Exercising with Baxter: Design and Evaluation of Assistive Social-Physical Human-Robot Interaction

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ABSTRACT

The worldwide population of older adults is steadily increasing and will soon exceed the capacity of assisted living facilities. Accordingly, we aim to understand whether appropriately designed robots could help older adults stay active and engaged while living at home. We developed eight human-robot exercise games for the Baxter Research Robot with the guidance of experts in game design, therapy, and rehabilitation. After extensive iteration, these games were employed in a user study that tested their viability with 20 younger and 20 older adult users. All participants were willing to enter Baxter's workspace and physically interact with the robot. User trust and confidence in Baxter increased significantly between pre- and post-experiment assessments, and one individual from the target user population supplied us with abundant positive feedback about her experience. The preliminary results presented in this paper indicate potential for the use of two-armed human-scale robots for social-physical exercise interaction.

CCS CONCEPTS

• **Computer systems organization** → **Robotics**; • **Human-centered computing** → *User studies*; *Activity centered design*;

KEYWORDS

socially assistive robotics, physical human-robot interaction, exercise games, personal robots

1 MOTIVATION

Increases in life expectancy foreshadow the need for more accessible in-home healthcare solutions in the United States and beyond [4]. One strategy to enhance our society's ability to keep older adults healthy and active in their homes is the introduction of assistive robots in everyday environments. Generally, low-impact exercises are recommended to keep older people cognitively and physically well [5]. Researchers have already found that robotic exoskeletons can promote upper-limb exercise by physically interacting with human users [16]. Other investigations have indicated that robots can motivate older adults to stay active via social communication [6]. As pictured in Fig. 1, the exercise games we designed fit at the intersection of physical human-robot interaction and socially assistive robotics. *Our central hypothesis is that a robot can use these novel social-physical exercise games to engage users in enjoyable light exercise activities.*

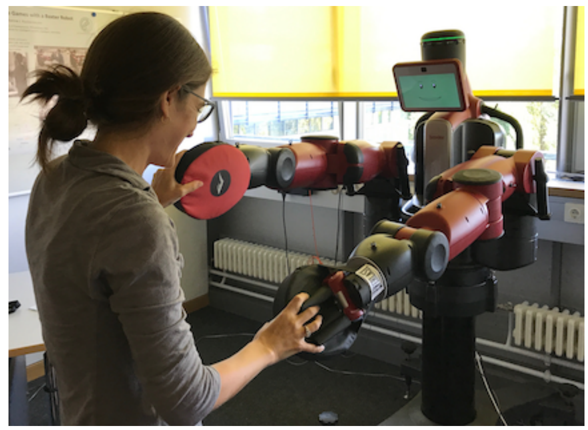


Figure 1: Example human-robot exercise game interaction. Our customization of this robot's facial expressions and end-effectors help Baxter serve as a gameplay partner.

This research builds on our previous investigations of playful hand-clapping robots [9], using similar hand contact detection strategies, compelling robot motion, and hardware to accomplish broader physical human-robot exercise interactions. Our work explores using the Rethink Robotics Baxter Research Robot to promote exercise via eight different exercise games, six of which involve physical human-robot interaction (pHRI). Initial prototypes for these six pHRI games were described in [7] and demonstrated at the 2017 ACM/IEEE International Conference on Human-Robot Interaction [10]. Section 2 of this paper outlines the later game design iteration steps. The proof-of-concept study described in Section 3 helped us judge the viability of using these games to engage older adults and promote exercise. The selected results in Section 4 and discussion in Section 5 demonstrated that people are willing and motivated to interact with the robot in this way and that different games promote unique physical and cognitive exercise effects.

2 HUMAN-ROBOT EXERCISE GAMES

To begin prototyping social-physical human-robot interactions for in-home assistive applications, we needed to identify robotic hardware that was safe for physical interaction, consult with experts, and create a set of games with some inherent exercise motivation. The resulting games include the Mimic, Stretch, Teach, Agility, Strength, Handclap, Roboga, and Flamenco Games.

Figure 2: Frames from the eight exercise games.

2.1 Hardware for Exercise Interactions

We selected a Rethink Robotics Baxter Research Robot for this investigation. This robot offers advantages for pHRI and exercise interactions because it is human-sized, anthropomorphic, and safe for physically interactive tasks. Baxter possesses safe mechanical features like series elastic actuators, fully backdrivable joints, and impact-absorbing shells. The humanoid anatomy of this robot results in intuitive mapping of game motions to the human body, and Baxter is available at a relatively low price (~$32,000).

Baxter's commercially available end-effectors proved unsuitable for our envisioned human-robot interactions. Instead, we used Everlast brand boxing pads easily placed over the standard parallel-jaw grippers as end-effectors. These lightweight pads allow users to interact quite forcefully with Baxter without hurting themselves.

External computer speakers were also incorporated into the system to add music and other sounds to game interactions. We used the Mingus synthesizer, a wrapper for the FluidSynth MIDI sound synthesizer, to compose, load, and play musical effects in the exercise games. FluidSynth requires a sound font file to run, so we selected the OmegaGMGS2 sound font, which suited our purposes of playing different notes in various instrument modes.

2.2 Human-Robot Exercise Game Design

We designed eight games for users to play with Baxter, as pictured in Fig. 2 and described throughout this Section. Our intention was to create safe and entertaining interactions that promote upper-arm mobility while inducing a moderate level of physical and cognitive exercise. To promote social engagement, the games were augmented by a suite of facial expressions [8] and nonverbal behaviors (blinking, changes in emotion, head movements, etc.) implemented using Baxter's LCD screen and head joints. Music and audiovisual feedback were incorporated into many of the games in an effort to enhance motivation and enjoyment. The games vary between user-led and robot-led interactions, competitive and cooperative premises, as well as symmetric and asymmetric motions; this diversity allows us to consider how these factors affect user motivation and overall interaction experience.

The Mimic Game was designed to make users hold up their arms and contact Baxter throughout the activity. In this game, the user gradually teaches Baxter a long pattern of left-, right-, and both-handed impacts which Baxter has to repeat at each step. The participant can win the game by demonstrating a sequence of hand impacts that is long and diverse enough to "confuse" the robot. The human user loses if they make a mistake when repeating their own hand impact pattern. This game involves a cognitive dimension that challenges users to remember a pattern. The motions in this game are mostly sagittally asymmetric. On the whole, the Mimic Game was designed to be an engaging, memory-intensive, and competitive experience.

The Stretch Game leverages Baxter's large workspace to encourage the user to make large arm motions. In this interaction, Baxter strikes a series of poses, cuing the user to mimic its pose and simultaneously hit both of its end-effectors within a fixed time after reaching each new pose. At the end of the game, Bater plays a series of chords with bad-sounding notes to represent any contacts that the user missed. People engaging with the robot must use their spatial awareness to reposition themselves and their arms as needed throughout the game. The motions in this game are sagittally asymmetric. The Stretch Game was designed to be an engaging and part-competitive/part-collaborative experience.

The Teach Game challenges users to support the weight of Baxter's arms while moving them around the robot's workspace to create a musical composition. The user can play and record notes by twisting Baxter's wrists while holding the robot's arms in poses of interest; locations map to notes. Once the user is done composing, Baxter plays back the recorded sequence of notes with the associated motions. If the user intends to create a particular composition, the game requires cognitive abstraction skills (to understand how the robot's pose relates to a musical note) and attention (to be able to explore the workspace and select notes before losing track of current and past notes). The motions in this game are sagittally asymmetric. The Teach Game was designed to be an engaging, attention-provoking, and collaborative experience.

The Agility Game was designed to encourage robot users to hold up their arms and rapidly contact Baxter. In this interaction, the user attempts to "wake" a sleeping Baxter by repeatedly hitting its end-effectors. This activity requires fast rather than forceful hand contact. The motions in this game are typically sagittally symmetric. Overall, the Agility Game was designed to be an engaging, physically demanding, and competitive experience.

The Strength Game encourages users to hit Baxter somewhat forcefully while going through a boxing training-like interaction set to energetic music. Baxter strikes a sequence of poses and prompts the user to contact its end-effectors with a one-two punch after reaching each new pose. This game requires attention (to perceive the cues indicating that Baxter is ready for a one-two punch). The motions in this game are sagittally symmetric. On the whole, the Strength Game was designed to be an engaging, physically demanding, and part-collaborative/part-competitive experience.

The Handclap Game was designed to make users hold up their arms and contact Baxter throughout the activity. This interaction is similar to a children's hand-clapping game, such as "Pat-a-Cake" or "Miss Mary Mack." Baxter demonstrates a series of hand-clapping motions and the user joins in the clapping game by physically contacting the robot's hands. The same hand-clapping game repeats with one new appended motion in each repetition. Users are challenged in the area of visiospatial cognition as they interpret and reciprocate robot movements. The motions in this game are sagittally asymmetric. The Handclap Game was designed to be an engaging and part-competitive/part-collaborative experience.

The Roboga Game is similar to related work in [6] and does not involve human-robot contact. Users are challenged by the requirement of holding up their own arms' weight. Baxter strikes a stretching pose, the user matches the pose, and both parties hold the pose for several seconds. The sagittally symmetric poses are concatenated to create stretching routines similar to those found in physical therapy exercises for shoulder and bicep tendon injuries. Overall, the Roboga Game was designed to be a less engaging experience that was physically demanding and collaborative.

The Flamenco Game challenges users to exercise by carrying out different dance moves, none of which involve human-robot contact. Baxter demonstrates a sequence of simple dance moves along with music, nods to the participant, and then waits for the human user to try the same dance along with music. Users are challenged in the area of visiospatial cognition as they interpret and reciprocate robot movements. The motions in this game are sagittally asymmetric. The Flamenco Game was designed to be a less engaging experience that was part-competitive/part-collaborative.

2.3 Feedback from Experts

This work was informed by expert guidance from a game designer, a rehabilitation robotics researcher, a physical therapist, an occupational therapist, and other roboticists. Feedback throughout these design steps helped us to enter the subsequent study with exercise games we believed would be robust and effective.

The game designer with whom we consulted encouraged us to think about ways to incorporate integrated forms of feedback, such as social cues delivered by the robot, into our exercise games. They were also curious about the possibility of using Baxter as an input device, an idea that contributed to the shaping of the Teach Game.

Constructive feedback from the rehabilitation robotics expert included cautions against making games too mentally demanding (difficult for older adults with cognitive impairment), too visually demanding (difficult for elders with macular degeneration), or too physically demanding (difficult for individuals with motor impairments or who are recovering from stroke). This expert's comments led us to design games with adaptive difficulty levels and redundant cues (for example, Baxter may display a particular face and make a noise to cue a user to do something). The rehabilitation robotics expert also suggested adding sound effects and musical premises to the games in order to make the associated interactions seem more naturally situated. For example, boxing with a robot along with a motivational song or moving Baxter's arms around to create music seemed more logical to this expert than hitting or manipulating a silent robot.

We incorporated the feedback from our rehabilitation robotics expert and next shared the exercise games with a physical therapist and an occupational therapist who had experience working with roboticists. These specialists played the exercise games and helped us to adjust the activity workspace, robot poses, and strength/speed requirements to ensure game usability by our target population.

Based on feedback from all of the specialists, we customized the games to fit each user's physical and cognitive abilities, as assessed at the start of the study session. Throughout the games, the maximum hand-to-hand span of the robot was limited to the user's height. We incrementally relaxed the action speed requirements in several exercise games for users with limited arm motion speed. For older adults, the memory requirements in some games were adjusted based on cognitive ability levels.

To gather feedback from robotics experts, we demonstrated our robot exercise games at the 2017 International Conference on Human-Robot Interaction in Vienna, Austria [10]. This demonstration helped us to find and correct any problems with the game logic. We observed that users were very active when playing the Agility Game with Baxter; they spoke to the robot, rapidly contacted the robot, and sometimes played the game with a friend. The Strength Game also seemed to promote high-energy and interest from users. Visitors to this demonstration shared ideas about new game features to entertain healthy young adults, such as having Baxter take "boxing selfies" of the user during their Strength Game interaction or play popular music throughout the chord-associated poses of the Stretch Game.

3 EXERCISE GAME USER STUDY

We conducted a user study to evaluate how people respond to prompts to play exercise games with Baxter and how such games may fit into assistive applications. Eligible participants played a sample of each game, reported perceptions of each game, and selected their favorite game to try again in a longer free-play interaction. The Penn IRB approved all experimental procedures under protocol 826370. This initial investigation was designed to inform future research on robot-motivated exercise.

3.1 Experiment Setup

Thirty-nine participants (20 male and 19 female) enrolled in our study, gave informed consent, and successfully completed the experiment. One additional male participant enrolled in the study but broke one of Baxter's parts and thus did not complete the full study. His data were omitted from the presented analysis. Participants were divided into two groups: a younger group from 18 to 36 years old (M = 23.6 years, SD = 4.1 years) and an older group from 54 to 70 years old (M = 59.6 years, SD = 3.9 years). The younger group was made up of seventeen technically trained and three non-technical individuals, while the older adult group comprised four technical and fifteen non-technical individuals. All participants possessed full function in their arms and hands.

Each person came to the lab for a single 90-minute session. Before the experiment interactions began, the participant completed several screening activities. Baxter then waved hello to the user, and the experimenter read a script to relay relevant background information on Baxter. This information was followed by an opening survey about user perception of Baxter. Next, the participant stood facing Baxter and played 90-second-long samples of the eight different exercise games in a unique pre-determined order that was balanced across subjects. After each exercise game, the user completed a survey about that game. After the eight games, the user refreshed their memory of the game options by watching video snippets of all the games, selected their favorite game, and entered a free play mode during which they could play that game for up to ten minutes. Lastly, participants completed a closing survey and a brief demographics survey. Participants also received $20 for participation and up to $10 for transportation.

3.2 Data Collection

Before interacting with Baxter, each participant completed Beck's Depression Inventory (BDI) [2], a standard Box and Blocks manual dexterity assessment (BnB) [14], and (in only the older adult group) the Montreal Cognitive Assessment (MoCA) [15]. Since depression has been shown to influence the activity motivation of depressed individuals, BDI scores were needed for a possible post-hoc analysis. The BnB activity helped us confirm that participants had full function in their arms and hands and also gave us an idea of their motion speed capabilities. Small adjustments to exercise game timeout periods were made based on the BnB scores, our proxy for maximum participant motion speed. We assumed that younger adult participants were cognitively well, but we administered the MoCA to older adult participants to quantify their cognitive function. The MoCA results were used to adjust the difficulty of memory tasks in the exercise games. We also recorded user height to ensure that the experiment activities stayed within the physical armspan of the user.

Our experiment software recorded the accelerometer data from Baxter's onboard wrist accelerometers, the key sensors used to accomplish the logical flow of most exercise games. We also asked participants to complete four types of surveys: (1) a robot evaluation after hearing introductory information about Baxter, (2) an exercise game survey after each game sample, (3) a concluding survey after the free play interaction, and (4) a basic demographic survey after the concluding survey. The exercise game survey used questions from the Self-Assessment Manikin (SAM) [3], the NASA TLX [11], and an enjoyability survey used in [12], plus questions about exercise level, pain level, and safety feelings. Questionnaires (1) and (3) were adapted from the UTAUT and other metrics employed in [17] and [13]. The exercise game survey and concluding survey also included free response questions to help elicit additional experiential data from users. Finally, the experiment was videotaped for later analysis of user behavior.

3.3 Conditions

This experiment employed a within-subjects design that enabled all participants to experience all eight exercise games described in Section 2, as pictured in Fig. 2. The experimenter read scripted instructions to each participants to prepare them for each game interaction. When referring to each game, the experimenter used only a letter label (A-H), rather than the game name, to avoid influencing participants' interaction styles.

4 PRELIMINARY RESULTS

All 39 users who completed the study played the eight exercise games with Baxter. Although participants were not universally able to "beat" the robot or "win" the exercise games, most people were able to win all of the games in the sample exercise game interactions throughout the experiment. Despite hearing the same instructions for how to play each exercise game, some users creatively interpreted the instructions and exercised harder than necessary to win certain games. All users were also able to identify a favorite game that they wanted to play again, and every participant interacted with this free play game condition for at least as long as the sample game interactions. As illustrated in Fig. 3, every game but the Flamenco Game was chosen by at least two users.

The additional user who broke a part of Baxter and did not complete the full study experienced only six of the exercise games before the robot's wrist motor coupler (W2 joint) broke. This individual hit the robot unusually hard compared to other study participants. In future work, we will modify our game introductions to avoid this problem. His data are omitted in this analysis.

4.1 Pre- vs. Post-Experiment Survey Results

We gathered two sets of robot perception survey responses, one before and one after the experiment; these results are shown in Fig. 4. Because we gathered this data from two different participant age groups, our main analysis tool for evaluating differences in the robot perception survey was a 2×2 two-factor mixed design repeated measures analysis of variance (rANOVA) performed in R using the anova function with an $\alpha = 0.05$ significance level. We additionally calculated effect sizes using eta squared.

Based on this analysis, we discovered that over the course of the experiment, users became more positive about the idea of using the robot (F(1,38) = 11.73, p = 0.002, $\eta^2 = 0.240$) but more afraid to make mistakes while playing with Baxter (F(1,38) = 8.09, p = 0.007, $\eta^2 = 0.154$). Participants also came to think that the robot was nicer to work with (F(1,38) = 6.69, p = 0.014, $\eta^2 = 0.151$) and easier to use (F(1,38) = 28.09, p <0.001, $\eta^2 = 0.428$) after the experiment. Users further reported liking the presence of the robot more (F(1,38) = 12.99, p = 0.001 , $\eta^2 = 0.259$) and being more able to imagine doing activities with the robot (F(1,38) = 9.78, p = 0.003, $\eta^2 = 0.207$).

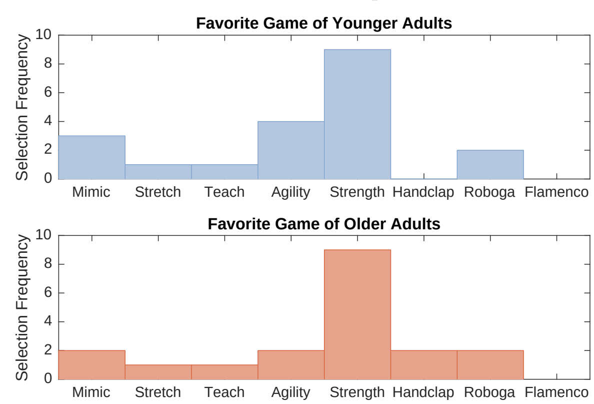
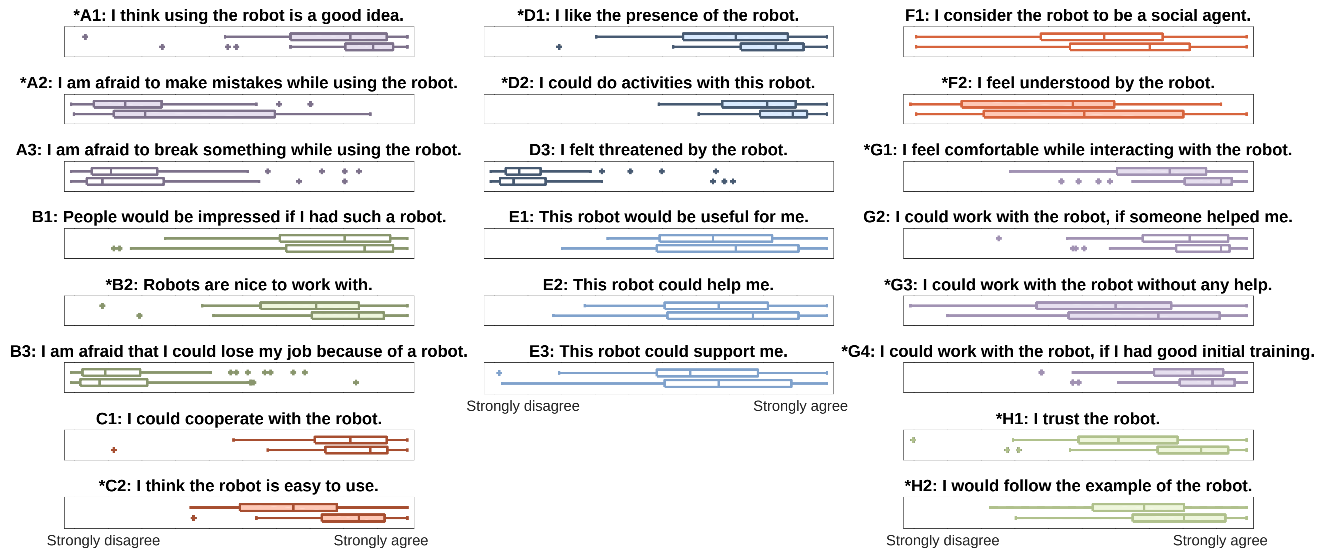


Figure 3: Favorite games of the two participant age groups.



	A1	A2	A3	B1	B2	B3	C1	C2	D1	D2	D3	E1	E2	E3	F1	F2	G1	G2	G3	G4	H1	H2
Before/After	0.002	0.007	0.419	1.000	0.014	0.512	0.700	<0.001	<0.001	0.003	0.941	0.867	0.357	0.512	0.085	0.011	<0.001	0.054	0.005	0.005	<0.001	<0.001
Younger/Older	0.923	0.778	0.968	0.053	0.068	0.851	0.483	0.232	0.097	0.804	0.226	0.136	0.117	0.273	0.321	0.377	0.253	0.202	0.115	0.846	0.847	0.453

Figure 4: Differences in responses to the UTAUT-inspired robot perception survey. In each plot, the top box plot represents the pre-experiment responses, and the bottom box plot represents the post-experiment responses. Filled in box plots with starred titles indicate significant differences. Clusters of plots with matching colors and letter codings represent survey question groupings. The table includes p-values from the rANOVA run to determine differences in the before vs. after and younger vs. older age group responses to each survey question. Shaded cells indicate significant differences.

Participants felt more understood by Baxter after the experiment (F(1,38) = 7.09, p = 0.011, η^2 = 0.158). Ratings of comfort interacting with the robot also increased (F(1,38) = 18.74, p <0.001, η^2 = 0.334), as did user confidence about using the robot without any help (F(1,38) = 8.90, p = 0.005, η^2 = 0.191) and with good initial training (F(1,38) = 8.76, p = 0.005, η^2 = 0.189). Lastly, respondents were more trusting of Baxter (F(1,38) = 23.16, p <0.001, η^2 = 0.371) and more willing to follow Baxter's example (F(1,38) = 21.13, p <0.001, η^2 = 0.319) after the experiment. No pre- and post-experiment survey rating differences occurred between the younger and older adult participant groups (all p >0.05). We interpret this lack of age-related effects as a promising sign that non-technical older adults may be as comfortable with and willing to accept the robot as technical younger adults.

4.2 Input from a Target User

We aimed to recruit some target prospective end users in our experiment (frail older adults who might benefit from socially assistive exercise robot systems). Although we included an older adult group in our study, the mean older adult age (59.6 years) is below the average retirement age in the United States, and most of our older adult users were active, in good health, and working full time. Six participants were older retired adults who represented individuals more similar to envisioned end users for a socially assistive exercise robot. Of these individuals, one person was eager to give the research team extensive verbal feedback about her experience. We took notes on what she had to say, and we view this feedback as useful information for shaping socially assistive exercise robot activities in the future. Her comments were as follows:

- "I would be interested in using this type of interaction to stay active."
- "This is a nice way to stay active at the right level for older adults. I can't keep up with exercise videos, and I find live exercise classes targeted toward older adults boring. This type of interaction was at the right challenge level, but was still interesting because of the robot's responsiveness. I would want to use a system like this."
- "It was exciting to experience cutting-edge technology since usually I don't have access, but this stuff is geared at me."
- "Once I mastered a challenging game, I felt accomplished."

Some additional participants in their fifties had enthusiastic feedback about the exercise games, saying for example that they didn't know how to use machines in the gym and preferred this robot-motivated type of exercise experience, or that this activity "is different and doesn't feel like standard exercising. Exercising with Baxter is fun."

5 DISCUSSION

The results of this experiment showed us how younger and older adults respond to exercise games with a robot. Participants were all willing to enter Baxter's workspace and make contact with the robot. Users typically "won" all the games, which emphasizes the readability and comprehensibility of the activities. This result was ideal because we wanted to verify that people can succeed in the games before testing more challenging or vigorous game modes.

The favorite game selection breakdown illustrates that we created a variety of games to satisfy different user preferences. The Strength Game was the most popular choice, but apart from the Flamenco Game, all games were selected by at least two participants. A combination of energetic music with organic boxing training-like contact may have contributed to the Strength Game's success. The Flamenco Game likewise involved high-energy music, but the dance move imitation interaction may have seemed less natural. Some users favored the Flamenco Game, but not as their single top choice; one participant mentioned that the Flamenco Game was their second choice, and free response comments revealed thoughts that "it was cool to see the robot dance and try to match it!" and this was "[one user's] lead game" at the time they experienced it, although in the end they chose a different favorite game.

Users also seemed to gain trust and confidence in Baxter over the course of the experiment. Although most participants did not belong to the ultimate target population for this type of technology (frail older adults), one woman who was retired provided strong positive feedback on the exercise game interactions. Her first and third comments may reflect the novelty effect of our robotic exercise system. We would need to do longer-term studies in homes or assisted living facilities before making any claims about Baxter as a socially assistive exercise robot. Her second and fourth comments, on the other hand, indicate that our exercise games may be designed at the right level for frail older adults. Although doable games are advantageous in a way, there is some need for challenge, perhaps both initial and incremental, to help users feel like they have accomplished something while playing exercise games. This observation is consistent with related findings that people are more motivated to undertake high self-efficacy tasks [1].

Some limitations arose from the study design. Although the user population was diverse, users were not uniformly representative of the target population for this research. Likewise, the lab setting of the experiment and the short duration of each interaction did not perfectly match our intended use case. To ensure broader applicability, it would be ideal to run a similar experiment in an assisted living facility. Additionally, the within-subjects nature of the experiment may have exaggerated differences between game conditions due to demand characteristics. Users reported a growing fear of making mistakes when interacting with Baxter. This change is likely a byproduct of the ability to lose the exercise games by making mistakes, but we monitor for this same concern in future studies and seek to understand why this change occurs. The biggest drawback of the study may be that one user broke Baxter's wrist motor coupler (W2 joint) by striking the robot too forcefully. The participant who broke the robot was contacting Baxter much harder than necessary for the games, and the experimenter was not correcting the user's behavior because one goal of the experiment was to see how people would naturally use the games. Rethink Robotics was able to repair the robot arm for a cost of $2,000. We recommend supplying cautionary feedback if participants use excessive amounts of force to interact with Baxter or other robots in similar future exercise studies.

Overall, the positive results of this study make us eager to continue this research. The enthusiasm from some of our older adult population indicates that we are pursuing a productive research direction with this work. Similar positive responses of older adults to social exercise motivation from a robot in [6] support the repeatability and viability of our work. We hypothesize that the combination of social skills like those explored in [6] with pHRI abilities in our system will result in even more lasting exercise motivation. We also anticipate potential for future longer-term evaluation of similar exercise interactions in more natural settings such as assisted living facilities. Most game activities have various built-in song/pattern modes and difficulty levels to preserve interest in the robot over multiple interactions. We additionally see potential to adjust games or select a specific subset of games to accomplish specific physical therapy goals during system engagement with users. Our future investigations of social-physical robots as exercise partners will help us understand how to use these agents to support older adults and other individuals with exercise needs.

REFERENCES

[1] Albert Bandura. 1982. Self-efficacy mechanism in human agency. *American Psychologist* 37, 2 (1982), 122–147.
[2] Aaron T. Beck. 1979. *Cognitive therapy of depression.* Guilford Press.
[3] Margaret M. Bradley and Peter J. Lang. 1994. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry* 25, 1 (1994), 49–59.
[4] Joseph F. Coughlin, James E. Pope, and Ben R. Leedle. 2006. Old age, new technology, and future innovations in disease management and home health care. *Home Health Care Management & Practice* 18, 3 (2006), 196–207.
[5] Doreen Dawe and Robin Moore-Orr. 1995. Low-intensity, range-of-motion exercise: invaluable nursing care for elderly patients. *Journal of Advanced Nursing* 21, 4 (1995), 675–681.
[6] Juan Fasola and Maja J. Matarić. 2012. Using socially assistive human–robot interaction to motivate physical exercise for older adults. *Proc. IEEE* 100, 8 (2012), 2512–2526.
[7] Naomi T. Fitter, Dylan T. Hawkes, Michelle J. Johnson, and Katherine J. Kuchenbecker. 2016. Designing human-robot exercise games for Baxter. In *Late-Breaking Results Report in Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).* 3434–3435.
[8] Naomi T. Fitter and Katherine J. Kuchenbecker. 2016. Designing and assessing expressive open-source faces for the Baxter robot. In *Proc. International Conference on Social Robotics (ICSR).* Springer, 340–350.
[9] Naomi T. Fitter and Katherine J. Kuchenbecker. 2016. Equipping the Baxter robot with human-inspired hand-clapping skills. In *Proc. IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN).* 105–112.
[10] Naomi T. Fitter and Katherine J. Kuchenbecker. 2017. Hand-clapping games with a Baxter robot. In *Demonstration in Proc. ACM/IEEE International Conference on Human-Robot Interaction (HRI).* 40.
[11] Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. *Advances in Psychology* 52 (1988), 139–183.
[12] Marcel Heerink, Ben Krose, Vanessa Evers, and Bob Wielinga. 2008. The influence of social presence on enjoyment and intention to use of a robot and screen agent by elderly users. In *Proc. IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN).* 695–700.
[13] Marcel Heerink, Ben Krose, Vanessa Evers, and Bob Wielinga. 2009. Measuring acceptance of an assistive social robot: a suggested toolkit. In *Proc. IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN).* 528–533.
[14] Virgil Mathiowetz, Gloria Volland, Nancy Kashman, and Karen Weber. 1985. Adult norms for the Box and Block Test of manual dexterity. *American Journal of Occupational Therapy* 39, 6 (1985), 386–391.
[15] Ziad S. Nasreddine, Natalie A. Phillips, Valérie Bédirian, Simon Charbonneau, Victor Whitehead, Isabelle Collin, Jeffrey L. Cummings, and Howard Chertkow. 2005. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society* 53, 4 (2005), 695–699.
[16] Robert J. Sanchez Jr., Eric Wolbrecht, R. Smith, J. Liu, S. Rao, Steven C. Cramer, T. Rahman, James E. Bobrow, and David J. Reinkensmeyer. 2005. A pneumatic robot for re-training arm movement after stroke: rationale and mechanical design. In *IEEE International Conference on Rehabilitation Robotics (ICORR).* 500–504.
[17] Astrid Weiss, Regina Bernhaupt, Manfred Tscheligi, Dirk Wollherr, Kolja Kuhnlenz, and Martin Buss. 2008. A methodological variation for acceptance evaluation of human-robot interaction in public places. In *Proc. IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN).* 713–718.