (i.e. how much control over the robot's autonomy people want to have) can affect the level of autonomy they give to a robot, while the second study aimed to uncover what type of criteria people considered to rate the criticality of a task.

A. First study: live study in the domestic environment

This study [1] was conducted in a smart house environment with two different robots: an autonomous mobile companion robot, Sunflower [9], and a vacuum cleaning robot, Roomba [10]. Three conditions were set: in the first condition, the companion robot mentioned to the participants that the bathroom needed to be vacuumed and the participant had to manually turn on the Roomba robot. In the second condition, the companion robot made the same statement as in the first condition, but offered the option for the user to remotely turn on the Roomba robot. In the third condition, the companion robot made the same statement as in the first condition, and turned on the Roomba robot without any confirmation needed from the participant. The robot companion mentioned to the participant that cleaning was ongoing. Twenty-five people (11 females and 14 males) participated in the study ($M_{age} = 36.16, SD_{age} = 13.04$). Each participants experienced each conditions in a randomised order. After each condition, participants had to complete a short questionnaire which measured the user's perception of who was in control of the interaction. Participants' level of desired control were evaluated before their interaction with the robots started, with the desirability control scale (DCS) [11], which is a validated standardised test [12].

B. Second study: Questionnaire study on attribution of criticality

This questionnaire study contained an open-ended questions section and a ranking section. Two pictures of robots were shown: a robot companion robot, Sunflower [9], and a vacuum cleaning robot Roomba [10] to provide context. In the open-ended questions section, participants were asked what they considered a high critical task and a low critical task were for a robot companion. The ranking section provided a list of 12 different tasks people had to rank, from the most critical task to the least. 101 participants were recruited from the University of Hertfordshire (50 females and 51 males with $M_{age} = 25.70, SD_{age} = 9.59$) for this study.

III. Results and Discussion

A. First study: type of control over the robot preferred by the user

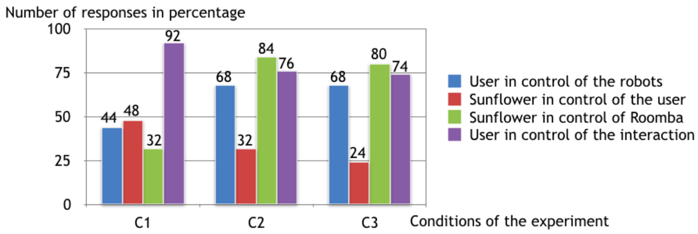

Fig. 1: User's perception of control of the robots

Results (see Fig.1) suggests there is a shift in the perceived level of control of the robot companion. It seems to increase as participants felt they could delegate more control to the robot, so they do not need to perform any physical action for the cleaning to happen. However the perception of control of the situation slightly decreases as the participant becomes more passive (see Fig.1). Although these results suggest a perception of decreased control, 60% of the participants preferred the third condition. This suggest that there is a tendency for people to accept to relinquish control of the action, if they believed to still possess some indirect control through the robot companion. The Pearson's chi square test shows there is an association between participant's level of desired control and their perceived level of control in each conditions ($\chi^2_{C1}(12) = 33.777, p_{C1} < 0.001$, $\chi^2_{C2}(12) = 33.014, p_{C2} < 0.001$, and $\chi^2_{C3}(12) = 29.565, p_{C3} < 0.03$). Further investigations are needed to validate these findings.

B. Second study: classification of tasks depending on criticality

The results of the questionnaire study show that among the 12 tasks given to rank, tasks related to safety and time constraint were consistently ranked as high critical ("There is some smoke in the kitchen. The robot is calling the fire service.", "You have just remembered that you need to see the doctor this week for a blood test. The robot is booking the appointment for you.", "You have lost your car keys and need to pick up your friend in an hour. The robot is looking for your car keys"). Tasks linked to entertainment were always rated as low critical ("You are sitting on the sofa, relaxed. The robot is performing a dance for entertainment.", "You are home and want to be entertained. The robot is telling you a joke." and "You are bored. The robot reads some poems to please you."). Over 75% of the participants considered safety orientated tasks as the most critical and over 80% of the participants rated entertainment-orientated tasks as the least critical.

IV. Conclusion and Future Work

To conclude, this work suggests that people accept to relinquish some control of the desired action if their perception of control of their robot companion was sufficiently high. It also showed that the most important factors that people take into consideration when rating the criticality of a task for high or low seemed to be safety and entertainment. Therefore, in our future study we will investigate if people are still ready to relinquish some control of the desired action for high critical tasks, and if the task itself affects the perception of the robot.

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F.1.3 RO-MAN 2018

Does the appearance of a robot influence people's perception of task criticality?

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***Abstract*—As home robot companions become more common, it is important to understand what types of tasks are considered critical to perform correctly. This paper provides working definitions of task criticality, physical and cognitive tasks with respect to robot task performance. Our research also suggests that although people's perceptions of task criticality is independent of robot appearances, their expectation that a robot performs tasks correctly is affected by it's appearance.**

I. Introduction

With the current popularisation of devices such as Google Home and Amazon Alexa, it is important to distinguish what people consider critical for a domestic robot companion to do reliably. Previous research ([1], [2]) suggests that evaluating the criticality of a task is difficult because of the lack of standardisation in the field. To tackle this problem, this study investigated how people defined task criticality, and whether there is a relationship between the (subjective) level of criticality people attributed to a task and the appearance of the robot performing the task. This work proposes a definition of task criticality, and also a definition of cognitive and physical tasks performed by robots. We also investigated if people's perception of task criticality depends on the appearance of the robot carrying out the task.

II. Background and motivation

A. What is criticality?

Criticality is an unclear concept that has been widely studied in different areas of research. In linguistics, criticality is defined as "an evaluative judgement made within any field of human activity about some aspect, object or behaviour of that field" [3], meaning that criticality is subjective and context dependent. In biology, criticality "describes sudden changes in the state of a system when underlying processes change slightly" [4]. Criticality is then perceived as a sudden dramatic change in the expected event [4], [5]. In the field of Human-Robot Interaction (HRI), Yanco and Drury [6] defined criticality as "the importance of getting the task done correctly in terms of its negative effects should problems occur". Since this definition was provided, no research has yet been performed to analyse how to apply it to standard tasks performed by robots, and more precisely, everyday tasks that home robot companions might be expected to perform. The current study investigated people's own definition of task criticality for domestic robot companions. Firstly, to validate and update the definition given by [6], and secondly, to understand better what influences people's perceptions of task criticality. In order to apply the definition of task criticality in practice, it is important to be able to distinguish between different levels of criticality. Tzafestas [1] described three levels of criticality in his research: low, medium and high, without providing any guidelines into how to distinguish these levels. The study described in this paper aims to provide guidelines as to what makes a task more or less critical. Some previous studies [7]–[9] have suggested that the level of perceived task criticality performed by a robot depends on how much people wanted the task to be performed by a human. Beer et al. [7], [8] and Mitzer et al. [9] used the example of giving medication in their studies and found that people preferred having a human for this task rather than a robot. However, their findings suggested that some other factors may have influenced their participants, such as trust or the visual appearance of the robot. Therefore our study also investigated if there is a relationship between how participants rate task criticality and robot appearance.

B. How does the appearance of the robot affects people's perception?

Several previous studies have shown that robot appearance affects the people's judgement of robot behaviour. In one of the early studies, Goetz et al. [10] investigated how to improve Human-Robot Cooperation by matching robot appearance and behaviour to the task the robot had to complete. Later on, Walters et al. [11] showed that there is a tendency for people to prefer some human-like attributes in robots. In a recent study, Malle et al. [12] demonstrated that robot appearance can also affect people's moral judgements about robots. In a moral dilemma, people blame robots more for inaction than action, and they blame humans more for the opposite. They also found evidence that people treated a mechanical-looking robot differently from a human-looking one, when both robots were described identically. Abubshait and Wiese [13] investigated how robot appearance and behaviour influence HRI and they found that a robot's appearance affects mind judgements (e.g the attributed intentions the robot has). Salem et al. [14] suggested in their study that "the robot's level of anthropomorphism may lead to different degrees of 'forgiveness' in humans". Although their study did not focus on appearance, as only one robot was used, potentially this could mean that the more human-like the robot appears, the less forgiving people will be when it makes mistakes. This can be linked to findings by Mitzer et al. [9] where the level of task criticality depends on how preferable it is for the user to have a human performing a critical task, such as giving medication.

C. Perception of tasks performed by the robots

Previous research has investigated how trustworthy a robot is perceived by people, depending on the task the robot is performing. Salem et al. [14] showed in their study that the type of task performed by the robot matters. It seems that the irreversibility of some actions to carry out by people which were suggested by the robot prevented most of their participants from performing them. Prakash and Rogers [15] showed that perceptions of robots' human-likenesses changes for different types of tasks (personal care, social, decision-making and chores). Their experiment underlined that robotic appearance was least appreciated for decision-making types of tasks, in their case money investment. Overall they found that older people prefered human-like robots for personal care, chores, social and decision-making tasks compared to younger people who expressed a more diverse preference (mechanical appearance, mixed appearance or human appearance). Hinds et al. [16] found that in an industrial context where robots and humans work together on various tasks (assembling objects, carrying objects, designing something with the participant), people preferred overall to have a machine-like robot over a human-like robot. This difference shows that robot appearance preferences may depend on the environmental context (e.g. home versus a factory). The current study investigated whether task criticality depends on the robot's appearance.

III. Method

To investigate how people rate task criticality according to the robot appearance, a questionnaire-based study was conducted.

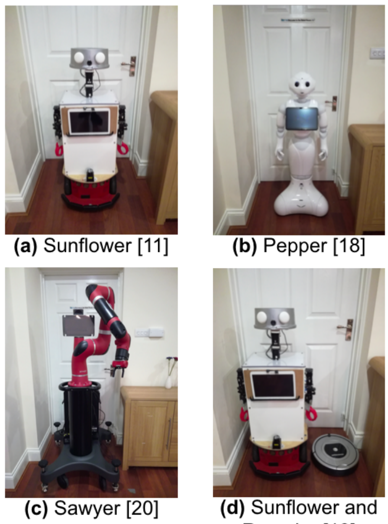
A. Research questions

- R1. What defines a cognitive task versus a physical task for a domestic robot companion?
- R2. What defines task criticality?
- R3. Are people's perceptions of task criticality influenced by the robot's appearance?

B. Experimental procedure

Four different questionnaires were prepared (see [17]), each containing identical questions, and each showing a different picture of a robot companion, for participants to imagine what the robot looks like when performing a given list of tasks. Each participant received one of the four questionnaires randomly. The questionnaire had five sections: demographics, usage of technology, people's expectations of a robot companion, rating of task criticality and defining task criticality. In a previous pilot study, when participants responded to an open-ended question asking to define criticality, many expressed confusion and difficulty in expressing the concept. Therefore, in the current study, we deliberately chose not to provide a definition of criticality in the study beforehand in order not to bias the participants, and instead to get participants' own definitions of criticality via a small set of statements that they had to rate on 5-point Likert scales (see Table IV). Open-ended questions were used for specific tasks to provide better context and were then classified according to keywords in the analysis.

Participants were recruited from University staff and students and through social media. As a result, 84 people completed the questionnaire (35 female and 49 male). Their ages ranged between 19 and 64 ($M = 35$, $SD = 12.221$). There were 22 people that answered the questionnaire showing the Sunflower robot picture (Fig.1a), 21 people showing the Pepper robot picture (Fig.1b), 21 people showing the Sawyer robot picture (Fig.1c) and 20 people showing the combined Sunflower and Roomba picture (Fig.1d). Participants were asked to rate the robot's appearance on a scale of 1 to 7 (1 being very-machine like and 7 being very human-like), apart from the ones who had both Roomba and Sunflower as robots pictures in their questionnaire. It was further decided to provide in one of the questionnaires a picture of both Sunflower and Roomba to see if the perception of the robot companion (Sunflower) changed with the presence of another robot that was task orientated.



(a) Sunflower [11] **(b)** Pepper [18] **(c)** Sawyer [20] **(d)** Sunflower and Roomba [19]

Fig. 1: Robot pictures shown to the participants

IV. Results

A. R1. Definition of cognitive and physical tasks

Participants were asked to define what they considered physical and cognitive tasks. Their definitions were classified according to recurrent keywords mentioned by the participants. For the definition of physical tasks, Table I, people mentioned, regardless of their questionnaire body, movements, strength and objects. It can be noted that none of the participants who were shown the Sawyer robot mentioned anything related to the body, while the majority of the participants who had Sunflower and Roomba as a picture mentioned the necessity of force in their definition of physical tasks. It also shows that participants that had Sunflower and Roomba as a picture focussed more on the Roomba robot for their definition, than the ones that only had the Sunflower picture. As a result, we can define for robots, a physical task as any task that requires body movements or motion, which may be qualified as a laborious task.

TABLE I: Definition of physical tasks depending on the image of the robot provided

Key words	Number of participants mentioning these key words			
	Sunflower	Pepper	Sawyer	Sunflower + Roomba
body (requires a body/body parts, embodiment, artificial/natural body....)	4	5	0	3
movement (requires to move, motion involved ...)	8	6	1	5
strength (requires force/effort, involves manual tasks...)	3	7	6	7
interaction with objects and or the environment	4	4	3	1

For the definition of a cognitive task, participants mainly mentioned a mind process, information analysis, decisions or qualify it as an antonym to physical task (see Table II). For robots, a cognitive task can therefore be defined as any task that requires mental activities or thinking processes and which may involve some decision making. Participants who were shown a picture of both Sunflower and Roomba, mainly mentioned information processing in their definition of a cognitive task for a robot, which again shows that these participants were more focussed on the Roomba robot than the ones who had the Sunflower only questionnaire. It might be that Roomba being a commercially available robot, participants may have more familiarity with it. Also, the Roomba being mainly a physical robot (vacuum cleaning being its sole purpose), people considered some cognitive aspects of cleaning such as "being able to distinguish a carpet from a tiled floor".

TABLE II: Definition of cognitive tasks depending on the image of the robot provided

Key words	Number of participants mentioning these key words			
	Sunflower	Pepper	Sawyer	Sunflower + Roomba
thinking (involves mental process, mind/thoughts ...)	9	8	5	3
information processing (requires analysis ...)	6	2	3	11
making use of the brain (decision making ...)	2	3	3	3
non-physical interaction	1	1	4	1

These definitions are supported by the way participants classify as either "physical", "cognitive", "both" or "other please specify", a list of tasks (see Table III) the robot could do for them. Tasks that clearly involve motion were classified either as physical or both (A. vacuuming, C. dancing, F. carrying or K. waving) and tasks that involve thinking as cognitive.

B. R2. Definition of task criticality

The Pearson Chi-square test showed there is no relationship between the classification (cognitive or physical) of a task and the level of its criticality ($\chi^2 = 0.400$, $df = 2$, $p < 0.819$). Participants were asked why they chose to classify a task as highly critical or not highly critical. Most of the reasons why participants rated tasks as highly critical were related to some dimension of risk. For example the potential harm of another person, impact related to health or money related ("expensive [champagne] flutes at risk"), and potential social impact such as "punctuality for interview". Tasks that were rated low critical were those that had low impact with reversible consequences, such as vacuuming or tasks focussing on entertainment. This is consistent with the results presented in Table V, illustrating factors which are taken into consideration for criticality. To investigate factors that people consider when evaluating the criticality of a task, they were presented a list of statements (see Table IV) and asked to rate on a scale of 1 to 5 (1 being not important for criticality at all and 5 being very important for criticality), which aspects they considered important to judge for the criticality of a task.

The results show people considered mainly four aspects when judging task criticality: the task being carried out safely, the importance of the task, the task being carried out correctly and the task being carried out with attention to detail. Therefore task criticality can be defined as the importance of a task being carried out safely, correctly and with attention to detail. Due to the low sample size for each set of questionnaire (each fewer or equal to 22 participants), and the lack of balance between gender and age, we could not apply the test for normal distribution. It was therefore chosen to perform non-parametric tests. A non-parametric Kendall's tau correlation test showed that there is a significant positive correlation ($n = 84$, $\tau = 0.246$, $p < 0.008$) between how people rated a task being carried out in a timely manner and the task being carried out with attention to detail. So the more important it is that a task has to be carried out in a timely manner, the more important it is that it is done with attention to detail. Figure 2 shows participants were consistent with their answers. There is significant positive correlation ($n = 84$, $\tau = 0.325$, $p < 0.001$) between how people rated a task being carried out with attention to detail and the difficulty of the task.

This result is also consistent with how people prioritised types of tasks (see Table V). Participants were asked to rank the statements in Table V from the most important thing the robot can do (rank 5) to the least important one (rank 1). As a result, "security" was consistently rated as the most important task and "entertainment" as the least important one (see Table.VI), when participants were asked "which

TABLE III: Classification of the type and the criticality of the tasks

Classification of task type and its percentage rating		Tasks	Classification of task criticality and its percentage rating		Chi square test with robot appearance
Physical	50%	M. Your paper bin is full. The robot is taking out the trash for you.	Low	61.9%	$\chi^2(10) = 11.965$ $p = 0.287$
	54.8%	A. There is some confetti on your living room floor. The robot is vacuuming confetti off the floor.	Low	71%	$\chi^2(10) = 16.895$ $p = 0.077$
	54.8%	C. You are sitting on the sofa, relaxing. You want to see a dance performance. The robot is performing a dance to entertain you.	Low	72.6%	$\chi^2(10) = 0.611$ $p = 0.611$
	61.9%	F. You want to transport some fragile crystal champagne flutes to the living room. The robot is transporting the glasses you cannot carry.	High	59.5%	$\chi^2(10) = 19.928$ $p = 0.030$
	67.9%	O. You have some hungry guests in the living room. The robot is helping you carrying appetizers from the kitchen to he living room.	High	45.2%	$\chi^2(10) = 13.363$ $p = 0.204$
Cognitive	65.5%	D. You need to prepare a drink for your sister's six-month-old baby. The robot is reading to you the instructions of the recipe sent by the mother.	High	58.3%	$\chi^2(10) = 6.400$ $p = 0.781$
	76.2%	P. You want to cook a new recipe sent by your friend for dinner. The robot is reading to you the instructions of the recipe.	Low	59.5%	$\chi^2(10) = 22.044$ $p = 0.015$
	83.3%	H. Your interview is upcoming. The robot is reminding you of the name of the company and the person you will meet with a short description of their profiles the day before the interview.	High	53.6%	$\chi^2(10) = 8.965$ $p = 0.535$
	84.5%	B. You have just remembered that you need to see the doctor this week for a blood test. The robot is helping you by checking your availability on your diary and booking a suitable appointment with the doctor via the Internet.	High	73.8%	$\chi^2(10) = 14.133$ $p = 0.167$
	85.7%	J. You want to send some flowers to your partner for Valentine's day. The robot is helping you ordering flowers online by showing a selection of your partner's favourite flowers and what time the selected bouquet is guaranteed to be delivered at.	Low	45.2%	$\chi^2(10) = 14.693$ $p = 0.144$
	85.7%	L. Nobody has watered your plants today. The robot is reminding you to water the plants by sending you a notification.	Low	56.0%	$\chi^2(10) = 11.965$ $p = 0.287$
	85.7%	Q. Your job interview is later on today. The robot is calculating the travel time and the best route required to get to the interview and will notify you when it is time to leave to arrive on time.	High	72.6%	$\chi^2(10) = 9.706$ $p = 0.467$
	86.9%	N. You have just received a challenge from your best friend, solving a deconstructed 3D wooden puzzle in less than 5 minutes. The robot is offering to help you to solve the puzzle by giving you clues and showing you pictures of the constructed puzzle.	Low	63.1%	$\chi^2(10) = 6.326$ $p = 0.787$
Both Physical and Cognitive	46.4%	R. You have set up your alarm clock to wake up in the morning to catch a flight. You give to the robot your alarm clock so the robot can move the ringing alarm clock in the morning to force you out of bed to stop the alarm clock.	High	59.5%	$\chi^2(10) = 4.553$ $p = 0.919$
	50%	K. Some visitors have arrived. Your robot approaches them and greets them cheerfully by moving in a circular motion.	Low	57.1%	$\chi^2(10) = 11.886$ $p = 0.293$
	57.1%	I. There is a mess in the living room, your six-year-old nephew left his toys everywhere. The robot helps you collecting the toys and putting them into a box.	Low	63.1%	$\chi^2(10) = 13.073$ $p = 0.220$
	66.7%	E. You have lost your car keys and need to drop off your friend at the train station immediately. The robot is looking for your car keys by moving around the apartment and scanning the area.	High	67.9%	$\chi^2(10) = 8.186$ $p = 0.611$
	75%	G. Your hamster pet escaped from its cage and got lost in the house. The robot is helping you looking for the pet by moving around the house, and scanning different rooms.	High	66.67%	$\chi^2(10) = 11.740$ $p = 0.303$

aspects do you consider important for judging the criticality of a task?" Although "security tasks" were rated as the most critical type of tasks across all sets of questionnaires, there was a noticeable difference depending on the image of the robot participants had viewed. Fifty-seven percent of the participants ranked security as the most important factor for Sawyer, which can be explained by the bulkier appearance of the robot, compared to only 41% of the participants who rated security as the most important factor for Sunflower.

C. R3. Perception of tasks influenced by robot appearance

The Kendall's tau correlation test showed a significant positive correlation ($n = 22$, $\tau = 0.396$, $p < 0.05$) between the Sunflower robot's human-likeness rating and how important it is for the robot to perform a given task correctly. However there was no such correlation for the Pepper robot ($n = 21$, $\tau = -0.44$, $p = 0.814$) and the Sawyer robot ($n = 21$, $\tau = -0.202$, $p = 0.306$). This suggests, the more human-like the Sunflower robot was perceived by participants, the more important they considered that the task performed by the robot should be carried out correctly. Perhaps participants were more likely to consider the importance of the task being carried out correctly, because of the custom-made appearance of the Sunflower's robot, as compared to both Pepper and Sawyer (both manufactured

TABLE IV: How participants scored statements defining task criticality on average

Statements	Sunflower	Pepper	Sawyer	Sunflower + Roomba	Total average
Task being carried out correctly (task being carried out wrongly can lead to irreversible effects such as glass being broken)	4.23	4.10	4.33	4.15	4.20
Task being carried out in a timely manner (task not being carried out in a timely manner could lead to nuisance such as hoovering being done in the living room while you are watching TV)	3.45	3.57	3.29	2.90	3.30
Task being carried out with attention to detail (for example ironing clothes at the right temperature)	3.95	3.90	4.38	3.95	4.05
Difficulty of the task (for example cooking which involves chopping vegetables, heating up a pot of water, etc...)	3.09	3.29	4	3.65	3.51
Importance of the task (for example reminding you to pick up your daughter from school)	4.5	4.52	4.29	4.30	4.40
How personal the task is (for example giving fashion advice)	2.63	2.42	2.14	2.90	2.51
Task being carried out safely in order not to break/damage objects or injure people (e.g. carrying glasses slowly)	4.5	4.62	4.67	4.60	4.60

Fig. 2: Correlations between statements related to participants' criticality rating

	Task being carried out in a timely manner	Task being carried out with attention to detail	Difficulty of the task	Importance of the task	How personal the task is	Task being carried out safely
Task being carried out correctly	0.418**	0.386**	0.024	0.319**	0.002	0.449**
Task being carried out in a timely manner		0.246**	0.097	0.185*	0.120	0.170
Task being carried out with attention to detail			0.325**	0.164	0.221*	0.233*
Difficulty of the task				-0.052	0.150	0.039
Importance of the task					0.067	0.225*
How personal the task is						0.010

**.Correlation is significant at the 0.01 level (2-tailed).
*.Correlation is significant at the 0.05 level (2-tailed).

TABLE V: List of types of tasks for considering what is the most important thing a house robot companion can do

Type of tasks
A. basic household chores (cleaning, taking out trash, vacuuming ...)
B. monitoring the house (checking if the oven is still on, if there is some milk left ...)
C. secretary tasks (acting as a reminder for appointments, setting up appointments, taking messages ...)
D.security tasks (acting as a bodyguard, calling the police when someone tries to break in the house ...)
E. entertainment tasks (displaying a dance to the owner, telling a joke, showing videos...)

TABLE VI: How people prioritised the type of tasks for a robot companion to do

Ranking	Sunflower		Pepper		Sawyer		Sunflower + Roomba		Total	
from the most important to the least	Type of tasks	Number of participants	Type of tasks	Number of participants	Type of tasks	Number of participants	Type of tasks	Number of participants	Type of tasks	Number of participants
Highest priority	D	41%	D	45%	D	57%	D	56%	D	49%
2nd highest priority	B	45%	C	40%	B	47%	B	50%	B	43%
3rd highest priority	C	50%	B	50%	B	33%	C	33%	C	36%
4th highest priority	A	41%	A	40%	AC	43%	AC	39%	A	41%
Lowest priority	E	82%	E	85%	E	90%	E	67%	E	81%

and commercially designed robots). When participants were asked to rate the robot appearance, on a scale of 1 to 7 (1 being very machine-like and 7 being very human-like), Sawyer was clearly classified as machine-like ($n = 21$, $M_{Sawyer} = 2.1$, SD_{Sawyer}=1.55), while Pepper was clearly classified as more human-like ($n = 21$, $M_{Pepper} = 3.76$, $SD_{Pepper} = 1.26$). Sunflower on the other hand was classified between Sawyer and Pepper in terms of human-likeness appearance ($n = 22$, $M_{Sunflower} = 2.57$, $SD_{Sunflower} = 1.12$). A Pearson's Chi square test showed no association between the way participants rated task criticality and the robot's appearance (see Table IV), with the exception of 2 tasks, carrying champagne flutes and reading a recipe sent by a friend. Perhaps there is an association for the carrying task because of the shape of the gripper/hand of the robot. Similarly for the task of reading a recipe sent by a friend, the association could be due to the human-likeness of the robot. But the Chi square test showed no significant results for carrying appetizers and reading a drink recipe. There was no statistically significant correlation between ratings of the robot's human-likeness and participants' ages ($n = 64$, $\tau = -0.054$, $p = 0.561$). This means there is no evidence that younger people tend to perceive robots as more human-like. Similarly the correlation tests showed no statistically significant correlations between the amount of time participants had previously spent interacting with robots, or their familiarity with robots, and how they rated the appearance of the robot. However, there was a significant positive correlation ($n = 64$, $\tau = 0.295$, $p = 0.004$) between how human-like participants rated the appearance of the robot, and how much time they had spent programming robots they previously experienced. So it seems that the more time people have spent on programming robots, the more human-like they tended to rate the robot's appearance. This result has to be taken with caution, because of the small number of participants per set (less than 22), and a tendency for the participants to have little programming experience.

V. Discussion and conclusion

The main outcomes of this study were to show that the perception of task criticality is independent of the robot's appearance, to clarify the definitions of physical and cognitive tasks for a robot, and to define task criticality. As a result, a physical task was defined as "**any task that requires body movement or motion processes, which may be qualified as a laborious task**". A cognitive task was defined as "**any task that requires mental activities or thinking processes, which may involve some decision making**". Task criticality can be defined as "**the importance of a task being carried out safely, correctly and with attention to detail**". The consistency of our findings for criticality shows there is a definite contribution to the community by clarifying how task criticality is perceived for a home robot companion. Moreover, the research highlights the main factors which are considered when assessing for high task criticality (i.e security and safety). For example, entertainment scored low on risks to security and safety, so it was classified as a low critical task.

This paper also showed that the majority of a tasks criticality classification was independent from people's rating of a robot's appearance. If a robot's appearance has the right balance between machine-likeness and human-likeness, the user will tend to focus more on how the robot should perform the task correctly. However further investigations are needed to confirm these results, and it is difficult to evaluate what the right balance is since this finding applied to a custom-made robot, Sunflower. Also the questionnaire study only showed images of the robots. Therefore people did not have an appreciation of how the robots acted dynamically in the real world, which is a limitation of this study. The low number of participants per set of questionnaires for this study is another limitation. But the findings indicate there is definitely a need to further investigate task criticality with live robots in order to further consolidate and refine the definition of task criticality. It is planned to conduct an experimental study with live robots in the future to confirm these results and to investigate further if task criticality can be linked to factors such as sense of control or trust.

In conclusion, this paper has provided working definitions of task criticality, physical and cognitive tasks, and indicated rating of task criticality is independent of robot appearance.

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F.2 Draft of the Journal paper

Research Article Open Access

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How perception of control depends on the criticality of the tasks performed by the robot

Abstract: Robot companions are starting to invade the public market. As people are becoming more familiar with devices such as Google Home, Alexa or Pepper, one must wonder, what is the optimum way for people to control their devices? This paper provides some answers by investigating how much in control of their robot companion people want to be, depending on the criticality of the task the robot performs. A live experiment was conducted in a smart house, with a robot companion performing four different type of tasks. The robot was asked to: book a doctor appointment, help the user to build a Lego character, do a dance, and carry biscuits. The selection of the tasks was based on our previous research. Fifty people took part in the study, and each experienced every tasks in a random order. It was found that participants prefer to be in control of the robot for each tasks apart from the task "carrying biscuits". The results also show that participants felt infantilised when the robot chose the date of the doctor appointment.

Keywords: task criticality, perception of control, robot companion

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1 Introduction

One of the first commercial domestic robot was Roomba from IRobot. Although this robot was single-task, and its main purpose was to vacuum clean the house, researchers found that after having the robot for some time, the users treated the robot more as a pet, in an affectionate way [1]. Some companies used this finding to cleverly market their products, for example Moulinex naming one of its 2018 cooking robot range "robot - cuiseur companion" [2] meaning cooking robot companion. Other companies desperately try to launch a domestic robot companion that can express some intelligence, with facial or voice recognition features, cameras, or an advanced AI able to teach you Yoga for example Lynx by Ubtech [3]. However, while a lot of these devices show technical challenges, they will be available in the near future. Researchers wonder if having such a robot is ethically acceptable [4–6]. Bernotat and Eyssel [7] suggested that anxiety towards robots come from these unanswered ethical questions that the pop-culture sometimes portrays in the worst possible way. Since some previous research in psychology link anxiety and perception of control [8], we previously conducted a live study [9] which demonstrated there is a link between anxiety towards robots and perception of control. This paper attempts to understand what type of interaction people want to have with their domestic robot. Are people ready for a robot that can take decisions on their behalf?

Our article investigates people's perception of control of their robot companion, by measuring how much supervision people consider the robot needs to perform its task correctly (Fig.1). Perception of control is a difficult topic to study as it needs to be explained clearly, what it is that we study. Based on Haggard and Chambon's schematic of sense of control [10], we adapted their schematic and simplified it for our current investigation (See Fig.1). When we consider an action, there are three

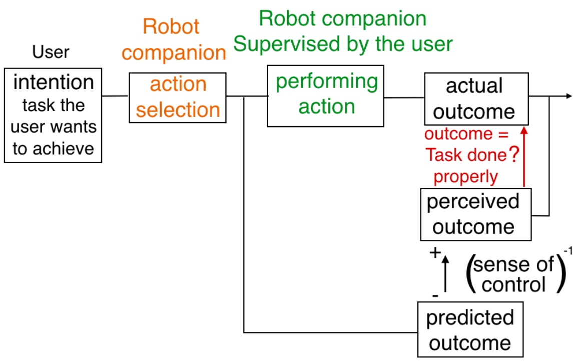

Fig. 1. How perception of control is being studied in this paper [10]

steps which we think of: what is the outcome that we want, what is the action that we need to perform to reach this outcome, and how to perform the action to get it right. This is what Fig.1 displays. To be able to get an accurate measurement, the investigation is conducted with the robot being supervised by the user in one condition, and with the robot performing the action without supervision in the other condition. The measurement of perception of control of the robot companion is therefore conducted through the level of autonomy of the robot. In one of our previous studies [9], we investigated what the preferred level of autonomy of the robot companion was, when the robot had to perform a cleaning task via a cleaning robot. So the robot companion would either activate directly the cleaning robot with or without the acknowledgement of the user depending on the condition, or would send the user to activate the cleaning robot. We found that people preferred the more automated version of the robot companion, when the robot companion activated the cleaning robot without acknowledgement needed from the user. The results also showed that the more controlling a person is, the more likely the person will want to have an autonomous robot, and by autonomous, we mean a robot can make decisions. To consolidate these results, it was chosen to conduct this current experiment with four different tasks. The tasks were chosen based on the results of a previous questionnaire study [11] which investigated what type of tasks are considered "high critical" or "low critical", physical or cognitive. We decided to use 2 high critical tasks, one physical (carrying biscuits), and one cognitive (booking a doctor appointment), and 2 low critical tasks, one physical (dancing), and one cognitive (building a Lego character), to balance the type of tasks for our current live experiment.

The chosen tasks were also evaluated in our current live study to confirm the results of our questionnaire study. We try to chose tasks that reflect what people could use today in an everyday life situation. One of the tasks relates closely to a recent product launched by Google, Google Duplex. Google Duplex was not specifically tested, but the robot used in this experiment was able to book appointments in an automated way, which is what the Google product was seen to be capable of doing in its promotional video. The other tasks were typical everyday tasks, such as helping carrying objects (in this scenario carrying biscuits), or entertainment based task such as building a Lego or dancing.

2 Background research

2.1 How do we study perception of control?

To be able to study perception of control, it is important to understand what locus of control is. Lefcourt theorised it by explaining that locus of control is how much people believe they can affect the relationship between actions and outcomes [13]. Pacherie [12] explained there are three types of intentions we have before executing an action: the practical reasoning of how to perform the intended action (mental effort), the physical requirements to make the action possible (physical effort), and the specification of the movements that are needed to execute the action. To illustrate Pacherie's theory, we draw a simplified schematics of her action specification in Fig.3. Haggard and Chambon investigated the biological pattern of sense of control, which is the neurology of perception of control [10]. We simplified their schematics to apply it for our investigation (see Fig.**??**). As displayed by Fig.**??**, sense of control is the difference between the perception of the outcome, and the predicted outcome. Therefore, to study the perception of control of an action performed by a robot, it is necessary to first identify the predicted outcome of the action performed by the robot. Another way to study perception of control as Pacherie mentioned [12] is also to identify the predicted execution of the action performed by the robot. There is then two ways to study perception of control, either by checking the outcome of the action and see if it matches the user's expectation, or either by verifying if the way the action is performed by the robot matches how the user expected it to be

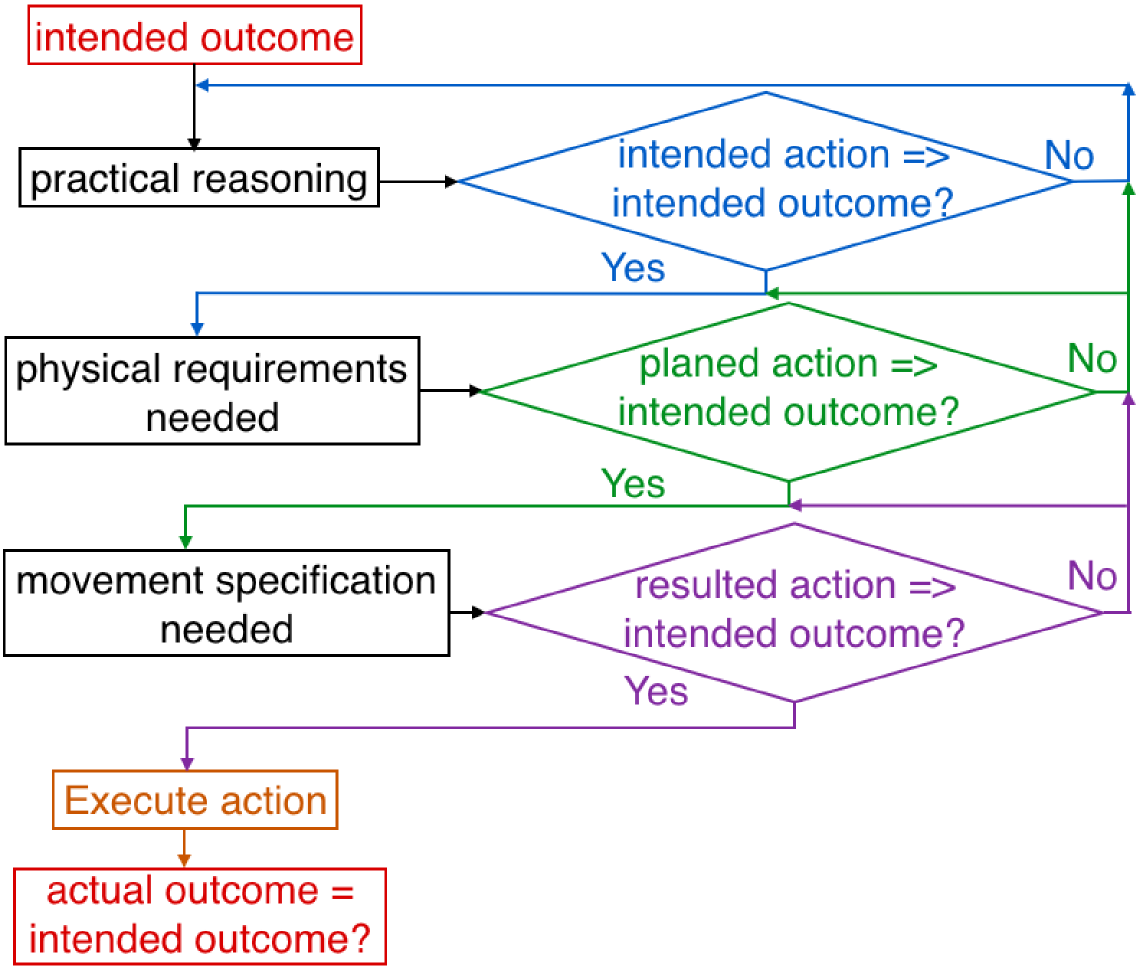

Fig. 2. Simplified schematics of the mental process behind planifying a specific action [12]

performed. For our current investigation, we decided to focus on the latter one.

2.2 What is the difference between a high critical task and a low critical task?

Yanco and Drury were the first researchers to attempt of providing a clear definition of criticality in Human-Robot Interaction (HRI) [14]. They defined criticality as "the importance of getting the task done correctly in terms of its negative effects should problems occur" and a critical task as "to be one where a failure affects the life of a human". As Tzafestas later developed [15], we can distinguish three levels of criticality: high, medium and low. However, none of them specified how to quantify the failure, and neither how to measure its consequences on a human life. Guiochet, Machin and Waeselynck [16] studied safety critical robots. They mainly focused on industrial and advanced robots (robots that have decisional autonomy and are in a non-structured workplace), and detailed well the steps of how to evaluate a task. They look at a task complexity, its function, and the type of safety rules that can be applied. However, thinking of a domestic companion, some household tasks that seemed simple such as ironing have proven to be complex to execute [17], as Dai, Taylor, Liu and Lin well explained in their paper. Ezer, Fisk, Rogers and Wendy [18] conducted a questionnaire study on a robot performing domestic tasks. They defined the criticality of a task depending on how much benefit participants perceived to have. As such, high critical tasks were re-

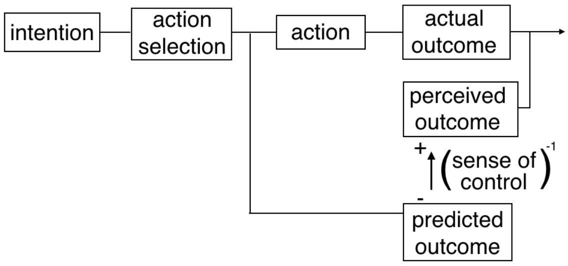

Fig. 3. Simplified schematics of the mental process behind planifying a specific action

lated to emergency tasks and low critical tasks to entertainment. But they did not ask their participants to confirm their rating of criticality. This is why we conducted a previous study on task criticality [11], to identify what the user perceives as a high critical task or as a low critical task. We found that tasks related to entertainment were mostly rated low critical unless the robot is meant to be use only for this purpose. As our users underlined, they would consider a task high critical if the robot were mainly design to do this particular task. For example cleaning would be a high critical task for Roomba. Our previous study showed that the tasks that people generally considered high critical were the ones that potentially had an irreversible effect or would have been difficult to change if a mistake was made (i.e. when rice becomes porridge).
Therefore, we decided to chose for this live investigation four tasks from the results of our questionnaire study. We wanted to vary the tasks, so we chose two high critical tasks and two low critical tasks. One of the task was rated as a physical task by the participants, and the other as a cognitive task. As high critical tasks, we chose booking a doctor appointment (cognitive), and carrying biscuits (physical) to implement in our scenario. We chose as low critical tasks building a Lego character (cognitive) as solving a puzzle was considered low critical. We decided to modify the task into building a Lego to make the task more interactive with the robot. The second low critical task we picked was doing a dance (physical).

3 Method

To investigate how task criticality influence the participant's choice of level of autonomy of a robot companion, a live study was conducted in the Robot House.

Fig. 4. Sunflower robot

This house is a typical British residential home owned by the University of Hertfordshire, and converted into a smart house, which purpose is to host studies in a realistic domestic environment. We used a mobile robot for the experiment called Sunflower (Fig.4). As explained in the introduction, we previously conducted a live study on perception of control [9], and the measurement of the level of control was made through the level of autonomy of the robot. By autonomy, we mean decision making. To remain consistent, we used the same type of measurement in this investigation, which led to two conditions: one in which the robot is supervised by the user while performing the action, another in which the robot is performing the action without supervision from the user.

3.1 Research questions and hypotheses

- **R1**: Is there a relationship between participants' desire to control and their preference of the robot's level of autonomy?
  - H1a: The more participants want to be in control, the less autonomous they want the robot to be.

  - H1b: The more participants want to be in control, the more autonomous they want the robot to be.
- **R2**: Is there a relationship between the perception of control participants had over the robot and their preference of the robot's level of autonomy?

- H2a: The more in control over the robot participants perceive they are, the less autonomous they want the robot to be.
- H2b: The more in control over the robot participants perceive they are, the more autonomous they want the robot to be.

- **R3**: Does the level of criticality (high or low) of the task performed by the robot influences participants' preferences of the robot's level of autonomy?
  - H3a: The higher the criticality of the task performed by the robot is, the less autonomous participants want the robot to be.
  - H3b: The higher the criticality of the task performed by the robot is, the more autonomous participants want the robot to be.
  - H3c: The more controlling a participant is, the higher they tend to rate the criticality of a task.
- **R4**: Is there a relationship between the type of task performed by the robot (physical or cognitive) and participants' preference of the robot's level of autonomy?
  - H4a: The participant's preference of the robot's level of autonomy is independent of the type of task performed by the robot.
  - H4b: The participant's preference of the robot's level of autonomy is dependent of the type of task performed by the robot.
- **R5**: Does a participant's tech savviness (experience and knowledge about technology) influence its preference of the robot's level of autonomy?
  - H5a: The participant's preference of the robot's level of autonomy is independent of how tech savvy the participant is.
  - H5b: The participant's preference of the robot's level of autonomy is dependent of how tech savvy the participant is.

3.2 Experimental design

To be able to investigate the influence of task criticality, four tasks were carefully selected for the experiment: a low critical cognitive task T1, a high critical cognitive task T2, a low critical physical task T3, and a high critical physical task T4. These tasks were classified and pre-validated in one of our previous questionnaire study [11]. Each task consisted of two conditions: one in which the robot was making decisions on how to perform the action, and the other one in which the robot was guided by the participant to perform the action. The tasks were performed by the Sunflower robot (see Fig.4), a custom-made robot that possesses a Pioneer DX robot base, a head and a tray. In the experiment, the robot navigation was autonomous, but the messages on it's tablet, the tray movements, and the robot dancing movements were controlled by the experimenter.

3.2.1 Tasks and conditions of the experiment

- **T1 low critical cognitive task**: The participant wants to build a Lego character with the help of Sunflower.
  - **C1 fully autonomous**: The robot decides when to show the next step of how to build the Lego character. The robot uses it's tablet to show the next step in order to help the participant. The robot displays the next step as soon as it sees that the participant is finished.
  - **C2 semi autonomous**: The participant decides when to see the next step of how to build the Lego character on the robot's tablet.
- **T2 high critical cognitive task**: The participant has to do a blood test in the following days. Sunflower reminds the participant and offers to book the appointment.
  - **C1 fully autonomous**: The robot decides which slot to take for the doctor appointment, after checking the diary. The robot then confirms that a notification will be sent on the day of the appointment 2 hours beforehand. It is implicitly suggested that the robot put the appointment in the digital diary.
  - **C2 semi autonomous**: The robot offers some slots available and the participant chooses the one he/she prefers. The robot asks when the notification should be sent and offers options.
- **T3 low critical physical task**: The participant does a dance with Sunflower. To do so the user shows a dance movement to the robot. The robot then shows a dance movement to the participant. This is then repeated once.
  - **C1 fully autonomous**: The participant does one movement and Sunflower does another random movement to express creativity. For example if the participant steps to the left, the robot will not move to its left but will step to another position, for example forward).
  - **C2 semi autonomous**: The participant does one movement and Sunflower repeats the movement (for example, if the participant turns

right, Sunflower turns right). The same applies to all movements.

- **T4 high critical physical task**: The participant is expecting guests. Sunflower wants to help the participant to carry some biscuits for the guests to the living room.
  - **C1 fully autonomous**: As soon as Sunflower's tray is loaded, the robot goes to the living room.
  - **C2 semi autonomous**: When the participant has finished loading Sunflower's tray, the participant provides voice commands to guide the robot to the living room by giving simple direction commands (go, left, right, stop, destination reached).

3.3 Participation

Fifty participants (28 females and 22 males) were recruited from the University of Hertfordshire and its surroundings, using email advertisements and posters. They were tested individually. Each participant received five pounds sterling as a travel compensation to come to the Robot House. Their age range varied from 19 to 80 (M = 39.98, SD = 14.88). Regarding technology awareness, every participant mentioned having a computer (86% of them use it daily, and 14% use it weekly). Ninety percent of our participants use their smartphone daily. The other ten percent do not possess a smartphone. Twelve percent interact on a daily basis with either a Google Home or an Amazon Alexa. A five-point Likert scale questionnaire (1 being not familiar at all and 5 being very familiar) showed that our participants were mostly unfamiliar with programming robots (M = 1.66, SD = 1.06), had little experience programming robots (M = 1.42, SD = 0.91), and had little experience interacting with robots(M = 1.74, SD = 1.03). Eighty-six percent of the participants have a job which is dominantly intellectual and cognitive (such as an office job as an IT consultant or a lecturer). Eight percent of the participants have a more physical job such as being a golf professional or a bus driver. The rest of the participants mentioned being either retired or being a homemaker.

3.4 Experimental procedure

3.4.1 Greetings

Participants were asked to come directly to the Robot House for the experiment. Each one of them were formally greeted and offered a tour of the Robot House. This allowed the experimenter to introduce the technology (the robot and sensors) and explained the purpose of the house. After this introduction, the visitor was given an information sheet, a consent form and an ID number (used for anonymisation purposes). Some hot beverage was offered while forms were completed. Then the participant was asked to fill in a questionnaire collecting data on demographics (age, gender, job...), technology savviness, and familiarity with robots. This was followed by a Big Five personality test and the desirability control scale (DCS) questionnaire. These questions will help answer the research questions R1 and R5.

3.4.2 Introduction to Sunflower

Sunflower was then introduced to the participant as a robot companion that can help people. It was explained that the interaction with the robot would mainly happen in the living room and in the kitchen. After this, the participant was asked to sit on the sofa and was given a set of questions assessing the user's expectations of the Sunflower robot. This allowed the experimenter to prepare the robot for the first interaction session and to turn on the cameras. One of the four scenario was presented to the participant. He or she was told that the same scenario would occur twice in a row. The experiment was designed this way so that after each scenario, participants could do an immediate comparison on the two conditions (C1 the Sunflower robot being fully autonomous, or C2 the robot being semi-autonomous). So each participant could live each task in a semi-randomised order (4x2). The randomisation was counterbalanced, as half of the participants started the experiment with the first condition C1, and the other half started with the second condition C2. A fourth of the participants started the experiment with Task 1, a fourth with Task 2, a fourth with Task 3 and a fourth with Task 4.

3.4.3 Interaction phase

Once the robot was set, the experimenter leaves the room and tells the participant that he/she can interact with the robot as soon as the experimenter leaves.
Task 1 "You have some time off and want to build a Lego character with the robot."
Condition 1 Sunflower comes to the participant. Sunflower displays the following message to the participant

on its screen: "Today we are going to build a Lego character together. I will guide you through the process. Please once you are ready, say ready so we can start". The participant has to click or say ready to start the process. Then the Sunflower robot opens it's tray to deliver the Lego pieces and starts showing the image instructions on how to build the Ironman Lego character. As soon as the participant finishes the first step, the robot shows the next step. Once the Lego is built, the experimenter comes out of the room and says to the participant now the same scenario will start again. The experimenter provides new pieces on the robot's tray.

Condition 2 The same process starts again except that this time, the robot mentions the participant has to say next to see the next instruction page. Once the session is over, the experimenter comes out of the room and provides a set of questionnaire to the participant.

Task 2 "You have just come back from a trip to Indonesia and you need to do a blood test to check for Dengue fever in the following days."

Condition 1 Sunflower comes to the participant, and displays the following message on its screen: "You need to do your blood test soon. Let me check your diary to see when you are available next for a blood test. I will check with the NHS when your appointment can be booked for." A waiting message appears next "Checking...." The robot then says: "I have found a free slot for you. I have added it to your digital calendar. I will send you a reminder the evening before the appointment and a notification 2 hours before the appointment." The experimenter comes out of the room and says: "Thank you. Now the same scenario will start again."

Condition 2 Sunflower comes to the participant and displays the following message: "You need to do your blood test soon. Let's check on your diary when you are available next for a blood test. I will check with the NHS when they have a free slot." But this time the robot offers free slots in a calendar format for the user to choose from: "I have found these slots for you. Please pick the one you prefer." Once the participant made a choice, the robot offers to choose when the notification of the appointment should be made: "Thank you, your appointment has been booked. When shall I give you a reminder?" The robot offers several options. Once the participant chooses an option, the robot says "Thank you, your choice has been recorded." Once the session is over, the experimenter comes out of the room and provides a set of questionnaires to the participant.

Task 3 "You want to do a dance with the Sunflower robot and show some movements. You will show a sequence of 2 movements from the list below, in any order you like, one step at a time. The list is: move right, move left, move forward, move backward. You can also say it out loud to help the robot identifying the movement."

Condition 1 Sunflower comes to the sofa and offers to the user to do a dancing activity together. The robot positions itself and waits for the participant to start. After each movements that the participant does, the robot produces a random movement different from the one shown by the participant. Once it is over, the experimenter comes out of the room to mention the same scenario will start again.

Condition 2 The same routine happens except that the robot repeats each movement the participant does. Once the two dance steps are done, the participant is given another set of questionnaire.

Task 4 "You are about to receive some guests home. You need some help from Sunflower to carry biscuits from the kitchen to the living room."

Condition 1 As in every scenario, the participant sits on the sofa and the robot comes to him/her. Sunflower reminds the user that some guests are coming: "Hello, you are about to receive guests, let me help you carrying some biscuits from the kitchen to the living room. Let's go to the kitchen." Then the robot and the participants go to the kitchen. Once there, Sunflower opens its tray: "My tray is open. Please put one biscuits box inside." As soon as the participant loads the robot's tray with a biscuit box (three biscuits boxes are on display in the kitchen), Sunflower goes to the living room. Once in the living room, the robot asks for the tray to be unloaded: "Please take the biscuits box off my tray." Once it is done it displays a thank you message: "I hope I was useful. I was happy to help you :)" The experimenter then comes in the room and reset the scenario. **Condition 2** The following scenario is this time given to the participant: "You are about to receive some guests home. You need some help from Sunflower to carry biscuits from the kitchen to the living room. To guide the Sunflower robot, you can give the following commands: go, stop, left, right, destination reached." The same process starts again but once the robot reached the kitchen it reminds the participant it needs to be guided back: " Please guide me with the following commands: go, stop, left, right, destination reached." The participant then says a command and the robot follows. As soon as the living room is reached, the robot displays another thank you message. The experimenter then provides another set of questionnaire.

3.4.4 Last questionnaire and the reward

After the interaction phase, the user is given one last set of questionnaire that evaluates the criticality of each task and provides some information on the the overall interaction. The participant was then offered to take a selfie with the Sunflower robot displaying a personalised message "Hello *name*, it was nice to meet you :)" and £5 was given as a travel compensation.

3.5 Statistical analysis

As a lot of data was collected for this experiment, the data analysis was systematically done this way:

- a descriptive analysis was done to have the general trend of the dataset.
- a Kolmogorov-Smirnov normality test was applied to see what type of correlation test can be done.
- the dataset that will be presented are non-parametric. Therefore a Kendall's tau correlation test was used.
- when a correlation test was not possible to be used due to categorical nominative data, a Pearson Chi Square test was used to measure associations.

4 Results

4.1 Preferred conditions for each task

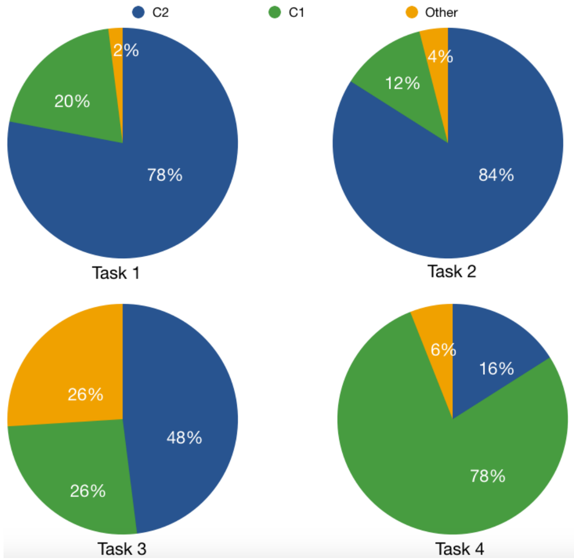

Fig. 5. Preferred conditions for each tasks

To evaluate which conditions people preferred for each tasks, participants answered a multiple choice questionnaire and had to provide the reason for their choice. As the pie charts Fig.5 show, there is clearly a preference for the C2 condition, when the user tells Sunflower how to perform the task, for T1, building a Lego, T2, booking a doctor appointment and T3, dancing. Although it can be noted that less than the majority preferred condition C2 for task 3. People that preferred condition C1 mentioned that they felt that Sunflower was more interactive, could do its own dance and demonstrated intelligence. However, some people that chose "other" said that they had no preferences, one said that the C1 condition was preferable at first due to the fun of the unpredictability of the movements, but would prefer overtime that the robot do as it is told. Some participants were not able to distinguish conditions and therefore pick the "other" category for this task. This is probably due to the design of the task. The scenario might have be unclear that the aim for the participant was to dance together with the robot. As such people may have expected the robot to always follow their movement as they thought they were teaching the robot dancing, or maybe the limitations of the movements of the robot may have made difficult for some people to understand the movement of the robot. Task 4, carrying biscuits, clearly show that participants preferred condition C1 when Sunflower decided to carry the biscuits to the living room on its own. Participants mentioned several reasons for it. Some said it was more comfortable to not micromanage the robot, a lot easier than the C2 condition, or that the robot was faster in this condition. However, some also said that they found it rather difficult to control the robot in the C1 condition and some participants even said that the right and left movement seemed to confuse the robot or the robot was not following the instructions. This could be because the C1 condition was set as a wizard-of-oz, therefore there was a delay between the voice commands and the robot's movements. However, the robot's navigation is autonomous. Therefore even if the experimenter click on the specific direction where the robot was instructed to go by the participant, the robot may prefer to take a shorter route. For example if the participant says to the robot "turn right", if the robot thinks it is more efficient to turn left before turning right, the robot will turn left before turning right, which may give the impression to the participant that the robot is not following the instructions. Sixteen percent still preferred condition C1 because they "retain control", one participant even said that he "wanted to have the biscuit on the other table, not where [he] was originally sitting", while another 6% said that having both options would be good to "test how much Sunflower is reliable" in the C2 condition before fully adopting it.

The Kendall's tau correlation test Fig.6 shows that there is no correlation between how controlling people are and their preferred condition for each tasks. However, there is a significant positive correlation between the preferred condition for Task 1 and the preferred condition for Task 3 (τ_b = 0.317, p = 0.017). So the more participants preferred the robot to be controlled in T1, the more they preferred the robot to be controlled in T3. There is a significant negative correlation between the preferred condition for Task 3 and the preferred condition for Task 4 (τ_b = −0.297, p = 0.025). So the more people preferred the robot to be controlled for Task 3, the more autonomous they wanted it to be for Task 4. This demonstrates consistency between the preferred choice of condition for low critical tasks.

To conclude it seems that participants prefer to be in control of the robot unless it is less efficient for the task to be done.

4.2 R3. Task criticality

To validate the classification of task criticality, participants were asked to rate the criticality of the task performed by the robot from a scale of 1 to 5, 1 being low critical and 5 being high critical. As observed on Fig.8, Task 2 and Task 4 were rated as highly critical tasks (M_{task2} = 3.9, SD_{task2} = 1.11 and M_{task4} = 3.42, SD_{task4} = 1.25). Task 1 seemed to be rated medium critical (M_{task1} = 3.1, SD_{task1} = 1.35) and Task 3 as low critical (M_{task3} = 2.62, SD_{task3} = 1.32). At the end of the experiment, participants were asked to rank the tasks between them from the most critical one to the least. Booking a doctor appointment was considered the most critical task by 72% of the participants. The second most critical task was carrying biscuits with 58%, it is to be noted that 18% considered this task the most critical task, the third most critical task was building a Lego character with 50% (26% ranked this task as the least critical), and finally dancing was considered the least critical task by 64% of the participants. The Kendall's tau correlation test indicated a statistically highly significant positive correlation between users' rating of criticality of Task 1, and users' rating of criticality of Task 3 ($\tau_b = 0.366, p = 0.002$), and between users' rating of criticality of Task 1 and users' rating of Task 4 ($\tau_b = 0.356, p = 0.002$). This means, the more critical people considered Task 1 to be, the more critical they would consider Task 3 and Task 4 to be too. There is also a strong significant positive correlation between people's criticality rating of Task 2 and people's criticality rating of Task 4 ($\tau_b = 0.469, p < 0.001$). So the more critical people rated Task 2, the more critical they also rated Task 4 which is consistent with the way people ranked tasks among them, as Task 2 and Task 4 were rated as the most critical tasks Fig.8, and the same goes between Task 1 and Task 3 as they were both rated the least critical tasks.

The Kendall's correlation test also showed there is a high significant positive correlation between Task 3 criticality rating and Task 4 criticality rating ($\tau_b = 0.388, p =$ 0.001), which means the more critical people thought Task 3 was, the more critical they thought Task 4 was too. It could be explained by the way Task 3 criticality was rated, as the boxplot Fig.8 displays a much wider spread rates compared to the other tasks. This is probably due to the way participants interpreted Task 3, doing a dance with the robots, as some may have thought they had to teach the robot, and this might have increased the criticality of this task.

However, the test revealed no statistically significant correlations between the way people rated the criticality of a task and their choice of preferred condition for any tasks. Therefore hypothesis H3a and H3b were not verified. We cannot say that the level of criticality of a task correlates with the choice of level of control of the Sunflower robot. Also, there was no correlation between the way people rated the criticality of a task and their desired control. It means that it cannot be said that the more controlling people are, the more critical they tend to rate tasks. Therefore H3c was not verified either.

4.2.1 Low critical tasks and perception of control

The test showed no correlations between Task 1 criticality rating and the perception of control of the action for any of the tasks and conditions, the perception of control of the outcome of the action for any of the tasks and conditions, or the perception of control of the robot for any of the tasks and conditions. This means that the way participants rated Task 1, building a Lego character as a low critical task, did not influence the way participants perceived to be in control of the action executed in any of the 4 tasks, or the way participants felt in con-

	Preferred condition Task 1	Preferred condition Task 2	Preferred condition Task 3	Preferred condition Task 4
Desired control	-0.129 0.273	-0.113 0.335	-0.047 0.676	-0.097 0.408
Preferred condition Task 1		-0.010 0.943	0.317* 0.017	0.022 0.876
Preferred condition Task 2			-0.080 0.549	0.088 0.522
Preferred condition Task 3				-0.297* 0.025

*. Correlation is significant at the 0.05 level (2-tailed).

Fig. 6. Correlation between desired control and the choice of the preferred conditions for each tasks

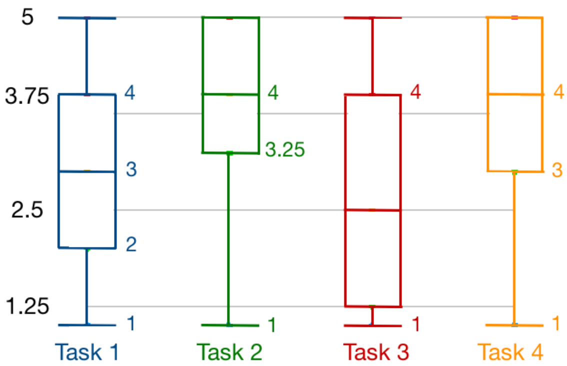

Fig. 7. Task criticality results

trol of the robot during the performance of any of the 4 tasks, or the way participants perceived to be in control of the outcome of the action in any of the 4 tasks, in either conditions. The same results were displayed for Task 3 criticality rating and the perception of control of the action/outcome of the action/robot for any of the tasks and conditions.

4.2.2 High critical tasks and perception of control

4.2.2.1 Task 2: Booking a doctor appointment

Task 2 criticality rating are statistically significantly positively correlated with the perception of control of the robot in T1C2 when the participant decided when the robot displayed the next instruction ($\tau_b = 0.255, p = 0.037$). This means, the more people rated Task 2, as a high critical task, the more people felt in control of the robot in Task 1 when they decided when the robot displayed the next instructions on its tablet to build the Lego character. This could be because participants felt that the success of Task 1 was depending more on their skills as their instructed the robot to show the next task. Therefore it could then be that participants considered that it was more important to do the task correctly when they felt in control of the robot.

There is a positive correlation between Task 2 criticality rating, and the perception of control of the action in T2C2 when the participant decided when to book the doctor appointment ($\tau_b = 0.394, p = 0.002$), and the perception of control of the outcome of the action in T2C2 ($\tau_b = 0.321, p = 0.011$), and the perception of control of the robot in T2C2 ($\tau_b = 0.303, p = 0.013$). So the more critical people thought Task 2 was, the more in control of the action "booking a doctor appointment" they felt, when they chose the time slot to be booked. They also felt more in control of the outcome, as they picked the

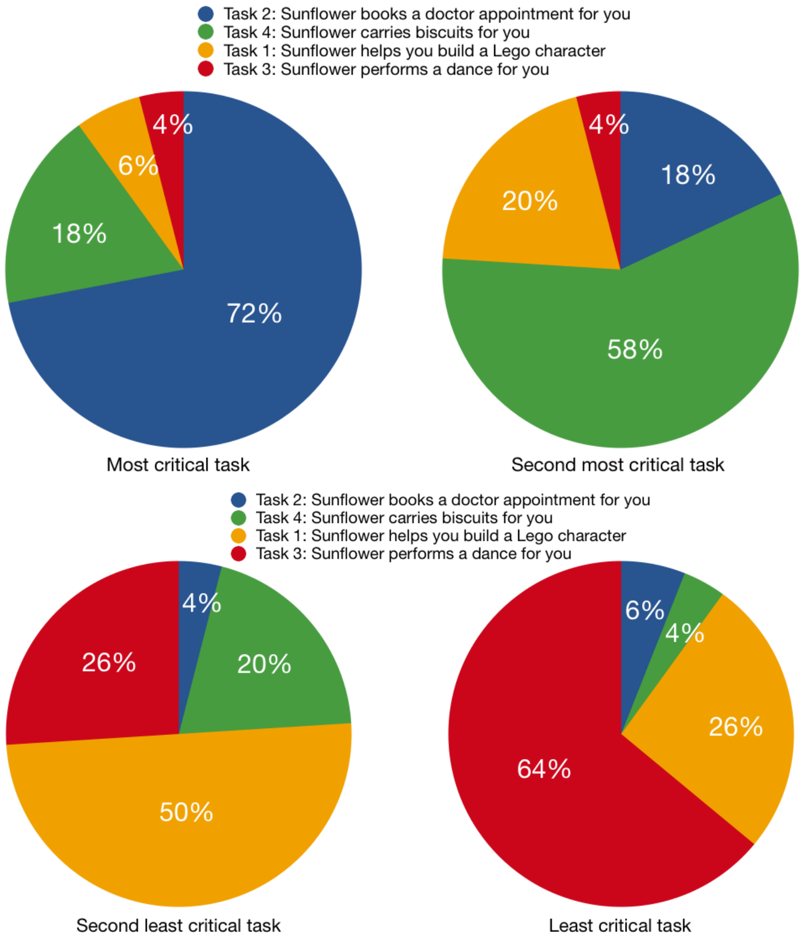

Fig. 8. Task criticality rankings

time slot of the appointment, and they felt more in control of the robot, as the robot was following the user's instructions. This result shows consistency within Task 2 perception of control.

There is also a positive correlation between Task 2 criticality rating and the perception of control of the action in T4C1 when the robot decided to carry the biscuits to the living room on its own ($\tau_b = 0.354, p = 0.003$). So the more critical Task 2 was, the more people felt in control of the action "carrying biscuits" when the robot was maneuvering without instructions. It could be that people felt more in control of the action as the robot was navigating faster and smoother than in the other condition, when the participant had to guide the robot. As Task 4 is a physical task, Sunflower had to move whenever a command was said and it could be that the distance was not matching what people expected or simply as one participant told the experimenter, they could see that the robot was not responding to its sensors, therefore knew in this particular set up that the robot was remote controlled.

4.2.2.2 Task 4: Carrying biscuits

The test revealed a statistically significant positive correlation between Task 4 criticality rating and the perception of control of the robot in T1C2 ($\tau_b = 0.274, p = 0.022$). This means the more critical people rated Task 4, the more in control of the robot people felt when they chose when Sunflower displayed the next step of the instructions to build the Lego character.

There is a significant positive correlation between Task 4 criticality rating and the perception of control the outcome of the action in T2C2 ($\tau_b = 0.285, p = 0.022$). So

the more critical Task 4 is for a participant, the more in control of the outcome, appointment booked, the participant feels in Task 2, when the robot was following the instructions of the user.
There is also a significant positive correlation between Task 4 criticality rating and the perception of control of the outcome of the action in T4C2 when the participant guided the robot to the kitchen with vocal commands ($\tau_b = 0.244, p = 0.037$). So the more critical participants thought Task 4 was, the more in control of the robot they felt when they were guiding the robot from the kitchen to the living room. This result is interesting as participants did not prefer this condition for this task. So although participants felt more in control when guiding the robot, they still prefer condition C1 for this task, when the robot chose to go to the living room as soon as the tray was full. It is most probably because participants prefer efficiency for this physical task compared to control. As many stated, "the [robot] autonomous movement was faster and it required less effort" from the participant.

To conclude, the results demonstrate there is statistically significant correlations between the rating of task criticality and the perception of control of the robot when the task is considered critical. When the task is not considered critical, conclusions cannot be draw regarding the importance of perception of control of the action/outcome of the action/robot. So H3a, H3b and H3c hypothesis were not verified.

4.3 R4. Type of task

Participants were asked to classify tasks according to their type (cognitive, physical, both or other). As expected, the choice of tasks was validated by the participants classification. Task 1 and Task 2 were considered cognitive by respectively 55% and 64% of the participants. Task 3 was either considered physical or both cognitive and physical by respectively 36% and 64% of the users. Task 4 was classified as physical by 28% of the people and both by 66%. A Pearson Chi square test indicated a statistically significant association between the way participants classified Task 2 and their choice of preferred condition for Task 1 ($df(6) = 15.783, p = 0.015$). There is also a significant association between users' classification of Task 2 and their choice of preferred condition for Task 3 ($df(6) = 14.158, p = 0.028$). And finally there is a significant association between people's classification of Task 4 and their choice of preferred condition for Task 4 ($df(6) = 16.873, p = 0.010$).

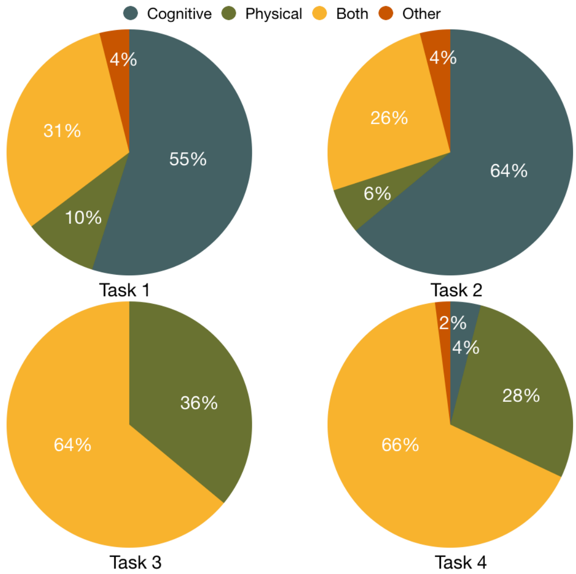

Fig. 9. Classification of tasks according to their type

So the type of task seem to influence participants' choice of preferred condition which disproves hypothesis H4a, but provides an explanation into why Task 4 preferred condition was condition C1 although participants felt less in control. It is more probably because the task is physical therefore, participants may find it more tedious to micromanage than a cognitive task.
People were asked to rate from the scale of 1 to 5

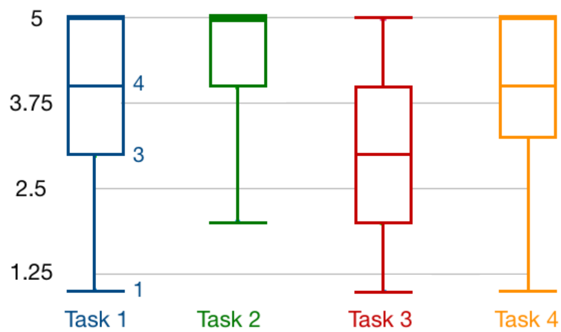

Fig. 10. Ratings of how realistic the task is

(1 being not realistic at all, and 5 being very realistic), how realistic they thought the task was. Task 2 and Task 4 were rated as very realistic ($M_{task2} = 4.28$, $SD_{task2} = 0.93$, and $M_{task4} = 4.04$, $SD_{task4} = 1.01$) while Task 1 was rated as half realistic ($M_{task1} = 3.74$, $SD_{task1} = 1.10$) and Task 3 as not realistic ($M_{task3} =$

2.92, $SD_{task3} = 1.34$). The Kendall's tau correlation test revealed no significant correlations between how realistic people rated a task and people's choice of preferred condition. However, the test indicated a statistically significant positive correlation between Task 3 rating of how realistic the task is, and Task 4 rating ($\tau_b = 0.246, p = 0.039$). So the more realistic people thought Task 3 was, the more they thought Task 4 was. There is also a strong positive correlation between Task 2 rating and Task 4 rating of how realistic the task is ($\tau_b = 0.562, p < 0.001$). The most interesting results is that there is a significant positive correlation between how realistic people rate a task, and how critical they rate the same task (see Fig.11). So the more realistic a task is rated, the more critical the task will be rated.
To conclude we cannot say that the participant's preference of the robot's level of autonomy is independent of the type of task performed by the robot as we found significant associations between the way participants classified tasks and their choice of preferred condition. Therefore hypothesis H4b was verified.

4.4 R2. Perception of control of the robot companion

Participants were asked to rate on a scale from 1 to 5, 1 being "I didn't feel in control at all", and 5 being "I felt I was fully in control", how much they felt in control of the action, how much they felt in control of the outcome of the action and how much they felt in control of the robot during the task, for both conditions (C1: when the robot decides what to do next, and C2: when the participant decides what the robot does next). First, as expected, the results show that people felt more in control when they decided what the robot had to do for each tasks (see Fig.12 for Task 1, Fig.14 for Task 2, Fig.16 for Task 3 and Fig.18 for Task 4). The results are consistent across each tasks. When the user did not feel in control of the action, the user also did not feel in control of the robot (see Fig.12 for Task 1 for example).

4.4.1 Task 1: Building a Lego Character

The results showed that on average, participants preferred the C2 condition compared to C1 for Task 1: 78% of the participants preferred the C2 condition when the robot displayed the following instruction after the user asked for it , while only 20% chose C1 when the robot chose when it was appropriate to display the following instruction, as their preferred choice. 2% was undecided. The Kendall's tau correlation test Fig.13 shows there is statistically a highly significant positive correlation between the perception of control of the action, and the perception of control of the outcome of the action for both conditions (for the preferred condition $\tau_b = 0.657$, and $p < 0.001$, for the other condition ($\tau_b = 0.591, p < 0.001$). There is also a highly significant positive correlation between the perception of control of the outcome of the action and the perception of control of the robot for both conditions (for the preferred condition $\tau_b = 0.689, p < 0.001$, for the other condition $\tau_b = 0.594, p < 0.001$). This means that the more people felt in control of the action building the Lego character, the more they felt in control of the outcome of the action (having a Lego character built) and the more they felt in control of the robot. This is true for the user's preferred condition and the user's non-preferred condition, which demonstrate the consistency of the results for Task 1.

4.4.2 Task 2: Booking a doctor appointment

For Task 2, the descriptive statistics Fig.14 tell us there is an even clearer difference of perception of control between C1 (the robot being fully autonomous) and C2 (the robot being semi-autonomous) compared to Task 1 Fig.12. Participants clearly did not feel in control at all in this scenario "booking a doctor appointment" in C1, when the robot chose the appointment time slot for its user. For this task 2, 84% of the participants preferred the C2 condition when they decided their time slot for the doctor appointment, while 12% preferred the C1 condition, when the robot chose the time slot, and 4% were undecided. The Kendall's tau correlation Fig.15 test reveals the same consistency found for Task 1: there is a statistically strong positive correlation between the perception of control of the action and the perception of control of the outcome of the action for both conditions (for the preferred condition$\tau_b = 0.805, p < 0.001$, and for the other condition $\tau_b = 0.701, p < 0.001$). There is also a strong significant negative correlation between the perception of control of the action for the preferred condition and the perception of control of the action for the other condition ($\tau_b = -0.498, p < 0.001$). This means that not only, the more in control of the action "booking a doctor appointment" the user perceived to be, the more in control of the outcome (doctor appointment booked) the user felt and the more in control of the robot the user perceived to be in his/her preferred condition, in

	Task 1 criticality rating	Task 2 criticality rating	Task 3 criticality rating	Task 4 criticality rating
Task 1 realism ratings	0.290* 0.014	0.166 0.169	0.239* 0.042	0.043 0.716
Task 2 realism ratings	0.224 0.064	0.542** 0.000	0.160 0.187	0.426** 0.000
Task 3 realism ratings	0.148 0.199	0.129 0.276	0.495** 0.000	0.164 0.160
Task 4 realism ratings	0.083 0.488	0.437** 0.000	0. 337** 0.005	0.468** 0.000

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Fig. 11. Correlation table between ratings of task criticality and task realism

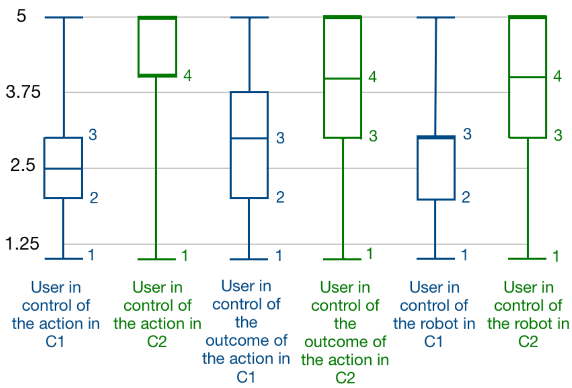

Fig. 12. Task 1: building a Lego character

this case mostly C2 (see Fig.14), it also means that the more in control of the action the user felt in his/her preferred condition, the less in control the user felt in the other condition.

4.4.3 Task 3: Doing a dance

Task 3 descriptive statistics results Fig.16 were less pronounced than the ones for Task 1 and for Task 2, in terms of difference between the C1 fully autonomous condition and the C2 semi-autonomous condition. However, the results still show that people perceive to be more in control in the C2 semi-autonomous condition compared to the C1 fully autonomous condition. 48% of the participants preferred the C2 condition when the robot was repeating the user's dance step, while 26% of the users preferred the C1 condition when the robot was doing an unpredictable dance step and 26% were not sure what they prefer. The Kendall's tau correlation test Fig.17 shows the same statistical significant correlation seen for Task 1. There is a highly significant positive correlation between the perception of control of the action "doing a dance" and the perception of control of the outcome of the action for both conditions (for the preferred condition $\tau_b = 0.887, p < 0.001$, and for the other condition $\tau_b = 0.793, p < 0.001$). We find the same consistency in the correlation results for Task 3 than the ones for Task 1. So the more the user perceived to be in control of the action "doing a dance", the more the user felt in control of the outcome of the action (dance done) and the more the user perceived to be in control of the robot in the preferred condition. The same results was found in the other condition.

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 1
User in control of the action in the preferred condition	-0.230 0.065	0.657** 0.000	-0.140 0.261	0.546** 0.000	-0.144 0.248	-0.073 0.587
User in control of the action in the other condition		0.165 0.183	0.591** 0.000	-0.237 0.053	0.500** 0.000	-0.158 0.233
User in control of the outcome of the action in the preferred condition			-0.076 0.539	0.689** 0.000	-0.001 0.992	0.111 0.408
User in control of the outcome of the action in the other condition				-0.174 0.156	0.594** 0.000	-0.051 0.702
User in control of the robot in the preferred condition					-0.139 0.258	0.186 0.162
User in control of the robot in the other condition						-0.014 0.916

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 13. Correlation table for Task 1 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.

4.4.4 Task 4: Carrying biscuits

It can be noticed that Task 4 descriptive statistics Fig.18 displays less difference between C1 the fully autonomous condition and C2 the semi autonomous condition compared to the other tasks. For Task 4, 18% of the users preferred C2 when they guided the robot to the living room, while 78% of them preferred C1 when the robot decided to go to the living room on its own, and 6% were undecided. The Kendall's tau correlation test Fig.19 indicates a statistical strong significant positive correlation between the perception of control of the action and the perception of control of the outcome of the action for both conditions(τ_b = 0.671, p < 0.001 for the preferred condition, and τ_b = 0.776, p < 0.001). There is also a highly significant positive correlation between the perception of control of the outcome of the action and the perception of control of the robot for both conditions (for the preferred condition τ_b = 0.641, p =< 0.001, and for the other condition τ_b = 0.803, p < 0.001). This means that the less the user perceived to be in control of the action "carrying biscuits", the less the user felt in control of the outcome "biscuits carried to the living room", and the less he/she perceived to be in control of the robot in his/her preferred condition. This is really interesting as for the majority of participants, the preferred condition was C1 when the robot decided to carry the biscuits to the living room on its own without guidance from the participant.

4.4.5 Perception of control across tasks

A Kendall's tau correlation test showed no significant correlation between the user's perception of control of the action/outcome of the action/robot in either conditions in Task 1, and the user's choice of preferred condition. However, the test revealed a significant negative

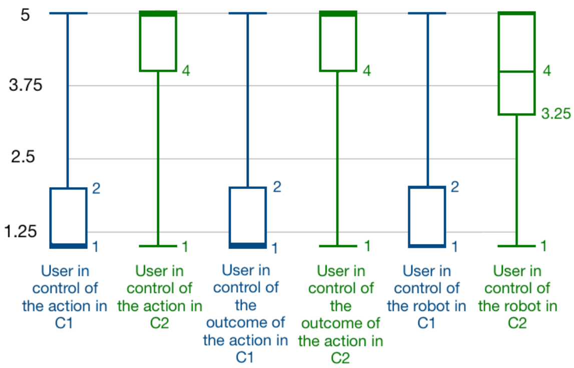

Fig. 14. Task 2: booking a doctor appointment

correlation between the participant's perception of control of the action in T2C1 and the participant's choice of preferred condition ($\tau_b = -0.297, p = 0.027$). We found the same significant negative correlation between the participant's perception of control of the outcome of the action in T2C1 and the participant's choice of preferred condition ($\tau_b = -0.299, p = 0.024$). So the more in control the user felt when Sunflower was in charge, the less the user wanted to "supervise" the robot meaning, the more autonomous the participant preferred the robot to be for Task 2. There is also a statistically significant negative correlation between the participant's choice of preferred condition and the participant's perception of control of the action in T4C1 ($\tau_b = -0.310, p = 0.015$), the participant's choice of preferred condition and the participant's perception of control of the outcome of the action in T4C1 ($\tau_b = -0.297, p = 0.018$), and between the user's choice of preferred condition and the user's perception of control of the robot in T4C1 ($\tau_b = -0.319, p = 0.012$). So the more the user felt in control of the action/outcome of the action/robot when Sunflower was in charge of carrying the biscuits to the living room, the less the participant wanted to look after the robot, so the more autonomous they wanted the robot to be. Task 3 results were different (see Fig.20. The test indicated a statistically significant positive correlation between the user's choice of preferred condition and the user's perception of control of the action in T3C2 ($\tau_b = 0.327, p = 0.008$), the user's choice of preferred condition and the user's perception of control of the outcome of the action in T3C2 ($\tau_b = 0.452 p < 0.001$), and between the user's choice of preferred condition and the user's perception of control of the robot in T3C2 ($\tau_b = 0.289, p = 0.018$). Therefore it can be said that the more in control the participant perceived to be when he/she was in charge of the dance, the more he/she wanted to supervise the robot, meaning the less autonomous he/she preferred the robot to be.

To conclude, we can see that the results are consistent across the tasks and conditions. When people felt in control of the robot for one condition, they would also feel in control of the action and in control of the outcome of the action for this same condition. The results did not validate the H2a hypothesis. There is a lot more subtlety into the link between how the user perceives to be control of the action/outcome of the action/robot and its preferred choice of level of autonomy of the robot. The results show that the more in control the participant felt for Task 2 and Task 4, the more autonomous they wanted the robot to be, which proves the H2a hypothesis. However, for Task 3 it was found that the more the participant felt in control, the less autonomous they wanted the robot to be, which proves the H2b hypothesis.

4.5 R1. Personality effect

To measure how controlling people are, we used the standard desirability control scale [19]. This test uses everyday life questions to study how much in control people want to be in general. A Kolmogorov-Smirnov normality test revealed that we have a normal distribution population in terms of how controlling people are ($D(50) = 0.104, p = 0.200$), which is illustrated by the boxplot Fig.21 and the histogram in Fig.22.

To measure personality, participants were asked to respond to the standard Big Five personality test [20]. This test is a 7 point Likert scale that measures extraversion, agreeableness, conscientiousness, neuroticism sometimes called emotional stability and openness. The results show that our participants were in average open-minded with a 5.73 score and conscientious with a 5.44 score. The average score of extraversion was high with a 4.36, while the average score of agreeableness and neuroticism were low (3.01 and 3.03 respectively). As the boxplots of the personality test displays in Fig.23, our pool of participants do not represent a normal distribution. The Kolmogorov-Smirnov normality test confirmed that Agreeableness ($D(50) = 0.144, p = 0.011$), Conscientiousness ($D(50) = 0.220, p < 0.001$), Neuroticism ($D(50) = 0.126, p = 0.045$) and Openness ($D(50) = 0.155, p = 0.004$) do not follow a normal distribution. Therefore it was decided to use non-parametric correlation tests. A Kendall's tau correlation test indicated that there is a statistically significant negative correlation between Extraversion and Neuroticism ($\tau_b =$

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 2
User in control of the action in the preferred condition	-0.498** 0.000	0.805** 0.000	-0.453** 0.000	0.701** 0.000	-0.463** 0.000	-0.289* 0.037
User in control of the action in the other condition		-0.463** 0.000	0.868** 0.000	-0.282* 0.027	0.749** 0.000	0.193 0.162
User in control of the outcome of the action in the preferred condition			-0.494** 0.000	0.698** 0.000	-0.471** 0.000	-0.165 0.234
User in control of the outcome of the action in the other condition				-0.407** 0.001	-0.787** 0.000	0.183 0.179
User in control of the robot in the preferred condition					-0.394** 0.001	-0.177 0.190
User in control of the robot in the other condition						0.211 0.117

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 15. Correlation table for Task 2 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.

Fig. 16. Task 3: doing a dance

$-0.218, p = 0.039$). This means that the more extraverted someone is, the more negative he/she will tend to be. The test also showed there is a highly significant negative correlation between Conscientiousness and Neuroticism ($\tau_b = -0.323, p = 0.003$). So the more conscientious someone is, the more he/she will tend to be moody and to experience feelings such as anxiety, worry, fear, anger, frustration, envy, jealousy, guilt, depressed mood, and loneliness.. Interestingly the test also revealed that the more openminded people are, the more controlling they tend to be, through a significant positive correlation test between openness and the desirability control scale ($\tau_b = 0.254, p = 0.016$).

There is a highly significant negative correlation between Openness and the preferred condition participants had for Task 1, building a Lego character ($\tau_b = -0.323, p = 0.009$). This means that the more openminded participants were, the less they preferred the semi-autonomous version of the robot (when they choose when Sunflower had to show them the next step of the instructions to build the Lego character), therefore the more willing participants were to have a fully autonomous version of the robot (when Sunflower decided when to show the user the next step of the instructions.). This was not verified for the other tasks. There is no statistically significant correlation between Openness and the preferred condition participants had for Task 2 ($\tau_b = -0.126, p = 0.309$), Openness and the preferred condition participants had for Task 3 ($\tau_b = -0.177, p = 0.138$), and Openness and the preferred condition participants had for Task 4 ($\tau_b = -0.26, p = 0.832$).

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 3
User in control of the action in the preferred condition	-0.126 0.378	0.887** 0.000	-0.104 0.468	0.753** 0.000	-0.014 0.925	0.066 0.651
User in control of the action in the other condition		-0.73 0.613	0.793** 0.000	0.052 0.718	0.798** 0.000	0.154 0.304
User in control of the outcome of the action in the preferred condition			-0.085 0.556	0.833** 0.000	0.055 0.706	0.080 0.583
User in control of the outcome of the action in the other condition				-0.007 0.963	0.795** 0.000	0.147 0.329
User in control of the robot in the preferred condition					0.202 0.164	0.278 0.57
User in control of the robot in the other condition						0.227 0.136

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 17. Correlation table for Task 3 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.

A Kendall's correlation test showed there is no statistically significant correlation between personality traits and the perception of control in the participants' preferred condition for Task 1. However, there is a statistically significant negative correlation between the desirability control scale and the perception of control of the Sunflower robot for Task 2 ($\tau_b = 0.274, p = 0.014$). So the more controlling the participant is, the less he/she felt in control of the robot when the doctor appointment was booked. There was no significant correlation between personality traits and the perception of control in the user's preferred condition for Task 3 and Task 4. Therefore, hypothesis H1a and H1b are not validated.

4.6 R5. Experience and knowledge of technology

To measure participants' experience of technology, participants were asked what type of technology they use and to estimate how often they use those everyday technology. Based on participants' answers, we scaled the frequency of usage of technology as such: 0= do not have one, 1= 2- 3 times a month, 2= 2- 3 times a week, 3=more than 3 times a week, 4=less than 30 min a day, 5=1- 2 hours a day, 6=2- 3 hours a day, and 7=More than 3 hours a day. Then we asked participants to rate their familiarity with robots on a scale of 1 to 5 (1 being not familiar at all and 5 being very familiar). As a results, 88% of our participants own a smartphone (98% of them would use it everyday), 86% possess a computer or a laptop they would use everyday, 32% own a tablet they would use everyday, 6% have a smartwatch they use everyday and 12% use a Google Home or Alexa ev-

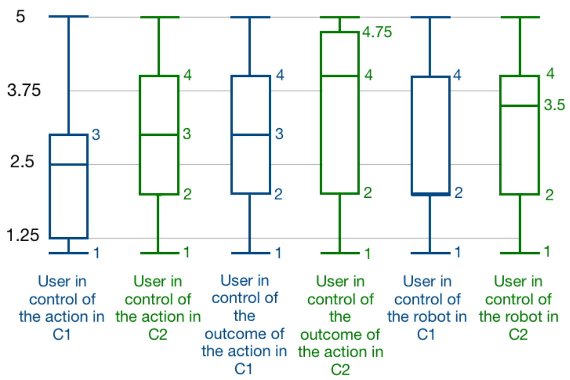

Fig. 18. Task 4: carrying biscuits

eryday. Regarding experience with robots, the mean was very low regarding familiarity with programming robots (M = 1.66, SD = 1.06), experience with programming robots (M = 1.42, SD = 0.91) and familiarity with interacting with robots (M = 1.74, SD = 1.03). When asked how often participants interacted with robots, half of them said never, and 36% of them mentioned on a few occasions before (see Fig.24).

A Kendall's correlation test revealed statistically significant correlations between the frequency of the usage of certain technology and the choice of the preferred conditions participants had for each tasks (see Fig.25). There is a significant negative correlation between how much time people spend on their computer and people's choice of the preferred condition for Task 1($\tau_b = -0.283, p = 0.030$). This means the more often people spend time on their computers, the less they will want to be in control of the robot, when the robot is giving instructions on how to build a Lego character. There is also a significant negative correlation between how often people spend time on their smartphone and people's preferred condition for Task 2 ($\tau_b = -0.306, p = 0.017$). So the more time people spend on their smartphone, the less they want to be in control of the robot when the robot is booking a doctor appointment. The same correlation was found for smartwatch ($\tau_b = -0.368, p = 0.009$). However, the same correlations for Task 3 and Task 4 were not found. Instead, there is a significant positive correlation between how often people use their tablet and their preferred condition for Task 3 ($\tau_b = 0.247, p = 0.049$). So the more people use their tablet, the more they want to be in control of the robot when the robot is dancing.

To conclude, there is a correlation between participants' technology savviness and their preferred level of autonomy of the robot, which proves hypothesis H5b. We found that for both cognitive tasks, the more participants spent time on their smartphone or computer, the less they want to be in control of the robot. However, our data did not indicate that experience with robots influence participants' preference of level of autonomy of the robot.

5 Limitations of the study

One of the main difficulty of the design of the experiment was to implement the 4 tasks with the 2 conditions in a consistent way. One of the weaknesses of this study is the Wizard-of-Oz set up. Although the navigation of the robot was fully autonomous, voice and gesture recognition were not implemented in the robot due to time constraint. Another weakness of the study is the selection of the tasks. For example the choice of dancing as a low critical task to perform for the robot. Many participants were confused into how Sunflower would perform a dance, and some did not see the movements of the robot as dancing movements. In addition, although the high critical tasks were previously validated [11], we could not use more extreme tasks (such as Sunflower helping to put off a fire in the kitchen) for ethical reasons. In such extreme cases, participants may react differently [21].

6 Discussion

In this study we investigated how much in control of the robot participants want to be depending on the task the robot is performing.

6.1 Effect of personality on perception of control

There is no correlation between how controlling people are and how autonomous they wanted the robot to be for any of our tasks, so hypothesis H1a and H1b were not verified. However, it was found that the more controlling people are, the less they perceive to be in control of the action in their preferred condition when the robot booked a doctor appointment. It was also found for the same action, that the more controlling people are, the less they felt in control of the robot in their preferred condition. Therefore it can be said that for a high critical cognitive task, controlling people are less

	User in control of the action in the other condition	User in control of the outcome of the action in the preferred condition	User in control of the outcome of the action in the other condition	User in control of the robot in the preferred condition	User in control of the robot in the other condition	User's preferred condition in Task 4
User in control of the action in the preferred condition	-0.090 0.462	0.671** 0.000	-0.139 0.258	0.718** 0.000	-0.168 0.171	0.127 0.343
User in control of the action in the other condition		-0.071 0.557	0.776** 0.000	-0.093 0.453	0.780** 0.000	0.116 0.377
User in control of the outcome of the action in the preferred condition			-0.099 0.415	0.641** 0.000	-0.178 0.143	0.043 0.747
User in control of the outcome of the action in the other condition					0.803** 0.000	-0.046 0.728
User in control of the robot in the preferred condition						-0.017 0.901
User in control of the robot in the other condition						-0.039 0.768

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 19. Correlation table for Task 4 between the participant's preferred condition and the participant's perception of control for their preferred condition and their non-preferred condition.

	Task 3: user's perception of control of the action when Sunflower is in charge (C1 condition)	Task 3: user's perception of control of the action when he/she is in charge (C2 condition)	Task 3: user's perception of control of the outcome of the action when Sunflower is in charge (C1 condition)	Task 3: user's perception of control of the outcome action when he/she is in charge (C2 condition)	Task 3: user's perception of control of the robot when Sunflower is in charge (C1 condition)	Task 3: user's perception of control of the robot when he/ she is in charge (C2 condition)
Task 2 choice of preferred condition	-0.179 0.180	-0.050 0.693	-0.279* 0.037	-0.031 0.806	-0.070 0.607	-0.050 0.694
Task 3 choice of preferred condition	-0.083 0.518	0.327** 0.008	0.087 0.498	0.452** 0.000	-0.001 0.992	0.289* 0.018
Task 4 choice of preferred condition	0.068 0.609	-0.131 0.301	0.022 0.866	-0.264* 0.037	0.068 0.613	-0.074 0.558

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Fig. 20. Correlation table between Task 3 perception of control and user's choice of preferred condition

likely to feel in control of the robot and the action the robot is performing, even if the robot is acting the way people preferred (being fully autonomous by taking all the decisions or being semi-autonomous, waiting for the

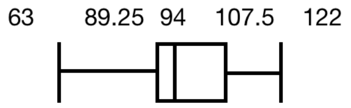

Fig. 21. Desirability Control Scale

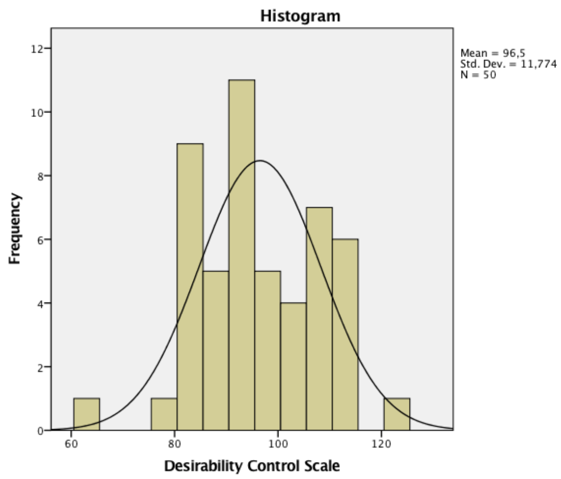

Fig. 22. Desirability Control Scale population distribution

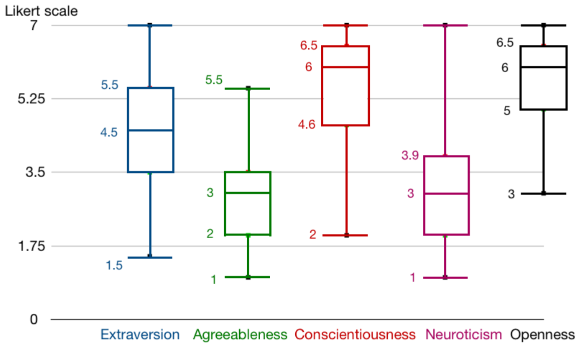

Fig. 23. Personality test results

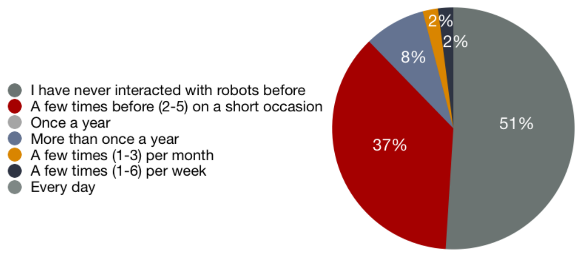

Fig. 24. Frequency of interaction with robots before the experiment

user to take the decisions). It could be that since this task (Task 2 booking a doctor appointment) was also rated as the most realistic task, people could relate to it more easily and imagine its consequences better than for other tasks, which would explain why we did not find this correlation for other tasks. Some personality effect across every tasks was also found, such as having a negative correlation between Openness and the user's preferred condition for each task. The more openminded people are, the less they are willing to control the robot, which means, the more they prefer the robot to be autonomous. These findings complement Meerbeek et al. [22] studies where they found that the personality of the robot influences the user's preferred level of control of the robot. However, personality results have to be taken with caution, as the literature have shown, some papers show that people preferred robot that express a similar personality [23] while others have shown the opposite [24]. It is suspected that this difference comes from the main function the robot expresses. As this live experiment demonstrated, depending on the type of task the robot performs, the user have different expectations from the robot.

6.2 Perception of control, task criticality and type of task

6.2.1 Low critical tasks

The results show that for Task 1, building a Lego character and Task 3, doing a dance, participants preferred the C2 condition when the robot was following their instructions. This contradict some early research done by Meerbeek et al.[22] where he found that for a TV assistant task, his participants show no preference on the user's level of control. But as the researchers mentioned in their article, they focus the contrast on the personality behaviour that the robot was displaying, therefore this has to be taken with caution. Also, it does not appear that the participants were asked to rate the criticality of their task. The results of this experiment regarding the low critical tasks are consistent with the findings of the first live experiment described in Chapter **??** regarding the cleaning task. And the questionnaire study described in Chapter **??** classified the cleaning task as a low critical task. The results of this live experiment are not only consistent with the previous results but also reinforced by the fact that 50 people took part in the study while only 33 people took part on the Meerbeek's study

	Frequency usage of smartphone	Frequency usage of computer/ laptop	Frequency usage of tablet	Frequency usage of smartwatch	Frequency usage of Alexa/ Google Home
Task 1 preferred condition	-0.107 0.404	-0.283* 0.030	0.085 0.514	0.138 0.323	-0.089 0.522
Task 2 preferred condition	-0.306* 0.017	0.024 0.856	0.117 0.370	-0.368** 0.009	-0.042 0.761
Task 3 preferred condition	-0.006 0.962	0.011 0.934	0.247* 0.049	0.050 0.707	0.045 0.735
Task 4 preferred condition	-0.077 0.545	-0.043 0.738	-0.248 0.056	-0.059 0.671	-0.085 0.536

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Fig. 25. Correlation table between the usage frequency of technology and participants' preferred conditions

that was conducted more than 10 years ago. Therefore it is safe to say that for low critical tasks, participants prefer to be in control of the robot.

6.2.2 High critical tasks

As our results show for Task 2 and Task 4, the more the participant felt in control when the robot was in charge (condition C1), the more the participant was willing to let the robot be in charge. Perhaps this was the case because Task 2 and Task 4 are both considered critical tasks and therefore, it is more of a relief for the participant if the robot can do the task correctly.
However, the data also shows that despite this result, the majority of our participants preferred the C2 semi-autonomous condition for Task 2 while they preferred the C1 fully autonomous condition for Task 4. Task 2 is a cognitive task which is about scheduling participants day life, therefore as many mention, they "need to have control of the situation", they "want to make [their] own decisions based on the options available" and they "like to make the final choice". When Sunflower booked the appointment for the participant in the C1 fully autonomous condition, the robot picked the first available slot on the digital calendar, which means if for a particular reason this day the participant wanted to leave the day open for other plans, he/she would have had to mention it in the digital calendar Sunflower was referring to. This means that it would have been more hard work for the participant to implement these plans and ideas in the calendar, and to let Sunflower know rather for the participant to take an overall decision based on an overview of potential events/appointments that could happen that day. Some participants felt they were "infantilised" which is one of the risks mentioned by early research on ethics [4]. This research confirms to some extent the danger mentioned by Lucidi [25]. This is most probably why almost every participants did not prefer the robot to take the decision for the doctor appointment as this relates to how people manage their life.
However, the same results did not apply for the high critical physical task "carrying a biscuit". For Task 4, carrying biscuits, people preferred the condition C1 as they mention it was difficult to maneuver the robot with voice commands in the C2 condition but also because many said it was easier this way ("it is more comfortable to not micromanage it") and that the robot demonstrated more intelligence. Task 4 being a physical task, people could also see the robot carrying the biscuits from the kitchen to the living room and therefore had an immediate overview of what is happening. So even if the robot is not as accurate as they would want it

to be regarding the exact location of where the biscuits should be carried in the living room, the main task carrying the biscuits was accomplished. When it comes to a physical task, people do not expect having to supervise and micromanage it, at least in this case with carrying biscuits, because it is more hard work for them to do the supervision rather than to do the task itself, while for the cognitive task, it is the opposite. Therefore it is most probably why participants prefer the C1 fully autonomous condition as they felt in control of the situation.
Those results could also be explained by how realistic people perceived the task to be. As Task 2 was perceived more realistic than Task 4, although both were rated very realistic on average, as people then could relate more easily to Task 2, this could also be why participants prefer the C2 semi-autonomous condition.
So our results here demonstrated that people would be willing to let the robot being fully autonomous if they feel in control of the situation, which is obviously more difficult to implement for cognitive tasks, as it is harder to adapt to each person's habit.

6.3 Effect of technology savviness

The results revealed that the more time people spend on their everyday technology, the more autonomous they want the robot to be. This could be the case because Sunflower's interface was a tablet. Since the tablet is a well-spread technology, people are used to manipulate one or at least something that is similar, such as a smartphone or a computer. If the robot's interface would have been something less familiar, people might have prefer the robot to be less autonomous. So our results confirm there is an habituation effect which can be exploited by roboticists. However, this is only true for smartphones and computers. There was no such findings for people having experience with robots. It could be because the majority of our participants were inexperience robot users, therefore it is difficult to draw conclusions with such data.

7 Conclusion

To conclude our results show there is a strong correlation between people's perception of control and their choice of how autonomous the robot should be. However, our results did not exactly corroborate our findings from our previous investigations [9]. As suspected, people's preference of level of autonomy are subtle. The type of task and the criticality of the task influence the way people want their robot to react. For a critical cognitive task, people prefer the robot to be semi-autonomous so they could take the final decision, whereas for a critical physical task, people prefer the robot to be autonomous as they did not want to micromanage the robot while it was performing the task. The results demonstrated that people would be willing to let the robot being fully autonomous provided they feel in control of the situation, which is more difficult to implement for cognitive tasks than for physical tasks, as it is harder to predict people's intentions and habits. It would be good to investigate in the future if we can change people's preference for cognitive critical tasks, by having a robot that would be more inquisitive.

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F.3 "The conversation website" article

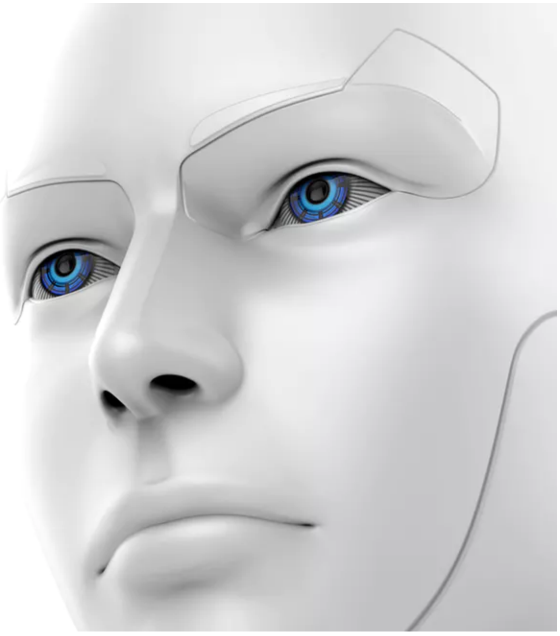
The original link where the article was published is: https://theconversation.com/robot-companions-are-coming-into-our-homes-so-how-human-should-they-be-63154
The website was last accessed on the 24th January 2019. The printed pdf version of the article is as followed:

THE CONVERSATION

Academic rigour, journalistic flair

Robot companions are coming into our homes – so how human should they be?

August 9, 2016 1.09pm BST



Shall I take the spare room? Shutterstock

Author

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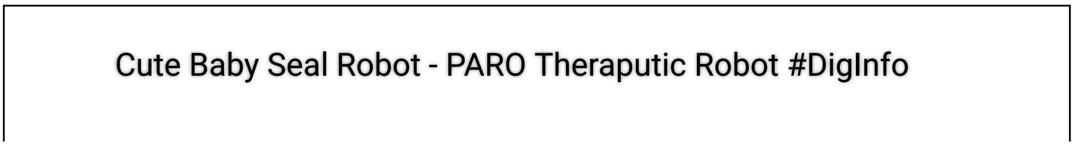
What would your ideal robot be like? One that can change nappies and tell bedtime stories to your child? Perhaps you'd prefer a butler that can polish silver and mix the perfect cocktail? Or maybe you'd prefer a companion that just happened to be a robot? Certainly, some see robots as a hypothetical future replacement for human carers. But a question roboticists are asking is: how human should these future robot companions be?

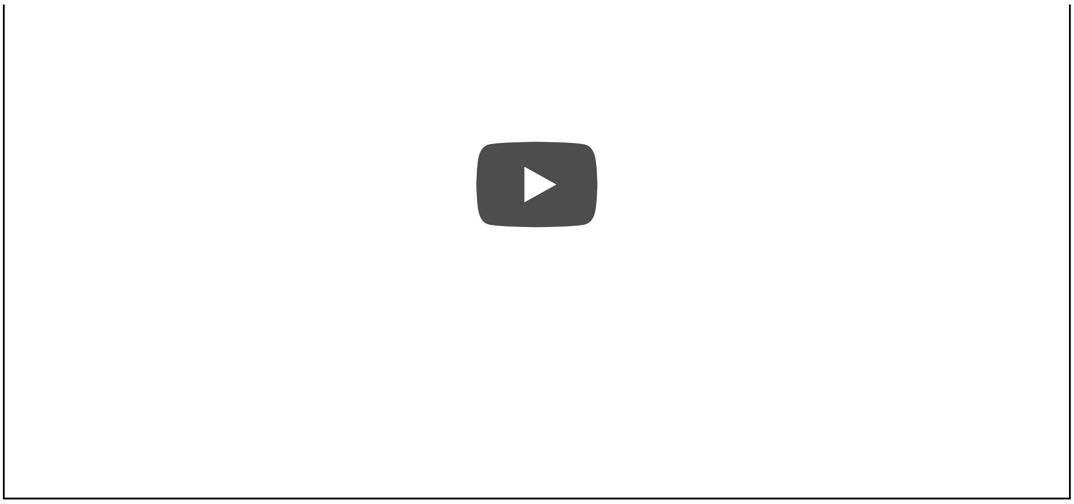
A companion robot is one that is capable of providing useful assistance in a socially acceptable manner. This means that a robot companion's first goal is to assist humans. Robot companions are mainly developed to help people with special needs such as older people, autistic children or the disabled. They usually aim to help in a specific environment: a house, a care home or a hospital.

At the beginning of the 20th century, one of the first pieces of technology designed to help in a household environment was the vacuum cleaner. Since then, technology has transformed the home. Nowadays, we even have a robot that can cook. The chef robot was developed by Moley Robotics, a start-up company that won the 2015 Asia Consumer Electronics Show. The robot is said to be able to cook 2,000 different meals.

Pepper, the latest robot from Aldebaran Robotics, is a good example of a humanoid robot companion. It can provide assistance in making choices, detect human facial expressions and communicate with people. Pepper can adapt its behaviour depending on its perception of a person's mood, and in this sense we can say that Pepper cares for people. At the moment, only research institutes and Japanese residents can acquire a Pepper robot. The robot costs around £8,710 for a Japanese customer.

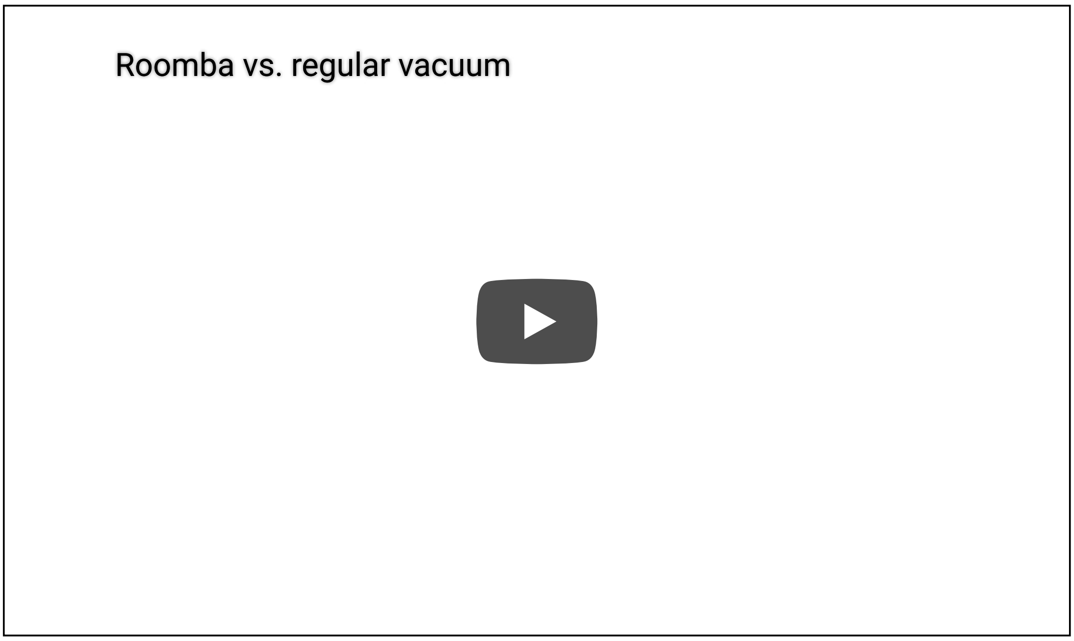
Companion robots can take the form of pets, too. Paro is a robotic seal developed to provide comfort to old people. And rather than taking care of you, this robot has to be taken care of. It is how Paro provides emotional support.





Sometimes people get attached to robots that are not actually made for companionship. Take Roomba, for example, the intelligent vacuum cleaner. In their studies, Ja-Young Sung and colleagues from the Georgia Institute of Technology found that people wanted to become tidier in order to allow the vacuum cleaner to run smoothly.

Although many of these robots show some form of initiative and encourage people to interact with them, many are responsive rather than active – in other words, the robot waits for a human request before acting.



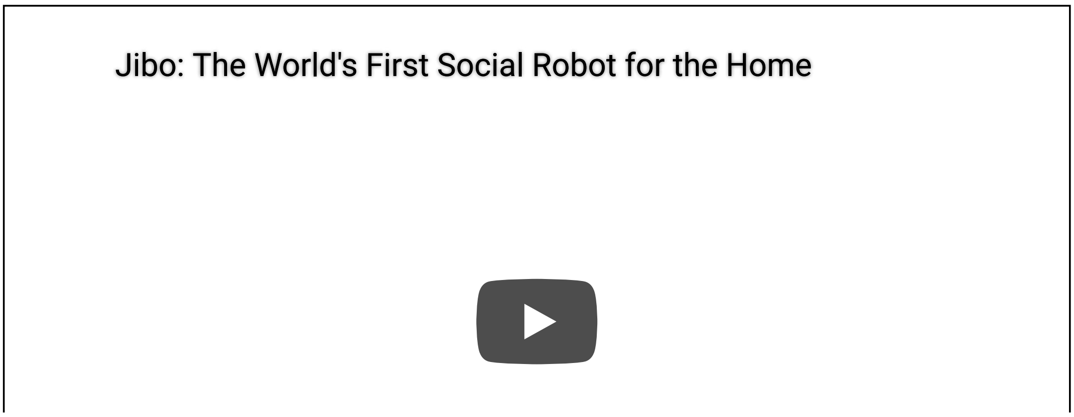
Should robots be more 'human'?

Thanks to progress in Artificial Intelligence and technology, we can now develop more intelligent systems that are capable of acting very much like a human. Last year, a few of them were presented to the public, such as Nadine, the robot receptionist, Yangyang, the singer robot, and Aiko Chihira, the robot that can communicate in sign language.

Although the popular and controversial Turing test is used in AI to measure whether a machine is as intelligent as a human, it is a very different thing when it comes to robots, since robots are also expected to act intelligently. There is not yet a standardised test to determinate how human a robot is. It may come in the near future. However, all robotic researchers seem to agree that the robot would have to be able to show some social awareness and personality, and be capable of understanding and recognising people's speech and expressions.

But do we want robots to have more personality and to be able to take more initiative? Ultimately, to act more like us? Some may argue, yes. If intelligent vacuum cleaners were able to differentiate a sleeping human from objects, for example, at least one unfortunate lady in South Korea wouldn't have had her hair "eaten" by her new domestic appliance.

But others argue that it is dangerous to give robots too much intelligence. And would it allow them to answer back? We are still at the beginning of research regarding the potential consequences this might have. Indeed, the scientific community is still debating whether a robot can ever have feelings or be self-conscious. Although AI has been able to perform certain tasks extremely skillfully, for example Alpha Go, the community is still a long way from developing an AI which closely resembles the human mind.



At present, robot companions are either focused on companionship or on task-execution. Jibo, for example, is a social robot that can talk, order food, remind you of things, or take pictures, while Roomba is an intelligent, but ultimately functional, vacuum cleaner.

Who is in charge?

But it's about striking the right balance, depending on the job at hand and the person it is working for. Our most recent study, Who is in charge? Sense of control and Robot anxiety in Human Robot Interaction, showed that the more controlling and anxious about robots a person is, the more initiative they expect the robot to show and the more willing they are to delegate tasks to it. The research focused specifically on what level of initiative people preferred their robot companion to have when executing a cleaning task.

Participants could choose between manually turning on the cleaning robot themselves, having their robot companion turn on the cleaning robot remotely when instructed, or having the robot companion turn on the cleaning robot when it noticed that cleaning needed to be done. It was found that most people wanted their robot companion to execute the task without being asked.

This paradoxical result may be explained by the fact that people are now more used to technology – from computers and smartphones to smartwatches and intelligent home appliances – acting semi-autonomously. Smart companion robots are just the next step in the long evolution of our relationship with technology.

In the future, it is likely that we will see more domestic robot companions that can be customised to people's individual preferences. And we will be able to shop for them as we now shop for vacuum cleaners and phones. Ultimately, it seems, there will be a robot for everyone.

Robotics Robots paro

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