Design Principles for Robot-Assisted Feeding in Social Contexts

Amal Nanavati*
amaln@cs.washington.edu
University of Washington
Seattle, WA, USA

Patrícia Alves-Oliveira*
patri@uw.edu
University of Washington
Seattle, WA, USA

Tyler Schrenk
tyler@thetsf.org
The Tyler Schrenk Foundation
Woodinville, WA, USA

Ethan K. Gordon
ekgordon@cs.washington.edu
University of Washington
Seattle, WA, USA

Maya Cakmak
mcakmak@cs.washington.edu
University of Washington
Seattle, WA, USA

Siddhartha S. Srinivasa
siddh@cs.washington.edu
University of Washington
Seattle, WA, USA

ABSTRACT

Social dining, i.e., eating with/in company, is replete with meaning and cultural significance. Unfortunately, for the 1.8 million Americans with motor impairments who cannot eat without assistance, challenges restrict them from enjoying this pleasant social ritual. In this work, we identify the needs of participants with motor impairments during social dining and how robot-assisted feeding can address them. Using speculative videos that show robot behaviors within a social dining context, we interviewed participants to understand their preferences. Following a community-based participatory research method, we worked with a community researcher with motor impairments throughout this study. We contribute (a) insights into how a robot can help overcome challenges in social dining, (b) design principles for creating robot-assisted feeding systems, (c) and an implementation guide for future research in this area. Our key finding is that robots' unique assistive qualities can address challenges people with motor impairments face during social dining, promoting empowerment and belonging.

CCS CONCEPTS

• **Human-centered computing** → **Participatory design**; **Accessibility technologies**; • **Computer systems organization** → **Robotics**.

KEYWORDS

assistive technologies, community-based participatory research, speculative design, qualitative research, robot-assisted feeding

ACM Reference Format:
Amal Nanavati, Patrícia Alves-Oliveira, Tyler Schrenk, Ethan K. Gordon, Maya Cakmak, and Siddhartha S. Srinivasa. 2023. Design Principles for Robot-Assisted Feeding in Social Contexts. In *Proceedings of the 2023 ACM/IEEE Int'l Conference on Human-Robot Interaction (HRI '23), March 13–16, 2023, Stockholm, Sweden.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3568162.3576988

*These authors contributed equally.

HRI '23, March 13–16, 2023, Stockholm, Sweden

ACM ISBN 978-1-4503-9964-7/23/03.
https://doi.org/10.1145/3568162.3576988

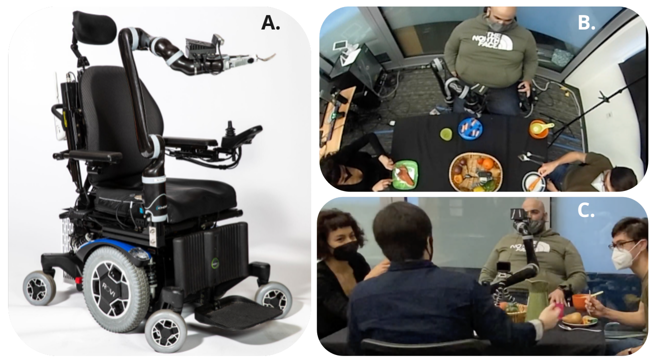

Figure 1: A. robot-assisted feeding system used in this work, with B. top-view and C. side-view of its social use.

1 INTRODUCTION

Take a moment to recall the last time you shared a meal. What made it meaningful? The company, the food, the ambiance? The stories that were told, relationships that were strengthened, milestones that were celebrated? If you were asked, "How does it feel to eat socially?", you might say it is a pleasant experience. Now consider this response from a participant in our study: *"Sometimes I wait longer to ask [my caregiver] for a bite or a drink because it might mess up a conversation. It's something that's always in the back of my mind when eating socially... Sometimes I'm not eating, or I'm barely eating, because I'm self-conscious of interrupting a conversation."* This participant is paralyzed from the neck down. For him and at least 1.8 million Americans who need assistance eating [69], social dining may be the opposite of pleasant.

Eating is not only a *functional* experience, but also a *meaningful* one. Specifically, social dining introduces nuances, such as synchronizing of eating pace [30], avoiding a bite while being addressed [48], and making special efforts to eat in a socially appropriate manner [75]. For those with motor impairments, robot-assisted feeding (Fig 1) has emerged as a promising technology to alleviate some of the challenges faced during dining. However, much prior work in this area focuses on the functional tasks of picking up food and moving it to a person's mouth [11, 28, 52, 55, 76]. These tasks are indeed technically challenging, and prior work significantly improves the state-of-the-art. Nonetheless, there is an open design space to create meaningful social dining experiences for people with motor impairments.

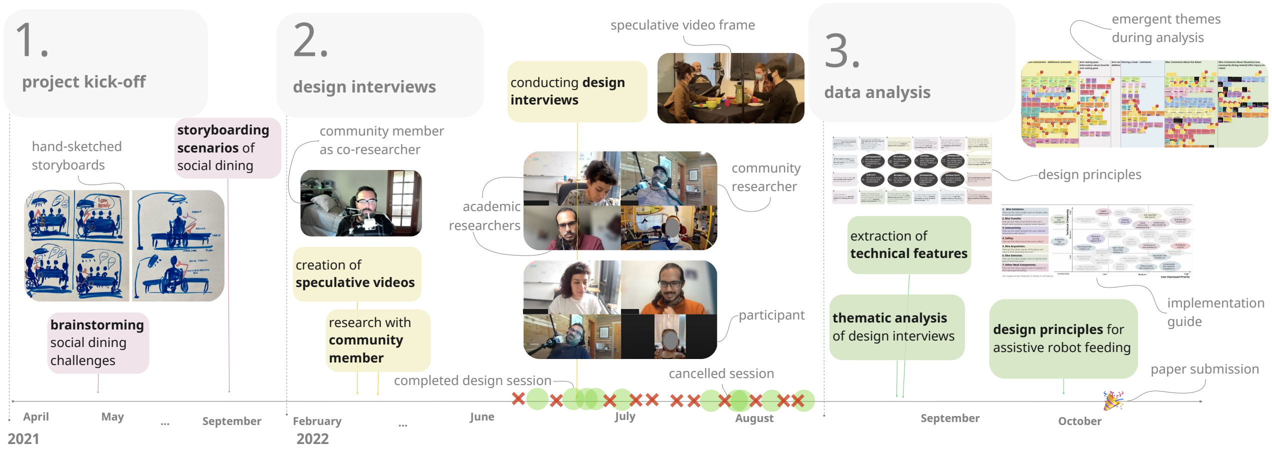

Figure 2: Timeline of our design project on robot-assisted social dining.

2 CONTRIBUTIONS

We conducted design explorations (Fig 2) of robot-assisted feeding in social contexts, driven by the following questions:

(1) **What *challenges* do people with motor impairments face during social dining, and how can robot-assisted feeding address them?** Participants' challenges include divided attention, caregiver variability, and more (Sec 6).
(2) **What *principles* should guide the design of robot-assisted feeding systems for social dining?** The robot should be subtle, customizable, reliable, and more (Sec 7).
(3) **How can these insights *guide the implementation* of robot-assisted feeding systems for social dining?** Our interview data reveals key features, such as unobtrusive bite transfers, feeding others (e.g., kids), and more (Sec 8).

While some social dining challenges cannot (and should not) be solved using a robot, **our key insight is that robots can be designed with assistive qualities that address some challenges people with motor impairments face during social dining.** Specifically, they can promote *empowerment* by enabling users to eat without human assistance and *belonging* by increasing user's opportunities for meaningful social interactions.

3 RELATED WORK

3.1 The Power of Social Dining

Social dining has biological, psychological, and cultural benefits [43, 45]. Food is a "vehicle" to establish social linkages, has symbolic functions, and is a medium for aesthetic expression [49, 62]. Families that eat together build stronger relationships that improve well-being and lower the rates of risk-taking behavior [73] and depression [72]. People with Alzheimer's who share meals show an increased sense of autonomy [19]. Unfortunately, for people with motor impairments who rely on caregivers to eat, shared meals tend to be less about *socialization* and more about *functionality* (e.g., meal prep, food intake) [44, 50]. This excludes them from social dining benefits [27, 65]. Our work surfaces priorities voiced by people with motor impairments, towards a robot that enables meaningful social dining experiences.

3.2 Robot-Assisted Feeding

Robot-assisted feeding systems have existed since at least the 80's [64, 71]. Since then, over a dozen such systems have been developed, both commercially [1–7, 60] and for research. Most research has focused on functional aspects of eating, not the nuances inherent to social dining. This includes the robot's ability to *acquire* food items with a fork [28, 31], spoon [36, 52, 61], or chopsticks [53, 76]; also, the robot's ability to *transfer* food items to the user's mouth by accounting for user comfort [11], learning from demonstrations [16], and adjusting based on how the food was acquired [24]. Needs assessments used interviews and ethnographic observations to develop evaluation indicators for robot-assisted feeding systems [13, 38] but did not directly examine social dining nuances.

Some research has included social dining. One work compared three robots and found that users preferred the one that enabled more socialization [32]. Another work found that users preferred a slower robot and a non-voice interface in social contexts [14]. Other studies modeled when a robot should automatically feed a user during social dining [31, 54]. To the best of our knowledge, there is no thorough investigation of user needs and priorities for robot-assisted feeding in social contexts. Our work fills this gap.

3.3 Design Principles for Assistive Technology

Universal Design (UD) originated in the 90's from the disability rights movement and consists of 7 principles, such as equitable and flexible use [37]. Critics of UD maintain that it tries to accommodate two contradictory goals: designing for mass marketing and designing for specialized communities, such as people with disabilities [20, 34, 58]. Previous work tried to reconcile these goals with the EMFASIS framework [57].

Our work unearths design principles that are distinctive to social contexts and tailored to robot-assisted feeding. The design principles we propose differ from others, [22, 37, 63], as they are actionable within the realm of robot-assisted feeding. They differ from work in robot-assisted feeding [13, 38], because the principles are meant to guide designers *throughout technology creation*, not just during evaluation.

Table 1: Study participant demographics. No participant used robotic assistance for feeding.

ID	Age	Gender	Living at	Self-described impairment	Impairment time	Eating assistance providers[1]
CR[2]	37	Male	Home	Paralyzed from the neck down	> 5 years	Formal caregivers, parents, friends
P1	28	Female	Home	Unable to move arms	> 5 years	Parents, formal caregiver
P2	40	Male	Home	Paralyzed from the neck down	> 5 years	Formal caregiver, girlfriend
P3	42	Male	Home	Muscular dystrophy	> 5 years	Formal caregiver, sister, mother
P4	40	Male	Home	Paralyzed from the neck down	> 5 years	Formal caregiver, family, friends
P5[3]	18	Male	Home	Cerebral palsy	> 5 years	Parent, friend, formal caregiver
P6	58	Male	Care facility	Quadriplegia due to multiple sclerosis	> 5 years	Formal caregiver, family, friends
P7	49	Male	Care facility	Quadriplegia due to multiple sclerosis	> 5 years	Formal caregiver, family, friends
P8	30	Male	Home	Spinal Muscular Atrophy	> 5 years	Wife, family, friends
P9	18	Male	Home	Almost paralyzed from neck down	3-5 years	Parent, formal caregiver
P10	34	Female	Home	Spinal Muscular Atrophy	> 5 years	Parents

4 DESIGN FRAMEWORK

4.1 Framework for Inclusive Design

Our work is based on Kat Holmes' framework for inclusive design [34]. This framework provides 5 questions to help teams avoid perpetuating exclusion: (1) *Why* make this artifact? (2) *Who* makes it? (3) *How* do we make it? (4) *Who* will use it? (5) *What* do we make? Fig 3 shows the framework applied to our research.

4.2 Community-Based Participatory Research

To wholly include people with permanent motor impairments in this work, we followed community-based participatory research (CBPR), which harnesses community wisdom in equal partnership with academic methodological rigor throughout the research process [29, 74]. According to CBPR, an equitable partnership between research and community requires sharing power, resources, credit, results, and knowledge [46, 56]. This method is increasingly common in assistive technology research [12, 17, 18, 21, 40, 68, 70].

Near the beginning of this project, the academic researchers[4] engaged a person with permanent motor impairments as a community researcher. This individual has been a recurring participant in our lab's user studies since 2019, which gives him familiarity with robot-assisted feeding. A C1 quadriplegic[5], he was injured in 2012. He runs a non-profit organization that connects people with motor impairments to assistive technologies (ATs), is on advisory boards related to AT, and runs a business focused on smart homes and AT, making him a valuable community researcher for our project. Throughout the project, he has been involved in creating design materials, co-running design interviews, analyzing data, and co-authoring this paper, spending an average of 1 hour per week since joining the team in Feb 2022.

[1]Formal caregivers are paid and trained professionals.
[2]This individual is the community researcher (Sec 4.2).
[3]Since P5 had difficulty speaking, their parent sometimes clarified what they said.
[4]Throughout the paper, "we" refers to the entire research team, including the community researcher. To differentiate, we use "academic researchers."
[5]A person diagnosed with a C1 quadriplegic injury will probably lose function from the neck down and be ventilator-dependent. For more information, see https://www.spinalinjury101.org/details/levels-of-injury.

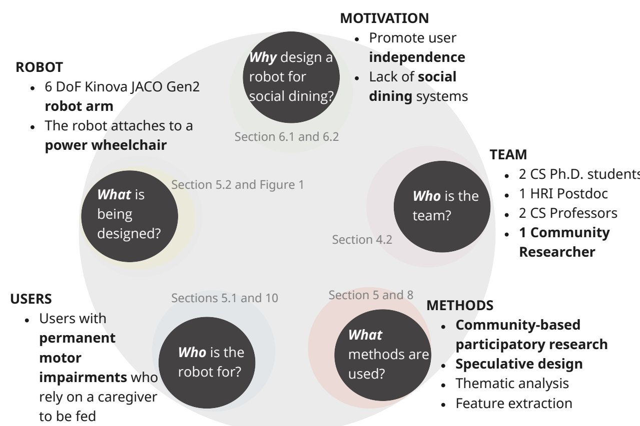

Figure 3: Applied framework for Inclusive Design [34].

5 DESIGN METHOD

We interviewed participants using speculative videos of robot-assisted social dining and applied qualitative analysis methods to identify key themes. Fig 2 shows an overview of our method.

5.1 Participants

We recruited participants primarily from the community researcher's connections. The inclusion criteria were to have a permanent motor impairment and to rely on a caregiver to be fed. Table 1 shows demographic information about our 10 participants.

5.2 Design Materials

5.2.1 Speculative Videos. We showed participants speculative videos of how robot-assisted feeding might be used in social settings[6]. These videos were intended to familiarize them with robot-assisted feeding and invite them to share their views on robot design. We created the videos following speculative design guidelines [47].

[6]https://youtube.com/playlist?list=PLv0SEVdRS7GqvB1eWGUrEvMwfNgdcbuMt

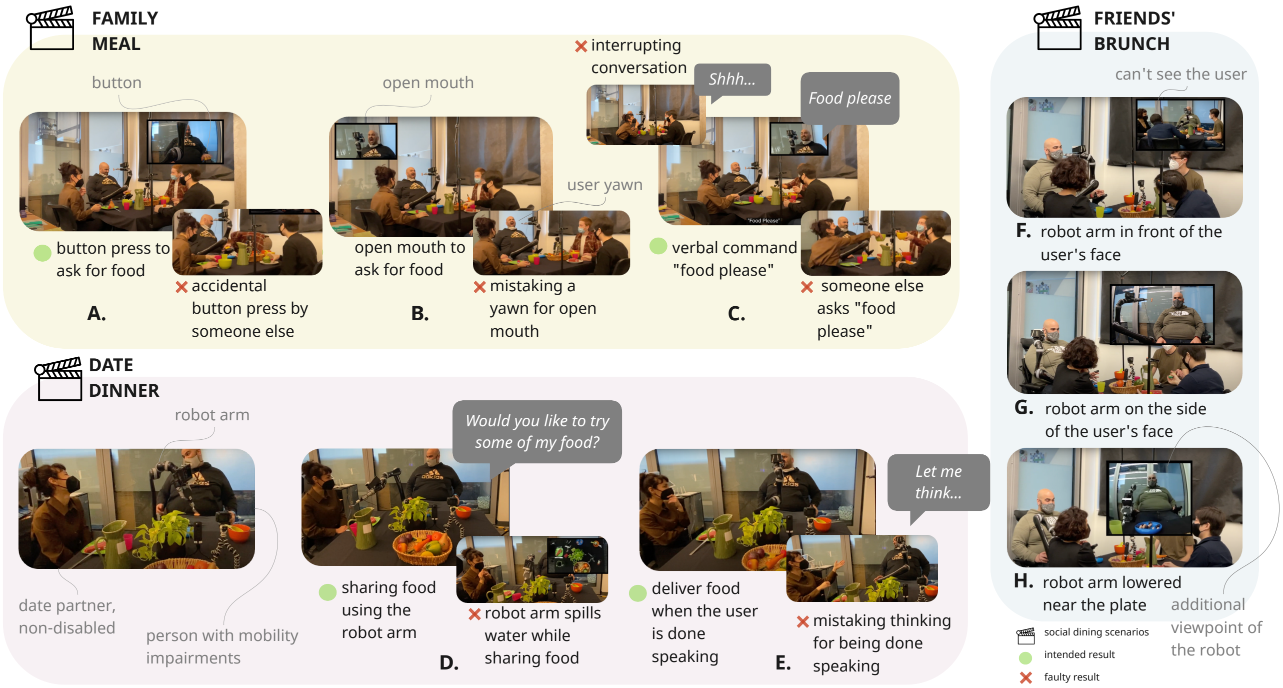

Figure 4: Speculative videos on robot-assisted social dining used during our design interviews.

These videos include three common social dining scenarios: family meal, dinner date, and brunch with friends. They feature a person who acted as someone with motor impairments using the robot and other social dining partners without motor impairments.

We themed the videos around areas where the design direction was unclear: (1) how should a user ask the robot for food? (2) should a robot share food with dining partners, and how? (3) where should the robot rest its arm while delivering food? We recorded polarized versions of each robot behavior, showing intended robot performance vs faux pas the robot could cause. The community researcher helped design the videos, ensuring they would be understandable to participants with little experience with assistive robots. In total, we created a playlist of nine 1 minute videos (Fig 4). More details can be found in our HRI'23 Video submission[7] [51].

5.2.2 Robot System. We used a 6 degree-of-freedom Kinova JACO Gen2 robot arm attached to a power wheelchair base (Fig 1). The robot arm has an RGB-D mounted on-board, which it uses to perceive food and the user's face. It uses a custom 3D-printed fork to pick up food, and a force-torque sensor to know when it has skewered food and to guarantee user safety. In the videos, the robot autonomously acquires pieces of fruits and vegetables and feeds them to the user.

5.3 At-Home Interviews

Design interviews were held virtually and consisted of the following steps: (1) introduction of the research team and participant, (2) questions about participants' current social dining routines, (3) watching and discussing videos, and (4) session wrap up. The decision to hold interviews virtually was made in consultation with the community researcher in order to promote accessibility for participants. The community researcher led the interviews, while other team members took notes and participated in the discussion.

[7] https://youtu.be/BInhARANKaU

5.4 Thematic Analysis

We employed qualitative methods since it can surface understanding around particular people's nuanced experiences, emotions, needs, and motivations [26, 59, 67]. Specifically, we used thematic analysis [67] to analyze the data, which consisted of video recordings from the design interviews. To develop the codes and themes that emerged from the data, two researchers independently coded each interview recording and performed calibration exercises to ensure consistency [39]. Overall, the two researchers met 10 times, with the community researcher participating in 5 meetings to reconcile divergence in the coding [25, 35]. The thematic analysis took over 70 hours across all researchers to transcribe and code the over 500 sentences from design interviews.

5.5 Synthesis as Visual Knowledge

From this thematic analysis, we extracted the **three key outcomes of this work: interview results (Sec 6), design principles (Sec 7), and an implementation guide for robot-assisted social dining (Sec 8)**. For each outcome, we synthesized key insights as standalone visual knowledge, presented in Figs 5-7. This builds upon the growing awareness that visuals have unique strengths compared to text [23, 66], particularly for "creating and articulating knowledge about interactivity" [15], and are becoming prevalent in interdisciplinary fields including HRI [8, 9, 33, 41, 42].

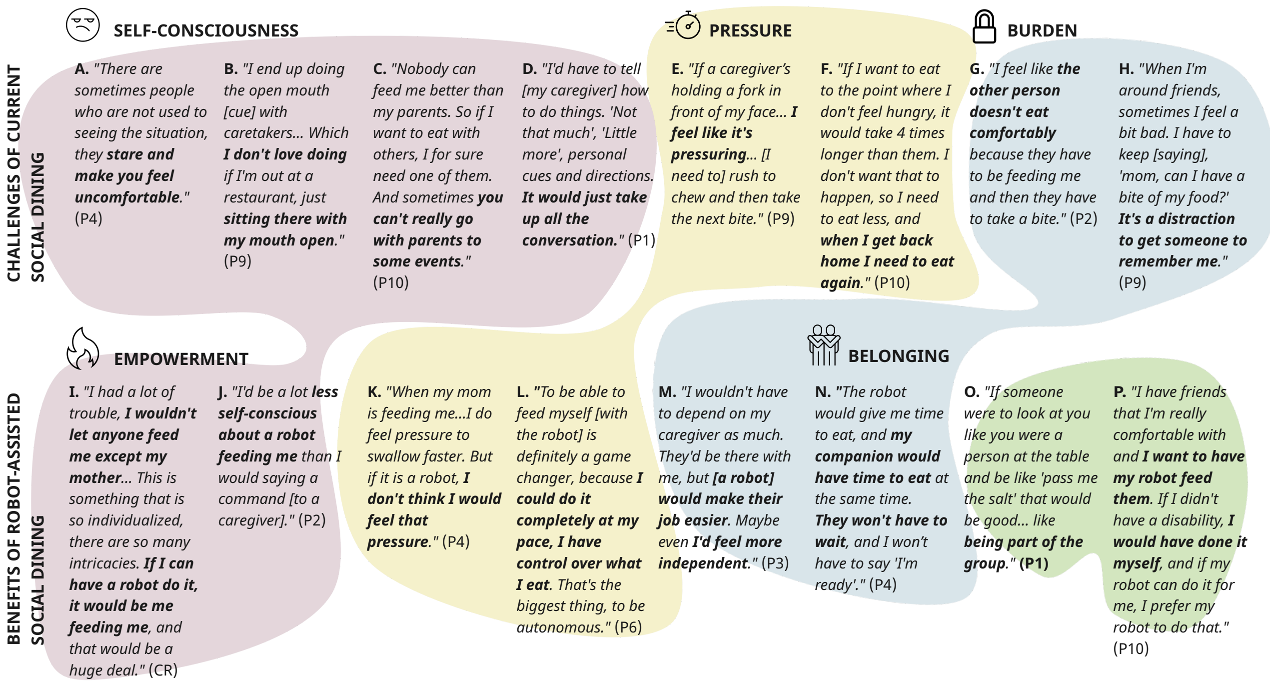

Figure 5: The top row shows the negative emotions participants felt during social dining, while the bottom shows benefits they perceived from robot-assisted social dining. Background shapes connect related quotes.

6 INTERVIEW RESULTS

Participants engaged in social dining in restaurants, breweries, sports games, picnics, road trips, theaters, and remote socialization. We now elaborate on their challenges during social dining (Sec 6.1), thoughts on how robot-assisted feeding could address them (Sec 6.2), and preferences with respect to robot behaviors (Sec 6.3).

6.1 Social Dining Challenges

Some participants enjoyed social dining: *"They take a bite, I take a bite, it becomes part of the interaction. We enjoy the meal together."* (P7). However, most **preferred not to eat socially** due to **repeated challenging experiences**. *"I don't like it. I'll arrive and be like 'nope, I'm good, I already ate'... A lot of people eat out for enjoyment. For me, it's not like that. Eating is a necessity, I don't do it for fun."* (P1). Fig 5A-H provides an overview of these challenging experiences.

6.1.1 Divided Attention. A challenge participants discussed is that caregiver attention is divided among feeding, eating, and social interactions. Therefore, participants have to verbally remind caregivers to feed them (Fig 5H), interrupting conversations and making them feel **self-conscious** (Fig 5D) or **burdensome** (Fig 5G, 5H).

6.1.2 Caregiver Variability. Participants noted caregivers' lack of consistency in meeting their needs because **different caregivers feed them differently**. Some feed too fast, causing **pressure** (Fig 5E), while others feed too slowly, causing **frustration**. Some offer bites that are too large, a **choking hazard**, while others' are too small: *"One day my dad's shoving half a chicken down my throat, the next a nurse is cutting the tiniest pieces; I'm like: 'I'm gonna be here for centuries!'"* (CR). To cope, some participants rely on a few consistent caregivers to feed them but felt that it can be **inappropriate to bring specific caregivers to some social events** (Fig 5C).

6.1.3 Undesired Attention. Participants raised the challenge of bystanders staring or pointing at them, causing **discomfort** (Fig 5A). Such discomfort could be sufficiently powerful to influence preferred dining venues: *"I prefer outside dining because it's more laid back, more distractions. It's not me in a big chair in this tiny diner. I have less people watching me."* (P9).

6.1.4 Mismatch Between Participant Needs and Social Dining Norms. Some participants felt that signaling readiness for a bite with an open mouth, a common non-verbal way to communicate with caregivers [13], was **awkward** in social settings (Fig 5B). Another said she needs to eat slower than is typical in social meals to avoid choking, resulting in feeling **hungry** (Fig 5F). Others wanted to avoid food spilling on them but felt **embarrassed** wearing a bib.

6.1.5 Mismatch with Environmental Factors. Participants faced challenges due to a mismatch between environmental factors, e.g., **a lack of space and too much noise**, and their needs. One needed to tilt his wheelchair to regulate blood pressure and was constantly concerned: *"Am I going to... tilt back and crash into a waiter?"* Others adjust how they sit, making it **difficult to interact with others**: *"My chair is oversized, so I don't fit going straight into a table. I have to sit sideways."* (P4). Noise is a concern, too: *"Communicating when it's loud is difficult. I don't have as strong a voice[8]"* (P2). This makes it **difficult to communicate** with dining partners and caregivers.

[8]Not having a strong voice was one of the impacts of this participant's disability.

6.2 Trade-Offs of Robot-Assisted Social Dining

6.2.1 Benefits. Participants felt that robot-assisted feeding systems could address the challenges they face with caregiver variability and divided attention. They felt that a robot could provide **customization and consistency** (Fig 5I), which is difficult to achieve due to caregiver variability. By using the robot to feed themselves, participants envisioned feeling **empowered** (Fig 5L), less self-conscious (Fig 5J), and less pressured (Fig 5K). Participants also felt that using a robot could promote a sense of **belonging**. Specifically, a robot would free up their caregiver's time (Fig 5M), enabling them to eat at the same time as the participant (Fig 5N). A robot could also open a new realm of belonging by enabling participants to share food with others (Sec 6.3.2). Notably, participants did not want the robot to replace their caregiver but rather sought **caregiver-robot teaming**: *"It wouldn't be a problem if my mom just cut the steak and put it in front of me, and the robot could then feed me"* (P4).

6.2.2 Lingering Challenges. Participants recognized that a robot-assisted feeding system could not address all challenges. For example, it was still likely to draw **unwanted attention**, and for some that would be a deal breaker: *"If it is going to cause more attention on me, then I probably wouldn't want it"* (P1). They also recognized that a robot **could not address mismatches with social dining norms**, such as taking longer to eat than a 'typical' social meal (Fig 5F). Further, they recognized that the robot arm was **unlikely to address mismatches with environmental factors**, too little space and too much noise, but they proposed desired features for the feeding system that could avoid worsening those experiences (see Sec 6.3).

6.3 User Preferences about Robot Behaviors

After watching the videos, participants shared their preferences and ideas for behaviors of the robot-assisted feeding system.

6.3.1 Initiating a Bite. Participants saw 4 ways to instruct the robot to initiate a bite: (1) button-based[9] (Fig 4A); (2) open mouth (Fig 4B); (3) voice command (Fig 4C), and (4) automatic (Fig 4E).

Button. This was the most desired option for bite initiation. Participants liked that a button is subtle (Fig 6P) and *"fewer things [can] go wrong"* (P7). Yet, some felt it would not work well if they have to press it frequently, like when they *"eat lots of popcorn"* (P8). Some participants wanted the button to be part of a phone app.

Open Mouth. Participants liked open-mouth bite initiation for its inclusivity (Fig 6D) and because it aligns with how they currently interact with caregivers (Fig 5B). Yet, some said they would feel awkward opening their mouth socially and were also concerned about face detection failures or robot misinterpretations: *"What if you're talking and the robot thinks you want food?"* (P5).

Voice. Participants had concerns about voice detection failing in loud social settings (Fig 6A). They also felt it would require them to interrupt conversations (Fig 5D), and that the robot may not understand them due to speech impediments. Yet, participants saw the value of voice commands for quieter social settings (Fig 6A).

Automatic. In automatic bite initiation the robot waits until participants stop speaking before feeding them. Participants were very concerned about no longer having control of the robot with this option (Fig 6E) and about potential misunderstandings, e.g., the robot feeds them while they are listening to someone else.

Customizable Bite Initiation. Participants saw the different bite initiation mechanism options as complementary. They repeatedly mentioned wanting to decide which option to use based on factors like noise (Fig 6A) or lighting. Others wanted multiple options as backup: *"If I'm having a bad day where I can't press [a button], then [I'd like] voice commands"* (P1).

6.3.2 Sharing Food. Some participants felt that using the robot to pass food to others would help them feel like an equal participant during a meal (Fig 5O). Others did not consider this a priority: *"[due to a] lifetime of being disabled, people don't expect that"* (P8). Some felt that feeding romantic partners was not part of their dynamic, whereas others were excited about letting good friends taste their food (Fig 5P) and feeding children (Fig 6I) or a pet.

6.3.3 Arm Resting Pose. Participants saw 2 aspects of the robot's arm resting pose: (1) *before delivering* a bite, the arm rests in front (Fig 4F) or to the side (Fig 4G) of them, and (2) *between* bites, the arm rests above the plate or is lowered (Fig 4H).

Before Delivering a Bite. Participants did not like the robot arm in front of their face since that would obstruct their interactions with others (Fig 6O). This was consistent even for participants who could not eat from the side: *"I can't turn my head, so I'd need the food to come directly from the front, but that's just the into-mouth motion. I think to the side is better [for the resting pose]"* (P8). This was an important finding since multiple current robot-assisted feeding systems have the arm rest in front of a user [14, 24, 55].

Between Bites. Participants had mixed preferences about where the arm should rest between bites. Some felt it should go above the plate to make the next bite faster: *"It has to reach over the plate to pick the food up. So if it rested in that position, it wouldn't have to make the extra motion"* (P6). Others felt it should be lowered since that *"is less obtrusive, and down out of the line of sight"* (P7). Yet others felt it should be configurable: *'If you want to eat quickly and have it over your plate, that could be one mode... But say you're letting the food settle, it would be nice to have it rest [lowered]."* (P8).

7 DESIGN PRINCIPLES

Using the thematic analysis method described in Sec 5.4, we synthesized 8 design principles from participant input to guide the development of robot-assisted social dining systems (see Fig 6).

Participants wanted to **customize** their robot so it could work in a variety of environments (Fig 6A), be tailored to impairment-specific needs (Fig 6B), and work with other individual preferences (Fig 6C). This relates to participants' desire for an **inclusive** robot that works across a spectrum of disabilities (Fig 6D).

Participants also wanted the robot to be **subtle**. They wanted to communicate with it in a way that would not be noticeable (Fig 6P) and not have the robot get in-between them and others (Fig 6O). They also wanted it to be **minimalist**, by not adding extra devices to their current assistive technology ecosystem (Fig 6H) and not interfering in others' personal space (Fig 6G).

Participants wanted a **reliable** robot. They did not want the robot to make errors that have social repercussions, such as spilling food (Fig 6M). They also wanted access to an emergency stop in

[9] This includes a micro-switch users can mount anywhere, e.g., a tongue switch.

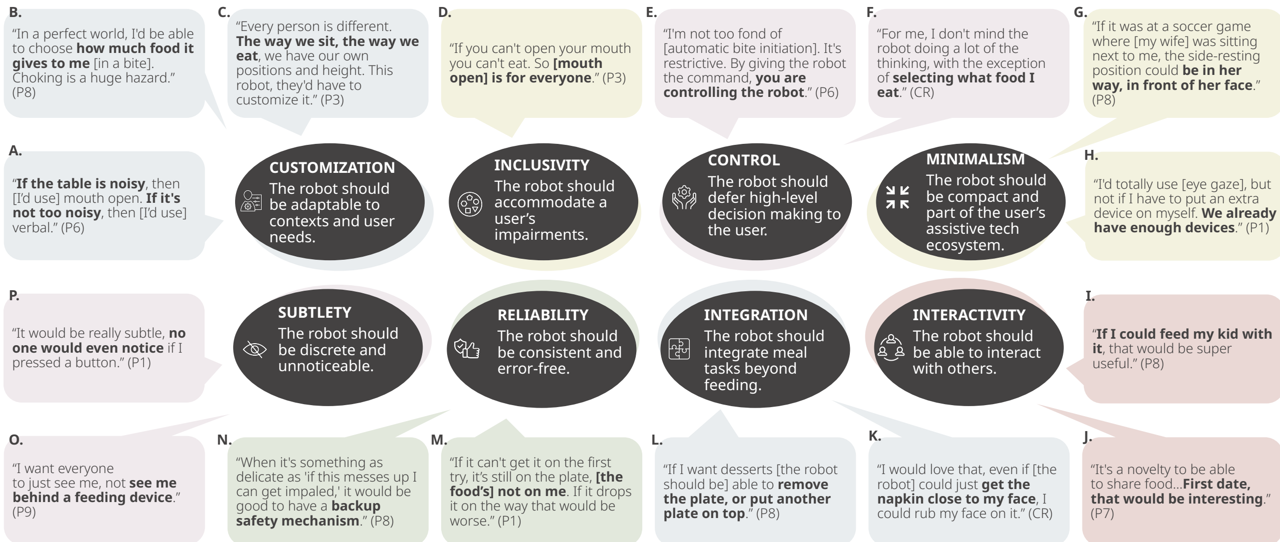

Figure 6: Design principles for robot-assisted feeding.

case of robot errors (Fig 6N). Further, they wanted to be in **control** of the robot; most participants reacted negatively to the proposal of a robot automatically deciding when to initiate a bite (Fig 6E) or what food item they should eat (Fig 6F).

Finally, participants wanted a robot that **interacts** with social partners and **integrates** with other meal components, e.g., using the robot to feed others (Fig 6I, 6J), move plates between courses (Fig 6L), wipe their face (Fig 6K), or team up with caregivers to achieve tasks it cannot do by itself.

Participants differed in how much, and in what realm, they prioritized each principle. For example, consider **control**. Some participants wanted to control the robot's pace of feeding (Fig 5L), while others were *"willing to let the robot decide pace...because it's a thing I already deal with with caregivers"* (CR). Or consider **reliability**. For some participants, unreliability in bite size would render the robot unusable because *"I can only open my mouth so far because of atrophy"* (P8). For others, the behavior that needed to be reliable was face detection because *"I have limited movement, so if it doesn't detect my open mouth that would be the most frustrating"* (P2). This diversity of user preferences is a reminder that design principles are only guides and cannot replace user studies for in-depth identification of specific users' priorities.

We recommend that researchers use these principles when making design decisions about robot-assisted feeding. For example, when designing the robot behavior of passing food, the principles of **control** might lead a researcher to not have the robot directly indulge a request from someone else, but rather wait for the user to instruct it to pass food. When designing the before-bite resting pose, the principle of **subtlety** might lead a researcher to have the arm rest on the side, not the front, of the user's face. However, if approaching from the side reduces the accuracy of face detection and impacts the robot's **reliability**, then design principles conflict and should be resolved via a user study.

8 IMPLEMENTATION GUIDE

Integrating the preceding findings, we present a guide for implementing robot-assisted social dining. This guide, Fig 7, is intended to help researchers identify and prioritize technical features to work on when developing a robot-assisted feeding system.

To develop this guide, two researchers with experience developing robot-assisted feeding systems analyzed all user quotes related to (un)desirable robot behaviors. For each quote, they identified the **technical features** that would be needed to implement that behavior and grouped similar features together. For example, participants' desired robot behavior when transferring food to their mouth contains multiple underlying technical features: "unobtrusive bite transfer" (Fig 6O) and "social obstruction avoidance" (Fig 6G).

The researchers then labeled each feature with a **technical complexity** (y-axis, Fig 7) of high, medium, or low. 'High' was assigned to features that require novel research to implement; 'medium' to features in prior work that require adaptation to implement; and 'low' to features implementable with out-of-the-box code. For example, "open mouth bite initiation" was assigned medium since it can use out-of-the-box face detection but requires camera calibration and accounting for obstructions (e.g., utensils blocking the mouth).

The researchers then analyzed the quotes associated with each feature and assigned the feature a **user-expressed priority** of high, medium, low, or undesirable (x-axis, Fig 7). For example, the feature "open mouth bite initiation" was given a priority of medium because some participants liked it but others had concerns about it failing or being socially awkward to use.

There are several ways to use this guide. A PhD student looking for a dissertation topic might focus on multiple features in the same group. A first-time researcher might focus on a feature with low complexity. A startup developing a minimum viable product might focus on features with high priority. In general, this guide serves to facilitate future work in robot-assisted feeding.

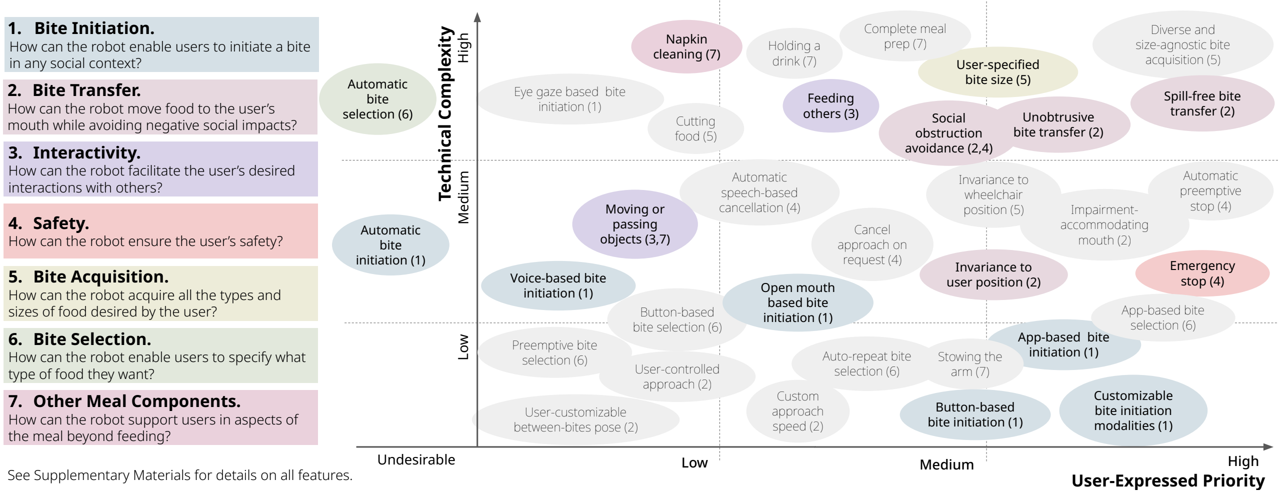

Figure 7: This implementation guide contains features users discussed, organized by user priority and technical complexity. Highlighted features are mentioned in the main paper; those in grey appear in Supplementary Materials (Sec 11).

9 REFLECTIONS ON COMMUNITY-BASED PARTICIPATORY RESEARCH (CBPR)

This was our first time working on a team with community and academic researchers. We present reflections on benefits of and best practices for CBPR, to facilitate the use of CBPR in HRI research.

Shared Experiences. During interviews, the community researcher and participants discussed shared experiences living with motor impairments, which the academic researchers did not have. These moments of empathetic support created trust that enabled deeper insights from the conversation, which would have been impossible without the community researcher.

Building Community. During interviews, participants sometimes raised challenges they faced with assistive technologies, and the community researcher offered advice. This occasionally extended further, with the community researcher sharing resources and meeting participants post-interviews to offer further support.

Demystifying Research. Research can be confusing for newcomers. For example, there are methods for asking questions without biasing participants, procedures for running studies, and terms like "semi-structured interview" that can be obscure. Thus, we integrated explanations of the research processes throughout our collaboration. Having common terminology and expectations enabled the community researcher to make informed decisions when co-creating timelines, protocols, and action items.

Accessible Collaboration. One topic we frequently discussed was how to collaborate accessibly. This included holding all meetings virtually, at a time that accommodated the community researcher's disability-related needs, and having preparatory meetings before design interviews. Holding weekly team meetings was also essential to counteract the knowledge imbalance between the academic team (more familiar with research) and the community researcher (more familiar with living with motor impairments).

Research Time. Throughout our collaboration, the community researcher and participants experienced challenges such as illness, insurance challenges, and technical problems. At those times, the academic team also paused, progressing only when the full team reunited (see Fig 2 for canceled interviews). Where possible, they provided support, such as by connecting the community researcher with a resource to appeal denied health insurance coverage. Accommodating delays and supporting the community researcher beyond the project are crucial to an equitable and sustainable partnership.

10 LIMITATIONS AND FUTURE WORK

Our sample does not represent all stakeholders in a few dimensions: (a) only 2/10 participants were women; (b) we did not interview caregivers or social dining partners who indirectly use the system; (c) and all participants had permanent impairments (as opposed to temporary, e.g., a broken arm). Future work involves diversifying participants, particularly including informal caregivers to understand how they think a robot might alter social dining dynamics.

Participant preferences were derived from discussing speculative videos. However, interacting with a physical robot involves nuances that cannot be captured in videos. An important future step is to implement the features in Fig 7 and have a long-term deployment. Participants may then evaluate the features in social settings and provide further insights into future directions for development.

Yet another interesting direction is investigating features that can facilitate the caregiver-robot teaming discussed in Sec 6.2.1.

11 SUPPLEMENTARY MATERIALS

Supplementary materials are hosted on the Open Science Foundation at [10]. They include the study protocol, codebook, tagged quotes, details on Fig 7 features, attribution for icons, and more.

12 ACKNOWLEDGMENTS

Sandy Kaplan helped with editing. This work was (partially) funded by UW CREATE, NSF GRFP (DGE-1762114), NSF NRI (#1925043 and #2132848) and CHS (#2007011), DARPA RACER (#HR0011-21-C-0171), ONR (#N00014-17-1-2617-P00004 and #2022-016-01 UW), and Amazon. This work received IRB approval, STUDY00014869.

REFERENCES

[1] 2004. Beeson Automaddak Feeder. https://larimer.co.networkofcare.org/aging/assistive/detail.aspx?id=18902&cid=797&cn=Feeders&org=
[2] 2020. The Mealtime Partner Dining System Description. https://www.mealtimepartners.com/dining/mealtime-partner-dining-device.htm
[3] 2021. Bestic. https://web.archive.org/web/20220120094337/https://www.camanio.com/us/products/bestic/
[4] 2022. Meal buddy. https://www.performancehealth.com/meal-buddy-systems
[5] 2022. Meet Obi. https://meetobi.com/
[6] 2022. My Spoon. https://web.archive.org/web/20210510063115/http://www.secom.co.jp/english/myspoon/
[7] 2022. Neater Eater Robotic. https://www.neater.co.uk/neater-eater-robotic
[8] Patrícia Alves-Oliveira, Matthew Bavier, Samrudha Malandkar, Ryan Eldridge, Julie Sayigh, Elin A Björling, and Maya Cakmak. 2022. FLEXI: A robust and flexible social robot embodiment kit. In *Designing Interactive Systems Conference*. 1177–1191.
[9] Patrícia Alves-Oliveira, Maria Luce Lupetti, Michal Luria, Diana Löffler, Mafalda Gamboa, Lea Albaugh, Waki Kamino, Anastasia K. Ostrowski, David Puljiz, Pedro Reynolds-Cuéllar, et al. 2021. Collection of metaphors for human-robot interaction. In *Designing Interactive Systems Conference 2021*. 1366–1379.
[10] Patrícia Alves-Oliveira, Amal Nanavati, Tyler Schrenk, Ethan Gordon, Maya Cakmak, and Siddhartha S Srinivasa. 2022. Design Principles for Robot-Assisted Feeding in Social Contexts (Supplementary Materials). https://doi.org/10.17605/OSF.IO/392HP
[11] S. Belkhale, E.K. Gordon, Y. Chen, S. S. Srinivasa, T. Bhattacharjee, and D. Sadigh. 2022. Balancing Efficiency and Comfort in Robot-Assisted Bite Transfer. In *IEEE International Conference on Robotics and Automation*.
[12] 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.
[13] Tapomayukh Bhattacharjee, Maria E Cabrera, Anat Caspi, Maya Cakmak, and Siddhartha S Srinivasa. 2019. A community-centered design framework for robot-assisted feeding systems. In *The 21st international ACM SIGACCESS conference on computers and accessibility*. 482–494.
[14] Tapomayukh Bhattacharjee, Ethan K Gordon, Rosario Scalise, Maria E Cabrera, Anat Caspi, Maya Cakmak, and Siddhartha S Srinivasa. 2020. Is more autonomy always better? exploring preferences of users with mobility impairments in robot-assisted feeding. In *2020 15th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 181–190.
[15] Eli Blevis, Sabrina Hauser, and William Odom. 2015. Sharing the hidden treasure in pictorials. *interactions* 22, 3 (2015), 32–43.
[16] Gerard Canal, Guillem Alenyà, and Carme Torras. 2016. Personalization framework for adaptive robotic feeding assistance. In *International conference on social robotics*. Springer, 22–31.
[17] Dorota Chapko, Pedro Andrés Andrés Pérez Rothstein, Lizzie Emeh, Pino Frumiento, Donald Kennedy, David McNicholas, Ifeoma Orjiekwe, Michaela Overton, Mark Snead, Robyn Steward, et al. 2021. Supporting Remote Survey Data Analysis by Co-researchers with Learning Disabilities through Inclusive and Creative Practices and Data Science Approaches.. In *Designing Interactive Systems Conference 2021*. 1668–1681.
[18] 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.
[19] Kevin Charras and Michèle Frémontier. 2010. Sharing meals with institutionalized people with dementia: a natural experiment. *Journal of Gerontological Social Work* 53, 5 (2010), 436–448.
[20] Albert M Cook and Janice Miller Polgar. 2014. *Assistive technologies-e-book: principles and practice*. Elsevier Health Sciences.
[21] Lilian de Greef, Dominik Moritz, and Cynthia Bennett. 2021. Interdependent Variables: Remotely Designing Tactile Graphics for an Accessible Workflow. In *The 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. 1–6.
[22] Cee W de Jong, Klaus Klemp, Erik Mattie, and Donald Goodwin. 2017. *Ten Principles for Good Design: Dieter Rams: The Jorrit Maan Collection*. Munich: Prestel,[2017].
[23] Johanna Drucker. 2014. *Graphesis: Visual forms of knowledge production*. Harvard University Press Cambridge, MA.
[24] Daniel Gallenberger, Tapomayukh Bhattacharjee, Youngsun Kim, and Siddhartha S Srinivasa. 2019. Transfer depends on acquisition: Analyzing manipulation strategies for robotic feeding. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 267–276.
[25] D Randy Garrison, Martha Cleveland-Innes, Marguerite Koole, and James Kappelman. 2006. Revisiting methodological issues in transcript analysis: Negotiated coding and reliability. *The internet and higher education* 9, 1 (2006), 1–8.
[26] Clifford Geertz et al. 1973. *The interpretation of cultures*. Vol. 5019. Basic books.
[27] Karen Glanz, Jessica J Metcalfe, Sara C Folta, Alison Brown, and Barbara Fiese. 2021. Diet and health benefits associated with in-home eating and sharing meals at home: A systematic review. *International journal of environmental research and public health* 18, 4 (2021), 1577.
[28] Ethan K Gordon, Xiang Meng, Tapomayukh Bhattacharjee, Matt Barnes, and Siddhartha S Srinivasa. 2020. Adaptive robot-assisted feeding: An online learning framework for acquiring previously unseen food items. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 9659–9666.
[29] Karen Hacker. 2013. *Community-based participatory research*. Sage publications.
[30] Amanda W Harrist and Ralph M Waugh. 2002. Dyadic synchrony: Its structure and function in children's development. *Developmental review* 22, 4 (2002), 555–592.
[31] Laura V Herlant. 2018. Algorithms, implementation, and studies on eating with a shared control robot arm. (2018).
[32] Richard P Hermann, Anna C Phalangas, Richard M Mahoney, and Micheala Alexander. 1999. Powered feeding devices: an evaluation of three models. *Archives of physical medicine and rehabilitation* 80, 10 (1999), 1237–1242.
[33] Marius Hoggenmüller, Wen-Ying Lee, Luke Hespanhol, Malte Jung, and Martin Tomitsch. 2021. Eliciting New Perspectives in RtD Studies through Annotated Portfolios: A Case Study of Robotic Artefacts. In *Designing Interactive Systems Conference 2021*. 1875–1886.
[34] Kat Holmes. 2020. *Mismatch: How inclusion shapes design*. Mit Press.
[35] Rick H Hoyle, Monica J Harris, and Charles M Judd. 2002. Research methods in social relations. (2002).
[36] Sumio Ishii, Shinji Tanaka, and Fumiaki Hiramatsu. 1995. Meal assistance robot for severely handicapped people. In *Proceedings of 1995 IEEE International Conference on Robotics and Automation*, Vol. 2. IEEE, 1308–1313.
[37] Simeon Keates, P John Clarkson, Lee-Anne Harrison, and Peter Robinson. 2000. Towards a practical inclusive design approach. In *Proceedings on the 2000 conference on Universal Usability*. 45–52.
[38] Hyun K Kim, Heejin Jeong, Jangwoon Park, Jaehyun Park, Won-Seok Kim, Nahyeong Kim, Subin Park, and Nam-Jong Paik. 2022. Development of a Comprehensive Design Guideline to Evaluate the User Experiences of Meal-Assistance Robots considering Human-Machine Social Interactions. *International Journal of Human–Computer Interaction* (2022), 1–14.
[39] Klaus Krippendorff. 2009. *The content analysis reader*. Sage.
[40] Raja S Kushalnagar and Christian Vogler. 2020. Teleconference accessibility and guidelines for deaf and hard of hearing users. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. 1–6.
[41] Joseph La Delfa, Mehmet Aydin Baytas, Rakesh Patibanda, Hazel Ngari, Rohit Ashok Khot, and Florian'Floyd' Mueller. 2020. Drone chi: Somaesthetic human-drone interaction. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.
[42] Matthew V Law, JiHyun Jeong, Amritansh Kwatra, Malte F Jung, and Guy Hoffman. 2019. Negotiating the creative space in human-robot collaborative design. In *Proceedings of the 2019 on Designing Interactive Systems Conference*. 645–657.
[43] David Lee. 2014. *The Origins of an Everyday Behavior: Why do People Share Meals?* Ph. D. Dissertation. The University of Mississippi.
[44] Dennis Maciuszek, Johan Aberg, and Nahid Shahmehri. 2005. What help do older people need? Constructing a functional design space of electronic assistive technology applications. In *Proceedings of the 7th international ACM SIGACCESS conference on Computers and accessibility*. 4–11.
[45] Herbert L Meiselman. 2000. Dimensions of the meal: Science, culture, business, art.
[46] Meredith Minkler and Nina Wallerstein. 2011. *Community-based participatory research for health: From process to outcomes*. John Wiley & Sons.
[47] Ivica Mitrović. 2015. An introduction to speculative design practice. *An Introduction to Speculative Design-Eutropia, a Case Study Practice, Croatian Designers Association, Department for Visual Communications Design, Arts Academy, University of Split* (2015), 8–23.
[48] Lorenza Mondada. 2009. The methodical organization of talking and eating: Assessments in dinner conversations. *Food quality and preference* 20, 8 (2009), 558–571.
[49] Anne Murcott. 1982. The cultural significance of food and eating. *Proceedings of the Nutrition Society* 41, 2 (1982), 203–210.
[50] Maia Naftali and Leah Findlater. 2014. Accessibility in context: understanding the truly mobile experience of smartphone users with motor impairments. In *Proceedings of the 16th international ACM SIGACCESS conference on Computers & accessibility*. 209–216.
[51] Amal Nanavati, Patrícia Alves-Oliveira, Tyler Schrenk, Ethan Gordon, Maya Cakmak, and Siddhartha S Srinivasa. 2023. Unintended Failures of Robot-Assisted Feeding in Social Contexts. In *Submitted to the Proceedings of the Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction* (Stockholm, Sweden) *(HRI '23)*. Association for Computing Machinery, New York, NY, USA.
[52] Yutaro Ohshima, Yuichi Kobayashi, Toru Kaneko, Atsushi Yamashita, and Hajime Asama. 2013. Meal support system with spoon using laser range finder and manipulator. In *2013 IEEE workshop on robot vision (WORV)*. IEEE, 82–87.

[53] Tomohiro Oka, Jorge Solis, Ann-Louise Lindborg, Daisuke Matsuura, Yusuke Sugahara, and Yukio Takeda. 2020. Kineto-Elasto-Static design of underactuated chopstick-type gripper mechanism for meal-assistance robot. *Robotics* 9, 3 (2020), 50.

[54] Jan Ondras, Abrar Anwar, Tong Wu, Fanjun Bu, Malte Jung, Jorge Jose Ortiz, and Tapomayukh Bhattacharjee. 2022. Human-Robot Commensality: Bite Timing Prediction for Robot-Assisted Feeding in Groups. *arXiv preprint arXiv:2207.03348* (2022).

[55] 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 (2020), 103344.

[56] Karie Jo Peralta. 2018. Politics of knowledge in community-based work. In *Dimensions of Community-Based Projects in Health Care*. Springer, 67–78.

[57] Ornella Plos, Stéphanie Buisine, Améziane Aoussat, Fabrice Mantelet, and Claude Dumas. 2012. A Universalist strategy for the design of Assistive Technology. *International Journal of Industrial Ergonomics* 42, 6 (2012), 533–541.

[58] Graham Pullin. 2009. *Design meets disability.* MIT press.

[59] André Queirós, Daniel Faria, and Fernando Almeida. 2017. Strengths and limitations of qualitative and quantitative research methods. *European Journal of Education Studies* (2017).

[60] Rehabmart Reviews. 2013. Winsford Self-Feeder. https://www.youtube.com/watch?v=vYG2dVuPmos&ab_channel=RehabmartReviews

[61] Travers Rhodes and Manuela Veloso. 2018. Robot-driven trajectory improvement for feeding tasks. In *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2991–2996.

[62] Paul Rozin. 2005. The meaning of food in our lives: a cross-cultural perspective on eating and well-being. *Journal of nutrition education and behavior* 37 (2005), S107–S112.

[63] Jon A Sanford. 2012. *Universal design as a rehabilitation strategy: Design for the ages.* Springer Publishing Company.

[64] W Seamone and G Schmeisser. 1985. Early clinical evaluation of a robot arm/worktable system for spinal-cord-injured persons. *Journal of rehabilitation research and development* 22, 1 (1985), 38–57.

[65] Teresa E Seeman. 1996. Social ties and health: The benefits of social integration. *Annals of epidemiology* 6, 5 (1996), 442–451.

[66] Richard K Sherwin, Neal Feigenson, and Christina Spiesel. 2007. What is visual knowledge, and what is it good for? Potential ethnographic lessons from the field of legal practice. *Visual Anthropology* 20, 2-3 (2007), 143–178.

[67] Shoshanna Sofaer. 1999. Qualitative methods: what are they and why use them? *Health services research* 34, 5 Pt 2 (1999), 1101.

[68] Tiffany Thang, Alice Liang, Yechan Choi, Adrian Parrales, Sara H Kuang, Sri Kurniawan, and Heather Perez. 2021. Providing and Accessing Support During the COVID-19 Pandemic: Experiences of Mental Health Professionals, Community and Vocational Support Providers, and Adults with ASD. In *The 23rd International ACM SIGACCESS Conference on Computers and Accessibility.* 1–6.

[69] Kristina A Theis, Amy Steinweg, Charles G Helmick, Elizabeth Courtney-Long, Julie A Bolen, and Robin Lee. 2019. Which one? What kind? How many? Types, causes, and prevalence of disability among US adults. *Disability and health journal* 12, 3 (2019), 411–421.

[70] Garreth W Tigwell, Roshan L Peiris, Stacey Watson, Gerald M Garavuso, and Heather Miller. 2020. Student and Teacher Perspectives of Learning ASL in an Online Setting. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility.* 1–6.

[71] Mike Topping. 2000. An overview of the development of Handy 1, a rehabilitation robot to assist the severely disabled. *Artificial Life and Robotics* 4, 4 (2000), 188–192.

[72] Jennifer Utter, Simon Denny, Roshini Peiris-John, Emma Moselen, Ben Dyson, and Terryann Clark. 2017. Family meals and adolescent emotional well-being: findings from a national study. *Journal of nutrition education and behavior* 49, 1 (2017), 67–72.

[73] Jennifer Utter, Simon Denny, Elizabeth Robinson, Theresa Fleming, Shanthi Ameratunga, and Sue Grant. 2013. Family meals and the well-being of adolescents. *Journal of Paediatrics and Child Health* 49, 11 (2013), 906–911.

[74] 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).

[75] Alan Warde and Lydia Martens. 2000. *Eating out: Social differentiation, consumption and pleasure.* Cambridge University Press.

[76] Akira Yamazaki and Ryosuke Masuda. 2012. Autonomous foods handling by chopsticks for meal assistant robot. In *ROBOTIK 2012; 7th German Conference on Robotics*. VDE, 1–6.