Older Adults' Expectations, Experiences, and Preferences in Programming Physical Robot Assistance

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Abstract

Robots are expected to be key enablers in assisting older adults with aging in place by providing cognitive, social, and physical assistance. Because older adults vary greatly in terms of their needs for robot assistance, there may be potential advantages to enabling them to tailor robot assistance to work for their unique contexts through end-user robot programming. However, little is known about the feasibility and potential of engaging older adults in programming robot assistance. In this work, we explore the possibility of engaging older adults in programming physical robot assistance through field study sessions in older adults' homes. Through interviews and observations of older adults' programming experiences using a contemporary commercial robot programming method, we found that familiarity with other forms of automation and interactions, changes in abilities due to aging, multi-user and collaborative programming, cognitive exercise, and mental model formation can play an important role in shaping older adults' expectations, experiences, and preferences in programming physical robot assistance. Based on these findings, we recommend guidelines to consider when designing future robot programming interactions for older adults.

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1. Introduction

Older adults are expected to become a key user group of robots, as robots are envisioned to become technological solutions to help older adults age in place and engage in activities of daily living that may become difficult as they age [1, 2]. In fact, findings from prior work have indicated that older adults would prefer to age in place with the support of robot assistance rather than move to a care facility [3]. Beyond helping older adults retain independence and adapt to aging-related changes in physical, sensory, and cognitive capabilities [4, 5], research studies in the human-robot interaction (HRI) field have produced evidence of various benefits to older adults adopting robot assistance, such as greater personal security and lower social isolation [6, 7]. Therefore, there has been growing interest in developing robot assistance for older adults and understanding more about older adults as prospective users of robots.

Older adults may differ from younger adults in what tasks they want robots to assist with [8] and what contributions they believe robots can bring to their lives [9, 10], which points to the need to conduct HRI research to better understand older adults' unique experiences and perspectives in interacting with robots compared to other end-users. This need has propelled increasing studies exploring factors influencing older adults' acceptance of robots [11, 12] and responses to specific functionalities of robots [11].

However, to date, few studies have explored involving *older adults as end-user programmers of in-home robot assistance*. End-user robot programming could enable older adults to better customize robot assistance according to their preferences, especially as their needs and abilities evolve over time. However, the feasibility and potential benefits or shortcomings of engaging older adults in end-user robot programming remain largely unexplored.

Our work builds upon prior HRI research with older adults by investigating programming interactions between older adults and a contemporary physically assistive robot (Figure 1). Furthermore, we use individual interviews with older

Figure 1: We observed older individuals' and couples' experiences in programming a contemporary robot arm to assist with household tasks, such as handling food, loading a dish rack, or retrieving a grocery bag.

adults at their homes to better understand what factors shape their perceptions of programming robot assistance, including affective and aesthetic factors particular to home-based technologies [13]. Our work aims to understand older adults' perspectives as prospective users within the contexts of their homes, while also eliciting design feedback on how contemporary robot programming methods may need to evolve to maximize usability and accessibility for older adults.

In the remainder of this paper, we describe related work on robot assistance and programming involving older adults (Section 2). We then provide details about our study, including information about our participants, settings, procedure, and data analysis (Section 3). In Section 4, we present our findings on how familiarity with other forms of automation and interactions, changes in abilities due to aging, multi-user and collaborative programming, cognitive exercise, and mental model formation play a role in shaping older adults' expectations, experiences, and preferences in programming robot assistance. Based on our study findings, we conclude with a discussion of recommendations for developing future robot programming interactions for older adults (Section 5).

2. Related Work

We summarize related work on robot assistance and programming involving older adults.

2.1. Robot Assistance for Older Adults

Robots are beginning to be used in various contexts, from nursing homes (*e.g.,* [14, 15]) to individual residences (*e.g.,* [16]), by older adults with different levels of physical and cognitive impairment (*e.g.,* [17, 18]). Robot assistance has produced positive outcomes such as improving older adults' activity [14], social interaction [14, 19], moods [18, 20], and health [21].

Robot assistance for older adults has largely been in the form of Socially Assistive Robots (SARs) that assist people primarily through social or cognitive, rather than physical, interventions [21, 22]. Examples of cognitive and social robot assistance include providing motivation for older adults to exercise (*e.g.,* [23, 24]) and eat meals (*e.g.,* [25]), engaging in social interaction (*e.g.,* [11, 26]), and providing cognitive assessment (*e.g.,* [27, 28]), stimulation (*e.g.,* [11]), and support (*e.g.,* [2, 17]). Cognitive and social robot assistance may help older adults adapt to aging-related changes through, for example, reminders (*e.g.,* [29]), navigation guidance (*e.g.,* [29, 30]), or emergency handling (*e.g.,* [16]).

On the other hand, robot assistance may also take the form of mobile manipulators that can provide physical assistance with household and care-related tasks. Physical robot assistance often involves robots helping with daily living activities (*e.g.,* [1, 31]) and healthcare (*e.g.,* [32, 33]). Household and care-related assistance can involve fetching items (*e.g.,* [34]), preparing food (*e.g.,* [34]), performing close-contact activities such as eating or shaving (*e.g.,* [25]), and cleaning (*e.g.,* [34]).

2.2. Older Adults as Computer Programmers

A large body of research has focused on older adults' use of computing technology [35]. The majority of this work has explored older adults' roles as consumers rather than producers of technological products [36], perhaps because stereotypes about older adults' inability to use technology have prevented opportunities for them to serve as designers or producers [37, 38]. Furthermore, most contemporary technologies have been designed without older adults in mind [39]. Therefore, much of the research on computer programming has failed to involve older adults [40].

However, there is a growing shift in research and education towards involving older adults as creators in the technological ecosystem [36] and promoting computer programming for all [40]. Creating digital content has been shown to produce positive benefits for older adults, including increased feelings of creativity, empowerment, engagement, and happiness [41–44]. Training older adults to create technologies through programming in particular is envisioned to have benefits such as improving older adults' quality of life, social connections, and employment prospects, particularly for individuals without access to educational or financial resources [40].

Prior work has primarily explored older adults' initial experiences in learning computer programming using textual or visual languages (*e.g.,* [36, 40, 45]). Older adults' motivations for engaging in computer programming include wanting the mental challenge of programming as they age, connecting with their family members through programming, and improving their employment prospects [36]. Their frustrations in programming stem from various factors, ranging from lack of peer or teaching support to the rapid change in software technologies, but primarily involve challenges due to aging-related cognitive decline [36, 40]. Older programmers may not just be different from younger programmers in terms of aging-related constraints but also in terms of programming preferences: prior work has indicated that programming methods that work well for younger novice programmers such as block-based programming may not be appropriate for older novice programmers [40]. Therefore, there is growing interest in understanding older adults' unique characteristics as programmers.

2.2.1. Older Adults as Robot Programmers

Few works have explored the possibilities of involving older adults in robot programming, with most previous work studying how to help caregivers or care staff program robots on older adults' behalves (*e.g.,* [46]). Some prior work has explored older adults' perceptions of prospective involvement in robot programming without having them try out programming. Such work has found that older adults are generally uninterested in the prospect of programming robots and would rather use robots that are already set up and programmed [47, 48]. However, older adults' perceptions of robot programming may improve once they try it out [49], which emphasizes the need for further research directly involving older adults in robot programming.

In recent years, a few studies have begun to explore the possibilities of engaging older adults in end-user robot programming. Robot programming has been used as an exercise for facilitating cognitive training and assessment of older adults with mild cognitive impairment [50] and as a means by which older adults can actively prototype their own interactions with robots [49, 51] and personalize the behavior of at-home robot assistance [48]. These studies have produced mixed results on older adults' experiences with programming, with some findings indicating that older adults find robot programming fun and educational (*e.g.,* [51]) and others indicating that older adults find programming too difficult and that programming should be the responsibility of caregivers and not older adults themselves (*e.g.,* [48]). Therefore, it remains unclear what factors may influence older adults' experiences in programming.

Older adults have primarily shown a preference towards voice-based methods for controlling and programming robots, though prior work indicates that they are more open towards other forms of programming upon learning about alternatives and viewing live demonstrations of contemporary robots [52]. Prior work has primarily explored the possibilities of older adults programming robots using visual programming and graphical interfaces (*e.g.,* [48, 51]). Although there has been little work engaging older adults in end-user robot programming by demonstration (a common end-user robot programming method where users can demonstrate tasks to the robot instead of coding task behaviors), an interview with older adults about their preferences toward different robot programming and control methods suggested that older adults are generally not open to kinesthetic teaching (a form of programming by demonstration where users guide the robot through task behaviors by hand) due to the effort they perceive it as requiring [52].

In this work, we study older adults' use of a contemporary commercial end-user programming method for programming physical robot assistance that primarily involves programming by demonstration through kinesthetic teaching. Based on prior work and our own observations from previous studies (*e.g.,* [53]), we expected that kinesthetic teaching may lack accessibility and usability for older adults. However, because most commercial end-user robot programming systems available today involve some degree of kinesthetic teaching, we opted to use a commercial kinesthetic teaching interface in this study to elicit older adults' thoughts, experiences, and feedback with respect to contemporary robot programming methods and to understand whether older adults' initial perceptions on kinesthetic teaching change upon trying it out in practice.

3. Methods

To understand older adults' expectations, experiences, and preferences with respect to using and programming in-home robot assistance, we conducted field study sessions at various older adults' homes. We used a combination of semi-structured interviews and observations in our study. Our protocol and methods were approved by an institutional review board (IRB).

3.1. Participants and Settings

We recruited individuals and couples living independently in their homes for this study by posting flyers in the local community, reaching out to participants who previously participated in studies at our institution, and snowball sampling [54]. Based on a pilot study session, we narrowed the eligibility criteria to include participants aged 65 or older with no significant mobility restrictions that could prevent them from physically maneuvering a robot. We enforced the eligibility criteria through screening calls. None of our participants had significant disabilities preventing them from participating, although we did not explicitly screen based on sensory or cognitive abilities. Participants received 25 USD/hour as compensation.

In total, we recruited 12 participants, which included six individuals and three married couples, from across the Baltimore area. The first participant was used to pilot the study procedure and is not included in our analysis. The remaining 11 participants were aged between 67 and 94 ($M = 75.09, SD = 7.18$) and consisted of six females and five males (Table 1). Five of the 11 participants reported that they have a chronic disease. Participants reported having mild physical impairment ($M = 2.00, SD = 0.77$) (*1: Good physical health, 5: Complete physical impairment*) and being able to perform everyday activities at a good capacity ($M = 2.09, SD = 0.94$) (*1: Excellent, 5: Completely impaired*). None of the participants reported having cognitive health conditions. Participants reported being moderately experienced with technology ($M = 2.82, SD = 1.17$) (*1: Extremely experienced, 5: Not all experienced*). Most participants owned phones, tablets, and computers. In addition, some participants reported having smart TVs and smart speakers. Participants reported being slightly familiar with robots ($M = 3.82, SD = 0.98$) (*1: Extremely familiar, 5: Not all experienced*) and primarily knew about robots from the media or from experience with robot vacuum cleaners, except *P6*, who worked with various robots at their workplace.

ID	Group	Race	Gender	Age	Degree	Field	Employed	Chron. Disease	PH	DP	TE	RF
1	Individual	White	Female	77	Vocational	Neurology	Retired	Yes	2	2	4	5
2	Individual	White	Female	69	Bachelor's	Nursing	Retired	No	1	2	2	3
3	Individual	White	Male	79	Some college	Publishing	Other	No	2	2	3	4
4	Individual	White	Male	75	Bachelor's	Social Work	Retired	Yes	3	3	3	3
5	Individual	Black	Female	74	Secondary	Manufacturing	Other	Yes	3	1	4	5
6	Couple A	White	Male	67	Bachelor's	Design	Full-Time	Yes	2	2	1	2
7	Couple A	White	Female	94	Master's	Education	Retired	Yes	3	4	4	5
8	Couple B	White	Male	75	Bachelor's	Business	Retired	No	2	2	3	4
9	Couple B	White	Female	74	Vocational	Nursing	Retired	No	2	3	4	4
10	Couple C	White	Male	71	Master's	Urban Planning	Part-Time	No	1	1	1	3
11	Couple C	Asian	Female	71	Master's	Education	Retired	No	1	1	2	4

Table 1: Study Participants. We refer to participants by their IDs throughout the paper. The last four columns represent 5-point Likert scale questions regarding participants' physical health (PH; *1: Good, 5: Completely impaired*), daily activity performance (DP; *1: Excellent, 5: Completely impaired*), experience with technology (TE; *1: Extremely experienced, 5: Not at all experienced*), and familiarity with robots (RF; *1: Extremely familiar, 5: Not at all familiar*).

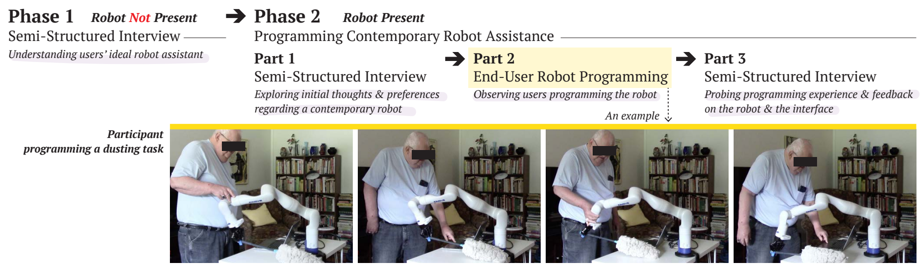

Figure 2: Our study procedure consisted of two phases. In Phase 1, we conducted a semi-structured interview to understand older adults' ideal robot assistance. In Phase 2, we explored users' thoughts, experiences, and feedback regarding programming a contemporary robot arm to perform household tasks such as dusting.

We conducted study sessions in participants' residences. All participants in our study lived in houses or condos that they owned, and their residences were not part of senior communities. Single-story and multi-story homes with and without outdoor properties were included in the study.

3.2. Study Design

We used a combination of semi-structured interviews and observations that we audio- or video-recorded and documented through field notes. Each study session took approximately 1.5 to 2.5 hours. After obtaining informed consent from the participant, we ran the following study procedure (Figure 2):

3.2.1. Phase 1: Semi-Structured Interview Regarding Participants' Ideal Robot Assistance (30 min. to 1 hr.)

We first conducted a semi-structured interview with questions regarding:

- Participants' perceptions and mental models of robots
- Participants' task and programming preferences, needs, and concerns regarding in-home robot assistance
- Participants' daily routines, challenges they face due to aging, and their current technology use

The goal of this interview was to have participants perform a cognitive walk-through of their daily routines, which has been shown to be effective for identifying activities that in-home robot assistance can support in participatory design research with older adults [55], and to understand their preferred design characteristics for their ideal robot assistance and programming interface unconstrained by current technological limitations. Therefore, we encouraged divergent design thinking [56] by instructing participants to brainstorm ideas without limiting themselves to their perceptions of current robots' capabilities, and we kept the robot arm out of view at this time.

3.2.2. Phase 2: Semi-Structured Interviews and Observations Regarding Programming Contemporary Robot Assistance (1–1.5 hrs.)

We then brought a contemporary robot arm into the participant's view to further probe their design ideas and encourage convergent design thinking [56]. We used a lightweight 7-DOF Kinova Gen3 cobot arm with a 2-finger gripper and web-based programming interface (Figure 3). This robot is an example of a contemporary robot used for assistive applications and was selected due to its compactness, which made it easy for us to transport it to, from, and within participants' homes, and because it has an off-the-shelf interface for end-users to program robot motions without prior robotics or coding knowledge. The robot is able to grip small household objects up to 85 millimeters in width and five kilograms in weight. Because we did not want to overconstrain participants' interactions with the robot due to its stationary nature, we mounted the robot on a table with wheels so that we could easily move the robot to different locations during the study and simulate how a mobile manipulator would operate.

While the Kinova arm is not meant to be fully representative of end product robots that may be used in older adults' homes in practice, we adopted it as a research tool to study older adults' experiences and design feedback to inform the design of future programming interfaces, which may use different robot hardware or modalities. Similarly, while the commercial kinesthetic teaching interface used in this study may not be the most accessible or user-friendly programming modality for older adults to use, kinesthetic teaching remains a common modality for many end-user robot programming systems (e.g., [57–60]). Therefore, we adopt a kinesthetic programming interface in this study to confirm whether kinesthetic teaching has any feasibility, benefits, or limitations that we can use to inform the future design of similar or alternate end-user programming modalities for older adults.

This phase of the study consisted of three parts:

Part 1. Semi-Structured Interview About Initial Thoughts and Preferences Regarding a Contemporary Robot. We asked questions regarding:

- Participants' perceptions and mental models of the robot
- Participants' preferred tasks for the robot to assist with
- Participants' preferred methods for programming the robot

When asking about participants' preferred methods for programming the robot, we encouraged them to use their imagination and provided examples of common options used to program robots from the literature, such as touchscreens, laser pointers, or joysticks, since prior work has indicated that older adults often limit themselves to voice-based methods when asked to brainstorm about their desired programming methods but are open to different methods when provided a list of options [52]. We conducted this interview before showing the participant how to operate and program the robot so that we could capture their initial mental models and preferences.

Part 2. Observations of Participants Programming a Contemporary Robot. We then had participants program a task that they wanted the robot to assist them with. As done in previous HRI studies (*e.g.,* [61]), we encouraged participants to choose programming tasks that simulated robot assistance they envisioned in their daily life, with the goal of demonstrating the relevance of programming to their lives as recommended by prior work [36, 40]. Examples of tasks participants chose to program included dusting surfaces (Figure 2), retrieving items from high shelves, and loading dishes onto a drying rack. Some examples are shown in Figure 1. In cases where tasks would require the robot to handle fragile items or would not be feasible given the robot's workspace, we simulated the desired task using our own objects that we brought to the study sessions. Programming tasks participants chose to complete are shown in Table

ID	Group	Programming Tasks	Pair Role
1	Individual	Retrieving pantry item (T1, T2)	N/A
2	Individual	Holding pantry item (T1, T2)	N/A
3	Individual	Retrieving bag of groceries* (T1), retrieving cup* (T2)	N/A
4	Individual	Retrieving cup* (T1), dusting table (T2)	N/A
5	Individual	Adding vegetable to pan* (T1), dusting table* (T2)	N/A
6	Couple A	Loading cup onto dish rack* (T1, T2)	Programmer
7			Observer
8	Couple B	Loading plate onto dish rack* (T1), loading utensils onto dish rack* (T2), loading cup onto dish rack* (T3)	Programmer (T1 & T2), Assistant (T3)
9			Assistant (T1 & T2), Programmer (T3)
10	Couple C	Moving cup to different spots* (T1), moving plate to different spots* (T2)	Programmer
11			Programmer

Table 2: Programming Tasks and Roles. Participants in the study chose programming tasks that represented tasks they desired robot assistance for (task examples shown in Figure 1). Participants in couples took on several roles during the programming tasks, either doing the programming or supporting or observing while their partners did the programming. An * indicates tasks for which participants elected to use objects we brought to their homes. Task order is indicated in parentheses.

2.

To program task motions, participants used the Kinova Kortex web app, a programming interface developed by Kinova that allows users to maneuver the robot to different positions by hand using kinesthetic teaching and engage in waypoint-based programming, where users specify waypoints that they want the robot to move to but not the trajectory the robot follows between waypoints, which is computed by the system (Figure 3). We gave participants a live tutorial on how to physically guide the robot in either of two admittance modes, Cartesian (which allows translation and rotation of the robot's end effector along x, y, and z-dimensions and is tailored to programming motions involving aligning the robot's gripper) and joint (which allows rotation of the seven joints of the

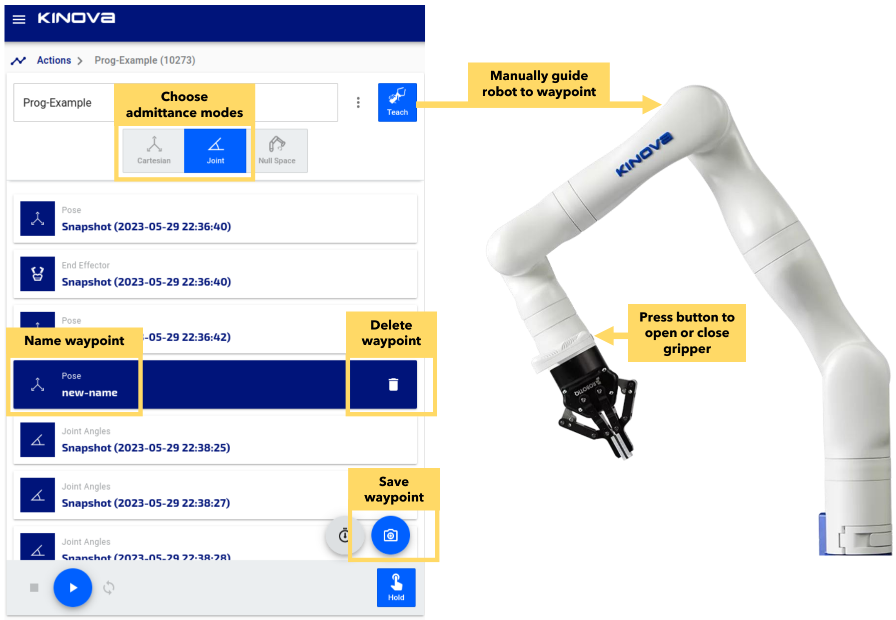

Figure 3: Programming Interface and Robot. Participants used a commercial web interface available to kinesthetically program the Kinova arm in this study. Participants were instructed on how to choose admittance modes and name, delete, and save waypoints using the web interface, as well as how to manually guide the robot and operate its gripper. The programming workflow requires users to switch between moving the robot to different waypoints and using the web interface to save, view, or edit waypoints, as shown in Figure 2. *(Source: Kinova Robotics)*

Kinova Gen3 arm and is better suited for programming motions requiring the robot to change its orientation). We also showed the participants how to name and save waypoints and open and close the robot's gripper. We did not include some programming capabilities available on the interface in the study to reduce training time. However, we told the participants the options would be available if they used the robot in practice. We ran the web app on a laptop computer for the study.

As the participants programmed, the researchers took field notes documenting their observations, with a focus on breakdowns and user difficulties, along with body language, paralanguage, and context beyond participants' verbalizations as recommended by prior work [62]. The researchers did not intervene unless the participant requested assistance or could not proceed further with the task due to a major breakdown or technical difficulties. Some participants (*P3*, *P5*) were unable to use the screen-based interface due to visual constraints or inexperience with using computers, so the researchers assisted them with any actions that required clicking or navigating on the screen according to the participants' instructions.

Upon completion of the programming task, the researchers reset the task objects to their initial positions and played the participant's program for them to see. The participant then completed a second programming task, which could be the same as the first if they wanted to try it again or could be a different task for which they wanted robot assistance. We instructed participants in *Couples A*, *B*, and *C* to work together with their partner to simulate a more naturalistic programming interaction than if each participant programmed the robot independently.

Part 3. Semi-Structured Interviews About Programming Experience and Feedback on Robot and Interface. After the participants completed the programming tasks, we conducted an interview containing questions regarding:

- Participants' perceptions of the programming process and interface and any challenges they faced
- Feedback on design changes participants would make to the robot or programming interface
- Participants' perceptions on whether they could envision using the robot and programming interface in their daily lives and what tasks they would want the robot to assist with

We encouraged participants to think beyond the current robot setup when answering these questions, particularly with respect to considering future possibilities such as mounting the robot on a mobile base or having the robot learn and generalize, instead of directly imitate, their demonstrations. Our goal was not to evaluate the Kinova Kortex web app specifically but rather use it as a means to understanding how an older population of novice users interacts with the system and what older adults' design needs are with respect to robot programming in general. Therefore, we asked participants to provide their thoughts and feedback with respect to their experience with the programming method as a whole instead of the web interface specifically. We also emphasized that we did not create the programming system and wanted participants' honest feedback about their experience in using it. For *Couples A*, *B*, and *C*, we conducted all interviews with both participants in the couple together and included a couple of questions regarding their experience collaborating with their partner. All interview questions are listed in Appendix A.

3.3. Data Analysis

All audio and video data and field notes were transcribed and then analyzed using applied thematic analysis based on the guidelines by Guest et al. [63]. The first author was familiar with the data from conducting the field studies and reviewed it to identify initial themes of interest. They then went through the transcriptions sentence by sentence to identify and code significant segments. This process was repeated until the codebook was finalized, at which point a secondary coder was trained to use the codebook and was instructed to code 20% of the data to assess inter-rater reliability. The reliability analysis indicated high agreement between the primary and secondary coders (86% agreement, Cohen's $\kappa = 0.85$) [64]. Disagreements between the coders were resolved through discussion, and then themes were derived based on the final codes in an iterative process. In this work, we primarily present themes related to our observations and interviews from Phase 2 of our study (Figure 2, Section 3.2.2). A portion of our findings from Phase 1 is presented in [65].

4. Results

Our analysis revealed five themes corresponding to factors shaping participants' expectations, experiences, and preferences regarding robot programming (Table 3). We use quotes from participants who permitted their use, with minimal edits for clarity.

Summary of Study Findings
Theme 1: Familiarity With Other Forms of Automation and Interactions
• Participants expected the level of effort and reliability involved in robot programming to be similar to the level required to engage with other forms of automation and interactions they are familiar with. • Participants preferred programming methods involving familiar and direct interactions that require minimal use of peripheral devices (e.g., talking, drawing, gesturing). • Participants who perceived programming the Kinova arm as familiar had more positive programming experiences.
Theme 2. Changes in Abilities Due to Aging
• Participants' preferred interaction modalities are determined based on their changing abilities as they age. • The programming method for the Kinova arm lacks accessibility for older adults with changing physical, sensory, and cognitive abilities.
Theme 3. Multi-User and Collaborative Programming
• Participants may need help from others to program robot assistance as they age. • Programming with a partner had advantages, such as helping with splitting the programming workload, providing encouragement and motivation, and identifying program errors.
Theme 4. Cognitive Exercise
• Some participants viewed programming the Kinova arm as a fun, interesting, and stimulating cognitive exercise.
Theme 5. Mental Model Formation
• Participants' primary concerns at the prospect of adopting robot assistance involved having insufficient or incorrect mental models of how the robot will behave. • Programming the Kinova arm helped some participants refine and strengthen their mental models about the robot's capabilities and limitations.

Table 3: Our study findings revealed five themes corresponding to factors that shape participants' expectations, experiences, and preferences in programming physical robot assistance.

4.1. Theme 1. Familiarity With Other Forms of Automation and Interactions

Participants' expectations, experiences, and preferences regarding programming robot assistance in the home were shaped by their previous experiences with automated technology and different types of interactions.

Participants expected the level of effort and reliability involved in robot programming to be similar to the level required to engage with other forms of automation and interactions they are familiar with. For example, *P4* indicated that they would expect *"the degree of involvement that it takes now to use a dishwasher"* to program a robot. *P2* expected to be specific when verbally instructing a robot because *"you gotta be pretty specific with Google or Alexa. You gotta tell them where, when, exactly what it is you want them to do or else they keep asking you what time or what day, [et cetera.]"*

Participants anticipated possible reliability issues in programming robot assistance based on their familiarity with automated technologies: *"I mean, you have the same with any device, it's going to have glitches, just like the Roomba [robot vacuum cleaner] does. You know, you have to go and fetch things out of it. And so you expect that there's going to be issues..."* (*P2*). For example, *P9* recalled that their robot vacuum cleaner often gets stuck or bumps into people when it runs, so they have to set up the environment beforehand any time it operates. Consequently, they expected that their ideal robot assistance should not operate completely autonomously but rather that they should have some programmatic control over when it operates. Furthermore, *P7* expected there could be issues with reliability in programming their ideal robot assistance using speech, stating *"I'd have to see what was effective [for programming the robot]. For example, I had a doctor who used to speak into this computer, and then it would print out what he said, except it got it wrong, so they stopped using it, I noticed."*

Participants preferred programming methods involving familiar and direct interactions that require minimal use of peripheral devices (e.g., talking, drawing, gesturing). Similarly to participants from previous related studies (*e.g.,* [47, 52]), they primarily suggested that the programming interface should not require additional devices beyond the robot itself (*e.g.,* computers, keyboard, or remotes) so that there is less need for technical experience (*P5*), fine motor control (*P3, P7, P8*), and keeping track of multiple devices (*P4*). However, if programming required the use of a device external to the robot, participants preferred for the device to be one that they are already familiar with, such as their phone (*P4*), with *P10* even suggesting that they would like to program the robot by communicating *"electronically through [their] hearing aid."*

Participants favored programming interactions that they would already be familiar with using in their daily lives. *P2*, who had limited mobility at their wrist and primarily required assistance with tasks involving gripping, suggested a direct method of programming similar to how they would use their grabber tool: *"It would be nice if it was an extension of my hand, and I could hold onto it and be able to make it go where I want it to go."* The most popular programming approach was verbal, however, with all participants indicating that the most familiar programming method they could envision is speech-based programming. Most participants were familiar with digital assistants such as Alexa or Siri and preferred to program the robot in a similar way using an activation phrase followed by a command specifying the robot's action and when and where it should take place: *"Hey Sam, dust my fan blades in the dining room today"* (*P2*), *"Hey Siri, go to the green wall"* (*P10*).

On the other hand, participants who did not use digital assistants regularly preferred to program the robot similarly to how they would instruct a human: *"It is time for you to clean the kitchen, and I'll do the living room"* (*P5*). Regardless of how they preferred to structure their verbal instructions, participants considered speech-based instruction to be the most intuitive and natural way to program the robot. *P4* stated, *"I don't think I would be interested in one that wouldn't accept voice commands. I think I've been spoiled by Alexa and Siri. I sort of expect voice commands to be a given."*

Participants suggested various changes that could make the programming method for the Kinova arm more familiar for older adults to use. Participants suggested moving from waypoint-based programming to continuous trajectory programming (*e.g.,* [66]) since people tend to be familiar with continuous, rather than discrete, representations of motions (*e.g.,* navigation routes on Google maps) (*P3, P6, P10*). Participants also suggested alternates to the Kinova method that involve more familiar interactions. *P2* suggested an augmented reality interface that would allow users to *draw out* their desired path over an image of the environment. *P4* indicated that they would want to move the robot using *finger swipe gestures*: *"I could make it move with my finger, come over, say, and grab the coffee cup, and save that but have it remember all the steps in between to achieve that effect. . . I think it's important to emphasize that moving the robot with my finger on either a touchscreen or pad is a whole lot better than having to physically take the robot and move it. I found that surprising that I couldn't just move with my finger,"* describing a swiping-based approach as more familiar *"because we all use smartphones."*

Participants who perceived programming the Kinova arm as familiar had more positive programming experiences. Participants who were able to tie the programming method back to interactions they were familiar with tended to have an easier and more positive experience programming the Kinova. For example, *P3* particularly liked the kinesthetic teaching aspect of the contemporary programming method, stating *"I like the intuitive nature of just manipulating the arm because it kinda simulates the movement that I want to accomplish. It's almost like it's kind of an extension of your arm."* We also found that participants who could link waypoint-based programming back to existing technological processes and features they are familiar with (*e.g.,* setting up macros in Excel (*P8*) or memory seats in a vehicle (*P4*)) programmed the robot with fewer breakdowns and errors.

On the other hand, participants who perceived programming the Kinova as unfamiliar were more likely to view the programming method as scary or difficult. For example, *P9* indicated that the process made them anxious and nervous, and *P5* said that they were initially scared upon trying the programming process because it was so different from anything they had done before.

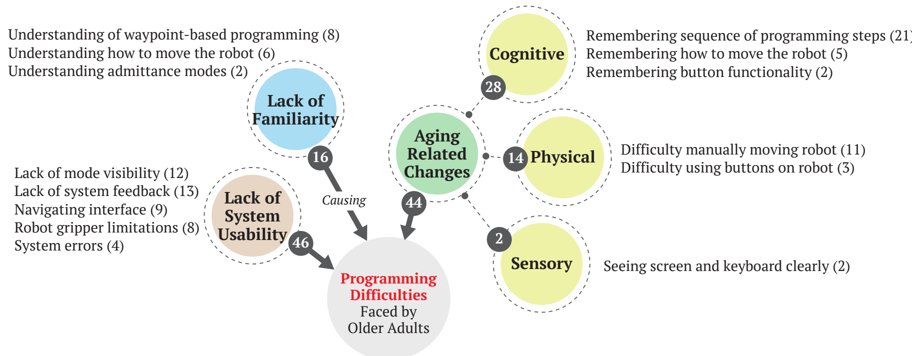

Figure 4: We observed participants experiencing programming difficulties due to lack of system usability, lack of familiarity, and aging-related changes. In this work, we primarily focus on user difficulties related to lack of familiarity and aging-related changes and design guidelines to address these difficulties. Numbers represent the number of programming difficulties we observed of the corresponding type.

Participants also indicated that their unfamiliarity with technical concepts in robotics made it difficult to understand aspects of the programming process (Figure 4), such as understanding the difference between the admittance modes available for kinesthetic teaching and when to switch between them.

4.2. Theme 2. Changes in Abilities Due to Aging

Participants' changing abilities in mobility, perception, and cognition as they age framed their expectations, experiences, and preferences with respect to programming robot assistance.

Participants' preferred interaction modalities are determined based on their changing abilities as they age. Most participants in our study had some form of limitation in their mobility. Participants considered their evolving mobility-related constraints in forming their preferences on how they would want to program robot assistance. For example, *P7*, who had the most mobility restrictions among our study participants and often had to stay seated or reclined, expected that programming the robot using a laser pointer (*e.g.,* [67]) *"might be nice because you could lie down and just point the laser."* Some participants who lacked fine motor control preferred not to program robot assistance using computer interfaces. For example, *P7* said, *"The trouble with* *computers is that you have to hit the buttons quite right, and if you don't, and you have trouble with your hands like I do, that might be a problem. It's a problem with my tablet."*

One of our study participants, *P3*, had constraints in their sensory capabilities, as macular degeneration made it difficult for them to perceive small or low-contrast details and interpret depth correctly, and a tumor in their ear affected their hearing. Therefore, *P3* expected that programming using a computing device could be problematic over time given limitations in their eyesight.

The programming method for the Kinova arm lacks accessibility for older adults with changing physical, sensory, and cognitive abilities. Participants experienced programming difficulties due to aging-related changes (Figure 4). Participants indicated that kinesthetic teaching using the Kinova involved too much friction (*P6, P10*) and pointed out the inaccessibility of the kinesthetic teaching method for older adults with motor restrictions: *"If you're an older person, and you have to do that, I would think that's not very appealing because they might have dexterity issues. I mean, if it automatically did all those things, fine, but you have to do it manually"* (*P11*).

We observed signs of physical fatigue in users during kinesthetic teaching, such as heavy breathing (*P6*), moving task objects closer to the robot by hand (*P8*), and sitting down or taking breaks during kinesthetic teaching (*Couple B*). One of the study participants, *P7*, chose to forego kinesthetic teaching completely as they perceived it as requiring more mobility than they currently had, instead watching as their husband (*P6*) maneuvered the robot. *P6* suggested that older adults with mobility restrictions like their wife would need an alternative to manually moving the robot, such as using a joystick to specify where the robot should go. In the course of kinesthetic teaching, *P4* observed, *"It's a little hard to move, isn't it? This is definitely some resistance. Can you do this? It's protesting... the robot is not very cooperative. Or easily moved."*

In addition to experiencing difficulties in moving the robot during kinesthetic teaching, we found that some participants also experienced difficulty in using the buttons onboard the robot for opening and closing the gripper (*P2, P5, P8*), particularly *P2*, who had mobility issues with their wrist. Furthermore, *P3* had difficulty seeing the keyboard and web-based interface while programming the Kinova arm, and the experimenter had to intervene and perform any interactions involving the computer on the participant's behalf.

Although none of the participants reported being diagnosed with any form of cognitive impairment, participants mentioned that their ability to remember things has declined over the years. Most of our participants had difficulty remembering all the steps–moving the robot, saving the waypoint, and using a button to operate the gripper–required to program the Kinova arm (*P1, P2, P3, P4, P5 P6, P7, P8*). While forgetting steps could be attributed to participants still learning to use the interface during the short programming session, some participants attributed the difficulty of keeping track of programming steps to their limited memory (*P5, P7*).

P3 described the cognitive activity required to use the contemporary programming method: *"I can see that you really have to think about every single movement, making sure that that's clear and that you recorded or built it into the program. Every single moment, you can't skip any steps. And that's just, you know, having clearly in mind how the technology works."* *P8* suggested what this could mean for an older user when they stated, *"It's a repetitive process. Once you've got it down, and you remember all the important things you need to do, steps, then that's easy. For an older person, that might prove to be a bigger challenge of, can they remember enough times, so that tomorrow when they want to do something, will it? You know, will they be able to go back and say, yeah, do such and such... the interface needs to be much simpler given that many older adults have cognitive constraints, so especially the saving for this interface involves multiple steps."*

4.3. Theme 3. Multi-User and Collaborative Programming

Our study revealed that multi-user and collaborative approaches to programming may be beneficial for older adults.

Participants may need help from others to program robot assis-

tance as they age. Although participants in our study generally indicated that programming and using the Kinova arm may not necessarily be useful at this point in their lives, participants did see potential benefits over the long term. For example, *P3* said, *"I don't feel like it fulfills an immediate need right at the moment, but I can see where it could definitely fill a need in the future. My limitations might become more pronounced."* However, although participants perceived themselves as needing robot assistance more as their capabilities become more constrained in the future, they also perceived programming a robot as less feasible at that point. For example, *P6* asked, *"Thing is, many times when people need to use a robot to do a task, they cannot do the tasks themselves. So if they cannot do the tasks themselves, how are they going to show the robot?"*

Participants particularly expressed skepticism that they would be able to program robot assistance using a method such as that used to program the Kinova arm as they get older. *P11* indicated that they could only perceive an older adult as using the programmed assistance and not doing the actual programming themselves. *P10* said, *"The [older adult] gets this robot and [they] have to program it, it might be difficult for some older people... a lot of people are not good with computers."* *P6* stated that, if they were to be generous with their estimate, a maximum of five residents in their building, which consisted of around 100 residents who are mostly older adults, would be able to program the Kinova arm. Their wife, *P7*, who was the oldest among our participants, stated that the interface was too complicated for them and that they would only use the arm if someone else programmed it for them. This suggests that there is a high likelihood that, in addition to or in lieu of older adults themselves, other users such as family members may also program robot assistance.

Participants in our study indicated that family members are their primary source of help when it comes to technology. Referring to the long time it took them and their wife (*Couple B*) to succeed in programming one of their tasks with the Kinova arm, *P8* said, *"This is why we've had children to help us with tech things... by the time we read instructions and do everything...,"* while *P9* expressed frustration during the course of programming a particularly difficult grip position, stating, *"This is when I would call my girls and say come help me."* In fact, *Couple B* specifically mentioned that their ideal robot programming method would allow family members to also program their robot.

Programming with a partner had advantages, such as helping with splitting the programming workload, providing encouragement and motivation, and identifying program errors. We observed potential advantages to multi-user programming. For example, we observed various effective collaboration strategies among the couples in our study who programmed the robot together, such as participants taking responsibility for aspects of programming that may be difficult for their partner and adopting different roles as needed during programming (Table 2). In *Couple A*, *P6* led the programming interaction since their wife (*P7*) did not have the mobility to easily guide the robot. In fact, *P6* indicated that they would take a collaborative approach in practice where they would take responsibility for performing the low-level motion programming but would involve *P7* in determining high-level task preferences such as what objects to use and when and where they should be set up.

Participants also indicated benefits to programming with a partner themselves. For example, *P9* stated, *"I would remember the things that he [(P8)] might forget and he might remind me of things that I will forget in the programming process."* In *Couple C*, *P10* and *P11* indicated that it would be easiest for them to program the Kinova arm together since each partner could focus on one of the two programming modalities (*e.g.,* kinesthetic or screen).

Partners often confirmed the correctness of their actions with one another, asked each other for suggestions or instructions, reminded each other not to forget programming steps or commands, and gave each other advice. They also made jokes or positive affirmations to provide encouragement but also made sure to point out errors and mistakes that they perceived their partner as making.

4.4. Theme 4. Cognitive Exercise

Robot programming may not only serve as a means for older adults to specify robot behaviors, but could also serve as a cognitive exercise.

Some participants viewed programming the Kinova arm as a fun, interesting, and stimulating cognitive exercise. We found that some participants especially liked programming the Kinova arm for the cognitive demand it required (*P2, P5, P8, P10*). For example, *P5* said that they loved programming the robot arm and would not make any changes to the programming method as it was an intellectually stimulating challenge for them. Participants also positively perceived the process of gaining mastery in programming task assistance, with some participants expressing pride upon completing a successful program (*P10, Couple B*). Several participants perceived the programming process and interface positively. They indicated that the process was fun, enjoyable, interesting, cool, and easy to learn, with some participants expressing nonverbal signs of enjoyment while programming such as smiling or applause. Therefore, difficulties participants encountered when programming the Kinova arm were not always perceived negatively, particularly when participants viewed them as opportunities to engage in cognitively demanding exercises.

4.5. Theme 5. Mental Model Formation

Participants had concerns relating to when robot behavior may deviate from the participants' mental models. Programming helped some participants refine their mental models of the Kinova arm.

Participants' primary concerns at the prospect of adopting robot assistance involved having insufficient or incorrect mental models of how the robot will behave. In our study, we found that participants' concerns regarding using robot assistance often related to having insufficient mental models about robots and how to operate them. *P3* said, *"I'm not very adept technologically. I could envision a very steep learning curve and maybe not be able to get it right the first time. Or the second time, having to practice, and I guess, like a lot of older people, I have this concern about, am I going to damage* *something or am I going to inadvertently cause it to shut down or break or whatever?" P5* indicated that they were worried about misusing robots by failing to account for any of their constraints that are not immediately visible, such as by taking them near water if they are not waterproof. While programming the robot, *P4* was concerned about the various modes available for moving the robot, asking, *"It won't certainly break if I'm in the wrong mode and move? People my age always think we're gonna break a computer. It took me a long time to believe I wasn't gonna break my computer." P5* similarly worried that they would "hurt" the robot in the process of kinesthetic teaching.

Participants were also unsure about what they should do if there is a breakdown that caused the robot to operate differently than their mental model on how it should operate: *"Do you have to call a robot repairman to come out to repair the robot?... I mean, so if it breaks down, what do you do? Now you're up a creek"* (*P9*). *P3* asked, *"Especially until I were to get used to it, wondering, can I really trust this? This machine. Is this assistant going to do what they say it's going to do?"*

Programming the Kinova arm helped some participants refine and strengthen their mental models about the robot's capabilities and limitations. Our study suggested that end-user robot programming could help alleviate some of older adults' concerns by helping with appropriate mental model formation. Based on their initial view of the Kinova arm prior to interacting with it, participants extrapolated that it could perform reaching motions and grasping and had joints and capabilities similar to a human arm, including the ability to perform manual tasks such as pick-and-place. However, they had mixed perceptions of the robot's range of motion, strength, flexibility, and tactile capabilities, which suggested that direct, physical interaction is necessary for users to develop an understanding of a robot's physical capabilities.

Participants also inquired about the robot's non-physical capabilities, such as its visual recognition capabilities, since these were not immediately obvious from just looking at the robot. After programming the Kinova arm, some participants indicated that they had a better idea of tasks they perceived the robot arm as not being able to do, such as washing dishes, cleaning ceiling fan blades, folding sheets, or taking out the trash, indicating that the experience of programming the robot had led them to revise their mental models of the robots' capabilities and what tasks it could realistically assist them with.

5. Discussion

In this work, we describe the results from our qualitative study which is among the first to explore the possibilities of involving older adults in programming robot assistance. Our study revealed five themes representing factors that shaped participants' expectations, experiences, and preferences in end-user robot programming: *familiarity with other forms of automation and interactions*, *changes in abilities due to aging*, *multi-user and collaborative programming*, *cognitive exercise*, and *mental model formation*. We translate our findings from each of these themes into recommendations for designing robot programming interactions for older adults. We also highlight future directions for research on how to enable older adults to adopt and customize robot assistance.

5.1. Recommendations for Designing End-User Robot Programming Interactions for Older Adults

Based on the findings from our study, we propose design recommendations for researchers and developers to enable older adults to use and program robots.

Design Guideline	Recommendation	Description
Leverage older adults' prior experiences *Based on findings from Theme 1 (Section 4.1)*	Familiarity-based training	• *Use metaphors as appropriate.* • *Draw comparisons and contrasts with other familiar interactions.*
	Minimal use of peripheral devices	• *Reduce the use of specialized hardware.* • *Incorporate familiar devices as needed.*
	Familiar interaction convention	• *Design familiar verbal or gesture-based interactions.* • *Alter familiar interactions to maximize accessibility.*

Table 4 continued from previous page

Design Guideline	Recommendation	Description
Support aging-related changes *Based on findings from Theme 2 (Section 4.2)*	Multimodal, redundant interactions	• *Enable users to choose between different input modalities for performing a programming action.*
	Cognitive support	• *Provide targeted reminders.* • *Group commands required for a programming activity together spatially.*
Enable collaborative interactions *Based on findings from Theme 3 (Section 4.3)*	Multi-user programming	• *Allow use by multiple users.*
	Virtual agent interactions	• *Include virtual agent interactions to provide peer support.*
Structure robot programming as a cognitive exercise *Based on findings from Themes 3&4 (Sections 4.3, 4.4)*	Gamification	• *Provide rewards for engaging in programming.* • *Incorporate social interactions in programming.*
Use robot programming to bolster mental models *Based on findings from Theme 5 (Section 4.5)*	Onboarding	• *Use programming activities to onboard users in adopting robot assistance.*

Table 4: Based on the factors we observed as shaping older adults' perceptions and experiences in robot programming, we provide recommendations to consider when designing robot programming interactions for older adults.

5.1.1. Leverage Older Adults' Prior Experiences

Similarly to prior work indicating that prior experience with computing interfaces can impact older adults' expectations about computer programming (*e.g.,* [40]), our work emphasized the role of familiarity with different forms of automation in framing older adults' expectations for programming robot assistance. In particular, participants' familiarity with other forms of automation, such as dishwashers, smart speakers, and GPS assistance shaped their expectations of what programming would entail (Section 4.1). Furthermore, participants indicated a preference for familiarity over unsolicited novelty. For example, *P8* said, *"I don't like a lot of change in my life... if I'm used to doing something, and I get everything done the way I like, I don't generally try and change it. I have adjusted things to make things better. But as long as it's working and things do what I want them to do, then I'm satisfied with that. I'm not just looking for change for the sake of change."* Given the role of familiarity in framing participants' expectations, experiences, and preferences, we recommend building upon older adults' prior experiences with other forms of automation and interactions in shaping how older adults learn and do robot programming.

Older adults may be less familiar with technology and consequently less likely to adopt technology into their lives [68]. Unfamiliar technologies can be perceived as too complex and difficult to use, which can deter older adults and novice end-users from investing the time required to learn how to use such technologies [69] and to remodel their existing knowledge [13]. Therefore, prior work has suggested incorporating familiarity into the design of technology to alleviate issues due to lack of technological knowledge and help older adults establish common ground with novel technologies [13]. Reliving past experiences when interacting with technology with familiar features can help older adults make better sense of interactions [13, 69] and reduce their cognitive load, training time, and help requests when using technology [69]. Furthermore, familiarity-based design can break down barriers standing between older adults and technology such as feelings of anxiety, hostility, or inadequacy regarding technology use or perceptions of being out of the "technology culture" [13, 68, 70]. Because familiarity emphasizes recognition over recall, familiar interfaces can also be more accessible for older adults with cognitive constraints that make it difficult to remember sequences of tasks [69].

Although familiarity is commonly used in designing gaming interfaces [69], it has received relatively little attention in the human-computer interaction (HCI) field as a whole compared to design concepts such as mental models, consistency, and accessibility [70, 71], particularly when it comes to designing human-computer interactions for older adults [13]. However, there is growing interest in using familiarity as a basis for human design [71] and as a means to establish a common language between machines and users [72], particularly for older adults who may have grown up prior to the technological revolution [13].

Prior work in HCI has primarily established familiarity in the design of computer interfaces for older adults by drawing from familiar cultural practices [13], metaphors (*e.g.,* [73]), and physical interactions that parallel real-world motor patterns (*e.g.,* [13]), such as direct manipulation and multi-touch interactions as opposed to point-and-click interactions (*e.g.,* [13, 69]). Such work has aimed to develop computer interfaces that represent the real world as closely as possible using familiar visual objects [13, 69] so that older adults can apply their existing skills to new domains [69] and draw from skills that they have practiced their whole life [69]. Based on prior work on familiarity in HCI and our study findings, we recommend *incorporating familiarity in designing training processes*, *minimizing the use of peripheral devices*, and *using familiar interaction conventions* to make human-robot interfaces more familiar for older adults to use.

Familiarity-Based Training. Training is a critical aspect to consider when designing technological interactions for older adults [74], as meaningful training could reduce negative attitudes older adults may have towards technology [73]. Furthermore, older adults may be unaware of what new technologies can do, how to access technologies, and what kinds of benefits technologies could bring to their lives [13, 68]. Training could enhance older adults' understanding of technology, as well as communicate why it is worth the effort of investing time towards learning a new technology [13].

Familiarity can serve as a strong basis for training older adults to use new technologies (*e.g.,* [69]). In our study, we found that older adults who were able to make connections between waypoint-based programming and technological interactions they were already familiar with were more likely to have positive perceptions and experiences when programming the Kinova arm (Section 4.1). Based on these findings, we recommend explicitly drawing connections between robot programming methods and interactions older adults are familiar with in training older adults to program robots. We recommend that training methods for end-user robot programming should draw from analogical learning [75], structure mapping [76], and learner-centered design [77] by highlighting similarities and differences between novel robot programming methods and interaction methods that older adults are already familiar with, which may help older adults form mental models of robots and robot programming more accurately and efficiently [78].

As an example, we found that participants in our study often had difficulties forming an appropriate mental model of waypoint-based programming when they lacked familiarity with discrete representations of motion (Section 4.1). To help alleviate such difficulties, a metaphor comparing programming robot motions to drawing could be used during training, where waypoint-based programming could be likened to connecting the dots in contrast to path-based programming, which could be likened to drawing out a curve. Furthermore, when training older adults to use voice-based robot programming methods, comparisons and contrasts could be drawn between the programming methods and voice-based interactions older adults are already familiar with, such as interactions with smart speakers or regular conversation, in terms of level of detail, structure, and effort required.

By drawing from metaphors and comparisons and contrasts against familiar interactions during training, it may be possible to alleviate fears and concerns that older adults may have when engaging in new technological interactions, while also setting up their expectations for the structure and potential limitations of different kinds of robot programming interactions. However, while such a learning approach may have the advantage of leveraging older adults' existing skills and knowledge, it is also important to avoid designing metaphors that may be too complex for older adults with cognitive constraints to understand [13] or that over-constrain the presentation of new technologies [71]. Furthermore, incorporating familiarity into technological interactions with older adults requires understanding a complex web of factors that include social practices, cultural schemes, motor patterns, sensorial perception, and emotional experiences unique to older adults [13]. Therefore, we encourage further research into how to appropriately incorporate metaphors and comparison-based learning into training for older adults.

Minimal Use of Peripheral Devices. Our work supported findings from previous studies that indicate older adults would prefer not to use peripheral devices for programming (*e.g.,* [52]). Most of our study participants preferred programming methods that could be used without interacting with devices external to the robot, such as speech-based programming. Therefore, we recommend that end-user robot programming methods should avoid the use of peripheral devices, particularly those involving specialized hardware, to lower the physical, sensory, and cognitive skills required for programming and reduce the need for older adults to learn unfamiliar interaction styles. If the programming method requires the use of a peripheral device, we recommend using devices older adults may already be familiar with, such as mobile phones.

Familiar Interaction Conventions. Given the potential benefits of incorporating familiarity into interfaces for older adults and participants' expectations and preferences towards familiar interactions (Section 4.1), we recommend that end-user robot programming methods use common interaction conventions [79] such as touchscreen gestures (*e.g.,* [80]) and verbal phrases (*e.g.,* [81]) in the design of programming interactions for robot assistance. Gestural interaction in particular has been shown to be easy and enjoyable for older adults to learn (*e.g.,* [73]). Touchscreen gestures (*e.g.,* pinch-to-zoom) have the advantage of transferring across multiple devices that older adults may be using [69], which may increase the familiarity of the interaction. Gestures that are strongly linked with the programming action they correspond with could also be particularly familiar for older adults to use [13].

However, familiarity should not be emphasized at the expense of accessibility when designing programming interactions for older adults. For example, while kinesthetic teaching may feel familiar for some older adults who perceive it as extending their own motion (Section 4.1), its lack of accessibility makes it largely infeasible for older adults with motor constraints (Section 4.2). Thus, familiar interaction conventions may need to be modified to work with older adults. For example, given the high variability in touch performance among older adults [73], drag-and-drop touchscreen interactions may need to be modified to work with halting motions [69, 73]. Furthermore, speech-based programming, which most participants in our study favored (Section 4.1), may need to be modified to work with older adults' hearing (*e.g.,* [82]), computer literacy (*e.g.,* [2]), and speech characteristics (*e.g.,* [27]).

5.1.2. Support Aging-Related Changes

End-user robot programming could serve as a means by which older adults could manage evolving aging-related constraints by progressively adding new forms of task assistance from robots based on their changing requirements and preferences. However, to leverage the full potential of end-user robot programming in enabling older adults to manage and adapt to aging-related changes, end-user robot programming methods must themselves accommodate changes in older adults' abilities as they age. We recommend providing multiple interaction modalities with input redundancy and cognitive support to produce programming methods that better adapt to older adults' changing contexts as they age.

Multimodal, Redundant Interactions. Different programming modalities may be more feasible for older adults at different points in their life; for example, kinesthetic teaching may be more feasible in early older adulthood [52]. In our own study, we found that participants had mixed experiences with kinesthetic teaching depending on their degree of mobility, from enjoying the intuitive nature of physically guiding the robot (*e.g., P3*) to foregoing kinesthetic teaching completely because of the physical demand (*e.g., P7*). The effect of aging-related changes on older adults' experiences with technology is well-documented: text can become harder to read, metaphors and icons harder to interpret, and interfaces harder to operate due to decline in memory and motion [13].

Given the strong influence of aging-related constraints on participants' expectations, experiences, and preferences regarding programming robot assistance (Section 4.2), we recommend that end-user robot programming methods should allow end-users to choose what interaction modality to use based on their individual preferences and constraints (*e.g.,* [16]). However multimodal programming methods should make it optional for the user to use multiple modalities at once since participants indicated that it is difficult to keep track of multiple interaction styles at once (i.e., having to switch between manually guiding the robot and using the web interface as shown in Figure 2) (Section 4.1). They should incorporate one-stop interfaces with redundant inputs whenever possible rather than requiring users to switch between multiple input modalities, as input redundancy can be particularly helpful for end-users with motor impairments [83].

Cognitive Support. Aging-related changes in cognition can make it difficult for older adults to learn and remember interaction sequences, particularly when such sequences have no personal relevance to them [69]. Therefore, interfaces that emphasize recall over recognition and include many dialog boxes, hidden affordances, nonessential functionality, scrollbars, and technical jargon can be challenging and frustrating for older adults to use [68, 69, 73]. In our study, we found that participants had particular difficulty scrolling through the Kinova programming interface to find different commands and remembering the sequence of actions required to add waypoints into a program (Section 4.2). Furthermore, the act of programming robots itself can involve high cognitive demands and may be especially difficult for older adults with cognitive impairments [50]. Prior work has indicated that most of the difficulties older adults face in programming are cognitive in nature [36, 40]. We recommend that end-user robot programming methods support older adults' cognition by providing reminders during programming and using activity-centered design.

When possible, end-user robot programming methods should reduce the number of steps required to perform programming actions to minimize the need for older adults to memorize sequences. However, when sequences of actions are necessary, reminders could be used to reduce the need for memorization. For example, the Kinova interface used in this study requires users to first select an admittance mode, physically maneuver the robot arm to a position, save the waypoint, and then optionally name the waypoint to add a waypoint into their program (Figure 3). In our study, older adults often forgot to perform at least one of the steps, such as switching to the appropriate admittance mode or saving the waypoint, which in turn led to reaching limits during kinesthetic teaching or collisions during program execution. Participants also often forgot when they needed to interact with the computer versus when they needed to interact with the robot. In similar cases where the programming method involves repeated and fixed sequences of actions, it should not be assumed that an older user will always be able to remember the sequences. Instead, reminders can be provided, particularly when the older adult deviates from the expected programming sequence, similarly to how reminders have been provided to older adults with cognitive impairment when they deviate from their daily activity routine (*e.g.,* [84]).

Besides including targeted reminders, end-user robot programming methods should adopt an activity-centered design approach towards reducing the number of cognitive steps required in programming by placing commands that are frequently used together close to one another (*e.g.,* [85]). An activity-centered approach can help make interfaces quicker and easier to navigate. Furthermore, reducing the number of cognitive steps and context switches involved in programming workflows can help simplify operating and programming robots for older adults. For example, the memorization and navigation steps required to use the Kinova programming method could be reduced by displaying kinesthetic teaching-related commands (*i.e.,* switching admittance modes) only while the user is physically guiding the robot and displaying commands related to saving or naming a waypoint only when the robot is stationary.

5.1.3. Enable Collaborative Interactions

As older adults age, it may become infeasible for them to program a robot over time, and a caregiver may need to take over programming robot assistance. Even among older adults who are able to program robots independently, such as the participants in our study, there may be potential advantages to collaborative programming approaches (Section 4.3). Prior work has indicated that older adults would benefit from programming together with peers, especially when they initially learn how to program [36, 40, 51].

Multi-User Programming. We recommend designing programming methods for use by multiple users or stakeholders (*e.g.,* [17, 30]). For example, speech-based programming methods could enable voice recognition for family members. Remote access could be supported to allow older adults' family members or caregivers to provide programming support away from the home.

Virtual Agent Interactions. Collaborative support could also be provided through interactions with a virtual agent, particularly for older adults who do not have access to peer or family support. Programming interfaces that are difficult for older adults to use may minimize users' sense of self-efficacy during programming [16, 40]. In fact, we observed several instances in our study where older adults blamed themselves for challenges they faced in the programming process. Encouragement from others could help counteract negative feelings during programming. Similarly to how married participants encouraged their spouses in our study (Section 4.3), a virtual agent could help provide encouragement during the programming interaction to minimize users' frustration and provide motivation, in line with how virtual agents have been used to provide encouragement for older adults to engage in social interactions (*e.g.,* [86]).

In addition to encouragement, a virtual agent could also provide other forms of support that we observed in the pairwise programming interactions in our study (Section 4.3). For example, the virtual agent could provide scaffolding during programming by guiding the user through different steps of the programming process and providing recommendations for aspects to consider for different programming commands (*e.g.,* [87]). The agent could also help with verifying the correctness of a program (*e.g.,* [88]) and recovering from errors (*e.g.,* [89]).

5.1.4. Structure Robot Programming as a Cognitive Exercise

Involving older adults in programming robot assistance could be a key driver in enabling older adults to retain agency, independence, and self-efficacy. Previous studies have indicated that maintaining agency and independence is the primary goal of older adults in adopting robot assistance [5, 33, 62, 90] and that robot assistance can serve to either enhance or diminish their autonomy [26, 91]. Similarly to participants in previous studies (*e.g.,* [62, 92]), some of our study participants expressed concerns that over-reliance on robot assistance could affect their independence and physical health by reducing their activity levels (*P5, P8*). Furthermore, prior work has indicated that relying on assistive technology can affect older adults' self-image [93–97]. One approach that could enable older adults to retain agency, independence, and self-efficacy is to have them play an active role in customizing their robot assistance through end-user robot programming. In particular, we recommend structuring robot programming as a cognitive exercise.

Prior work has shown that competition and cognitive stimulation are key motivators for older adults in using computers [68] and learning programming [36]. There is preliminary evidence indicating that end-user robot programming can be a stimulating activity for older adults [16, 50]. In fact, initial findings suggest that programming robots may even help strengthen older adults' cognitive processes [50]. In our study, we found that some participants embraced the cognitive stimulation involved in programming the Kinova arm (Section 4.4).

Gamification. Preliminary evidence suggests that gamification can have benefits for some older adults, from increases in positive emotions to improved cognition [98]. Therefore, we recommend building upon older adults' interest in cognitive stimulation and competition (Section 4.4) by incorporating gamification in end-user robot programming methods. End-user robot programming methods could provide older adults with points, badges, or other rewards for creating, editing, and executing robot programs. Programming interfaces could also enable older adults to share the news with family members or friends when they create a program, which could enhance feelings of mastery and add a social component to programming, which was important to participants in our study (Section 4.3). Furthermore, gamification could be incorporated into training and onboarding for end-user robot programming and could serve as means to enable collaborative learning interactions across multiple end-users.

5.1.5. Design Programming Interactions That Support Mental Model Formation

Our prior work demonstrated that bringing end-users in the loop in determining the behaviors of artificial intelligence technologies could help shape their perceptions of the capabilities of such technologies and increase their comfort in prospectively adopting the technologies [99]. Similarly, in this study, we found that participants were able to get a better idea of the Kinova arm's physical characteristics and task capabilities through their involvement in programming the arm (Section 4.5). Therefore, involving end-users in programming robot assistance may not only serve as a means by which users can customize robot behavior but could also be a way for users to better understand a robot's capabilities and limitations.

In line with prior work [100], many of our participants were primarily familiar with robots from fictional depictions of robots in TV shows and movies such as *Star Wars*, *Lost in Space*, or *2001: A Space Odyssey* and consequently viewed robots as blocky, humanlike, giant, and mechanical or similar to robots such as *R2-D2*. *P10* indicated their preference for anthropomorphic robots, stating: *"We're conditioned that way by all the Hollywood movies."* Participants' previous exposure to media portrayals of robots may reduce their anxiety towards robots, influence their evaluation of the usefulness and difficulty of prospectively using a robot, and shape what design characteristics they expect robots to have, especially as positive portrayals of robots may be more memorable to older adults in the long term [100, 101]. Therefore, providing the opportunity for older adults to program robot assistance may help ground their understanding of what robots can look like and do beyond fictional depictions [47, 102].

Onboarding. We recommend designing programming activities for use in introducing and training older adults on how to use new forms of robot assistance. Even when robot assistance is completely autonomous and does not require older adults to engage in programming to determine actual robot operation, including programming as a means of onboarding could help shape older adults' expectations and understanding of robot assistance. Furthermore, by helping them form a more accurate mental model of how the robot operates, end-user robot programming could also alleviate some of the worries older adults may have stemming from uncertainty about a robot's operation and ease of use (Section 4.5).

5.2. Limitations and Future Work

To understand how the findings from our study may apply to different contexts, our future work will focus on *recruiting diverse study samples*, *investigating naturalistic human-robot interactions*, and *representing older adults' perspectives*.

5.2.1. Recruiting Diverse Study Samples

HRI with older adults is a broad space [103], and our study only presents one perspective into older adults' perceptions and experiences regarding programming robot assistance.

Health Status and Social Connection. Our study was limited to participants who require no major assistance with activities of daily living, which influences our findings [12]. An extensive body of literature shows that older adults' perceptions and preferences regarding robot assistance depend on their health status (*e.g.,* [4, 14, 15, 18, 25, 61, 93, 104–106]). For example, participants with greater cognitive constraints are more interested in cognitive support [6, 17] and safety monitoring from robot assistance [107]. In line with prior work (*e.g.,* [16, 17, 61, 92, 105]), several of our study participants indicated that they do not currently need robot assistance since they consider themselves healthy and independent, particularly if they live with their spouse, but could see it being useful in the future when they face greater constraints on their capabilities. For example, *P10* said, *"I don't think I need any robot. But it would be nice. If I [became] non-ambulatory. . . I can ask a robot to go make me a cup of coffee or bring me something out of the refrigerator or basically do the things that a non-ambulatory person could not do."*

Similarly to participants in past studies [106], because our study participants did not have significant limits on their capabilities, several participants did not find it practical to use the robot or programming system at this point in their lives as they thought they could complete the task being programmed more quickly themselves. Furthermore, our study participants reported engaging in social activities often, which may have made programming social interactions from an assistive robot less of a design priority. In addition, none of our participants were in circumstances where they have to stay at home to take care of their spouse or family members, which can be emotionally and temporally demanding [108] and could affect older adults' perspectives on programming robot assistance. Finally, although we did ask participants to report any chronic health conditions they have, we did not directly ask participants about their cognitive health in this work. Consequently, additional studies with participants with a more diverse range of physical, sensory, and cognitive capabilities and social connections are required to see how our findings on users' perceptions and experiences regarding programming robot assistance apply to different kinds of users.

Experience and Familiarity With Robots and Technology. Participants in our study were relatively experienced with technology and had some degree of familiarity with robots, particularly from media representations of robots (Section 5.1.5). Technological knowledge and experience can affect older adults' task preferences [33], perceptions [8, 33, 109], and use [2] of in-home robot assistance. Additional studies with users with less technological experience are needed, especially since lack of technological experience is one of the primary barriers in acceptance of assistive technologies by older adults [11].

In addition, because we mentioned robots during our study recruitment, our study sample may have been skewed towards older adults who are interested in robots [8, 110]. Our study participants' positive perceptions towards robots may be indicated through their show of sympathy towards robots, such as when they commiserated with robots that break down (*P5*, *P8*), indicated that they would let the robot help them so that it could feel useful (*P5*), or said please to the robot (*P10*). Together with their interest in robots, participants' previous experience with media representations of robots may have influenced their expectations and experience during our study (Section 5.1.5). Thus, it is important to conduct additional studies with users with a more diverse background in terms of technology use and familiarity with robots, including in low-income settings where technological literacy may be lower (*e.g.,* [30, 40]). As our study participants were limited to older adults living in the United States, future work should also explore how our findings apply to different cultural contexts (*e.g.,* [111]), as well as in more rural settings where older adults may have different technological needs (*e.g.,* [68]).

In this work, we sought to conduct an in-depth qualitative study of the most common issues older users may experience during robot programming, which may be feasible using a smaller sample size [112]. In our future work, we will dive deeper into addressing specific issues observed in this study, such as lack of accessibility to aging-related changes, with larger, more representative study samples.

5.2.2. Investigating Naturalistic Human-Robot Interactions

In future work, we would like to investigate longer-term interactions where older adults have more time and flexibility in choosing how they learn to use and program robots. Furthermore, we would like to explore interactions between older adults and other forms of physical robot assistance besides the Kinova arm in the home.

Long-Term Interactions. Our study examined single interaction sessions between participants and robots, which may not have included sufficient time for participants to learn how to use the robot and programming system [11]. Furthermore, the relatively small interaction time may have resulted in user feedback about the robot being overly positive due to novelty effects [113]. Prior work has indicated that older adults' perceptions, attitudes, and interactions with in-home robot assistance can evolve over time (*e.g.,* [2, 15, 61]) and that longer-term usage of robots is required for older adults to provide informed feedback on their use [33, 114]. Further work in a longer-term, naturalistic context where participants can decide how and when to interact with a robot (*e.g.,* [16]) is needed to understand how our findings would apply in a truly "in-the-wild" context.

Instruction and Exploration. In future work, we would like to examine users' programming behaviors and the memorability of programming methods [61] after participants receive more gradual training (*e.g.,* [2]). Prior work has indicated that lack of instructional scaffolding can make programming frustrating for older adults [36]. In this work, we did not give participants extensive training or the opportunity to set up and learn about the Kinova arm and its programming interface themselves. This may have influenced their expectations and experiences in using and programming the arm. For future studies, we would like to explore a more naturalistic interaction where older adults have more time to explore the robot and interface before programming the robot. Furthermore, we plan to explore how to effectively train and onboard older adults before they engage in robot programming, with a particular focus on instructional methods that incorporate gamification and utilize older adults' existing mental models of technologies and interactions to ground their exploration of novel programming methods (Sections 5.1.1 and 5.1.4).

Direct Interactions With Kinova Arm. We explored direct, physical interactions between older adults and robots in the context of end-user robot programming in our study. Previous studies investigating older adults' preferences and perceptions of robot assistance to support aging-in-place have primarily been conducted in laboratory settings (*e.g.,* [17, 61, 92, 104, 110]) and included limited opportunities for older adults to directly interact with robots in their homes, instead providing live demonstrations (*e.g.,* [11]) or videos (*e.g.,* [4, 62, 115]) to showcase robot capabilities. However, prior work has indicated that direct experience can be an important factor in determining older adults' acceptance, attitudes, and understanding regarding robots [33, 47, 49, 51, 61, 116]. Direct interaction may also help older adults better evaluate robots' ease-of-use [11, 61], determine how they would want to improve robot behaviors [51], and articulate their perceptions of robots [49] compared to viewing videos of robots. Furthermore, hands-on interaction with technology can foster more active learning among older adults compared to interacting with passive demonstrations such as videos and manuals [68].

However, we found that our approach towards studying direct interactions with a contemporary robot had limitations. State-of-the-art robot platforms are generally incapable of performing the kinds of tasks older adults want assistance with [104]. By showing participants a robot programming system that only allows programming of motions and not tasks that would require sensing or generalization, we may have overconstrained our participants' ideas and feedback about robot assistance and limited their imagination on how programming robot assistance could benefit them [117]. Furthermore, many of the programming difficulties older adults experienced stemmed from issues due to the lack of usability of the Kinova web interface, such as difficult navigation and limited mode visibility (Figure 4). This may have negatively influenced participants' experience with kinesthetic teaching and provided them with a limited view of the possibilities of robot programming. Furthermore, system limitations, such as a bug that prevented some programs from being executed, made it difficult to distinguish programmer errors from system errors, limiting our observation of user behaviors such as debugging. In future work, we would like to conduct studies with different robots and interfaces to broaden our understanding of involving older adults as end-user robot programmers.

Additionally, while we used a mobile table to simulate mobile platforms for manipulators, which we found to be a useful approach for simulating robot motion around the home and standardizing programming interactions across participants, we found that participants still tended to focus on the stationary nature of the Kinova arm as a limitation and found it hard to imagine the robot as a mobile or intelligent entity, which may have limited their experience using the robot [118]. Furthermore, the limited force and width of the Kinova arm's gripper, as well as the task objects we brought to their homes, may have constrained the complexity and diversity of programming tasks older adults could imagine or try in our study. Therefore, our approach towards direct, physical interactions with contemporary robots may potentially overconstrain users' ideas and could be less useful for exploratory, open-ended research. However, for participatory design research examining more developed technology, such an approach may be helpful in guiding users' brainstorming. We hope our initial work using direct interactions with a contemporary robot can guide further research using existing technologies as design tools.

5.2.3. Representing Older Adults' Perspectives

Prior work has primarily used questionnaires, surveys, and group interviews to investigate older adults' expectations for robot assistance (*e.g.,* [8, 12, 119]). In our work, we conducted individual interviews about older adults' expectations for robot assistance situated in the contexts where they would prospectively adopt robot assistance. By using in-context individual interviews, we captured concrete details about how participants' settings influence their expectations of robot assistance and gained a deeper understanding of the reasoning behind different individual preferences, as well as personal emotions and perspectives that could be difficult to access in group interviews [49] or outside of the home [13].

In addition to discovering common themes in how older adults use and perceive robot assistance in our study, conducting individual interviews also helped us uncover a variety of individual differences regarding users' expectations for in-home robot assistance and end-user robot programming interfaces, a diversity which has also been observed in previous studies examining older adults' expectations for robot assistance (*e.g.,* [119]). Indicative of the variety of individual differences in older adults' preferences and strategies in programming, we found that even within couples living in the same household, individuals had differences in how they expected to program the robot. For example, in *Couple B*, *P8*, who was process-oriented, preferred to name each waypoint according to its order in the sequence, while *P9* preferred to forego naming each waypoint as they thought it slowed down the already lengthy process for saving waypoints into a program.

Through individual interviews, our work adds to the literature demonstrating that older adults are far from a homogeneous user group (*e.g.,* [35]) and that they have a variety of backgrounds, circumstances, and preferences that influence their views and expectations towards robot assistance (*e.g.,* [52]). While surveys, questionnaires, and group interviews can be a valuable means by which researchers can quickly understand older adults' general needs or preferences as potential users of robots, we hope our work highlights the potential of conducting more individual interviews to better unravel the complex web of factors that can affect older adults' individual perspectives on robot assistance. Nevertheless, we acknowledge potential shortcomings of our approach.

We attempted to represent participants' voices and perceptions as accurately as possible by confirming our interpretations of users' behaviors with them in the context of the study according to contextual inquiry principles [120]. However, we acknowledge that the presentation of this work may be influenced by our background and perceptions as HRI researchers.

Recent work has criticized representations of older adults in the HRI literature for reducing older adults to essentialist terms and assuming that older adults need robots or that robots will undoubtedly provide a positive benefit to older adults' lives [103]. To avoid similar pitfalls due to any bias in our findings stemming from our preconceptions of robots and older adults, we aim to improve our future research with older adults by checking our interpretations from this work with focus groups (*e.g.,* [61]) so we can better amplify older adults' voices as potential users (or non-users) of robot technology. We hope this work, which is among the first to explore end-user robot programming for older adults, can drive the HRI community in further understanding the feasibility and possibilities of involving older adults as key players in determining how they adopt and use robot assistance in their homes and lives.

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Appendices

Appendix A. Interview Questions

We asked participants the following questions in our semi-structured interviews.

Appendix A.1. Phase 1: Semi-Structured Interview Regarding Participants' Ideal Robot Assistance

- What do you think of when you think of robots?
- What benefits do you think having a robot that can assist you could bring to your life?
- What does your ideal robot assistant look like? Do you want it to have social features? You may draw it out if you'd like.
- Do you have any concerns about a robot assisting you?
- Can you describe a typical day in your life?
- What tasks do you experience difficulties with in your daily life? You may demonstrate the tasks if you'd like.
- If you had access to a robot that could help you with your daily tasks, what tasks would you prefer it to help you with?

- Are there any tasks that you would not want a robot to help with?
- How would you want to communicate with the robot what you want it to do?
- What kind of computing devices (such as tablets and phones) do you typically use?
- How do you use computing devices?
- How often do you spend time at home?
- Do you spend most of your day alone?
- Do you call anyone for help with technology? If so, who?
- (*For couples only*) What tasks do you usually help one another with?

Appendix A.2. Phase 2, Part 1. Semi-Structured Interview About Initial Thoughts and Preferences Regarding a Contemporary Robot.

- What do you think this robot can do?
- What would you want this robot to help you with?
- How would you want to communicate with the robot what you want it to do? (Example prompt: Would you want to use a computer/device, tell it what to do by speaking, etc.? Prompt them to be as specific as possible.)
- (*For couples only*) If you needed to take care of your partner, what tasks would you program the robot to do to help take care of them?

Appendix A.3. Phase 2, Part 3. Semi-Structured Interviews About Programming Experience and Feedback on Robot and Interface.

- How did you feel about programming the robot?
- Did you face any challenges?
- What changes would you make to this programming method, if any?

- Could you see yourself using this programming method and robot in your daily life? If not, why not?
- What changes would you make to the robot? To the programming system?
- Now that you have used the robot, do you have a sense of what tasks you would and wouldn't want the robot to help you do in your daily life?
- (*For couples only*) Could you program this robot on your own? Do you prefer to program the robot with your partner?

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