What My Eyes Can't See, A Robot Can Show Me: Exploring the Collaboration Between Blind People and Robots

Mayara Bonani[1,3], Raquel Oliveira[2], Filipa Correia[3], André Rodrigues[4], Tiago Guerreiro[4], Ana Paiva[3]

[1]Escola de Engenharia de São Carlos, Universidade de São Paulo
[2]Instituto Universitário de Lisboa (ISCTE-IUL), CIS-IUL
[3]INESC-ID, Instituto Superior Técnico, Universidade de Lisboa
[4]LASIGE, Faculdade de Ciências, Universidade de Lisboa
mayarabonani@gmail.com, rsaoa@iscte-iul.pt, filipacorreia@tecnico.ulisboa.pt, afrodrigues@fc.ul.pt, tjvg@di.fc.ul.pt, ana.paiva@inesc-id.pt

ABSTRACT

Blind people rely on sighted peers and different assistive technologies to accomplish everyday tasks. In this paper, we explore how assistive robots can go beyond information-giving assistive technologies (e.g., screen readers) by physically collaborating with blind people. We first conducted a set of focus groups to assess how blind people perceive and envision robots. Results showed that, albeit having stereotypical concerns, participants conceive the integration of assistive robots in a broad range of everyday life scenarios and are welcoming of this type of technology. In a second study, we asked blind participants to collaborate with two versions of a robot in a Tangram assembly task: one robot would only provide static verbal instructions whereas the other would physically collaborate with participants and adjust the feedback to their performance. Results showed that active collaboration had a major influence on the successful performance of the task. Participants also reported higher perceived warmth, competence and usefulness when interacting with the physically assistive robot. Overall, we provide preliminary results on the usefulness of assistive robots and the possible role these can hold in fostering a higher degree of autonomy for blind people.

ACM Classification Keywords

K.4.2 Social Issues: Assistive technologies for persons with disabilities

Author Keywords

Human-Robot Interaction; Blind People; Collaboration.

INTRODUCTION

Blind people face challenges in their daily lives in tasks that are taken as granted if you are sighted. Examples are varied and include finding objects, correctly placing items, and identifying different colours, text, or other visual patterns. These difficulties render several common activities hard to accomplish without the help of others. The inclusion of visually impaired people in a society that fights for equal rights is severely hindered by this dependence and it manifests itself in an household setting but also in school and in the work environment.

ASSETS '18, October 22–24, 2018, Galway, Ireland

ISBN 978-1-4503-5650-3/18/10…15.00

DOI: https://doi.org/10.1145/3234695.3239330

Figure 1: Baxter, in the Collaborative Assistive Robot (CAR) experimental condition, introduces itself to the participant.

Accessible (mobile) computing devices, together with their increasing abilities to sense the environment, have provided opportunities to support blind people in their day to day. As an example, previous work has explored the usage of cameras within mobile devices to recognise colours, currency, or to allow people to perform visual questions to a crowd of sighted volunteers [6]. Robots, on the other hand, have been limitedly explored outside the domain of supporting orientation and mobility. These devices, however, may present a variety of sensors and actuators alongside the ability to physically interact with the environment and their users. These qualities make them suitable candidates to collaborate with blind people in performing other demanding tasks, that could only be performed with the help of other humans.

In this paper, we first explore how blind people perceive robots nowadays and what are their expectations and fears regarding the increasing dependence on these devices. To do so, we performed 4 focus groups with a total of 20 visually impaired people. Results showed that the participants take a practical stance to the inclusion of robots in their day to day albeit presenting common place concerns regarding safety, over reliance on robots, and mistrust in their abilities.

In a second study, we invited 12 visually impaired people to perform an assembly task collaboratively with a robot, in two conditions that varied in the degree of collaboration: in one condition, the robot would only issue voice instructions to the participants and react to requests for past instructions; in the second (see Figure 1), the robot would physically indicate pieces and their target position and orientation, provide feedback on the current step of the assembly, and correct the participant, when needed. Results showed that the engagement in a physical form of collaboration by the robot enabled and improved the success on the task at hand when compared to the voice-only condition. Furthermore, this physical form of interaction between the two parties, human and robot, was welcomed by the participants that reported the robot to be more competent, useful and warm when it interacted with them through physical collaboration than through a voice-only collaboration.

Overall, we contribute to the area of human-robot interaction and accessibility by bringing new insights on the collaboration between people and robots. Particularly, 1) we provide knowledge on the acceptance, perceived usefulness, foreseen scenarios, and concerns regarding the inclusion of robots in blind people daily lives; and 2) we inspect the collaboration between a robot (Baxter) and blind participants in an assembly task, paying particular attention to the effect of two different forms of collaboration in participant's success on the task and on the engagement with the robot. This research yields valuable insights to researchers exploring the role of assistive robots in supporting blind people achieving a higher degree of independence and autonomy.

RELATED WORK

Nowadays, there is a wide variety of assistive technologies that support blind users in orientation and mobility tasks [45, 30, 28, 29, 21] and facilitate the translation of visual information to audio feedback (e.g. Optical Character Recognition). In this context, smartphones have been pivotal in the democratization of assistive technologies that facilitate real-world tasks that had only been previously available through expensive specialized assistive technology. For example, today users have access to Optical Character Recognition [37], colour identification [42] and even assistance from remote crowd-workers [6, 22, 5] in visual identification tasks. Through the use of computer vision and/or crowd-workers, blind users are able to rely on their smartphone camera to take photos [6] or stream video [5, 22] in order to receive assistance with real-world tasks. Users take advantages of these services to identify, read and understand objects [8]. In mobility scenarios, smartphones have been used as navigational aids providing guidance to blind users [38, 1].

Conversely, robots, in addition to the features found in smartphones and other forms of assistive technology are also able to physically collaborate with users. Robot's particular embodiement possibilities, along with their increasing levels of social and technical autonomy, fostered by advances in artificial intelligence and robotics witnessed in the last decades, open the door to the introduction of a new, more physical, form of assistive technology. In past research, mobile robots have been used to assist users navigate their environment often mimicking a white cane in form factor, detecting obstacles and points of interest through ultrasonic sensors [45], radio frequency identification (RFID) [30, 29, 28], among others. Other projects have explored how drones can guide blind runners [2], provide indoor navigation assistance [3, 36], for instance, in supermarket areas [19]. In some solutions, when obstacles or points of interest are detected, users receive navigational aids through audio feedback to make an informed decision on their path [29]. In others, obstacles are avoided and the user is guided by following the robot motion [45, 3]. In Azenkot et. al [4], researchers used participatory design to investigate how building service robots could guide blind people indoors. The study revealed that the needs and preferences of users were vastly different with some users displaying concern about the "attractiveness" of the robot, and others displaying concerns with its functional features. Moreover, the functional needs differed depending on the user knowledge of the building and their visual capabilities (i.e. low vision/blind).

Recent contributions started to explore how the social aspects of communication can enhance interactions, in particular, haptic approaches where robotic arm manipulators can convey or interpret intentions [43]. A similar approach is also being currently used in an entertainment game scenario for children with vision and hearing impairments, where movement is the main source of feedback [11]. Another interesting study explored how visually impaired people explore the physicality of an unknown robot and describe it to someone else [35]. The preliminary results showed that their descriptions were consistent in mentioning the robot's appearance first, followed by its functionality and, lastly, its capability.

Summarily, robots are becoming increasingly popular and helpful for blind users, however most research has focused on mobility and orientation assistance. However, there is still a gap in the literature regarding the role of assistive robots in other everyday tasks. Most of those tasks constitute challenges for blind and visually impaired individuals that can, therefore, benefit from the physical component offered by this type of technology. A good starting point might be to begin exploring their acceptance and perceptions of such social assistive robot, as well to analyse what are the performance related benefits that the collaboration with an assistive robot can yield for blind and visually impaired individuals.

RESEARCH QUESTIONS

With this paper, we propose to answer the following research questions:

1. How do blind people perceive and envision robots in their daily lives?

2. What are the practical benefits, in an assembly task, of a collaboration with a robot? How does the degree of active collaboration of the robot influence performance of the task?

3. How is user perception of a robot influenced by its collaborative behaviours?

Study 1, composed of a set of focus groups performed with blind people, explores the first question, while Study 2 addresses the second and third question, in a comparative study where blind participants performed an assembly task with two different versions of a robot, varying in the type of support (verbal directions and physical collaboration) provided.

UNDERSTANDING STIGMAS AND EXPECTATIONS

In a first study we were interested in understanding how blind people currently conceptualise a robot, what it can do for them and what are the positive and negative impacts it can have in their day to day. We recruited a total of 20 blind people, all screen-reader users, from a local training centre for blind people and conducted focus group sessions to discuss their views on robots. We divided the participants in four groups and conducted a session with each group. There were two researchers leading the conversation in each group and it lasted about one hour.

Procedure

The focus groups were conducted in the centre and we gathered five participants in each session. The discussion was conducted informally and followed a semi-structured script. First, we asked participants their permission to audio record the discussion. Afterwards we prompted participants to present themselves. We started by asking what is a robot, what they thought about it and prompt them to give us some examples. This allowed us to collect diverse opinions regarding previous knowledge, doubts, expectations and fears. We then presented a brief description of what a robot is and what it can do with the variety of sensors and form factors it can have. We mentioned a couple of examples in different areas such as industrial, domestic, social and entertainment robots to promote the discussion. Afterwards, we presented the Baxter robot[1] in detail. We described what were the capabilities and limitations of the current robot and asked participants how they could foresee Baxter or a robot like it to have an impact in their daily lives. Next, we presented two scenarios one where Baxter would help assemble a piece of furniture and another where it helped them cooking. We were interested in understanding if and how participants envisioned how the interactions between a human and a robot would be. Lastly, we asked participants what would a robot have to do for them to consider it to be a social robot.

Findings

We analysed each of the recordings following a pre-established high level coding scheme and inductively added specific categories. Below, we present the findings anchored in four main themes.

Previous knowledge on robots

Participants struggled to provide a description on what exactly constitutes a robot and would instead provide examples of existing ones. When prompted to describe the form factor of a robot some would immediately state they are square-shaped objects. Others would state they are becoming more like humanoids and gave the example of the Sophia robot[2]. The examples given were vast and varied from soccer playing robots, to house cleaning ones. Most users had never interacted with a robot before but were aware of their usage in multiple fields (e.g., industrial robots that assist factory workers, robots for military use and robots that assist during surgery). There were three references to assistive technologies that participants classified as robots. One participant referred a cane with sensors, another described a street light that gave navigational instructions, and a third pair of glasses that had Optical Character Recognition. The users that provided most of the examples were aware of how currently robots are already integrated in some aspects of our lives, while others were oblivious to how much can already be accomplished through technology.

Fears and concerns

Prior to us presenting examples, participants discussed how robots have the potential to revolutionise industries but at the cost of human jobs. On the other side of the argument others were debating how robots actually just shift jobs from one place to the other.

> "Well someone has to build the robots."

Participants expressed concerns on how they must always feel in control of the robot. A participant commented how a few years ago a factory worker was killed by an industrial robot. Robots should be predictable and only do exactly what they are programmed to do.

> "If the robot upsets you, you should be able to turn it off at any time."

They were concerned about the robot reliability and its possible consequences. From miss recognising an object to ruining an expensive item while manipulating it, or even assaulting a user due to an unexpected movement.

> "We might just get slapped."

A major concern was on the price and maintenance costs that a robot could have. If it is too expensive they felt they would not be able to afford it. Participants were also aware the more technology becomes embedded in our lives, the greater the security risks are, which previously simply did not exist. Some feared that robots might be used to wage war. On a more personal level users feared for computer virus that could affect their home robots.

> "In a few years, a virus can turn off everything in your house. You get home and your fridge is not on. That worries me."

How should a robot be

Participants described robots of all sizes and describe everything from pure functional designs (e.g. cubes) to humanoids or even animal like (e.g. dog robot). Depending on the purpose of the robot, they were described with different sizes.

[1] http://www.rethinkrobotics.com/baxter/

[2] http://www.hansonrobotics.com/robot/sophia (last visited on 17/04/2018)

> "[For a navigational aid robot] It should be small, how else will I be able to take it on the bus?"

They expected robots to be able to engage in social conversation and be able to respond to commands and questions. Moreover, they expected 24 hour availability and robots to be quick and efficient in performing any tasks they asked. Some participants mention some interaction concerns they had depending on the size of the robot. If it was small it should be able to avoid collisions with people. On the other hand, if it were big it should announce its movement with beeps or other forms so people around him be aware of its movement. For robots that would come in physical contact with people, participants mention how one should be careful designing a robot that has a pleasant material on physical contact.

What can a robot do for or with me

The topic that generated the most discussion was what participants would like for a robot to help them with.

Navigation

As struggling with real-world navigation is one of the most dramatic consequences of vision loss, in all groups participants wanted a robot that would help them navigate. Some wanted a dog-like robot, while others wanted an attractive humanoid robot. Robots were described in different navigational scenarios, from finding a street to guiding a user in the beach from his towel to the sea and back. One participant wanted robots to provide a public transportation service.

> "There should be robots spread out throughout the city. If I needed to go anywhere I would just go up to the robot dude, put a card, and say - take me to X -, and he would take me there."

Housekeeping tasks & Chores

Stemmed by examples of robot vacuum cleaners, participants wanted robots to help them with all house chores. Participants debated cleaning, cooking, taking care of the laundry among others. For most tasks, the purpose was for the robot to take over all of the duties. However, in some the robot was a facilitator in the task. Participants wanted robots to help them taking containers out of the oven, detect when the food was cooked, warn them when a dish was clean enough or even to peel the vegetables to assist them cooking.

Education

In education, participants mentioned robots could be used to help either blind children or assist blind parents. They could help children play with legos by separating colours and assessing the beauty of the final piece in terms of colour coordination. They could also provide lessons teaching about the shapes and sizes of objects while collaboratively manipulating plasticine.

> "[The robot would ask] how is an apple? The child would then show the mold. The robot could correct and mold the plasticine."

For blind parents, the assistance users wanted was the robot to have the ability to judge if their children handwriting was good or not so he could take some action towards instructing them.

Social Robots & Entertainment

For leisure activities, and for participants to consider robots to be social companions, some participants wanted robots to take an active role. They wished robots would chat, dance, hug and play games.

> "[What would you want it to do?] To dance with me."

Others had more reservations and only wished robots to take a passive role such as playing music and switching records.

Servent

Participants discussed how they would like robots to follow their commands and assist them with whatever they needed. Many examples are of finding and fetching objects.

> "Go get me a coffee, oh and by the way pass me the butter."

Others were more complex tasks: help assembly furniture, change the lights, paint the ceiling and open jars.

> "While you were making dinner, the robot could be assembling the dresser."

Contextual Information

In most of the domestic chores the robot would physically collaborate to complete a task, while in the others it would only be used as a substitute for vision (i.e. check if food is cooked). This kind of contextual information about their surroundings and the state of elements was another venue in which participants were invested in. They wanted robots to identify and find objects.

> "If I had a robot and I had dropped a pen, I would ask where it was and it would tell me."

Other examples were motivated by what they can already achieve with their smartphones but they wished they could do so in a more convenient way: evaluate user attire in colour coordination, detect stains, read letters and check food validity.

ASSESSING A COLLABORATIVE SCENARIO

We conducted a user study to assess if a collaborative robot could effectively assist in an assembly task. Furthermore, we explored the acceptance and perceptions participants had of a collaborative robot when contrasted with voice-only assistance. Our goal with this study was to validate the practical benefits of collaborating with a robot that is able to identify the surrounding environment, provide the user with feedback and physical assistance (by guiding the user with its hand). In order to establish a baseline for comparison of the practical benefits, we compared this condition to a condition in which participants interacted with a voice-only assistive robot that provided verbal directions to help the user complete the task. We considered the latter to be close to what is currently possible through the use of assistive mobile applications.

Tangram Assembly Task

Participants were requested to assemble a Tangram, which is a 7-piece Chinese jigsaw puzzle containing 2 large triangles, 1 medium triangle, 2 small triangles, 1 square and 1 parallelogram. The pieces were handmade using Styrofoam material with 4 centimetres thickness and they were covered by coloured paper. Participants were asked to assemble those pieces in the shape of a square (length of 40 centimetres on each side). As such, the goal of the assembling task was to place all the 7 pieces inside a square box, which constitutes the "square puzzle". Initially, the pieces were randomly spread over a table around a 41 centimetres card box, as seen in Figure 2. The task ends when all the pieces are correctly positioned inside the box.

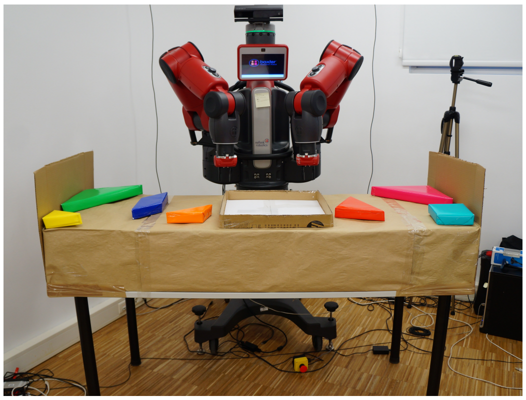


Figure 2: Initial setup of the assembling task.

We chose this task for two main reasons: first, due to its similarity to many everyday-tasks that involve the assembly of objects (e.g: furniture, as mentioned by the participants). Secondly, due to the wide use of this task as a mean to explore physical or haptic collaboration in human-robot interaction by leveraging the robot's embodiment [26, 17, 41].

The Assistive Robot

For this study, we used a human-safe, commercially available Baxter robot. This upper torso stationary humanoid robot was positioned behind a desk in a closed laboratory space.

Baxter is a humanoid robot with two arms, each with seven degrees of freedom, state-of-the-art sensing technologies, including force, position, and torque sensing and control at every joint, cameras in support of computer vision applications, integrated user input and output elements such as a head-mounted display, buttons, knobs and more. As hands, Baxter has two grippers. One of the key features of this robot is its compliance due to the fact that its movements are not completely rigid and it can sense and control the forces it applies to things. As a result, Baxter is suitable for collaborative interactions.

Experimental Design

We used a within-subjects design where the independent variable was the type of assistance provided: (1) Voice-Only Assistive Robot (VOAR); (2) Collaborative Assistive Robot (CAR). The order of the conditions was counterbalanced and the puzzle solution changed (i.e. we applied a 180°rotation) between conditions to mitigate learning effects. Each participant was given a maximum of 15 minutes to assemble the puzzle in both conditions. Furthermore, participants were only given one trial per condition. A detailed description of the behaviour of the robot in each condition is presented below.

Voice-Only Assistive Robot

In VOAR, Baxter assists participants using only voice instructions. We used a Wizard-of-Oz (WOz) experimental technique to trigger those behaviours, which was being controlled by a researcher next to the participant. The predefined set of possible voice instructions was previously recorded using the Amazon Polly Text-To-Speech[3]. There was one instruction per piece, which contains information about (1) the piece (what is the piece name, the number of edges, and the length of the edges compared to each other) (2) its final position and (3) its orientation. For example: *"The third piece is a triangle of medium size. You have to place it on the bottom left side of the box. Its two edges have to fit the bottom left corner of the box. If necessary, rotate the piece until it fits."*. Moreover, there was an introductory speech act where Baxter would introduce itself.

Collaborative Assistive Robot

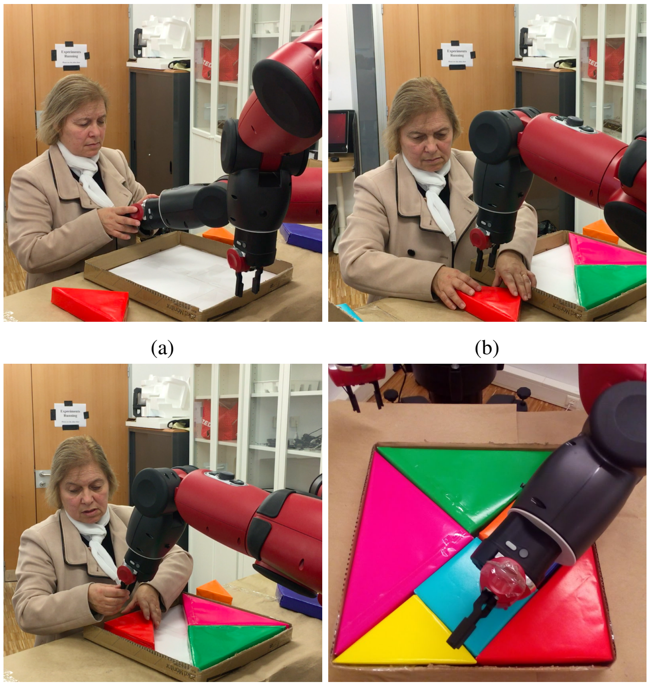
In CAR, Baxter, in addition to the voice instructions, also provided physical instructions and feedback according to the task progress, which were also performed with WOz technique. Due to the addition of physical movements of Baxter's arms, the initial introduction was slightly different. It included a "handshake" where participants could touch and explore the robot's arms. Before the assembly task started, Baxter also exemplifies its movement to the left and right side of the card box, as well as its neutral position (this position can be seen in Figure 2).

The instructions for the assembly task follow a predefined protocol of four steps for each piece. The "wizard" was responsible for triggering the behaviours according to his perception of the participant's progress. (1) Baxter extends one of its arms so that the person can locate and then hold it (Figure 3a). Baxter always chooses the closest arm depending on where is the current piece to assemble. It also says *"I am going to extend my arm towards you for us to pick the next piece. Please, hold it and follow my movement."*. (2) Baxter then guides the person to the piece to be picked (Figure 3b) announcing the piece (e.g. *"My fingers are now pointing to the triangle's position over the table. You can release my arm and pick the piece."*). (3) Baxter moves its grippers to indicate the position inside the box where the piece should be placed (Figure 3c) and announces it (e.g. *"Now I am going to show the location where you should place the triangle inside the box."*). (4) This step was only used in case the participant did not put the piece in the right position after two attempts. Baxter would then indicate the orientation of the piece in the box using its arms or grippers, as shown in Figure 3d. It also announced instructions like *"The longest edge of the triangle should be placed parallel to the bottom of the box"*.

Participants

Data was collected from 12 blind participants (light perception at most) that were recruited from an institution dedicated to support blind people and taken to our lab to participate in this experiment. Participants were on average 48 years old ($M = 47.6$; $SD = 14.0$), ranging from 21 to 64 years old.

[3]https://aws.amazon.com/polly/ (last visited on 17/04/2018)



(a) (b) (c) (d)

Figure 3: (a) (1) Baxter extends its arm; (b) (2) Baxter indicates the position of the next piece to assemble; (c) (3) Baxter indicates the final position for the current piece; (d) (4) Baxter provides orientation instruction with its arm.

Seven (i.e. 58.3%) of the participants were male and only one reported not having formal education of any kind. All participants reported regularly using screen readers. Participants indicated that they felt extremely comfortable using new technologies ($M = 6.5$; $SD = 0.8$; on a scale from 1 to 7, in which 1 meant "Not comfortable at all" and 7 meant "Completely comfortable"). None of our participants reported having any kind of interaction with social robots before.

Procedure

Each session started with a short briefing about the user study. Participants were informed they were going to evaluate two versions of the Baxter robotic assistant during an assembly task and that participation was voluntary. Moreover, in order to avoid self disappointment, due to the possible unsuccessful puzzle completion, the participant was reassured that the goal of the study was to evaluate the robots and not the participant's skills. Then, participants answered a socio-demographic questionnaire. We then asked the participants consent to video and audio record the study session. Participants were then instructed to perform the Tangram assembly in each condition. After each condition, participants completed a questionnaire about the robotic assistant. Lastly, we conducted a semi-structured debriefing interview. Overall, each session took approximately 1 hour to complete. Participants did not receive any type of compensation for their participation in this study.

Data and Measures

We collected and analysed the average piece placement time and success rate in each condition.

In order to assess people's judgements about the social attributes displayed by the robot, we used the RoSAS questionnaire [10]. This questionnaire is composed of 18 items, divided equally in three dimensions: warmth (e.g. happy); competence (e.g. capable); and discomfort (e.g. awkward). Participants were requested to indicate how well each of the traits presented described correctly the robot they had interacted with, on a 7 point Likert-scale (in which, 1 meant "Nothing at all" and 7 meant "Describes it perfectly"). To assess the internal consistency of each of these dimensions, we calculated Cronbach's alpha for each dimension of the questionnaire, in both groups of participants. Overall, in the condition participants interacted with the voice-assistive robot we observed acceptable and good levels of internal consistency. More specifically, we observed an acceptable value of internal consistency in the competence dimension ($\alpha = 0.74$) and good values in the warmth and discomfort dimensions ($\alpha = 0.86$ and $\alpha = 0.84$, respectively). In the condition participants interacted with the collaborative robot, we observed a poor level of consistency in the competence dimension ($\alpha = 0.53$) and a good level of consistency in the warmth ($\alpha = 0.84$) and discomfort ($\alpha = 0.86$) dimensions.

Furthermore, participants were asked to respond to nine further questions with the goal of evaluating performance and task related factors. More specifically, participants were initially asked to evaluate how useful Baxter help was and how hard the task in itself was, using a 7-point Likert-scale (in which, 1 meant "Nothing at all" and 7 meant "Completely").

Finally, participants engaged in semi-structured interview to explain in more detail their opinion about the two versions of the assistive robot. The script can be consulted in [39]. Following guidelines for methodological validity, the debriefing interviews were later coded by two independent coders, following a pre-defined coding scheme. In this case, one coder coded one third of the interviews (i.e. 4), whereas the main coder coded all of the interviews. An excellent level of agreement was observed between coders (91.25%).

RESULTS

The data collected was analysed by comparing the average scores between the two conditions. Additionally, we aggregated the questions according to their dimension (i.e. warmth, competence and discomfort). For every comparison, paired-sample t tests were conducted. In the instances where the assumptions for the previously mentioned test were not observed, we opted to conduct the non-parametric alternative (i.e. Wilcoxon test).

Evaluating the Practical Benefits of Voice-Only and Physical Assistive Robots

Efficacy

All participants managed to correctly assemble the Tangram puzzle in the CAR condition. In VOAR, only 2 participants out of 12 (16.7%) completed the assembly using the correct configuration. This association between the condition and the completion of the task was statistically significant ($\chi^2(1) = 17.143, p < 0.001$).

Average Time to Place each piece

Considering only correctly placed pieces, we calculated the average time each participant took to place the piece (Figure 4). We compared the differences between conditions using a Wilcoxon test and found a statistically significant ($U = 16.0, W = 94.0, Z = -2.902, p = 0.003$). Participants that were assisted by the PAR took less time to place each piece ($M = 63.857, SD = 8.129$) than participants assisted by the VOAR ($M = 202.171, SD = 46.155$).

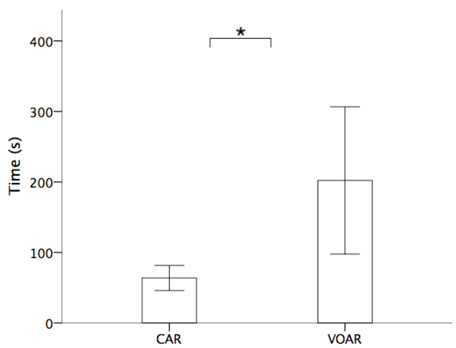


Figure 4: Average time to place each piece per condition *p<0.05

Social Attributes

Figure 5 summarises the comparison between the two conditions regarding the attributes of perceived warmth, competence, and discomfort.

Perceived Warmth

Given that this variable did not present a normal distribution in both conditions (VOAR: $SW(12) = 0.98$; $p = 0.96$ and CAR: $SW(12) = 0.94$; $p = 0.4$), we opted to conduct a Wilcoxon test to assess possible differences between the two conditions. In this context, we observed statistical significant differences between the perceived warmth reported by the participants ($Z(11) = 2.2$; $p = 0.0$). Participants evaluated CAR as being warmer ($M = 5.5$; $SD = 1.2$) in comparison with VOAR ($M = 4.6$; $SD = 1.4$).

Perceived Competence

We observed that the participants perceived the robot as being more competent when it provided them help by guiding them collaboratively (CAR), in comparison with the condition when it only read the instructions for assembling the puzzle (VOAR) ($Z = -2.6$; $p = 0.00$; $M = 6.4$; $SD = 0.56$ and $M = 5.7$; $SD = 1.0$, respectively).

Perceived Discomfort

A paired-sample t test was conducted. No significant differences in the perceived discomfort between the two conditions were observed ($t(11) = 0.11$; $p = 0.91$; VOAR: $M = 1.3$; $SD = 0.52$ and CAR: $M = 1.3$; $SD = 0.60$). In congruence with this result, no differences in level of reported (dis)comfort while performing the task (single item) were observed between the conditions ($t(11) = -2.0$; $p = 0.07$; $SW(12) = 0.63$; $p < 0.00$).

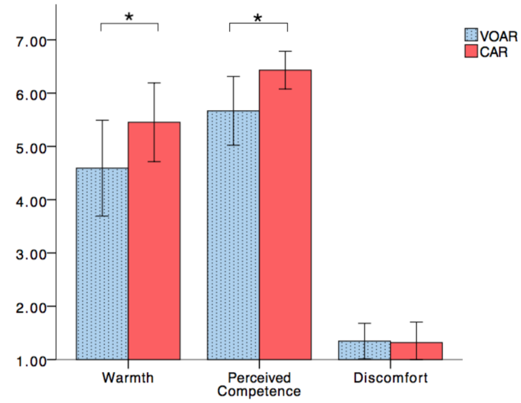


Figure 5: Average levels of the social attributes perceived on the Baxter Robot per condition. *p<0.05

Task-related Attributes

Figure 6 summarises the comparison between the two conditions regarding the task-related attributes of perceived difficulty of the task, perceived usefulness of Baxter's help, perceived usefulness of Baxter's help in everyday life, and positive feelings.

Perceived Level of Difficulty of the Task

A Wilcoxon test yielded significant differences between perceived level of difficulty of the Tangram puzzle ($Z = -2.6$; $p = 0.01$). As such, we observed that when participants interacted with the CAR, they perceived the Tangram puzzle as being easier to solve, then when they relied on the VOAR ($M = 1.9$; $SD = 0.99$ e $M = 4.5$; $SD = 1.9$, respectively).

Perceived Usefulness and Positive Interaction Feelings

Participants evaluated the help provided by the CAR as being more useful than the help provided by the VOAR in completing the Tangram puzzle ($t(11) = -3.0$; $p = 0.01$; $M = 6.9$; $SD = 0.28$ and $M = 5.0$; $SD = 2.3$, respectively). Moreover, participants reported a higher level of perceived usefulness in everyday life, for the CAR than for the VOAR (($t(11) = -2.7$; $p = 0.0$; $M = 5.7$; $SD = 1.94$ and $M = 3.7$; $SD = 2.4$, respectively). Lastly, participants also reported a higher level of positive feelings (i.e. happiness) when interacting with the CAR in comparison to when interacting with VOAR ($t(11) = -2.7$; $p = 0.02$; $M = 6.3$; $SD = 1.1$ e $M = 5.2$; $SD = 1.5$, respectively).

Final considerations from the interview

A summary of the main issues approached during the final discussion follows bellow.

Causal Attribution

The speech of the participants was analysed regarding the predominant causal attribution. In this instance, two categories were considered: (1) internal causal attribution (referring to attribution of blame for failure in some component of the task (e.g. not completing the puzzle or not putting a piece in the correct position a first try); e.g. "It [VOAR] was helping, maybe

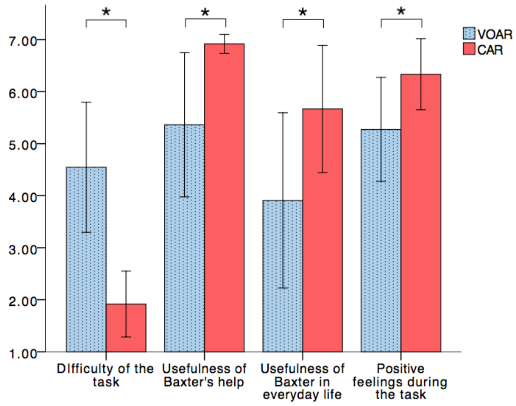


Figure 6: Average levels of the task-related attributes per condition. *p<0.05

I just did not understand it correctly") and (2) external causal attribution (attribution of failure to an external entity (e.g. "I was listening to what it [VOAR] was saying, but when it said left, I did not know if he meant my left or its left. He should always say which one is it."). A third category was considered to include participants that provided both types of casual attribution. Overall, we observed a predominance of internal causal attributions, referred by 5 participants. An equal number of participants displayed ambiguous causal attributions and 2 participants engaged in external attributions.

Noise, velocity and proxemics
During the interview, participants were also asked to reflect about the adequacy of the movements and noises that the robot did. All of the participants replied that was useful for the robot to make some noise as it allowed them do identify what was the position and state (i.e. moving vs. not moving) of the robot. 11 out of 12 participants considered the velocity of movements to be adequate and the same number of participants also considered that the robot was respectful of their personal space and did not perform intrusive movements.

Usefulness
Most participants agreed that having a robot like Baxter in their day-to-day life was useful (n=11). When asked in what contexts of their life participants felt that it would be useful, they pointed out mainly in the household. One participant referred that it would also be useful if it was able to navigate and accompany him in the street. Another participant did not think that Baxter would be useful in everyday life because she was already used to get by using other strategies (e.g., with the help of her family members).

Likeability
All of the participants thought that Baxter was a nice robot and indicated that also helped during the task. Moreover, all participants except one preferred to interact with the CAR rather than with the VOAR.

DISCUSSION
The results obtained with blind participants in the two studies allow us to answer our research questions:

Study 1: How do blind people perceive and envision robots in their daily lives?

Technology has an important role in the lives of people with disabilities, by allowing them to overcome social and infrastructural barriers that limit their autonomy and quality of life [25]. As such, the first step in adapting and creating new accessible technologies, must be to consider the prospect of it's acceptance by members of the group they are intended to assist. In this paper, our goal was to explore the usefulness of the introduction of robots as assistive technological agents for blind people. As such, we began by exploring what were the needs, expectations and fears that blind users had towards robots. Overall, our findings revealed that blind participants displayed a positive level of acceptance towards robots, despite also displaying some concerns about its use. Participants in our focus group, that had never had contact with robots before, listed a long range of everyday scenarios in which robots could be useful. This list included domestic and navigation scenarios, as well as social or leisure scenarios, among others, hinting at the wide prospect acceptance of this new form of technology. Moreover, participants also elaborated on what characteristics it should have (both physically and socially). Looking at this long list of expectations and needs that our participants, piece by piece, put together, we can see an overall picture of the characteristics an assistive robot for blind people should have. However, and despite the fact that technology is growing exponentially, we are still far, today, from being able to produce robots (or any type of assistive technology) that ticks every box on that list.

Study 1: What are the specific needs of blind users and how do these relate to the needs of sighted users?

Autonomy can be defined as the ability for *"... detachment, critical reflection, decision making and independent action"* [32]. Sensory and contextual information play a relevant role in accomplishing many of these activities and are an important factor in achieving autonomy. Blind people however have developed many forms to overcome these limitations and increase the range of activities they can perform. Indeed, collaboration with sighted peers has been important for this end, as pointed both by our participants and previous literature (e.g: [9, 5].

When comparing the needs or expectations of participants who participated in our focus group with those indicated by sighted people, we observed many similarities. For example, in the domain of domestic activities, our participants indicated that robots could provide help and provided many instances as examples (e.g: opening cans). This is congruent with some of the expectations identified by sighted people (e.g: [40, 14, 18]). In these studies, that explore the expectations of sighted users about robots, the latter are expected to intervene in a wide variety of scenarios, including both the functional perspective, and the companionship or entertainment perspective, which was also identified by our participants.

In terms of overall preferences expressed by sighted participants in those studies, they also present similar shades to those presented by our blind participants. Namely, sighted participants describe similar idealised characteristics of the robots [40], i.e. that the robot should be small in order to allow easier transportation and manoeuvring, and that they should be able to control it (e.g: turn it off whenever they are feeling upset or bored by it).

Navigation seems to be the aspect where blind and sighted people depart in a more significant manner [40, 14]. In these studies, navigation is not mentioned as an important factor. However, this seems to become increasingly more important when older sighted users are considered (e.g: [27], specially those with mobility impairments, who need to make use of a mobility aid [14].

Safe navigation has been identified in the literature as one of the major challenges for blind people in which technology can play a fundamental role [7, 20]. Technological navigation aids, currently existing, can be mostly divided in two categories: (1) short distance mobility aids and obstacle detectors (e.g: [12] or [16]), and (2) long distance aid and providers of more detailed contextualised information (for a review see [33]). In the latter category, continuous and ongoing advancements in technology and engineering have allowed the development of novel navigation aids, such as self-driving cars. Although the impact of these vehicles has already begun being considered [31], its accessibility needs to be further considered and embroiled in the development of these autonomous vehicles as navigation aids [24]. However, in the context of walking navigation aids, robots can play an important role in facilitating navigation for blind people. Human-aware robot navigation has long been a subject of interest for researchers that adds to the two previous categories (long and short distance navigation aids) by considering both the users' comfort and the social norms of an inherently social environment [27].

Study 2: What are the practical benefits, in an assembly task, of a collaboration with a robot? How does the degree of active collaboration of the robot influence performance of the task?

There is a wide range of literature that focuses on the collaborative aspects of human-robot interactions. This is a relevant topic to explore due to the increasing pervasiveness of this type of social agents in our everyday life. However, very little work has been conducted to explore how these can be adapted to engage in collaborative interactions with disabled people. Thus, the role that robots can hold in providing assistance to disabled users, remains a gap in the literature, that is worth exploring due to the possible advantages in assistive interactions that its embodiment might offer.

As such, we began by exploring a task that, despite having a narrow applicability in everyday life contexts, if decomposed, presents interesting parallels to a large range of daily activities. Solving a Tangram means participants are required to organise different sized and shaped pieces in the form of a square, but to do so, they need to accomplish a set of smaller steps. The importance and relevance of this task relies exactly on these steps: finding a specific piece in a group of similar pieces; recognising its colour and shape; placing the piece in a desired position that is relative to the position of other pieces, so on. This is not an easy task for a blind person, however all the participants that collaborated with the CAR managed to do it. Furthermore, participants attributed to CAR higher ratings of usefulness both in this particular task and in their everyday life.

This is indicative of the practical benefits that can be gained from introducing assitive robots in the life of blind people. By providing physical, in addition to verbal feedback, robots can significantly improve the range of assistive technology by collaborating with users in a manner that is more similar to the way they collaborate with sighted peers, than with assistive machines.

Study 2: How is user perception of a robot influenced by its collaborative behaviours?

Perceptions of warmth and competence are important to be evaluated because previous literature has suggested that these are central dimensions of social perception and are thus, good predictors of emotional and behavioural responses towards other social agents [13, 10]. Moreover, the performance or perceived competence of a robot in task is a crucial perception for the establishment of a trustworthy relation and, therefore, an effective collaboration [23].

Our results have also shown that the robot that provided a collaborative assistance is perceived as warmer and more competent. As a result, we believe assistive robotics for visually impaired people would extremely benefit from collaborative features in order to enable and support positive interactions and an efficient cooperation with blind people.

Collaborative relations in Human-Robot Interaction among non-disabled individuals has been thoroughly explored in the past years. However, little has been said to inform the creation of robots that can effectively collaborate with disabled individuals. We believe this study adds to the literature a contribution to this line of research by emphasising its the importance, by providing preliminary results on blind people's acceptance and needs for this type of technology, and also by exemplifying its practical benefits.

LIMITATIONS

Despite the common nature and generalisation of the use of subjective scales, both in Human-Robot Interaction and in Accessibility studies, these instruments can present significant limitations. The pervasive effects of social desirability have been already demonstrated across a broad range of scientific inquiry and data collection domains [15]. In the particular case of this study, the authors recognise the possibility of this effect being magnified by the fact that participants had to verbally indicate their opinion about the robots, while standing in the presence of a researcher. This physical closeness between interviewer and interviewed might have caused participants to feel self-conscious about providing negative feedback about the robots.

Furthermore, limitations of the use of Likert-like scales with blind participants have already been reported elsewhere ([44]), but we feel the need to refer to them here, due to the possible effects that these limitations might bare in the understanding of our data. Moreover, the participants that agreed in taking part of this study, might have done so due to the fact that they already had positive perceptions about robots to begin with. Therefore, a possible positive bias effect can be explained both by their preconceptions about robots, and also by the novelty factor of interacting with this type of technology. Both these limitations were considered when designing this study and we believe that an effective manner to counteract its effects is by imposing methodological means of procedural triangulation and opting for mixed methods research options. As such, in this study we opted for using different qualitative and quantitative measures, with the goal of reducing the effect of social desirability and positive response bias.

Generalisation of the results observed in this study must be conducted with caution. Abnormal distribution of responses was observed in the dimensions of warmth and competence and the size of the sample collected does not present the optimal criteria for the generalisation of the conclusions. Nonetheless, a clear tendency of positive evaluations for the CAR, in comparison with the VOAR, can still be observed.

Finally, the difference between our two experimental conditions consists of several collaborative aspects (i.e. physical assistance, awareness of the current state of the task, providing feedback). As a result, we acknowledge that our results cannot ascertain the effect of each one individually, and a further analysis to evaluate these effects would be beneficial. All things considered, we believe that this study still yields interesting results that support the usefulness on integrating robots as forms of assistive technology in the lives of people with disabilities.

CONCLUSIONS AND FUTURE WORK

Previous work has focused on alleviating the difficulties of people living with different forms of disability, by creating technological devices and platforms that are able to assist and foster their independence in everyday life tasks. However, as technology and artificial intelligence expand at a fasting pace, it is necessary to update our concept of assistive technology and to keep devising forms of adapting emerging types of technology to help disabled people becoming more autonomous and fulfilled.

While exploring the role of robotic agents in improving accessibility and increasing independence for blind people is an interesting avenue of research on its own, it is important that it is done in the context of a contextualised effort for developing more accessible technology in general. This includes, not only giving an active voice to the subjects of our work, but also to bridge the gap between researchers working on assistive studies and those working on assistive technologies and disability studies by considering the "... individual, cultural, societal and theoretical foundations of the concept of assistance and the design and disability-related technologies" (pag. 9) [34]. As such, we consider this study provides a stepping stone to bridge that gap by providing positive evidence in favour of the usefulness of robots in helping people with disability, more specifically blind people. However, further analysis and research needs to be conducted with the aim of exploring how robots can have an impact on other possible areas of assistive intervention.

In this study, we focused on an assembly task (i.e. Tangram), as this task presents a useful parallel to some of the difficulties experienced by blind people. More specifically, considering difficulties in finding objects, sorting objects by their physical characteristics (e.g. colour or shape) and organising them according to an intended final physical form, which are component parts of many different everyday tasks. However, research must strive to further explore the assistive role of robots in many other activities blind people struggle with. In study 1, we present an overview of examples provided by our participants of what these activities could include.

In summary, in this paper we presented a qualitative analysis of the expectations, fears and needs pointed by a sample of blind participants. In study 2, we implement and discuss the effect of two types of robotic assistance during the assembling task. One type of assistance (i.e. voice assistive instructions) presents a functional similarity to the types of verbal feedback provided by currently existing forms of technology (such as screen readers). While the other type of assistance (collaboration oriented assistance) provides a more human-like type of aid, not only by physically guiding the hands of participants towards the desired target, but also by providing them with contextualised feedback regarding their progress on the task.

Results from our two studies support the usefulness of developing and introducing this form of collaborative assistive technology in the lives of people with visual impairments. Positive outcomes for users (such as an increased level of autonomy in everyday life tasks) are outlined and discussed.

ACKNOWLEDGMENTS & AUTHOR CONTRIBUTIONS

We thank all the participants of our studies and FRMS for their collaboration. This work was supported by FCT through funding of the scholarship, ref. SFRH/BD/103935/2014, ref. SFRH/BD/118031/2016, project AMIGOS PTDC/EEISII/7174/2014, INESC-ID Research Unit UID/CEC/50021/2013 and LASIGE Research Unit UID/CEC/00408/2013.

MB (lead) and AP contributed to the initial Conceptualization of the project, while all authors have contributed to Conceptualization throughout. MB (lead), AR (equal), TG (equal), FC (supportive) and AP (supportive) defined the Methodology of study 1 and 2, with RO (equal) contributing to study 2. MB (lead), with acknowledgment to other researchers (Miguel Faria, Hang Yin, and Michał Ostapowicz), contributed to Software development and designing of the system to support study 2. MB, FC, AR, TG performed the Investigation in study 1, while MB (equal), RO (equal) and FC (equal) performed the Investigation in study 2. RO (lead), MB, FC and AR contributed to Data Curation. AR (lead), RO (equal), MB (supportive) and FC (supportive) contributed to Formal Analysis of study 1. RO performed the Formal Analysis of study 2. RO (lead), FC, TG, and AR wrote the original draft. RO, FC, AR, TG, and AP contributed to reviewing and editing. Only substantial contributions are listed. The paper follows ACM Authorship Policies and uses CASRAI contribution terminology.

REFERENCES

1. Dragan Ahmetovic, Cole Gleason, Chengxiong Ruan, Kris Kitani, Hironobu Takagi, and Chieko Asakawa. 2016. NavCog: A Navigational Cognitive Assistant for the Blind. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16)*. ACM, New York, NY, USA, 90–99. DOI: http://dx.doi.org/10.1145/2935334.2935361
2. Majed Al Zayer, Sam Tregillus, Jiwan Bhandari, Dave Feil-Seifer, and Eelke Folmer. 2016. Exploring the Use of a Drone to Guide Blind Runners. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '16)*. ACM, New York, NY, USA, 263–264. DOI: http://dx.doi.org/10.1145/2982142.2982204
3. Mauro Avila Soto, Markus Funk, Matthias Hoppe, Robin Boldt, Katrin Wolf, and Niels Henze. 2017. DroneNavigator: Using Leashed and Free-Floating Quadcopters to Navigate Visually Impaired Travelers. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '17)*. ACM, New York, NY, USA, 300–304. DOI: http://dx.doi.org/10.1145/3132525.3132556
4. S. Azenkot, C. Feng, and M. Cakmak. 2016. Enabling building service robots to guide blind people a participatory design approach. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. 3–10. DOI: http://dx.doi.org/10.1109/HRI.2016.7451727
5. BeMyEyes. 2015. Screen Reader User Survey. (2015). Accessed January 3 2018. https://www.bemyeye.com/.
6. Jeffrey P. Bigham, Chandrika Jayant, Hanjie Ji, Greg Little, Andrew Miller, Robert C. Miller, Robin Miller, Aubrey Tatarowicz, Brandyn White, Samual White, and Tom Yeh. 2010. VizWiz: Nearly Real-time Answers to Visual Questions. In *Proceedings of the 23Nd Annual ACM Symposium on User Interface Software and Technology (UIST '10)*. ACM, New York, NY, USA, 333–342. DOI: http://dx.doi.org/10.1145/1866029.1866080
7. Bruce B Blasch, William R Wiener, and Richard L Welsh. 1997. Foundations of orientation and mobility. (1997).
8. Erin Brady, Meredith Ringel Morris, Yu Zhong, Samuel White, and Jeffrey P. Bigham. 2013. Visual Challenges in the Everyday Lives of Blind People. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 2117–2126. DOI: http://dx.doi.org/10.1145/2470654.2481291
9. Stacy M Branham and Shaun K Kane. 2015. Collaborative accessibility: how blind and sighted companions co-create accessible home spaces. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2373–2382.
10. Colleen M Carpinella, Alisa B Wyman, Michael A Perez, and Steven J Stroessner. 2017. The robotic social attributes scale (RoSAS): development and validation. In *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 254–262.
11. Álvaro Castro-González, Xiang Zhi Tan, Elizabeth Carter, and Aaron Steinfeld. 2018. Social Haptic Interaction between Robots and Children with Disabilities. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 81–82.
12. Sakmongkon Chumkamon, Peranitti Tuvaphanthaphiphat, and Phongsak Keeratiwintakorn. 2008. A blind navigation system using RFID for indoor environments. In *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, 2008. ECTI-CON 2008. 5th International Conference on*, Vol. 2. IEEE, 765–768.
13. Amy JC Cuddy, Susan T Fiske, Virginia SY Kwan, Peter Glick, Stephanie Demoulin, Jacques-Philippe Leyens, Michael Harris Bond, Jean-Claude Croizet, Naomi Ellemers, Ed Sleebos, and others. 2009. Stereotype content model across cultures: Towards universal similarities and some differences. *British Journal of Social Psychology* 48, 1 (2009), 1–33.
14. Kerstin Dautenhahn, Sarah Woods, Christina Kaouri, Michael L Walters, Kheng Lee Koay, and Iain Werry. 2005. What is a robot companion-friend, assistant or butler?. In *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*. IEEE, 1192–1197.
15. Dimitra Dodou and Joost CF de Winter. 2014. Social desirability is the same in offline, online, and paper surveys: A meta-analysis. *Computers in Human Behavior* 36 (2014), 487–495.
16. José Faria, Sérgio Lopes, Hugo Fernandes, Paulo Martins, and João Barroso. 2010. Electronic white cane for blind people navigation assistance. In *World Automation Congress (WAC), 2010*. IEEE, 1–7.
17. Mary Ellen Foster, Ellen Gurman Bard, Markus Guhe, Robin L Hill, Jon Oberlander, and Alois Knoll. 2008. The roles of haptic-ostensive referring expressions in cooperative, task-based human-robot dialogue. In *Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction*. ACM, 295–302.
18. Susanne Frennert, Håkan Eftring, and Britt Östlund. 2013. What older people expect of robots: A mixed methods approach. In *International Conference on Social Robotics*. Springer, 19–29.
19. Chaitanya P Gharpure and Vladimir A Kulyukin. 2008. Robot-assisted shopping for the blind: issues in spatial cognition and product selection. *Intelligent Service Robotics* 1, 3 (2008), 237–251.

20. Nicholas A Giudice and Gordon E Legge. 2008. Blind navigation and the role of technology. *The Engineering Handbook of Smart Technology for Aging, Disability, and Independence* (2008), 479–500.

21. João Guerreiro, Dragan Ahmetovic, Kris M. Kitani, and Chieko Asakawa. 2017. Virtual Navigation for Blind People: Building Sequential Representations of the Real-World. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '17)*. ACM, New York, NY, USA, 280–289. DOI: http://dx.doi.org/10.1145/3132525.3132545

22. Anhong Guo, Xiang 'Anthony' Chen, Haoran Qi, Samuel White, Suman Ghosh, Chieko Asakawa, and Jeffrey P. Bigham. 2016. VizLens: A Robust and Interactive Screen Reader for Interfaces in the Real World. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 651–664. DOI: http://dx.doi.org/10.1145/2984511.2984518

23. Peter A Hancock, Deborah R Billings, Kristin E Schaefer, Jessie YC Chen, Ewart J De Visser, and Raja Parasuraman. 2011. A meta-analysis of factors affecting trust in human-robot interaction. *Human Factors* 53, 5 (2011), 517–527.

24. Susan Henderson and Marilyn Golden. 2015. Self-Driving Cars: Mapping Access to a Technology Revolution. (2015).

25. Marion Hersh and Michael A Johnson. 2010. *Assistive technology for visually impaired and blind people*. Springer Science & Business Media.

26. David Kirschner, Rosemarie Velik, Saeed Yahyanejad, Mathias Brandstötter, and Michael Hofbaur. 2016. YuMi, come and play with Me! A collaborative robot for piecing together a tangram puzzle. In *International Conference on Interactive Collaborative Robotics*. Springer, 243–251.

27. Thibault Kruse, Amit Kumar Pandey, Rachid Alami, and Alexandra Kirsch. 2013. Human-aware robot navigation: A survey. *Robotics and Autonomous Systems* 61, 12 (2013), 1726–1743.

28. V. Kulyukin, C. Gharpure, and J. Nicholson. 2005. RoboCart: toward robot-assisted navigation of grocery stores by the visually impaired. In *2005 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2845–2850. DOI: http://dx.doi.org/10.1109/IROS.2005.1545107

29. Vladimir Kulyukin, Chaitanya Gharpure, John Nicholson, and Grayson Osborne. 2006. Robot-assisted wayfinding for the visually impaired in structured indoor environments. *Autonomous Robots* 21, 1 (01 Aug 2006), 29–41. DOI: http://dx.doi.org/10.1007/s10514-006-7223-8

30. V. Kulyukin, C. Gharpure, J. Nicholson, and S. Pavithran. 2004. RFID in robot-assisted indoor navigation for the visually impaired. In *2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (IEEE Cat. No.04CH37566)*, Vol. 2. 1979–1984 vol.2. DOI: http://dx.doi.org/10.1109/IROS.2004.1389688

31. Mark Lee Levine, Libbi Levine Segev, and Stephen F Thode. 2017. A Largely Unnoticed Impact on Real Estate–Self-Driven Vehicles. *Appraisal Journal* 85, 1 (2017).

32. David Little. 2007. Language learner autonomy: Some fundamental considerations revisited. *International Journal of Innovation in Language Learning and Teaching* 1, 1 (2007), 14–29.

33. Jack M Loomis. 2002. Sensory replacement and sensory substitution: Overview and prospects for the future. *Converging Technologies for Improving Human Performance* (2002), 213.

34. Jennifer Mankoff, Gillian R Hayes, and Devva Kasnitz. 2010. Disability studies as a source of critical inquiry for the field of assistive technology. In *Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility*. ACM, 3–10.

35. Byung-Cheol Min, Aaron Steinfeld, and M Bernardine Dias. 2015. How Would You Describe Assistive Robots to People Who are Blind or Low Vision?. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction Extended Abstracts*. ACM, 91–92.

36. Amal Nanavati, Xiang Zhi Tan, and Aaron Steinfeld. 2018. Coupled Indoor Navigation for People Who Are Blind. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 201–202.

37. Sensotec NV National Federation of the Blind and KNFB Reader LLC. 2014. KNFB Reader. (2014). Accessed January 3 2018. https://www.knfbreader.com//.

38. Hugo Nicolau, Joaquim Jorge, and Tiago Guerreiro. 2009. Blobby: How to Guide a Blind Person. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems (CHI EA '09)*. ACM, New York, NY, USA, 3601–3606. DOI: http://dx.doi.org/10.1145/1520340.1520541

39. Raquel Oliveira, Filipa Correia, Tiago Guerreiro, André Rodrigues, Mayara Bonani, and Ana Paiva. 2018. Semi-structured interview after interacting with Baxter. (Apr 2018). osf.io/frgy2

40. Céline Ray, Francesco Mondada, and Roland Siegwart. 2008. What do people expect from robots?. In *Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on*. IEEE, 3816–3821.

41. Markus Rickert, Andre Gaschler, and Alois Knoll. 2016. Applications in HHI: Physical Cooperation. *Humanoid Robotics: A Reference* (2016), 1–39.

42. GreenGar Studios. 2010. Color ID. (2010). Accessed January 3 2018. https://itunes.apple.com/us/app/color-id-free/id402233600?mt=8/.

43. Xiang Zhi Tan and Aaron Steinfeld. 2017. Using Robot Manipulation to Assist Navigation by People Who Are Blind or Low Vision. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 379–380.

44. Shari Trewin, Diogo Marques, and Tiago Guerreiro. 2015. Usage of Subjective Scales in Accessibility Research. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility*. ACM, 59–67.

45. I. Ulrich and J. Borenstein. 2001. The GuideCane-applying mobile robot technologies to assist the visually impaired. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 31, 2 (Mar 2001), 131–136. DOI: http://dx.doi.org/10.1109/3468.911370