Understanding Human-Robot Collaboration for People with Mobility Impairments at the Workplace, a Thematic Analysis

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Abstract— **Assistive technologies such as human-robot collaboration, have the potential to ease the life of people with physical mobility impairments in social and economic activities. Currently, this group of people has lower rates of economic participation, due to the lack of adequate environments adapted to their capabilities. We take a closer look at the needs and preferences of people with physical mobility impairments in a human-robot cooperative environment at the workplace. Specifically, we aim to design how to control a robotic arm in manufacturing tasks for people with physical mobility impairments. We present a case study of a sheltered-workshop as a prototype for an institution that employs people with disabilities in manufacturing jobs. Here, we collected data of potential end-users with physical mobility impairments, social workers, and supervisors using a participatory design technique (Future-Workshop). These stakeholders were divided into two groups, primary (end-users) and secondary users (social workers, supervisors), which were run across two separate sessions. The gathered information was analyzed using thematic analysis to reveal underlying themes across stakeholders. We identified concepts that highlight underlying concerns related to the robot fitting in the social and organizational structure, human-robot synergy, and human-robot problem management. In this paper, we present our findings and discuss the implications of each theme when shaping an inclusive human-robot cooperative workstation for people with physical mobility impairments.**

I. INTRODUCTION

According to the World Report on Disability, collected data from 69 countries showed that 20% of people live with severe or extreme difficulties in mobility [1]. People with physical mobility impairments (PWPMI) have limitations in their activities of daily living and work life, causing lower economic participation. However, if adequate environments are settled with the help of assistive technologies, PWPMI could be one step closer to participate in economic activities. Different employers' perspectives about hiring people with disabilities across industries have been debated in terms of acceptance, hiring probability and co-workers' attitudes [2]. An interesting fact presented by the U. S. Bureau of Statistics shows that from the employed population with disabilities in that country, almost the same percentage of people with and without disabilities would be likely to work in manufacturing and leisure/hospitality industries [3]. Manufacturing industries could provide opportunities for PWPMI, wherein human-robot cooperative tasks are already becoming a common synergy [4], [5], [6]. For instance, PWPMI could perform manipulation and grasping tasks by controlling robotic arms that allow interaction in a safe shared space, e.g., Kuka LBR iiwa [7], Kinova [8], Universal Robots [9].

As a use case, we considered a sheltered-workshop. Sheltered-workshops are institutions that provide a safe environment for people with disabilities to develop work-related skills and offer employment opportunities[10]. Our particular choice employs people with different types of disabilities and in variety of manufacturing tasks. Here, we carried out a set of observations at different already existing workstations and had special interest in manufacturing (assembly line) workstations. Therein, we took a closer look at employees with upper and/or lower limb disability to understand their needs, expectations, and preferences. In order to achieve this, we chose a participatory design approach through a technique known as Future-Workshop (FW). Our goal was to collect data about potential hands-free modalities and human intervention techniques, but we later discovered that there were underlying concerns that the FW brought to light and will be discussed Section 4.

When analyzing collected data, qualitative methods have been suggested to be appropriate when doing research with vulnerable population [11]. Thematic analysis is a common approach in health journals [12], and its versatility allows researchers to analyze data collected from different resources, including focus groups [13]. That is why we opted for thematic analysis to gain a better understanding of PWPMI in a human-robot cooperative workstation.

The purpose of this paper is to present the views of PWPMI to design a human-robot cooperative workstation. We organized the information as follows. Section 2 presents an overview of Human-Robot Collaboration (HRC) in manufacturing and for people with disabilities. Section 3 presents our method, participants, and results. These include a design-workshop (FW), the steps followed for our thematic analysis, a description of participants, and our outcomes. We further interpret and discuss our results in Section 4 to finally present our limitations and conclusions in Sections 5 and 6.

II. RELATED WORK

A. Human-Robot Collaboration in manufacturing and for people with disabilities

The goal of HRC within manufacturing is to create an environment which counters the inherent limitations of both humans and robots through working collectively [14]. The main difference between industrial and collaborative robots

*This work is funded by the German Federal Ministry of Education and Research (BMBF)

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regards the possibility of working in close contact and coordination with humans. Here, safety has been found to be the most important enabling factor [14], while trust determines the achievement of successful human-robot cooperation [15].

Kolbeinsson et al. highlight that cooperation and collaboration are often used interchangeably in HRC; and describe cooperation as sequential actions towards a shared goal, conversely to collaboration, described as shared sequential actions towards a shared goal [16].

There have been few research efforts within HRC that consider people with disabilities in manufacturing environments. An example is presented by Stöhr et al. who introduce a work HRC model for users with disabilities considering a pool of robot capabilities and the user's types of disabilities [17]. Kyrarini et al. investigate possible human-robot cooperative scenarios that include people with disabilities performing manipulation tasks [18]. Both works show the potential of HRC for PWPMI in manufacturing.

A number of published studies have focused on technology testing with people with disabilities, however, there have been fewer studies that focus on capturing the needs of this group of people. There is only a handful body of research that consider co-designing with people with disabilities (i.e. [19], [20]). Also, human factors need to be considered when implementing industrial HRC such as, operator participation in the implementation, visible senior management and commitment, and empowerment of the workforce [21]. The following research addresses this issue as it approaches HRC from a participatory design perspective and considers the social arrangement of primary users (PWPMI) and secondary users (caregivers, social workers, supervisors) to design a human-robot cooperative workstation.

III. METHOD

A. Procedure

1) Future-Workshop: This technique focuses on understanding particular situations, helps to identify common problems, and aims at developing a vision of the future [22]. Having participants in a group has the advantage of participants interacting with each other, i.e. challenging or building upon other's ideas; conversely to conducting individual interviews where information from one single participant is collected at a time [23].

We carried out a FW at the sheltered-workshop with two distinct groups of stakeholders, PWPMI, as primary users and social workers and supervising personnel, as secondary users. As a possible scenario, we presented an already existing manufacturing workstation of the sheltered-workshop. At this workstation, different metal pieces are currently assembled by hand. As part of the participatory design approach taken, there were previous sessions where we introduced the technology that could potentially be used in the workstation to gather experiences and impressions. Therefore, participants were already familiar with the broad research theme as well as the researchers from an ongoing research cooperation. The FW was held on a single day but divided into two sessions, one for each group of stakeholders.

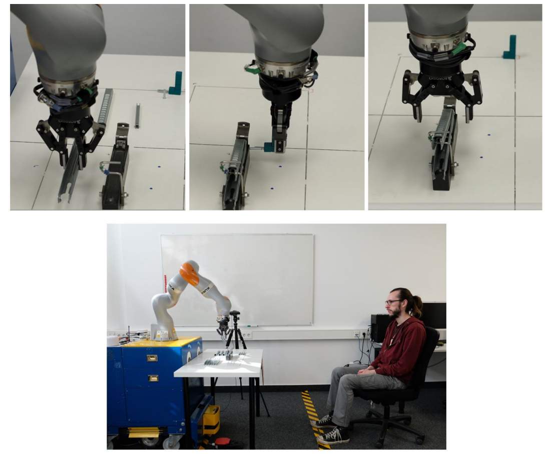

Fig. 1. Top: Screenshots from the video shown during the preparation phase. Bottom: Representation of a human-robot cooperative workstation.

Two researchers conducted the sessions, one taking notes of ideas shared and the other was encouraging ideation, discussion, and feedback through a set of open questions.

A FW is divided into different phases: preparation, critique, fantasy, and implementation [24]. During the preparation phase, we explained our goals for the workshop, handed a written consent form, explained some terminology that would be used, and created an inviting atmosphere that could promote sharing ideas. As a baseline, we presented two videos of the manufacturing scenario. On the first video the metal pieces were assembled by hand and on the second video they were built by the robot (Fig.1). The assembled piece is used in adjustable beds and it is one of the products that is already being produced in the manufacturing workstation. The second video showed how the robot could move (speed, distance) and the way in which it could manipulate objects. It also represented a human-robot cooperative workstation and therefore allowed participants to ponder about factors such as the distance between the robot and the human, as seen in Fig. 1. We then moved on to the critique phase were we mainly encouraged participants to think about problems or concerns through questions like: "What problems do you see in performing this task with a robot?" or "What worries you about working together with the robot?"

For the fantasy phase, we divided it into two general topics: hands-free interaction and human intervention techniques. Our goal was to discover preferences in different hands-free modes of interaction, e.g. eye-gaze, head-gaze, or speech to control the robot. For this topic, we asked a set of questions together with first-person-perspective videos to present a task wherein an industrial robot executes a set of actions, e.g., moving, turning, picking and placing objects, which are common in manufacturing and assembly tasks at the sheltered-workshop. Some of the questions related to modalities were: "How do you communicate with the robot?" "How can you control the robot and command certain movements?" "As an example: controlling the robot could be like controlling your wheelchair; if you want to go forward you would tilt your joystick as long as you reach the position where you want to be.” The second topic, human intervention, infers that a robot operator steps in during an autonomous robot action to stop or modify such action. To represent intervention techniques, we showed a pick-and-place task, wherein the robot fails to place an object inside a box due to an unexpected movement of that box. Then, we asked questions such as: “How can we make the robot stop?” “When would you consider necessary to make a stop and when not?” “The system can also warn you about things that are happening around you. How would you like to get this alert?” Finally, in the implementation phase, we summarized the ideas of the group and shared our thoughts on the feasibility of the shared ideas.

TABLE I

LIST OF PRIMARY USERS

Participant	Diagnosis	Functional Ability
EU1	Duchene Muscular Dystrophy	Some head mobility, limited hand and finger mobility, help needed to position arms, no functional legs mobility
EU2	Duchene Muscular Dystrophy, learning disabilities, restrictive lung disease	Limited head mobility, limited finger mobility, help needed to position arms, ventilation, no functional legs mobility
EU3	Achondroplasia, learning disabilities, incapacity to walk, breathing difficulties	Some head mobility, some hand and arm mobility, no functional legs mobility

2) Participants: We organized two separate sessions (Fig. 2), both with the same general structure and topics. On the first session, we had 6 participants (P1 social pedagogist, P2, P3, P5, P6 social workers, P4 mechanical engineer) among which P1, P4, P6 were supervisors. The second session was held with our potential end-users (PWPMI), see Table 1. Our sessions lasted 90 and 75 minutes with the primary and secondary users respectively. The time invested in these sessions was considered part of their working hours.

B. Thematic Analysis

The data collected from the FW was analyzed using thematic analysis. This method was chosen because of its flexibility in finding patterns that are not necessarily theoretically bounded [13]. Our main goal was to recognize overarching conceptions of a human-robot cooperative workstation which might go beyond the specific line of questions of the FW.

First, we organized the data collected (detailed notes, summaries) and sorted them into the phases and topics from the FW. However, only the ideas from the critique and fantasy phase were analyzed, since the preparation and implementation phases were of explanatory nature without participants engaging in discussions. Then, the data was translated into English to be analyzed by two different researchers, a facilitator from the FW and a second researcher

Fig. 2. Top: Workshop with secondary users. Bottom: Workshop with primary users .

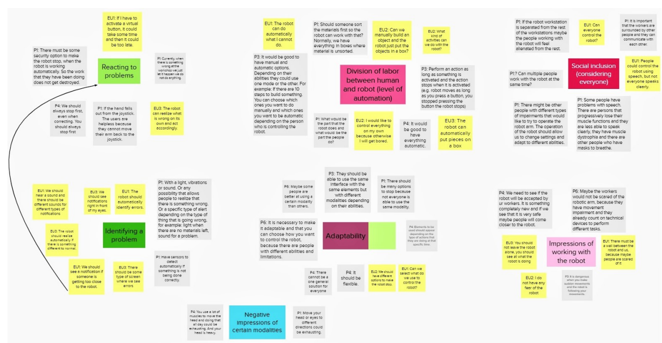

Fig. 3. Thematic map from coder 1: different shades of green and pink indicate themes that are related. Primary users’ comments are shown in yellow and secondary users’ comments in gray.

who had not been involved in this particular research. The reason behind that was to have a neutral perspective that could strengthen the reliability of the results. To provide context, the second researcher was briefed on the research goals and context of the workshop. Both researchers followed the same procedure but performed it separately.

We considered Braun & Clarke’s six phases of thematic analysis and carried it out with an inductive approach [13]. First, the available textual information was read several times to gain familiarity. Second, comments describing emotions or impressions were identified to generate initial codes. Third, similar comments were grouped and descriptive keywords assigned. In order to have a visual representation of the information, we developed thematic maps. One of the thematic maps is shown in Fig. 3. Some comments were found to be related to multiple themes; however, they were placed on the best fitting theme. Fourth, themes were revised and evaluated to understand how they can fit together and were presented in a developed visual thematic map. Fifth, both coders analyzed their maps and together developed a final thematic map that encompasses all the findings. Similar and complementing themes were found by both coders, revealing a certain pattern

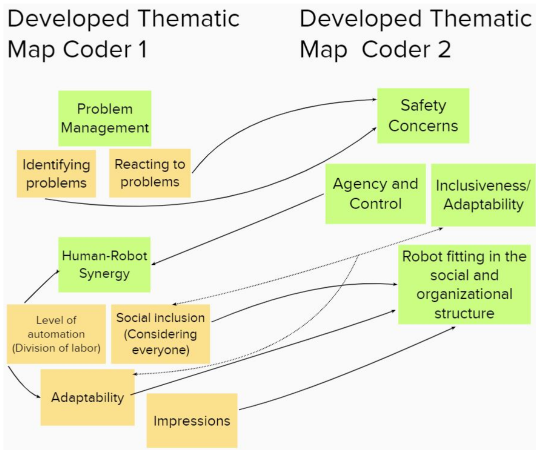

Fig. 4. Developed thematic maps of both coders. Overarching themes are presented in green and sub-themes are shown in orange.

in the data. The final thematic map is presented in Fig. 4 with respective sub-themes and connections between them. Both researchers looked for connections between the maps and produced one that encompasses the resulting themes and sub-themes that will be later used in this paper. Once the thematic analysis was performed the resulting thematic map was revised by a third researcher, who was the second facilitator at the FW. The third researcher evaluated if the comments matched the proposed themes, and looked for misconceptions on the researchers' side, e.g., check if comments were accidentally taken out of context. Sixth, considering these comments a summary of results was elaborated.

C. Results

The consolidated map, produced by both coders, identified patterns suggesting themes we labeled as: **the robot fitting in the social and organizational structure**, **human-robot synergy**, and **human-robot problem management**. Along with these themes, we identified sub-themes that contribute to each overarching theme and are described as follows.

1) The robot fitting in the social and organizational structure: This theme comprises the views of different stakeholders about the way that a robot can affect their pre-existing social and organizational structure. Both groups of stakeholders highlighted concerns with respect to the robotic arm disrupting social interactions. This was explicitly mentioned by P1, "It is important that the workers are surrounded by other people and they can communicate with each other. If the robot workstation is separated from the rest of the workstations maybe the people working with the robot will feel alienated from the rest." Adding to that, primary users were mostly worried about **being included**, e.g. EU1, "Can everyone control the robot?" Later the same person mentioned that "People could control the robot using speech, but not everyone speaks clearly." P4 mentioned the social acceptability of the robot, "We need to see if the robot will be accepted by our workers." Related with the concerns of being included, they mentioned the need for **Adaptability** on a social and organizational level. Secondary users mentioned that the robot should not create a sense of division between the workers. P1 elaborated "There are people with different types of impairments that would like to try to operate the robot arm. The operation of the robot should allow us to change settings and adapt to different abilities." Besides, we could identify that primary users had **contradicting impressions of working with a robotic arm**. Some expressed reservations about working with it. EU1 pointed out, "There must be a wall between the robot and us, because maybe people are scared of it." Conversely, EU2 said, "I do not have any fear of the robot." Additionally, P6 mentioned, "Maybe the workers would not be scared of the robotic arm because they have movement impairment, and they already count on technical devices to perform different tasks."

2) Human-robot synergy: This theme integrates the stakeholders' concerns and impressions about how PWPMI can work with a robot. The first evidence regards the **division of labor**. P1 asked "What would be the part that the robot does and what would be the part the people do?" EU2 also asked "What kind of activities can we do with the robot?" to which EU1 added, "The robot can do automatically what I cannot do." This brings the next concern regarding the **level of automation** that primary users would have in manufacturing tasks. EU2 asked, "Can we manually build an object and the robot just puts the objects in a box?" and P3 mentioned, "It would be good to have manual and automatic options. Depending on their abilities they could use one mode or the other." In this context, the need for **adaptability** was also mentioned, P3 said, "They should be able to use the same interface with the same elements but with different modalities depending on their abilities." P4 also expressed the need to have a flexible interface, "Elements to be used should appear depending on the type of actions that they are doing at that specific time." Additionally, primary users mentioned a sense of agency when controlling the robotic arm. EU3 said "You should not leave the robot alone, you should look at what the robot is doing," followed by EU2, "I would like to control everything on my own because otherwise, I will get bored." Conversely, a secondary user (P4) stated, "It would be good to have everything automatic."

3) Human-robot problem management: Safety is a prominent theme when working with PWPMI, who might not be able to react and protect themselves when there is a safety hazard. Therefore, secondary users wondered how unexpected situations may be handled. P1 mentioned, "If many people are working with the robot at the same time maybe they can make mistakes and accidentally harm people who are around." Here, two aspects were determined, identifying a problem and reacting to it. For **identifying problems**, secondary users expected that **the robot is responsible** for this task, to what P1 said, "The robot should have sensors to detect automatically if something is not being done correctly." This was also expressed by the primary users, EU1, "The robot should automatically identify errors." And EU3 added, "The robot should realize automatically if there is something different to normal." Similarly, primary and secondary users also expected the robot to be in charge of **reacting to problems**. EU3 demanded, “The robot can realize what is wrong on its own and act accordingly.” The reasoning behind it can be found in the limitations that PWPMI have, to what EU1 said, “If I have to activate a virtual button, it could take some time, and then it could be too late.” P1 also mentioned problems that some PWPMI with finger mobility have when controlling their wheelchair with a joystick, “If the hand falls out from the joystick, our workers are helpless because they cannot move their arm back to the joystick.” Adaptability was also mentioned when the users needed to stop the robot because of a failure, P1 mentioned, “There should be many options to stop because not everyone is able to use the same modality.”

IV. Discussion

The first identified theme was labeled as the robot fitting in the social and organizational structure. Adding a robot to the regular workflow will certainly alter social behaviors. Primary and secondary users coincided in the viewpoint about a space where people with different abilities can be included. They raised concerns regarding the robot disrupting the sense of community that exists at the sheltered-workshop. Here, working close to each other and in an open area with different workstations was emphasized. Hence, the robot should adapt to the current space without drastically altering the social interactions that take place. Further, these concerns led us to consider an industrial robot as a social factor, since it can enable the inclusion of people with different conditions to take part in a certain type of work (manufacturing) that has been often excluded for PWPMI.

Adaptability in an industrial human-robot cooperative environment infers that a robot can adapt to perform different tasks. However, the analysis showed that for PWPMI adaptability goes beyond task execution and relates to being part of the community. Within the same line of thinking, industrial robots could potentially act as social facilitators for PWPMI, a topic that to our knowledge has been scarcely researched. In fact, social facilitation has been primarily analyzed with social robots [25], and has had promising results with children with autism [26].

In human-robot industrial environments, adaptability is closely tied to acceptability, since it could increase the willingness of people to cooperate with robots [27] and this aligns with the comments about adaptability from both primary and secondary users. Finally, different reactions are invoked when working with robots – some primary users explicitly expressed their fear of the robotic arm, while others mentioned the lack of it. Secondary users mentioned the familiarity of PWPMI with technological devices as a factor that could reduce the fear of the robotic arm. Thus, paying close attention to adaptability could minimize opposed impressions of a human-robot cooperative workstation.

The second theme concerns human-robot synergy. Primary and secondary users were not only interested in the division of labor between people and the robot, but they at the same time wanted to determine how much the robot can autonomously achieve. Additionally, there were controversial views about levels of automation within each group. It is noteworthy that both groups were interested in automated options. Previously, we hypothesized that primary users would be eager to use a robotic arm as an extension of their arms, i.e., teleoperate it to perform manipulation tasks. However, the workstation in a manufacturing environment, the use of an industrial robotic arm, and the diversity in impairment conditions might have contributed to driving people away from this line of thinking. Primary users did not only consider the robotic arm as an external entity but as a tool used at work, deriving in the desire to increase efficiency and thereby also consider automation. David & Nielsen, consider that robots have capabilities that can be autonomous in a certain context and need human intervention in others [28]. Building upon this, we shall consider an approach that combines different levels of automation through supervisory control of robots (semi-autonomous robotic arms), as a potential workstation for PWPMI. This could also provide them with the possibility of observing and judging the tasks that the robot is performing at the workstation, creating a sense of agency.

The third finding relates to the human-robot problem management theme. Note that we only considered problematic situations deriving from interaction problems, which Steinbauer defines as problems coming from “uncertainties in the interaction with the environment, other agents and humans” [29]. We left software and hardware problems aside, since this topic was not mentioned in our FW, and we believe that our primary users should not be responsible for solving these type of problems.

In our findings primary and secondary users agreed that they would prefer and even expect the robot to be the one that detects problematic situations and reacts accordingly. This is also related to the robot being considered as a tool and expected to work as such with a fault-tolerant design. However, this would require a high level of automation and disregard the advantages of human cognition and HRC. A possible reason behind automation preferences is that some participants have cognitive disabilities added to their physical impairments, which affects greatly their ability to handle problems. In fact, Honig & Oron-Gilad mention that interacting with a robot when there has been a failure, is an information processing task, and cognitive factors influence the ability to perceive and act to problems [30]. Another rationale points to the fact that PWPMI cannot physically react when a problem is found, added to the fact that some of them need and are used to the caregivers’ assistance. We believe that this phenomenon could be particularly different in a group of people without disabilities, who might want to investigate and solve problems either themselves or together with the robot. However, the motivation to solve human-robot problems is an aspect that to our knowledge has not yet been subject of study in HRC.

In general, viewpoints from primary and secondary users coincided in most aspects within the three presented themes. However, there were a a few opposing postures within the primary users group and almost none among secondary users. A possible explanation is the heterogeneity of PWPMI, who despite having a similar type of condition have other factors that influence greatly their needs and attitudes, e.g., the amount of time living with a certain condition, degrees of severity, and other disabilities (mental or cognitive).

V. Limitations

We acknowledge that due to the size of our sample our results mainly serve as basis for exploration. Our results provide an underrepresented voice to research and shows attitudes and reactions in an HRC workplace context, which is a topic that has not received much attention.

VI. Conclusions

The analysis performed unveiled three underlying concerns from primary and secondary users of a human-robot cooperative workstation. First, **the robot fitting in the social and organizational structure** should be carefully evaluated, especially in places that employ people with disabilities. Second, allowing for adaptability can be the key for successful **human-robot synergy**. As such, it is an essential part that allows for inclusion in a human-robot cooperative workstation. Third, viewpoints about **human-robot problem management** lean towards relying on the robot to detect or assist human operators to detect and solve human-robot problems deriving from interaction.

In this paper, we identified themes that can be used to influence design decisions for HRC at the workplace for PWPMI. This could serve to motivate further research in the area of designing human-robot cooperative workspaces for people with disabilities.

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