Exploring Opportunities for Augmenting Homes to Support Exercising

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ABSTRACT

Although exercising at home has benefits, it is not always engaging or motivating. Augmented Reality (AR) head-mounted displays (HMDs) offer the potential to make in-home exercising and exergaming more inclusive and immersive, but there is limited research investigating how such systems can be designed. We employed a participatory design approach involving semi-structured interviews to investigate how homes can be augmented to facilitate exercising experiences. We developed 10 recommendations for developing home-based exercising experiences using AR HMDs. Our results further contribute to the existing body of research on the use of AR for exercising, home applications, and everyday objects by presenting the first foundational study investigating the wide range of exercises that can be supported through AR HMDs in home environments and the different ways home elements may support these exercises, and laying the groundwork for future work developing home-based exergaming through AR HMDs to increase people's physical activity levels.

CCS CONCEPTS

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

KEYWORDS

Augmented reality, Exercising, Exergaming, Home environment, Participatory Design

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1 INTRODUCTION

Exercising can improve energy levels, quality of life, and mental well-being [24, 36, 37]. However, exercise is difficult to start, and even harder to maintain, with many people not getting enough exercise. A survey conducted in 100 cities in America found that only 40% of female and 57% of male adolescents complied with the national physical activity guidelines [12]. Regular exercise requires discipline, but exercise routine can be repetitive, causing people to lose motivation and stop exercising [4, 29]. In addition, lack of time or proximity to exercise facilities can reduce physical activity [4, 18], while unexpected external circumstances (e.g., COVID-19 lockdowns) can disrupt exercise routines [19, 41]. Financial, cultural, or personal reasons can also affect willingness to exercise [21, 28, 35, 46], such as the cost of gym membership or home exercise equipment, lack of separation between men and women in exercise facilities, feelings of embarrassment from exercising in front of others, or medical conditions. Exercising at home can enable people to overcome these barriers, as they do not need to commute or have nearby facilities, with the option to continue exercising during unexpected or personal circumstances. However, exercising at home is not always engaging or motivating, and therefore the effectiveness of home-based exercises usually depends on individual adherence and commitment to following the exercise routine [13, 34].

Exercise video games (exergames) have been used to increase physical activity levels at home. An 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" [44]. Sween et al. [58] conducted a literature review of previous studies that investigated the impact of active video game(s) or exergaming on energy expenditure (EE) levels. Based on a review of 27 studies, they found that exergaming can increase EE to levels that meet the American College of Sports Medicine (ASCM) recommended guidelines for health and fitness (≥ 150 min/week of moderate intensity), up to 300% above resting level. As most of the studies reviewed were conducted in lab-based settings, Sween et al. [58] also argued that the increase in EE levels could be even higher in a home environment where people spend a longer time playing video games. An important determinant of the amount of time allocated to an activity is the perceived enjoyment of the activity [38]. Because exergaming has been shown as an enjoyable activity

for multiple age groups, it has the potential for sustained activity (exercise) participation [38]. Exergaming can promote physical activity, especially for people who are less motivated by traditional exercising [38]. However, popular exergaming systems are not always safe or inclusive, especially for some groups of people. For example, the Nintendo Wii handheld controller and balance board are unsuitable for people with motor limitations such as tremors (e.g., people with Parkinson Disease (PD) [45]) due to difficulties holding on to the controller, and for people at higher risk of falling (e.g., older adults) due to the risk of falling when trying to stand on a raised platform. In addition, making exergames more immersive could further improve motivation and enjoyment when exercising [53, 63].

Immersive virtual reality (VR) exergaming has been shown to be more engaging than standard exercise [21]. Plante et al. [47] found that participants' heart rate and enjoyment were higher while fatigue rating was lower in VR compared to standard exercising conditions. VR also allow users to quickly identify 3D poses in space from any angle, which can be beneficial for exercising [39]. However, there are shortcomings to using VR for exercising at home, particularly because users are unable to see their real surroundings, including all of its physical objects and obstacles [39]. This creates safety concerns such as falling, tripping, and hitting objects at home. On the other hand, using augmented reality (AR) head-mounted displays (HMDs) could eliminate these safety concerns as users are able to see their real surroundings. Mostajeran et al. [39] explained how allowing users to see their real surroundings can bring three benefits, including: (1) psychological feeling of safety due to being in a familiar environment (i.e., the home); (2) physical safety from being able to view and grab onto nearby objects in case a fall is about to happen; and (3) physical safety from being able to view and avoid physical obstacles, even with any dynamic change in the environment (e.g., another person crossing the exercise area). Because AR HMDs are also wireless in nature [56] and they do not require a raised platform to support exercising, the risk of falling and tripping is further reduced. Finally, AR HMDs can help reduce accessibility issues such as difficulty holding on to video game controllers due to motor limitations [16], since users' hand gestures can be registered as inputs.

Despite the potential benefits of using AR HMDs to increase physical activity levels at home, there is limited research investigating the design of such systems to promote exercising or exergaming at home. Previous research investigating how AR HMDs can be used to promote exercising/exergaming has mostly focused on specific health-related problems (e.g., [4, 6, 14, 16, 23, 34, 39, 56]), without exploring how home objects and environments can be fully utilised to facilitate the exercise. There is a lack of foundational research investigating the wide range of exercises that can be supported through AR HMDs in home environments, and the different ways home elements may support these exercises. Therefore, to address these gaps in the literature, we identified the following research questions to explore how AR HMDs can be used to support exercising at home:

RQ1 What kind of exercises are suitable for homes in an AR environment?

RQ2 What home objects can be augmented to facilitate exercising and how can they be augmented?

In this paper, we report on an initial exploration of how homes can be augmented for exercising, to lay the foundation for future research into designing augmented home-based exergames. As part of a participatory design approach, we conducted semi-structured interviews with 17 potential users living in Australia and two senior physiotherapists. We found themes across our interviews regarding suitable home exercises, home objects, augmentation, and additional stimuli. We developed 10 recommendations for future designers and researchers of home-based exercises in AR, grouped into three categories: (1) properties of suitable home-based exercises in AR; (2) home objects that can be used for exercising at home; and (3) approaches to follow when augmenting home objects and environment to facilitate home-based exercising in AR. Our results **contribute** to the existing body of research on the use of AR for exercising, home applications, and everyday objects by:

- Developing 10 recommendations for designers/researchers aiming to develop home-based exercising experiences using AR HMDs;
- Presenting the first foundational study investigating the wide range of exercises that can be supported through AR HMDs in home environments, and the different ways home elements may support these exercises; and
- Laying the groundwork for future work developing home-based exergaming through AR HMDs to increase people's physical activity levels.

2 RELATED WORK

We investigated the existing body of research on the use of AR for exercising/exergaming, home applications, and everyday objects to develop an understanding of the current state-of-the-field on how AR HMDs can be designed to facilitate home-based exercising.

2.1 Augmented Reality for Exercising/Exergaming

Previous research investigating how AR can be used to promote exercising/exergaming has mainly focused on mobile AR applications, including popular location-based AR games such as Pokémon GO [7, 42, 52]. To facilitate an immersive, inclusive, and accessible exercising experience in AR, the user must be able to freely use their hands to exercise and to utilise their whole surrounding as the exercise environment. When engaging with mobile AR applications, users are not able to fully use their hands and bodies. Therefore, we need to consider AR HMDs as an alternative. Key themes appearing from previous research on exercising/exergaming through AR HMDs include individual customisation and the importance of motivational elements.

Individual customisation has been shown to affect how AR HMDs exercises should be designed. Most importantly, the target of the exercise must be tailored and adapted to the user's current physical and mental condition, to increase motivation and avoid exposing users to potential dangers if the exercise does not cater to their limitations [6, 14, 34, 56]. The user's prior expertise should also be considered when determining how much guidance they get. Jo et al. [30] found user preferences on how online yoga videos

can be presented dynamically through AR HMDs, depending on the user's prior expertise in yoga, with experienced users preferring user-anchored layout (a screen that follows the user's head) and less experienced users preferring trainer-anchored layout (a screen that moves following the trainer's viewpoint). Concerning the types of virtual elements to be added in AR, the game environment should be tailored based on user type and player type (e.g., [8]) [56]. Individuals with low intrinsic motivation were found to prefer an immersive, illusory environment (e.g., beautiful landscapes), whereas those with high intrinsic motivation preferred the real environment with the addition of vital data (e.g., heart rate, blood pressure, and exercise time) or feedback regarding the exercise [56]. Sports environment was also found to be associated with high intrinsic motivation, but not low intrinsic motivation [56]. The game narrative, which is an important motivational element, should also be tailored to the individual (e.g., not involving war scenarios for older adults as many of them experienced World War II) [56].

Motivational elements, including social elements, storytelling, and rewards, are important considerations for designing an engaging experience. Social elements have been regarded as an important part to enhancing motivation to exercise among older adults [39, 56]. Stamm et al. [56] reported that their older adults participants greatly valued social interaction and wished for a multiplayer mode, even if they preferred a comparison with their own previous data to show progress instead of a comparison with other people. Storytelling has also been perceived as an important motivator for exercising [56], while rewards should be used to increase people's desire to complete the exercises [14].

Previous research investigating the use of AR HMDs to support exercising/exergaming has focused on healthcare contexts, such as rehabilitation for shoulder injuries [23], stroke [4, 6, 14], and cognitive/motor conditions [16] or physical training for older adults [34, 39, 56]. Studies investigating the use of AR HMDs for physical training for older adults have particularly focused on employing virtual coaches [34, 39, 56]. Virtual coaches can provide supervision and real-time feedback in the absence of a physiotherapist [34], and are also socially accepted by older adults [39]. Overall, it has been shown that the use of AR HMDs for home exercises could increase people's adherence to exercising, although people needing rehabilitation and older adults have different requirements from other user groups due to additional risks and factors.

Studies investigating the use of AR HMDs for rehabilitation have also discussed the benefits of using haptic feedback and tangible objects in facilitating exercises [4, 23]. The incorporation of haptic technology or tangible objects for virtual environments can provide physical means to interacting with virtual objects, a more natural interaction mode, and a chance to improve the user's motor strengths [4, 14, 23]. Garcia Hernandez et al. [23] also argued that only interacting with virtual midair objects during shoulder rehabilitation could diminish or reduce the limbs' proprioception since the user's hands are not in contact with an object. However, haptic devices can be expensive, bulky, heavy, and difficult to put on [4, 6]. Wearing haptic gloves may also restrict freedom of movement [6] and interfere with assessment of natural hand movements [14]. On the other hand, using real tangible objects can provide the same benefits, while also decreasing the hardware and software complexities of haptic systems [4]. Tangible objects, such as mugs [4] and dowel rod [23], have been used in conjunction with AR HMDs to facilitate rehabilitation. However, there is a lack of studies investigating how other tangible objects can be used to support exercising through AR HMDs.

2.2 Augmented Reality for Home Applications and Everyday Objects

As AR technologies continue to develop and become more accessible, researchers have begun investigating how AR can be used to improve the experience of living at home. Several studies have investigated how AR can be used as a tool for supporting assistive home modifications [5, 9, 25]. Bonanni et al. [10] designed and built a conventional kitchen augmented with projection of digital information onto objects and surfaces, to support users when working in the kitchen. Ventä-Olkkonen et al. [61] investigated how home windows can be augmented to present additional information to users by augmenting windows, while Colley et al. [15] explored how AR can be used to help remember things at home, such as remembering the Wi-Fi password or the history behind a home object. Knierim et al. [32] conducted an initial exploration on how AR can seamlessly be integrated into people's home environment to benefit users at home, identifying potential use-cases and opportunities. While exercise was not the main focus of their research, some participants from this study discussed topics relating to physical activity. For example, the study reported that one participant imagined a virtual trainer who can provide necessary exercise instructions, correct mistakes, and prevent injuries. Participants also imagined how existing devices or artefacts at home can be augmented (device augmentation), such as augmenting a weighing scale to show a more detailed breakdown of a person's weight and how it compares to four weeks ago, or augmenting a couch to show how much time a person has spent idle in front of the television and not being active. Among studies investigating the use of AR for home applications, multiple authors have stressed the importance of selective augmentation, to prevent information and cognitive overload [32], since attention is limited [10]. The quality and quantity of augmentation needs to be carefully considered based on the amount and type of attention for each task.

Using everyday tangible objects for home AR applications can bring similar benefits to using tangible objects for exercising, by providing physical means to interacting with virtual objects and a more natural interaction mode [4, 14, 23]. However, for many previous studies on the use of AR for home applications, virtual images were mainly overlaid on flat surfaces (e.g., a virtual grab bar on the wall [9] or a virtual interface displaying information on a window glass [61]), or simply floating in the 3D space near an object (e.g., a rectangular window displaying the Wi-Fi password above a Wi-Fi router [15]). Holding virtual objects with the lack of tactile stimuli was deemed unsatisfying for some people [33]. To prevent a brittle experience in the virtual environment, the immersive capabilities of audio and visual outputs need to be matched with equally immersive haptic experiences [27]. The theme of device augmentation from [32] also highlighted people's desire to use AR to add new functionalities to existing home objects that were considered well-integrated into the home environment, which aligns with the idea that existing, well-integrated home objects can

be used as tangible objects that can be augmented to support home exercising.

Previous studies investigating how everyday tangible objects can be utilised to enhance experiences in AR have mainly investigated how they can be used as mixed/augmented reality inputs, either by overlaying the entire tangible object with a virtual object [64], or only overlaying the edges of the tangible object (e.g., the rim of a cup) [26]. Overlaying the entire tangible object with a virtual object can be challenging, as it is difficult to find everyday objects that perfectly match the digital function geometrically and semantically [26]. Hettiarachchi and Wigdor [27] investigated how haptic experiences can be introduced for virtual objects by matching them with a similarly-shaped everyday object. For example, a virtual torch can be matched with a soda can, while a virtual light saber can be matched with a wine bottle. The authors argued that it is important to select a physical object that is as similar as possible to the virtual object in terms of shape and size for the user's suspension of disbelief. On the other hand, a mismatch would negatively affect the user's feeling of immersion and engagement [54]. In the case of the virtual light saber example, a wine bottle can be a good match if the intention is only for the user to hold the handle of the light saber. However, if the user needs to be able to feel being hit by the light sabre, the wine bottle might not be a good match and a different, longer physical object needs to be chosen instead. This highlighted the importance of carefully considering the specific use-cases before deciding what physical objects can be augmented to facilitate home exercising/exergaming, and the shape and size of the object in relation to the intended use-case.

2.3 Conclusions

Previous studies on the use of AR (both mobile and HMDs) for exercising or exergaming have highlighted the importance of individual customisation, elements to consider to increase motivation and immersion, and using real tangible objects to enhance the exercising experience. Previous research investigating how AR HMDs can be used to promote exercising/exergaming has mostly focused on specific health-related domains, such as rehabilitation or home training for older adults. There is a lack of foundational research investigating the wide range of exercises that can be supported through AR HMDs in home environments. This gap gives rise to **RQ1: What kind of exercises are suitable for homes in an AR environment?** Meanwhile, previous studies on AR for home applications and everyday objects have provided two important insights to consider for the design of home-based exercising/exergaming experiences through AR HMDs. First, the quality and quantity of augmentation for homes must be carefully considered depending on each task. Second, everyday tangible objects at home can be used to enhance the experience of exercising at home, but the intended use-cases must be considered before selecting the home objects that can be augmented. Despite these insights, there is still limited knowledge on the types of home objects that can be augmented for different home exercise-related use-cases. As a result, we identified **RQ2: What home objects can be augmented to facilitate exercising and how can they be augmented?** Therefore, our research aims to build on previous research by investigating the wide range of exercises that can be supported through AR HMDs in home environments (through **RQ1**), and the different ways home elements may support these exercises (through **RQ2**).

3 METHOD

To address our research questions RQ1 and RQ2, we employed participatory design to gain insights from future users as to how they might want to exercise in an AR environment in their own home. Simonsen and Robertson [55] demonstrated that participatory design can be employed: (a) to design digital parts or layers in an originally non-digital environment to create a new digitally enhanced experience; and (b) for studies involving mixed reality environments. As our research investigates how homes (an originally non-digital environment) can be augmented (with digital layers) to facilitate an enhanced exercising experience in AR, participatory design is an appropriate approach following the examples set out by Simonsen and Robertson [55].

For our initial exploration, we conducted semi-structured interviews with 17 potential users to understand how people exercise, or would like to exercise at home, and how that could be supported in an AR environment. To supplement results from our pool of potential users, we conducted semi-structured interviews with two senior physiotherapists to gain further, professional insights on how exercising can be done at home particularly in an AR environment. The senior physiotherapists' experience and expertise can help bridge any knowledge gap from interviews with our current pool of potential users. Qualitative data from semi-structured interviews was analysed with a six-phase thematic analysis process as outlined by Braun and Clarke [11]: familiarising the data, generating initial codes, searching for themes (in this case, themes about qualities that make safe and suitable home exercises in AR, home objects that can be used for home exercises in AR, and how home objects and environments can be augmented to support exercising), reviewing the themes, defining and naming the themes, and producing the report. Data was analysed and coded manually by the first author with an inductive approach. Our research received approval from the university's human research ethics committee and an informed consent was obtained from all participants.

3.1 Interviews with Potential Users

We recruited participants living in any type of housing in Australia, who were 18 years or older. Interviews were conducted online for a maximum of 20 minutes per participant. Participants were offered a $5 voucher for their participation. During the interview, participants were asked to describe their level of physical activity. Participants who reported having done any exercise at all were asked to share some details on their exercising habit, including: (1) how often they exercise; (2) what kind of exercise they do; (3) where they do the exercise; and (4) how they exercise during the COVID-19 lockdown. Meanwhile, participants who reported not doing any exercise were asked if there was any particular reason for their lower levels of physical activity and to describe their level of interest in trying out different types of exercises. Then, all participants were asked if they have exercised or considered exercising at home before, followed by questions about the types of exercise they think can be done at home and how they can be done in terms of tools, equipment, or technology needed. Towards

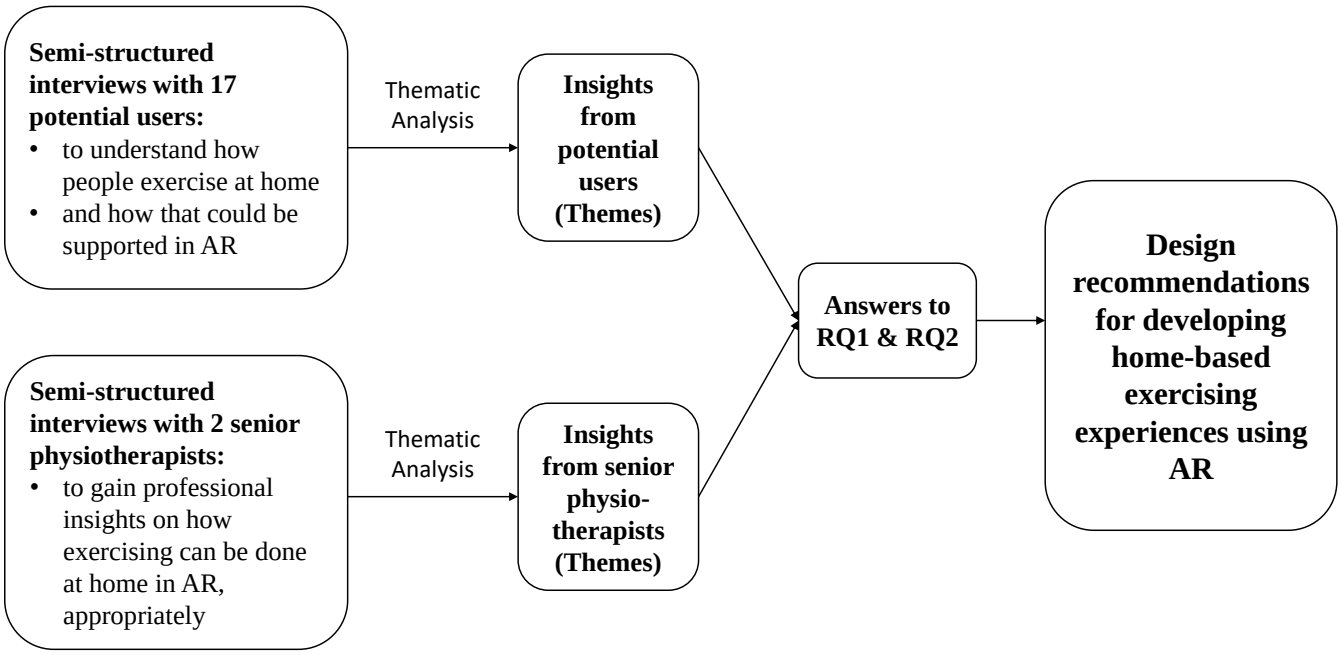


Figure 1: Participatory design approach for this research

the end of the interview, participants were reminded of the context of the research, and then asked how they feel the exercises they have discussed can be replicated in an AR environment, especially if they do not have the necessary tools or equipment to exercise, such as a dumbbell. Participant demographic included 11 female and 6 male, with ten aged 25-34, three 18-24, two 35-44, and one each of 45-54 and 55-64.

3.2 Interviews with Physiotherapists

Interviews were conducted online for a maximum of 30 minutes per participant. Participants were not offered monetary compensation; instead they were invited for continuous collaboration as the research progresses. Participants were asked to share their responsibilities/activities at work, exercises that their clients can benefit from, exercises that can be done at home, and how these exercises can be done at home in terms of tools, equipment, or technology needed. Participant demographic included 1 female and 1 male from two different clinics, both aged 55-64, who both work professionally as senior physiotherapists.

4 INSIGHTS FROM POTENTIAL USERS

We identified seven themes grouped into two categories, relating to: (1) suitable home-based exercises; and (2) home objects, augmenting homes for exercising, and motivational elements beyond augmentation. In this section, we present each theme with supporting participant quotes.

4.1 Category 1: Suitable Home-based Exercises

Our first three themes related to defining suitable home-based exercises. The themes defined that home-based exercises should 1) be mostly stationary, 2) use minimal special equipment, and 3) incorporate both structure and novelty.

Theme 1: Home-based exercises should mostly be stationary. Not all exercises can be done inside the house; for safety reasons and for preservation of the home, home-based exercises should not involve large, aggressive movements. A 'home' can look different for different people (e.g., a studio apartment in a student accommodation versus a large house with a backyard, a dedicated home exercise space versus multi-purpose areas). However, we found a common theme in terms of the types of exercises that participants reported doing inside the house: they were mainly stationary. Participants described stationary exercises as not needing to move around the room too much and usually taking place in a set position. This included exercises such as strength-based exercises (lifting weights or core exercises such as push-ups), flexibility exercises (touching hands behind the back and other workouts during yoga), martial arts (Tai Chi), or light aerobic activities (jumping, burpees, dancing). Stationary exercising is largely to avoid "stuff getting broken" (P03) inside the house, especially if people become too immersed in the exercise activity.

Theme 2: Home-based exercises should use minimal special equipment. To avoid cluttering the home environment and to minimise the financial barriers to exercising, home-based exercises should require little to no specialised equipment. Some participants shared that part of the reason they do not exercise at home is "because of the lack of equipment" (P01). Participants reported that exercise tools and equipment can be costly and take up storage space (particularly in smaller homes). Therefore, some participants preferred home exercises that require little to no equipment (e.g., only using their body or requiring a yoga mat). One participant shared how they had to be creative when it comes to exercising at

home because "the limiting factor with exercising at home is you don't have all access to all the equipment you need" (P13), particularly when exercising at home during COVID-19 lockdowns: *P13: "I had to come up with creative ways to essentially replicate what I do in the gym without the heavyweights. So, what I did there was kind of try to find body weight alternative exercises; instead of a bench press I did a push up, so a lot of that replaced with body weight exercises"*.

Theme 3: Home-based exercises should incorporate both structure and novelty. Home-based exercises can be more effective when there is an evolving structure that people can follow. Some participants preferred shorter, targeted exercises that they can do on a regular basis. Examples include watching or listening to video or audio instructions, such as fitness videos from YouTube. Participants indicated that these video or audio instructions provide a structured and effective 10-30 minute workout that they could fit into their daily routine. One participant noted that following these instructions "is more convenient and more easy to continue" (P06). Having instructions to follow can be beneficial for people to exercise 'correctly' at home: *P14: "You can do yoga and Pilates [at home], but the thing with these exercises is that you need to know what you're doing, otherwise it is pointless"*. On the other hand, having a structure that is too rigid and repetitive can backfire and demotivate some participants from continuing the exercise routine: *P08: "I resorted to online YouTube videos as I didn't have access to gym equipment at that time, but I did find that it got quite repetitive and I did lack a bit of motivation during then"*. Comments related to this theme indicated that both structure and novelty needs to be incorporated to facilitate effective home exercises.

4.2 Category 2: Home Objects, Augmentation, and Beyond Augmentation

Our final themes from the semi-structured interviews with potential users related to home objects, augmentation, and considerations beyond augmentation. The themes related to 4) suitable home objects for exercising at home, 5) individual preferences for home object augmentation, 6) augmenting the home environment, and 7) motivational elements.

Theme 4: Different home objects can be used for different exercises. Participants shared a variety of home objects that they have used as replacements for exercise tools or equipment. Most participants had some ideas when it comes to a replacement for weightlifting. Common objects mentioned by participants were water bottle, cans, kettle, milk bottle, iron, or other kitchen utensils for lifting, instead of using a dumbbell. Objects with a handle were also preferred as the handle made it easier for them to lift. Some participants added that they like how using objects like a water bottle means the weight can be adjusted for a more personalised weightlifting exercise, using water or even sand. If these objects are not heavy enough, some participants shared that they could resort to using university textbooks, laptops, backpacks, rice bags, shopping bags filled with items, or even a bin. Interestingly, a couple of participants mentioned lifting their pets (P17) or "children" (P11) as a form of exercising. However, some participants expressed their concerns that household items might not be functionally suitable for exercising or could even lead to injuries. For example, one participant (P05) shared that having a home-based object that has the same weight as a dumbbell does not necessarily mean it has the right handle that can support a safe and correctly-executed weightlifting exercise to avoid injuries. Meanwhile, another participant (P03) shared how difficult it is to find two items that would weigh the exact amount in your household, to act as two dumbbells that you would need to lift at the same time for time efficiency and balance.

While participants had many suggestions about home objects for weightlifting, participants found it more difficult to think of replacements for other types of exercises. Some participants discussed using a piece of clothing if they do not have resistance bands or elastic bands: *P11: "I guess you might be able to use clothing, like recycle some clothing that you don't care about, like old stockings*". Similarly, another participant (P20) added that the elastic waist band in pants could be tied to a door, stretched, and then used for specific exercises. A participant (P12) shared how they used a towel as a visual line to exercise their legs when lying on their back, such that their legs could continuously move above and below the towel. Another participant (P13) recounted how they tried tying up a bed sheet and hanging it over an open door to do pull-ups, although the participant added that this exercise was one of the hardest exercises to try to replicate.

Another common suggestion for non-weightlifting exercises was to use furniture at home. Some participants discussed having utilised furniture as a form of support to help them exercise. For example, a participant (P11) shared that chairs and the wall can be used for "stretching out the nerves or as props for doing squats as a stability thing so you don't fall over". Participants added that a few things at home can be used for stepping or jumping exercises, such as the edge of the bed (or a mattress if it is on the floor) or other surfaces like tables and chairs. Similarly, fixtures can be used as a form of support to exercise, like "the edge of a bath" for "squats" or "the edge of the kitchen table to do push-ups" (P07).

Theme 5: Preference for home object augmentation for exercising varies between individuals. We found two types of preferences for augmentation of home objects for exercising in an AR environment – augmenting objects to resemble exercise equipment and to resemble other personally motivating objects. For object augmentation to resemble exercise equipment, participants shared ideas like augmenting a table into a gym platform or a water bottle into a dumbbell. One participant (P19) shared how having the option to make a water bottle look like a dumbbell would make them "feel more professional and motivate [them] to exercise even more". Another participant (P21) noted that exercising using a bottle does not really feel like an exercise and therefore preferred for the water bottle to be augmented. For object augmentation to resemble personally motivating objects, preferences included augmenting a water bottle or a rice bag into an animal, or something else that might be unusual, "completely different from what it should be, depending on the personality of the person", like "a very large red lipstick" (P19). One participant suggested that the edge of a bath and a kitchen table could be augmented into "a cute chair" and "a very huge stone", respectively (P07). Another suggested that a rice bag could be augmented into a pet dog that needs to be carried and rescued (P08). However, some participants did not like the idea of having 'personally motivating' augmented objects when exercising: *P20: "First of all, if it's a dog then.. I need to worry about whether it's*

hold carefully or not, it feels comfortable or not, so it's distracting me a bit. But for some people, maybe it's another thing. It's more like a motivation. So for me personally, I think I prefer gym equipment".

Theme 6: Augmenting the surrounding environment could enhance immersion. Participants discussed the importance of augmenting their home environment and not just the objects they use for exercise. For example, one participant mentioned augmenting a book rack to look like a gym rack, just to give the feel that they are in a gym to motivate them to exercise more: *P04: "Let's say, a bookshelf? Can that be augmented into a rack filled with dumbbells? I can get the benefit of… psychologically, I'm inside gym and work out harder instead of being in the same apartment that I usually spend my day in. That'll be nice because, well, I guess if someone is using AR and they are being placed in a different environment compared to their own place, and still have the same benefits of working out in the gym.".* Another participant (P07) suggested augmenting their ceiling to look more interesting while they are lying down, as their room is small, narrow, and crowded: *P07: "So, if with the AR glasses when I lie down maybe I can see the sunshine, the sea here, not in my bedroom, maybe I will feel happier and feel more fun about the exercise. My biggest problem as I mentioned, I don't want to exercise in the bedroom because it's just too crowded and I only have a bed and the desk. If the AR technology can let me see more things in the bedroom, change the environment, maybe [it] will make me more engaged".* Augmenting the surrounding environment can not only increase immersion, but also help support some exercises. For example, a participant (P13) discussed the idea of using AR to create a visual "boundary on the floor" when exercising, "like a pseudo yoga mat ... to ensure you're not moving away from [the intended position]".

Theme 7: Home-based exercising could benefit from motivational elements beyond augmentation. Regardless of how well home objects and the surrounding environment are augmented, some participants wanted additional stimuli to motivate them to exercise at home. Some participants did not like, or were not interested in, exercising at home. Other than the lack of space at home, participants reported a lack of interest in exercising or wanting to use their home only as a space for relaxation. Participants revealed that some form of additional stimulus might help motivate them to try exercising at home. For example, some participants mentioned relaxing elements (e.g., a massage bed), while other participants preferred elements of fear: *P08: "Maybe if you added a bit of a fear factor. So, if I'm lifting a rice bag for example, and if I don't lift it through enough reps, then I don't know, the floor becomes lava or I sink or something. I think anything fear inducing would really encourage me to exercise.".* One participant (P21) provided an interesting example of how game elements can be included for exercising in AR, where they shared how they would like to obtain golden coins like in Super Mario Bros. [43] when jumping.

5 INSIGHTS FROM PHYSIOTHERAPISTS

We found two themes from our interviews with physiotherapists, related to the importance of tailoring home exercise programs to the evolving needs, abilities, and interests of each individual, and the variety of home objects that can be used for home exercises. We present each theme with supporting participant quotes.

Theme 1: Exercises need to be tailored to each person's evolving needs, abilities, and interests. Both physiotherapists emphasised that exercising at home needs to be highly personalised to the individual. First, exercises need to be tailored to focus on the person's needs and/or issues: S02: *"In our treatment we'll look at where their deficits are. So whether it's balance or strength or mobility or pain, and then just trying to give them something that is achievable. We'll usually practice it in the rooms here. So it's achievable for them, you know, at the time, but it's pushing them a little bit as well".* For example, balance training should be incorporated into a person's exercise program if they have issues around balance, which could help prevent falls. From the interviews, we found that both physiotherapists use the same software to prescribe exercise videos to patients: *S01: "We've got a snazzy bit of software called Physitrack, which is great because we can then assign them the exercises for them for their own personalised program and we can send it to the phone and we can track their progress and modify exercises easily".* One physiotherapist (S02) discussed the added benefit of having a video library of exercises that can be assigned to patients: S02: *"It's something we used to write it down on paper. So if they lost the paper, that's gone. So they can carry their exercises around on their phone with them because they download an app to view their exercises and there's a video of it showing the technique and we can write notes about their technique in it and how many we want them to do. And there are other feedback things so they can tick off when they've done their exercises, if they had any pain".*

Second, exercises should also be continuously tailored to the person's evolving abilities, not just based on their abilities at the start of the exercise program. People might have made some progress after some time exercising, or circumstances might have changed, requiring the exercise program to be adjusted. It is also important to ensure that the individual is appropriately challenged, without being required to overexert themselves. For example, one physiotherapist (S01) discussed how they individualise the GLA:D® (Good Life with Arthritis: Denmark) program [1] for people depending on how well they are doing and progressing. The other physiotherapist discussed the importance of timing: S02: *"Exercise that could cause some really bad pain one week, you know, three weeks later might be really good exercise for them. So, you know, trying to just pitch the exercise at the right level for their strength and stage of where they're at. So yeah, they should be really personalised to each individual patient. And I guess that's a big part of our role in training and it's trying to get that match between where they're at and what will push them a little bit further and help them without going too far and making them sore".*

Finally, exercises should be tailored to the individual's personal interest in order to increase motivation. Both physiotherapists discussed how a big part of their role is getting to know their patients, not only in terms of abilities, but also interests. One physiotherapist described how they approach tailoring exercises to patient interests: *S01: "We usually ask people, what is it you like to do? You know, if you like to garden then using the pots and things that you're filling and picking them up repeatedly, they're good resistance exercise".* The other physiotherapist shared the importance of aligning exercises with patient interests: *S02: "The focus will shift depending on their abilities and their interests as well. So, someone with no interest in sport may not want to do a running thing as an exercise, whereas*

for other people that are, you know, that's what they're trying to get back to. So it's really trying to get as close a match to that person and their interests as we can. I think that a really important thing as a physio is knowing your patient". They further explained the balance between needs and interests and the impact on patient motivation. For example, although "exercises in the water" may be beneficial, it is "completely inappropriate" for people who "don't want to get their body wet" (S02).

Theme 2: Home objects can be used as alternatives to exercising tools. There are small, affordable tools that physiotherapists might ask their patients to use for exercising at home, such as elastic bands or pulley systems. However, there are times when a patient is in a location without these specialised tools or they might prefer not to spend extra money to purchase these tools. In such cases, the patient can consider using household items as a 'good-enough' replacement. For example, the TheraBand [2] is a colour-coded elastic band used for resistance exercises that can be attached to a door for exercising (S01). A patient who did not bring their TheraBand on vacation but who still wants to exercise could consider another elastic band, like "bungee cords" or "luggage ropes/straps" (S02). Another example is a pulley system that can be used for shoulder injury-related exercises, which can be replicated using "a towel over a door frame", although "it's not as smooth" (S01).

During the interviews, both physiotherapists discussed how common household items can be used for exercising, such that people "don't have to go and buy equipment and use what's already in their house" (S01). One physiotherapist (S02) said that they ask their patients what they have at home, to discuss what they can use for exercising. Both physiotherapists shared a variety of household items that can be used for exercising and how they can be used. Water bottles, cans, or a bag of rice from the kitchen can be used as weights. Items that are non-breakable with the weight written on them (e.g., a can of soup) are useful and can also help the patient get a better sense of how much weight they are lifting to target the amount of weight they want to lift. Cushions can be used for balance practice, for example, by standing on a cushion on one leg while trying to do another task people normally do at home (dual-tasking), such as putting out the washing (S01). As part of an exercise routine, household items can also be used to self-massage. For example, soccer ball or glasses case can be used for self-massage, instead of foam rollers (S02).

Furniture works well as a support for exercising. Both physiotherapists provided examples where patients could use the back of a couch for stretching (S02), a chair for squatting exercise (S02), or a settee to be in a comfortable position for sit-ups or pelvic lifts (S01), or as balance support (S02). Furniture can also be used to practice "getting on and off the floor" (S01). Household fixtures like stairs can also be used for exercising. For example, stepping up and down a stair can be done as a knee exercise and to improve coordination and strength (S02). One physiotherapist (S02) even noted that people who are handy with wood might make their own appropriately-sized step, depending on their needs and desired challenge.

6 DISCUSSION

Our research aimed to investigate how AR HMDs can be used to facilitate more engaging, motivating, and personalised exercising at home. We conducted semi-structured interviews with 17 potential users and two senior physiotherapists. Together, our studies provided multi-source insights into home exercising in AR, taking into account different requirements and considerations. We present our discussion organised into three categories of recommendations, in descending order of priority as the exercises (the use cases) must first be determined before deciding which home objects to augment and how to augment these home objects: (1) suitable home exercises in AR; (2) home objects to augment for exercising; and (3) approaches to augmenting the home for exercising. We additionally examine motivational elements that can be considered to transform augmented exercising into augmented exergaming.

6.1 Defining Suitable Home Exercises in AR

The first step to designing an engaging home exercising experience in AR is to determine the answers to our research question RQ1, **"what kind of exercises are suitable for homes in an AR environment?"**. Overall, we found that although there is no single exercise program that is suitable for everyone, there are common recommendations that can be followed, each with equal importance. While recommendations 1 and 2 provide foundational guidance for home-based exercises in AR, it is equally important to maintain people's motivation over time through recommendation 3, and to ensure that the exercises are matched towards different people's requirements through recommendation 4.

- **Recommendation 1: Home-based exercises should be mostly stationary to avoid breaking objects at home, injuring the person, and disturbing others.** This includes exercises such as strength-based exercises, flexibility exercises, martial arts, or light aerobic activities.

Figure 2: Tai chi (a martial art) is an example of a suitable exercise that can be done at home in an AR environment.

- **Recommendation 2: Home-based exercises should use minimal special equipment to save cost and storage space.** For example, exercises only requiring the user's body or a yoga mat are preferred. This is to reduce the financial

barriers to exercising and especially relevant for people living in smaller homes.

Figure 3: Yoga is a suitable home-based exercise for an AR environment, as it requires minimal special equipment.

- **Recommendation 3: Home-based exercises should incorporate both structure and novelty to keep the individual engaged and motivated, which can be facilitated with a library of exercises with details of the relevant goal or expected outcome.** Exercises labelled with the outcome/goal can provide users with information on how they can tailor their exercise program and keep it interesting, while still retaining the desired benefits. This was inspired by the success of the library of exercise videos that physiotherapists use, and by our participants who changed the type of exercises they did during COVID-19, such that they can be done at home yet provide the same benefits as exercises they used to do in the gym. Following insights from the literature, allowing people to set, measure, and achieve their goals can facilitate engagement and increase their motivation towards engaging in the activity [49].
- **Recommendation 4: Home-based exercises should be individually tailored to the person's evolving needs, abilities, and interests.** This ensures that the exercise is not only tailored to the user's current physical and mental condition [6, 14, 34, 56], but also interesting and motivating for the user. Our theme on the importance of tailoring exercises to each person's evolving needs, abilities, and interests further signifies the importance of individual customisation from the literature. In addition to tailoring the game environment [56], the game narrative [56], and the amount of guidance provided based on their level of expertise [30], future AR systems for home-based exercising and/or exergaming should individually customise the exercise based on people's evolving needs, abilities, and interest too.

6.2 Home Objects to Use and Augment for Exercising in AR

Insights from our literature review suggested that using tangible objects to facilitate home-based exercises in a virtual environment can enhance the exercising experience, by providing users with immersive haptic experiences that matched the immersive audio and visual outputs of the system [27]. Our interviews with both types of participants revealed that different home objects can be used for different exercises. As different objects have different features and potential functionalities for exercising, the 'right' home object is dependent on the exercise the user wants to do. This finding supports previous literature that highlights the importance of carefully considering the specific use-cases before deciding what physical objects can be augmented to facilitate home exercising/exergaming [27]. In relation to the first part of our research question RQ2, **"what home objects can be augmented to facilitate exercising?"**, we proposed the following recommendations:

- **Recommendation 5: Light to moderately-heavy objects, such as water bottles and cans, can be used for weightlifting exercises at home.**
- **Recommendation 6: Furniture, such as tables and chairs, can be used as support for exercising.**
- **Recommendation 7: Elastic objects, such as stocking or luggage rope, can be used for resistance-type exercises.**

Our findings add to the literature by specifying the list of tangible home objects that designers and researchers can consider to facilitate home-based exercising/exergaming through AR HMDs. These findings also support the theme of device augmentation reported by Knierim et al. [32], where participants discussed their desire to use AR to improve or add new functionalities to existing devices or home artefacts that are already well-integrated into the home environment. However, not every home object can be used for exercising. For example, although there were discussions on using heavier objects (e.g., rice bag) for weightlifting, there were concerns about the safety and feasibility of the exercise. Additionally, home objects will not always be as effective as exercise tools and equipment (e.g., using a towel over a door frame versus a proper pulley system). Therefore, it is important to set the level of expectation of users when using home objects to exercise at home. Where necessary, small, affordable specialised tools can be purchased, ensuring that the individual can exercise more effectively without compromising cost and storage space. For example, a proper elastic band costs around $10 and they take up almost no space at home. Thus, in relation to the first part of our research question RQ2, we add one more recommendation:

- **Recommendation 8: If necessary, small, affordable specialised equipment can be purchased for more effective exercising.**

6.3 Augmenting the Home for Exercising

In relation to the second part of our research question RQ2, **"how can home objects be augmented?"**, augmentation depends on the home objects being used and the exercises being done. We found that preferences vary between individuals, but two general recommendations can be made:

- **Recommendation 9: Home objects can be augmented into their equivalent exercising tools or equipment, or other personally motivating objects, depending on the user's preference.** For example, a water bottle can be augmented to look like a dumbbell for weightlifting activities

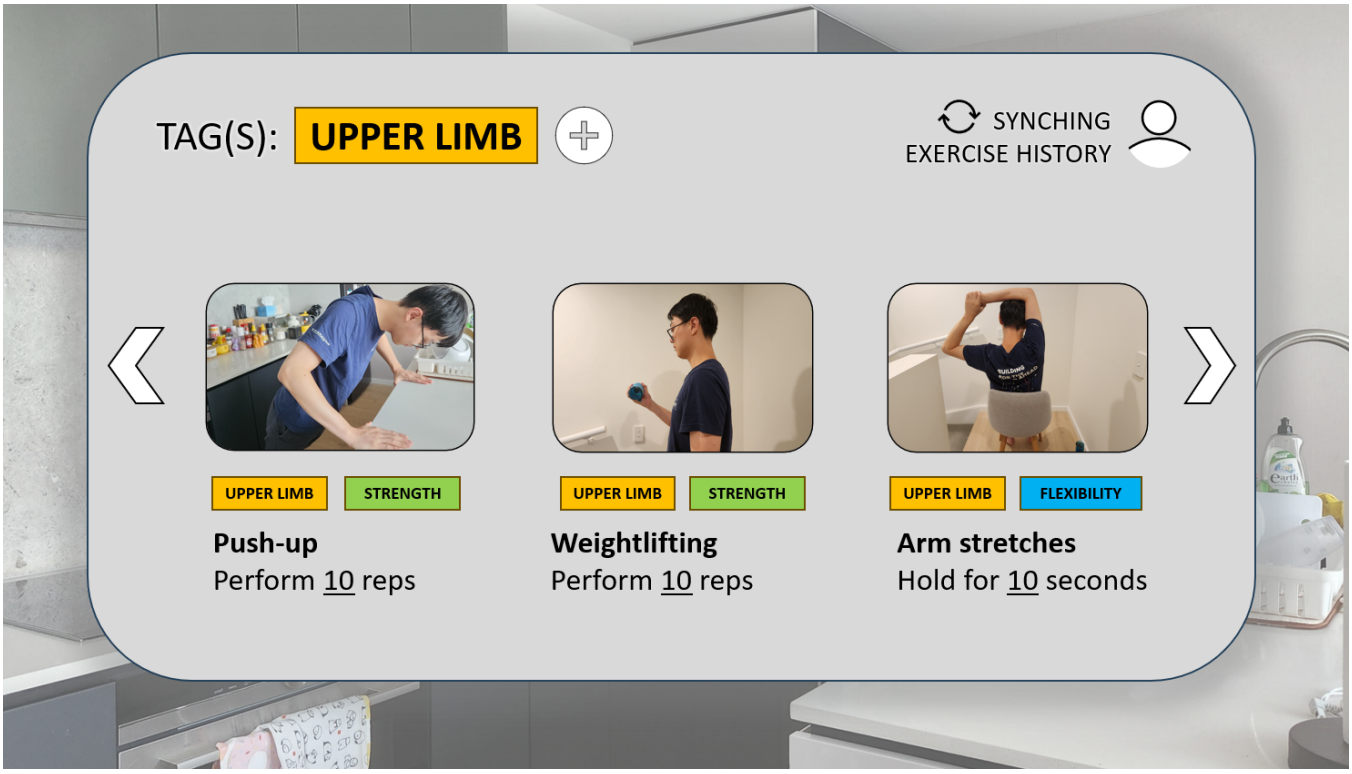


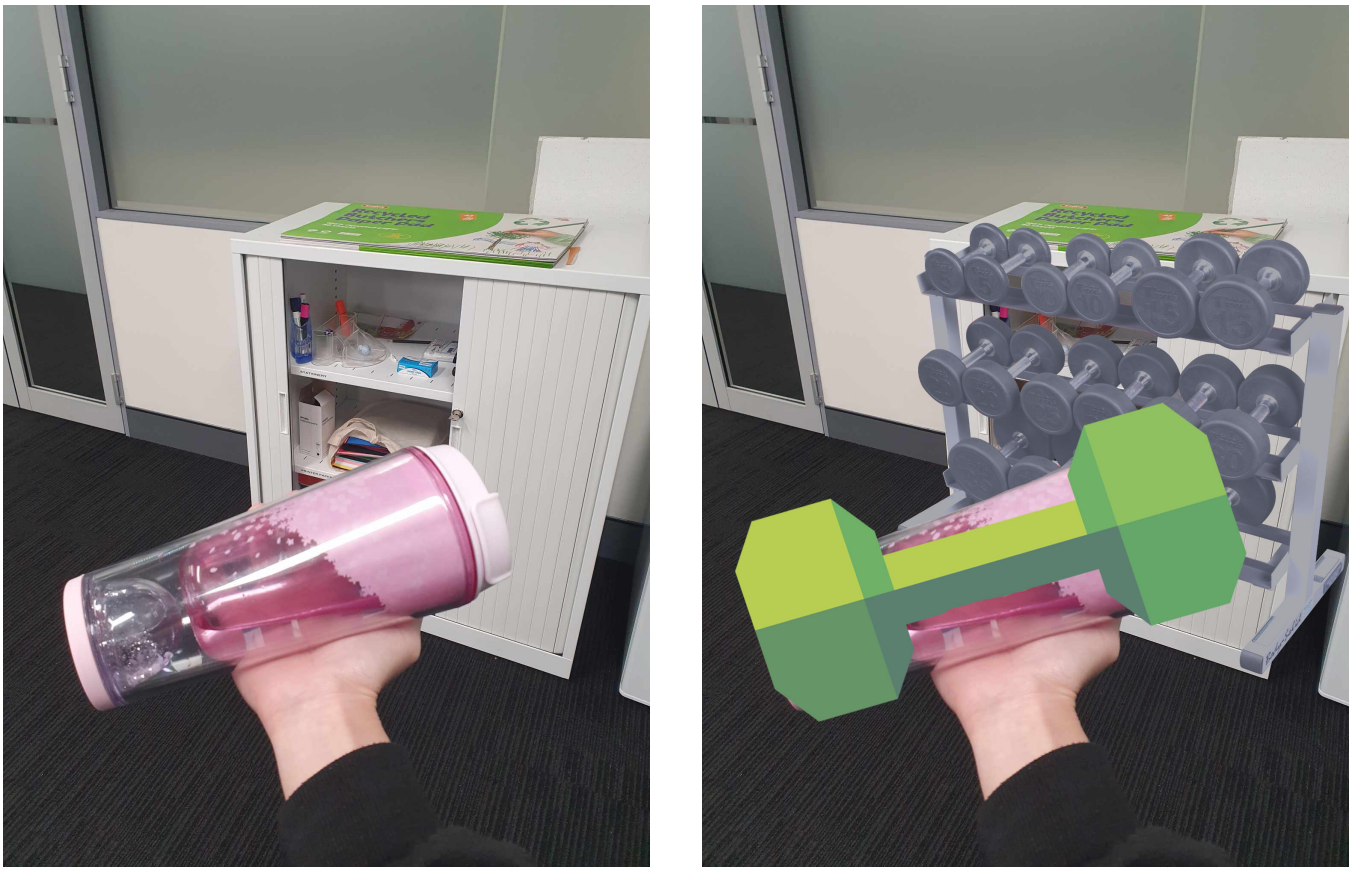
Figure 4: Illustration: A library of exercise in AR that allows users to tailor their exercise based on their desired goals and current progress.

at home, or other personally motivating objects, such as a pet. Some participants also shared that augmenting household items into their equivalent exercising tools or equipment can replicate the feeling of being in a gym, which motivates them to exercise. The different user preferences again suggests the importance of individual customisation. This may be related to results from [56], where preference for sports environment was only associated with high intrinsic motivation, but not low intrinsic motivation. When designing an AR system for exercising at home, there should be a variety of options for object augmentation.

- **Recommendation 10: Nearby home objects not directly used for exercising can still be augmented to further enhance immersion for exercising, but the home environment should not be over-augmented.** For example, not only should the water bottle be augmented into a dumbbell or a pet, but the nearby bookshelf can be augmented into a gym rack or into other personally motivating objects (see Figure 5). It is important to remember that although augmenting home objects and environments can enhance the home exercising experience, over-augmenting could lead to information and cognitive overload among users as our senses are biologically limited [32]. Generating too much sensing input through AR can interfere with regular vision, which limits user perception [32]. Designers should carefully consider how additional stimuli can be combined with naturally-perceived stimuli, without overloading the users [51]. Following the recommendations of Bonanni et al. [10], the quality and quantity of augmentation should also be tailored based on each task/exercise. While further work needs to be done to investigate how this can be achieved, findings from prior studies can serve as insights. For example, the shape and size [27] of the home object chosen for the exercise can be used to determine the shape and size of the virtual object being overlaid, to prevent a mismatch that would negatively affect the user's feeling of immersion and engagement [54].

6.4 Augmented Exercising to Exergaming

Our interviews with potential users revealed that home-based exercising could benefit from motivational elements beyond augmentation, including game elements and social elements. Some people simply do not like exercising at home or exercising in general (e.g., P02) and would need additional stimuli to motivate them to exercise. We also found that different people proposed different types of additional stimuli that could successfully motivate them to exercise. For example, participants talked about having a progress bar that keeps track of how many push ups they have done in comparison with the goal, a point system that tracks your ability and challenges you for the next day, or collecting golden coins while exercising in AR, just like how they would in Super Mario Bros. [43]. One physiotherapist (S01) also discussed the potential benefits of having



(a) A water bottle and a nearby book rack

(b) Augmenting the water bottle and nearby book rack

Figure 5: Illustration: Augmenting not only the water bottle, but also a nearby book rack to simulate weightlifting experience at home through AR.

virtual people in an AR environment, including as a form of encouragement or peer-pressure to keep exercising, or even as a form of support to keep track of the progress of the exercise especially for people with memory problems. This insight adds to the results of previous work on the use of virtual coaches [34, 39, 56] in AR at home for exercising, by suggesting that virtual coaches can bring the additional benefits of further enhancing users' motivation and perception. These comments suggest the potential of gamification of home-based exercise programs, which needs to be explored in the context of exercising at home through AR. Although our results on the importance of additional motivational elements does not currently answer our initial set of research questions, they can be serve as an additional source of insights for future research aiming to transform AR exercising into AR exergaming, alongside the rich pool of previous research specifying different strategies for increasing motivation.

Prior research suggests that gamification can have a positive impact on exercise motivation [31]. Gamification elements such as points, leaderboards, levels, badges, competition, and cooperation have been used to promote physical activity in health context [3, 20, 40]. For example, points can be given to users for completing different activities, which will be ranked in a leaderboard against other users to promote competition. Badges, as a form of rewards, can be given to users who have completed their goals. The inclusion of rewards can motivate people to be more physically active, for example as demonstrated in [17], where users of activity rewards programmes in South Africa (earning discounts/cashbacks for having 'active days') were more than twice as active than non-users. In the context of AR exergaming, similar gamification elements can be applied to increase people's motivation to exercise at home. For example, users can obtain points for completing exercises in real-time (e.g., one sit-up equals one point), which can also help them keep track of how many times they have done the exercise, especially if they have memory problems. The GameFlow model [59] identifies the importance of social elements to the enjoyment of video games, noting that people will play games for the social experience, even when they do not like games or the type of game being played. Social elements can enhance motivation to exercise, especially among older adults [56]. Similarly, for home-based exercises in AR, incorporating social incentives in the form of competition and/or cooperation can further increase people's motivation and willingness to exercise. For example, users can be grouped into teams to

compete with each other (e.g., most rope-skips done as a team [20]) and the winning team can be provided with rewards, to encourage participation through peer-pressure. However, prior research also found that interest in the gamification aspect of exercises can decrease over time [17, 60]. Because novelty is an important cause of motivation [62], enjoyment can decrease when novelty of the gamification aspects wears off [60]. Therefore, designers should also investigate how novelty can be sustained for different gamification elements, to foster long-term engagement and motivation.

6.5 Ethical Considerations

While our interviews did not include any discussion about ethical considerations, we acknowledge that there are physical, privacy, social, and psychological concerns that need to be considered when developing AR applications [57]. Although physical concerns, including the risk of falling down, have been reduced by using AR instead of VR HMDs, they have not been completely eliminated. Notably, users can still experience dizziness [57] from the weight of the HMD. Privacy concerns can arise when using AR at home, as AR devices need to extensively sense and record the spatial information of the user's environment. In the case of this research, the environment is the user's home, which contains a variety of sensitive and personal information. In addition, users' health data recorded by the system is also at risk from being exposed and/or exploited. Participants from Knierim et al. [32] discussed their concern that AR devices would constantly record their actions, which threatened their privacy. In social settings, privacy concerns can arise when users share a physical space with other people while using AR devices, or when users remotely share virtual content with other users [50]. Non-users could be recorded without their consent, and being immersed in AR can lead to an absence of engagement with others in real time [57], triggering social concerns. In a shared AR environment, there can be issues relating to psychological ownership when virtual objects are augmented onto another user's body, belongings, or personal space [48].

In addition to our design recommendations, future AR systems should be designed in a way that respects the privacy of both users and non-users, is transparent about how they are protected (regarding data collection, use, sharing, and storage), and facilitates access control for shared virtual content [22, 32, 50]. AR interactions must also be designed to respect existing social structures and support social activity, especially in a shared environment [32]. Finally, initial design stages should include considerations on how issues relating to psychological ownership in shared AR can be handled, to create a safe, enjoyable, and productive shared AR environment [48].

6.6 Limitations and Future Work

There may be potential biases arising from the current pool of participants. As most participants from our pool of potential users were young adults, the needs and preferences of people from other age groups might be under-reported. Next, while our results suggest that augmentation needs to be personalised based on user preferences, there was a lack of insights provided by participants regarding the specific set of items that can augment home objects and how augmentation can be tailored to each task/exercise. This is especially relevant for users who prefer augmenting home objects with personally motivating objects. Finally, we acknowledge that there is a risk of coder/experimenter bias as the studies were conducted and analysed by the first author.

Future work should also involve further interviews with more participants in relevant professions to gain more insights on how home objects and environments can be augmented to facilitate exercising. This can include exercise-related professionals (physiotherapists and professional trainers), experienced AR developers, exergame designers, and other stakeholders. The research could also be expanded to include AR exercising/exergaming in other locations, such as a gym, clinic, or physiotherapist's office. To gain further insights on the specific items that home objects can be augmented with, our ongoing work will incorporate a photo elicitation activity, inspired by Knierim et al. [32], and co-design workshops with participants to further brainstorm how home objects can be augmented. This combined participatory design approach will further contribute to the development of a set of design principles on how home objects and environments can be augmented for exercising. With an initial set of design principles, future research can investigate how game design principles can be incorporated to transform augmented exercising into augmented exergaming, building on our theme for motivational elements. The overall long-term goal of this ongoing research is to investigate how exergames can be designed for augmented home environments to lead to improved adherence and effectiveness of exercising at home and reduced barriers to exercising, transforming future exercises with AR technology and game design principles.

7 CONCLUSIONS

Exergames have the potential to increase people's motivation and adherence to exercise. Current exergaming systems could be made more accessible, inclusive, and immersive, with AR HMDs as one potential candidate. However, there is limited research investigating the design of such systems to promote exercising or exergaming at home. We conducted interviews with potential users and senior physiotherapists as the first step in understanding how homes can be augmented for exercising, to lay the foundation for future research into designing augmented home-based exergames. We developed 10 recommendations related to suitable home-based exercises, home objects, and augmentation, which can help guide future designers/researchers aiming to develop home-based exercising experiences using AR HMDs. Our results further contribute to the existing body of research on the use of AR for exercising, home applications, and everyday objects by presenting the first foundational study investigating the wide range of exercises that can be supported through AR HMDs in home environments and the different ways home elements may support these exercises, and laying the groundwork for future work developing home-based exergaming through AR HMDs to increase people's physical activity levels. While certain specialised equipment and tools for exercising cannot be easily replaced, our ongoing work to design exergames for home-based exercises using AR HMDs aims to create a more affordable, accessible, inclusive, and immersive way to exercise.

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