Can Augmented Reality Head-Mounted Display Exergames Support the Management of Multiple Sclerosis at Home? Workshop Discussions with Researchers and Experts with Lived Experience of MS

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Exercising is a beneficial rehabilitation strategy for people with Multiple Sclerosis (MS). Exergaming provides an alternative to traditional rehabilitation programs, increasing accessibility and adherence to home-based exercise. Augmented reality (AR) head-mounted displays (HMDs) offer a promising solution for safer and more inclusive in-home exergaming experiences, which is important for people with MS. However, research on AR HMDs for exergaming in MS rehabilitation is still limited and evolving. It is still unclear whether these systems are suitable for supporting physical rehabilitation, particularly in managing MS at home. To investigate, we conducted an online workshop with eight multidisciplinary researchers and experts with lived experience of MS conducting research in MS and related technologies. We produced themes relating to accessibility and equipment considerations, and the importance of social interaction. We present our key findings from the workshop and offer recommendations for using AR HMD exergames in the rehabilitation of MS.

CCS Concepts: • **Software and its engineering → Interactive games**; • **Applied computing → Computer games**; • **Human-centered computing → Participatory design**; **Mixed / augmented reality**.

Additional Key Words and Phrases: Augmented reality, Exercising, Exergaming, Home environment, Participatory Design

ACM Reference Format:
Michelle Adiwangsa, Hanna Suominen, and Penny Sweetser. 2025. Can Augmented Reality Head-Mounted Display Exergames Support the Management of Multiple Sclerosis at Home? Workshop Discussions with Researchers and Experts with Lived Experience of MS. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25), April 26-May 1, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 11 pages. https://doi.org/10.1145/3706599.3720214

1 Introduction

Multiple sclerosis (MS) is a chronic, incurable neurological disorder that leads to progressive physical and cognitive disabilities [26], affecting a wide range of activities of daily living (ADLs). Apart from available pharmacological treatments, a carefully selected set of exercises can serve as a beneficial rehabilitation strategy. Exercising helps manage symptoms, restore function, optimise quality of life, promote wellness, and boost participation in ADLs [21, 22, 26]. Traditionally, patient rehabilitation occurs in hospitals and other medical facilities under the constant supervision of a physiotherapist [26]. However, in-person rehabilitation is not always accessible due to limited healthcare resources,

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coupled with the increasing prevalence of MS in both developed and developing countries [7, 26, 35]. This makes it challenging to rely solely on traditional approaches, highlighting the need to extend patient training beyond the clinic environment [26]. Traditional physiotherapy programs can become repetitive and predictable, which may lead to decreased interest and motivation, ultimately causing patients to disengage from the program [16, 18, 25].

To increase accessibility and adherence to physiotherapy and regular exercise, a growing number of studies discussed the use of exergames. Exergame is defined as "a video game that promotes (either via using or requiring) players' physical movements (exertion) that is generally more than sedentary and includes strength, balance, and flexibility activities" [24]. Exergames offer the potential for increasing physical activity levels at home, enabling physical rehabilitation or training to be conducted remotely. Prior work has found that exergaming can increase energy expenditure to levels that meet the American College of Sports Medicine (ASCM) recommended guidelines for health and fitness ($\geq$ 150 min/week of moderate intensity), up to 300% above resting level [33]. In recent years, exergaming has seen widespread adoption for rehabilitation programs and clinical studies [11], demonstrating acceptability, feasibility, safety, enjoyment, stimulation, and self-motivation as a therapeutic approach [13]. Exergaming, which has been shown to be enjoyable across multiple age groups, holds potential for sustained exercise participation, as an important determinant of time spent on an activity is its perceived enjoyment [19]. Kato [16] argued that patients may "cooperate more fully with the procedures required in physical therapy" when an entertaining game is involved, especially since video game play can serve as an engaging distraction from patients' aversive symptoms.

Although exergames have the potential to increase physical activity levels, current games and systems are not always suitable for rehabilitation. Commercial exergames can be too challenging due to the motor limitations of patients, rapid progression of the games, and lack of impairment-focused training that specifically addresses the patient's needs [3, 12]. In addition, many systems are not always safe or inclusive. Systems with handheld controllers (e.g., Nintendo Wii) may be unsuitable for individuals with tremors, as they may struggle to hold the controller, while balance boards pose fall risks [25]. Current exergames could also be more immersive to further improve motivation and enjoyment [31, 37].

Augmented reality (AR) head-mounted displays (HMDs) offer a promising alternative for facilitating safer and more inclusive exergaming experiences at home. Users' hand gestures can be registered as inputs and AR HMDs do not require a raised platform like a balance board. This removed the need for controllers and minimised fall risks. AR HMDs are also wireless [32], and unlike virtual reality (VR), they allow users to see their real surroundings, including objects, obstacles, and other people [20]. This visibility helps preserve the home by reducing the risk of collisions. The immersive nature of AR, especially through HMDs, also enables users to view 3-D poses from any angle, which is particularly useful for exercising [20].

Despite its potential, research on the use of AR HMDs for exergaming in MS rehabilitation is still limited and evolving [34]. It remains unclear whether these systems are suitable for supporting physical rehabilitation, particularly in managing MS at home. Existing research has primarily focused on the technical evaluation of HMDs for rehabilitation in people with MS or has involved healthy young adults as participants, which may have led to an underreporting of the specific needs, preferences, and concerns of individuals with MS. This gap led to our research question (RQ): **To what extent can the use of augmented reality head-mounted displays for home-based exergaming support physical rehabilitation for the management of Multiple Sclerosis?**

To investigate our RQ, we conducted an online workshop with a group of multidisciplinary researchers and experts with lived experience of MS, who conducts research in MS and related technologies (personalised precision health and medicine). From workshop discussions, we produced themes relating to accessibility and equipment considerations, and the importance of social interaction for people with MS. In this late-breaking work, we present the key findings

from the workshop and offer recommendations for using AR HMD exergames in the rehabilitation of MS. We highlight the importance of working with participants with lived experience, who can provide valuable insights especially in the early stages of research.

2 Related Work

Multiple studies have examined the potential of exergames to support physical rehabilitation of people with Multiple Sclerosis (MS) [9, 27, 30, 36], showing they are well-accepted, enjoyable, and can improve balance, functionality, and quality of life, and reduce fatigue severity. However, research on AR-based exergames for MS is still limited and evolving [34]. Pruszyńska et al. [26] investigated the feasibility of a commercially-available AR system for telerehabilitation of MS patients, where participants saw a real-time reflection of themselves on a screen augmented with virtual elements to interact with during upper limb exercises. The authors reported that the system had a positive impact on the strength and efficiency of the participants' upper limbs. Bucchieri et al. [8] explored the potentials of Microsoft HoloLens 2 (AR HMD) for upper limbs assessment of people with MS, developing two applications where participants with MS were required to pick up a physical bottle or plastic boxes and place them in a target area. However, the focus of this study was to assess the performance of the HMD as a tool to consistently record hand-tracking and eye-tracking data during pick-and-place task. Other studies investigating the use of Microsoft HoloLens 2 for upper limbs rehabilitation in people with MS [18, 34] have demonstrated how the engaging aspects of the system can help mitigate the negative effects of repetitive exercises, thereby improving adherence to clinical procedures, and that participants valued game elements, including auditory feedback, counter, and goals in the exergames. However, since these studies recruited healthy participants, the needs and preferences of people with MS were not fully addressed. Overall, while prior research on AR HMDs for exergames in MS rehabilitation shows promising results, the specific needs and preferences of people with MS remain underexplored, especially as many studies recruited healthy participants.

In contexts other than MS, prior work investigating the use of AR HMDs to support exercising/exergaming has focused on physical training for older adults [17, 20, 32] or rehabilitation for other conditions, such as stroke [2, 4, 10, 14]. Virtual coaches have been used in training for older adults [17, 20, 32], to provide supervision and real-time feedback in the absence of a physiotherapist [17]. In rehabilitation, the benefits of using haptic feedback and tangible objects for facilitating exercises have been discussed [2, 14], as they can provide physical means of interacting with virtual objects, a more natural interaction mode, and a chance to improve the user's motor strengths [2, 10, 14]. In the context of shoulder rehabilitation, only interacting with virtual midair objects can reduce the limbs' proprioception, as the user's hands are not in contact with any object [14]. However, haptic devices can be expensive, bulky, heavy, difficult to put on [2, 4], restrictive in terms of freedom of movement [4], and a hindrance to the assessment of natural hand movements [10]. On the other hand, the hardware and software complexities of using haptic systems can be reduced with the use of tangible objects [2]. Tangible objects, like mugs [2] and dowel rod [14], have been used in conjunction with AR HMDs to facilitate rehabilitation. Common household objects can also be used with AR HMDs for in-home exercising, including light to moderately-heavy objects for weightlifting exercises, furniture as support for exercising, and elastic objects for resistance-type exercises [1]. However, there is limited research on how tangible objects can be used within AR HMDs for home-based rehabilitation, particularly in the context of MS. This is important as incorporating tangible objects in AR HMD exergames may help translate rehabilitation gains to real-life activities, particularly since ADLs involve object manipulation [8]. Prior work has also highlighted the importance of individual customisation. Notably, the target of the exercise should be tailored and adapted to the user's current physical and mental condition, to increase motivation and avoid potential dangers [4, 10, 17, 32]. Prior expertise in the exercise, preference for game environment/narrative [32],

Table 1. Participant characteristics.

Participant ID	Age Group	Gender	Role/Background
P1	55-64	F	Academic Researcher with Expertise in Studying MS, HET Member[a,b]
P2	35-44	F	Big Data Program Leader with Expertise in Studying MS, HET Member[a,b]
P3	55-64	F	Person with MS, HET Member and Research Partner[a,b]
P4	25-34	F	Academic Researcher with Expertise in Science Communication[a,b,c]
P5	65+	F	Person with MS, HET Member and Research Partner [a,b,c]
P6	55-64	F	HET Leader with Expertise in Studying MS[a,b,c]
P7	25-34	M	Person with MS, HET Member and Research Partner[a,b]
P8	65+	F	Person with MS, HET Member and Research Partner[a,b,c]

and level of intrinsic motivation [32] should also be considered when tailoring exercise experiences for AR HMDs. To address the varying needs and preferences of different user groups, Karaosmanoglu et al. [15] argued that different tasks, possibly even different exergames, should be considered for each user group.

3 Methodology

We conducted a workshop with a group of multidisciplinary researchers and experts with lived experience of Multiple Sclerosis (MS), who conducts research in MS and related technologies (personalised precision health and medicine). The workshop aimed to gain unique, expert insights from a diverse group of participants, who may understand or have additional requirements for exercising/exergaming with AR HMDs at home, particularly in the context of physical rehabilitation for MS. Given that the study took place before the end of the COVID-19 quarantine period, we conducted the workshop online using free tools to ensure greater accessibility. The workshop consisted of discussions and activities around exercising, exergames, and AR HMDs. Participants were offered a $40 voucher for their participation.

There were eight participants, including experts with lived-experience of MS and researchers with an interest in MS and related technologies (See Table 1). Many participants were members of the group's Health Experience Team (HET), who have worked closely together. Participants' backgrounds include: (a) health services researchers; (b) health data researchers; and (c) science communicators/researchers. Our research received approval from the university's human research ethics committee and informed consent was obtained from all participants.

3.1 Procedure

Before the workshop, participants were asked to fill in a short survey to indicate their age group and affiliation with the research group. The workshop, which was facilitated through online slides, included:

(1) A brief introduction to home exercises (1 minute);
(2) An activity for participants to share their current home exercise routines, beneficial exercises they know, and exercises they would like to try at home, followed by a group discussion about their responses (17 minutes);
(3) An introduction to exergames and AR HMDs, including an explanation of the difference between AR and VR through video examples of AR and VR applications (19 minutes); and
(4) An activity for participants to share how they envision home exercises can be performed in an augmented environment, followed by a group discussion about how objects at home can be augmented for exercising (8 minutes).

For the workshop activities (parts 2 and 4), participants were provided with prompts on the slides and a link to a real-time collaborative web platform for creating virtual bulletin boards (Padlet). The Padlet board started as an empty virtual bulletin board with an image of an empty room as its background. Participants were asked to imagine that the room was one of the rooms in their own home, and provided with text prompts. Participants were asked to respond to the prompts by attaching images to the Padlet board using Padlet's image search function. Participants were provided with a live demonstration on using Padlet and were asked about any issues with the Padlet board throughout the activities.

For the first activity, participants were provided with the following prompts: (1) **"How do you usually exercise at home?"**; (2) **"What kind of home exercises do you know are particularly beneficial?"**; and (3) **"What kind of exercises would you be interested in doing at home?"**. For the second activity, participants were provided with the prompt: **"How do you envision AR-based exercising at home?"**. At the end of the workshop, some participants stayed in the online meeting by their own accord to discuss a variety of topics about exercising, physical therapy, and specialised tools for MS, including local gyms they visit, exercising in VR with an ice climbing simulation, body suits, and personal goals and/or issues about exercising (20 minutes).

3.2 Analysis

To analyse qualitative data from the workshop discussions, we conducted reflexive thematic analysis [6] guided by the six-phase thematic analysis process as outlined by Braun and Clarke [5]: familiarising the data, generating initial codes, searching for themes, reviewing the themes, defining and naming the themes, and producing the report. Data was coded and analysed manually by the first author with an inductive approach. The resulting Padlet board (see Figure 1) was quantitatively analysed, by counting the number and types of items that participants attached onto the board.

4 Results

The final state of the Padlet board contained 18 items relating to home-based exercises (90%, from the first activity) and two items relating to augmentation (10%, from the second activity). Some participants also added text-based notes instead of images. Most items added for the first activity were exercises requiring minimal equipment (i.e., shadow boxing, yoga, Pilates, bed-based exercises, chair yoga, and exercises using dumbbells or elastic bands) (12/18, 67%) (see green-highlighted images in Figure 1). One participant (P4) added exergames as a way to exercise at home before exergames were discussed in the workshop. Some participants also added specialised equipment onto the Padlet board, such as a vibrating machine that stimulates the feeling of being massaged while exercising on the machine (Whole Body Vibration Platform Exercise Machine) (see the bottom-right non-highlighted image in the middle of Figure 1). The two items added by participants for the second activity were an image of a person meditating by the ocean and a text box with the words "surrounded by trees", which are both related to relaxing elements. Thematic analysis of the workshop discussion produced two themes: accessibility and equipment considerations, and the importance of social interaction.

4.1 Theme 1: Accessibility and equipment considerations.

While participants welcomed the idea of using AR HMDs for exercising and exergaming at home, they also raised important accessibility and equipment considerations, including potential issues with the HMD itself and the need for specialised equipment that can be highly beneficial for people with MS in their exercise routines. During a discussion about potential motion sickness in a virtual environment, one participant expressed their concern: *P3: "A lot of people, well, particularly with MS, have symptoms of vertigo and it's just you mentioned before that it makes you feel a bit dizzy*

Fig. 1. Padlet board at the end of the workshop. The green border highlighted exercises with minimal equipment, while the red border highlighted augmentation ideas. Text within the screenshot has been enlarged for readability.

after a while. People might have that. It might be an issue for people". Another participant shared that pressing the power button on the HMD, located behind their head, could be challenging, and suggested that an AR-based exercise program might be more effective if supervised by exercise professionals: *P7: "I could see this being useful in a gym setting when you're actually with your exercise physiologist, for instance, and they can actually assist you in getting set up and yeah, working through exercises with them. ... so potentially you could be doing something like boxing with this AR on your head and with some assistance for me, I wouldn't be able to do this on my own, but if I had someone helping me and just like putting me through my paces a little bit"*. Another participant (P8) agreed and added that having someone else help them in the context of exercising in AR "helps you feel safe".

Some participants also discussed the inclusion of specialised equipment in their exercise routines. One participant shared how the vibrating machine is "allegedly good at certain frequencies for people with MS" (P8), providing examples of how the machine can be used for exercises like squats while offering a massaging sensation from the vibrations. Another participant added that the vibrating machine "sort of wakes up your legs a little bit" (P7). One participant also shared examples of people exercising while receiving electrical stimulation: *P7: "It's called a functional electric stimulation bike where they have a monitor in front of you showing you cycling as your muscles are being stimulated by electricity and you're moving your legs around"*. These discussions and personal stories about specialised equipment indicated how such equipment can be highly beneficial in the exercise routines of people with MS, particularly through vibrations and electrical stimulation.

4.2 Theme 2: Importance of social interaction in exergames for people with MS.

Many participants emphasised the importance of social interaction to motivate them to exercise: *P3: "It would be really interesting to see if you could have, say, a number of people online doing a shared activity, just have that interaction because that's... one of my issues is exercising on my own for the sake of exercising, I'm not very good at it, but if I go somewhere or*

come with others... If it's a game where you're hitting blocks or something like that, then you could try and outdo each other. It could be quite fun". Other participants agreed that they would enjoy the social aspect, providing examples such as dancing in a virtual environment with people who look like their friends (P2) or cycling by the French Alps with friends (P8). One participant further added that the inclusion of social elements are particularly important for people with reduced accessibility: *P3: "Because what we've seen, there's been a trend towards putting a whole lot of exercise routines et cetera online, but for a lot of people, say if you're in your home and you've got reduced accessibility, sometimes just having that.. being able to link up with a few other people doing a similar task and have a laugh at the same time, it would be, I think, a really good thing"*.

5 Discussion

Our research aimed to investigate the extent to which the use of AR HMDs for in-home exergaming can support physical rehabilitation in the management of Multiple Sclerosis (MS). We conducted an online workshop with a group of eight multidisciplinary researchers and experts with lived experience of MS. Quantitative analysis of the Padlet board showed a preference for home exercises requiring minimal equipment, which aligns with prior groundwork suggesting that home-based exercises should use minimal special equipment to save cost and storage space [1]. We produced two themes from the qualitative analysis, namely accessibility and equipment considerations in AR-based exercises for MS, and the importance of social interaction. The inclusion of participants with lived experience proved crucial, as it provided valuable insights and perspectives that were not captured in prior groundwork.

While participants welcomed the idea of using AR HMDs for exergaming for physical rehabilitation at home, a key limitation identified in our workshop was the physical constraints of AR HMDs for rehabilitation. Participants highlighted that many people with MS experience symptoms of vertigo, which may be exacerbated by prolonged use of AR HMDs. The location of the power button for the HMD could also be a challenge for some people with MS. These concerns pointed to potential accessibility issues when deploying AR HMDs for in-home physical rehabilitation. Such limitations could affect users' ability to engage in sustained exercise or exergaming sessions, thereby limiting the current feasibility of AR HMDs for home-based exergaming to support management of MS. Our participants suggested how it would be safer and more effective to exercise using AR HMDs in a gym setting, where exercise physiologists could assist with the setup and guide participants through the exercises. This controlled environment would allow for closer supervision, ensuring both safety and optimal use of the AR HMD for rehabilitation purposes. While virtual coaches [17, 20, 32] may guide users through some aspects of exercise, such as pacing, they cannot provide physical assistance if issues arise during rehabilitation. **Instead of using AR HMD exergames solely at home, we recommend incorporating them into a hybrid model that combines in-home and clinic-based rehabilitation, where the balance between home and clinic use will depend on the user's comfort with the technology, approval from exercise professionals, and the presence of a clear rehabilitation program.**

Our workshop also revealed the importance of specialised equipment that can be highly beneficial for people with MS in their exercise routines. Participants provided examples, such as the vibrating machine and the functional electric stimulation bike, both designed to stimulate the muscles. This can be crucial as it may provide symptoms relief for people with MS [29]. While prior research [1] has shown that tangible household objects can be used with AR HMDs to facilitate home exercises and exergaming, it is important to note that some specialised tools and equipment cannot be replaced by household objects. This is especially true in the context of physical rehabilitation, where certain therapeutic needs may require more advanced or specific equipment. However, incorporating tangible objects into AR HMD exergames remains crucial, as object manipulation helps translate rehabilitation progress into real-life activities [8].

Participants' responses on the Padlet board showed common tangible objects that can be augmented, including yoga mats, chairs, and beds. Our findings suggest that although AR HMDs alone may not be sufficient for exergaming in MS rehabilitation, they can supplement traditional rehabilitation programs. **Therefore, we recommend using a combination of AR HMD, tangible objects, and when necessary, specialised equipment.**

Our workshop also reinforced the critical role of social interaction for people with MS in the context of AR HMD exergames for rehabilitation, particularly those with reduced mobility. For people with MS, social isolation can result from mobility challenges, making it harder to engage in physical activities with others [28]. Participants expressed a strong desire to exercise with friends in virtual environments, such as competing in a block-hitting game, dancing with avatars resembling their friends, and cycling together in AR. In addition to game elements [34], social interaction can also serve as an engaging distraction from the aversive symptoms experienced by people with MS [16]. While the importance of social interaction in exergames and for individuals with MS has been widely documented in previous research [23, 32], few studies have explored its integration within AR HMD exergames for MS rehabilitation. This gap may be associated with the technical limitations and availability of current AR HMD technology. **Social interaction could potentially be incorporated into AR exergames without requiring concurrent play, for instance, through asynchronous interactions or virtual environments that simulate social scenarios.** This approach could help accommodate varying rehabilitation needs that are specific to each individual, allowing people to play games tailored to their abilities while still enabling meaningful social interaction.

We also found an unexpected, but welcomed outcome of conducting the workshop. Some participants stayed after the official activities to continue discussing topics related to exercising, physical therapy, and specialised MS tools. Participants shared a video about exercising in VR with an ice climbing simulation, and talked about local gyms they visit, specialised body suits for managing MS, and personal goals or challenges related to exercising. The first author stayed to listen to these conversations, demonstrating how participating in a workshop on a specific topic, such as AR exergaming, can increase participants' awareness and interest in related topics. In this instance, participants benefited from exchanging valuable information, while the researcher gained unexpected insights from the additional discussions.

5.1 Limitations and Future Work

We acknowledge the limitations of our study. While we gained a better understanding of how AR HMDs can facilitate exergames for rehabilitation in people with MS, our findings were limited regarding how home objects can be augmented to support rehabilitation, aside from participants' preference for relaxing elements. While participants added 18 items relating to home-based exercises on the Padlet board, only two items were contributed on how they envisioned home exercises can be performed in an augmented environment. This may be related to the online nature of our study and the chosen tools for the workshop. To ensure greater accessibility and considering the timing of the study during the COVID-19 quarantine period, we conducted the workshop online using free tools, which may not have been as engaging. We acknowledge that different tools or activities could have better engaged participants. Future studies should consider alternative tools or activities to enhance engagement with researchers and experts with lived experience while still addressing accessibility needs.

Future work should explore how to make the transition between clinic and home rehabilitation use seamless, ensuring that the augmented experience is consistent and effective in both settings. Additionally, future work could explore the development of an adaptive system that dynamically adjusts the recommended ratio of clinic and home rehabilitation use. This is particularly relevant for individuals with degenerative conditions, where rehabilitation needs may evolve as the condition progresses. Future work should also investigate ways to incorporate asynchronous social interaction into

AR HMD exergames for rehabilitation, such as by using simulated avatars based on a friend's historical performance data. For future developments of AR/VR HMDs, engineers should prioritise the placement and accessibility of essential controls, such as the power button, to ensure that the devices are inclusive and easy to use for individuals with mobility impairments. Finally, developers may explore ways to enhance safety measures during home-based rehabilitation, such as implementing an alert system that notifies physiologists or caregivers in case of an emergency or if something goes wrong during a session.

6 Conclusions

Our workshop findings showed that while current feasibility of AR HMDs for *home-based* exergaming to support physical rehabilitation for the management of MS is limited, they can be part of a hybrid model combining both home and clinic-based rehabilitation. The extent of home use will depend on the user's comfort with the technology, professional approval, and a clear rehabilitation program. To improve the rehabilitation experience, combining AR HMDs with tangible objects and, when necessary, specialised equipment can provide more comprehensive support. Additionally, incorporating engaging elements like social interaction and game elements can help distract users from the aversive symptoms of MS and further improve the rehabilitation experience. Incorporating asynchronous social interaction into AR HMD exergames could allow individuals to engage socially without requiring concurrent play, helping to address diverse rehabilitation needs. Our study highlighted the value of including participants with lived experience. By conducting a workshop with subject-matter experts, particularly those with lived experience, we gained insights that were not captured in prior research. We encourage researchers to adopt this approach, particularly in the early stages of research. Additionally, an unexpected but welcome outcome of the workshop was the increased awareness and interest in the topics discussed, benefiting both the participants and the researcher. We hope that future researchers can apply the lessons from our workshop to foster more inclusive design in their studies.

Acknowledgments

This research has been delivered in partnership with Our Health in Our Hands (OHIOH), a strategic initiative of the Australian National University, which aims to transform health care by developing new personalised health technologies and solutions in collaboration with patients, clinicians, and health-care providers.

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Accepted 23 February 2025