Co-Designing with Older Adults, for Older Adults: Robots to Promote Physical Activity

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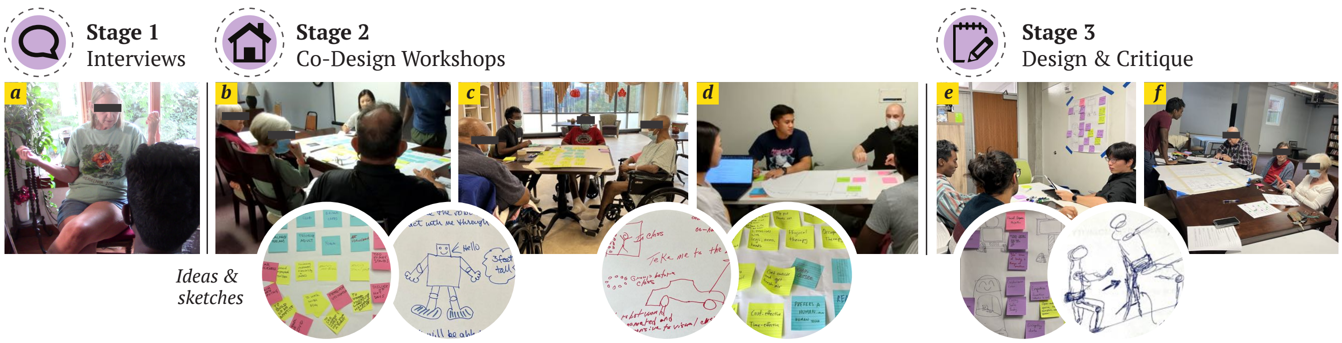

Figure 1: We co-designed robots to promote physical activity with older adults in 3-stages: stage 1—interviews with older adults (a); stage 2—co-design workshops with older adults (b,c) & physical therapists (d); stage 3—design (e) & critique (f) workshops.

ABSTRACT

Lack of physical activity has severe negative health consequences for older adults and limits their ability to live independently. Robots have been proposed to help engage older adults in physical activity (PA), albeit with limited success. There is a lack of robust understanding of older adults' needs and wants from robots designed to engage them in PA. In this paper, we report on the findings of a co-design process where older adults, physical therapy experts, and engineers designed robots to promote PA in older adults. We found a variety of motivators for and barriers against PA in older adults; we, then, conceptualized a broad spectrum of possible robotic support and found that robots can play various roles to help older adults engage in PA. This exploratory study elucidated several overarching themes and emphasized the need for personalization and adaptability. This work highlights key design features that researchers and engineers should consider when developing robots to engage older adults in PA, and underscores the importance of involving various stakeholders in the design and development of assistive robots.

CCS CONCEPTS

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

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1 INTRODUCTION

Regular physical activity (PA) has a wide range of positive impacts on the well-being of older adults from disease prevention and improved mental health to the ability for independent living [1, 2]. Yet, over 60% of Americans over the age of 50 do not engage in the recommended levels of PA (*i.e.,* 150 minutes of moderate-to-vigorous exercise per week) [3]. The global context is similarly dismal with the World Health Organization attributing 3.2 million deaths each year to physical inactivity [4]; moreover, an estimate evaluated the cost of physical inactivity on the healthcare system to be $53.8 billion annually [5]. Several socio-economic disparities (racial, gender, income, education, etc) tend to be reflected in levels of inactivity as well [6, 7]. Addressing low PA levels may bring us closer to a more equitable society on top of being healthier.

Digital technologies such as wearable motion trackers, gamified eHealth systems, socially assistive robots have been used to engage older adults in PA and have had varying degrees of impact [8–12]. Robots, specifically, are a promising avenue for encouraging PA in older adults due to their physical embodiment and ability to engage with people through situated, multi-modal interactions [13]. However, current robotic systems' efficacy with older adults is largely limited due to high variability in their personal preferences, abilities and living conditions [14]. A robust understanding of the needs and wants of older adults and the impacts of individual abilities and living situations in the PA context is critical for designing robots of the future to be effective promoters of PA for this population.

Co-design, also called participatory design, is a method that actively involves various stakeholders in the design process to improve user acceptance and usability of emergent technologies [15–17]; it has been effective in integrating older adults and relevant caregivers in designing potential support technologies [18, 19].

In this work, we employ the co-design methodology to empower older adults as drivers of the design for robots to engage them in PA (Figure 1). We, first, conducted semi-structured interviews with older adults. Then, we conducted co-design workshops with older adults, physical therapists specializing in older adults, and engineering students to collaboratively design robots for promoting physical activity. We found a wide range of roles robots can play to engage older adults in PA—a reflection of the diversity of PA older adults engage in, motivators that they experience and barriers that they face. We also found distinct features desired in such robots, nonetheless older adults' preferences had significant individual variance underscoring the need for personalization and adaptability.

2 BACKGROUND AND RELATED WORK

2.1 Robots and Older Adults

Older adults have been a key target population for assistive robotics. There have been a range of robotic applications aimed at older adults from reducing loneliness to improving sleep health; these robots could improve the well-being of older adults but the quality of evidence is limited due to the experimental design [20].

Robots have played a variety of roles to support older adults; social robots have been proposed to empower older adults to age in place [21], to augment social interactions [22], to lead group sensory therapy for older adults with dementia [23], and to help nursing home staff improve sleep quality and safety of older adults [24, 25]. However, large-scale uptake of these technologies remains limited due to lack-luster impacts or absence of clinical evidence.

There have been a handful of attempts at designing and evaluating robots for engaging older adults in physical activity (PA). A common approach involves robots monitoring the pose of the user and providing feedback on the users' performance [11, 14, 26, 27]. Robots have also been used to facilitate rehabilitation exercises and lead group exercises [28]. These systems were reported to largely be enjoyable and helpful albeit limited due to the lab-restricted and short-term nature of the experiments. Moreover, these systems were designed with general human-robot interaction and social robot design principles in mind, rather than being designed explicitly around the preferences and requirements of older adults.

2.2 Co-Design and Older Adults

Co-design is a powerful tool for understanding the needs of special groups such as older adults [17, 29]. For instance, co-design has been used to successfully re-frame how aging should be perceived for design of assistive robots [19]; the co-design process helped elucidate key interpretations of aging and consolidate views of various stakeholders toward robust design guidelines for robots for successful aging [19]. Co-design has also been used to produce tangible solutions in form of a robotic dog to enhance independence, social agency and well-being in older adults [30].

The co-design methodology has also been effective in designing robotic aids for more vulnerable sub-groups of older adults such as people with dementia, depression, and/or Parkinson's disease [18, 31]. By allowing for assimilation of people with dementia and their caregivers (both formal and informal), co-design led to a novel understanding of the lived experiences of these stakeholders and nuanced dementia-stage-centered proposals for robots to assist in care-giving for people with dementia [18]. Moreover, co-design has been a compelling design method for other groups such as children and teens [32–34] in unique domains such as fostering creativity.

The use of co-design has not been simply limited to the conception of robotic systems. The co-design process has yielded innovative proposals for digital tools to aid fall rehabilitation for older adults; the power of involving older adults in the conceptual stages of tools designed for their well-being was especially clear during the design of these rehabilitation tools [35]. Co-design is a powerful tool to leverage people's lived experiences to inform the design of assistive technologies for effective long-term engagement.

3 CO-DESIGNING WITH OLDER ADULTS

Our co-design approach involves three stages (Figure 1) to:

- Understand the barriers and motivators for older adults to engage in physical activity; and
- Collaboratively design, with various stakeholders, assistive robots to engage older adults in physical activity.

Participants. We recruited 14 participants (age range 65–94) with a variety of physical abilities and living conditions to participate in the co-design process. All participants were compensated at the rate of $20–25 USD per hour as approved by our institutional review board (IRB). We also employed pseudonyms to attribute quotes to participants rather than depersonalizing IDs (such as p1, p2, etc) [19]. See Table 1 for detailed demographic information.

Process. We began with conducting semi-structured interviews with older adults (n=9), then conducted co-design workshops with physical therapists (n=2x1 session) and older adults (n=3x3 sessions). We concluded the study with a design workshop (n=3x1 session) aimed at cultivating the ideas conceived in the previous

Table 1: Overview of Older Adult Participant Demographics

Psuedo.	Gender (Age)	Ethnicity	Living Condition
Joe	Male (75)	Caucasian	Condo (Solo)
Lois	Female (74)	Caucasian	Condo (Solo)
Gloria	Female (80)	Caucasian	Condo (Solo)
Alfred Patricia	Male (67) Female (94)	Caucasian Caucasian	Condo (Couple)
Albert Betty	Male (71) Female (71)	Caucasian Asian	Condo (Couple)
Dolores	Female (74)	African-American	House (Solo)
Clement	Male (79)	Caucasian	House (Solo)
Eileen	Female (77)	Caucasian	House (Solo)
Sidney	Female (69)	Caucasian	House (w. Family)
Eugene	Male (65)	African-American	Rehab. Center
Roger	Male (75)	African-American	Rehab. Center
Abraham	Male (70)	African-American	Rehab. Center

steps, and a workshop with older adults (n=3x1 session) aimed at critical analysis of the outputs of the design workshop.

3.1 Stage 1: Semi-Structured Interviews

The first stage was centered around semi-structured interviews conducted to gain an initial understanding of the PA context of older adults from a range of living conditions (n=9), to probe them to think more about potential robots for promoting active living, and to build rapport. These interviews were recorded and analyzed prior to planning the co-design workshops. Each interview lasted around 40 minutes. The specific questions used in the semi-structured interviews and analysis details are reported in the Appendix [1].

3.2 Stage 2: Co-Design Workshops

3.2.1 Physical Therapist Workshop. We recruited two experts in older adult physical therapy and personal training, and conducted a 1.5-hour co-design workshop with them. We aimed to leverage their experience in the overall older adult physical therapy and training domain to inform interaction guidelines for potential PA-supporting robots; moreover, we wanted to understand the overlaps between their perspective and that of older adults.

We used collaborative map-making to drive conversations to determine the types of PA older adults should be engaging in and the related barriers and motivators. Furthermore, we used sketching and open-ended discussions to facilitate a dialogue regarding how robotic systems could promote PA in older adults.

3.2.2 Older Adult Workshops. We conducted three older adult workshops each lasting around 1.25 hours. We used personas (see Appendix) during the older adult workshops #1 and #2 to help participants disconnect from their current living conditions while retaining their lived experiences to explore design opportunities [35]. We created personas using the understanding gained from the semi-structured interviews (Stage 1) and the physical therapists' workshop. We created two sets with three personas each from three age ranges (60s, 70s, 80s), with specific physical and social conditions as discovered at Stage 1. The two sets have the same age ranges but different physical and social conditions to help compare the overarching themes with issues of individual situations; each persona was described using text and an image. Older adult workshop #3 was conducted at a rehabilitation center with three older adults with amputations. We were fortunate to capture their unique insights to construct more inclusive robot design directives. We did not have interview data to create appropriate personas for this sub-group of older adults, thus, did not use personas here.

Across all older adult workshops, we employed collaborative map-making as the key dialogue driver around what physical activities the personas should and could do and what their barriers and motivators may be. We, then, facilitated open-ended dialogue to brainstorm possible ways in which robots may alleviate the barriers and augment the motivators to promote PA in older adults. Lastly, in workshop #1, we asked participants to sketch their vision for their proposed robots, whereas we substituted sketching with a further discussion due to workshops #2 & #3 participants' preferences.

[1]https://intuitivecomputing.github.io/publications/2023-hri-antony-supp.pdf

3.3 Stage 3: Design and Critique

3.3.1 Design Workshop. We realized that older adults had exciting ideas for robotic systems to promote PA; however, their ability to communicate their creative vision was restricted due to a general lack of comfort with sketching. In order to further realize their imagination, we conducted a design workshop with three graduate students from CS, Robotics and HRI backgrounds. We consolidated design guidelines (see Appendix) and robot proposals from the previous stages to allow the students to visualize and develop the older adults' ideas into more concrete robotic plans.

3.3.2 Critique Workshop. We conducted a final workshop with older adults (n=3) to receive critical feedback on the designs formalized in the design workshop (see Figure 5). We presented each design one at a time and utilized collaborative map-making to gain a robust understanding of older adults' perception of the artifacts. Participants were asked to mark features they liked and disliked with different markers and this led to further discussions.

3.4 Methodology Choices

Our primary co-design methodology centered around group workshops, which are known to increase persistence and enjoyment for the members, and yield positive outcomes [36]. To maximize the benefits of group interaction, we elected to keep the workshops fairly limited in size (n=3) to make sure we can delve deeper into each participant's perspective. We also employed the collaborative map making [37] technique to further ensure all ideas were recorded and addressed. We noticed that this method helped facilitate group conversations as they could also see each others notes on the map. *Alfred (M/67)* remarked "*I was surprised at how much information you got out of Patricia (F/94)*" after workshop #2.

Throughout this process, we ensured that we did not value the opinions of other stakeholders more than that of older adults.

3.5 Data Analysis

We transcribed all the conversations and conducted thematic analysis to identify overarching themes and ideas. Digitizing the maps created during the workshops helped identify these underlying

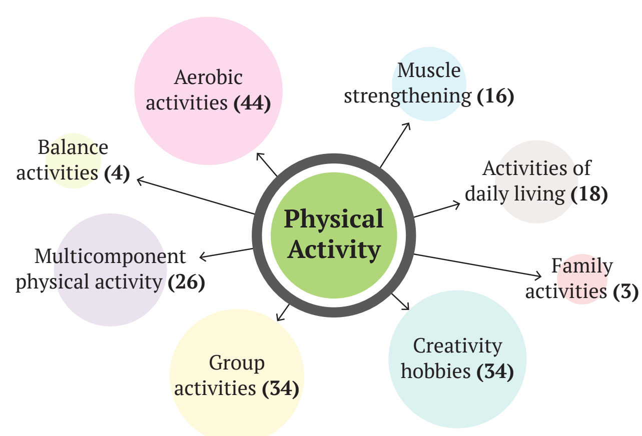

Figure 2: Physical Activities for Older Adults

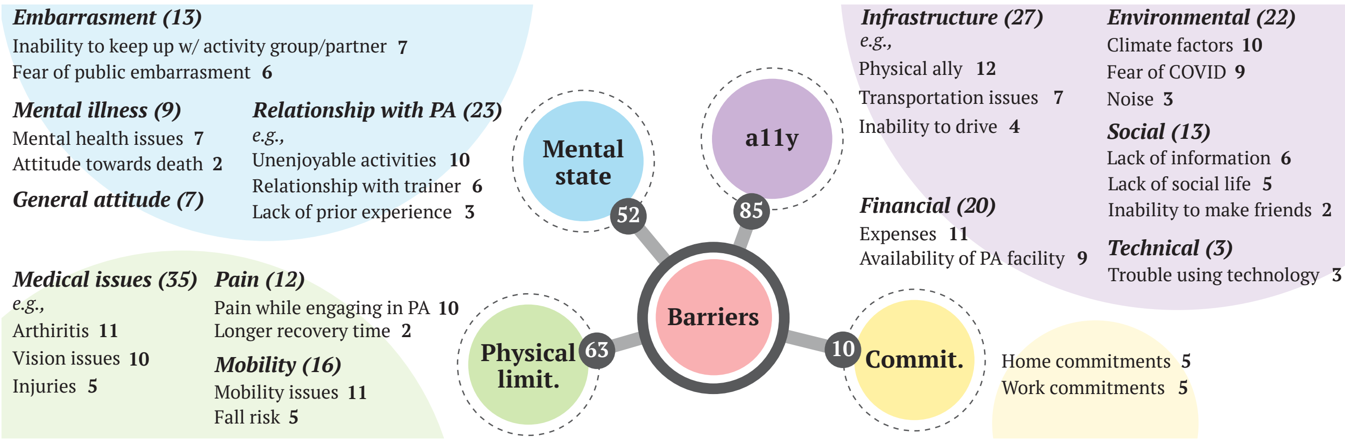

Figure 3: Barriers to Physical Activities (numbers in the figure are occurrences of thematic codes).

trends as well. We organized these themes in the context of PA, motivators, barriers and robot preferences. We also employed mind-maps to help visualize the codes and identify higher level motifs to drive our thematic analysis process [38]. Two researchers coded all the transcripts from the interviews and the workshops to generate data on the frequency of each code. The inter-rater reliability using Cohen's Kappa on 20% overlap data was 0.81 which signals strong agreement [39]. It should be noted that different hierarchical systems can be used to represent the data; the coding scheme in this study was developed through mutual agreement of the researchers.

4 RESULTS

Our co-design process yielded many insightful and unexpected findings; our thematic data analysis helped organize these findings into a coherent narrative. We found significant variety in the types of PA older adults find enjoyable (Figure 2).

Our dialogues also illuminated various motivators and barriers that older adults faced with regards to PA. We found that barriers (Figure 3) included accessibility issues (*i.e.,* infrastructure, environmental, financial, technical, social), physical limitations, mental state, and commitments, and were consistent with previous findings [40–44]. Motivators (Figure 4) were also consistent with literature and included social benefits, mental benefits, physical benefits, progression, active lifestyle, and community factors [41, 44, 45].

The discussion on barriers and motivators helped facilitate the exploration of a variety of roles robots can play to amplify PA in older adults. Below, we present the robots that were proposed along with synthesized rationales for their functions.

4.1 Robots as Trainers

Robots functioning as trainers was an apparent yet practical solution to promote PA. These robots were intended to improve accessibility to learning how to exercise and trying different exercises. These robots were envisioned to facilitate targeted workouts such as yoga and strength training for individuals and as leaders of group classes such as water aerobics and group dance. These robots could address the limited availability of highly trained and expensive trainers and group class leaders, thus alleviating some financial and infrastructure accessibility barriers that older adults face.

4.1.1 Intended Role: Personal Trainer. Robots were suggested to lower barriers to initiating exercises due to lack of prior experience and fear of embarrassment by facilitating individual workout sessions. These trainer robots can also lead to improved relief from certain medical conditions (*e.g.,* arthritis, balance issues), pain when moving, injuries and limited mobility; robots can help build strength and confidence thus allowing older adults to pursue enjoyable PAs. Robots specifically for conducting physical therapy sessions can further enhance recovery from injuries and chronic pain, further empowering older adults to pursue PAs of interest.

By ensuring variety in sessions through facilitating a wide range of exercises and utilizing various interaction modalities, robots may help avoid repetitiveness that leads to boredom and loss of interest.

> **Joe** (M/75): *"Repetitive work in physical therapy was boring to me. The water aerobics classes? Well, it's a different instructor with a different technique every class."*

4.1.2 Intended Role: Group Activity Leader. Social contact is a significant motivator for PA as it presents opportunities for growing one's social network and combating loneliness. Furthermore, group activity was widely cited to make the PA more enjoyable and peer-presence was said to be highly motivational.

> **Joe** (M/75): *"The social activity that comes with doing group exercises is very, very valuable... when it's hard to differentiate between social activity and exercise activity. That's good."*

As a group activity leader, the robot's modalities of interaction and responsibilities will evolve with a focus on ensuring the engagement and pace of everyone while facilitating social interactions.

4.1.3 Intended Roles: Motivational Coach. Robots can subtly remind users of their inherent motivators for PA—for instance, being able to interact with grandchildren was a key motivator for several older adults. By indirectly leveraging such powerful motivators, robots may help further reinforce habitual PA.

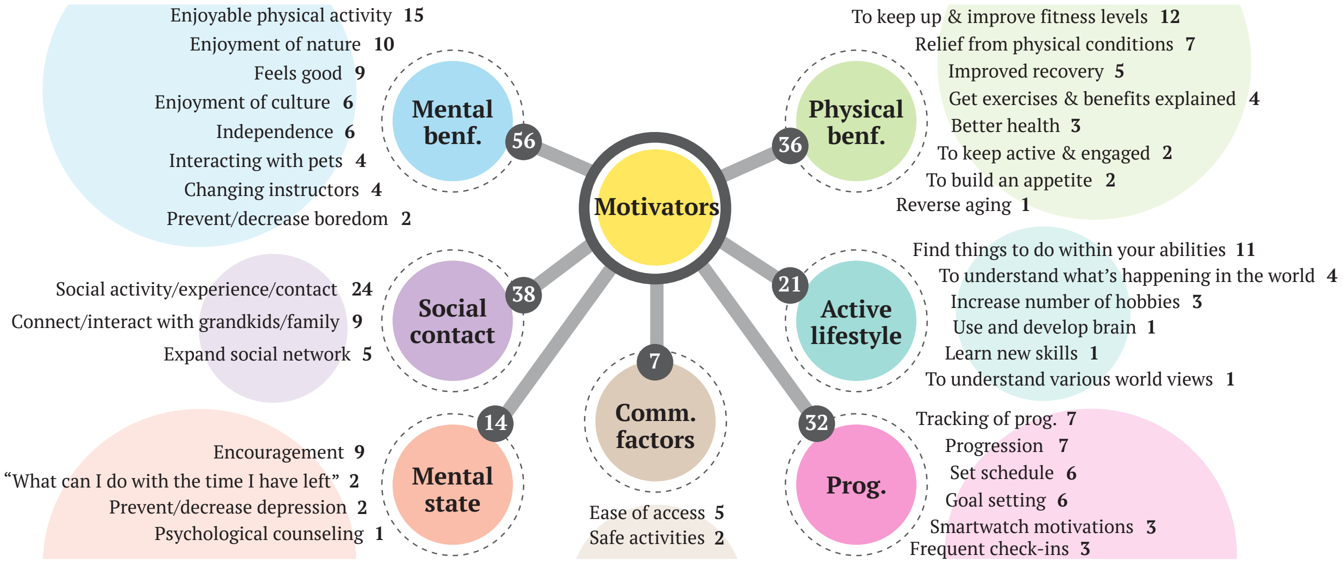

Figure 4: Motivators for Physical Activities (numbers in the figure are occurrences of thematic codes).

> **Eileen** (F/77): *"I really want to walk and be able to walk, because I'd like to take my grandchildren to Europe when they've turned 16... And the youngest is five, so that's a motivator for me to stay fit."*

4.1.4 Intended Features: Progression and Adaptation. The ability to track and display the users' progress was a popular feature tapping into the motivating power of seeing personal progression. Coupling progression tracking with objective benchmarks of performance and goal setting was expected to further enhance older adults' consistency in engaging with PA promoting robots [46, 47]. Robots were expected to modify sessions based on user's progression and affective state to optimize physical and mental benefits.

4.1.5 Intended Features: Encouragement. By fostering a positive outlook towards exercising, robots can help ensure long-term engagement, address lack of experience, and offset negative mental states [44]; this can be achieved by providing encouragement [12, 48] through affective communication, such as compliments and supportive feedback, thus increasing user comfort and confidence.

> **Arlo** (PT Expert): *"Just letting the older adults know that they're capable of doing something is the biggest thing... For them to feel like they're self sufficient, makes their world, the moment they start giving up on that, they will stop doing the exercises"*

4.1.6 Intended Features: Informative Feedback. Along with affective feedback, robotic trainers should provide informative feedback to ensure safe exercising; this can be achieved by correcting the user's form, showing objective biophysical benchmarks, explaining the benefits of particular exercises etc. Correct form not only prevents injuries, another barrier to PA, but also leads to better improved physical outcomes, a motivator for consistent PA.

4.1.7 Potential Design. Design 1 was devised as the trainer robot and its main features can be seen in Figure 5. The large touchscreen can display demonstrations of exercises and the adjustable height allows ergonomic posture for the user. This robot also has multiple sensing capabilities including motion tracking that can scan the user in 360° as well as adaptive voice recognition. All three evaluators found the large touch screen to be useful, but suggested including remote control (mouse/keyboard) as well because not all older adults may be comfortable with using a touch screen and having remote control will allow the user to interact with it from a distance. They perceived the exercise demonstration and the camera monitoring to be valuable features for the robot. The participant found demonstrations to be very desirable, and suggested two additions to this feature: dividing the screen so that a demonstration is shown on one side and mirrored self on the other, and keep track of the evaluation and progression over time and share with the user.

4.2 Robots as Companions

A recurring idea for robots to promote PA in older adults was companionship, which can be realized in many forms to directly and indirectly encourage them to pursue enjoyable physical activities.

4.2.1 Intended Roles: Friend/Partner. Robots can accompany older adults during PA (*e.g.,* walking, creative hobbies) to counter loneliness and augment the PA as a social activity that may not be otherwise possible due to an inability to keep up with a partner or group in a meaningful way.

> **Betty** (F/71): *"I think for older people, as their friends pass away, and their partner passes away, it gets harder to meet other people and they're lonely. But that's the thing. Sorry, and because they have physical limitations, they can't just go out and make friends."*

4.2.2 Intended Roles: Informant/Personal Assistant. Robots can provide information and reminders on PA facilities and opportunities, thus, promoting a diverse range of PA in older adults while combating loss of interest and keeping PA enjoyable and exciting. Furthermore, having a set schedule and frequent check-ins with respect to PA was suggested to help construct an active lifestyle.

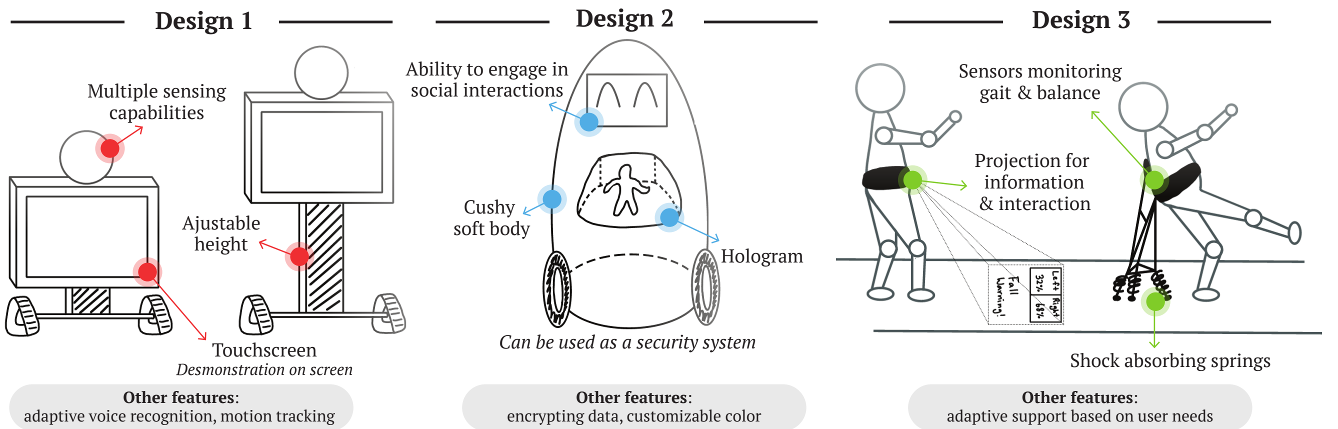

Figure 5: Designs of Robots to Promote Physical Activities

4.2.3 Intended Roles: Housekeeper. Engaging in daily living activities, such as cooking and cleaning can be a way for older adults to engage in PA. Some older adults experience a lack of motivation to partake in these activities, but if a robot could make these chores more interactive and enjoyable for the users, it would engage them in PA while ensuring an active lifestyle. On the other hand, some older adults believe these daily commitments rather restrict themselves from pursuing the kind of PA that they would like to engage in. Thus, a consistently arising suggestion was home-care robots that take care of tough and troublesome chores such as cleaning and dusting so that they have more time to engage in enjoyable and social PA such as playing with their grand-children.

4.2.4 Intended Features: Emotional Support. Participants suggested that emotional support from robotic companions can help maintain a healthy mental state, a vital motivator for PA. For instance, a soft robot could offer hugs or a "robot dog" could substitute real pets that are difficult for older adults to maintain.

Participants also mentioned that companion robots can help manage debilitating mental states that exist in form of mental illnesses (*e.g.,* depression, addiction), negative self-image, and in overall attitude towards life and death by facilitating behavioural therapies.

4.2.5 Intended Features: Social Support. An intriguing use case for companion robots to promote PA was by helping older adults practice social skills and overcome the inability to make friends and hence leveraging the powerful social contact motivator for PA.

These robots may also help older adults expand their social network by informing them about the local social calendar and helping them practice different social skills; this will help overcome the hurdle of a lack of social life and an inability to make new friends that feeds into reduced PA.

> Conversation snippet: **Albert** (M/71): *"Robots will help people meet other people."* **Joe** (M/75): *"Maybe in a less intrusively, tell you what the area's social calendar is"*

4.2.6 Potential Design. The engineers created Design 2 as a companion robot with features shown in Figure 5. The engineers envisioned this robot to engage in social interactions with the user and can also be used as a security system, in which the data is encrypted. Its exterior is a customizable color and cushy, soft texture. The hologram can be used for user interaction or entertainment. The robot has a charging home, in which the robot can recharge and provide a physical privacy barrier for the user.

Evaluators were favorable towards the design of Design 2 as well. *Joe (M/75)* expressed a strong interest in the hologram and charging home features: "*I like this (hologram). I like that idea (charging home) very much because then the robot is self-sustainable.*" Evaluators suggested touch screens and voice activation for this design as a means of interaction. The physical privacy solutions were appreciated and led to further dialogue regarding privacy.

4.3 Robots as Augmenters of Physical Abilities

Physical limitations such as fall risk and arthritis were widely specified barriers for older adults which lead to a transition from a more active lifestyle to a more sedentary one. Deteriorating vision, hearing and balance were also found to widely impair older adults' mobility and hence limiting their access to PA opportunities.

> **Clement** (M, 79): *"Fall risk is more of a factor in my mind, I just try to be honest with myself about the reality of those things... I've definitely made the involuntary transition from more active to less active"*

4.3.1 Intended Roles: Physical Support Robot. Robots can augment older adults' physical abilities enabling them to engage again in enjoyable PA (*e.g.,* biking, skiing and hiking) in a safe and meaningful manner thus counteracting the reduction in PA that occurs as people's physical abilities change due to old age. These robots would only provide support as needed and allow the user to exert themselves as much as they safely can.

4.3.2 Intended Feature: Wear-ability. On-body robots were suggested to help stabilize users and augment their mobility in the form of a car's lane assist system. Aesthetics also play a vital role here; these robots should not amplify the barrier of embarrassment certain older adults feel while using walkers and other aides.

4.3.3 Intended Feature: Informative Guidance. Apart from the required physical support, wearable robots for improving mobility could also provide gait and navigation information allowing users to reach their destination safely while maintaining self-reliance and independence—a valued factor for older adults.

4.3.4 Potential Design. The engineers conceptualized a robotic aid in the form of a belt to provide support by projecting gait information on the ground and catching the user in case of an unavoidable fall. The main features of Design 3 can be seen in Figure 5. While this design was futuristic in nature, it served as a good testbed to understand evaluators' perceptions of this idea.

Evaluators were not convinced by the envisioned robotic aid and emphasized the need of simplicity, practicality, and ease of use for realistic uptake of such mobility augmenters. They found it very hard to imagine using such a device and indicated a preference for a more familiar design of a walker.

Evaluators were also not optimistic about the projection based information system and instead preferred non-projection based communication through voice and perhaps even haptic feedback.

5 DISCUSSION

This study has reinforced findings of previous studies in understanding older adults' preferences for robots and PA [40–45, 49, 50] while adding new perspectives from a more user-centered and hands-on design process.

5.1 General Robot Design Guidelines

A wide range of robotic assistance can help promote PA in older adults, each with its own set of required functions. However, there are also general features desired in PA robotic aids by older adults. Regardless of robots' intended roles in promoting PA, the following general design guidelines should be considered.

5.1.1 Interactivity. There was a wide spectrum of interactivity that participants desired in their conceived robots. Concurring with past work [12], we found that engaging dialogue with motivational feedback is a vital feature for many older adults and use cases. Although, the required level of interactivity depends on the scenario; for instance, if most of the interaction happens between participants of a session, the robot would only need to facilitate interactions rather than being overtly social.

> **Joe** (M/75): *"It would not matter whether it was a robot instructor or human instructor... The instructor should be social in terms of being friendly. But the interaction, the social interaction is really, between the students"*

5.1.2 Verbal and Non-Verbal Communication. Our participants believed that effective and task-appropriate communication is a crucial feature of any interactive robot further emphasizing the needs for clear speech, visible text, proper gaze and discernible movements as suggested by previous findings [48, 51, 52]. A universal translator feature was proposed where the robot would speak the user's language, understand the user's speech patterns as they evolve with age, and facilitate communication with other people.

With gradual loss of hearing through aging, older adults utilize various nonverbal cues for communication, and believed it would be beneficial for robots to also be able to convey such cues, such as eye and body movements. Interestingly, an expressive face was also suggested, not necessarily for the obvious simulation of sociability, but for the more functional reason of allowing users to lip-read.

> **Alfred** (M/67): *"A lot of people as they get older, rely on being able to see a mouth. I see the mouth, and what the mouth shape say of the sound becomes very important."*

5.1.3 Adaptive to Users Preferences and Abilities. Robots for promoting PA need to learn users' preferences to modify their interactions and adapt their interventions to users' abilities. This is critical to ensure that the contents of robotic interventions are effective—as individuals grow, their abilities evolve and their living conditions change, the robots need to account for these changes. Furthermore, robots need to detect the user's mood and adjust their interactions accordingly to optimize interactions. These insights expand on the need for customizability found previously [53, 54].

> **Ian** (PT Expert): *"[An older adult client] could be in a really good mood today and not the next day. So I take that into account [during each session]."*

5.1.4 Easy to Use. To maximize uptake of any robotic aid to boost PA in a population that is not co-dependent on technology, the value of usability cannot be understated. Older adults were found to have a complicated relationship with digital technology where usage depended highly on familiarity with the interface and perceptions of its benefits [54–56]. Long-term uptake would be dependent on a shallow learning curve and effortless usage.

> **Clement** (M/75): *"I find that getting myself to learn some new technologies is an increasingly higher hurdle."*

5.1.5 Mindful Towards Privacy. A wide range of privacy concerns was expressed and said to impact people's comfort with having robots in their homes or in sensitive physical care situations. Almost all older adults expressed concern for the misuse of their data, however, were open to relevant data being transmitted to appropriate stakeholders such as physicians and informal caregivers

> **Lois** (F/74): *"[It'd be okay if the robot] links to a physical therapist or... even family members. When people get older, it's not so much a matter of privacy."*

5.1.6 Appearance. Participants exhibited a diverse range of preferences for robot morphology. Those looking for more social support (*e.g.,* companionship) preferred a humanoid or zoo-morphic look, whereas, those in search of more functional support preferred an utilitarian look (*i.e.,* a form that prioritizes functionality). There was a clear desire for a compact robot and participants also voiced their preference for the robot to look "good" as defined by their standards described as "cute", "fitting the decor" and "not toy-like"; this complemented past studies reporting on need for small-form factors [53, 54], however, we could not establish to what degree appearance mattered. Virtual robots and characters were also proposed either rendered in a physical display or in AR/VR environments.

5.1.7 Respectful Interactions. Older adults expressed a desire to be the ones in control in terms of interacting with robots. Robotic interactions need to be respectful of older adults' expectations for self-reliance and independence. Furthermore, condescending or discouraging behaviours can damage relationships with them.

> **Arlo** (PT Expert): *"If you discourage [an older adult client], or if they felt like you were like condescending to them, they will just stop showing up."*

Robots need to build a respectful repertoire with users to optimize their impact; they need to be aware of the users' sentiments, both explicit and implicit, and adapt their behaviors and suggestions appropriately. For instance, robots will need to strike a careful balance between motivating users to reach their set goals and being aware of their mental and physical limits.

5.2 Older Adults: A Diverse Population

The diversity of the older adults lived experiences are reflected in their preferences and needs. Although we found general trends for older adults' desires for PA robots' roles and behaviors, these robots must be personalized to individual preferences in terms of the robots' role, morphology, and behavior.

What role a robot should play to encourage PA is dependent on how variables such as living conditions, physical abilities, motivators, and barriers, manifest collectively. This reality is reflected in how widely robots were construed—from trainer robots to autonomous vehicles to mobility augmenting on-body systems. Some individuals may only need companionship and reminders, while others may need personal training and mobility assistance to achieve an active lifestyle. As participants mentioned in workshops #1 and #2, *"age is more than a number"*, and *"it takes courage to grow old"*; respecting the diversity of older adults' living experiences while designing robots is critical to ensure uptake of robots.

Apart from the roles of robots, the preferences for robots' morphology and behavioral paradigms also varied across participants despite overarching themes. For instance, while most participants preferred voice-based interactions, a few participants were wary of the social factors of robots, albeit these individuals had relatively more opportunities for social interactions by living near family. Moreover, there are varying levels of tech-friendliness between generations that need to be accounted for.

All in all, how and what kinds of robots are used for promoting PA in older adults need to account for individual variations in the context of the overarching themes discovered here.

5.3 Access Equals Impact

A major use case for PA promoting robots is improving access to PA opportunities. These robots need to be financially accessible to be effective as a large portion of older adults are on fixed incomes [57]. Technical accessibility in the form of usability is also critical.

The socio-economic disparities in the older adult PA context [58] is very concerning and serve as a reminder that if robots are only available to the most privileged class of individuals, their impact would not be large enough to counter this societal challenge. By designing robots for all, we can achieve larger impact.

Robots cannot independently provide all PA support that older adults need. There needs to be societal actions to lower barriers (*e.g.,* improved access to PA facilities) to see change at a societal scale. The impact of existing social programs aimed at engaging older adults in PA may be augmented through the use of robotics; robots are a compelling tool but not a comprehensive solution.

5.4 Ethics and Liabilities

5.4.1 What is a Robot Liable For? Individuals working as personal trainers and physical therapists have to adhere to strict protocols that limit them to only providing advice on the narrow domain of the specific PA they are certified to facilitate. Furthermore, if a client is hurt during a session, they are liable for damages. The issue of liability needs to be addressed for the use of robots to promote PA in older adults; there are a wide range of scenarios that could lead to physical and emotional harm to users given the variety of roles robots have been envisioned to play in this domain. There is a critical need for an exhaustive exploration of what robots for PA may be liable for and how to ensure user safety, which will have downstream policy implications for developing PA assisting robots.

5.4.2 Balancing Privacy and Safety. Ensuring user safety may thwart user's privacy in many situations; for instance, a companion robot may detect signs of progressing dementia while the user refuses to seek medical attention despite suggestions. How can a PA robot with a wide array of biophysical sensors balance respecting users' privacy—a fiercely desired feature for most older adults—and ensuring users' well-being by informing appropriate authorities?

The subjects of privacy, liability and safety are quite complex and would require dedicated research to resolve [59]. Tackling these complex topics is out of the scope of this current study; however, to establish robots as an effective tool to engage older adults in PA, there is a critical need for a code of robotic conduct.

5.5 Limitations

5.5.1 Participant Recruitment. Despite our effort to recruit participants from a diverse background, the distribution in diversity (*e.g.,* race, ethnicity, disabilities, living conditions) is not representative. There might be a potential selection bias in the study sample since the participants may be more enthusiastic about robots and technology than the general older adults population. Furthermore, we were not able to recruit informal caregivers in this study, but their involvement would augment the valuable insights we acquired from the various stakeholder groups (PT, Older Adults, Engineers).

5.5.2 Exploration and Low-Fidelity Designs. As an exploratory study, we aimed to understand the overarching themes in the needs and wants of older adults in robotic assistance for PA. The findings from this study show that robots can be developed with varying purposes, roles, and functions, and take form in diverse designs. We explored potential robot designs with low-fidelity designs to allow for more open-ended discussion. The designs were well received by the evaluators in theory; however, it was established that a 2D sketch made it hard to visualize the robot and how it would realistically feel. For future studies, high-fidelity robot designs can be built using 3D printing and iteratively evaluated to investigate more fine-grained interactions and preferences.

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