Design Research Society
DRS Digital Library

DRS Biennial Conference Series DRS2024: Boston

Jun 23rd, 9:00 AM - Jun 28th, 5:00 PM

Step-by-step: Using low-fidelity, physical prototypes of enabling technologies to gain feedback from clinicians, prior to older patients

Johnell O. Brooks
Clemson University, United States of America

Casey F. Jenkins
Clemson University, United States of America

Stephanie L. Tanner
Clinical Research Unit, Upstate, Prisma Health

Ian D. Walker
Clemson University, United States of America

Keith Evan Green
Cornell University, United States of America

Follow this and additional works at: https://dl.designresearchsociety.org/drs-conference-papers

Part of the Art and Design Commons

Citation

O. Brooks, J., F. Jenkins, C., L. Tanner, S., D. Walker, I., and Evan Green, K. (2024) Step-by-step: Using low-fidelity, physical prototypes of enabling technologies to gain feedback from clinicians, prior to older patients, in Gray, C., Ciliotta Chehade, E., Hekkert, P., Forlano, L., Ciuccarelli, P., Lloyd, P. (eds.), *DRS2024: Boston*, 23–28 June, Boston, USA. https://doi.org/10.21606/drs.2024.355

This Research Paper is brought to you for free and open access by the DRS Conference Proceedings at DRS Digital Library. It has been accepted for inclusion in DRS Biennial Conference Series by an authorized administrator of DRS Digital Library. For more information, please contact dl@designresearchsociety.org.

DRS BOSTON 20 DRS 24 JUNE 24 — 28

Step-by-step: Using low-fidelity, physical prototypes of enabling technologies to gain feedback from clinicians, prior to older patients

Johnell O. Brooks[a], Casey Jenkins[a], Stephanie L. Tanner[b], Ian D. Walker[c], Keith Evan Green[d,*]

[a]Clemson University, Automotive Engineering, USA
[b]Clinical Research Unit - Upstate, Prisma Health, USA
[c]Clemson University, Electrical & Computer Engineering, USA
[d]Cornell University, Human Centered Design, Mechanical Engineering, Information Science, USA

*Corresponding e-mail: keg95@cornell.edu

doi.org/10.21606/drs.2024.333

Abstract: Designers of enabling technologies need a deep understanding of what patients want and need. But prototypes with working sensors and actuators may be far outside the experience of the vulnerable populations (e.g., older patients) targeted and may prove harmful to them, requiring a more cautious, "step-by-step" design approach. We report on how designers gain feedback from, before older patients, clinicians, using low-fidelity, full-scale prototypes without electronics to anticipate how such patients will interact with full-functioning technologies. Three hypothetical patient-personas with varying degrees of injuries were developed with clinicians. Clinicians then offered feedback on the assistance needed from our assistive robotic furniture by their patients to complete tasks at home to maintain independence. This design step was quick and effective in gaining meaningful feedback from clinicians who can speak for a wide range of patients in anticipation of studying interactions with older patients in a step-by-step process of design.

Keywords: Enabling technology, user study, research methods.

1. Introduction

The market is rapidly expanding with new, novel, "smart" interventions for the home aiming to support and augment our daily lives. Indeed, the global market for smart technologies for the home is expected to be valued at $135.3 billion USD by 2025 ("Smart Home Market worth $135.3 billion by 2025"). These technologies include assistive robotic systems (Mataric & Scassellati, 2016) targeted for the home (Prassler et al., 2016) and elderly populations therein (Forlizzi, DiSalvo, & Gemperle, 2004). There is a need for design interventions supporting the independence of vulnerable populations ("Aging in Place: Growing Older at

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International Licence.

Home") who, overwhelmingly, wish to live in their homes ("Aging in Place vs. Assisted Living"). But such new and novel interventions can be complex and complicated for both the population they are designed to serve as well as their family and professional caregivers. Practically, immature technological developments have the potential to "harm" vulnerable individuals by confounding them and even causing them physical harm (Weld and Etzioni, 1994).

Consequently, in the process of designing new smart products and interventions, designers need to be creative in the methods used to conduct meaningful user studies on interventions (i.e., designed artifacts and environments) that are novel and/or not yet developed to a high level of fidelity. Otherwise, designers may easily frustrate their participants and learn little from the study.

In this paper, our multi-disciplinary research team including individuals from the fields of design, engineering, human factors, and medicine presents a case study that provides insights on (1) how researchers can gain feedback from stakeholders on a design intervention using low-fidelity physical prototypes, and (2) what kind of interactions with those prototypes are most suitable for individuals participating in user studies to gain meaningful insights for future iterations. In the case study described in this paper, the design intervention is robotic furniture (see Figure 1): essentially, a floor lamp and a side table, but with added functionality, intended to support the independence of older adults living at home who might otherwise be forced into assisted living facilities. A secondary contribution of this paper is to gain insights regarding the type of user interaction (i.e., controlling or commanding) that is appropriate for these robots for a broad range of potential users with varying levels of physical functioning in their home environment.

Figure 1 Left, a picture of the home lab with set up for the start of the study. Right, the low-fidelity robotic table and lamp (with no working electronics).

2. The design intervention: A pair of robotic furniture

To help older individuals complete daily activities in one's home that support independent living, the pair of robotic furniture elements is being designed to be mobile (i.e., able to

move across the floor), to fetch (identify and collect things from the floor, shelves, cabinets, and table and work surfaces), and to carry objects from one place to another. Our team has conceptualized the design and, since then, has been working on developing the functionality of the prototypes, which largely can perform the essential mobility, fetching, and carrying functions described above, mostly as a proof-of-concept for ourselves. We previously conducted lab experiments with the robotic furniture ("prototype1") to determine if these could assist a member of our lab team, in a wheelchair, to accomplish routine, domestic tasks as enumerated by the CS-PFP10, the *Continuous Scale Physical Functional Performance-10*. The CS-PFP10 is used (Cress, n.d.) by healthcare providers to evaluate, with great validity and reliability, whether individuals have the functional capacity to live independently, based on their ability to perform ten tasks such as fetching and retrieving items. Our two subsequent studies presented five older adults and, on another occasion, twelve healthcare professionals across a spectrum of specialties who work in a rehabilitation hospital with older adults, with our iterated prototypes (prototype3). During these studies, participants were shown videos of these iterated pieces of robotic furniture assisting a member of our lab team while performing CS-PFP10 tasks. These studies aimed to collect initial feedback from older adults and healthcare providers without direct interaction with the robots, using in such studies three-dimensional models and a video of the design, presented on a computer display.

We learned that participants understood the general concept of how the two pieces of robotic furniture function while performing routine domestic tasks, and that this robotic furniture has potential for helping individuals with limited mobility and sometimes mild cognitive challenges now and as they either age in place or as functioning declines (Verma et al, 2018). Necessary to the research team in advancing their design concepts, these two early studies were successful in gaining valuable information and advice to help support the team's direction. However, the studies were limited because participants did not directly get to experience the robotic furniture in a domestic space, see/judge their size, or experience what it would be like to be near these robots. For the study described in this paper, the objective was to determine if low-fidelity mock-ups of the robotic furniture can be effectively used to introduce the general premise of the robotic furniture and evaluate their potential usefulness for individuals with a broad range of physical, cognitive, and visual limitations. Mock-ups have previously shown to be effective in healthcare design (Jouppila & Tiainen, 2020).

The target population for our design is older patients struggling to maintain home independence. This population, with mobility and perhaps mild cognitive challenges, can be overwhelmed by the introduction of an interactive, mobile machine, cohabitating with them. Before inviting this vulnerable population to interact with a relatively large-scale, novel technology, the research team believed it was critical to have healthcare professionals engage as user-study participants, well positioned to provide early feedback on a broad range of patient-users due to their experience working with older adult patients.

3. Objective of the user study

Our user study invited clinicians to interact with nonfunctioning prototypes (see Figure 1—Right) of the robotic furniture, assuming their own roles as professional healthcare providers while thinking of their typical patients. By "nonfunctioning prototypes," here on referred to as simply, "prototypes," we mean physical prototypes absent of envisioned electronic components, robotic or otherwise. The reason for studying the healthcare professionals' interactions with such prototypes was to gain a better understanding of healthcare professionals' opinions of what their patients would likely want and need in their own homes based on their clinical experience.

Practically, the physical artifacts we introduced to participants were low-cost, easily assembled, nonfunctioning prototypes of the actual, functional robotic furniture we are developing. The rectangular volumes of the two prototypes, matching our design for the robot sidetable and floor lamp in shape and size, were fabricated from corrugated plastic; their bases were made of plywood, each base sitting on casters, and the mast of the floor lamp was made of PVC. The apparent low-fidelity and low (or non) functionality of the prototypes left a "gap" for participants to fill with their input on ideas and suggestions for advancing our design. Further objectives of the study were to gain the clinicians' feedback on appropriate methods for the end-users, their patients, to interact with the robotic furniture based upon the patient's physical functioning and comfort with technology as well as to understand the clinicians' opinions regarding the path and speed of the technology.

4. Participants

Participants were recruited from a local rehabilitation hospital. Six healthcare clinicians participated in this study: four occupational therapists, one speech therapist, and one physical therapist. These clinicians routinely primarily provide treatment to older adult patients who have experienced strokes, spinal cord injuries, traumatic brain injuries, orthopedic patients with hand injuries, and patients with Parkinson's. The healthcare professional participants, five females and one male, ranged in age from 35 to 49 years with a mean of 42.7 years (SD = 5.4 years).

5. Materials

The rehabilitation hospital has a "home lab" (see Figure 1—Left) designed by our research team which is used both for patient treatment as well as to study interactions between users and new technologies developed by the authors. The home lab is organized as a studio apartment containing kitchen, dining, and bedroom areas, closets for storage, and a laundry room.

In addition to the two nonfunctioning, robotic furniture prototypes, "smart" coasters were strategically placed around the home lab as landing spots for items in case participants asked how the robots knew where to place an item. If participants asked, it was explained that there could possibly be an RFID tag on the item and the coaster, which would allow the

robot to know where to place the item. Additional supplies needed for the study tasks were also place around the home lab and included a stainless-steel coffee mug, a plastic water bottle, a cell phone, a hardcover book, a box of tissues, and a box of tea.

6. Procedure

For our study, two members of our research team were present. One researcher (standing in as the motor and brain of the robotic furniture) moved the two prototypes in real time as they interacted with and were guided by the clinician participants. The other researcher, meanwhile, moderated the session and took notes.

The study duration ranged from 39 to 53 minutes with a mean of 45 minutes (SD = 5.8 minutes). One participant completed the study at a time. Each participant read and signed the consent form. After the consent form was signed, the researcher asked the participant background questions, including age, gender, occupation, and types of patients they work with. The study began with the participant reading background material that described the purpose of the study, as well as pictures and information about the robots (see Figure 2, left).

Background

We are going to describe three different women who are each 55-years-old and work or worked full time. We would like you to imagine each of these individuals in their own homes where they live with their partner. They each have smart home technologies in their home like Alexa, Roomba, etc. All of the women are suffering from seasonal allergies and are just about out of Kleenex. Their partners called the, forever helpful neighbor, who dropped off an almost full box of Kleenex before going to work in the box outside of the home next to the door. This awesome neighbor also dropped off a box of tea and a book. More information will be provided on each of the women, their physical functioning and their comfort with technology.

Based upon your interactions with the patients you treat, we would like your advice regarding:
1) the appropriate level of assistance needed for each person, and
2) the most appropriate way for each of the three individuals to complete the following tasks using a pair of smart tables (see photos below).
Both smart tables can move around one's home. The smaller table has an arm that bends with a rotating gripper at the end (like a rotating wrist with a hand where the thumb and fingers pinch). The larger table can move up and down, offers storage compartments on its side, has a wireless charging pad for cell phones and can carry the items the arm picks up.

Figure 2 Captions Left, the one-page background describing the smart tables. Right, the background of the three hypothetical personas plus the options for operating the tables.

The researchers then pointed out the prototypes in the home lab and made it clear that the prototypes were just there to give an idea of the size of the actual robotic furniture, but the real ones shown in the pictures were under development in our labs at the university. Next, the participants read a one-page summary that described the three hypothetical patients that served as use cases (see Figure 2, right). These hypothetical patients were developed

based upon common patient characteristics; clinicians who did not participate in the study provided feedback on the personas. There was a description of each patient's injury or ability level, capabilities, physical functioning, and their comfort with technology (see Table 1). Each hypothetical patient was created to represent limitations of the functioning of different parts of the body to help facilitate discussion from the healthcare providers while considering patients with varying degrees of injuries and a narrow difference in comfort with technology (narrow, given that today, most older adults regularly use a smart phone, tablet and/or computer) with the goal of designing the robotic furniture to help as many individuals as possible with a broad range of physical functioning.

Table 1 A summary of the hypothetical personas' injuries, physical functioning, and comfort with technology.

Persona	**Injury / ability level**	**Physical Functioning**	**Comfort with Technology**
"Amy"	10 days out of rotator cuff surgery	Struggling with her sling and pain management.	Has a computer at work and plays on her iPhone at home.
"Beth"	Rheumatoid Arthritis	Copes very well. Has very limited fine motor control with both hands.	Loves voice to text on her computers as well as Siri and Alexa.
"Cate"	Car crash with multiple lower extremity fractures on both legs	Non-weight baring and is using a manual wheelchair.	Computer programmer. Enjoys playing complex video games.

For this study, based on the point of development of the robotic furniture, we were especially interested in gaining participants' perspective on: (1) the most appropriate interface needed for each of the three personas to interact with the robotic furniture and (2) opinions regarding the path and speed of operation of the robotic furniture. After reading the document about the three individuals (personas) to each clinician, the researchers pointed out the different interfaces for operating the robotic furniture and showed an example of each interface when applicable: 1. voice commands, such as Siri or Alexa; 2. large individual buttons; 3. touchpad, such as an iPad, tablet or cellphone; 4. simple game controller like a Wii controller; 5. complex video game controller like an Xbox controller. Participants were then given the opportunity to ask questions before the study began.

Seven different tasks were used (see Table 2). The clinician participants read a description of the task before the task was demonstrated for tasks 1 through 5. For tasks 6 and 7, the participants were asked to describe how they think their patients could accomplish these tasks using the robotic furniture after a description of the task was read to the participants.

Table 2 A description of the seven tasks used in the study.

Task	**Description**
1	____ wants her coffee mug from the kitchen.
2	____ wants her coffee mug brought to her recliner.
3	____'s phone rings on the charging port. She wants her phone.
4	____ drops her empty mug. She needs the table to pick it up.
5	____ wants her empty coffee mug taken to the kitchen.
6	____ wants the table to get the bin with the three items that is outside the front door.
7	____ wants the table to take the book to the nightstand, the tea to the kitchen, while she will keep the box of tissues.

Since one of the goals of this study was to gain the clinicians' perspective on the most appropriate interface needed for each of the three personas to interact with the system, the researcher demonstrated each task using the prototypes, starting with task 1. After each demonstration, the participants completed a worksheet at their own pace, using their own strategy to complete the worksheet (i.e., some participants completed each persona before starting the next while other participants worked on answering questions for all three personas simultaneously), where they rated the appropriateness of each interface while considering both the personas' physical functioning and comfort with technology (see Figure 5).

The clinician participants circled yes or no for each given method of interaction to rate if each method was appropriate for each persona's physical functioning as well as for each persona's level of comfort with technology. The participants were encouraged to complete the yes-or-no questions in the order that was most intuitive for them. The purpose of the yes-or-no questions was to help each participant determine the single most appropriate method of interaction for each persona for that given task. After each task, the participant provided comments and suggestions where they typically described their reasoning for their choices.

The fully automatic ("auto") option (i.e., no user interface) was only used on the worksheets for tasks 2 and 5, since it did not apply to the other tasks. For example, on task 2 the user wanted her coffee mug brought to her recliner. Since, in task 1, she requested her coffee mug be brought from the kitchen, in task 2, the robotic furniture could automatically bring the coffee mug to the location where the request was made in task 1. During task 5, the user wanted her coffee mug to be taken to the kitchen. Since the robotic side table picked up her

dropped coffee mug in task 4, the table could automatically take the empty coffee mug to the kitchen when it picks up the mug during task 4.

Questions:	***1. Physical Functioning*: Is this method of interaction appropriate based upon this person's physical functioning?** ***2. Comfort with technology*: Is this method of interaction appropriate based upon this person's comfort with technology?**					
	Amy Rotator cuff		Beth Rheumatoid Arthritis		Cate Crash / both lower legs	
	Physical Functioning	*Comfort w/ technology*	*Physical Functioning*	*Comfort w/ technology*	*Physical Functioning*	*Comfort w/ technology*
a. Auto…	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No
b. Say	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No
c. Buttons	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No
d. Pad	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No
e. Wii	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No
f. Game Contr.	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No
	***3. Most appropriate*: What is the most appropriate level of interaction based upon this person's combined physical functioning & comfort with technology?**					
Most appro-priate	a b c d e f		a b c d e f		a b c d e f	

Figure 3 The worksheet completed by the participant after each task.

For tasks 6 (the persona wants the robotic furniture to get the bin with the three items that is outside the front door) and 7 (the persona wants the robotic furniture to take the book to the nightstand, the tea to the kitchen, while she will keep the box of tissues), the task description was read aloud, and the participant was asked to describe how they thought the robotic furniture would complete each task. Then the researcher acted out their proposed method. If their proposed method did not work, they then revised their response, and the researcher demonstrated their new proposed method. Once again, the other researcher typed their comments. Participants did not complete a worksheet for these two tasks. Then, participants were asked to answer a series of questions about the concept, using a scale of 1 to 5, where 1 is strongly disagree and 5 is strongly agree (see Table 3).

The final stage of the study asked clinician participants about their opinions regarding the path (including a "home" for re-charging located on a wall in a convenient spot) and speed the robotic furniture should travel, followed by their opinions about how they anticipate their own patients utilizing the technology in their own homes. The three paths included: (1) using a grid on the floor with several 90 degrees turns, (2) using the minimum number of straight lines with the table rotating at the intersection of two lines (like a number 7), and (3) a curved path (similar to the letter C). The speeds were a "normal" walking speed, a "very brisk" walking speed, and a "very, very slow" walking speed.

Table 3 Questions regarding the concept completed after all tasks were demonstrated.

	Questions
1	I understand how *this concept* might help my patients.
2	I understand how *this concept* works on a basic level.
3	I think *this concept* will help make routine tasks easier to perform for my patients.
4	I could envision *this concept* in my patients' homes.
5	*This concept* could help my patients with their daily tasks.
6	I believe my patients could become productive quickly using *this concept*.
7	*This concept* has all the functions and capabilities I expect it to have.
8	I think my patients would like to use something like *this concept*.
9	I think my patients would need the support of a technical person to be able to **set up** *this concept*.
10	I think my patients would need the support of a technical person to be able to use *this concept* **daily**.

7. Results and Discussion

To evaluate if each method of interaction (i.e., voice commands, large individual buttons, touchpad) was appropriate for each of the three personas for the five different tasks, the percentage of "Yes" responses was calculated. The average results of the percentage of "yes" responses of the participants' ratings for each method of interaction based upon a persona's physical functioning as well as the clinician participants' average rating for each persona's level of comfort with technology are presented (see Table 4). The personas are discussed individually.

Based upon the level of physical functioning of "Amy," one of the three personas (as per Table 1) who uses only her non-dominant hand (due to her rotator cuff surgery, while her dominant arm is in a sling), the data suggests that for all five of the tasks, the methods that the clinician participants believed are most appropriate for her were voice commands, the use of the large buttons, and the automatic option. The touchpad ranked in the middle while the Wii type controller and gaming controller ranked the lowest. The same pattern was observed based on Amy's comfort with technology. Voice commands, the large buttons, and the automatic options were deemed the most appropriate for her to use, while the Wii controller and gaming controller were never identified as being appropriate for her to use to interact with the tables based upon her comfort with technology. The touchpad fell directly in the middle of the two extremes.

"Beth's" Rheumatoid Arthritis may have been the reason the clinician participants' attitudes towards Beth's physical functioning showed no variability. The automatic option was always appropriate when it was available, as were the voice commands and large buttons. Half of the participants believe the touchpad would be appropriate for her to use based upon her physical functioning, while none of the participants selected either the Wii controller or the gaming controller for any task. Based on Beth's comfort with technology, 100% rated the automatic option, voice control and large buttons as appropriate options. Based upon Beth's comfort with technology, the touchpad was rated higher than it was for Amy. For the first two tasks, one participant felt that both the Wii controller and gaming controller could be appropriate for her to use to operate the tables, however no other participant was in favor of either the Wii or gaming controller for any of the tasks.

"Cate" is a programmer and gamer who is wheelchair bound due to her body being non-weight-bearing due to multiple lower extremity fractures on both legs. Based upon Cate's physical functioning, the clinician participants provided a minimum of 96.7% support for all technologies with 100% support for the automatic option, voice commands, the Wii controller and gaming controller for any task. Based on Cate's comfort with technology, the pattern stayed the same, where the automatic option, voice commands, the Wii controller and gaming controller all had 100% support. Across the three participants, Cate had the highest rating for comfort with the touchpad (93.3%) and the lowest rating for the large buttons (80%).

Table 4 The average percentage of "Yes" responses for all tasks for each person, for both physical functioning and comfort with technology. N/A means that that method of interaction was not an option for that task.

		Physical functioning						Comfort with technology					
		Auto	Voice commands	Large buttons	Touch pad	Wii controller	Gaming controller	Auto	Voice commands	Large buttons	Touch pad	Wii controller	Gaming controller
Amy: Rotator Cuff	Task 1	N/A	83.3%	100.0%	83.3%	66.7%	16.7%	N/A	100.0%	100.0%	50.0%	0.0%	0.0%
	Task 2	83.3%	83.3%	100.0%	66.7%	16.7%	16.7%	100.0%	100.0%	100.0%	50.0%	0.0%	0.0%
	Task 3	N/A	83.3%	83.3%	66.7%	0.0%	0.0%	N/A	100.0%	100.0%	66.7%	0.0%	0.0%
	Task 4	N/A	100.0%	100.0%	83.3%	16.7%	16.7%	N/A	100.0%	100.0%	50.0%	0.0%	0.0%
	Task 5	100.0%	100.0%	100.0%	50.0%	16.7%	16.7%	83.3%	100.0%	100.0%	50.0%	0.0%	0.0%
	Average	91.7%	90.0%	96.7%	70.0%	23.4%	13.4%	91.7%	100.0%	100.0%	53.3%	0.0%	0.0%
Beth: Rhuematoid Arthritis	Task 1	N/A	100.0%	100.0%	50.0%	0.0%	0.0%	N/A	100.0%	100.0%	83.3%	16.7%	16.7%
	Task 2	100.0%	100.0%	100.0%	50.0%	0.0%	0.0%	100.0%	100.0%	100.0%	66.7%	16.7%	16.7%
	Task 3	N/A	100.0%	100.0%	50.0%	0.0%	0.0%	N/A	100.0%	100.0%	83.3%	0.0%	0.0%
	Task 4	N/A	100.0%	100.0%	50.0%	0.0%	0.0%	N/A	100.0%	100.0%	83.3%	0.0%	0.0%
	Task 5	100.0%	100.0%	100.0%	50.0%	0.0%	0.0%	100.0%	100.0%	100.0%	83.3%	0.0%	0.0%
	Average	100.0%	100.0%	100.0%	50.0%	0.0%	0.0%	100.0%	100.0%	100.0%	80.0%	6.7%	6.7%
Cate: Crash / both lower legs	Task 1	N/A	100.0%	100.0%	100.0%	100.0%	100.0%	N/A	100.0%	83.3%	83.3%	100.0%	100.0%
	Task 2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	83.3%	100.0%	100.0%	100.0%
	Task 3	N/A	100.0%	83.3%	83.3%	100.0%	100.0%	N/A	100.0%	83.3%	100.0%	100.0%	100.0%
	Task 4	N/A	100.0%	100.0%	100.0%	100.0%	100.0%	N/A	100.0%	83.3%	83.3%	100.0%	100.0%
	Task 5	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	66.7%	100.0%	100.0%	100.0%
	Average	100.0%	100.0%	96.7%	96.7%	100.0%	100.0%	100.0%	100.0%	80.0%	93.3%	100.0%	100.0%

8. What we learned 1: About mode of interaction

The physical functioning and comfort with technology ratings were designed to help the clinician participants think about the components that play into their decisions regarding the single most appropriate level of interaction for each persona based upon their combined physical functioning and comfort with technology. The graphs in Figure 4 show the most appropriate method suggested for Amy, Beth, and Cate separately by task.

For "Amy," voice commands were the most appropriate level of interaction for tasks 1 (coffee mug from the kitchen), 3 (phone rings on the charging port), and 4 (drops her mug and wants it picked up). When the automatic option was available, for tasks 2 (wants coffee mug brought to her recliner) and 5 (wants her empty coffee mug taken to the kitchen), this option was picked as the most appropriate for those tasks. The large buttons were the next most appropriate choice for Amy for all tasks. The touchpad was only selected by one participant for task 1. Neither the Wii controller nor the gaming controller were ever picked as most appropriate for Amy for any of the tasks.

A very similar pattern continued for "Beth." The voice commands were selected as the most appropriate methods for tasks 1, 3, and 4. When the automatic option was available, for tasks 2 and 5, this option was picked as the most appropriate for her as well. The difference between Amy and Beth was that the large buttons were never picked as most appropriate for Beth. Instead, the touchpad was selected as the second most appropriate option after voice or automatic, for four of the tasks. The large buttons, Wii controller and gaming controller were never picked as most appropriate for Beth for any of the tasks.

"Cate" had a very different pattern for all the tasks where the gaming controller was picked as most appropriate for Cate to use, followed by voice commands and automatic (when this option was available). What is particularly interesting about Cate is that, while the pattern of results is not consistent, the large buttons, touchpad and Wii controller were all selected as an option at least once. Cate was the only persona where every method of interaction was picked by at least one participant as the most appropriate method of interaction.

Tasks 6 and 7 are retrieving the box from outside and placing the objects around the home. For task 6, the persona wants the robotic furniture to get the bin with the three items that is outside the front door, while for task 7, the persona wants the robotic furniture to take the book to the nightstand, the tea to the kitchen, while she will keep the box of tissues. For task 6, five participants said that the robotic floor lamp with the arm (i.e., the floor lamp's mast, which actively bends and has a gripper at its end) would complete all tasks. Most of the clinician participants said the robotic floor lamp with the arm would open the door and attach itself to the bin, while some said the robotic side table would go with the robotic floor lamp and prop the door open. One clinician participant said only the floor lamp would open the door and then its arm would reach down and get the bin. After the demonstration, this participant decided it would be easier for the side table's embedded magnets to attach to and bring the bin inside instead of using the robotic lamp's arm to do this. Only one participant said that the robotic side table with embedded magnets would go and attach to the bin to

bring it in. After the demonstration showed that the door needed to be opened, the participant changed their response to include the robotic floor lamp where its arm would open the door. For the final task of placing the objects around the living space, all clinician participants selected to disperse the items one at a time using the robotic floor lamp with its active arm. Three participants said they would use voice commands to tell the robotic floor lamp where to take the items. One participant said they would get the box of tissues out of the bin and then use the Wii controller to send off the robotic floor lamp with the items to the places they need to go.

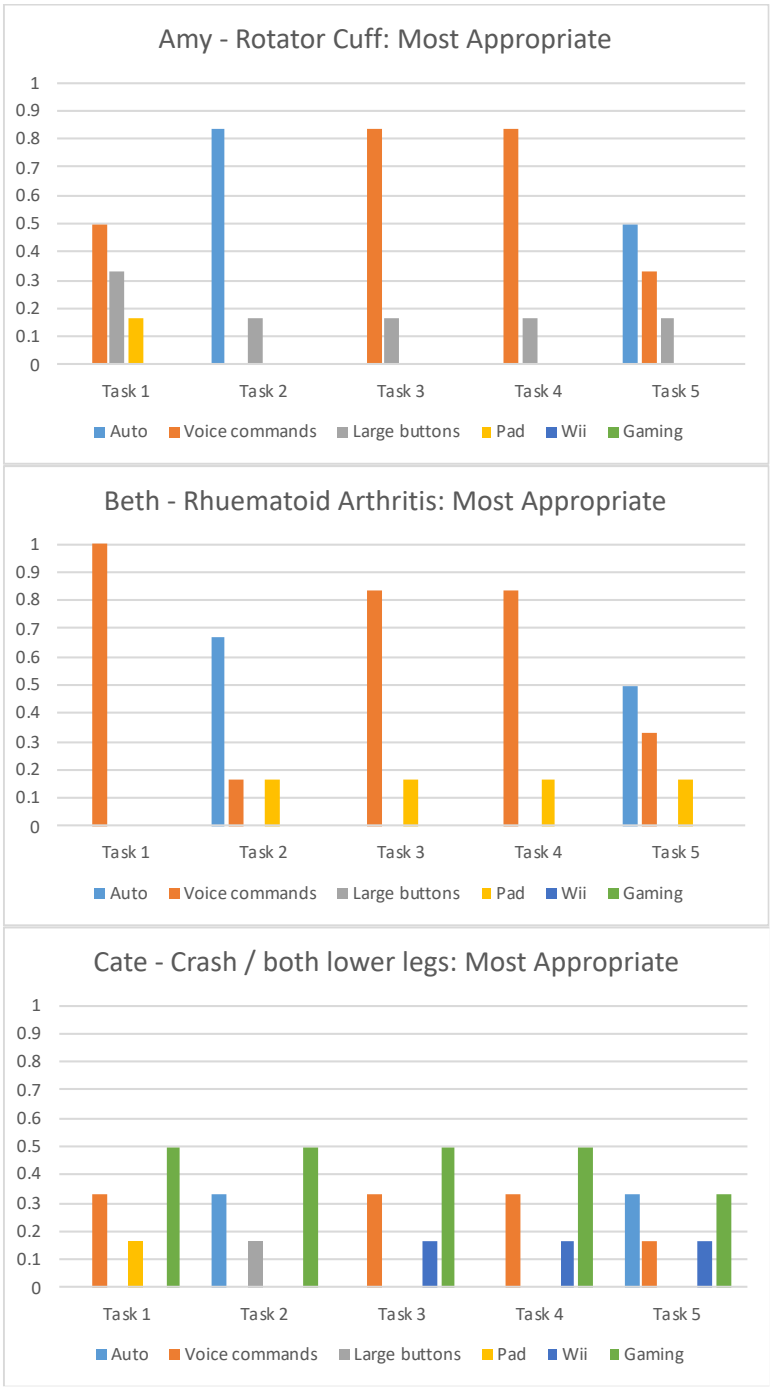

Figure 4 The most appropriate level of interaction for each persona for each task.

9. What we learned 2: About usability

The clinician participants responded to a series of usability statements, using a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree (see Table 5).

Table 5 Usability questions regarding the participants' beliefs.

	Question	Average	SD	Min.	Max.
1	I understand how *this concept* might help my patients.	4.7	0.5	4	5
2	I understand how *this concept* works on a basic level.	4.3	0.5	4	5
3	I think *this concept* will help make routine tasks easier to perform for my patients.	4.5	0.5	4	5
4	I could envision *this concept* in my patients' homes.	4.0	0.6	3	5
5	*This concept* could help my patients with their daily tasks.	4.5	0.5	4	5
6	I think my patients would like to use something like *this concept*.	4.0	0.6	3	5
7	*This concept* has all the functions and capabilities I expect it to have.	3.0	1.1	1	4
8	I think my patients would like to use something like *this concept*.	4.0	0.0	4	4
9	I think my patients would need the support of a technical person to be able to **set up** *this concept*.	4.8	0.4	4	5
10	I think my patients would need the support of a technical person to be able to use *this concept* **daily**.	2.5	0.5	2	3

Overall, the clinician participants' attitudes towards the robotic furniture were quite positive. For all but two of the statements, the average of the participants' responses was 4.0 or higher. While all participants agreed or strongly agreed that their patients would need the support of a technical person to be able to set up the concept (average 4.8), it is encouraging that the participants disagreed or were neutral towards the statement "I think my patients would need the support of a technical person to be able to use this concept daily"; that is

the only statement where a low score is desired (average 2.5). For the statement, "This concept has all the functions and capabilities I expect it to have," the two low scoring participants who disagreed, commented that they did not know all the capabilities of the robotic furniture based upon the demonstrations given today. For example, many participants were visibly surprised that the robotic side-table would be able to rise to allow for easier access to the contents on the top of the table. The participant who rated the statement "I could envision this concept in my patient's homes" with a 3, provided the reasoning that many of their patients are unfunded or do not own homes, so for financial reasons it was hard to envision this kind of technology for them. One participant commented that it was hard to answer these questions because cognition is so variable between patients.

10. What we learned 3: About path of motion

The clinician participants were shown three different possible paths the robotic furniture might take in one's home: 1. a grid-like pattern on the floor with several 90 degree turns, 2. using the minimum number of straight lines with the table rotating at the intersection of two lines (like a number 7), and 3. a curved path (like the letter C). Participants were first asked if each path was acceptable or not. All three paths were acceptable to all participants. Then, after seeing all three path options, participants were asked to rank order the paths. Half of the participants picked the curved path as their first choice, 50% ranked the straight-line path (like a number 7) as their second choice, and two-thirds ranked the grid path as their last choice. One participant had no idea how they would rank the paths. Figure 5 shows the ranking data for the robotic furniture's' path.

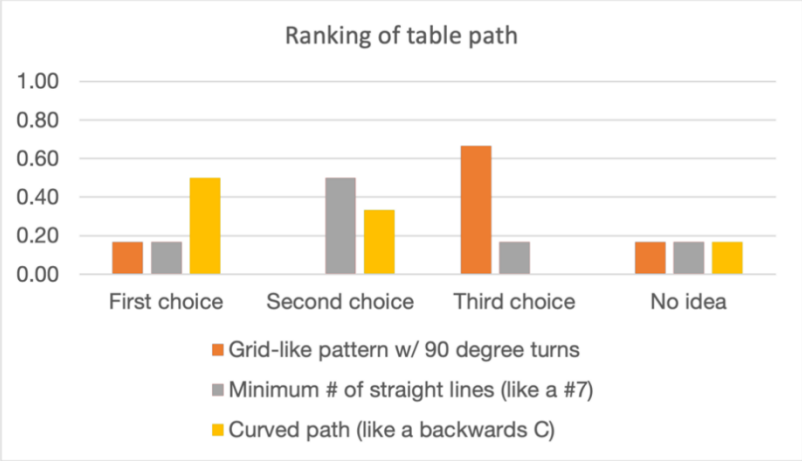

Figure 5 The first, second, and third choice of the path pattern.

11. What we learned 4: About speed of motion

The clinician participants were shown a demonstration of three different possible speeds for the robotic furniture where a researcher carried a coffee mug from the bedroom area to the table to demonstrate the speed in a real situation: 1. a brisk walking speed, 2. a normal

walking pace, and 3. a slow walking pace. Participants were first asked if the speed was acceptable or not. Then, participants were asked to rank the speeds in order from first choice to last choice. The brisk walking speed was acceptable for 66.7% of the participants, the normal walking pace was acceptable for 100% of the participants, and only 50% found the slow walking pace acceptable. Two participants felt like the brisk walking speed was a little too fast for older patients. Interestingly, there were three participants who felt that the slow walking pace, even though it was potentially safer, was way too slow for patients.

When asked to rank order the speeds, 100% picked the normal walking speed as their first choice. Two-thirds of the participants picked the slow walking speed as their second choice while one-third picked the brisk pace. The opposite pattern was observed for the third choice, where 66.7% picked the brisk walking speed. Participants offered that safety must take priority over inconvenience; consequently, participants picked the slower pace for the second choice before the faster one, even though the slower speed might be annoying for patients.

12. What we learned 5: About smaller things

Participants were asked if they thought the robotic furniture should return to a "home position" after each task, and if so, how. Two clinician participants said the robotic furniture should return to a home position but don't necessarily need to automatically go "home." One of these participants thought it would be nice to use voice commands to tell the robotic furniture where to go after each task, but that it would be good if the robotic furniture would automatically go home after a certain amount of downtime. The other participant suggested that the robotic furniture will need to go to their "home position" for wheelchair users, and there should be a large button to press for them to go "home." The other four clinician participants said the robotic furniture should not automatically go home. Several of these participants believe going "home" would be a waste of time and energy after each task; however, it would be nice to just be able to tell it where to go, in case one wants it to stay near them or get out of the way.

When asked how to differentiate two mugs on a "smart" coaster and how to tell the robotic furniture which mug to get, four participants said they would use directional words like left or right. One participant said they could tell the robotic furniture to pick the heavier one. Another participant suggested that the robotic furniture stream a picture of the coaster, so the user can indicate which one to get.

If an individual had to control both pieces of robotic furniture, the clinician participants were asked if they think the patient would need one or two controllers. All of the participants picked one controller. Five out of the six clinician participants said that it would be overwhelming for their patients to have two controllers, and it would be hard for the patient to have to keep up with two controllers.

When asked what types of patients could benefit from this concept, the most common response was for patients who have limited mobility and upper extremity use but have intact

cognition skills, such as spinal cord injury patients, quadriplegics, and/or wheelchair-bound patients. One clinician participant mentioned it would be great for patients who have frequent falls. Another participant mentioned only patients who are physically impaired and can't do anything with their arms, like paralysis or multi-trauma patients, would benefit from this technology while patients like Amy and Beth should be walking as much as possible. The clinicians also stressed the importance of movement and that patients' need to walk and move as much as possible, stressing that "if you don't use it, you will lose it."

Finally, the clinician participants were asked what types of situations they could envision their patients using this concept. Assistance tasks, such as picking items up and retrieving items patients are unable to reach were mentioned the most. The second most frequent response was when patients are home alone and there isn't a helper. Other situations that were mentioned include carrying a basket of laundry, carrying a plate of food or drink, and other self-care tasks.

Overall, the clinician participants stressed the importance of keeping user interactions as simple as possible. For one, participants recognized voice activation as the easiest way to control such assistive technologies given the patient population's familiarity with Siri and Alexa and because there are no buttons, tablet interfaces, or controllers required. Talking to a table may also help patients who are apprehensive of technology be able to overcome their technology anxieties. At the same time, the clinician participants recognized that patients with gaming and computer skills will be able to use any of these interfaces successfully to operate the robotic furniture; however, keeping up with the interface devices may still be a challenge.

Some clinician participants had mixed feelings over the automatic option; they could envision use cases where it could frustrate or confuse individuals. For example, the robotic lamp automatically takes a cup to the kitchen, but the patient wants the cup elsewhere.

Participants asked the price of the robotic furniture, if the top of the side-table robot can rotate or just its base, if the two pieces of robotic furniture have the same speed, and will patients have to reach for items or will the robotic furniture always set items down on smart sensor pads.

13. Discussion: Research aims and a summary of findings

The purpose of this study was to invite clinicians to interact with nonfunctioning robotic furniture to gain a better understanding of what their patients would want and need in their homes based upon their clinical experience. A second aim was to gain the clinicians' feedback on appropriate methods for their patients to interact with the robotic furniture. A third aim was to understand the clinicians' opinions regarding the path and speed of the robotic furniture. Hypothetical personas were created to represent common limitations of the functioning of different parts of the body to help facilitate discussion from the healthcare providers while at the same time considering patients with varying degrees of physical functioning

and comfort with technology. A limitation of the study is that the three personas were the creation of the study participants, a kind of "familiarity" that might impact responses.

After the clinicians observed how the robots could move and function within the domestic environment, the clinicians provided feedback on potential methods of interaction, ranging from voice commands to game controllers. Even though the appropriate method of interaction for the five tasks differed with each of the three personas as anticipated, there were several similarities based upon the level of physical functioning and the level of comfort with technology. For "Amy" who uses only her non-dominant hand, the clinicians suggested that, for all five of the tasks, the most appropriate method of communication was voice commands followed the use of large buttons. For "Beth" who has Rheumatoid Arthritis, the automatic option was always appropriate, as were the voice commands and large buttons. Half of the participants believed the touchpad would be appropriate for Beth to use based upon her physical functioning, while none of the participants selected the video game controllers for any task. For "Cate" who is wheelchair-bound, the participants provided a minimum of 96.7% support for all technologies with 100% support for the automatic option, voice commands, the Wii controller and gaming controller for all tasks based on her physical functioning.

For the most appropriate method of interaction, Amy and Beth both had the same pattern: voice commands were selected as the most appropriate methods for tasks 1 (mug from kitchen), 3 (phone from charging port), and 4 (table pick up empty mug) while the automatic option was picked as most appropriate for tasks 2 (mug to recliner) and 5 (empty mug to kitchen). "Cate" had a very different pattern for all tasks: the gaming controller was picked as most appropriate, followed by voice commands and the automatic option. Proficient with technology, Cate was the only persona for whom every method of interaction was picked by at least one participant.

All three paths (grid-like, like a number "7," and a backwards "C") were acceptable to all participants, and all participants picked the normal walking speed as their first choice.

Overall, the clinicians provided a very positive rating on the concept of the robotic furniture. They felt this robotic pair could help many of their patients in their own homes when they are alone, need help with tasks, or when completing self-care tasks. Overall, the clinicians stressed the importance of keeping the user interactions as simple as possible. The clinicians especially liked the voice activation because there are no additional buttons, tablet interfaces, or controllers for the individual to keep up with. There were frequent comments that voice commands will always be the easiest way to control the robotic furniture. Due to the popularity of Alexa, Siri and other similar technologies, the clinicians frequently commented that their patients of all ages have a growing level of comfort with using voice commands.

14. Contribution and Future Work

In his short story of 1942, "Runaround," Isaac Asimov offered his "Three Laws of Robotics" that continue to inform robot development (e.g., for Neznamov, 2018). The first of these

laws is that "a robot may not injure a human being" (Asimov, 1991). More than fifty years after the first publication of "Runaround," Weld and Etzioni (1994) considered the significance of Asimov's first law, posing critical questions about it such as "*How should one formalize the notion of 'harm'?*" and "*How can an agent avoid performing harmful actions…?*" As computer scientists, Weld and Etzioni responded to these questions by offering a computational framework focused on motion planning that would best ensure that robots do no harm to those who use them or are simply in their proximity. The authors of this paper, coming from design, numerous engineering disciplines, and clinical healthcare, responded differently than the computer scientists, offering a design approach that incrementally delivers robots to their intended users via a "step-by-step" approach to robot design.

Practically, this paper presented a quick, effective, and inexpensive method to gain meaningful feedback from clinicians who can speak for a wide range of patients during early stages of developing enabling technologies. Interacting with nonfunctioning, physical prototypes early in design development, clinicians can envision the rough shape and form of an enabling technology, how their patients might embrace and control this technology, and how the technology might interact and support them in their daily activities. All of this is done prior to exposing vulnerable, target populations to enabling technologies (especially, sophisticated, cyber-physical ones) that have not yet been well developed – that might, given their immaturity, cause vulnerable individuals "harm" by confounding them and even causing them physical harming.

Following the design research exemplar reported here, user studies with low-fidelity, physical prototypes are one step in a longer arc of a design process which, step-by-step, with more refined, robust-functioning prototypes, will necessarily involve older adults. In our case, based upon the findings of the user study with clinicians reported here, our design research team will make refinements to how the robotic furniture will operate, including speed and path planning. The lessons learned from this study will inform the team's next step: conducting a very similar study but with older adults who use or have used assistive devices, specifically a walker, in their own home. At the earlier stages of design, however, insights gained from clinicians, based on their clinical experience, can constructively inform design development, with the overarching goal of designing technological systems that improve the wellbeing of individuals striving to maintain their independence, step-by-step.

Acknowledgements: This research was supported by the U.S. National Science Foundation, award IIS-1703267. Thank you to Yixiao Wang, Deanna Kocher, and Robert Shield.

15. References

Aging in Place: Growing Older at Home. The National Institute on Aging of the National Institute of Health, Available February 12, 2024 at https://www.nia.nih.gov/health/aging-place-growing-older-home.

Asimov, I. "Runaround" in *I, Robot*. (1991). New York: Bantom Books.

Aging in Place vs. Assisted Living. Available February 12, 2024 at https://aginginplace.org/aging-in-place-vs-assisted-living/.

Cress, E. M., Petrella, J. K., Moore, T. L, and Schenkman, M. L., Continuous-Scale Physical Functional Performance Test: Validity, Reliability, and Sensitivity of Data for the Short Version, *Physical Therapy*, Volume 85, Issue 4, 1 April 2005, pp. 323–335, https://doi.org/10.1093/ptj/85.4.323

Etzioni, O. and Weld, D. (1994). "The First Law of Robotics (a call to arms). AAAI Technical Report SS-94-03. Available Feburary 19, 2023 at https://cdn.aaai.org/Symposia/Spring/1994/SS-94-03/SS94-03-003.pdf.

Forlizzi, J., DiSalvo, C., & Gemperle, F. (2004). Assistive Robotics and an Ecology of Elders Living Independently in Their Homes. *Journal of Human-Computer Interaction*, Volume 19, Issue 1-2, pp. 25-59, 2004. https://doi.org/10.1207/s15327051hci1901%262_3

Jouppila, T. & Tiainen, T. "Nurses' Participation in the Design of an Intensive Care Unit: The Use of Virtual Mock-Ups." *HERD: Health Environments Research & Design Journal*, July 2020. https://doi.org/10.1177/1937586720935407

Mataric, M. J. & Scassellati, B. (2016). Socially Assistive Robotics. *Springer Handbook of Robotics*, B. Siciliano and O. Khatib, Eds., pp. 1973-1993.

Neznamov, A. (2018). New Laws of Robotics: Towards the Future Regulation. In *Proceedings of the 2018 International Conference on Robotics, Control and Automation Engineering* (RCAE 2018). Association for Computing Machinery, New York, NY, USA, pp. 91–95. https://doi.org/10.1145/3303714.3303728.

Prassler, E., Munich, M. E., Pirjanian, P., & Kosuge, K. (2016). Domestic Robotics. *Springer Handbook of Robotics*, B. Siciliano and O. Khatib, Eds., Chapter pp. 1729-1758, 2016.

Smart Home Market worth $135.3 billion by 2025. Available February 12, 2024 at https://www.prnewswire.com/news-releases/smart-home-market-worth-135-3-billion-by-2025--exclusive-report-by-marketsandmarkets-301087964.html.

Verma, S. Gonthina, P., Hawks, Z., Nahar, D. Brooks, J. O., J., Walker, I.D., Wang, Y,. de Aguiar, A., and Green, K. E. 2018. Design and Evaluation of Two Robotic Furnishings Partnering with Each Other and Their Users to Enable Independent Living. In *Proceedings of Pervasive Health 2018*, New York, NY., May 21-24, 2018. In *Proceedings of the 12th EAI International Conference on Pervasive Computing Technologies for Healthcare* (PervasiveHealth '18). Association for Computing Machinery, New York, NY, USA, 35–44. https://doi.org/10.1145/3240925.3240978

About the Authors:

Johnell Brooks is a Human Factors and Industrial–Organizational Psychologist whose research focuses on the intersection of Psychology, Healthcare, and Engineering.

Casey Jenkins works with Dr. Brooks specializing in data collection from at-risk user populations.

Staphanie Tanner is the Director of the Clinical Research Unit – Upstate for Prisma Health.

Ian Walker is a Professor of Electrical and Computer Engineering at Clemson University, USA. His research interests are in robotics.

Keith Evan Green is *Jean and Douglas McLean Professor of Human Centered Design* at Cornell University with expertise in Architectural Robotics.