Implementation of Virtual Reality Motivated Physical Activity via Omnidirectional Treadmill in a Supported Living Facility for Older Adults: A Mixed-Methods Evaluation.: Virtual reality to motivate physical activity for older adults

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ABSTRACT

Virtual reality (VR) can support healthy ageing, but few devices have been trialed with frail older adults to increase physical activity. We conducted a preliminary mixed-methods implementation evaluation of an omnidirectional VR treadmill and a static VR experience with seven older adults over a six-week period in a supported living facility. Frequency of use and pre-post physical functioning measures were collected, mainly to establish technology suitability based on person characteristics. Diary entries following technology use, resident focus group and staff interview revealed technology acceptance and perceived potential for increasing physical activity, health and wellbeing through accessing virtual environments, which motivated continued activity. Results demonstrated technology suitability for a range of older adults with various mobility and physical impairments. However, residents noted interest in a seated treadmill for physical activity without perceived risks of falls with standing treadmills. Staff raised considerations around care home implementations including usability, cost and space.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI)**; • **HCI design and evaluation methods**;

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KEYWORDS

Social care, physical activity, technology, virtual reality, innovation

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1 INTRODUCTION

The ongoing demographic shift towards older populations as a consequence of increasing life expectancy globally means that a growing proportion of adults are at retirement age or above [1]. These changes continue to put pressure on health and social care (H&SC) resources [2] due to the physical and mental deterioration associated with advanced age [3]. Frailty is one syndrome associated with ageing, defined as clinically notable increases in vulnerability associated with decline due to ageing [4]. This challenge is exacerbated further through diminishing numbers of care workers to provide required support [1]. To counter this, policy-makers have called for research and innovation focusing on technologies that support healthy ageing [5], thereby promoting longer healthy, independent living with less reliance on H&SC.

Virtual Reality (VR) is one technology of interest with potential to support the wellbeing of ageing adults [6, 7]. VR systems can be useful through a range of mechanisms; they can allow users to engage with immersive physical activities in virtual spaces that can facilitate reminiscence [8] or incorporate social activity remotely [6], or be used for improvements in physical functioning such as balance [9]. One such example described in the literature is of a

VR based application using a stationary bike for older adults living independently at home to explore VR worlds while peddling [7]. The VR technologies under investigation in this study have been designed by MOTUS VR (formerly known as ROVR Systems) and include an omnidirectional treadmill for interaction with VR worlds (MOTUS Adventure) and a static 360° VR experience (MOTUS Relieve). In this study, we therefore gained feedback not only on standard VR experiences for relaxation and wellbeing, but also the VR motivated treadmill designed to increase levels of physical activity. The Adventure system has been designed to exploit the benefits of VR in engaging users in interacting with immersive environments to promote physical activity (PA), while also incorporating social connectedness and reminiscence for older adults. Regarding PA, the MOTUS VR developers recognised the physical deconditioning experienced by older adults and those in residential care settings. Research has shown care home residents spend most of their day sedentary [10]. Remaining physically active is a significant and well documented challenge for the older population, who are generally not able to sustain engagement with exercise over time on their own [11]. This is problematic as PA through the life course has clear benefits, including PA sustained over 6 months being associated with reduced falls [12]. Further, there are numerous health benefits for older adults, with exercise providing a protective factor against diseases including cancer, diabetes, cardiovascular disease and stroke, and delaying dementia onset [11]. Therefore, there has been increasing interest in reablement strategies to support older adults engaging in PA [10]. Regarding the social interaction on the MOTUS VR platform, the potential for technologies to aid with social connectedness is of significant interest for supporting older adults but is particularly relevant for those in residential care who are principally vulnerable to feelings of isolation and loneliness [13]. The Relieve system has been designed to provide meaningful activity and opportunity for mindfulness and reminiscence. Meaningful activity is an important aim within care, contributing towards physical and mental health, further to quality of life [14], however, one challenge is a lack of high-quality activities available. Consequently, many care home residents' days are characterised by apathy and lack of activity [14]. As such, both systems aim to improve health and wellbeing for older adults.

Beyond increasing PA motivation, social connectedness and meaningful activity, VR has also generated research interest as a vehicle to engaging with culture and heritage [15]. Heritage is an often-overlooked contributor to wellbeing, personal happiness and social connectedness. Interaction with heritage sites supports these components of wellbeing by providing remote access to both physical locations and online resources [16–18]. The restrictions in place during the COVID-19 pandemic limited access to heritage sites, and the wellbeing benefits associated with heritage access [19]. Heritage resources are thought to support wellbeing through facilitating connectedness with places of cultural importance, motivating PA, and facilitating reminiscence [17]. Further benefits arise from heritage-based opportunities to engage with a shared identity and take part in social contact [17]. Access to heritage resources has been shown to support improvements to several markers of mental wellbeing, including empowerment, social connectivity, sense of belonging, worth, confidence, and social inclusion [20]. Older adults are often the age group most invested in heritage [21], yet they can also experience the greatest barriers to access due to combinations of reduced mobility and the heritage sites physical accessibility issues (e.g., uneven ground, lack of accessibility features due to conservation) [21]. The use of heritage sites within VR experiences could therefore also aid inclusivity for older adults, particularly those with physical or sensory barriers [22].

Considering these potential outcomes of VR innovations, and the requirement for research into technological innovations for healthy ageing [5], this study aimed to contribute through evaluation of VR systems with potential in this area. In other work, the authors explored professional health and care stakeholder perceptions towards the MOTUS Adventure system, and documented perceived benefits, challenges and design requirements [23]. However, the prior work did not engage older adults themselves and was based on short-term interactions (60 minutes), gaps we respond to here.

Prior work more broadly includes a study by Campo-Prieto et al. [24], who acknowledged the importance of PA for healthy ageing, and explored the use of VR to motivate exercise for older adults. The study had a small sample, with only four healthy men recruited (ages 65-77), who completed exergaming programs and measures of usability and adverse effects. Participants reported high levels of satisfaction and no adverse effects or sickness, suggesting general feasibility of the VR intervention. However, all participants were healthy and independent, limiting understanding of VR exercise for older adults in supported or care home accommodation, which by definition implies some physical or mental impairments, requiring greater understanding of feasibility and person characteristics for safe use. Campo-Prieto et al. [24] also relied on upper-body movements with use of a VR headset and handheld controllers, for games such as boxing.

In a recent editorial on VR exercise for health and wellbeing of older adults [25], the authors conclude that VR exercise could be an effective intervention for fall prevention, but suggested further research was needed to understand the effect of VR exercise on a range of outcomes, and understanding of which types of VR-based exercise are most effective, to support future technology developments. A literature review by Piech et al. [26] also notes the potential for VR exercise in fall prevention, having reviewed 21 randomised controlled trials using VR dancing and exergames. In another review, Baragash et al. [27] reviewed literature classifying VR and AR for improved quality of life for older adults. The authors identified 57 studies, finding motion based exergames and augmented reality systems the most common. Ali et al. [28] also recently published a systematic review of VR-based techniques for human exercises and health improvement but focused on studies of visual and mental exercises, rather than physical, but did conclude the use of VR for health has not yet been thoroughly explored. In a systematic review by Zheng et al. [29], the authors identified seven RCTs with 243 prefrail and frail older adults using physical outcomes including muscle strength, balance ability, mobility function, gait and falls, as well as subjective feeling outcomes, feasibility, attendance. Exergames improved balance and mobility function of frail elderly, and showed a tendency to increase muscle strength when combined with resistance training. As far as the limited evidence was concerned, exergames were feasible and generally accepted by participants. There remains much exploration in the area of VR exercise for older adults, and based on the prior work, there is particularly limited research among frailer older adults not living independently, such as those in care homes or supported living facilities. The prior work does suggest potential for VR for reduced falls, improved wellbeing and health, but further work is necessary on feasibility and safety across a range of person characteristics. We respond here with a longitudinal implementation study with older adults residing in supported living. Studies such as this are essential for novel technologies with potential positive implications for health and social care. To consider real world use of these devices to support exercise of older adults in care settings, research should first seek to understand suitability and the person characteristics required for safe use, while also exploring user perceptions and initial indications of impacts.

2 METHODOLOGY

2.1 Aims

We aimed to recruit a residential home supporting older adults and trial a new treadmill approach (MOTUS Adventure) for VR motivated exercise, alongside a more 'traditional' seated VR for relaxation and reminiscence (MOTUS Relieve).

Research aims:

- To explore the physical abilities that are necessary to make use of (a) MOTUS Adventure, the standing/walking treadmill and (b) MOTUS Relieve, the static VR experience.
- For those who can safely use MOTUS Adventure, to explore user-experience, feasibility, and acceptability of both devices, and to document use and impact following implementation.
- To document and report on the implementation process and any barriers encountered.

2.2 Design

This study was a mixed methods implementation and evaluation study. The use of mixed methods can address the limitations of each individual method alone, with the weaknesses of each method offset by the other [30]. We employed use of both quantitative measures and qualitative feedback. With the quantitative measures, we aimed to garner an initial understanding of person characteristics and physical abilities relating to use of these technologies. This is preliminary mixed-methods work to gain an early understanding of potential barriers and uses of VR treadmills in general by older adults with various frailties or challenges in supported living care, thus the quantitative measures were indicative of the range of people who could suitably use the treadmills rather than used for outcomes/impact. With the qualitative feedback, we aimed to gather a rich understanding of participant experience of using the technologies, including suitability and perceptions on design. We chose two separate methods of qualitative data collection, diary entries upon use of the technologies and end-of-study focus group/interview, to ensure rich data on experience was not lost to memory strain aggregation.

2.3 Materials

This study involved the use of the MOTUS Adventure omnidirectional treadmill (Figure 1), and the static MOTUS Relieve 360° VR

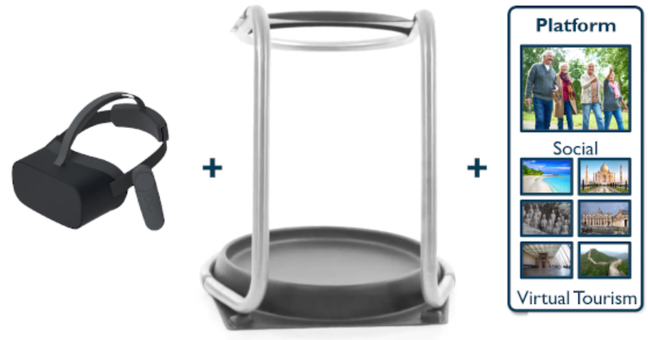

Figure 1: VR headset with the MOTUS Adventure omnidirectional treadmill and example of the app to access VR worlds.

experience (Figure 2) further to audio recording devices to capture stakeholder feedback. The MOTUS Adventure treadmill is a smooth plastic dish coated thinly with lubricant on which people stand wearing overshoes (Figure 3) with ceramic plates on the base. This allows for a low friction, slippery surface on which people 'slide' their feet backwards and forwards to represent walking. The treadmill is supplied with a training mat (circular ring that reduces range of motion by decreasing active dish size). The treadmill links to the MOTUS VR PC software (for this study, it was connected to a Lenovo ThinkPad 13) and VR system (Figure 1) via Bluetooth, and translates movement on the treadmill into movement through VR worlds. To change direction, participants swivel around and point their bodies the direction of desired travel. VR worlds include 3D scanned, real world, heritage locations as well as animated worlds ranging from simple houses to museums and historical coastal sites (Figure 4). The VR worlds were presented within a Pico Neo 2 headset that is equipped with a 4k LCD display that provides a resolution of 1920 x 2160 pixels per eye. The MOTUS Adventure VR worlds can also be a social experience, with several users entering the same world from distant locations, being able to walk and talk together via the microphone and speakers inbuilt in the VR headset. The MOTUS Relieve system is a simpler unit, providing 360° videos of a range of countryside, city and heritage locations, including Oxford, canals, farms, waterfalls and beaches. Therefore, participants were both physically and mentally stimulated using the Adventure but only mentally stimulated using the Relieve. A Pico Neo 3 headset was used to immerse users in the videos and connected via Bluetooth to a Samsung Galaxy Tab s6 Lite Tablet to allow researchers/staff to easily control the worlds residents were viewing.

2.4 Setting

From our very good network of care homes and aged care facilities across Cornwall, UK we approached some 'likely candidates' to recruit one that was willing and able to trial the technology. Some sites were unable to facilitate the trial due to the physical space requirement to host the MOTUS VR treadmill. The first site to agree and the setting for this study was a supported living facility in Cornwall, UK, with 12 resident older adults of varying degrees of mobility and independence. All had their own room/apartment

Figure 2: MOTUS Relieve system, VR headset and tablet displaying 360° content.

Figure 3: Overshoes to be worn on MOTUS Adventure.

within the supported living house and were generally independent but had staff on site who provided cooking, cleaning, site management and instrumental support where required for activities of daily living, but not personal care. Of the 12, seven agreed to participate.

2.5 Procedure

The site received an initial visit from researchers, during which participants were recruited and provided written informed consent, and baseline measures of physical function were collected. The measures are described below, but researchers explained and demonstrated the process of each measure to the residents to ensure they understood the task before allowing residents to complete the physical function tests. Researchers also documented participants' self-reported health and diagnoses to provide an understanding of individual person characteristics and abilities.

During the first visit, participants also underwent a 'decision tree' process to document their decisions on whether to try the technologies or not and their preferences for trying the standing (Adventure) or static (Relieve) version. This process involved asking participants which technology they would be most comfortable to try first, if any, and subsequently if they wanted to try the other technology after the first. During the decision tree process, direct quotes from participants were captured and recorded in writing by researchers as justifications for their decisions. Following this initial visit, the technologies were left on site. Staff and residents were shown how to use the VR sets and had the option to use the technologies independently without researchers present but researchers also visited 1-2 times weekly for 6 weeks to facilitate sessions (Figure 5). During facilitation visits, researchers set up the VR technologies and residents joined together to try them out and discuss the experience. Residents took turns in trying either of the technologies and watched as other residents engaged also. Considering the participants were older adults and some had mobility limitations, the researchers took precautions in ensuring adequate support and stability for residents. This included explaining the technologies in detail prior to use, so residents knew what to expect and ensuring residents held on to the support bar when using the VR treadmill to reduce any risk of falls. Researchers also provided verbal support, ensuring the necessary steps were taken to safety enter and exit the treadmill.

During the facilitated visits, researchers supported residents in maintaining diary sheets (Supplementary File A), to record if/when they used which device, for what experience and some short feedback directly following the interaction (event-based sampling). Following the six weeks, researchers made a final visit to conduct an end-of-study focus group with a sub-group of four residents (those who were present on the day and had engaged most in the study) and interview with site manager, to collect feedback on user-experience (interview schedule Supplementary File B). In total, researchers conducted 8 visits to the site to facilitate sessions.

2.6 Data Collection

2.6.1 Quantitative Measures. To understand participants' physical functioning, we collected senior fitness test measures [31] and the Fall Risk Questionnaire [32] [as used by Peng et al. 33]. Fitness tests included: Sit to stand test (number of times resident rises and sits in 30 seconds); Two-minute step test (number of times resident steps onto and down from one standard ~30cm house step in two minutes); Chair sit and reach test (measuring distance between finger-tips and toes when reaching for outstretched leg); Back scratch test (distance between left and right hand fingertips when reaching behind back); Timed up and go test (time taken to rise from seated, walk 2.45 meters and return to seat); and the Foot tapping test (number of times foot sole tapped on floor in 10 seconds). The foot tapping test is not standard in the Rikli & Jones [31] senior fitness tests, but was used in conjunction by Peng et al. [33] as we have here. The senior fitness test measures were used

Figure 4: Example of a virtual heritage site participants could explore by walking on the MOTUS Adventure

Figure 5: Participants at the implementation site interacting with MOTUS Adventure (left) and Relieve (right) with the support of researchers

to provide an indication in this preliminary study on the general suitability of VR treadmills when considering participants scores on the physical functioning measures.

2.6.2 Qualitative Feedback. Throughout the study, researchers supported residents in maintaining diary logs of their feedback during and immediately following an interaction with the MOTUS VR devices. This form of event-based sampling was used to increase validity of the data, with the immediate perceptions captured, and therefore not suffering from aggregation or memory strain. The written diary entries were copied into electronic text and the digital copy anonymised for analysis. These paper diaries were also used to document the number of times each resident interacted with each technology.

An end of study interview and focus group were conducted with the site manager and four residents, respectively, to further ascertain user-experience and feedback. The sessions were audio recorded and transcribed verbatim. We used a focus group to gather the opinions of residents, firstly to consider the burden of participation for residents needing to schedule and attend separate interviews, and also to capitalise on the shared experience residents had of using the technologies, watching each other engage with them and discussing their thoughts. The discursive nature of the focus group led to open conversations between residents and researchers and informed qualitative data. We chose to complete an interview with the site manager separately, as we anticipated more practical perceptions from the staff member than the residents (as her experience of the technologies was not through using them herself, but through hosting them in her care setting), while the residents would focus on the first-person use of the device.

2.7 Data Analysis

The quantitative measures are reported descriptively as a comparison of pre and post implementation scores. Due to the small sample

Table 1: Participants, their stated physical mobility or health limitations, and their interactions with each technology.

Participant (Age/Sex)	Response to "do you have any physical mobility or health limitations that we should know about?"	Total number of interactions	Seated VR	Standing treadmill
P1 (83/F)	Some mobility and flexibility limitations	2	1	1
P2 (90/F)	Atrial fibrillation, hearing loss (uses hearing aids), short term memory loss, balance impairment (uses walking stick)	5	2	3
P3 (67/M)	Shoulder mobility limitations	2	1	1
P4 (103/F)	Fear of heights	6	4	2
P5 (72/F)	Coronary obstructive pulmonary disease (oxygen treatment)	8	1	7
P6 (54/F)	Fractured pelvis, Rheumatoid arthritis, Sjogren's syndrome	1	1	0
P7 (85/F)	New heart valve, new hips, new knees	6	4	2
ALL		30	14	16

size, these are mainly to provide an indication of person characteristics in relation to use of the technologies, for insight into device suitability. The qualitative texts from the diary entries, resident focus group and staff interview were combined as a whole data set and analysed using thematic analysis. Braun et al. [34] describes the process of thematic analysis, a form of analysing qualitative data, often in health and social sciences, that involves familiarising with the data set, generating initial codes, searching for themes and reviewing and defining those themes. The sub-type of thematic analysis used was reflexive, in generating codes from explicit content, which evolve and adapt through considerable analytic work, to produce themes, representing an understanding of meaning across a dataset [34]. Analysis was inductive, as researchers had predetermined aims. We used the NVivo 12 data analysis software for data management to ensure a clear audit trail, enhancing dependability [35].

2.8 Ethics

This study received ethical approval from the Faculty of Health Ethics Committee at the University of Plymouth, project ID 2887. Participants have given permission for their photos to be included in this publication.

3 RESULTS

3.1 Participants

Seven participants were recruited to this study, one male and six females. Considering a primary aim of this study was suitability of such devices to older adults, participants provided details on their physical health and mobility when asked (Table 1).

3.2 Use of two devices

All residents were able to use both technologies, apart from resident 6 who was a wheelchair user and had carer visits (Table 1). As this participant relied on her wheelchair rather than walking, she felt it unsuitable to try the treadmill. Those who did try the standing treadmill included participants with balance impairments, mobility challenges, replaced joints and COPD. Compared to other studies our population was very frail. We were able to assess them using standard measures and compared to reference populations, all but two presented a fall risk due to frailty and most did not reach the senior fitness cut-point scores [36].

Despite the technology remaining in situ for the study, staff and residents reported that they did not feel comfortable or confident enough to use the technology without researcher assistance. There were a total of 30 interactions between residents and technology, 14 of which were with the static VR (MOTUS Relieve) and 16 with the standing treadmill (MOTUS Adventure) (Table 1). The key results are presented in three sections below. First, a narrative is provided of the decision tree process during the first visit, where residents decided on their preference for trying the standing treadmill or static VR experience.

3.3 Participant perceptions comparing the two devices

During the first sessions with the MOTUS VR devices, participants were offered a choice as to which device they felt more comfortable trying initially. One participant (P3) opted for the standing treadmill option (Adventure), whereas the remaining six participants expressed feeling more comfortable attempting the seated MOTUS Relieve device initially. After a familiarisation phase with each device, where the researchers demonstrated and talked through the devices, all participants proceeded to try the seated or standing device with the virtual reality headset. P3, who started on the standing option (with the training mat), reported the device was "very good" and that it was "more physical than I thought it would be." However, he suggested that further sessions would be needed to use the standing device to its full potential as they "would need to get used to it to go a bit quicker," but did find himself "sweating" from the movement he achieved. The other six participants, who opted for the seated MOTUS VR initially, reported how immersive they found the experience and that it "feels like I'm there, like it's right in front of me" (P4) and that they were "in the waves" (P6) when experiencing a 360° beach video. They reported that the device allowed them "to go anywhere and see beyond four walls" (P5), with particular enthusiasm for the nature options and the audio incorporated as they "loved being by the sea" (P5) and the "water is fantastic, the sound of it" (P7). Although the participants reported it being "easy to look around and see everything" (P7), they noted that "looking down felt a bit off putting" (P5) and that they "feel a bit sick if [they] moved [their head] too fast" (P2). Despite this,

Table 2: Senior fitness test results: mean of pre- and post-measures where available.

Participant	Sit to Stand Test (n stands)	2-minute Step Test (n steps)	Chair Sit & Reach Test (cm)	Back Scratch Test (cm)	2.45m Up and Go Test (seconds)	Foot Tapping Test (n taps)	Risk of Falls (0-14)
P1	**18**	69.5	**0**	22	7.2	33	0
P2	**13.5**	15	**0**	4.5	10.5	28	8
P3	10	50	**0**	-	7.3	44	2
P4	5.5	-	**0**	18.5	33.8	15	7.5
P5	6	15	**0**	15	9.5	30.5	4
P6	8	28	**0**	39	-	28	12
P7	**16.5**	37	**0**	1.5	7.4	32	5.5
Mean	**11.1**	35.8	**0**	16.8	12.6	30.1	5.6

[a] Scores in bold meet fitness cut-point scores [36]. Full pre-post scores are included in Supplementary File C.

overall, the participants enjoyed the experience saying they were "loving this [...] really enjoy this. Thank you" (P6) and that it was "wonderful to be able to go anywhere" (P7).

After trying their first option, the participants were offered use of the other device. P3, who initially chose the standing option, went on to try the static VR experience and reported it was "very effective" but he "wanted to be able to move somewhere" after having the standing option. Five of the six participants who initially chose the seated version went on to try the standing treadmill; for one participant (P6), a wheelchair user, the standing option was not possible. The five participants who tried the standing version as their second option with the training mat felt that it was still an immersive experience as it was "so easy to forget it's not real" (P5) and that they were "getting [their] exercise in" (P5) as well as reporting being "more out of breath walking" (P7). They felt the training mat, which restricts the range of motion to avoid over-reaching with the legs, was beneficial initially as it "only goes so far and that's enough" (P7), and that overall, the "sliding was no problem" (P5) and the movement was "very easy" (P2).

3.4 Senior fitness assessment and falls risk

Researchers examined the feasibility of collecting six standard pre-post measures of physical function, also to provide further information on the suitability and physical characteristics required for device use (Table 2). Of a potential 84 measures (6 (pre-post) for 7 participants) we were able to collect 64 (76%). Some missing data was due to participants not wishing or feeling up to completing certain measures on the assessment day, although the missing post-intervention data was mainly for P3 and P6 (7/12 each) as they missed the follow-up assessment day (social excursion, health appointment). For such a short study with few participants we do not present any analysis of pre-post differences but present the actual scores for each individual, in additional to the mean of pre and post where available to allow comparison of our participants relative to other populations.

Table 2 presents the scores for each individual on each fitness test. The sit to stand test involved participants rising to standing from a seated position in an armchair without the assistance of their hands/arms, and then returning to seated position, as many times as possible within 30 seconds. The 2-minute step test involved participants standing before the staircase in their home, stepping up onto the first step with both feet, then back to the floor, for as many times as possible in two minutes. The chair sit and reach test involved participants sitting in an armchair, with their legs straight in front of them, and reaching their hands to touch their toes, the distance between finger tips and toes was measured in centimeters. Similarly, the back scratch test was the distance in cm between the fingertips of the left and right hand when the participant tried to touch them behind their own back, with one hand reaching over its shoulder and the other reaching from below. The timed 2.45m up and go involved participants rising from a seated position in an armchair, walking to and around a marker 2.45 meters away and returning to the original position, as fast as possible. The foot tapping test involved participants raising and lowering the front of their foot (keeping heel on the ground) as many times as possible in 10 seconds. The risk of falls score is a result of the Rubenstein et al. [32] questionnaire.

Overall, few participants met fitness cut-point scores for the senior fitness test measures [36] with the exception of Chair Sit and Reach, where all participants were able to touch their toes. These scores represent criteria that indicate a level of fitness required to maintain independence and physical mobility later in life. P1, P2, and P7 each met these criteria for the Sit to Stand test. All other scores failed to meet these criteria, indicating some loss of functional abilities required for physical independence [31] within this group of participants. All but P1 and P3 had fall risk scores greater than 4 (Table 2) indicating a future risk of falls. These two participants with no fall risk made the joint second fewest interactions with the MOTUS VR systems.

The average sit-to-stand scores in this sample (11.1) are comparable to the normative data for this measure (11 sit to stands for 85-89 year olds) [37]. In the 2-minute step test, this sample averaged 35.8 steps, which is considerably lower and about half that expected for their age in the original normative data for any quintile of age from 60-94 years which ranged from 60 in the eldest quintile to 89 steps in those aged 60-64 years. The range of sit and reach scores for 60-89 year olds ranges from -0.4 (60-69 and 70-79 year olds) to -3.3 (80-89 year olds) in the original data from the development of these tests [38] whereas the present sample scored 0 suggesting they were slightly more able than the typical 70-79 year old. The back scratch

Table 3: Results of thematic analysis of the resident focus group, staff interview and resident diary entries. Evidence to support each code can be found in Supplementary File D.

Themes	Codes
Perceived benefits	Accessing places seated and standing, physical exertion of standing VR, novelty, residents new to VR, reminiscence, familiar scenes supported reminiscence, VR useful reminiscence tool, accessible activity with standing VR, social interactions, social interaction, residents shared activity, facilitated social activity, motivates exercise with standing VR
Perceived concerns of use	Concerns seated and standing, Difficulties moving on standing VR, risk of falls with standing VR
Perceived concerns of implementation	Cost, cost of adoption, maintenance cost, care homes don't typically use subscription, space and storage, too large for some care homes, needs to be storable, staffing, not all care homes can spare staff for MOTUS VR, residents need supervision, training required for staff
Suggested improvements	Suggestions for improvement seated and standing, foldable treadmill easier for storage, HMD could be lighter, some scenes more engaging than others, better content to motivate more use, content too artificial, content suggestions, more realistic content, more nature scenes, more heritage scenes, make seated treadmill
Negative effects	Negative effects seated and standing, unpleasant feelings, claustrophobia, dizzy, funny head, travel sick, vertigo
User experience	Content seated and standing, immersive seated and standing, content praise, would enjoy more to see, nature, familiarising, growing confidence, immersive, seated experience is too passive, more to see and more engaging on standing MOTUS VR, unengaging content with not enough to do
Usability	Ease of use, improved over time, MOTUS VR equipment usability, technical difficulties, simplified setup, nervous to use alone, headset heavy
Suitability	Independent older adults, residents go out often, no increase in activity, residents with hearing difficulties struggled with MOTUS VR social interaction, residents with mobility issues struggled, MOTUS VR useful for those with mobility issues, not useful to those still going out, future use
Acceptability and adoption	Praise, safety, adoption, implemented well for residents, rapid uptake by residents, residents enjoyed using MOTUS VR, praise, adoption, novelty motivation to use

test here averaged 16.8cm which is poorer than the comparable score in inches in the original sample (-1.8inches = 4.5cm) for 80-89 year olds. However, the present sample were much slower on the up and go test (averaging 12.6s) than elders in the original development paper where 80-89 year olds managed this in 7.1s [38] and also the normative sample of 90-94 year olds (8s) [37] with a mean speed of 12.6s. Finally, the average foot tap score of 30.1 in the present data compares to the average of 28.29 for older adults aged 65-92 years [39]. It should be noted that these differences likely reflect the wide age range and therefore range of ability of the present small sample, and that the original normative data for the fitness measures was based solely on community-dwelling older adults rather than those residing in residential care [37]. The average falls risk score was 5.6, which is above the falls risk cut-off score of >4 with 71% of this small sample meeting the criteria for being at risk of falls on the measure used. This is somewhat higher than population data on actual falls occurrence which suggests that two out of three adults aged 65+ years have at least one fall per year, which increases to one in two in those aged 80 years and older [31].

3.5 Qualitative results

The diary entries, focus group and interview data were divided into 9 themes (Table 3). Narrative results are provided with participant identifiers, data from diary entries rather than focus group is marked with DE, and residents are marked with R, while the staff member is S.

3.5.1 Perceived benefits. Older adults felt there were numerous benefits of using both of the MOTUS VR systems. These included access to different places, which was "amazing to go to places where couldn't normally go" (DE, R5), and particularly to "see beyond four walls" (DE, R5). This provides an example of VR allowing perceived escapism from the residential environment and access to experiences otherwise not accessible to the older adults. Participants felt it was "a lovely bit of exercise" which they "felt in my hips [. . .] you can always tell when something's doing good can't you?" (R5). It was almost surprising to participants how well the device promoted activity; being "more physical than I thought it would be" (DE, R3), and being comparable to real-world activity; "I still got out of breath as if I was walking" (R5). The exercise achieved was felt to be worthwhile, described as "quite a workout" (R5). The exercise benefits were felt more relevant for people "restricted" on walking outdoors (R5), suggesting the technology wouldn't replace outdoor activity for those capable of achieving it, but would provide an alternative form of exercise for those less capable of getting out due to mobility or disability The site manager also noted benefits for reminiscence to "stimulate their memories" (S1). Further positive effects included social interactions, with the site manager describing that "[a resident] kept telling everyone about it" (S1). The benefits related to the standing treadmill focused more on the physical exercise provided, whereas the standard seated VR was praised for accessibility of places and experiences.

3.5.2 Perceived concerns of use. Despite perceived benefits, participants did have some concerns on the technology. Older adults were worried about the slipperiness of the treadmill, the site manager suggested supervision was required "just to supervise that nobody fell and they got in all right" (S1), while a resident also noted they "felt like it would be easy to slip over" (DE, R2). These perceptions are important for developers to consider, as such concerns could contribute towards failure to use the technologies, or indeed a risk of injury.

3.5.3 Perceived concerns of implementation. The site manager also had some practical concerns relating to implementation, she was concerned about cost of such devices "because we are, we're a charity [. . .] we would probably have to fundraise for that" (S1). Due to the size of the standing treadmill, she also felt many places would lack the physical space to accommodate the treadmill "my other two houses [. . .] I'd have a job to find a place for it" (S1). The need for supervision also raised staff burden concerns, as "you do need to have someone trained [. . .] that know how to work the machines [. . .] I don't know if it's something that they could do on their own" (S1). These factors were less of a concern for the standard seated VR, which did not pose the risk of falls (and therefore wouldn't require the same degree of supervision) or take up as much physical space as the treadmill. For both technologies, the staff member also raised "maintenance" asking if "anything went wrong [with the technology] how would that work" (S1). Whilst maintenance or repair is a factor to consider for all technology implementations, space, resource requirement (e.g. staff supervision) and cost are key considerations for technologies aimed at social care settings.

3.5.4 Suggested improvements. The data from residents and staff also contained a range of suggested improvements that could be used to enhance the usability or suitability of the VR devices. The site manager suggested the issue of treadmill size could be overcome "for storage" if the treadmill could "fold flat against the wall" (S1), which could be a consideration for large technologies such as the MOTUS VR treadmill. In relation to the training mat that limits range of motion on the treadmill, one resident also suggested "having different sized training mats so it's not all or nothing" (DE, R5). The resident felt having smaller mats that allowed graduated increases in range of motion would be good for older adults to gain confidence and physical ability. Participants additionally requested a version of the VR treadmill as a seated experience, "could you make a seat?" (R2), "would like a version to sit on but still be able to move" (DE, R2). Participants felt the treadmill was beneficial in increasing their activity levels but that a seated version could feel safer than the slippery treadmill to stand on. Participants were also very interested in requesting varied content, such as "walk along a canal" (R2), suggesting some current content is "too artificial" (R7), as they'd like to visit real places, such as "the Victoria and Albert Museum [. . .] proper museums" (R5). Residents also had an interest in finer details, including "insects [. . .] what's in the water, you know, like swans and ducks" (R2).

3.5.5 Negative effects. There were only a few negative comments related to effects of using the technology, mainly related to motion sickness, as "it made me dizzy" (R2), and "a little bit claustrophobic" (R1). While this related to both seated VR and standing treadmill, the standing treadmill and associated movement appeared to induce more dizziness or disorientation. One resident suggested they "could be sick if I did it too long" (DE, R2).

3.5.6 User experience. In terms of user-experience, residents noted over time a preference for larger maps to explore, "I really enjoyed Maker Heights [historical site in Cornwall with large VR map] because every time I went on it, I went a different way, so I saw different things [. . .] it needs to be more so it remains entertaining" (R5). This related specifically to the standing treadmill, that facilitates exploration of VR worlds over large areas. In the smaller maps, like the museum, participants reported they "didn't feel there was much to see" although they could "see the potential" (DE, R3) should there be more to explore. Participants valued the realistic content in the static version, including "the one I shall never forget is the waterfall" (R7), but "preferred the walkie one" "the sitting down one, you're just looking around [. . .] so you look around, you see everything and that's it. [. . .] with the walky one, you can move to it and see different bits [. . .] a bit more engaging" (R5). There was a clear preference for the ability to interact and explore the VR environments rather than passively experience static 360 experiences. Some participants expressed that it took some time to get used to the feeling as "I wasn't too sure whether I liked it or not at first but I do now. Okay. I think it's very good. [. . .] Yes. I, got used to seeing that. And being able to move" (R7).

3.5.7 Usability. Participants felt the MOTUS VR systems were usable but only with the support of researchers facilitating, suggesting "I would be nervous without you lot here" (R2). The site manager echoed this, suggesting "unless it [setup] was very much simplified. That could be a barrier" (S1). The setup for the treadmill was perceived as more complicated, due to the additional connections to establish between device and laptop and additional hardware. The lack of usability with researchers facilitating is also evident through residents not using the technologies outside of researcher visits. For real-world implementation, simplifying set-up and training on use would be key requirements.

3.5.8 Suitability. Some thought that the treadmill would be most suitable for those who were less mobile, for example the site manager suggested "for some of them who can't get out [. . .] it would be absolutely excellent" (S1). A resident also suggested it would be more suitable to them if they were "stuck in bed one day" (R2), and "because I can go out. It was very unreal to me. [. . .] But when I can't go out, I might appreciate it more" (R2). The treadmill was thought to be a good exercise option for those with limitations in their access to the outdoors, while less useful to those who could remain active otherwise. To this regard, participants seemed to understand the device as a rehabilitation tool, to support exercise for residents able enough to use the treadmill but limited in their mobility or access to outdoor activities.

3.5.9 Acceptability and adoption. Overall, the residents and staff were positive about the potential for such technology, suggesting "if we had one. Yeah. Yeah. Yeah, I think if we had one (standing MOTUS VR), I'd try to use it at least every day" (R5), and "I'm loving this [. . .] really enjoying this" (DE, R6). The site manager suggested "they [residents] were fascinated. And it really lifted their spirits the whole day was absolutely fantastic for them. They really enjoyed it" (S1).

4 DISCUSSION

This study aimed to explore the physical abilities necessary to use the standing VR treadmill and static VR experience. We were able to recruit a residential home and seven residents to trial a new treadmill approach for VR motivated exercise, alongside the more 'traditional' seated VR for relaxation and reminiscence. Six out of the seven were able to use both treadmill and the seated VR even though they had many physical impairments and limited physical ability. The oldest user was 103 and participants with knee and hip surgeries, mobility issues and complex illnesses felt able to use the standing treadmill, albeit with supervision and support. The one wheelchair user was not able to use the treadmill. This suggests VR motivated exercise on devices such as the MOTUS VR treadmill could be appropriate interventions to enhance activity levels in aged care settings.

Few other studies have included such participants in using VR and certainly not in using a treadmill. Campo-Prieto et al [24] used only upper body movements in their exploration of VR exercise. The prior work by Campo-Prieto et al [24] on exergaming involved only healthy and independent adults, which does not add to understanding of suitability of such devices to various person characteristics, particularly when considering older adults in supported living or care settings who therefore are likely to have some form of physical or cognitive limitations.

Participants thought that within the range of people able to use the treadmill it would be of more benefit to those who were less physically able, those with restricted mobility who were unable to leave the home, and therefore would benefit from virtual access to experiences and a method of being more active. Those more active and able to engage freely in outdoor experiences felt the technology may be less relevant to them. In a small sample we cannot conclude anything from the senior fitness scores but note that two participants with the best physical ability scores interacted with the standing MOTUS VR system less often than the other four that used the treadmill. It seems possible that those least able to go out and experience real-world walking will use a VR-linked treadmill more for exercise and to access to virtual heritage/nature experiences. Future research with a larger sample would be worthwhile to test this hypothesis, as the small number of participants in the present study limit generalisability of this finding.

An additional aim of this study was to explore (for those who could safely use the devices) the user-experience, feasibility and acceptability of the standing or seated VR experiences, further to use and impact. Both the VR-treadmill and the seated VR were seen to be acceptable by this group of relatively frail older adults. They clearly enjoyed the experience, feeling benefits for their activity, access to heritage, nature and experiences and therefore wellbeing. Both the more novel treadmill as well as the more usual seated VR were acceptable. Although this will require further research and validation, technologies that enhance access to experiences have the potential to improve inclusivity and wellbeing [16–18], while methods of motivating physical activity have clear implications for health outcomes [11]. Technologies such as those studies here, if routinely implemented longitudinally, could therefore have societal benefits for remaining independent as we age and reducing the burden on health and social care services.

In terms of content, participants in this study much preferred realistic VR experiences, criticising more cartoonish and unrealistic models and requesting finer details and virtual visits to real world locations. There was particular interest in heritage locations such as museums, as could be expected due to older adults' particular investment in history and heritage [21]. Our prior work documented many health and care stakeholders reporting concerns of negative effects such as dizziness and motion sickness. However, the short interaction period of our prior work limited validity of participant assessment of these effects, as there was limited time for participants to familiarise themselves with the VR systems and overcome any initial motion sickness. These types of reactions are common among all VR systems, and work is underway to generally reduce cybersickness experiences for users of head mounted displays [40]. Repeated exposure to the same VR content has been shown to reduce severity of motion sickness [40], thus a longitudinal study would more accurately report the extent to which motion sickness is a barrier to the use of VR. This is supported in this study, where residents reported feeling better when using the devices over time, suggesting for future implementations, facilitators should encourage perseverance with VR experiences where possible. One factor to consider in future implementations would be ethical considerations, when considering the target population of older adults, and ensuring comfort and familiarisation before trying technologies, as well as capacity to consider any risks of negative effects of the VR or treadmill for informed choices on using the technologies.

As an interesting finding, participants here voiced desire for a seated version of the treadmill. Participants discussed a compromise between the low-friction, slippery treadmill (Adventure) and static 360 VR (Relieve) experience, where they could remain seated without risking a fall, but also move and explore VR worlds as opposed to passively watching video footage. It could be possible that the motivated movement of a seated treadmill could provide an answer to the suitability issue we have presented, that less physically able people are more motivated to use such technologies but less suited to the standing treadmill. As such, a seated treadmill could act as a facilitating exercise, to support leg movement and strengthening, and perhaps increase confidence and ability ahead of using the standing treadmill. MOTUS VR has responded to the findings of this study with a redeveloped seated treadmill which is currently undergoing trials. A seated treadmill provides an alternative, but congruent approach to seated VR cycling, as used by D'Cunha et al [41]. Future research could seek to explore the level of activity and muscle activation achieved using both treadmill and cycle methods.

This study also aimed to document and report on the implementation process, and any barriers important to consider. We had approached a number of care homes before we found one able to carry out the study, with other homes noting limitations including lack of staff and physical space to accommodate the equipment. Although the treadmill was felt advantageous in increasing physical activity, for use in care homes there is a requirement for staff supervision, physical space to host the treadmill and investment potential to buy and maintain the equipment. The standard seated VR system was felt easier to use and implement, and was perceived as safer for the frailer residents, therefore, as suggested by care staff in prior work [23], a seated treadmill was noted as a potential solution to increase confidence in being active and using a treadmill, perhaps before graduating to the standing treadmill. The space requirement for technologies within care settings is a consideration with implications for future developments and studies. One suggested improvement was being able to fold or pack the treadmill down when not in use, the site manager did feel the treadmill was a considerable size to occupy space in the resident's home.

The site manager in the current study raised further interesting practical considerations, one of which was cost. The social care sector has very limited investment potential, something for technology developers aiming products at the market will need to consider. A key finding of this study is also that staff and residents reported not being comfortable or confident enough to use the devices without researchers present. We left devices in situ and gave training demonstrations to staff so that use could be facilitated in our absence. However, further research will need to explore what would be required to allow end-users the confidence for real-world use without researchers present for facilitation and for stakeholders to feel comfortable with independent use, in order for future end-users to receive any real-world benefits of the increased PA. It is possible that as the technology was not 'owned' by the site, there were latent concerns of damage or breakages to the equipment. It is also possible the training given did not give the staff ample confidence in use. However, this is an important outcome with implications for any real-world implementations of such technology, thus deserving additional attention in future research, potentially taking a behaviour change approach to examine predictors of use and facilitate the impact of staff training on uptake.

As subsidiary aims of this study, we also hoped to comment on the feasibility and validity of the senior fitness data. There should be further exploration of various fitness tests used in this regard, as the missing data in the present study could suggest easier fitness measures are required, or additional time and resources are required to ensure a full data set considering the time commitment of conducting all of the senior fitness test measures. For the data that was collected, the measures appeared to provide useful and accurate indicators of participants physical functioning, based on congruence between physical fitness scores and qualitative feedback on ability and health conditions, and could be useful measures for future research of this kind.

There are a range of implications from this work, principally, these findings have implications for developers of VR motivated exercise technologies for older adults, in providing user-centered understanding of design requirements, challenges and barriers to consider. The MOTUS VR treadmill has been designed specifically for older adults, and the design is notably different to more gaming-oriented treadmills on the market. Gaming treadmills are much more commonplace than those targeting older adults [42], but the findings of this study may be useful for developers going forwards as the older generations of the future may be more accustomed to varied gaming experiences, and gaming for older adults is a developing market [43]. The study is also useful for developers and researchers within this field to gain initial insight into the potential suitability and person characteristics that make this type of technology useful and feasible, with implications for future research and implementations of such devices. Finally, this work has implications for stakeholders within the aged care sector, in demonstrating the potential usefulness (in terms of physical activity, accessibility of experiences and engagement) of VR and technology generally in the support of older adults.

Although there are useful implications and contributions from this work, there are a number of limitations to acknowledge due to this being a preliminary study. The first is the small sample size, meaning we can draw limited conclusions from the quantitative pre and post data, other than the indications of person characteristics for device use, when understood alongside the qualitative data. A further limitation is the reasonably limited number of technology interactions which again inhibits any potential to quantitively measure impact of device use, although this was not a key aim of this study. Future research should consider a comparative study with a control group and larger sample size to directly measure any impact of VR treadmill use on activity levels and health outcomes. While our participants had access to the technologies over six weeks, they did not use the VR without researchers present. The finding that residents were not confident enough to use the VR without researchers to facilitate is a key outcome of this work with implications for future developments. As such, future devices will need to provide thorough digital or in-person training to overcome this barrier.

5 CONCLUSION

Overall, our results suggest promising potential for technologies such as the MOTUS VR aimed at increasing physical activity and supporting wellbeing. We found that older frail people were able to use this technology. Further research will be required to fully explore the impact of interventions such as these with larger samples, and over longer time periods, to establish any significant quantitative impact on physical function in older adults.

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To see further information from MOTUS Ltd please see [44].

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