Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Older Adults' Acceptance of Robot-Led Rehabilitative Exercise

Lily Kennedy

lily.kennedy@alumni.emory.edu

Emory University School of Medicine

Benjamin Pak

Emory University School of Medicine

Matthew Lamsey

Georgia Institute of Technology

Meredith D. Wells

Emory University School of Medicine

Charles C. Kemp

Hello Robot Inc.

Madeleine E. Hackney

Emory University School of Medicine

Research Article

Keywords: Human-robot interaction, Gerontechnology, Technology acceptance, Robot-led exercise

Posted Date: September 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10630332/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: Competing interest reported. Charles C. Kemp worked for Hello Robot Inc. at the time of the study. However, the other authors certify that the research was not influenced by financial or personal motivations that would be considered a conflict of interest.

Older Adults' Acceptance of Robot-Led Rehabilitative Exercise

Lily Kennedy[1*†], Benjamin Pak[1†], Matthew Lamsey[2], Meredith D. Wells[1,3], Charles C. Kemp[4], Madeleine E. Hackney[1,5,6,7]

[1*]Department of Geriatrics and Gerontology, Emory University School of Medicine, 57 Executive Park South NE, #219, Atlanta, GA, 30324.
[2]Institute for Robotics and Intelligent Machines, Georgia Institute of Technology, 801 Atlantic Drive, Atlanta, GA, 30332.
[3]Exponent Inc., Biomechanics Practice, 39100 Country Club Dr, Farmington Hills, MI, 48331.
[4]Hello Robot Inc., 825 Ferry Street, Suite A, Martinez, CA, 94553.
[5]Department of Rehabilitation Medicine, Emory University School of Medicine, 1441 Clifton Rd NE, Atlanta, GA, 30307.
[6]Center for Visual & Neurocognitive Rehabilitation, Atlanta VA, 1670 Clairmont Road, Decatur, GA, 30033.
[7]Geriatric Research Education and Clinical Center, Birmingham/Atlanta VA, 3101 Clairmont Road, Brookhaven, GA, 30319.

*Corresponding author(s). E-mail(s): lily.kennedy@alumni.emory.edu;
Contributing authors: benjamin.pak@emory.edu; lamsey@gatech.edu; mwells@exponent.com; ck@hello-robot.com; mehackn@emory.edu;
†These authors contributed equally to this work.

Abstract

An aging global population has increased the demand placed upon physical therapists and caregivers. Regular exercise has been established as a key component of healthy aging, but adherence is negatively affected by factors such as a lack of intrinsic motivation and limited access to quality coaching. Assistive robots may address this rising demand, but there are mixed results regarding the acceptance of robotic assistants, and few exercise and physical therapy robots are widely available. Prior work evaluating one such system demonstrated that older adults with Parkinson's disease accepted the system and found it useful for personalized

exercise coaching. Building upon this work, feedback from 21 neurotypical older adults, after having exercised with this system, was utilized to explore the social acceptance of robot-led exercise and identify facilitators and barriers to adoption. This study's findings inform improvements to the system's design, which represents a step towards the deployment of this technology beyond limited trials in research clinics.

Keywords: Human-robot interaction, Gerontechnology, Technology acceptance, Robot-led exercise

1 Introduction

From 2022 to 2050, the number of people aged 65+ in the United States is projected to rise by 42% [1]. With this aging population comes increasing health challenges such as degenerative diseases, neurological disorders, cardiovascular diseases, and other physical challenges [2]. One frequently cited issue that older adults face is a diminished range of motion (ROM) at key joints, such as the shoulder and hip [3]. Maintaining or improving the ROM in key joints for optimal mobility has been correlated with a decrease in the likelihood that elderly people will experience falls. Regular and consistent exercise has also been cited as a treatment and prevention tactic to reduce the severity of age-related health challenges [4]. Additionally, older individuals are more susceptible to cognitive impairment, which can make dual tasking more challenging and further impact mobility. Aerobic exercise and resistance training have been associated with improvements in cognitive function, particularly for those with cognitive impairment [5]. In general, regular exercise prolongs the functional independence of older adults, increasing the potential quality of life [6].

While regular exercise provides numerous health benefits for people of all ages, maintaining a regular exercise routine is often challenging for older adults. Physical activity guidelines recommend 150 min/week of moderate-to-vigorous activity [7]. The National Health Interview Survey suggests that the proportion of Americans meeting these guidelines has increased from 25.7% in 1998 to 35.8% in 2013. However, adherence to aerobic and strength training programs remains insufficient on average to meet the Physical Activity Guidelines and mitigate age-related declines [7]. Other barriers to regular exercise among older adults include feeling intimidated by going to an organized exercise facility or slowing other individuals down in a group exercise setting [8]. Older adults who report fewer instances of exercise also report a lack of motivation due to perceptions of physical activity being neither effective nor fun [8]. Despite the physical activity guidelines clearly outlining the recommended minimum volume of exercise per week and the known health benefits of exercise, older adults often fall short in reaching this goal.

To increase the number of people who meet these physical activity guidelines, technology has been used to make exercise more accessible through home exercise devices, such as treadmills and spin bikes. Technology also has the potential to make exercise more fun and interesting, as seen with the Wii, online fitness classes, and

augmented reality workouts. There has also been an emergence of interactive exercise robots. For example, the Dynamically Adapting Robot for Cooperative Interactions (DARCI), a mobile robot with two end effectors, engages its users in partner-based dance [9]. Additionally, the Rethink Robotics Baxter Research Robot, a humanoid robot with a human-sized upper body, plays various exercise games with its users [10]. These interactive robots are currently more expensive and less readily available than other, simpler technologies, such as treadmills or bikes. Despite current limitations in the availability of these robots, they provide an exciting direction for technological development due to their capacity for user engagement and enjoyment.

Qualitative analysis is crucial for understanding and enhancing the human–robot interaction because for a robot to be helpful in some capacity, users must be willing to work with robotic devices. Perceived ease of use and perceived usefulness are hypothesized to be fundamental predictors of technology acceptance [11]. These predictors were expanded with the Technology Acceptance Model (TAM), which was developed to identify a causal link between perceived usefulness (PU), perceived ease of use (PEOU) of a technology, attitude toward the technology (ATT), intention to use (ITU), to the actual adoption of the device by participants [9, 11]. The TAM was traditionally applied to information technology (IT) but can be extended to other technologies, such as assistive robotic devices. Surveys are often used to query TAM concepts. For example, the Robot Opinion Questionnaire (ROQ) adapts constructs from the TAM, such as PU, PEOU, ATT, ITU, as well as perceived enjoyment (PENJ), to help predict user acceptance of robotic assistants [9].

In addition to predicting user acceptance of an exercise system, it is important to determine the psychosocial impact that an assistive device may have on the user. The Psychosocial Impact of Assistive Devices Scales (PIADS) is a 26-item questionnaire that aims to identify the effects of assistive devices on its user's functional independence, well-being, and quality of life [12]. This questionnaire is divided into three categories. The first category is competence, which measures the perceived impact of the assistive device on performance and efficacy. The second category is adaptability, which reflects an openness to trying new things. The third category is self-esteem, which reflects the impact of assistive technology on the confidence and emotional well-being of the user [12].

Perceived workload while engaging with an assistive robot is another important factor to assess qualitatively. Perceived workload potentially informs participants' self-efficacy and adherence to exercise routines [8]. The NASA Task Load Index (NASA-TLX) was developed as a reliable estimate of workload based on a multi-dimensional rating system that measures mental demand, physical demand, temporal pressure (perceived time pressure to complete the task), performance satisfaction, effort level (the combined physical and mental exertion), and frustration [13]. Together, these rating scales provide a holistic assessment of users' subjective experience with assistive devices.

Though these assessment tools are beneficial for gaining insight into one's view and potential acceptance of new technology, they do not tell the full story. Semi-structured interviews complement the numerical assessments of the previously mentioned surveys. These interviews allow participants to expand upon their ideas in ways that surveys

do not allow. These interviews are then analyzed thematically to provide a framework for identifying and tracking commonly occurring patterns across interview responses [14]. Thematic analysis of semi-structured interviews ultimately allows researchers to categorize interview feedback to identify meaningful takeaways.

A custom programmed Hello Robot Stretch RE1, previously referred to as Stretch with Stretch, was evaluated by people with Parkinson's Disease (PWP) for its ability to deliver interactive physical therapy exercises [15]. This study found the robot easy to use and useful for performing exercises for PWP [15]. In a subsequent study, this robot, which was then referred to as the Zesty Exercise System for Therapeutic Engagement (ZEST-E), was evaluated by exercise specialists who viewed the robot positively and highlighted its potential to supplement physical therapy [16]. The exercise specialists suggested making the robot more user-friendly and providing more human-like feedback [16]. Members of the healthy older adult population (HOAs) were recruited to exercise with ZEST-E to further assess social acceptance, identify areas of improvement, and analyze broader applications of ZEST-E. It was hypothesized that participants would view the robot favorably, perceive the robot as potentially useful in their lives or in the lives of others, and intend to use the device.

2 Methods

2.1 Robotic System for Rehabilitative Exercise

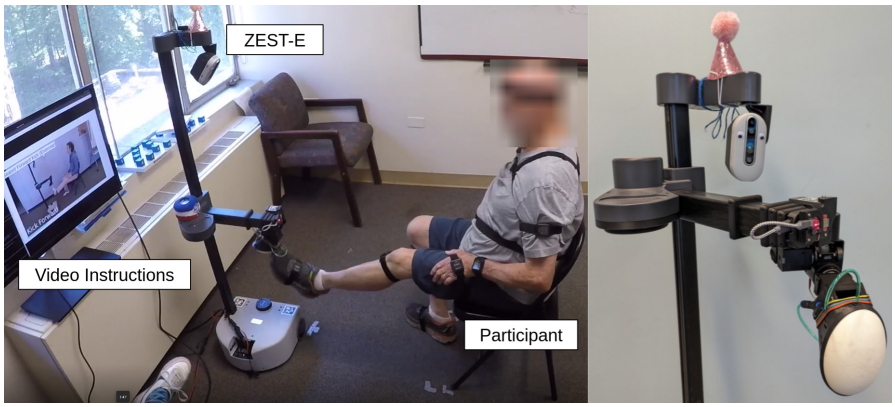


Fig. 1 (**Left**) Experimental setup with a participant performing a seated forward kick exercise with ZEST-E. (**Right**) ZEST-E, a robotic rehabilitative exercise system with a soft bubble end effector that serves as an external cue for stretching. Reprinted from [16] under the Creative Commons Attribution (CC BY) license.

This study utilized a custom programmed Stretch RE1 robot from Hello Robot. For the study and throughout the remainder of this manuscript, the robot is referred to as ZEST-E. A detailed description of the technical design of the ZEST-E robot was previously published by Lamsey et al. (2024) [15]. An overview of the experimental setup is shown in Figure 1. The baseline Stretch RE1 capabilities included a camera

that detects individuals' spatial location and the physical dimensions of their body. The ZEST-E system's software was customized to use the baseline capabilities to estimate the participants' ROM while performing each of the session's exercises. ZEST-E features an inflated bubble target for users to press on with different body parts when performing the exercises. The robot was also paired with a monitor to display visual instructions. ZEST-E was programmed to lead various exercises intended to encourage repetitive large-amplitude stretching motions. These exercises involved both isolated and compound movements that required moderate effort without adding additional resistance.

2.2 Protocol

Twenty-one HOAs participated and performed two sets of six different exercises with ZEST-E. These participants completed a written informed consent form for the 2.5 to 3-hour experience, with 30 minutes spent performing mobility assessments, 1-1.5 hours spent exercising, and approximately 45 minutes spent completing surveys and an exit interview. The exercises included a seated forward reach, seated forward kick, seated calf raise, standing cross-body reach, standing downward cross-body reach, and standing high knees [15]. Before each exercise, a monitor displayed visual instructions on how to perform the motion along with verbal instructions from ZEST-E, and a calibration was performed to determine the user's ROM. Participants were also given a short practice trial to ensure understanding of the instructions. The exercises were performed for 30 seconds, twice on each side of the body. The research staff supervised the participants and were available for assistance when needed.

2.3 Surveys

After completing the exercise program, researchers administered standardized surveys, as seen in Table 1, to each of the participants. These surveys aim to provide insight as to how the participants generally perceive technology and robots, using the TAM as reference [17]. These surveys included the Technology Attitudes Questionnaire [18], ROQ [9], PIADS [12], and the NASA-TLX [13, 19]. In addition to these surveys, this study also adopted the ZEST-E Evaluative Questionnaire (ZEQ) from Lamsey et al. (2025), which was specifically created for post-exercise interviews with ZEST-E [16]. The Technology Attitudes Questionnaire results were categorized into four themes. These themes were rated on a 5-point Likert-type scale. Similar to the ROQ, the ZEQ results were also aggregated into a Likert-scale from one to five. Each of the PIADS responses is rated on a scale from negative three (strongly decreases) to positive three (strongly increases). The NASA-TLX plots represent the "Raw TLX" scores for the six task-loading metrics [13]. Each of the questionnaires were scored based on the respective study's previously published methods.

2.4 Exit Interview

After administering the surveys, the researchers conducted a semi-structured interview with each participant to further explore the participants' perception of ZEST-E and other similar robotic devices. The questions are listed in Table 2.

Table 1 Summary of surveys given to HOA participants.

Instrument	Purpose	Item Count	Format
Technology Attitudes Questionnaire [18]	Assess perception of robots and technology prior to exercise	16	5-point Likert (1–5)
NASA Task Load Index (NASA-TLX) [13, 19]	Investigate different forms of task load while using ZEST-E	6	Task load rating (1–5)
Psychosocial Impact of Assistive Devices Scale (PIADS) [12]	Assess beliefs towards ZEST-E as an assistive device	26	7-point Likert (−3 to +3)
Robot Opinions Questionnaire (ROQ) [9]	Collect perceptions of robot–human interactions	21	5-point Likert (1–5)
ZEST-E Evaluative Questionnaire (ZEQ) [16]	Evaluate attitudes regarding aspects of ZEST-E related to exercise	23	5-point Likert (1–5)

Table 2 Semi-structured interview questions.

No.	Question
1.	How was the overall experience with ZEST-E?
2.	What did you like about the ZEST-E system?
3.	What about the ZEST-E system could be improved?
4.	What additional things would you like ZEST-E to do?
5.	What additional features would you like ZEST-E to have?
6.	What would make you more likely to use the ZEST-E system?
7.	For what purpose would you want to use the ZEST-E system?
8.	Where would you want to use the ZEST-E system?
9.	How do you see ZEST-E becoming a system that would be most beneficial to you?
10.	How likely are you to recommend this ZEST-E system to someone else?
11.	What additional feedback do you have regarding the system or the experience?

Interviews were coded using the QualCoder software program [17]. Thematic analysis can be conducted inductively, deductively, or using a combination of the two. In inductive analysis (bottom-up), researchers start with observations seen in the interviews and then construct broader themes based on these findings. In deductive analysis (top-down), researchers use pre-determined theoretical patterns and then test the interviews against these patterns. Combining inductive and deductive analysis allows researchers to start with theoretical frameworks based on findings from the previous literature while creating new themes or adapting pre-existing themes based on new data [20].

This study used a combined inductive and deductive approach to guide the thematic analysis of semi-structured interviews. Three researchers began with an inductive phase, where they independently read the automatically transcribed interviews to identify common themes. To organize these themes, the codebook in this work was derived from the inductive coding framework established by Lamsey et al. (2025) [16]. The three researchers then integrated a deductive, or theory-driven phase, in which three researchers reviewed the pre-existing codebook and discussed which patterns applied to the HOA participants' feedback [16]. The primary inductive interview analysis was used to remove irrelevant codes and reorganize the categories to apply to HOAs. New sub-themes, such as future expected use cases, based on insights from the participants were also included in the codebook [21]. One of the added sub-themes categorized those who used personal versus impersonal pronouns when referring to ZEST-E to provide insight on if pronoun type correlates with acceptance of the robot. The codes were organized by several overarching parent themes, each of which contained several sub-themes. Due to the variance in responses, each sub-theme had a positive and negative valance indicating those that agreed or disagreed with each theme, with the exception of the "preferred location" sub-theme and all sub-themes under the "suggestions and questions" parent theme.

Once the researchers formed a preliminary codebook, two independent coders deductively coded one sample interview and discussed discrepancies in coding with a third independent researcher to refine the codebook definitions. The two independent coders continued to code and re-code this interview until a Cohen's kappa greater than 0.6 and intercoder agreement of 85% was achieved, updating the codebook definitions after each discussion [22, 23]. A Cohen's kappa greater than 0.6 suggests that there is moderate to substantial agreement in the codes and the coding overlap was likely not due to chance [22]. Intercoder agreement measures the degree of agreement between two coders with 80-90% considered a minimal standard of agreement [23]. The two coders then repeated this process with four more interviews until they finalized the codebook, which is visualized in Table 3.

Using the finalized codebook, two researchers independently coded the first 10 interviews, after which they analyzed their codes by verifying the Cohen's kappa and intercoder agreement to ensure it was greater than 0.6 and 85% respectively. They then went through each code for all 10 interviews, compiling the agreed upon codes into a master document for later analysis. The coders then proceeded to code the remaining 11 interviews and repeat these same steps until all interviews were coded in the master document, which served as the foundation for the thematic analysis presented in the results.

3 Results

Demographics for 21 HOA participants are provided in Table 4. All participants successfully completed the robot-led exercise protocol.

Table 3 Codebook for semi-structured interviews

Parent Theme	ID	Sub-Theme
Aesthetics and Design	AD1	Robot has an appealing physical design and accessories.
	AD2	Participant uses personal pronouns to describe and refer to the robot.
Engagement and Motivation	EM1	Robot could improve exercise adherence.
	EM2	Robot is engaging, motivating, and fun.
	EM3	Participant can visualize use of the robot in daily life.
Expected Use Cases	EU1	Robot would be useful for healthy people.
	EU2	Robot would be useful for people with disabilities.
	EU3	Robot would be useful for tracking health data.
	EU4	Robot would be useful in the future.
	EU5	Preferred location (home, gym, clinical setting, or other).
Quality of Communication	QC1	Robot communicated clearly and effectively.
	QC2	Robot provided useful feedback on users' performance.
Usability and Reliability	UR1	Robot is portable.
	UR2	Robot is easy for participants to set up and operate.
	UR3	Robot could adapt to an individual's physical capabilities.
Suggestions and Questions	SQ1	Amplifying positive aspects.
	SQ2	Rectifying negative aspects.
	SQ3	Neutral changes to existing features.
	SQ4	Do something novel that the robot does not already do.
	SQ5	Questions and suggestions about affordability of the robot.

3.1 Surveys

As mentioned in previous sections, the participants were administered the surveys before beginning exercise with the robot. The responses to the Technology Attitudes Questionnaire are presented in Figure 2. The outcomes from the ROQ and ZEQ are shown in Figure 3. The results from the PIADS and NASA-TLX are presented in Figure 4. The black dots indicate outliers, which are defined as being below 1.5 IQR from the first quartile and above 1.5 IQR from the third quartile.

3.2 Exit Interview

Comments and suggestions from the interviews are organized by broader parent themes and their corresponding sub-themes (Table 3). The number of participants who provided a response(s) aligning with the positive and negative valance for each sub-theme are indicated below. For example, AD1 had 0 positive occurrences and 2 negative occurrence and is denoted "AD1; pos=0, neg=2." For sub-themes lacking valance, such as those under preferred location, pronoun usage, and suggestions and questions,

Table 4 HOA participant demographics.

Measure	Value
Age (y)	70.7 ± 4.9
Gender	10 F, 11 M
Height (in)	67.5 ± 4.1
Weight (lbs)	166.8 ± 39.7
Dominant Hand	19 R, 2 L
Dominant Leg	19 R, 2 L

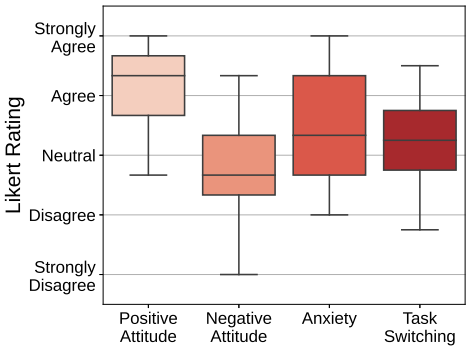


Fig. 2 Technology Attitudes Questionnaire. Positive Attitude: (M=4.33, IQR=1.00); Negative Attitude: (M=2.67, IQR=1.00); Anxiety: (M=3.33, IQR=1.67); Task Switching: (M=3.25, IQR=1.00)

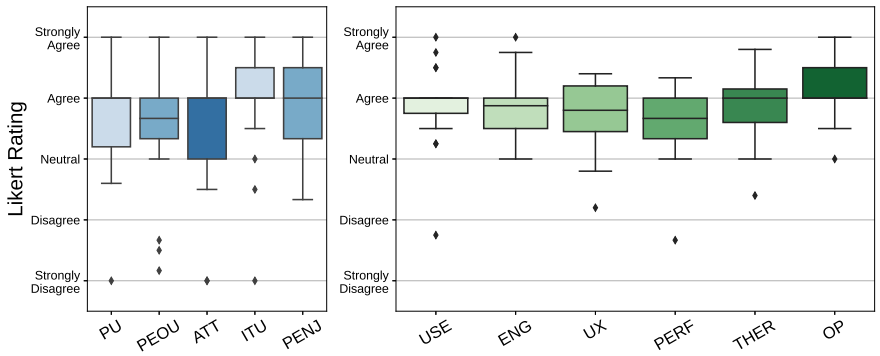


Fig. 3 (**Left**) **ROQ Attitudes**. Perceived Usefulness (PU): (M = 4.00, IQR = 0.80) with outlier S10 (1.00); Perceived Ease of Use (PEOU): (M = 3.67, IQR = 0.67) with outliers S10 (1.50), S12 (1.17), and S16 (1.67); Positive Attitude (ATT): (M = 4.00, IQR = 1.00) with outliers S10 (1.00), and S16 (1.00); Intent to Use (ITU): (M = 4.00, IQR = 0.50) with outliers S10 (1.00), S12 (2.50), and S19 (3.00); Perceived Enjoyment (PENJ): (M = 4.00, IQR = 1.17); (**Right**) **ZEQ Attitudes**. Usability and Interaction (USE): (M = 4.00, IQR = 0.25) with outliers S04 (4.75), S06 (3.25), S07 (3.25), S09 (1.75), S10 (5.00), S12 (4.50), and S18 (4.50); Engagement and Motivation (ENG): (M = 3.88, IQR = 0.50) with outlier S10 (5.00); User Experience (UX): (M = 3.80, IQR = 0.75) with outlier S09 (2.20); Performance and Accuracy (PERF): (M = 3.67, IQR = 0.67) with outlier S09 (1.67); Therapeutic Efficacy (THER): (M = 4.00, IQR = 0.55) with outlier S09 (2.40); Operational and Environmental Considerations (OP): (M = 4.00, IQR = 0.50) with outlier S17 (3.00)

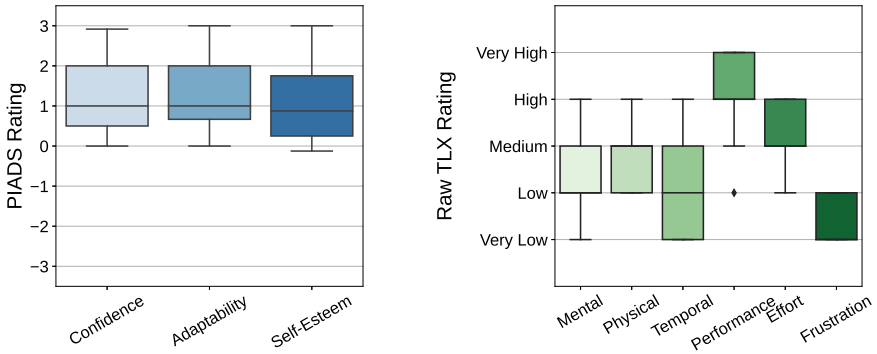


Fig. 4 (**Left**): **PIADS Attitudes**. Confidence: (M = 1.00, IQR = 1.50); Adaptability: (M = 1.00, IQR = 1.33); Self-Esteem: (M = 0.88, IQR = 1.50); (**Right**) **NASA-TLX**. Mental: (M = 2.00, IQR = 1.00); Physical: (M = 3.00, IQR = 1.00); Temporal: (M = 2.00, IQR = 2.00); Performance: (M = 4.00, IQR = 1.00) with outlier S17 (2.00); Effort: (M = 3.00, IQR = 1.00); Frustration: (M = 1.00, IQR = 1.00);

the total number of participants who addressed each sub-theme was recorded. For example, SQ1 did not have valance and had 13 occurrences; therefore, it was denoted "SQ1; sum=13." Each participant ID is indicated in parenthesis, such as (S01).

3.2.1 Aesthetics and Design (AD)

(AD1; pos=0, neg=2): There was limited feedback on the visual appearance of ZEST-E. However, both comments regarding the system's physical design were negative. One participant noted how ZEST-E "looks daunting, ... expensive" and "like a vacuum [cleaner]" (S16). Another noted how "[ZEST-E] looks fragile" (S18).

(AD2; Personal=7, Impersonal=20): Most participants used impersonal pronouns, such as it/its, to refer to ZEST-E. Of these 20 participants who used impersonal pronouns, 6 of them also referred to ZEST-E using personal pronouns. Of the 7 participants who gave ZEST-E personal pronouns, 6 assigned ZEST-E feminine pronouns such as she/her, and 1 assigned ZEST-E masculine pronouns such as he/him.

3.2.2 Engagement and Motivation (EM)

(EM1; pos=8, neg=3): The majority of the participants believed that ZEST-E would help increase their adherence to their workouts. Users found that with ZEST-E, they "might actually exercise more rather than just talk about exercising" (S22). They liked that it would encourage them to "be healthier—to work out more" (S14).

However, some users could not see ZEST-E improving their workout adherence. These participants believed that its novelty "would wear off quickly" (S07) or did not find it any more encouraging than "just putting on a video or just doing an exercise routine ... on a piece of paper" (S22).

(EM2; pos=16, neg=2): It was widely noted that ZEST-E was "interesting and fun" to use (S10). Participants generally felt encouraged and engaged while working out with ZEST-E.

The few negative instances of EM2 were due to frustration in working with the robot or not seeing ZEST-E as any more encouraging than just "putting on a video" (S22).

(EM3; pos=12, neg=11): Despite favorable views on ZEST-E's engagement and improving workout adherence, it was more common for users to note being resistant to using it in their own lives. The most commonly reported barrier to visualization among the participants was a lack of difficulty in the exercises. For example, one participant noted how "most of the exercises were not challenging," therefore, "I'm not sure I would want to use it for a real workout" (S06). Other barriers to visualization included being "less willing to attempt new technology" (S16) and a desire for "more refinement" (S09).

Instances where participants could visualize using ZEST-E often focused on utilizing it for "exercising and stretching" (S09) and/or "part of an integrated total workout" (S06). Several participants mentioned using it "to have an exercise routine that [they] could tweak as [they] became more skilled at various exercises" (S02).

3.2.3 Expected Use Cases (EU)

(EU1; pos=11, neg=8): Participants tended to view ZEST-E as being "very useful for stretching and mobility exercises" (S19). Some users saw ZEST-E as a tool "to stay in good physical shape ... to stay strong" (S16). It was noted to be a "really good notion for how to incorporate regular exercise for people in my demographic" (S07).

Although users mostly noted positive impacts on their health, many did not find ZEST-E useful for improving their health or the health of other HOAs. For example, one participant stated, "I didn't see how lifting my knee, and stretching ... was really all that beneficial" (S09). Many participants mentioned that the exercises were not hard enough and would not fit into their current workout routine.

> I needed to work on upper-body strength so I could lift a 45-pound wheelchair in and outta the car. It didn't do that for me today, but that doesn't mean it can't. (S16)

(EU2; pos=4, neg=1): Several participants believed that, "for people with mobility and strength issues, [ZEST-E] could be very, very helpful" (S19). One participant went on to visualize a use for people with physical limitations where "their home-health people ... could bring it with them. [You could have] the caregiver there to supervise [so] that patient could learn how to operate it. It'd be perfect" (S08).

However, one participant worried that "for people who have limited mobility ... I could see where they're gonna end up with some injuries" (S04).

(EU3; pos=3, neg=4): Among participants who discussed tracking health data with ZEST-E, most noted that ZEST-E currently does not support tracking their health information over time.

Those who saw ZEST-E as beneficial for tracking health data in its current form focused more on the immediate feedback during the workouts and found it helpful for more short-term data tracking. One user stated, "I liked that it gave you measured parameters. It felt like having a goal to reach for" (S07).

(EU4; pos=5, neg=1): Although many of the participants expressed that the exercises were not challenging enough for them, several individuals were open to utilizing

ZEST-E in the future when they may benefit from this level of exercise. For example, S16 said, "as we become more and more house-bound, I can see ZEST-E becoming more of an option for us."

Only one user gave feedback indicating that they "don't see it being beneficial" (S10) and could not visualize a future use for it.

(EU5; home=16, gym=9, clinical=4, other=2): The most commonly preferred location was "at home" (S13). One participant elaborated that, "I don't wanna have to drive five miles or whatever ... I wanna run upstairs and do it" (S18). The second most commonly mentioned location was "in a gym setting" (S07). Others mentioned using ZEST-E "in a physical therapist's office" and would want "somebody who really knows the system to be available to operate it" (S10). An alternative location listed was "at the spa" (S15).

3.2.4 Quality of Communication (QC)

(QC1; pos=6, neg=6): Opinions and perceptions of the clarity and overall effectiveness of the system's communication with the participants were measured in this sub-theme. There were mixed opinions on the clarity and effectiveness of the robot's communication. Several participants expressed their appreciation of the communication of the system, namely the graphics and verbal instructions (S19).

In contrast, other participants noted that, as members of the older adult population, there is an increasing demand for higher volume or more clearly pronounced instructions due to hearing loss. Some users were unable to understand the instructions and "had to ask [the researcher] what [ZEST-E] said" (S13).

(QC2; pos=5, neg=5): Overall, participants felt that ZEST-E's feedback and encouragement was helpful in completing the movement and positively impacted their workout.

> I enjoyed the fact that the machine is making all these positive affirmations while you were doing it. ... I like that she told you how many you were doing because it made me wanna try to do at least one more the next time. (S03)

However, some users found that "the feedback was sometimes distracting" (S07). Others voiced an aversion to the overly positive comments and would have liked to hear more corrective feedback (S19).

3.2.5 Usability and Reliability (UR)

(UR1; pos=1, neg=1): There was limited feedback regarding the portability of ZEST-E. One user stated that "being able to easily move it from one location ... to another" makes them more likely to use the ZEST-E system (S07).

However, another user found that the mobility of the robot needs improvement (S01).

(UR2; pos=2, neg=7): The overall attitudes of participants towards setting up and operating the robot were largely negative. Many users noted that the system "needs to set up quicker" and found that the slow setup speed made it frustrating to operate (S22). Additionally, as members of the older adult population, several participants lacked confidence in their ability to work with technology. Due to the

perceived difficulty of setting up the system, many only felt comfortable using the robot with expert supervision.

Only two users noted that ZEST-E was "easy to use" (S07).

(UR3; pos=5, neg=7): ZEST-E was evaluated based on its ability to scale the exercise difficulty to individual user capabilities. Between participants, the sentiment of how effective the exercise level scaling was varied. The majority of comments indicate that the "exercises were not challenging" and therefore, ZEST-E did not adequately adjust the difficulty of the workout to the capabilities of the HOA participants (S06). Additionally, some users expressed that the robot had a difficult time assessing their proxemics, which translated to the robot not effectively scaling the exercise to an adequate difficulty (S10).

While ZEST-E did not appear to properly adapt to some users, others found the workout to be an effective difficulty relative to their capabilities. For example, one participant commented, "[ZEST-E] was challenging, but not overly so" (S06).

3.2.6 Suggestions and Questions (SQ)

(SQ1; sum=13): Participant responses were analyzed to assess which positive aspects of the robot were most effective and should be amplified to improve the robot. For the participants who enjoyed the exercises, the majority of suggestions were simply integrating a "wider variety of exercises" (S02).

(SQ2; sum=15): Participants were also asked to assess the robot for areas that could be rectified or improved upon in future robot designs. For this theme, there was much more variation in the suggestions. The two most common suggestions were improving the clarity of the instructions and correcting the sensitivity of the touch pad. Many users seemed to agree that the instructions need to be at a "higher volume and maybe just a little bit clearer" (S10). Others believed the "touch pad ... can be improved" because it "doesn't always register, [and] sometimes you hit it too hard" (S15).

(SQ3; sum=7): Subjects also made neutral suggestions for changes in the robot's design and structure. Most of the suggestions centered around the placement of certain system elements, namely, the location of the instructional screen.

> I think the screen could be located a little differently from where it is. It needs to follow the robot around, so I'm not lookin' off to the side to see what they're wantin' to do. (S18)

Participants also suggested altering the existing communication system via different voice options or having the existing feedback include more corrective elements.

(SQ4; sum=14): Participants had the opportunity to provide suggestions for additional features or designs outside of the normal functions or objectives of the system. While some of the ideas were unrelated to exercise, other suggestions involved improving data storage and a "scoring capability [to] measure progress or success over time" (S01). Participants appeared to want more user-friendly features, with one user suggesting, "some kind of a graph at the end of saying, 'You did these things. Today you earned a blue star. Your next star would be orange,' ... some visual feedback of how I did and what my next goal would be" (S16). Similarly, others suggested implementing workout reminders to help users adhere to their routine.

> [The workouts] can all be so easily stored in there on a chip, and the frequency of using it could be recorded too ... It could send me a text and say, "Oh, you haven't been doing ZEST-E in three days, it's time to do it again." (S09)

Another reoccurring suggestion within this sub-theme was the frequent requests to include resistance training as an expansion to the robot's exercise regime. Because the robot's physical design does not support highly dynamic interactions such as high speeds and large forces, a variety of additional exercise suggestions were outside the current scope of the system. For example, participants suggested "boxing-type exercises" (S08), "footwork exercises" (S08), and "weight training" (S18).

(SQ5; sum=7): A large sub-theme identified from the subjects is the frequent concern for the robot's economic accessibility. Across interviews, the price point of the robot was cited as a key factor in willingness to incorporate the system into one's exercise routine. For example, one participant remarked, "depending on how much she [the system] costs, I wouldn't mind having her in my home with me" (S03).

4 Discussion

This study aimed to assess the reception, social acceptance, and usability of a robot custom-programmed to deliver physical therapy exercises with the goal of determining feasibility of future large-scale use. Both survey data and qualitative interview feedback from the participants were analyzed. Using this feedback, several major facilitators and barriers to use for robot-led exercise are identified. The HOA participants positively viewed ZEST-E's ability to improve their health and increase workout adherence. Implementing more challenging, strength-based workouts, and a more user-friendly interface would further enhance ZEST-E's acceptability among HOAs.

4.1 Social-Acceptance among HOAs

The results suggest positive social acceptance of ZEST-E among HOAs. Survey results indicate agreement in ITU, suggesting that, on average, HOAs appear open to using ZEST-E themselves. Additionally, for those who did not visualize using ZEST-E at the time of their interview, many were willing to suggest ZEST-E to others who would benefit from its use or would be willing to use it themselves in the future if it was enhanced to meet their exercise needs. This indicates that HOAs tended to accept the use of ZEST-E for themselves or others and did not show signs of stigma towards this robotic exercise partner. These findings appear to align with the general acceptance of other assistive robots among older adults [9, 24].

4.2 Strengths of Robot-Led Exercise

4.2.1 ZEST-E shows potential to provide positive perceived health benefits for HOAs

Previous studies on ZEST-E have indicated that this robot shows promise in leading physical therapy exercises with PWP [15]. The study expands the target population to include HOAs and has found that ZEST-E appears to offer stretching workouts that

may benefit the health of HOAs. In the interviews, participants often mentioned the positive impacts that using ZEST-E would have on their health. They overwhelmingly cited it as being beneficial for "stretching and mobility" (S19) and many visualized using it for a "good warm-up" (S06). Similarly, the ZEQ Attitudes survey leans towards agreement in ZEST-E's therapeutic efficacy (Figure 3). Overall, this feedback suggests that ZEST-E may positively impact the health of HOAs in addition to people with Parkinson's Disease through stretching-based exercises.

4.2.2 ZEST-E could increase workout adherence

The physical interaction between the user and the robot and the system's verbal encouragements appeared to enhance user engagement. Prior research has documented the motivational capacity of robotic assistants designed to engage older adults in physical exercise [25]. In the semi-structured interviews, participants frequently mentioned how much fun they had with ZEST-E, and doing exercises with a robotic partner made them feel more engaged in what they were doing than when exercising alone. Similarly, in the surveys, ratings tended to lean favorably in perceived enjoyment and user experience (Figure 3). Due to the enjoyment of the exercise tasks and the accountability of this robotic partner, many participants believed that they would be more likely to adhere to their exercise routine with ZEST-E.

4.2.3 ZEST-E has the potential to serve as a personalized exercise partner

ZEST-E was designed to modify the difficulty of the workout according to the user's abilities, providing a personalized exercise experience. This robotic exercise partner guides its user through a personalized workout routine. Additionally, several participants reported that ZEST-E's verbal encouragement motivated them to try harder and keep pushing through each set, illustrating this robot's ability to motivate its users through their exercises.

There were several suggestions that would further improve ZEST-E's abilities. Many participants liked how ZEST-E reported how well they performed on the exercises and suggested that this data could be tracked across workout sessions to assess their progress. Additionally, ZEST-E could be further developed to converse with its user about how they feel and modify the exercise accordingly (S09). These findings suggest that this robot may have potential to act as an engaging, personalized fitness partner.

4.3 Areas for Improvement

4.3.1 Improved Communication

Hearing impairments are common among older adults, with almost one in two adults aged 60 and older experiencing hearing loss [26]. Therefore, one of the major barriers to adoption by HOAs is ZEST-E's current level of communication. Several participants noted difficulty in understanding the instructions due to the volume being

too low and/or ZEST-E speaking too fast. Participants commonly reported feeling confused by the instructions and, therefore, initially had trouble completing the exercises as intended.

In addition to making the instructions slower, louder, and clearer for users, repositioning the monitor screen will serve to improve user instruction comprehension. The system was paired with a monitor that supplemented the auditory instructions with visual depictions of the movements. The monitor was detached from the robot, and several users reported frustration in having to look off to the side to see the monitor. Integrating the digital screen onto the body of the robot would further improve the user-robot communication.

Finally, the quality of communication could also be improved. The robot provided positive feedback, such as "good job," after an exercise, which is intended to encourage users. However, including more corrective feedback would ensure users are completing the exercises correctly and feel as though they are receiving personalized coaching rather than pre-set motivation. In the semi-structured interviews, several participants reported frustration with the overly positive phrases during the workout, suggesting more correction when performing the movement incorrectly. For ZEST-E to serve as a personalized fitness coach for HOAs, it needs to be able to effectively communicate with its users in a manner that is understandable and helpful in completing the exercise routine.

4.3.2 Improved Workout Intensity

One of the main limitations to the adoption of ZEST-E appears to be its lack of intensity. Although many participants commented on how ZEST-E would have positive health benefits, most participants found the exercises too easy. The current exercises are stretching and mobility based, so they do not provide the level of difficulty the majority of the participants were accustomed to in their current workout routines. Previous research has echoed this finding that some older adults desire a higher level of exercise difficulty or complexity than some robotic partners can provide [9].

To accommodate this greater level of exercise intensity, ZEST-E will need to be strengthened to provide more challenging movements to match the fitness level of many HOAs. Several participants mentioned that the machine felt fragile, which held them back for fear of knocking it over or breaking it. Others also commented on the touch-pad's sensitivity, with some reporting that hitting it too hard prevented it from counting the repetition. Improving the sensitivity of the sensor so that it can accommodate more difficult movements will be a key factor in adoption among HOAs.

4.3.3 Improved Accessibility for Independent Use

One of the major goals of these robotic exercise partners is to increase access to personalized workouts. For users to independently use ZEST-E, it needs to be easy to set up and operate by the general population. User-friendliness is especially important for HOAs, as studies have shown that older age is strongly associated with less familiarity with technology [27]. Additionally, ease of use has commonly been cited as a major determinant in older adults' adoption of assistive technology [24, 28]. However, this robot currently lacks user-friendly features necessary for independent

operation. Many participants expressed apprehension regarding operating the robot themselves, which turned many away from using ZEST-E at home. Therefore, they would prefer to use it in a public facility with an expert to help operate the system and troubleshoot issues. Decreasing the setup time and limiting the number of steps to run the robot would greatly improve the ability of HOAs to work with ZEST-E on their own.

In addition to ease of use, affordability is an important determinant in the accessibility of assistive technology; more than half of the participants indicated that the price of the robot would be a large factor in their willingness to use it. This focus on economic accessibility reoccurs across multiple studies outlining the acceptance of assistive technology [24, 28, 29]. Using ZEST-E in shared fitness spaces such as commercial gyms or physical therapy clinics could be one way to reduce the cost per user. Leasing ZEST-E for home use could also offer a way to use the machine without purchasing it outright. Ultimately, to improve access to personalized assistive robotics broadly among HOAs, future models must minimize these economic barriers.

5 Conclusion

ZEST-E shows potential to provide engaging, personalized workouts for the HOA population. These findings suggest that HOAs hold a positive impression of the ZEST-E robot and appear to be socially accepting of this interactive robotic partner. However, additional improvements, such as increasing workout difficulty and user-friendliness, are necessary for ZEST-E to be widely adopted among HOAs. Future studies should also focus on quantifying the health benefits for HOAs after using ZEST-E over a prolonged period and how this affects their perception of the robot.

Acknowledgments. Thank you to Jerry Feldman for his assistance with developing ZEST-E and Jill Bishop for her help coordinating the experiment.

Declarations

- Funding: This work is supported by the Toyota Research Institute grant GR00010714, the McCamish Parkinson's Disease Innovation Program Blue Sky grant DE00021631, and the Emory Center for Health and Aging grant.
- Conflict of interest: Charles C. Kemp worked for Hello Robot Inc. at the time of the study. However, the other authors certify that the research was not influenced by financial or personal motivations that would be considered a conflict of interest.
- Ethics approval and consent to participate: The study protocols were approved by the Institutional Review Boards at the Georgia Institute of Technology (protocol H22359) and the Emory University School of Medicine (protocol STUDY00004909) for studies with human participants. This study was conducted in accordance with the Declaration of Helsinki and all relevant institutional and regulatory guidelines. All participants provided written informed consent prior to participation.
- Consent for publication: All authors have approved the publication of this work. Informed consent was obtained from all the individual participants for publication.

- Data availability: The data generated in this study is available upon request from the corresponding author in order to protect participant privacy.
- Materials availability: The ZEST-E system is maintained at Dr. Hackney's Neurokinesiology Laboratory and is available for collaborative access upon request from the corresponding author. This system is customized from the Stretch RE1, which is commercially available from Hello Robot.
- Code availability: The software used for data processing, QualCoder 3.7, is publicly available via GitHub.
- Author contribution: LK and BP were responsible for coding the interviews, analyzing data, and writing the main manuscript text. ML programmed the robot, designed and carried out the experiment, helped with publication writing, and provided guidance throughout the project. MDW assisted with study design and protocol development, designed the robot-led exercises, set up the databases, led the exercise sessions with the participants, carried out the data collection, and assisted with manuscript preparation. CCK conceptualized the project, provided advice, and obtained funding. MEH obtained funding, provided advice throughout the study, and provided comments on the publication.

References

[1] Mather, M., Scommegna, P.: Fact sheet: Aging in the united states. Population Reference Bureau (2024)

[2] Sharma, G., Morishetty, S.K.: Common mental and physical health issues with elderly: a narrative review. ASEAN Journal of Psychiatry **23**(1), 1–11 (2022)

[3] Stathokostas, L., McDonald, M.W., Little, R.M., Paterson, D.H.: Flexibility of older adults aged 55–86 years and the influence of physical activity. Journal of aging research **2013**(1), 743843 (2013)

[4] Galloza, J., Castillo, B., Micheo, W.: Benefits of exercise in the older population. Phys Med Rehabil Clin N Am **28**(4), 659–669 (2017)

[5] Wan, M., Wong, R.Y.: Benefits of exercise in the elderly. Canadian Geriatrics Society Journal of CME **4**(1), 5–8 (2014)

[6] Phillips, E.M., Schneider, J.C., Mercer, G.R.: Motivating elders to initiate and maintain exercise. Archives of physical medicine and rehabilitation **85**, 52–57 (2004)

[7] Keadle, S.K., McKinnon, R., Graubard, B.I., Troiano, R.P.: Prevalence and trends in physical activity among older adults in the united states: a comparison across three national surveys. Preventive medicine **89**, 37–43 (2016)

[8] Costello, E., Kafchinski, M., Vrazel, J., Sullivan, P.: Motivators, barriers, and beliefs regarding physical activity in an older adult population. Journal of geriatric physical therapy **34**(3), 138–147 (2011)

[9] Chen, T.L., Bhattacharjee, T., Beer, J.M., Ting, L.H., Hackney, M.E., Rogers, W.A., Kemp, C.C.: Older adults' acceptance of a robot for partner dance-based exercise. PloS one **12**(10), 0182736 (2017)

[10] Fitter, N.T., Mohan, M., Kuchenbecker, K.J., Johnson, M.J.: Exercising with baxter: preliminary support for assistive social-physical human-robot interaction. Journal of neuroengineering and rehabilitation **17**, 1–22 (2020)

[11] Davis, F.D.: Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS quarterly, 319–340 (1989)

[12] Jutai, J., Day, H.: Psychosocial impact of assistive devices scale (piads). Technology and Disability **14**(3), 107–111 (2002)

[13] Hart, S.G., Staveland, L.E.: Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: Advances in Psychology vol. 52, pp. 139–183. North-Holland, Amsterdam (1988)

[14] Ahmed, S.K., Mohammed, R.A., Nashwan, A.J., Ibrahim, R.H., Abdalla, A.Q., Ameen, B.M.M., Khdhir, R.M.: Using thematic analysis in qualitative research. Journal of Medicine, Surgery, and Public Health **6**, 100198 (2025)

[15] Lamsey, M., Tan, Y.L., Wells, M.D., Beatty, M., Liu, Z., Majumdar, A., Washington, K., Feldman, J., Kuppuswamy, N., Nguyen, E., *et al.*: Stretch with stretch: Physical therapy exercise games led by a mobile manipulator. In: 2024 IEEE International Conference on Robotics and Automation (ICRA), pp. 5569–5576 (2024). IEEE

[16] Lamsey, M., Wells, M.D., Hamby, L., Scanlon, P.E., Siddiqui, R., Tan, Y.L., Feldman, J., Kemp, C.C., Hackney, M.E.: Exercise specialists' evaluation of robot-led rehabilitative exercise for people with parkinson's disease. In: Healthcare, vol. 13, p. 1590 (2025). MDPI

[17] Curtain, C., Dröge, K., Missaghieh–Poncet, J., Salomón, L.: QualCoder (Version 3.7). https://github.com/ccbogel/QualCoder/releases/tag/3.7. Computer software (LGPL v3) (2026)

[18] Rosen, L.D., Whaling, K., Carrier, L.M., Cheever, N.A., Rokkum, J.: The media and technology usage and attitudes scale: An empirical investigation. Computers in human behavior **29**(6), 2501–2511 (2013)

[19] Hart, S.G.: Nasa-task load index (nasa-tlx); 20 years later. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 50, pp. 904–908 (2006). Sage publications Sage CA: Los Angeles, CA

[20] Proudfoot, K.: Inductive/deductive hybrid thematic analysis in mixed methods research. Journal of mixed methods research **17**(3), 308–326 (2023)

[21] Wu, Y.-H., Wrobel, J., Cornuet, M., Kerhervé, H., Damnée, S., Rigaud, A.-S.: Acceptance of an assistive robot in older adults: a mixed-method study of human–robot interaction over a 1-month period in the living lab setting. Clinical Interventions in Aging **9**, 801–811 (2014) https://doi.org/10.2147/CIA.S56435

[22] McHugh, M.L.: Interrater reliability: the kappa statistic. Biochemia medica **22**(3), 276–282 (2012)

[23] Saldaña, J.: The Coding Manual for Qualitative Researchers. SAGE Publications, Thousand Oaks, CA (2012)

[24] Wang, Y., Chen, H., Cheng, H., Qiu, J., Huang, R., Zou, C., Song, G., Liu, M., Liu, Q., Zhang, J., *et al.*: The attitudes and acceptance of functional assistive robots among older adults with disabilities: a mixed-methods study. Innovation in Aging **9**(9), 097 (2025)

[25] Fasola, J., Mataric, M.J.: Using socially assistive human–robot interaction to motivate physical exercise for older adults. Proceedings of the IEEE **100**(8), 2512–2526 (2012)

[26] Reed, N.S., Jiang, K., Deal, J.A.: Hearing loss among older adults: Epidemiology, disparities, and gaps in research. Annual review of public health **47** (2025)

[27] Nicosia, J., Aschenbrenner, A.J., Adams, S.L., Tahan, M., Stout, S.H., Wilks, H., Balls-Berry, J.E., Morris, J.C., Hassenstab, J.: Bridging the technological divide: stigmas and challenges with technology in digital brain health studies of older adults. Frontiers in Digital Health **4**, 880055 (2022)

[28] Kabacińska, K., Vu, K., Tam, M., Edwards, O., Miller, W.C., Robillard, J.M.: "functioning better is doing better": older adults' priorities for the evaluation of assistive technology. Assistive Technology **35**(4), 367–373 (2023)

[29] Yusif, S., Soar, J., Hafeez-Baig, A.: Older people, assistive technologies, and the barriers to adoption: A systematic review. International journal of medical informatics **94**, 112–116 (2016)