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A Pattern Language

Karaosmanoglu, Eda; Rozendaal, Marco C.; Alcubilla Troughton, Irene; Bleeker, Maaike; Vallery, Heike; Cramm, Jane Murray

DOI
10.1145/3727990

Publication date
2025

Document Version
Final published version

Published in
ACM Transactions on Human-Robot Interaction

Exploring the Potential of Spherical Robots to Promote Physical Activity at Home: A Pattern Language

EDA KARAOSMANOGLU, Erasmus School of Health Policy and Management, Erasmus University Rotterdam, Rotterdam, Netherlands and Faculty of Industrial Design Engineering, Delft University of Technology, Delft, Netherlands
MARCO C. ROZENDAAL, Faculty of Industrial Design Engineering, Delft University of Technology, Delft, Netherlands
IRENE ALCUBILLA TROUGHTON and MAAIKE BLEEKER, Department of Media and Culture Studies, Utrecht University, Utrecht, Netherlands
HEIKE VALLERY, Institute of Automatic Control, RWTH Aachen University, Aachen, Germany, Faculty of Mechanical Engineering, Delft University of Technology, Delft, Netherlands, and Department of Rehabilitation Medicine, Erasmus University Medical Center, Rotterdam, Netherlands
JANE MURRAY CRAMM, Erasmus School of Health Policy and Management, Erasmus University Rotterdam, Rotterdam, Netherlands

Social robots have become increasingly prominent in the realm of physical activity promotion. However, the technological complexity and primarily anthropomorphic designs of these robots pose challenges for their application in everyday settings. This study positions spherical robots as an emerging subtype of social robots and explores their potential to promote physical activity at home by identifying useful behavioral design patterns. To this end, we engaged theater professionals and human-robot interaction researchers in a 4-day workshop, leveraging a speculative design methodology. A puppeteer controlling a robotic ball and two actors improvised human-robot encounters in a staged home setting. These encounters were analyzed to identify instances where the ball triggered physical activity. From this analysis, we extracted nine design patterns that articulate robot behaviors for initiating physical interaction. Additionally, our findings revealed that these patterns could be combined into complex sequences to sustain physical activities, which are experienced as meaningful when framed within a narrative. We discuss the contents of these patterns and their potential

The work presented in this article is part of research projects *Acting like a Robot* funded by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) (Grant No: CISC.KC.206) and *Spherical Robot for Motor Rehabilitation with Equal Access for All* funded by the Convergence (an alliance of Delft University of Technology, Erasmus Medical Center, and Erasmus University Rotterdam) (Grant No: 2022036).
Authors' Contact Information: Eda Karaosmanoglu (corresponding author), Erasmus School of Health Policy and Management, Erasmus University Rotterdam, Rotterdam, Netherlands and Faculty of Industrial Design Engineering, Delft University of Technology, Delft, Netherlands; e-mail: karaosmanoglu@eshpm.eur.nl; Marco C. Rozendaal, Faculty of Industrial Design Engineering, Delft University of Technology, Delft, Netherlands; e-mail: m.c.rozendaal@tudelft.nl; Irene Alcubilla Troughton, Department of Media and Culture Studies, Utrecht University, Utrecht, Netherlands; e-mail: i.alcubillatroughton@uu.nl; Maaike Bleeker, Department of Media and Culture Studies, Utrecht University, Utrecht, Netherlands; e-mail: m.a.bleeker@uu.nl; Heike Vallery, Institute of Automatic Control, RWTH Aachen University, Aachen, Germany, Faculty of Mechanical Engineering, Delft University of Technology, Delft, Netherlands, and Department of Rehabilitation Medicine, Erasmus University Medical Center, Rotterdam, Netherlands; e-mail: h.vallery@irt.rwth-aachen.de; Jane Murray Cramm, Erasmus School of Health Policy and Management, Erasmus University Rotterdam, Rotterdam, Netherlands; e-mail: cramm@eshpm.eur.nl.

ACM 2573-9522/2025/5-ART54
https://doi.org/10.1145/3727990

value for home-based healthcare applications. Our contribution lies in articulating the potential of spherical robots for promoting physical activity at home through design patterns informed by a performative approach to human-robot interaction.

CCS Concepts: • **Human-centered computing → Interaction design**; **Scenario-based design**; **Empirical studies in interaction design**; *HCI theory, concepts and models*;

Additional Key Words and Phrases: Spherical robots, Speculative enactments, Design patterns, Physical activity

ACM Reference format:
Eda Karaosmanoglu, Marco C. Rozendaal, Irene Alcubilla Troughton, Maaike Bleeker, Heike Vallery, and Jane Murray Cramm. 2025. Exploring the Potential of Spherical Robots to Promote Physical Activity at Home: A Pattern Language. *ACM Trans. Hum.-Robot Interact.* 14, 3, Article 54 (May 2025), 26 pages.
https://doi.org/10.1145/3727990

1 Introduction

Leveraging social robots to promote **physical activity (PA)** within domestic settings offers a promising avenue for maintaining and improving the health of diverse populations [37]. In PA promotion, the social interaction abilities and technological features of social robots can provide motivation, guidance, and assistance to patients while facilitating remote monitoring by healthcare professionals and caregivers [57, 68]. However, designing social robots for domestic use poses challenges due to the diverse, private, and complex nature of this everyday setting [44, 88]. To ensure long-term use and acceptance, these robots must continuously transform and adapt to the everyday practices of the users [44, 63].

Predominantly, researchers and practitioners in **human-robot interaction (HRI)** aim to foster the user acceptance of social robots by exploiting anthropomorphism, capitalizing on the innate tendency of humans to attribute human-like characteristics, such as intention and animacy, to non-human entities [38]. While endowing these robots with human-like attributes may enhance their predictability and familiarity [38], it may also increase their technical complexity and limit the range of responses these robots can elicit [1, 43]. Furthermore, Winkle et al. [87] report that this pseudo-sociality introduces ethical risks, including the potential for deception (i.e., believing that a robot has genuine emotions) and over-trust (i.e., assuming that a robot possesses greater capabilities than it actually does). Additionally, Złotowski et al. [89] caution against the risk of reproducing human stereotypes, further underscoring the potential pitfalls associated with anthropomorphism.

In contrast to anthropomorphic approaches, the advancing *more-than-human* perspective in HRI transformed the design of social robots by focusing on the characteristics, features, or qualities unique to robots [27]. This perspective crafted a design space for robots that engage socially and appeal to diverse forms of interaction without thoughtlessly adhering to the trope of anthropomorphism. Spherical robots, which possess both robot- and ball-like qualities [23], exemplify these types of robots. Their *hybridity* makes them suitable candidates for achieving flexible forms of interaction, mitigating the ethical risks and complexities associated with their anthropomorphic counterparts.

Previous research has shown that spherical robots can convey sociality through expressive behaviors and be perceived as agents while also being interacted with as ordinary balls [36]. These robots have demonstrated potential for providing companionship and physical and cognitive stimulation to children with autism spectrum disorders [51, 58–60] and enhancing neurorehabilitation outcomes among stroke survivors as adjuvant exergaming devices [61, 62]. In these studies, the robots either exhibited no agentic behavior or were programmed to mimic human- or animal-like behavior, after which they were tested with the target populations. Our study extends this body of work by exploring the flexible forms of interaction that can spontaneously emerge from people's encounters with spherical robots and examining how these interactions can promote PA at home. Unlike previous research, we focus on the emergent, situated behaviors that arise during these interactions, providing new insights into designing spherical robots for everyday environments.

In this study, we utilized a spherical robot that looks like a simple everyday ball while possessing agentic qualities based solely on movement. Through its minimalism in appearance, interaction capabilities, and hardware, this robot aims to offer ease of use, low cost, and flexible forms of interaction to facilitate home-based healthcare services, such as geriatric rehabilitation. As a first step towards this goal, this study explored the robot's potential to promote PA at home by collaborating with theatre professionals and HRI researchers.

This exploration used a speculative methodology underpinned by a performative lens, similar to [1, 42, 43, 73]. This lens posits that a robot's social characteristics do not inherently reside within the robot and cannot be attributed to predefined behaviors that aim to express or convey specific messages, emotions, intentions, or drives. Instead, these social characteristics are co-created through encounters between humans and robots within particular situations [1, 42, 43, 73]. To facilitate this co-creation, we staged the encounters through improvisation in a fictional home setting over a 4-day workshop. By unpacking these improvisations, we identified design patterns—a concept introduced by [7] and adopted and applied in HRI by [48, 52, 76, 85]—to inform the behavioral design of spherical robots. Our contribution to the literature lies in articulating the potential of spherical robots to initiate and sustain PA at home through these design patterns. These patterns capture the robot's expressive behavior in relation to human responses while accounting for contextual factors. Moreover, we discuss how these patterns provide practical value for creating behavioral libraries to support the development of spherical robots designed for home-based healthcare services.

2 Related Work

In our discussion of related work, we explore social robots as a PA promotion strategy aimed at home-based healthcare. We then present spherical robots as a distinct robotic paradigm and examine their place within the social robot landscape, highlighting the potential of their hybrid character to stimulate PA at home. Finally, we introduce the concept of design patterns in HRI, which helps us articulate the potential of spherical robots in terms of their behavioral design.

2.1 Social Robots in PA Promotion

PA plays a pivotal role in the prevention, management, and rehabilitation of complex and chronic diseases such as cancer, stroke, and diabetes [3, 46, 84, 86]. Therefore, incorporating PA into daily life is essential to maintain and improve health [79]. PA can be part of daily life in the form of structured, planned, purposive, and repetitive exercises, as well as household tasks and leisure activities [3, 24, 34]. Nevertheless, initiating and maintaining PA may be challenging due to factors such as lack of motivation and the variability in daily routines [65]. To address these challenges, innovative strategies, such as technology use, are being explored for their potential to support and sustain PA at home.

Among these strategies, social robots have gained traction [57]. These robots are autonomous entities often embodying human- or animal-like (i.e., *life-like* [28]) appearances, behaviors, interaction styles, and/or social abilities [21, 40, 45, 57]. Although some social robots incorporate functional embodiments that reflect technical features rather than life-like characteristics [11, 40], life-like designs are generally preferred in health applications due to their ability to foster user trust, encourage interaction, and facilitate the development of emotional bonds [50]. For PA promotion, life-like social robots were deemed beneficial to enhance motivation [26, 37, 77], foster engagement [71, 78], and provide personalized and social support [20], such as by serving as a coach providing verbal encouragement and feedback [66], a partner for dancing or playing games [39], and an instructor demonstrating exercises [67]. Additionally, prior research suggested that social robots can alleviate the time and workload of healthcare professionals by enabling remote monitoring and assistance [8, 25], through their often complex technical infrastructure. While their potential benefits are promising, several barriers hinder their widespread adoption in home settings [2, 44, 74].

A significant barrier stems from users' tendency to develop emotional connections and expectations that the robot may not fulfill. Contrary to the intended effect of fostering trust, life-like qualities may also lead to disappointment, reduced trust, and eventual abandonment over longer periods of use [28, 82]. Another barrier arises from the technological complexity necessary to support these robots' life-like characteristics, such as the integration of cameras for vision or natural language processing for understanding and communicating in human language [13, 29]. For an intimate and private use context like home, this complexity raises concerns about safety, reliability [9], privacy [54], and technology accessibility in terms of usability [69] and cost for implementation [81]. These challenges are further compounded by the dynamic and unpredictable nature of the home environment [44], which requires a level of adaptability that many current social robots lack.

Home is an everyday social and physical setting surrounded by distinct routines, situations, and interpersonal dynamics; therefore, it is "messy" [56], ever-changing, and diverse [64, 88]. Thus, social robots intended for the home must account for the dynamicity of this context and unique living arrangements influenced by cultural norms and socioeconomic factors. Despite this requirement, interactions with many social robots often exhibit rigidity, as they are designed to mimic life-like behaviors based on presumed HRI scenarios [10, 28, 43]. This rigidity limits their ability to adapt to unforeseen situations in domestic settings and undermines their flexibility to maintain sustained engagement—an essential factor for promoting PA.

2.2 Spherical Robots in PA Promotion

Spherical robots present a compelling solution for encouraging PA in home environments. These unique computational artifacts integrate features of both a ball and a robot [23], allowing them to be interacted with as creatures and as an everyday ball concurrently or alternately [72]. Their association with an everyday ball is particularly meaningful for promoting PA, as it inherently affords movement and action such as kicking, throwing, or rolling [16]. Products on the market and previous studies have highlighted the potential of these robots for promoting PA across varied contexts, including clinical and home settings.

For instance, Leka supports children with neurodevelopmental disorders with gross motor development in homes, schools, or hospitals [51, 90]. Similarly, Roball has been shown to encourage physical and social play among kindergarteners and individuals with autism spectrum disorder [58–60]. Furthermore, Boon [15] developed Fizzy, a robotic ball for increasing PA among hospitalized children, which expresses itself solely through movement and responding to physical interaction. Boon et al. [16] observed that children engaged with Fizzy as they would with a regular ball, a pet, or a playmate in a constantly shifting and blending way—using it in football games, giving it a name, or involving it in activities such as hide-and-seek. Similarly, in [36], despite PA not being the primary focus, young adults played catch or football with the Sphero and BB-8 robots. At the same time, they waved goodbye or called the robots as if they were pets [36]. These examples highlight the *hybrid quality* of these robots, which allows them to "be experienced as tools and agents alternately, shifting from one role to another, or concurrently by the blending of their distinct features" [72, p. 171].

Hybridity offers two key advantages for PA promotion at home. First, it enables robots to convey sociality without requiring overtly life-like qualities, helping to mitigate ethical concerns related to emotional attachment and privacy, which are more prominent in home settings [33, 82]. Instead of life-like qualities, hybrid robots feature a combination of ambiguous or abstract robot embodiments and expressive movements, allowing users to frame robots as social entities while being aware of their *robotness* [27] (e.g., being non-living, non-conscious, and non-emotional [33]). For example, Lat-Sac and Blo-Nut [14], Cube Performer [42], and Sympartner [33] feature ambiguous and open-ended forms (i.e., a latex sack and a donut, a cube, and a blend of pet, furniture, and computer, respectively) along with movements that do not mimic living entities. These robots foster a sense of presence and engagement while promoting transparency, ensuring users remain aware that they are interacting with machines that can be turned off at will [14, 33, 42]. Second, hybridity challenges users to explore and conceptualize the robots, offering users flexibility in their interactions with the robot and allowing them to remain intrigued over an extended period [14]. When embodied in a robot with the characteristics of an everyday ball, this dynamic reframing created by hybridity is particularly promising for PA promotion at home, as it fosters sustained motivation and engagement through spontaneous and flexible HRI.

2.3 Design Patterns in HRI

We refer to design patterns as a concept to help us articulate robot behaviors that can initiate and sustain PA. Originally introduced by Alexander et al. [7] in architectural and urban design, design patterns refer to general, reusable, yet adaptable solutions to recurring design problems or opportunities observed in a specific context. These patterns can be combined to create more complex systems [7]. For example, in the context of designing human habitats, Alexander's "Child Caves" pattern addresses an opportunity: children's affinity for small, cave-like spaces [7]. The pattern also describes how to use this opportunity by suggesting the creation of small caves wherever children play (e.g., at school or home) and provides specific guidelines: "Keep the ceiling heights low—2 feet 6 inches to 4 feet—and the entrance tiny" [7, p. 929]. Moreover, the pattern specifies that it can be combined with another pattern to form a more complex pattern named "Adventure Playground" [7]. As this example illustrates, patterns guide users in constructing a complex system while offering flexibility to create a unique outcome.

This practical idea of creating fundamental building blocks for designing complex systems has influenced various fields, including HRI. Kahn et al. [48] proposed eight design patterns as reusable methods for planning and implementing sociality in HRI by observing child-robot interactions and comparing them to human-human interactions. This work was later followed by Wang and Green [85], who generated spatial design patterns to create socially intelligent robotic environments through co-design with university students. Additionally, Sauppé and Mutlu [76] created seven interaction patterns as building blocks for HRI by observing predefined scenarios of human-human interactions and translating them into HRIs. Lastly, Ligthart et al. [52] implemented three predefined patterns into an autonomous social robot for storytelling and tested these patterns with children.

Building on [7] and the aforementioned HRI scholars, we view the design patterns in this work as primitives for creating HRI; however, aimed at PA promotion at home. This approach facilitates the development of a versatile library for spherical robots, encompassing various robot behaviors designed to trigger different forms of PA or combinations of those. Unlike previous work, our patterns are neither predefined nor framed within foundational social categories. These patterns are generated by examining HRI through a performative lens, viewing interactions, identities, and agencies as co-created by humans and robots in their encounters, influenced by contextual and situational factors [12, 42, 43].

Table 1. Roles and Responsibilities of the Workshop Team

Role	Number of people associated with the role	Responsibilities
Theatre professional: Actor	2	Performing improvisations with robotic ball prototypes and reflecting on their experiences of these improvisations
Theatre professional: Puppeteer	1	Performing improvisations with the actors by assuming the role of the prototypes (i.e., remotely controlling robot movements) and reflecting on their experiences of these improvisations
HRI researchers	6	Organizing the workshop, observing and instructing actors and the puppeteer, and reflecting on the improvisations through the lens of their disciplines (i.e., Design, Theatre, Science and Technology Studies, and Engineering)
Roboticists	2	Designing, programming, and producing the robotic prototypes, providing technical support to resolve prototype issues, observing the improvisations, and facilitating discussions on technological design aspects with the team
Documenters	3	Recording the workshop through video, audio, and written notes, contributing to discussions, and posing critical questions to the team to address both the enactments and the workshop's organization

3 Workshop

A workshop was designed to pursue two overarching objectives: First, to explore HRI through a performative lens, drawing on insights from the performing arts to create engaging robot behaviors; and second, a more practical aim, to develop a minimalistic, low-cost robotic ball aimed at promoting PA at home. The design patterns identified in this study primarily support the second objective, contributing to generalizable knowledge about spherical robots and providing practical guidance for creating feasible, low-cost, and privacy-preserving technologies suitable for home-based healthcare services. Insights related to the first objective will be published elsewhere.

During the workshop, we employed a speculative methodology, drawing inspiration from Rozendaal et al. [73], who expanded on Gemeinboeck and Saunders' "Performative Body Mapping" [41] and "Speculative Enactments" by Elsden et al. [35]. This methodology adopts a performative approach to HRI, which views human-robot encounters as creative starting points to explore how robot morphology and behavior can elicit specific responses while foreclosing others [73]. Moreover, it informed the development of the robot we utilized, which was still in its early stages of engineering and implementation in real-world contexts.

In applying this methodology, we collaborated with theatre professionals, similar to previous works [4, 5, 9, 14, 47] that leveraged expertise from the performing arts to design robot expressions and behaviors. Through this collaboration, we co-created human-robot encounters in a staged home setting and unpacked the embodied experiences of these professionals within these encounters. The aim was not to replicate target users or their potential behaviors nor to test or validate predefined robot behaviors. Instead, we sought to explore how a human and a robot sharing the same space could afford interactions and ultimately, how these interactions became meaningful for promoting PA.

3.1 Workshop Team

A total of 14 people contributed to the workshop with their distinct expertise. Table 1 provides a detailed overview of their roles and responsibilities.

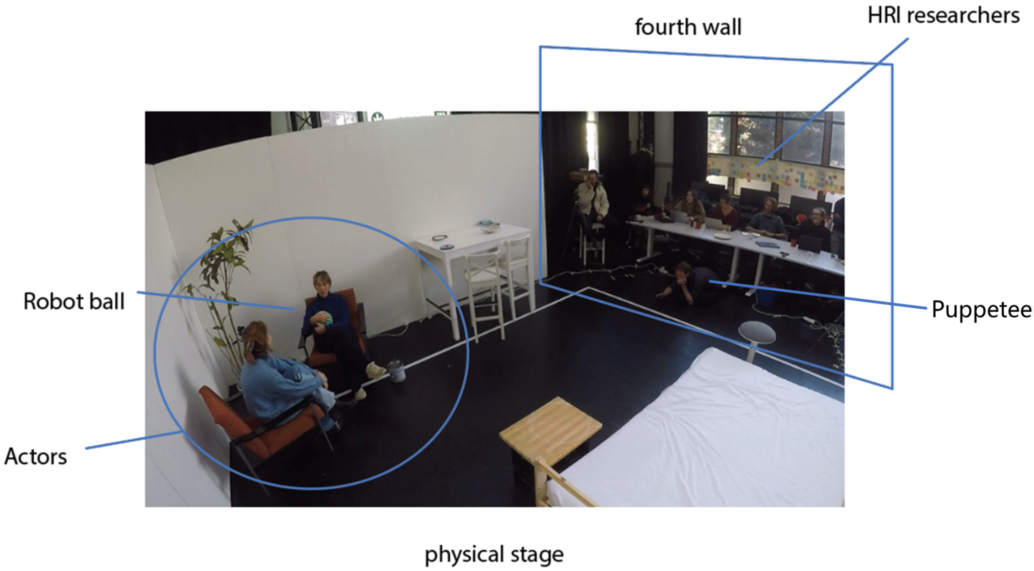

Fig. 1. Stage setup.

3.2 Setup and Materials

The workshop took place in a theater environment. A living space was staged by enclosing three sides with walls and furnishing the space with items such as a bed, a plant, armchairs, a closet, a dining table, and chairs. An open side allowed the researchers, roboticists, and documenters to observe the enactments. The puppeteer was also strategically positioned on this side to be able to operate the robot with a remote controller (Figure 1). The arrangement of furniture could be changed depending on the kind of improvisations that were carried out.

3.3 Prototypes

The workshop featured three distinct spherical robot prototypes varying in appearance, materiality, and drive mechanism (Figure 2). One prototype had a hard plastic shell and was open, while the other two were covered with a foam layer, giving them a softer feel. The open and covered yellow-red prototypes incorporated a drive mechanism comprising LEGO Mindstorms parts, while the green prototype featured a custom-designed mechanism. Despite these differences, all prototypes shared the same minimalistic actuation principle, realized through a single motor-driven pendulum [83], aiming to offer a lower-cost alternative to commercially available spherical robots. Additionally, each prototype contained an **inertial measurement unit (IMU)**, which could provide information on its acceleration, angular rate, and orientation.

Each prototype was operated remotely throughout the workshop, except during two enactments on the first day, where a simple pre-programmed rolling behavior was used. The robot rolled through the space without the ability to detect its surroundings or respond to people. During remote operation, the puppeteer controlled the prototypes by adjusting motor speed using the thumbstick of an Xbox joystick. He was instructed to think like a robot, operating within the robot's intended sensory limitations. For example, he responded exclusively to physical inputs, simulating how an IMU would work, by relying on his sight to mimic the sensor's functionality. By the end of the second day, roboticists added four presets to the LEGO-based prototypes to simplify control: back-and-forth movements at three different frequencies and a wiggling motion. The puppeteer

Fig. 2. Spherical robot prototypes used in the workshop (left and middle: LEGObased system, right: custom-designed system).

could activate or stop these presets by pressing or releasing one of the four joystick buttons (X, Y, A, B). Throughout the workshop, the covered yellow-red ball was used most frequently due to its easier handling and covered appearance.

3.4 Procedure

The workshop lasted 4 days, with each day consisting of a morning session lasting about 3 hours and an afternoon session lasting about 2 hours. In the mornings, one or both actors performed enactments with the puppeteer while the rest of the workshop team observed these enactments. Following each enactment, theatre professionals engaged in a reflective dialogue with the team, sharing their experiences and addressing specific questions from the group. During the afternoon sessions, the team reflected on the enactments without the theatre professionals present. This flexible structure allowed the workshop's organization to evolve in response to emerging themes and insights from the enactments. However, each day maintained a distinct predetermined focus, progressing from general to specific throughout the workshop.

At the start of the workshop, the entire team was briefed on the overarching aims of PA promotion and the performative approach to HRI, indicating that the workshop sought to explore what the encounters between a robotic ball and human(s) can bring about, particularly regarding PA in home environments. The first 2 days were dedicated to the free exploration of the robotic ball. The first day focused on exploring the robotic ball's affordances, with actors independently defining both their own roles and the robot's role. On the second day, the focus shifted to examining how different framing cues influenced interaction. Actors were instructed to engage with the robot as if it were a specific "thing," such as an exercise device, a companion, or a toy.

The third and fourth days focused on exploring how the robot's movements could initiate and sustain PA within specific healthcare scenarios (i.e., a home physiotherapy session for a hernia patient and an older adult living with a robot designed to promote daily activity). These scenarios were provided to the actors and puppeteer as starting points for the enactments. The constraints set by these scenarios, along with the robot's technological limitations mentioned previously, encouraged improvisation, leading to novel behaviors and interaction strategies, echoing the improvisational dynamics described in [73]. By the end of the fourth day, the enactments evolved into a dialogue between the actors and the workshop team, allowing for collective speculation on how the robot could be further developed as a home-based healthcare service.

3.5 Data Collection

All enactments and reflections following the enactments were documented using video recordings and written notes of a documenter. Video recordings were captured using four GoPro cameras

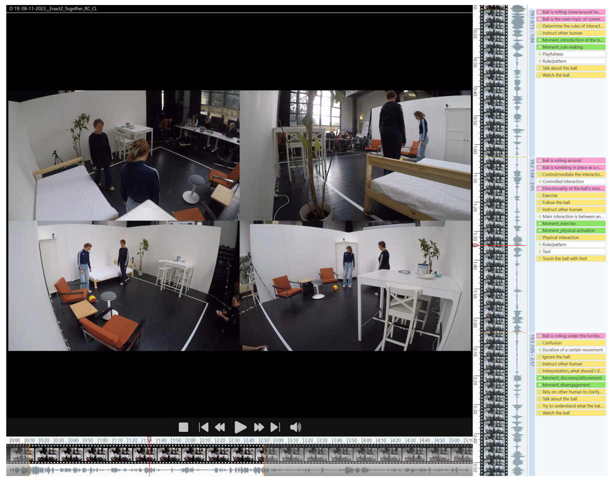

Fig. 3. A snapshot exemplifying the analysis process in ATLAS.ti, event (green), robot behavior (pink), human response (yellow), and contextual details (white).

strategically positioned to encompass the entire stage area and capture accompanying sounds. Additionally, audio recordings and detailed notes captured discussions among researchers during the afternoon sessions. In total, the workshop generated 10 hours of video data and 6 hours of audio data. Following data collection, all recordings were organized by day, and segments of video data capturing only the enactments were isolated. This separation was done to streamline the data analysis process, allowing for a focused examination of these specific video segments during later analysis.

3.6 Analysis

The data were analyzed using the reflexive thematic analysis by Braun and Clarke [19], where themes are actively created by the researcher(s) through engaging with the data and continually challenging their assumptions and interpretations of it. As a first step, a bottom-up analysis [18] was conducted to examine the video data of the enactments using the ATLAS.ti software (Figure 3). One researcher (EK) coded the video fragments containing an encounter between the robotic ball and the actor(s). Each fragment received (1) a descriptive label identifying the event, annotated with three additional categories to detail: (2) the robotic ball's behaviors and movement characteristics, (3) the actor's experiences and responses, and (4) contextual details such as material, spatial, and social factors relevant to the event. In this analysis, we aimed to ensure accuracy by cross-referencing the professionals' reflections documented during the workshop and discussing observations extensively within the research team. As a result, codes underwent iterative adjustments, reorganizations, or grouping into relevant categories, resulting in a dataset of 198 codes that provided highly detailed descriptions of the interactions that unfolded.

As the next step, a top-down analysis [18] was employed to identify design patterns indicative of robot behaviors that stimulate PA. This involved isolating fragments portraying instances of PA and reviewing their movement characteristics and uniqueness within the dataset. The final identification and articulation of these design patterns emerged through multiple reviews and discussions with the research team throughout the analysis and writing process. This approach yielded nine distinct design patterns observed across various enactments, both individually and in combination with each other.

4 Resulting Design Patterns

4.1 Basic Patterns

This section introduces various design patterns observed to initiate different types of physical interactions with varying levels of intensity. These patterns fall into the category of basic patterns, each representing a robot behavior that elicits specific human responses encompassing experiential and physical dimensions. In alignment with our objective of creating a minimalistic technology to promote PA at home, we present these patterns according to their increasing levels of control complexity in relation to their prospective enabling technology (Table 2). We start with passive and simple random behaviors, then progress to behaviors requiring motion control, and finally advance towards context awareness. After describing these basic patterns, we provide accounts of three situations where these design patterns were combined to form more complex ones (see also: Supplementary video). These instances demonstrate how basic patterns were integrated into intricate sequences structured around a narrative, leading to more elaborate PA.

4.1.1 Passive–Handle. In the passive–handle pattern, the person interacts with the ball as much as they would with an ordinary ball because the robot remains passive without any observable movement or distinct behavior. Depending on its embodiment and materiality, the ball's mere presence invites people to engage by throwing, holding, or rolling it. We observed actors beginning to interact with the ball as they would with a regular ball once it stopped moving. They initiated a game of throwing it back and forth among themselves, turning it into a ball game (Figure 4). During the reflection sessions, discussions highlighted the view that the robot simply being a "ball" was sufficient in some instances; its presence alone could stimulate movement and play. Our puppeteer remarked, "*I think in these scenarios, the ball was a catalyst; because of the ball, they started to play.*"

4.1.2 Ineffective–Help. The ineffective–help pattern describes situations in which the ball appears unable to control its movements effectively and may become stuck, prompting people to help it. The ball triggers a helping response because it is perceived as vulnerable and in need of assistance. During our workshop, we observed several instances of actors helping the robot. In one enactment, the ball became stuck under the bed. Actor 2 initially waited for the ball to free itself, but upon seeing it was unsuccessful, she knelt and rolled it out (Figure 5). We noticed that this robot behavior prompted actors to engage in PA in various ways, such as through locomotion, bending, kneeling, reaching, or manipulating both the robot and its surroundings to facilitate its movement. For example, Actor 1 described how she had to rearrange chairs to assist the ball, seeing it as a potentially beneficial and enjoyable exercise: "*...That is an exercise; I have to lift these chairs, I have to use my hips well, and then I should repeat it. The ball motivates me to go there, and then I must also move the other chair away. I thought that is a nice, good thing to do because I have to move...*"

4.1.3 Wander–Follow. The wander–follow pattern is characterized by the ball's movement throughout the available space. Its moderate-speed locomotion without a clearly identifiable pattern or target gives the impression of wandering and provides a sense of aliveness. This behavior, noticeable yet not disruptive, can elicit various bodily responses, from simply tracking the robot passively with head or eyes (orientation) to actively following it with movement (locomotion), depending on the individual's willingness to engage. In one enactment, actors occasionally glanced at the ball as it calmly rolled while they were chatting (Figure 6(a)). In another, the ball's wandering turned into an exercise (Figure 6(b)). During a post-enactment reflection session, Actor 1 indicated that she perceived the ball as something alive and co-present, yet she could sometimes choose to ignore it: "*...in a way, I am used to the ball going around in the house, like there is some living creature, which I am not always sure what to do with it...*"

Table 2. Basic Design Patterns and Their Key Characteristics

Design pattern	Robot behavior	Human response	Control complexity
Passive–Handle	*Passive (no behavior)* The ball is not showing any behavior	*Handle the ball* Feeling appealed to manipulate the ball	No behavior
Ineffective–Help	*Ineffective behavior* The ball showing ineffective behavior	*Help the ball* Attributing feelings of vulnerability and helplessness to the robot	+ Spontaneous behavior
Wander–Follow	*Wandering behavior* Spontaneous rolling performed within a wide area	*Follow the ball* Perceiving the ball as alive and feeling appealed to follow it	
Annoy–Stop	*Annoying behavior* Noticeable visible and loud behavior	*Stop the ball* Attributing stubbornness or an annoying personality to the ball	
Repeat–Mimic	*Repetitive behavior* Rhythmic behavior performed within a smaller area	*Mimic the ball* Feeling compelled to resonate and move along with the ball	+ Motion control
Signal–Interpret	*Signaling behavior* Brief demarcated behaviors while standing still	*Communicate with the ball* Feeling appealed to interpret a message	
Roll away–Pursue	*Rolling away from a person* Rolling away from a person with variable speed	*Pursue the ball* Feeling compelled to pursue the ball	+ Context awareness
Roll towards–Pick up	*Roll towards a person* Rolling towards a person with moderate speed	*Pick up* Feeling acknowledged and invited to pick up the ball	
Hide–Seek	*Hiding behavior* Rolling underneath or behind an object	*Seek the ball* Feeling compelled to seek and retrieve the ball	

4.1.4 Annoy–Stop. The annoy–stop pattern indicates an interaction in which the ball exhibits behavior that is considered annoying, prompting people to intervene and stop its actions. This behavior involves movements that draw visual attention and/or generate noise. Stopping the ball may include locating and physically retrieving it from challenging locations, requiring

Fig. 4. Actors throwing the ball to each other.

Fig. 5. Actor 2 helps the ball when it is trapped under the bed.

individuals to bend or reach. For example, in one of the enactments, Actor 2 was resting on the chair while the ball was hitting against the objects around. Expressing annoyance and wish for quietness multiple times, she attempted various methods to silence the ball, including hugging it, placing it back on the floor, and even putting it inside a cabinet (Figure 7). During the reflection sessions later on, she described her experience: "*...Actually, I felt a bit like the ball was against me or something...It did not feel like a friend because it was not responding to my requests for silence.*"

4.1.5 Repeat–Mimic. The repeat–mimic pattern describes an interaction where the ball sways steadily and rhythmically within a bounded area, prompting people to mirror its movements. During the workshop, this behavior elicited physical responses such as dancing or exercises like side-stepping, depending on the robot's rhythm. For example, in one enactment, actors swayed their bodies left and right to synchronize with the ball's movements (Figure 8). Actor 2 described the ball's smooth, swinging motion as inviting, encouraging them to dance alongside it: "*...the smooth*

(a) (b)

Fig. 6. (a) Actors glancing at the ball. (b) Actor 2 follows the ball around.

Fig. 7. Actor 2 attempts to stop the ball by putting it in the closet.

movements, the swinging gesture, that invited me to dance." In another enactment, Actor 1 was lifting one leg at a time and passing it over the ball while it moved back and forth. She suggested that this could be an exercise with varying difficulty levels based on the ball's rhythm.

4.1.6 Signal–Interpret. In the signal–interpret pattern, the ball performs short, clearly articulated movements. These can include wiggling or rocking motions with clear beginnings and endings, often repeated with pauses in between. These demarcated expressions help draw the person in and compel them to pay attention, interpret, or act upon the perceived message or cue. Overall, the robot's behavior sparks curiosity and conveys an intent to communicate. For instance, Actor 2 perceived the ball's wiggling as a form of communication, similar to how a dog might wiggle or move to express a desire or request attention: "*There was this movement, small wiggle, a little bit like a dog or something, that gives me the feeling like, oh it wants something.*"

This behavior can prompt various levels of physical engagement, ranging from light to active exploration of the ball. During the workshop, the clarity of the perceived signal determined this response. At times, the signal was clear within the context, prompting specific actions such as picking up the ball (Figure 9(a)). In other cases, ambiguous signals still captivated attention and encouraged actors to delve into their potential meanings (Figure 9(b)).

Fig. 8. Actors synchronizing their movements with the ball's rhythm.

(a) (b)

Fig. 9. (a) Actor 1 acts on the perceived message from the ball. (b) Actors try to understand what the ball expresses.

4.1.7 Roll Away–Pursue. The roll away–pursue pattern entails an interaction where the ball, initially in proximity to the person, rolls away with variations in its speed, compelling the person to pursue it. The ball exhibits directional behavior by accelerating and then decelerating along a mostly linear trajectory. It initiates PA as a visceral response since the person is compelled to pursue the robot. However, the way that the person pursues the robot may differ depending on the robot's magnitude of initial acceleration. For instance, in various enactments, the actors walked, jogged, or ran after the ball, depending on its acceleration (Figure 10). Theatre professionals indicated that the ball's linear trajectory, speed differences that mark the beginning and end of its movement, and sequence of rolling to a point and stopping made its action clear, recognizable, and inviting. Furthermore, the puppeteer highlighted the significance of a pause after the ball reaches a point: "*I have the feeling that the ball has to be fast to move but also in between, the moments of pause... The duration of that pause is inviting them to come.*"

4.1.8 Roll Towards–Pick Up. In the roll towards–pick up pattern, the ball rolls towards the person with a moderate speed, gradually stops near the person, and is then picked up. The robot's moderate speed holds significance in eliciting this human response. The PA resulting from this pattern involves locomotion and posture changes, such as bending and reaching, and manipulation through holding and lifting the robot (Figure 11). This pattern was observed in three enactments,

(a) (b) (c)

Fig. 10. Actors (a) walking, (b) jogging, and (c) running after the ball.

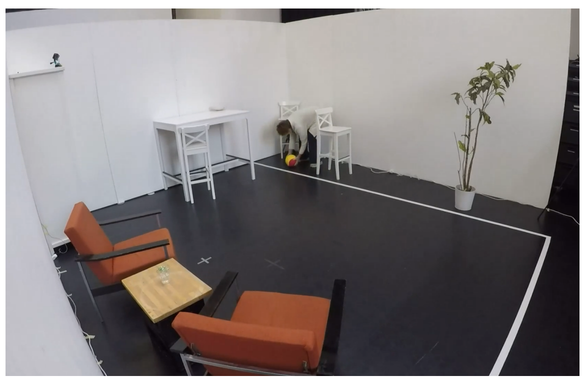

Fig. 11. Actor 1 picks up the ball by bending and lifting it.

each showcasing variation. In the first instance, the ball rolled from a short distance away towards Actor 2 at a moderate speed and stopped in front of her, where she picked it up. In the second scenario, the ball approached Actor 2 with increasing speed first, slowed down upon nearing her, and briefly stopped, prompting her to retrieve it. In the third case, the ball rolled to Actor 1 from a short distance, tapped her feet softly, and stopped. She then bent down to pick it up.

4.1.9 Hide–Seek. The hide–seek pattern describes an interaction in which the ball rolls under or behind objects in the environment, rendering it temporarily out of sight. This behavior prompts individuals to perceive the ball as intentional and playful, motivating them to actively search for and retrieve it. This activity involves physical movements like walking, kneeling, or bending as part of the engagement with the ball.

The attribution of intention and playfulness was evident in the enactments. For example, Actor 2 questioned the ball humorously, "*Are you challenging me or something?*" as she bent down to look under the bed to see what the ball was doing (Figure 12). Actor 1 also emphasized how this behavior required PA: "*…the ball went under the bed, making it inaccessible for me to pick up directly, so I had to figure out how to retrieve it, continuously using my body in the process.*"

4.2 Framing Complex Patterns through Narratives

Building on these basic design patterns, we report how they could be combined into more complex patterns, leading to sustained PA. These complex patterns combine basic patterns in longer sequences and require narratives to imbue resulting interactions with meaning. These narratives can either be pre-established (e.g., might have been taken as a starting point for the enactment) or emerge during the interaction itself. We present three complex patterns as examples to illustrate how basic

Fig. 12. Actor 2 tries to retrieve the ball from under the bed.

Table 3. Complex Patterns and Their Key Characteristics

Complex pattern	Narrative	Example sequences
Pet training	Animistic framing of the ball	Hide–seek + ineffective–help + annoy–stop + wander–follow
Therapy session	Tool-oriented framing of the ball	Signal–interpret + roll away–pursue
Creative play	Activity focused on frame creation	Signal–interpret + repeat–mimic

patterns meaningfully come together and how similar behaviors can be given different meanings based on a narrative (Table 3).

4.2.1 Pet Training. The pet training narrative frames the robotic ball as an artificial creature with its own intent. In one enactment, the ball initiated the interaction by rolling under the bed (*hide–seek*). Actor 1 requested Actor 2's help to retrieve it, but before she could help, the ball rolled out on its own. Actor 1 then picked it up and shook it twice, deciding within the context of the enactment that this action would stop its movement. After stopping, she placed the ball next to her chair. Shortly afterwards, the ball rolled towards the table and became stuck underneath (*ineffective–help*), where it attempted to get out in a noisy way but failed. Actor 1 again decided within the context of the enactment that she needed to get up and retrieve the ball. Upon retrieval, she applied the shaking gesture to stop its movement again (*annoy–stop*). After a brief period, the ball continued rolling around (*wander–follow*), which the actors easily ignored as they maintained their conversation.

This pet-training frame allows the person to attribute meaning to the robot's behavior as that of an autonomous entity—one that can hide, act stubbornly, or appear in need of help—and further guides how they respond to these behaviors and how the robot reacts in return. For example, they might proactively retrieve the robot before it goes under the table, knowing it would be harder to reach it later. These anticipations foster a perception of the robot as responsive and attentive to user input, like teaching a pet new tricks, thereby facilitating the resumption of interaction and engagement.

4.2.2 Therapy Session. The therapy session narrative frames the robotic ball as a training device. This narrative was given as a starting point for an enactment where actors portrayed a physiotherapist and a hernia patient. The enactment started with Actor 1 and Actor 2 chatting while the ball was rocking intermittently (*signal–interpret*). This behavior prompted Actor 1 to introduce the ball to Actor 2, explaining its self-moving nature and its role in therapy sessions. Actor 1 then instructed Actor 2 to follow the ball as it rolled away (*roll away–pursue*). At one point, the ball stopped and wiggled (*signal–interpret*), prompting Actor 1 to instruct Actor 2 to pick up the ball. This sequence was repeated several times.

Within this narrative, Actor 1 portrays the role of a physiotherapist who knows about the ball's behavior and uses it as a tool in her therapeutic exercise. By explaining the ball's behavior to Actor 2, Actor 1 guides her through the exercise. Therefore, together with the robot behaviors resulting from the combination of basic patterns, the other person's presence allows the user to engage with the robot and sustain PA.

4.2.3 Creative Play. The creative play narrative frames the ball as an ambiguous thing that triggers meaning-making, leading to the construction of new narratives. This narrative unfolded in an enactment where Actor 2 portrayed an elderly individual living alone with the ball. During the enactment, the actor interpreted the ball's intermittent rocking as a signal to start dancing (*signal–interpret*). Subsequently, the ball swayed steadily and rhythmically, prompting the actor to mirror its movements (*repeat–mimic*). After some time, the ball stopped moving by itself, which triggered a creative exploration between the actor and the puppeteer. This collaborative performance led the actor to discover that touching the top of the ball could reignite its motion, restoring its repetitive rhythmic movements. From then on, the actor consistently used this gesture whenever the ball paused.

A crucial aspect of this narrative is the balance it struck between randomness and predictability. We noticed how this balance was required to raise curiosity and also provide stability on which the creative interactions could be prolonged. As the interaction progresses, unexpected signals, such as periods of unresponsiveness, maintain user engagement by challenging the user to find ways to continue their PA. Once the user overcomes these challenges, repeating these patterns fosters familiarity with the robot.

5 Discussion

This study aimed to explore how a spherical robot—that is minimalistic, low-cost, and still at an early stage of its technical development—could trigger PA at home and its potential role in home-based healthcare services. In this exploration, we have benefited from theatre professionals' expertise and skills to create collectively human-robot encounters that were situation- and robot-specific. Similar to [73], the focus of this collaboration was to find opportunities for HRI rather than assessing whether these interactions would work for actual target groups. As a result, we identified nine design patterns that are not meant to be exhaustive. Our study showed that a spherical robot can trigger diverse forms of PA through various mechanisms: functioning as an ordinary ball, getting stuck, wandering around, being annoying, engaging in rhythmic, repetitive movements, signaling, rolling towards or away from a person, or hiding. Our results further suggested and exemplified that these patterns can be combined into complex sequences to generate prolonged interactions, potentially leading to increased durations of PA. Given these findings, we propose that these design patterns can serve as a valuable starting point for developing spherical robots intended for home-based healthcare applications.

In the following subsections, we first discuss the behavioral patterns in comparison with the previous work on design patterns. We then reflect on how spherical robots can be positioned as a hybrid subtype of social robots and discuss the practical implications of this approach for their integration into home-based healthcare services. Finally, we present the methodological lessons learned from this study.

5.1 Design Patterns

This study leveraged the concept of design patterns by Alexander et al. [7] to illustrate how spherical robots can potentially stimulate PA at home. We believe that our patterns, like those of Alexander et al. [7], serve as adaptable strategies for crafting situated HRI. While our findings expand upon their work, there are areas where we both align with and diverge from their approach. Moreover, we reflect on contributions from other HRI scholars to position our work within the broader discourse on interaction patterns.

Both ours and the patterns of Alexander et al. are goal-oriented yet retain a degree of open-endedness. Alexander et al. describe their patterns as addressing specific *recurring issues* in living environments (e.g., children's preference for small spaces) and offering specific *solutions* to these issues (e.g., constructing caves with low ceilings and tiny entrances) [7, pp. 927–929]. Despite their specificity, these patterns show flexibility, manifesting diversely across different contexts in terms of materials, locations, and forms [7]. Similarly, our patterns aim to stimulate various types of mobility and describe how to achieve this goal through specific robot behaviors (e.g., hide, repeat, roll away) while being open-ended. For example, a user of the *roll away–pursue* pattern can flexibly determine what acceleration, deceleration, or mostly linear trajectory means for their specific robot, resulting in different manifestations of this pattern.

However, unlike the patterns of Alexander et al., which remain unchanged once implemented, our patterns will likely manifest differently, even when applied by the same person to the same robot, due to their situated nature. We observed this in our workshop, such as with different instantiations of the *ineffective–help* pattern, where contextual factors like where the robot became stuck influenced whether individuals chose to help it by adjusting chairs or manipulating the robot. We argue that this divergence stems from the different purposes these patterns serve—the patterns of Alexander et al. aim to create static and "timeless" built environments [7], while ours target achieving dynamic and flexible interactions.

The patterns of Alexander et al. inherently form a cohesive "pattern language" [7], as they are intrinsically interconnected and designed to function collectively within larger systems. This hierarchical structure suggests that smaller patterns can only be combined in specific ways to create larger patterns. In line with Alexander et al., the HRI patterns of Kahn et al. [48] and Sauppé and Mutlu [76] also necessitate a rigid, sequential order to form a coherent *language*, likely because they are based on human-human interactions or predefined social scenarios. In contrast, our nine basic design patterns can be combined more flexibly without requiring a predefined structure, as they are grounded in a performative understanding of HRI. However, these combinations still require narratives to become meaningful.

Like those of Kahn et al. [48] and Sauppé and Mutlu [76], our patterns have an empirical basis; they were observed in speculative enactments of human-robot encounters. Although Alexander et al. claim to have this empirical basis [7], their methodology—relying on extensive observation and documentation of successful architectural practices—has faced criticism [30]. Similarly, our patterns' speculative and situated nature might induce concerns regarding their validity and generalizability. While our goal was not to achieve universally valid and generalizable patterns at this stage, we acknowledge these limitations and plan future studies to address them.

Despite these limitations, our patterns show promise as they emerged consistently across multiple enactments and workshop days, with some showing similarities to findings from other studies. For example, in the study by Boon et al. [16], which involved a spherical robot that we have further developed, the robot effectively engaged hospitalized children in PA through a continuous shift of play activities. Children played hide-and-seek with the robot or interpreted the robot's rolling away as an invitation to follow [16]. Similarly, Faria et al. [36] found that 12 of 17 young adults followed Sphero when it engaged in the movement sequence of approaching a person, bumping into them, and moving away. These parallels across different contexts and age groups suggest that certain patterns such as *roll away–pursue* may be useful in initiating movement.

Our patterns also partially meet the three criteria by Kahn et al. for validating interaction patterns in HRI: (1) drawing conclusions directly from the data by asking whether a pattern "works" or is "useful" and defining what "works" or "useful" means, (2) ensuring the patterns account comprehensively for the data, and (3) substantiating the labels assigned to the patterns themselves [49]. To address the first criterion, our patterns "worked" since they could trigger various forms of PA, including locomotion, postural changes, and active play. However, they "worked" for two healthy individuals who were experts in movement, creatively inclined, open, and familiar with the study goals within the context of the speculative enactments. Moreover, the social dynamics and peculiarities of the setting (e.g., the ball primarily rolling on the floor, limitations of the prototypes, and the simulated home environment) significantly influenced the patterns' characteristics. Therefore, our future endeavors aim to validate the effectiveness of the identified patterns in promoting and sustaining PA among target populations in real home settings.

Regarding the second and third criteria, we triangulated our data with participant reflections and team discussions and labeled each pattern as a combination of robot behavior and corresponding human response to provide clarity for interpreting and applying these patterns. However, time constraints might have hindered our exhaustive exploration of all patterns within the rich dataset. Additionally, our labeling strategy may reflect some degree of subjectivity due to the methodology employed. Hence, studies with experimental designs and more comprehensive analysis are essential to refine these patterns further.

5.2 Spherical Robots as Hybrid Social Robots for PA Promotion

Through the patterns identified, we have observed that people interacted with the robotic ball interchangeably and concurrently as a creature, tool, or plaything, aligning with the results of Boon [16]. Based on these findings, we propose that simple, ambiguous, and open-ended artifacts like spherical robots, when positioned within narratives, can open up new, situated ways to engage with social robots. This resonates with Dautenhahn's suggestion that an agent's non-specific appearance or behavior regarding life-likeness can enhance its usefulness by offering greater freedom in how the robot is used and interpreted [28]. Therefore, we recommend leveraging hybridity, which creates ambiguity and open-endedness [17, 53], to design social agents without relying on overtly life-like characteristics and to promote PA.

Using this strategy to design social agents may potentially lower the ethical risks typically associated with life-like robots, such as the tendency to overestimate the robot's intelligence and sociability [87]. Still, we did encounter people's inherent human tendency to overestimate robot intelligence in our study. For example, before learning about the robot's limitations, the actors tried to engage in conversation with the robot, expecting it to respond. However, unlike more anthropomorphic robots, these interactions did not lead to attributing complex human-like emotions or capabilities to the robot, as cautioned by [82] and [87]. Nonetheless, this remains an area of focus for future studies, particularly those involving older individuals.

For PA promotion, narratives are required when leveraging hybridity. If narratives are lacking, ambiguity and open-endedness fostered by hybridity may lead to confusion, especially in environments where users struggle to invoke creativity or spontaneity [17]. A similar challenge emerged during our workshop, particularly in enactments where the actors were not provided with specific scenarios or information about the robot's functions. In these cases, the resulting ambiguity led to some insecurity, with actors unsure of how to engage with the robot, highlighting the importance of narratives in cultivating the productive potential of hybridity. Narratives not only made the robot's behaviors more legible but also shaped how those behaviors were valued. For example, the *annoy–stop* pattern was considered cute in an animistic framing of the ball but not when used as a tool.

Regarding the potential home-based healthcare applications, the narratives also offer an opportunity to personalize spherical robots for a specific population and PA needs. The application context, a patient's personal preferences, therapy goals, and physical and cognitive abilities can help shape an appropriate narrative. This narrative can then serve as a preset or package that meaningfully integrates basic design patterns to support people with PA. For example, in the context of geriatric rehabilitation, activities such as side-stepping or lifting chairs triggered by the basic design patterns such as *repeat–mimic* and *ineffective–help* can be further developed as a preset since they resonate with the strength, speed, coordination, and endurance training offered in geriatric physiotherapy programs [22, 31]. In cases where patients have low motivation or limited physical abilities, the basic design patterns can be combined within a game narrative leveraging social interaction—an identified motivator for exercise [55, 80]. A low-threshold two-player game can be created, similar to one observed in the workshop, where the actors rolled the robot to each other while sitting (*passive–handle*) and, occasionally, the robot would roll out of the trajectory, prompting the actors to reposition themselves (*roll away–pursue*).

By creating personalized basic behaviors or combining them into presets or packages, targeted behavioral libraries can be developed for minimalistic and low-cost spherical robots. However, this process presents technical challenges. Depending on the basic patterns involved, the autonomous operation of these packages may require precise, directional motion and context awareness. This can pose challenges for robots with a single motor-driven pendulum and IMU, like ours [32]. While these difficulties can be addressed by integrating more complex control systems and adding more sensors, such modifications would increase the robot's cost and complexity and potentially compromise its privacy-preserving nature, limiting its affordability and accessibility. Therefore, future steps in our project will focus on achieving a balance between enhancing our robot's capabilities and maintaining its simplicity.

5.3 Methodological Lessons Learned

This study employed two key methodologies: speculative enactments with theatre professionals [35, 73] as an explorative research approach and design patterns [7] as a framework for articulating our findings. Speculative enactments allowed us to envision the future use and experiences of a robot, which was still in its early development stages. As the name suggests, this envisioning process *is* speculative, and the value of this methodology lies in exploring possible futures through the lens of people's experiences, focusing on what the speculation brings about in the present moment [35]. In this study, reflexive dialogues among the workshop team after each enactment provided critical insights into why specific actions, reactions, or situations emerged during the sessions (e.g., why actors attributed helplessness to the robot). These insights were instrumental in shaping the design patterns presented in this work.

In these enactments, our collaboration with theatre professionals was valuable in several ways. First, these individuals possess the expertise to craft and perform HRI that closely resemble real-life interactions while being able to adapt to changing or unforeseen events in these performances easily. However, in our workshop, putting this expertise into practice productively required a balance between complete creative freedom and strict instructions on what to perform due to our robot's specific application goal. We achieved this by allowing professionals to improvise freely, however, within the frame of PA promotion. Second, they are skilled in analyzing and articulating their experiences and interpretations of what happens in an enactment and why [73]. This analysis and articulation provided clarity and context for the observations made during the enactment by the rest of the workshop team. It helped clarify how the presence of the ball facilitated PA, addressing both the ball's characteristics and the actors' intentions, social dynamics, and the influence of the surrounding context. Third, the puppeteer could skillfully control the robot and invent ways of moving by considering the robot's limitations and devising rule-based strategies, such as roll, stop, and wiggle, to trigger the actor's PA. Consequently, we could not only reflect on the effect of these new ways of moving but also on their technical requirements and feasibility. Therefore, as Riek et al. highlighted [70], employing the Wizard of Oz technique allowed us to simulate and iterate on attainable future robot behaviors.

Regarding the design pattern approach, it provided us with a structural manner of performing thematic analysis on rich video data and articulating a robot behavior and its effect. It took many iterations and discussions among the team to decide on what constituted a basic pattern, as we first identified the complex patterns and worked our way to the basic ones by questioning whether they could further be divided into smaller segments. By moving from complex to basic, we gained insights into how these patterns might work together coherently. We believe that this approach may help address the issue Alexander identified in his own work regarding the insufficient details on how to create generative pattern languages [6]. A second challenge was the level of abstraction required for the practical use of patterns as starting points for crafting HRI, which was also identified by [76]. It was difficult to articulate our observations in a way that was open-ended enough to inspire practitioners and researchers yet structured enough to offer clear and actionable insights. We addressed this challenge by revisiting multiple instances of each pattern and carefully extracting the essence that best captured the key aspects of a specific robot behavior, human reactions, and contextual elements. As Salingaros [75] noted, this approach helped us manage the complexities of what we observed during the workshop.

6 Conclusion

This article described the process and outcomes of speculative enactments with theatre professionals that explored the potential of spherical robots to initiate and sustain PA in a staged home setting. The design patterns identified from the enactments exemplify how the basic behaviors of a robotic ball can trigger various types and intensities of physical interactions. Additionally, combinations of these behaviors in complex sequences lead to sustained PA that require narratives to be experienced as meaningful. The results showed how the robotic ball was flexibly framed as a creature, tool, or plaything, suggesting the emergence of a hybrid subtype of social agents. These results offer valuable insights into the potential of spherical robots as minimalistic, low-cost devices due to their simplicity and adaptability. They also offer guidance for developing robotic balls for home-based healthcare services. We have discussed how the identified patterns can inform the creation of behavioral libraries that enable spherical robots to act autonomously, with narratives helping to guide their integration into various applications. However, further studies with the actual target groups are needed to assess their effectiveness. As we continue to develop the form and behavior of these robots, it is crucial to recognize that people's experiences and interactions with them are shaped by both the physical environment and human factors. This emphasizes the need for further research to deepen and expand these design patterns, informed by their real-world applications.

Acknowledgments

We would like to thank Jenne van Herpen, Janna Adank, and Joris de Jong, who played a central role in this study. We also thank Bart Horstman, Robin Taborsky, Michael Fritschi, Marit Adriaanse, Hyunmin Lee, Arturo Briasco, and Edwin Dertien for their insights and support in prototyping and documentation. We would like to express our gratitude to the Innovation: Lab of Theater Utrecht and their Head of Creative Technology Abdelhadi Baaddi, for providing the venue, stage décor, and insights. The study was approved by the TU Delft Human Research Ethics Committee (HREC application ID: 3588).

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Received 9 July 2024; revised 10 January 2025; accepted 6 March 2025