Reflecting upon Participatory Design in Human-Robot Collaboration for People with Motor Disabilities: Challenges and Lessons Learned from Three Multiyear Projects

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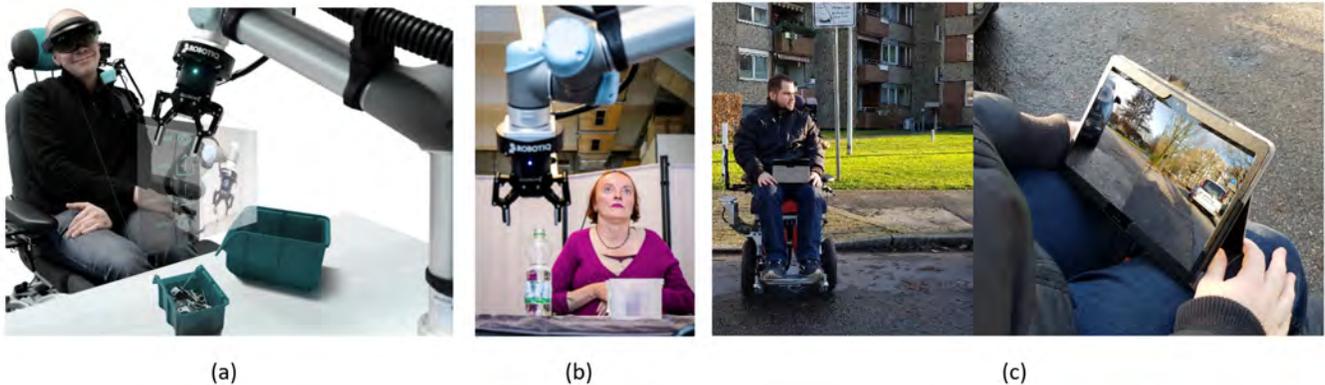Westphalian University of Applied Sciences
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Figure 1: Different use cases of Human-Robot Collaboration. (a) Workplace (b) Home (c) StreetX

ABSTRACT

Human-robot technology has the potential to positively impact the lives of people with motor disabilities. However, current efforts have mostly been oriented towards technology (sensors, devices, modalities, interaction techniques), thus relegating the user and their valuable input to the wayside. In this paper, we aim to present a holistic perspective of the role of participatory design in Human-Robot Collaboration (HRC) for People with Motor Disabilities (PWMD). We have been involved in several multiyear projects related to HRC for PWMD, where we encountered different challenges related to planning and participation, preferences of stakeholders, using certain participatory design techniques, technology exposure, as well as ethical, legal, and social implications. These challenges helped us provide five lessons learned that could serve as a guideline to researchers when using participatory design with vulnerable groups. In particular, young researchers who are starting to explore HRC research for people with disabilities.

CCS CONCEPTS

• **Human-centered computing** → **Participatory design**; **Accessibility design and evaluation methods**.

KEYWORDS

human-robot collaboration, people with motor disabilities, participatory design, challenges and lessons learned

1 INTRODUCTION

The WHO collected data from 69 countries and found that 15% of the world's population lives with some sort of disability [53]. Among these, 20% report a severe form of disability with a further 10.3% found to have an extreme form, and 9.7% have difficulties in mobility [52]. Motor disabilities affect upper and/or lower limbs due to injuries, diseases, or congenital problems [16]. These limit physical dexterity and different life aspects of People With Motor Disabilities' (PWMD).

Human-robot technologies have the potential to enhance the abilities of PWMD. PWMD frequently require the assistance of others to perform activities of daily living including reaching and manipulating objects around them. This can affect their sense of autonomy and self-efficacy [8]. PWMD emphasize the desire to live independently, i.e. being able to be on their own for several hours without the need of a care assistant [41]. We consider that robot designers can benefit greatly from the adoption of a Participatory Design (PD) approach in their practices to achieve a truly inclusive human-robot collaborative environment.

PD has been considered a tool for sharing expertise among stakeholders and designers, but most of all for inspiring change [30]. PD is used to better engage with all stakeholders and involve potential users as full partners in the design process, which leads to empowerment of stakeholders [28]. This provides an additional benefit as it leads to greater democratization between designers and stakeholders [34]. Additionally, it results in greater inclusion, as PWMD have been previously largely overlooked in the design process [51]. Further, this involvement has shown to positively influence their attitudes and behavior [26].

During the last three years, we have been involved in several multiyear projects related to Human-Robot Collaboration (HRC) for PWMD. The projects we include in this paper cover different use-cases: a home-support scenario for PWMD (eating and drinking with a robotic arm, HOME project, 2017-2020 [39], a workplace environment (working in collaboration with a robotic arm in a sheltered-workshop to perform manufacturing tasks, WORKPLACE project, 2017-2021) [40], and an urban mobility issue (crossing streets in a sensor enhanced wheelchair, STREETX project 2018-2019) [7], see Figure 1. This variety allowed us to explore and apply a multitude of methodological approaches and therefore achieve a better understanding of individual and overarching challenges. The outcomes of each project are not intended to be part of this paper, as they deserve their own analysis in separate publications.

Managing the different aspects of having a PD approach with PWMD can be a challenge for early-career researchers with limited knowledge of user-centered design. Research that has been carried out with PWMD has long been a matter of ethical concern in social sciences [45], [18]. Also, methodological challenges have been evaluated and compared to carrying out research with mainstream participants [37]. We build upon these works and align our experiences with those previously reported. Our paper takes a user-centered design perspective for HRC and highlights the particularities of using PD designing for PWMD.

Holone & Herstad [23] point out that "the ideals of Participatory Design must be approached with pragmatism." This leads us to present our experiences and thus offer a guide from the lessons we

have learned. Our contribution is twofold. First, our related work section presents an approach to HRC from a PD perspective which emphasizes the role of PWMD in this context. Second, we present a short overview of our projects and discuss the challenges we experienced. Based on this, we provide a set of practical lessons learned when designing a human-robot collaborative environment for PWMD. Through this, we aim to generate a dialogue about the advantages of PD in HRC for PWMD. This paper is directed to people who are starting to explore research areas that use robots to assist people with disabilities, often coming from a more technical background and less experience in user-centered design.

2 RELATED WORK

People with disabilities have been of interest among the HRC research community. Previous work has focused on exploring the use of different modalities [14], interaction [33], and graphical user-interfaces [44]. However, designing technology that has the potential to increase self-sufficiency calls for special attention to the social aspect and the relevance of evaluating social situations when designing assistive technologies [46]. The upcoming section presents a review of PD and HRC in design for people with disabilities.

2.1 Human-Robot Collaboration and People with Motor Disabilities

HRC addresses research where humans and robots are considered partners in carrying out joint goals [6]. In recent years, HRC has become widespread in manufacturing lines [13]. However, HRC has also been of interest in assistive environments for the aging population [20] and disability care [29] to collectively overcome obstacles.

In a space where humans and robots coexist, there are a number of factors requiring consideration. For instance, the role of safety in the prevention of collisions by optimizing timing and intervention [36]. Situation awareness is a pertinent component of safety in HRC. It involves determining when it is appropriate to take an action, and what information needs to be communicated to the human counterpart [50]. HRC must consider the socio-technical arrangement of primary (end-users) as well as the one of secondary users (e.g. caregivers). These perspectives can differ from each other and need to be appropriately reflected in the designed technology. Here, a previous study showed that primary users stressed autonomy, privacy, and choice, whereas caregivers perceived safety as important as autonomy [27]. Additionally, work-load is another aspect that should be addressed. Tan et al. [49] found a correlation between mental workload with robot motion speed and distance, i.e., people experienced an increase in mental workload when the robot moved faster and in closer proximity.

2.2 Participatory Design in Human-Robot Interaction for People with Disabilities

Participatory research according to Balcazar et al. [4] has the power to influence the design and research agenda. It addresses problems that people with disabilities experience by providing them an active role in the decision making process. PD can therefore be described as a "verbal exchange of ideas" [32], which can be used

when working together with PWMD. Focus groups and workshops are common techniques implemented within PD. These have also been used when designing for different types of disabilities in the context of accessible design, e.g., people with visual impairments [35], or people with lower-limb impairments to design a wheelchair [15]. Interviews are a technique that is commonly used, wherein semi-structured interviews can be effective to collect individual experiential knowledge [32] together with participatory observations. The latter is particularly useful when participants are not able to talk in detail about specific tasks that they perform with the help of their caregivers.

PD techniques have proven to show better results when combined. For instance, Azenkot et al. [3] used interviews, workshops, and individual Wizard-of-Oz session to collect design insights about a robot tasked to help people with visual impairments to navigate indoors. Ferati et al. [19] took a closer look at different PD techniques (cartographic mappings, future-workshop, cultural probes). These techniques were used to determine the main concerns of the target user group regarding their daily living situation and thus design solutions tailored to specific needs.

PD can also affect expectations in users. Bratteteig et al. [9] explore expectation management and idea selection to encourage reflection in pursuit of feasible and realistic outcomes, thus increasing end user acceptance. This is particularly relevant among PWMD. Many PWMD are used to customized designs, and designers should avoid discarding their ideas without providing the necessary argumentation. Further, Reich-Stiebert [43] showed how involving users at the earliest stages of design can positively influence their attitudes towards robots. It is important not to underestimate the designers' behavior and skills, since these are crucial to achieving a true interchange of ideas always respecting the users' knowledge [10].

In her Disability Interaction Manifesto, Holloway points out the need for a new body of knowledge acquired by co-creation with people with disabilities [22]. Thus, opening discussions in Human-Robot Interaction (HRI) about PWMD and encouraging research efforts towards extending people's capabilities.

2.3 Empowering Users through Participatory Design

PD has the ability to connect different stakeholders with designers with the common goal to share knowledge. Lee et al. [31] showed how carrying out PD improved the understanding of their target demographic, and showed a path to the creation of new knowledge in the development of better social robots. Another way of empowerment occurs when users recognize their ideas in the end solution. For instance, Bratteteig & Wagner [10] used nurses' ideas and translated them directly into a user interface.

The feeling of self-efficacy assists in the well-being of people with motor impairments [21] since it provides a feeling of achievement by one's efforts. Hence, involving people with disabilities in the design process not only boosts the feeling of ownership of a solution but also adds a feeling of self-efficacy and empowerment derived from their co-creator's role. Further, Barbareschi et al. [5] used an emotional design model to evaluate the design and production of a wheelchair. Their results showed that a user-centered

approach, when producing a customized solution, is perceived as an "empowering and meaningful form of self-expression".

3 CONTEXT AND METHODS

This section will provide the foundation to understanding our research carried out over the last years. Further, it puts the challenges and lessons learned we present in § 4 and § 5 in perspective. In user-centered design approaches and PD in particular, involving all stakeholders during the design process is essential. Table 1 presents a summary of the participants with motor disabilities who partook in our projects.

An overview of the methods used is presented in Table 1. One essential approach we relied upon was contextual inquiry and subsequent interviews and participatory observations. This allowed us to observe participants in-situ and gain further context through interaction with participants. With regards to the evaluation methods, user-testing with the group of PWMD focused on qualitative analysis of systematic exposure to demonstrators, factoring in trust, well-being, and placing quantitative measures in second place. Our prototypes, see Figure 2, were evaluated with participants without disabilities prior to the evaluation with PWMD due to (1) the high individual variability of PWMD; (2) the potential of physical harm. High individual variability makes interpretation difficult. Thus, establishing a base-line with people without physical constraints can help to put results in perspective and it avoids physical harm when participants cannot physically move.

3.1 Home Project (HOME)

The goal of the HOME Project is to explore the opportunities and limitations of a robotic arm to assist PWMD with food consumption. To that end, we investigated the personal living and care spaces of our user group. Technology-wise, we focused on autonomous behaviors of a robotic arm, where PWMD can recognize the robot intentions and develop intervention strategies when/if needed. Our solutions aim to provide visual feedback about the robot intentions and its status to keep PWMD informed at all times. We highlighted safety and trust since the robotic arm would come into close proximity to the users' face.

3.1.1 Participants. In this project, we worked together with a hospital that put us in contact with 15 people with quadriplegia (and their caregivers). They were scattered across the country and were individually visited at home. Subsequently, they took part in a series of workshops that addressed different issues of ethical, legal, and social implications. In addition to this selected participants' group, we reached out to an anonymous, but larger user base through online surveys.

3.1.2 Method. We carried out interviews and participatory observations at the participants' homes along with prepared video-props to illustrate a potential HRC scenario. We documented audio and video materials together with pictures of the physical environment.

Based on the difficulty of getting access to larger populations of the end-user group, we also conducted surveys via Amazon Mechanical Turk [1] and similar platforms including SurveyCircle [48]. We used this approach to collect feedback on a variety of robotic setups regarding its position, speed, and proximity to the user. These
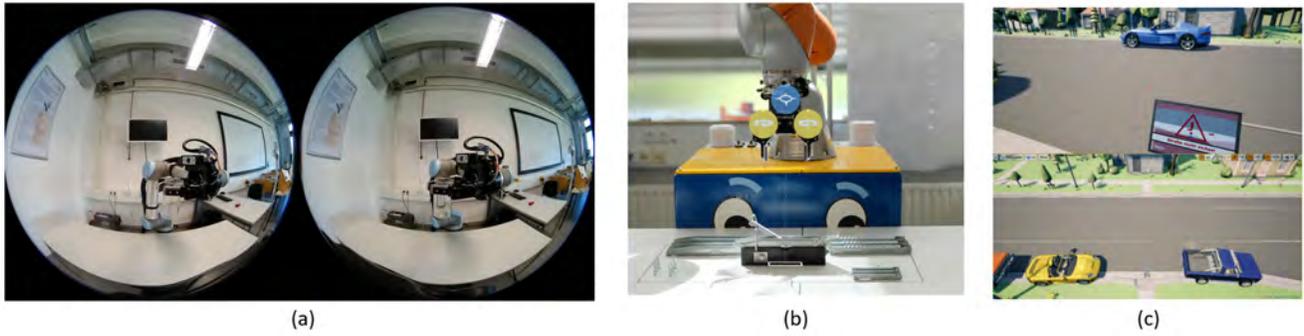
Figure 2: (a) HOME. View of the videos wearing Google Cardboard. (b) WORKPLACE. View of the workstation wearing a Microsoft HoloLens. (c) STREETX. VR simulation of street crossing

Table 1: Description of participants and methods per project

Project (Number of Participants)	Diagnosis	Technique	Materials
WORKPLACE (3)	Duchene Muscular Dystrophia, learning disabilities, restrictive lung disease, achondroplasia, incapacity to walk, breathing difficulties, multiple sclerosis	Participatory observations, future workshop, videos, technology testing, prototype testing	AR prototypes (Microsoft HoloLens)
HOME (15)	Locked-in Syndrome, inclusion body myositis , multiple sclerosis, physical trauma, arthrogryposis multiplex congenita	Participatory observations, surveys, interviews, videos	Google Cardboard, pictures, videos, prototype testing with VR simulations
STREETX (4)	Spastic quadriplegia, paralyzed limbs, spina bifida, quadriplegia	Interviews, participatory observations, prototype testing	VR simulations

aspects could not be verified quickly in a physical environment but could be easily represented through videos within the survey structure.

3.1.3 Materials. As mentioned above, we relied on videos documenting a first person perspective of the view on a HRC scenario. For our interviews at the participants' homes, we used stereoscopic videos shown through Google Cardboard. Additionally, we showed pictures of different robotic settings, which are currently on the market, e. g. iEat [11], Obi [38], JACO [25], and iArm [12]. In our surveys, we used monoscopic videos visualized through a standard display rather than VR or Cardboard headset. In addition to videos, we developed interactive 3D environments to simulate HRC scenarios and presented those to potential users.

3.2 Workplace Project (WORKPLACE)

The main goal of the WORKPLACE project is the development of an interaction concept that allows PWMD to execute manipulation and grasping tasks with a robotic arm in a work environment. We aim to simplify existing complex robot control. Especially for people without prior experience and who are still mostly able to move their heads, eyes, and are able to speak. Hence, we focused mostly on Augmented Reality based approaches to overlay the visual space

with basic robot controls and use visual cues to ease understanding the relationship between the robot and the workspace.

3.2.1 Participants. Due to the nature of this project we chose to collaborate with a sheltered-workshop. Sheltered workshops employ people with a variety of physical and cognitive disabilities. Here, a "lead" user group of three PWMD was established with the goal to accompany the project. This lead user group was involved in various stages of the project including design workshops, technology demonstrations, and further interviews. The lead user group was selected based on their availability and interest to participate. In addition to that, we included secondary users such as caregiving personnel, engineers, social workers, social pedagogists, and workstations' supervisors.

3.2.2 Method. We used contextual inquiry to gain an overview of the tasks, behaviors, and social protocols at various workstations. Thus, evaluating the possibility of adding a collaborative robot to the current working environment.

In a flipped exploration/observation setting, we invited our lead users from the WORKPLACE project to visit our laboratory. They were able to see our robots and prototypes, and experience firsthand the technologies that would be used. For instance, during these visits they used devices such as the Microsoft HoloLens 1 (head-mounted augmented reality display), see Figure 3, or a customized

sensor-enhanced headband that allows operating a robot through head movements.

Also, we applied a "future-workshop" as an envisioning method. Primary (PWMD) and secondary users (staff from the sheltered-workshop such as social workers and supervisors) ideated about problems and envisioned novel design approaches collaboratively with researchers [2].

3.2.3 Materials. In our future-workshop, we worked with first-person videos of different interaction scenarios to help participants envision such an environment. Additionally, we used the Microsoft HoloLens 1 to present augmented reality prototypes that enhance the workstation to provide relevant task information.

3.3 Crossing Streets (STREETX)

The aim of the STREETX project is the development of an assistive system that allows wheelchair users to safely cross streets. We analyzed their habits and concerns about independently crossing streets to improve road safety. In order to achieve this, we aimed to modify an electric wheelchair to simulate a robotic assistant that provides information about the current traffic. This is performed in a way similar to the intersection assistants used in cars.

3.3.1 Participants. To avoid common limitations of access to the target group, we explored a different and less formal approach. We identified a Reddit [42] community and analysed existing posts and discussions to extract frequently mentioned needs and problem areas for PWMD. Among other trends, we identified the problem of street crossing. Based on this, we conducted a user research similar to the one from the WORKPLACE project and cooperated with a local sheltered-workshop. The potential users that were interested in cooperating in the project were again contacted for prototype testing and feedback.

3.3.2 Method. For our Reddit analysis, we conducted text-based thematic content analysis to identify main issues hidden in the casual conversations and threads. Additional information was collected through interviews with PWMD from sheltered workshops. Based on this, we developed a prototype and carried out usability testing.

3.3.3 Materials. The collected information helped us to create 3D simulations that were displayed on a computer screen and in VR. This setup was chosen as a situation like street crossing would be potentially dangerous for participants in reality.

4 CHALLENGES

To the best of our knowledge, much of the challenges from previous literature leave aside the pragmatic use of PD in HRC for PWMD. Thereby, we grouped the challenges we found into different topics. Concerning participants, we found challenges in planning & participation and preferences of stakeholders. Regarding the methods used, we identified the advantages of using several PD techniques. With respect to the materials used, we realized the importance of technology exposure. Finally, we highlight that ethical, legal, and social implications go beyond consent.

Figure 3: Primary users testing an Augmented Reality prototype on the Microsoft HoloLens.

4.1 Planning & Participation

Vines et al. [51] have previously highlighted the benefits of having end-users as project partners, although, it might not always be possible. Hence, it is crucial to consider different means to approach a target group that is not easily accessible. That is why we contacted and recruited participants in manifold ways. We had a sheltered-workshop as a project partner (WORKPLACE & STREETX project), we analyzed a Reddit community for PWMD (STREETX project), and we were directed to PWMD through hospital medical staff and support groups (HOME project).

When working together with PWMD, planning takes in particular an important role. For example, when recruiting participants in a sheltered workshop for the WORKPLACE project, in despite of the willingness of users to participate, caregivers expressed their concerns about disrupting participants daily routine. Caregives expressed that this can add severe stress to some participants. Therefore, together with the social workers and caregivers, we decided to establish a lead user group approach, wherein we carefully selected participants that would be able to handle this involvement. Then, we carefully planned the research sessions to avoid unnecessary disturbances and focused on inclusion into regular routines of participants.

In the case of interviews and observations, participants might be located in geographically distant locations which hinders the access to them. For example, the HOME project had participants scattered across the country, making it difficult for the researchers to visit every participant. In addition, a caregiver presence was needed in case of emergency. During the future-workshop, caregivers mentioned the importance of choosing an adequate time of day and duration for the workshop. Appointments should not interfere with lunchtime and restroom schedule, as this could cause an extra burden to PWMD. Also, we needed to arrange transportation (a van that can transport wheelchairs), since not all participants were located at the same building where the workshop took place. Finally, we considered as well the fact that some PWMD might need assistance during the workshop, hence, at least one caregiver was in an adjacent room.

Further, to enable user testing with PWMD, we found it very demanding (size, connectivity, and also safety) to move an industrial robot to the location of PWMD. The alternative, have PWMD visit

our premises, involves also a lot of planning and added resources, e.g. for secondary users.

4.2 Preferences of Stakeholders

Holloway highlights the importance of "creating a new body of knowledge with disabled people through the exchange of ideas around domain-specific knowledge" [22]. We capitalize on that and included not only researchers from different fields but worked with stakeholders from different domains as well, e.g., WORKPLACE, social workers, civil-engineers, social pedagogists. Yet, we sometimes found difficulties in handling opposing viewpoints of different stakeholders.

An important matter when involving different stakeholders comes in terms of the diversity of interests and concerns that they may have and how these would be considered in the design process. Laitano [30] already identified that finding consensus among stakeholders is a challenging task. Additionally, Spiel et al. [47] mentioned the importance of negotiating multiple agendas through mediation and withdrawing. The involvement of each stakeholder provides valuable input from different perspectives, some bound to their respective professional backgrounds. Even in organizations wherein it is assumed that everyone shares the same goal, nuances in perspectives can be identified. For instance, some supervisors at the sheltered workshop prioritize production, while social workers highlight well-being. This suggests that different perspectives are clearly visible and can be controversial, even among small groups of people that share a common organizational goal.

From our experiences, while PWMD encompasses people with similar diagnoses, there are huge differences on the resulting type of impairment and the degree of severity. Related variables such as age or the duration a person has lived with a disability also contribute to very different individual characteristics. These aspects add complexity when deriving knowledge. For instance, we involved participants with quadriplegia, multiple sclerosis, locked-in syndrome, duchene muscular dystrophia, and cerebral palsy. Some of these participants had other cognitive and learning disabilities in addition to motor impairments. This high degree of individual differences leads to variability when measuring quantitative data and makes interpreting the results difficult, e.g. task times with a certain input modality.

Qualitative assessments can also be biased due to these particular differences. For example, a participant might prefer the use of certain modality. This preference is related to a part of their body that is the least affected or one that they maintain control despite the progression of a disability. Hence, qualitative approaches allow to find deepen into the reasoning behind certain choices and opinions. Forming thus together a collective understanding of the population.

Luck [32] calls for attention to the users' difficulties in articulating their preferences. These can be unrelated to the type of disability and suggest different understanding of certain terms used. Thereby, it is important to clarify the terminology and share a common understanding of the terms used.

4.3 Using Various PD Techniques

Using different PD techniques allows to better capture different views on HRC. However, every PD technique involves different types of challenges. For instance, interviews often require a one-to-one interaction. Such personal interactions were difficult in the case of PWMD. Caregivers need to be present in case of unexpected emergencies or to act as a spokesperson when physical communication abilities were limited. We observed that participants tend to be more open when their caregivers are not in direct proximity but located in a different (adjacent) room.

Idealizing participation versus having realistic expectations has been previously discussed in the literature [10]. In our experiences we realized that this is particularly the case with PWMD, some with added cognitive disabilities, e.g. they might lose focus easily, get distracted, or experience physical discomfort. Hence, participation and engagement of PWMD depend more prominently on their current physical and mental state, when compared to people without disabilities. For example, one participant who is typically active and talkative was suddenly very quiet during our future-workshop due to only recently recovering from a sickness.

Secondary users also perceive design sessions differently. While it might raise curiosity in some attendants it can be considered as a burden and loss of time to others. Sometimes, stakeholders have the feeling that they lack expertise in certain topics, e.g., during our design workshop some social workers felt unease when approaching topics related to technology.

Another methodological aspect concerns the researchers in the design team. In the HOME project, our team consisted of social scientists and computer engineers, which allowed interviews to both cover social and technological aspects. Also, using different PD Techniques and materials allows researchers to be prepared for unexpected situations. For instance, showing videos to participants was still possible to be carried out remotely. It further allowed us to continue our research during the SARS-CoV-2 pandemic and subsequent restrictions.

4.4 Technology Exposure

Holzinger et al. [24] identified a positive correlation between technology exposure and acceptance. Further, they mention the importance of further exploring ways to expose people to technology in the design process.

Designing HRI is not abstract and virtual like designing a new mobile app. It involves interacting with a robot and other sensors and actuators, as well as with other feedback devices, e.g. head-mounted displays. This results in a complex and rather large technical setup. This compromises the desired technology exposure in the real environment. Hence, we recurred to other manners of presenting prototypes, e.g., through videos and VR simulations (HOME, STREETX projects)

As previously shown [17], familiarization is crucial in HRI since it can lead to users feeling more comfortable and trusting during interaction with robots. In the WORKPLACE project, carrying an industrial robot to the sheltered workshop is not something that can be done regularly due to specific spatial and connectivity configurations. Therefore, we looked to gather first impressions of the robot by having end-users visit the research laboratory. All of the end-users had never seen an industrial robot, thus, it served us to collect impressions. It also enabled end-users to become familiar

with the human-robot affordances. However, we encountered several difficulties regarding the devices used. For instance, putting on the Microsoft HoloLens when wearing an oxygen mask was not possible, certain eye-shapes did not allow for calibrating an eye-tracker or for proper visualization of the imagery displayed in a head-mounted display. Additionally, some participants' neck could not hold a head-mounted display and not everyone was able to execute head-movements (yaw, pitch, and roll) to the same extent.

4.5 Ethical, Legal and Social Implications (ELSI) in the research process

The consideration of ethical, legal and social implications is a funding requirement of European and other international publicly funded projects. These aspects affect the research process as well as the technology to be developed. Here we focus on the research process and the challenges observed. Doing research with people with disabilities usually requires an ethics board. In particular, in technology research, finding a responsible ethics board might not be straight forward—most ethics boards we are aware of, focus on topics such as medical or social research and do not have technology expertise.

In order to comply with legal data protection, security requirements, and international standards, an informed consent is necessary. For interviews, observations, and workshops, the standard procedure is signing a consent form. However, some PWMD in our projects could not physically sign by themselves. As long as the user does have cognitive disabilities, a video record of a verbal agreement is also generally a legally accepted form of consent. In the case of cognitive disabilities, an authorized representative needs to be on-site to physically sign the forms. In all cases, it is necessary to closely monitor the desires and physical state of the person in the current situation and be prepared to stop the study at any point.

Spiel et al. [47] invite to go beyond managing ethics as a checklist approach in PD. Our experiences align with this statement. For instance, to obtain reliable statements, it was important to consider the experience and knowledge of the technology to be developed. Pictures, video-clips, mock-ups, or prototypes can be means to inform participants and allow for the same level of knowledge. As PWMD and other stakeholders had different ideas and fears with respect to technology. In the HOME project, a participant believed that the robotic arm would be literally attached to the body and requires the amputation of their own arm.

In general, we align with the findings of Bratteteig et al. [9] regarding expectation management. We stress the need for transparency about the goals and a realistic outcome of the research. PWMD might not directly benefit in the immediate future or even long-term from the research outcomes. Consequently, it is important to communicate this to primary and secondary users.

5 LESSONS LEARNED

We present five significant lessons learned that could guide other researchers and practitioners when designing HRC for people with disabilities. These lessons consider Holloway's action plan for disability interaction, "learn from what has been done" [22] and are based on our own challenges.

(1) Approach participants through different channels and allow for multidisciplinarity in the research team. Having hospitals, sheltered-workshops, support groups, or similar institutions as partners can ease participant recruitment. Moreover, getting involved in online communities can help to get in touch with people who are willing to participate but not in close physical proximity. Also, a design team with members from different disciplines allows for in-depth analysis with different viewpoints and facilitates solution development.

(2) Consider the social dependencies in the selection of a PD technique. Designers should consider inter-dependencies between primary and secondary users when gathering information. Interviews gather individual experiences, however, the trustworthiness of the information can be affected by the presence of secondary users, e.g., caregivers. Focus groups or workshops foster discussions and co-design but cause additional stress for PWMD, compromising the discussions. Having a lead user-group can reduce stress in PWMD and ease their involvement along the different design stages. Therefore, it is crucial to set a detailed meeting plan together with secondary users since they have important information about daily routines, requirements, and organizational factors.

(3) Plan for early exposure to robots and other technology. It is vital that participants experience or familiarize themselves to some extent with the technology to be used at an early phase. This could contribute to better evaluate the use of different devices/possibilities; especially, when a certain device/idea has been found difficult to use by the end-users. Further, there is high variability on what type of device works for an individual, especially in the case of PWMD. Also, research technology is often not "ready-to-use" which makes it difficult for participants to experience it at the same level as commercial products, affecting their evaluation. Designers should be prepared for alternative ways of emulating interaction with a robot. It might not always be possible to transport a certain type of industrial robot so that stakeholders have first-hand experience. Hence, showing videos and using immersive 3D technology, can help to create an experience of interacting with a robot.

(4) Take into account all opinions in design sessions. Managing design sessions separately is decisive when stakeholders have potential divergent approaches. This contributes to gain specific perspectives, favor the flow of ideas, and avoid bottleneck discussions. Stakeholders can be grouped by similarities in their backgrounds and goals, and researchers should carry out separate design sessions for each group of stakeholders. For example, session 1 for end-users; session 2 for social workers, caregivers, and medical staff; and session 3 for supervisors and managers. Designers should share the gathered insights from different sessions among all stakeholders to favor mutual information discoveries and allow future collaborations. This allows sensitizing different stakeholders to diverse perspectives, as well as, getting insights about the connectivity of arguments and possible hindrances for technology/solution acceptance.

(5) Acknowledge that ethical implications go beyond consent. Information on the technology to be developed should be transparent, precise, and carefully communicated in order to avoid misunderstandings and manage expectations. Designers should take time to ensure that the purpose and outcomes of the research

are fully understood. Also, participants' physical and mental well-being should be carefully analyzed along the design process, and this could be better achieved with the help of social workers, caregivers, and medical staff (secondary users).

Our last two lessons learned align with those of Spiel et al. [47] in terms of prioritizing topics, negotiation of needs, and commitment to participants. Their work reflected on micro-ethical decisions for PD with marginalized children. This hints the relevance of publicizing this type of work when using PD with vulnerable groups and the particular insights that can be derived from each group.

6 LIMITATIONS

We acknowledge that some of the challenges we encountered align with those previously found by people who carry out research with people with disabilities. However, we consider it relevant to present them in a human-robot collaborative context. To the best of our knowledge presenting insights of PD for PWMD in a HRC context is a novel approach. Our goal is that this type of research invites discussions.

Another limitation comes in terms of the techniques used along the research process. Other techniques could provide additional challenges and thereby lessons learned. However, we consider that the aforementioned techniques are among the most frequently used in PD.

Additionally, the use of robotic arms and our specific choice of technology certainly limits the applicability of the proposed lessons learned. Still, many of our observations and insights are not tightly bound to certain technology but should be applicable to other HRC technologies as well.

7 CONCLUSION

Participatory Design has the potential to create solutions that help researchers empathize with the needs of the end-users, which is essential when designing with and for people with motor disabilities. However, in particular in the context of Human-Robot Collaboration, technology still takes a dominant role and makes the application of Participatory Design difficult. Thereby, designers of a human-robot collaborative environment for people with disabilities might encounter similar crossroads to the ones we found in our research.

In this work, we presented 5 lessons learned, summarized as follows:

- Approach participants through different channels and allow for multidisciplinarity in the research team.
- Consider the relationship between social dependencies in the selection of a PD technique.
- Plan for early exposure to robots and other technology.
- Take into account all opinions in design sessions.
- Acknowledge that ethical implications go beyond consent.

We highlight that Human-Robot Collaboration calls for special attention to two main aspects: technology and ELSI. Technology exposure plays a important role since the novelty and complexity factors in the resulting solution to participants. In addition, ELSI is per se a complex and vast aspect that requires careful evaluation in the design process which does not only involve consent but expectation management.

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