Multiple Ways of Working with Users to Develop Physically Assistive Robots

Amal Nanavati*
amaln@cs.washington.edu
University of Washington
Seattle, United States of America

Max Pascher*
max.pascher@udo.edu
TU Dortmund University
Dortmund, Germany
University of Duisburg-Essen
Essen, Germany

Vinitha Ranganeni
Ethan K. Gordon
Taylor Kessler Faulkner
{vinitha,ekgordon,taylorkf}@cs.washington.edu
University of Washington
Seattle, United States of America

Siddhartha S. Srinivasa
Maya Cakmak
{siddh,mcakmak}@cs.washington.edu
University of Washington
Seattle, United States of America

Patrícia Alves-Oliveira
robopati@umich.edu
University of Michigan
Ann Arbor, United States of America

Jens Gerken
jens.gerken@udo.edu
TU Dortmund University
Dortmund, Germany

ABSTRACT

Despite the growth of physically assistive robotics (PAR) research over the last decade, nearly half of PAR user studies do not involve participants with the target disabilities. There are several reasons for this—recruitment challenges, small sample sizes, and transportation logistics—all influenced by systemic barriers that people with disabilities face. However, it is well-established that working with end-users results in technology that better addresses their needs and integrates with their lived circumstances. In this paper, we reflect on multiple approaches we have taken to working with people with motor impairments across the design, development, and evaluation of three PAR projects: (a) assistive feeding with a robot arm; (b) assistive teleoperation with a mobile manipulator; and (c) shared control with a robot arm. We discuss these approaches to working with users along three dimensions—individual- vs. community-level insight, logistic burden on end-users vs. researchers, and benefit to researchers vs. community—and share recommendations for how other PAR researchers can incorporate users into their work.

CCS CONCEPTS

• **Computer systems organization** → **Robotics**; • **Human-centered computing** → **User studies**; **Accessibility technologies**.

KEYWORDS

physically assistive robots, human-robot interaction, user studies

1 INTRODUCTION

When designing, developing, and evaluating physically assistive robots (PARs) for people with motor impairments, it is crucial to work with them to ensure the technology addresses their needs and integrates with their lived circumstances [16, 22]. However, only about half of PAR user studies, and less than half of summative studies[1], incorporate members of the target community [20]. Reasons for this include: (1) outreach and recruitment of people with disabilities is challenging because they tend to have lower technology access and usage [26]; (2) systemic barriers hinder people with disabilities' access to college education [1], making them underrepresented amongst a population that is commonly used for studies; and (3) coordinating travel to the research venue is challenging, as transportation access and usage tends to be lower amongst people with disabilities [2]. These factors extend the time it takes to do rigorous studies with participants with motor impairments, which can be incompatible with rapid research timelines.

2 CONTRIBUTION

We critically reflect on our experiences and methodological insights working with users with motor impairments across three PAR projects: **(1)** assistive feeding with a robot arm; **(2)** assistive teleoperation with a mobile manipulator; and **(3)** shared-control with a robot arm. These projects were conducted independently by 3 different research labs, and the insights emerged from joint discussions. Across the projects, we employed diverse ways of engaging end-users: community research, remote studies, home deployments, and an in-the-wild study at a trade fair. We discuss these approaches along three key dimensions:

(1) **Individual- vs. Community-Level Insights**: *How should we balance between conducting deep research with few participants versus broad research with many participants?*

(2) **Logistical Burdens on End-Users vs. Researchers**: *How can we navigate the differential logistical burdens that end-users and researchers face during a user study?*

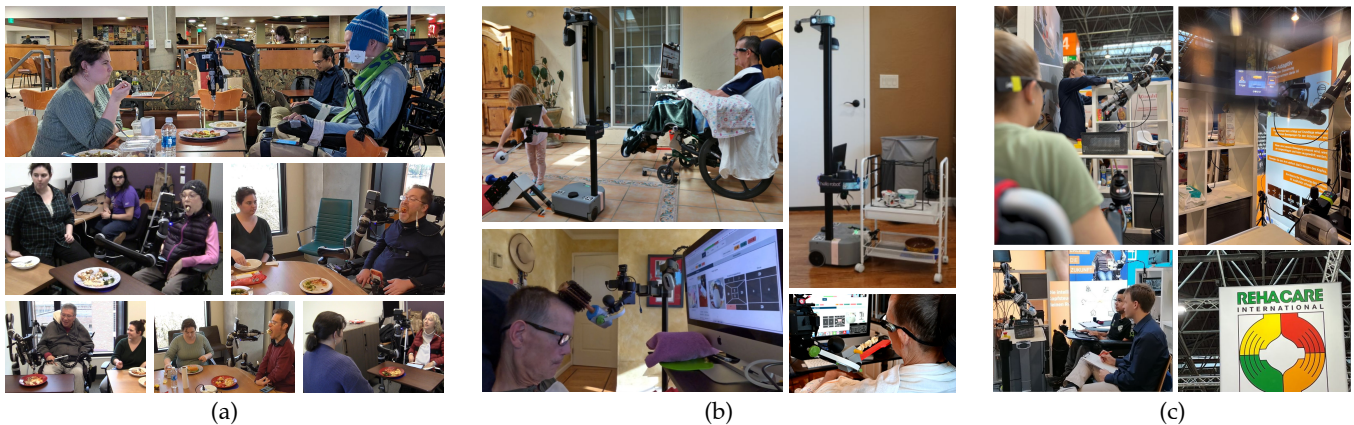(a)   (b)   (c)

Figure 1: The three projects highlighted in this work: (a) assistive feeding with a robot arm, (b) assistive teleoperation with a mobile manipulator, (c) shared control with a robot arm.

(3) **Benefits to Researchers vs. Community**: *What benefits do researchers and end-users get from study participation? How should that knowledge influence researchers' work with end-users?*

3 RELATED WORK

In recent years, there has been growing recognition of the importance of user participation in the design of assistive technologies. Thielke et al. [31] and Merkel and Kucharski [17] expressed the need for this collaborative approach to maximize user acceptance, and presented various methods for integrating users, family members, caregivers, and assistants into the innovation process.

3.1 Participatory Design

Assistive technologies are becoming a vital factor in assisted living, minimizing the need for constant caregiver presence and restoring some independence to people with motor impairments [13, 21]. However, assistive technologies can have high rates of non-acceptance and non-use [29, 32], partly due to end-user exclusion during the design process [8]. Participatory Design—where developers work collaboratively with end-users (and/or their advocates) throughout the design process [15, 30]—has become a recommended way to increase acceptance of the final product [33]. All three projects in this paper involve such a collaborative approach. Across all projects, we found that participants valued their inclusion in the design process of a device developed specifically for them.

3.2 Empowerment Design

In the words of Ladner [14], "some of the best work comes when there are people with disabilities on the design and development team, contributing to all aspects of the design and implementation...I call this strong engagement by users *design for user empowerment*, meaning, in its strongest sense, that the users of the technology are empowered to solve their own accessibility problems."

Empowering users with disabilities in PAR research is crucial[2], so they are not just brought in as part of a few studies, but are instead empowered to design and build the technologies themselves [7].

Empowerment Design focuses on developing socio-technical structures to provide that empowerment [3]. Several methods discussed in this work, although not originally conceptualized as empowerment design, include empowerment as a core focus.

4 DESCRIPTIONS OF THE THREE PROJECTS

Three projects (Figure 1) underlie this paper's critical reflection.

4.1 Assistive Feeding with a Robot Arm

The ultimate goal of this project is to develop a robot-assisted feeding system that users with motor impairments can use to feed themselves an entire meal of their choice, in an environment of their choice, without researcher interventions, while aligning with their preferences. The system consists of a *Kinova JACO Gen2* [11] robot arm with an RGB-D eye-in-hand camera. The robot's gripper holds a custom 3D-printed fork with an attached force-torque sensor. The system is fully portable; it can be mounted onto and powered from standard power wheelchairs. This project has been ongoing for 10 years, with 100s of user-hours in co-designing and evaluation.

The most recent iteration of system design, development, and evaluation—over the last two years—involved end-users in two main capacities. The first is as a community researcher; we worked with two end-users throughout the entire design and research process, from ideation to dissemination, following principles from Community Based Participatory Research (CBPR)[3] [18, 19]. The second is as traditional participants; we invited 6 people with motor impairments to come to out-of-lab environments (a cafeteria, conference room, and office) to eat a meal with us, using the robot [19].

4.2 Assistive Teleoperation with a Mobile Manipulator

The ultimate goal of this project is to develop an assistive teleoperation interface that empowers people with motor impairments to complete their desired tasks around the house. These tasks include: physically assisting oneself (e.g., itch-scratching, self-feeding); physically assisting one's caregiver (e.g., transporting a meal or laundry

---

[2]This is exemplified in the disability rights slogan "nothing about us without us" [6]

[3]In CBPR, academics work equitably with community members throughout all research stages. CBPR is used in health [9, 34] and assistive technology [4, 5, 12, 18] research.

cart to/from the bedroom); and participating in social interactions (e.g., playing poker, playing indoor basketball with a child) [27]. The system consists of a *Stretch* mobile manipulator [10] and a cursor-based, customizable teleoperation interface [28].

The design, development, and evaluation of the teleoperation interface involved end-users in two main capacities. First, 10 users with motor impairments participated in a remote study; they were not co-located with the robot but used the teleoperation interface to have the robot perform kitchen tasks [28]. Second, we conducted multiple week-long deployments and co-design sessions in the home of one end-user. We identified tasks he wanted to do, extended the system so the robot could complete those tasks, allowed him to freely use the system, and iteratively incorporated his feedback.

4.3 Shared-Control with a Robot Arm

This project began with an ethnographic study involving semi-structured interviews and in-situ observations in participants' homes to understand how an assistive robotic arm could support them. The analysis revealed: (1) participants' desire for alone-time without caregiver assistance; (2) their wariness about fully autonomous robots' failures; (3) their desire to always be in control of robotics aids; and (4) most participants only have access to 1 or 2 degrees-of-freedom (DoFs) to control a robot arm. Thus, we developed a shared-control approach [23] to allow users to interact with a robotic arm for everyday tasks (e.g., picking up an object, opening a door) [25]. The approach utilizes a convolutional neural network to perceive the visual scene and suggest input mappings, thereby reducing the control complexity of a 7-DoFs robot arm to 2 input-DoFs. The DoF mapping suggestions are visualized in an arrow-based representation so users can understand the robot's motion intent [24]. The user interacts with the robot through head motion and receives visual feedback through a *Google Glass* interface. This project was heavily informed by a "lead user" with motor impairments we met regularly to discuss the research direction and system design.

To evaluate the final prototype of this system, we sought access to many participants with diverse motor impairments. Thus, we rented a booth at the *REHACARE*,[4] trade fair, one of the largest trade fairs in rehabilitation and care. This allowed us to conduct individual study sessions with 24 participants, with a diverse variety of motor impairments or related disabilities, over just four days.

5 DISCUSSION

Here we reflect upon our research methods along three dimensions.

5.1 Individual- vs. Community-Level Insights

Given the reality of time and resources constraints, there is often a trade-off between conducting deep research that involves long-term engagement with a few end-users, versus broad research that involves shorter-term engagements across many end-users.

Conducting *deep research with a few individuals* can result in insights on the nuances of their preferences and environments, which is necessary to develop robots that work very well for those specific people (which is arguably the goal of personal robotics). However, such research requires a large commitment of time and relationship-building per individual.

Conducting *broad research across many individuals* can result in insights on the diversity of needs and wants in the community,

which is necessary to develop a robot that can be distributed at scale. However, this involves spending just a few hours per participant, not long enough to understand individual-level nuances.

5.1.1 Methods. Across all projects, we navigated this dimension by working deeply with few users *for the full duration of the project*, and working broadly across several users *for specific studies*.

We found multi-faceted benefits of working deeply with a few individuals for the entirety of the project:

- They taught us nuances of their lived experiences that we may not have expected: e.g. day-to-day vocal strength varies, influencing the accuracy of speech assistive technologies. Understanding these nuances led to a more user-centered design.
- They grew familiar with the technology, providing glimpses into end-user perspectives after the novelty effect wears away.
- Our partnership lowered the barrier of entry for new students to do user-centered work, since the relationship was established.

How can researchers find long-term partners from the community? Across all projects, these individuals were technology enthusiasts. In one case, they were participants in past studies who wanted to get more involved. In the other cases, they heard about the research (e.g., through media) and reached out to get more involved.

To complement the deep research with few individuals, at multiple points within the projects (both for formative and summative studies) we conducted broad research across many community members. We recruited participants with motor impairments by: (a) contacting local organizations that work with them; (b) posting on relevant social media groups; (c) traveling to events frequented by target users (e.g., an assistive technology trade fair); and (d) word of mouth from other participants. Community researchers also helped by connecting us to participants and even co-running a study [18].

5.1.2 Key Takeaways.
(1) A research project is a long time, often spanning several studies. There is room to *combine both deep and broad research*.
(2) Technology enthusiasts from the target community may be excited to work deeply with you over the long-term. One way of finding such individuals is presenting the project at events that are geared towards the target community.
(3) Recruitment for deep and broad research is complementary; broad research can connect you with people to work deeply with, and they in turn can connect you to future participants.

5.2 Logistical Burdens on Users vs. Researchers

Research with end-users inevitably involves logistical burdens. On the one hand, asking participants to come in-person to a lab where the robot already is places considerable logistical burden on the participant. They may need to schedule a caregiver, arrange a vehicle, account for transportation delays, shift their daily schedule (e.g., morning routines to get ready, mealtimes, medicine-taking times) to accommodate the study, and more. Although research labs often compensate participants for their time spent in the study, and sometimes for transportation costs to get to/from the lab, that does not account for the time and mental energy spent coordinating the aforementioned logistics. However, a research benefit of this approach is that it is easier to run controlled experiments in a lab, and robots typically work better in their development environment.

On the other hand, bringing the robot to the end-user shifts the logistical burden onto the researchers. It is challenging to develop

---

[4]*REHACARE* trade fair. https://www.rehacare.de, last retrieved March 7, 2024.

a robot that is portable enough to be transported, robust enough to work reliably in a new location, and flexible enough to be debugged on the fly. Transporting and setting up the robot in a new environment (e.g., power supply, networking, mapping the environment, etc.) is challenging. However, benefits of this approach are that it is easier for participants and has more ecological validity.

5.2.1 Methods. The assistive feeding project navigated this dimension by conducting formative research remotely over video call [18], so the only logistical burden on participants was getting set up on their computer at home. In our most recent in-person study [19], we had participants travel to our campus, but held the study in an out-of-lab venue (e.g., cafeteria, conference room, office). Although this still places a high logistical burden on participants, it can be a stepping stone to home deployments. We designed the system to make it easier to transport and set up out-of-lab, by making it portable with an easy customization interface.

The assistive teleoperation project has conducted multiple home deployments [27]. This shifts much of the burden to the researcher; the chief logistical burden for the participant and their caregiver(s) is hosting researchers. We also ran studies where participants joined remotely and teleoperated the robot [28]. This approach had lower logistical burden on both the researcher and user, and geographically expanded the pool of potential participants.

The shared control project found another way of reducing the logistical burden on participants; we went to an event that is well-attended by members of the target community. This provided access to many participants, and enabled us to run a study with high ecological validity. However, in practice, this approach came with additional challenges on the researchers. The dynamic environment brought difficulties with wireless communication, light pollution, noise, and interruptions. Each participant required a slightly different technology setup. These challenges required adaptation on-the-fly, and we could not reschedule participants; any robot down-time directly reduced the number of study participants.

5.2.2 Key Takeaways.
(1) Remote studies can decrease the logistical burden on participants without increasing the logistical burden on researchers.
(2) When studies require co-location (i.e., cannot be done remotely):
    (a) If many participants are desired, go to a venue the community frequents, like an assistive technology trade fair.
    (b) If fewer participants are acceptable, do an in-lab study if you desire more internal validity, or an out-of-lab study or home deployment if you desire more ecological validity.
(3) When bringing the robot to another location, take preemptive system design steps to make it easier to transport, setup, and use the robot in a new and dynamic environment.

5.3 Benefits to Researchers vs. Community

The fact that researchers get benefits from research is self-evident; it can lead to career growth, access to funding, fame and renown, future research opportunities, and more. End-users are no doubt indispensable to PAR research—they influence our system design, system evaluations, and the key insights that motivate future work. However, what benefits do end-users get from their participation, how does that align with the benefits they would like to get, and is that commensurate with their indispensable role in PAR research?

Compensation is one benefit for participants; however, as mentioned above, it may not cover the additional logistical burdens involved in participating in a research study. Some people participate to learn about robotics. Others because they want to accelerate research that benefits their community. Others may not have an explicitly stated motivation, but the user study might unearth ways the researchers can support them beyond the study.

5.3.1 Methods. In the assistive feeding work, we sought ways to benefit participants beyond just using the robot. One participant was interested in learning technical details of how the robot acquired food—we explained this as part of the social conversation during her meal. For another participant, we showed him how to use an assistive technology feature he did not know about. We also sought opportunities to cross-pollinate across participants; one participant had open-sourced a 3D-printed tool for self-feeding, which we shared with other participants with similar mobility.

The idea of benefiting end-users beyond the research was particularly salient with a community researcher. One time, he was struggling with manually populating a mailing list from a spreadsheet; we wrote a script to automate that. Another time, he was appealing denied health insurance coverage; we connected him with resources to help. He also mentioned additional benefits, such as stronger grant applications after he co-authored a paper with us.

In the assistive teleoperation work, we developed our in-home deployment to match the needs and expectations of the user. For example, the user expressed a desire to play with his granddaughter, since he had never played with her before and she barely acknowledged him. After three play sessions with his granddaughter using the robot (Figure 1b) he has developed a relationship with her.

In the shared control work, it was important to accept the diverse reasons that participants came to our booth; although some were interested in the study, others just wanted to talk, which required researchers to subordinate the study goals for the broader goal of sharing knowledge with the community. Further, since the trade fair had commercial products, it was important to manage expectations by clarifying that this robot may not be available anytime soon.

Across all three projects, having a dedicated focus on benefiting participants beyond the study helped to strengthen ties, build empathy, and gain broader exposure within the community, all of which strengthened long-term project goals.

5.3.2 Key Takeaways.
(1) Be attuned to ex/implicit signs of how you can benefit participants beyond the study; where possible, provide that benefit.
(2) Working with the user to co-design the robot's task can increase the likelihood of them benefiting from the study in the present.
(3) Focusing on helping the community more broadly has long-term positive impacts on a project, due to a positive relationship between researchers and members of the target community.

5.4 Limitations and Future Work

This work presents key dimensions for working with end users in PAR research. A limitation is that the three projects were conducted independently and the synthesis was done afterward; thus, the study do not follow a cohesive research agenda An exciting direction for future work is expanding these dimensions into a framework to clarify how researchers can situate themselves at different stages when conducting this type of research.

ACKNOWLEDGMENTS

REFERENCES

[1] 2015. People with a disability less likely to have completed a bachelor's degree. *U.S. Bureau of Labor Statistics* (Jul 2015). https://www.bls.gov/opub/ted/2015/people-with-a-disability-less-likely-to-have-completed-a-bachelors-degree.htm

[2] 2022. Travel Patterns of American Adults with Disabilities. https://www.bts.gov/travel-patterns-with-disabilities

[3] Sasha Barab, Michael Thomas, Tyler Dodge, Tami Goodrich, Bob Carteaux, and Hakan Tuzun. 2002. Empowerment design work: Building participant structures that transform. In *Keeping learning complex: The proceedings of the fifth International Conference of the Learning Sciences (ICLS)*. Lawrence Erlbaum Associates Mahwah, NJ, 132–138.

[4] Jeanette Bell and Tuck Wah Leong. 2019. Collaborative futures: Co-designing research methods for younger people living with dementia. In *Proceedings of the 2019 chi conference on human factors in computing systems*. 1–13.

[5] Dorota Chapko, Pino Frumiento, Nalini Edwards, Lizzie Emeh, Donald Kennedy, David McNicholas, Michaela Overton, Mark Snead, Robyn Steward, Jenny M Sutton, et al. 2020. " We have been magnified for years-Now you are under the microscope!": Co-researchers with Learning Disabilities Created an Online Survey to Challenge Public Understanding of Learning Disabilities. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–17.

[6] James I Charlton. 1998. *Nothing about us without us: Disability oppression and empowerment*. Univ of California Press.

[7] Marie Ertner, Anne Mie Kragelund, and Lone Malmborg. 2010. Five enunciations of empowerment in participatory design. In *Proceedings of the 11th Biennial Participatory Design Conference*. 191–194.

[8] Stefano Federici, Fabrizio Corradi, Fabio Meloni, Simone Borsci, Maria Laura Mele, Saveria Dandini De Sylva, and Marcia J. Scherer. 2015. Successful assistive technology service delivery outcomes from applying a person-centered systematic assessment process: A case study. *Life Span and Disability* 18, 1 (1 Jul 2015), 41–74. http://www.lifespanjournal.it/client/abstract/ENG290_2.%20Federici.pdf

[9] Barbara A Israel, Amy J Schulz, Edith A Parker, and Adam B Becker. 1998. Review of community-based research: assessing partnership approaches to improve public health. *Annual review of public health* 19, 1 (1998), 173–202.

[10] Charles C Kemp, Aaron Edsinger, Henry M Clever, and Blaine Matulevich. 2022. The design of stretch: A compact, lightweight mobile manipulator for indoor human environments. In *2022 International Conference on Robotics and Automation (ICRA)*. IEEE, 3150–3157.

[11] Kinova inc. 2021. Jaco assistive robot - User guide. Published online: https://assistive.kinovarobotics.com/uploads/EN-UG-007-Jaco-user-guide-R05.pdf (last visited on March 7, 2024). EN-UG-007-r05-202111.

[12] Raja S Kushalnagar and Christian Vogler. 2020. Teleconference accessibility and guidelines for deaf and hard of hearing users. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. 1–6.

[13] Maria Kyrarini, Fotios Lygerakis, Akilesh Rajavenkatanarayanan, Christos Sevastopoulos, Harish Ram Nambiappan, Kodur Krishna Chaitanya, Ashwin Ramesh Babu, Joanne Mathew, and Fillia Makedon. 2021. A survey of robots in healthcare. *Technologies* 9, 1 (2021), 8. https://doi.org/10.3390/technologies9010008

[14] Richard E Ladner. 2015. Design for user empowerment. *interactions* 22, 2 (2015), 24–29.

[15] Hee Rin Lee, Selma Šabanović, Wan-Ling Chang, Shinichi Nagata, Jennifer Piatt, Casey Bennett, and David Hakken. 2017. Steps Toward Participatory Design of Social Robots. In *HRI'17*, HRI (Ed.). IEEE, Piscataway, NJ, 244–253. https://doi.org/10.1145/2909824.3020237

[16] Jennifer Mankoff, Gillian R Hayes, and Devva Kasnitz. 2010. Disability studies as a source of critical inquiry for the field of assistive technology. In *International ACM SIGACCESS conference on Computers and accessibility (ASSETS)*. ACM, 3–10.

[17] Sebastian Merkel and Alexander Kucharski. 2018. Participatory Design in Gerontechnology: A Systematic Literature Review. *The Gerontologist* 59, 1 (5 2018), e16–e25. https://doi.org/10.1093/geront/gny034

[18] Amal Nanavati, Patricia Alves-Oliveira, Tyler Schrenk, Ethan K. Gordon, Maya Cakmak, and Siddhartha S. Srinivasa. 2023. Design Principles for Robot-Assisted Feeding in Social Contexts. In *ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (Stockholm, Sweden) *(HRI '23)*. ACM, New York, NY, USA, 24–33. https://doi.org/10.1145/3568162.3576988

[19] Amal Nanavati, Ethan Gordon, Taylor A. Kessler Faulkner, Bernie Zhu, Tyler Schrenk, Jonathan Ko, Atharva Kashyap, Raida Karim, Haya Bolotski, Rosario Scalise, Hanjun Song, Ramon Qu, Maya Cakmak, and Siddhartha S Srinivasa. 2024. Lessons Learned from Designing and Evaluating a Robot-Assisted Feeding System for Out-of-Lab Use. In *Under Peer Review*.

[20] Amal Nanavati, Vinitha Ranganeni, and Maya Cakmak. 2023. Physically Assistive Robots: A Systematic Review of Mobile and Manipulator Robots That Physically Assist People with Disabilities. *Annual Review of Control, Robotics, and Autonomous Systems* 7 (2023).

[21] Daehyung Park, Yuuna Hoshi, Harshal P. Mahajan, Ho Keun Kim, Zackory Erickson, Wendy A. Rogers, and Charles C. Kemp. 2020. Active robot-assisted feeding with a general-purpose mobile manipulator: Design, evaluation, and lessons learned. *Robotics and Autonomous Systems* 124 (2 2020), 103344. https://doi.org/10.1016/j.robot.2019.103344

[22] Max Pascher, Annalies Baumeister, Stefan Schneegass, Barbara Klein, and Jens Gerken. 2021. Recommendations for the Development of a Robotic Drinking and Eating Aid - An Ethnographic Study. In *Human-Computer Interaction – INTERACT 2021* (2021-09-01), Carmelo Ardito, Rosa Lanzilotti, Alessio Malizia, Helen Petrie, Antonio Piccinno, Giuseppe Desolda, and Kori Inkpen (Eds.). Springer, Cham. https://doi.org/10.1007/978-3-030-85623-6_21

[23] Max Pascher, Felix Ferdinand Goldau, Kirill Kronhardt, Udo Frese, and Jens Gerken. 2024. AdaptiX – A Transitional XR Framework for Development and Evaluation of Shared Control Applications in Assistive Robotics. *Proc. ACM Hum.-Comput. Interact.* 8, EICS (2024). Preprint on arXiv: https://arxiv.org/abs/2310.15887.

[24] Max Pascher, Uwe Gruenefeld, Stefan Schneegass, and Jens Gerken. 2023. How to Communicate Robot Motion Intent: A Scoping Review. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery (ACM), New York, NY, USA, Article 409, 17 pages. https://doi.org/10.1145/3544548.3580857

[25] Max Pascher, Kirill Kronhardt, Felix Ferdinand Goldau, Udo Frese, and Jens Gerken. 2023. In Time and Space: Towards Usable Adaptive Control for Assistive Robotic Arms. In *2023 32nd IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. Institute of Electrical and Electronics Engineers (IEEE), 2300–2307. https://doi.org/10.1109/RO-MAN57019.2023.10309381

[26] Andrew Perrin and Sara Atske. 2021. Americans with disabilities less likely than those without to own some digital devices. *Pew Research Center* (Sep 2021). https://www.pewresearch.org/short-reads/2021/09/10/americans-with-disabilities-less-likely-than-those-without-to-own-some-digital-devices/

[27] Vinitha Ranganeni, Vy Nguyen, Henry Evans, Jane Evans, Julian Mehu, Samuel Olatunji, Aaron Rogers, Wendy age Edsinger, Charlie Kemp, and Maya Cakmak. 2024. Robots for Humanity: In-Home Deployment of Stretch RE2. In *Companion of the 2024 ACM/IEEE International Conference on Human-Robot Interaction*.

[28] Vinitha Ranganeni, Noah Ponto, and Maya Cakmak. 2023. Evaluating Customization of Remote Tele-operation Interfaces for Assistive Robots. (2023), 1633–1640. https://doi.org/10.1109/RO-MAN57019.2023.10309395

[29] Marcia Joslyn Scherer. 2005. *Living in the state of stuck: How assistive technology impacts the lives of people with disabilities*. Brookline Books.

[30] Jesper Simonsen. 2013. *Routledge international handbook of participatory design*. Routledge, New York.

[31] Stephen Thielke, Mark Harniss, Hilaire Thompson, Shwetak Patel, George Demiris, and Kurt Johnson. 2012. Maslow's Hierarchy of Human Needs and the Adoption of Health-Related Technologies for Older Adults. *Ageing International* 37, 4 (12 2012), 470–488. https://doi.org/10.1007/s12126-011-9121-4

[32] R Verza, M L Lopes Carvalho, M A Battaglia, and M Messmer Uccelli. 2006. An interdisciplinary approach to evaluating the need for assistive technology reduces equipment abandonment. *Multiple Sclerosis Journal* 12, 1 (2 2006), 88–93. https://doi.org/10.1191/1352458506ms1233oa

[33] J. Vines, R. Clarke, P. Wright, J. McCarthy, and P. Olivier. 2013. Configuring Participation: On How We Involve People in Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 429–438. https://doi.org/10.1145/2470654.2470716

[34] Meera Viswanathan, Alice Ammerman, Eugenia Eng, Gerald Garlehner, Kathleen N Lohr, Derek Griffith, Scott Rhodes, Carmen Samuel-Hodge, Siobhan Maty, Linda Lux, et al. 2004. Community-based participatory research: Assessing the evidence: Summary. *AHRQ evidence report summaries* (2004).