Hospitalized older adults' experiences of virtual reality-based group exercise therapy with cycle ergometers

An early feasibility study

Høeg, Emil Rosenlund; Andersen, Nikolaj B. ; Malmkjær, Nicolai; Vaaben, Adrian H. ; Uth, Jacob

Published in:
Computers in Human Behavior Reports

DOI (link to publication from Publisher):
10.1016/j.chbr.2023.100301

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Contents lists available at ScienceDirect

Computers in Human Behavior Reports

journal homepage: www.sciencedirect.com/journal/computers-in-human-behavior-reports

Hospitalized older adults' experiences of virtual reality-based group exercise therapy with cycle ergometers: An early feasibility study

Emil R. Høeg [a,*], Nikolaj B. Andersen [b], Nicolai Malmkjær [b], Adrian H. Vaaben [c], Jacob Uth [b]

[a] Aalborg University, A.C. Meyers Vænge 15, Copenhagen, 2450, Denmark
[b] University College Copenhagen, Sigurdsgade 26, Copenhagen N, 2200, Denmark
[c] Frederiksberg Inpatient Rehabilitation Unit, Ndr. Fasanvej 57, vej 6, Frederiksberg, 2000, Denmark

ARTICLE INFO

Keywords:
Virtual reality
Motivation
Rehabilitation
Self-determination theory
Social presence
Older adults

ABSTRACT

Sedentary behavior among hospitalized older adults is a well-described challenge that can increase the risk of loss of function and mortality. Therefore, it is important to encourage physical activity (PA) during hospitalization. Exertion Games (exergames) have repeatedly been suggested as a tool to encourage and sustain motivation in rehabilitation programs. This article presents early findings from a convergent parallel mixed methods study that explored whether social presence and PA could be combined through the novel use of immersive virtual reality technology in a feasible group exercise constellation. Inpatients (n = 10, 50% female, 80.3±8.2 years) were invited to participate in a bi-weekly VR group session. Most participants (62%) responded that it was a good experience to a large/great extent, which they would like to use repeatedly (76%). The technology was easy for untrained healthcare professionals and had minimal adverse events for the participants. However, a major finding illustrates that the enclosing immersiveness of the headset hindered conversation during exercise sessions. The exclusion of sight likely had a negative effect on forming relations between the participants, which conversely caused the participants to experience a lack of cohesion and relatedness with the other participants. VR-mediated group therapy may be a promising solution to existing physiotherapy practices since it may incorporate basic psychological needs. However, to optimize for social interaction, future systems will need to afford a higher degree of social presence, e.g., through avatar embodiment in a shared virtual environment, to support older adults' autonomous motivation for PA through social interaction and novel technologies.

1. Introduction

Sedentary behavior, i.e., staying physically inactive for long periods of time, tends to increase with advanced age (Suryadinata et al., 2020). Unfortunately, this tendency amplifies the risk of metabolic disorders and chronic diseases, which require hospitalization and rehabilitation and may result in 3.2 million annual deaths in the geriatric population (Taylor, 2014). Sedentary behavior during hospitalization is well described by Zisberg et al. (2011); Pedersen et al. (2013) with studies finding that older adults capable of walking independently spend 83% of a hospital stay in bed (Brown et al., 2009). Consequently, muscle mass may decrease by 10% within just two weeks, which can decrease functional capacity and increase the mortality risk (Covinsky et al., 1997, 2000; Hespel et al., 2001). Thus, maintaining sufficient physical activity (PA) levels during hospitalization and post-discharge is a pivotal priority in this population with well-established positive effects on physical- and mental health and quality of life (Gill et al., 2013; Gopinath et al., 2018). A popular device to assist PA in both in- and outpatient settings is the cycle ergometer, which has been demonstrated to be a safe exercise method that may improve postural balance (Bouillon et al., 2009; Oja et al., 2011; Bouaziz et al., 2015), reduce fall risk (Buchner et al., 1997), and reverse frailty in older adults (Bray et al., 2016). Additionally, loneliness and social isolation are increasingly recognized concerns in the aging population, which is associated with poor health and well-being (Courtin & Knapp, 2017; Grenade & Boldy, 2008), cognitive decline (Steptoe et al., 2013; Wilson et al., 2007), depression (Heikkinen & Kauppinen, 2004), and increased risk of mortality similar to the effects of smoking, obesity, and physical inactivity (Heikkinen & Kauppinen, 2004; Holt-Lunstad et al., 2010).

* Corresponding author.
E-mail addresses: erh@create.aau.dk (E.R. Høeg), jaut@kp.dk (J. Uth).
URL: https://vbn.aau.dk/da/persons/136589 (E.R. Høeg).

https://doi.org/10.1016/j.chbr.2023.100301
Received 31 August 2022; Received in revised form 8 May 2023; Accepted 25 May 2023

1.1. The role of motivation and need satisfaction in physical activity

Motivation plays a major role in health and health behavior change Ryan et al. (2008), and in exercise interventions, patients often display low adherence and motivation (Maclean et al., 2000; Bassett, 2003; Teixeira et al., 2012; Valenzuela et al., 2018). A main tenet of the earlier operant behavior theories was that self-regulation could only be achieved through external reward contingencies (Skinner, 1965; Vansteenkiste et al., 2010). An important advancement in motivation theories came with the recognition that humans are capable of autonomous behavioral drive, which is a shared premise of Self-Efficacy Theory (SET) and (Bandura, 2006) and Self-Determination Theory (SDT) (Ryan & Deci, 2000). SDT is a broad macro theory on human motivation and well-being, which seeks to explain why individuals decide to engage, participate, and exert effort in activities (Ryan & Deci, 2020). Moreover, SDT researchers argue that humans have three basic psychological needs: autonomy, competence, and relatedness. *Autonomy* implies control over the consequences of one's own behavior. *Competence* refers to the need to achieve mastery over (optimally challenging) activities. Finally, *relatedness* addresses the desire to feel a sense of belonging and connection to other people (Ng et al., 2012; Ryan & Deci, 2020). SDT researchers posit that if any of these needs are thwarted or undermined, it can be detrimental to an individual's autonomous motivation and well-being Ng et al. (2012). One of the more popular concepts from SDT is intrinsic motivation, i.e., the tendency to engage in activities due to the perceived interest, enjoyment, and inherent satisfaction (Ryan & Deci, 2000, 2020). However, research suggests that both intrinsically oriented motives and need satisfaction, such as social engagement, optimal challenges, and skill development, are associated with greater exercise participation and effort (Teixeira et al., 2012). In addition to commonly used subjective measures that constitute regular SDT questionnaires (intrinsic motivation inventory or self-regulation questionnaires), SDT researchers also employ objective measures such as the free-choice paradigm to assert intrinsic motivation. In the free-choice paradigm, participants can engage in an activity of their own volition after they believe they are no longer observed. If they persist in the activity, it indicates intrinsic engagement (Vansteenkiste et al., 2010; Peters et al., 2018).

1.2. Computer-mediated technologies to support motivation and well-being

Exertion games or exercise games (exergames) Bogost (2005); Mueller et al. (2008), have repeatedly been suggested as a tool to encourage and sustain motivation in rehabilitation programs (Staiano et al., 2012; Marker & Staiano, 2015; Levac et al., 2017; Keshner et al., 2019; Reis et al., 2019; Høeg, Povlsen, et al., 2021; Koivisto & Malik, 2021). Researchers have explored how novel computer-mediated technologies, such as virtual reality (VR), can foster patients' feelings of enjoyment and satisfaction while undergoing tedious (or even painful) exercises (Anderson-Hanley et al., 2011; Feltz et al., 2011; Goršič, Cikajlo, Goljar, et al., 2017; Kaos et al., 2019; Pereira et al., 2019; Goršič et al., 2020; Høeg, Povlsen, et al., 2021). Yet, although there is plenty of examples of how VR technology can influence the gaming experience positively by increasing enjoyment, happiness, and a sense of competence, the underlying mechanisms remain largely understudied (Reer et al., 2022). A new SDT-based theoretical framework, the Motivation, Engagement, and Thriving in User Experience (METUX) model (Peters et al., 2018), provides a minimal set of well-being requirements applicable to all kinds of technologies, i.e., they should fulfill the three basic psychological needs (Peters, 2022). Therefore, researchers and developers must rely on designs that promote sustained motivation and well-being by supporting the basic psychological needs (Peters et al., 2018; Reer et al., 2022).

1.3. Virtual reality and cycle ergometers

Historically, the term 'VR' has been used to describe both non-immersive VR (NVR) and immersive VR (IVR) based on the system's immersive capabilities (Nilsson et al., 2016; Høeg, Povlsen, et al., 2021). IVR systems utilize, e.g., head-mounted displays (HMDs) that allow the user to view the virtual environment (VE) in all directions. Recently, 360-degree video, captured in real-world scenarios (sometimes called 360° VR) has also emerged (Ortet et al., 2022). In contrast, NVR systems only offer a limited field-of-view (FOV), e.g., through a computer screen, televisions, or projection systems (Høeg, Povlsen, et al., 2021).

The first researchers to combine cycle ergometers with interactive VEs were Johnson et al., who conducted an experiment on severely brain-injured adults (N = 20) by combining cycle ergometers with an NVR environment displayed on a 29-inch monitor positioned in front of an exercise bike (Johnson et al., 1996). Kim et al. were the first to utilize immersive technology for developing a purposeful rehabilitation training prototype for postural balance rehabilitation (Kim et al., 1999). Yet, it is worth noting that the prototype was evaluated on healthy adults. Most of the previous research has largely utilized NVR applications, likely because the cost of immersive devices in the early millennium was too high to integrate into clinical settings. Within the last 12 years, there's been increasing interest in IVR and NVR applications for health purposes. For example, as an exergame experience to promote health and fitness following stroke (Ranky et al., 2010; Deutsch et al., 2013; Ranky et al., 2014), to motivate PA in nursing home residents (Bruun-Pedersen et al., 2014, 2016a, 2016b) and pulmonary rehabilitation (Rutkowski et al., 2021; Høeg, Bruun-Pedersen & Serafin, 2021), as well as for home-based exergaming (Arlati et al., 2019).

1.4. Social interaction in virtual environments

There is a dearth of research on the impact of different social game styles in immersive experiences in rehabilitation contexts (for instance, co-action, cooperation, collaboration, and competition) Marker and Staiano (2015); Pereira et al. (2019); Høeg, Bruun-Pedersen, Cheary, et al. (2021). In NVR studies, social experiences have been previously been addressed. For instance, Anderson-Hanley studied the effect of social facilitation and competitiveness against virtual avatars on a video screen (Anderson-Hanley et al., 2011, 2012), Kaos et al. discovered that participants who primarily engaged in group play had superior adherence compared to participants who played alone (Kaos et al., 2019), Arlati et al. utilized virtual biking to increase elderly's exercise adherence (Arlati et al., 2019), and Høeg et al., investigated the social impact of a co-located immersive tandem-bike exergame among older adult outpatients (Høeg, Bruun-Pedersen, Cheary, et al., 2021).

In social interactions, the concepts of co-presence, i.e., the feeling of sharing the same virtual space with another person and being mutually aware of each other, originated from Goffman's work on behavior in public places (Goffman, 1966). Slater et al. distinguish co-presence as a separate attribute from social presence in VEs, arguing that a simple phone call conversation with someone can create a strong social feeling of being with them but may not necessarily instill a sense of physically being in the same virtual space with them (co-presence) (Slater et al., 2000). This implies that users can still experience social presence even with limited or no avatar fidelity and appearance, similar to how it occurs in a phone call or virtual meeting.

Against this background, we aimed to offer the older adult inpatients an activity that combined social interaction and PA with the overall perspective of improving their well-being by supporting the need for autonomy, competence, and relatedness. More specifically, the goal of the study was to explore the influence of social presence on engagement, feasibility, safety, and self-perceived exercise benefit of IVR group cycling from the inpatients' point of view.

Fig. 1. The commercial solution from Syncsense LCC presented 360-degree recorded videos of scenic walks through a Pico G2 VR headset.

Fig. 2. A group of four participants engaged in the same selected 360-degree experience.

2. Methods

2.1. Study design

The study was based on an idiographic research approach designed as an exploratory phenomenological study. A convergent mixed methods design was used, a type of design where both qualitative and quantitative data are collected in parallel, analyzed separately, and then merged (Creswell & Creswell, 2018). The reason for collecting both quantitative and qualitative data was to create an integrated interpretation (Creswell & Poth, 2015) and explore convergence, contradictions, and incongruence through data triangulation (Creswell, 2013).

The study was conducted between October and November (2021), during a low-incidence period of the COVID-19 pandemic. Participants were recruited from an inpatient care unit in the Danish municipality of Frederiksberg. Potential participants were screened for eligibility by a physiotherapist through a non-probability purposive sampling approach Creswell and Poth (2015).

2.2. Ethical approval

Aalborg University's Technical Faculty of IT and Design prospectively approved that the study complied with the Danish Code of Conduct for Research Integrity. The study protocol (ID: NVK-21065364) was submitted for approval by the Danish National Committee on Health Research Ethics (NVK), which concluded that the study did not require additional ethical approval.

2.3. Materials

The equipment used in the study included four Pico G2 4K VR headsets (Pico Immersive Pte. Ltd., San Francisco, USA) paired with a commercial hardware/software solution (Syncsense LLC, Copenhagen, Denmark) (see Fig. 1). The solution contains a pedal sensor that interfaces with the HMD to play 360° pre-recorded videos of various walking tours. The pedal sensor connected automatically to the HMD, and the participants had to keep their cadence for the video to keep playing. Thus, the pedaling speed did not influence the playback speed of the video. The gym room was preprepared with four Lemco B'fit (Lemco Mobility LCC, Elsinore, Denmark) portable cycle ergometers positioned on non-slip surfaces.

2.4. Intervention

Potential participants were screened and invited to participate in the study by the unit's development therapist. Participants were excluded if they were non-native speaking, delirious, febrile, or incapable of understanding and giving informed consent. The consenting participants were invited to attend bi-weekly voluntary sessions for approximately 15-20 minutes of PA at an individually preferred cadence. Participants were led into the room, and the chairs were adjusted for optimal knee angle and efficient pedaling. Then they were handed a leaflet containing images and descriptions of the different virtual tours and encouraged to agree on which VE to try. The VR headsets were fitted and adjusted, and when all participants were ready, the VEs were started in quick succession to ensure synchronous playback (see Fig. 2). Meanwhile, on a tablet computer, the research team could monitor the VE. Upon completion, participants were offered refreshments and encouraged to discuss the experience among themselves.

2.5. Hygienic requirements

Since the COVID-19 outbreak, there has been increased attention to safety and proper hygiene related to the clinical use of VR equipment (Stradford et al., 2021; Steed et al., 2020). We used a locally approved cleaning protocol based on World Health Organization (WHO) recommendations and had it approved by the affiliated hygiene nurse specializing in Infection Prevention and Control (IPC). The equipment was disinfected before and after each session, and the VR equipment was subsequently stored in a closed box.

2.6. Data collection and analysis

2.6.1. Qualitative methods

Qualitative data was collected through session and interview observations performed by a research member, with low involvement with the participants (Spradley, 2016; Bjørner, 2016). Semi-structured single interviews were conducted with two participants. The interview guide contained the questions: What were your expectations before starting the VR group exercise? What motivated you to say yes? What is your experience of wearing the VR headset? What would make the VR headset better to use? What was your experience of the conversations and the social interactions within the group? How is your general mood in this place? What is your attitude towards rehabilitation and physical activity?

The interviews were transcribed by verbatim method to preserve complete accuracy (Halcomb & Davidson, 2006). We examined the individual transcriptions through theoretical thematic analysis (i.e., working deductively with predefined themes) by identifying and marking notable natural meaning units and explicating main themes (Braun & Clarke, 2006; Kvale & Brinkmann, 2009). Both predefined and emerging themes were included. The coding was performed using NVivo (version 12). The interviews were in [*danish*], and the quotations are translated versions.

2.6.2. Quantitative methods

Quantitative data was collected in the form of voluntary session evaluation cards (see Supplementary Appendix) that contained four Likert-type items, indicating agreement on a 5-point scale ranging from “Not at all” (1), “Somewhat” (3) to “To a great extent” (5). The questions represented constructs relevant to the study: “Was group exercise with VR a good experience?” (Experience quality), “Did you get anything out of it, in terms of exercise?” (Exercise output), “Was the social interaction meaningful?” (social meaningfulness), and “To what extent would you like to try VR group exercising again” (Activity persistence/retention). To evaluate the safety, dizziness was measured after each training session on a numerical rating scale inspired by the simulator sickness questionnaire (SSQ) Kennedy et al. (1993) based on the severity of symptoms from “0” (“None”) to “3” (“Severe”).

The reason for not using standardized instruments was primarily out of consideration for the older adults, to not cause information overload during the experience. Other authors have recommended using shorter and simpler questionnaires in similar virtual rehabilitation evaluation studies (Goršič, Cikajlo & Novak, 2017). Moreover, the SSQ instrument is commonly used to evaluate VR sickness. However, recent research has raised concerns about its validity, as it has been found to have limited scope without accounting for visual and cognitive after-effects Szpak et al. (2019), not considering ergonomics and wearability Genaro Motti and Caine (2014), and digital eye strain Hirzle et al. (2021). Additionally, the SSQ item ‘sweating’ in the scale may be misleading, as it could be interpreted as a symptom of nausea rather than physical exertion Høeg, Bruun-Pedersen, Cheary, et al. (2021).

Thus, to evaluate adverse events, the instructors noted any events or statements from participants about feeling uncomfortable (physiological or psychological discomfort), eye strain, ergonomic or wearability issues, and any other adverse events. The Quantitative data analysis was handled using Microsoft Excel (version 365). The data were treated as ordinal data and presented as descriptive statistics through mean, median, standard deviations (SD), and percentage frequency distribution for demographics, number of sessions and session evaluations.

3. Results

3.1. Participants

Ten inpatient participants consented to partake in the study. There was an even sex distribution of the participants (50% female) and a mean age of 80.3 (±8.2 years). Characteristics are summarized in Table 1. Four participants completed a single VR session, two completed two sessions, three completed three sessions, and a single participant completed five sessions. On average, participants completed 2.2 (±1.3) sessions. The primary reason for the difference in the number of attended sessions was patient discharge. All participants fully adhered to possible sessions they could participate in, and no drop-outs were recorded.

3.2. Quantitative findings

A total of 21 session evaluation cards were collected during the study. In experience quality, most respondents answered either “to a large extent” (48%) or “to a great extent” (14%). 29% answered that it was “somewhat” a good experience, and the rest answered either “Not at all” (5%) or “to a small extent” (5%). In terms of exercise output, a majority (52%) answered that it was “somewhat” beneficial, 14% answered “to a large extent,” and 10% answered, “to a great extent”. 10% answered that it was “not at all”, and 14% answered that it was only beneficial “to a small extent”. Concerning social meaningfulness, most respondents agreed that it was “not at all” (15%), “to a small extent” (30%), or “somewhat” (40%) meaningful. Only 15% responded that it was meaningful “to a large extent”. When asked if they wanted to try VR group exercising again (activity persistence), most respondents answered either “to a large extent” (43%) or “to a great extent” (33%). See results in Fig. 3.

Table 1
Characteristics of participants: ID, sex, age, diagnoses, and the number of sessions attended. The last row indicates the number of females (%), central tendency (mean) ± dispersion as standard deviation (SD). The ‘*’ indicates an interviewed participant, and ‘-’ denotes missing data. Change in attendance was primarily because the participants were discharged and not because of study drop-out.

ID	Sex	Age	Diagnosis / admission cause	Sessions
P1*	F	91	Femoral neck fractures after fall	5
P2	M	86	Acetabular fracture after fall	3
P3	M	85	Frailty, dyspnoea, osteoarthritis.	3
P4	F	85	Cerebral infarction	3
P5	M	80	-	2
P6*	M	81	Pancreatic and sigmoid cancer	2
P7	M	78	Recurrent falls	1
P8	F	69	Ankle fracture	1
P9	F	84	-	1
P10	F	64	Stroke	1
	F = 50%	80.3±8.2		2.2±1.3

For the participants (P1-P5) who completed several sessions (S), we included comparative ratings for S1-S3 (see Fig. 4). Median scores were consistent in all three sessions for experience quality (S1:4; S2:4; S3:4), exercise output (S1:3; S2:3; S3:3) and changed slightly in social meaningfulness (S1:2.5; S2:2; S3:3) and activity persistence (S1:4; S2:4; S3:5).

3.3. Side effects and adverse events

Two participants reported feeling dizzy during VR exposure. Symptoms were found in two sessions among single-session participants. One participant (P9) from session 1 responded “1” (“Slight”), and another participant (P6), from session 4 responded that he felt (“Moderate”) dizziness. One participant (P1) remarked that she was in an uncomfortable seated position during the session and thus did not want to try again next time (she did attend again next time). There was no recorded dizziness in 19 of the 21 instances (90%). Another participant (P3) experienced that the headset was poorly fitted and complained that: “*the headset bounced, and it was uncomfortable and blurry when it fell out of my field of vision.*” (P3). Otherwise, there were no recorded issues with device weight or that the ergonomics of the headset were described as uncomfortable.

3.4. Qualitative findings

Using the predetermined and emerging codes, we synopsized the qualitative data analysis results based on the thematic analysis. The study only succeeded in interviewing two participants. The interviewed participants (P1 and P6) commented on aspects related to expectations for the experience, motivation for participating, and the benefits of social interaction during a group exercise. Participants displayed positive affirmation of their intention to continue performing PA with the VR system. A total of five themes emerged from the analysis.

3.4.1. Finding 1: VR instilled exercise enjoyment and engagement

The participants were observed to be immersed in the experience, with some making remarks about what they experienced *“That’s when I thought, this is incredible”* (P1). P6 compared it to previous experiences with cycle ergometers as part of therapy *“Yes, it (previous therapy) was extremely boring!”* (P6). Observed conversations also highlighted frequent unidirectional conversations, i.e., one participant verbalizing what she experienced: *“Oh look, there are also two ducks!”* (P8). The participants were observed to be very focused on the experience, all completing the sessions without breaks at a steady pace.

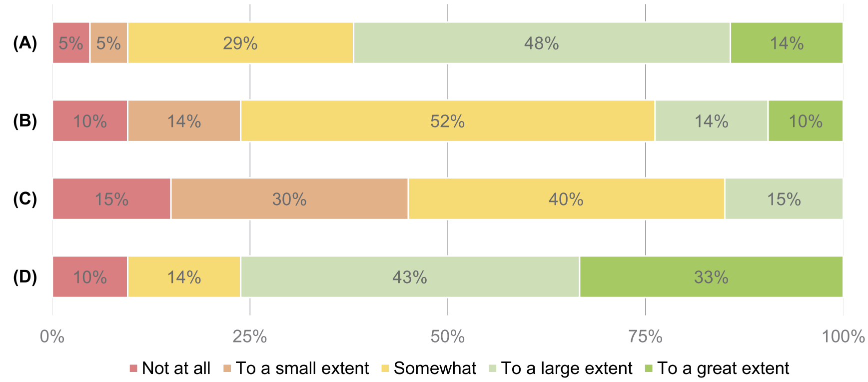

Fig. 3. Stacked frequency plot of the aggregated responses from all participants and sessions in percentage (%) agreement. (A) *Was group exercise with VR a good experience?, (B) Did you get anything out of it, in terms of exercise?, (C) Was the social interaction meaningful?, and (D) To what degree would you like to try VR group exercising again?*

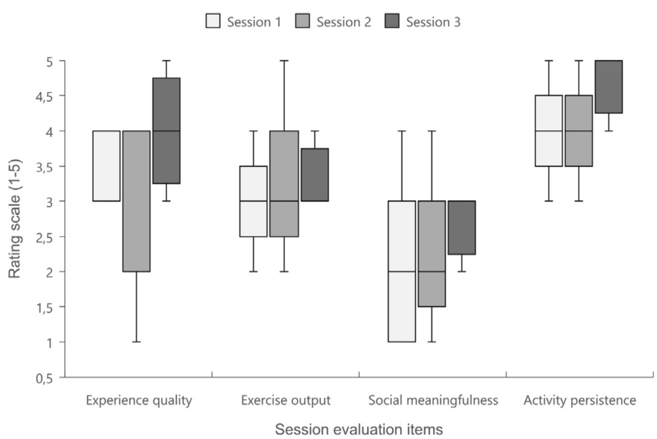

Fig. 4. Boxplot of the four session evaluation items across three consecutive sessions (1-3), in the order the participants experienced them. Data is based on P1-P5, who had several sessions.

3.4.2. *Finding 2: immersion inhibited social interaction*

Social interaction was not an active ingredient in driving the experience. It was seemingly difficult for the participants to cultivate social relations while being visually deprived. Social presence, as described by Slater et al. (2000) was facilitated to a small extent by the participants recognizing the co-location, but without virtual avatars to support co-presence, the sense of 'community' was of low salience. One participant described the experience as *being alone*: *"Yes, I could hear the other participants.. but [. . .] It wasn't group training... We were just.. alone, actually"* (P1). P6 further elaborated on this by suggesting a good session would require pre-established relationships *"... If you don't know the others [patients], then there are not many back-and-forths. We need to know each other for a while first."* (P6). However, not knowing each other was not the primary reason. The immersive experience inhibited social interaction during sessions. It was repeatedly observed that participants talked with each other before commencing the exercise. Still, once they started cycling, they became quiet or occasionally directed their conversation at the therapists and researchers.

3.4.3. *Finding 3: the VR cycling system was safe and feasible to use*

No participants were harmed during exercise sessions nor experienced any severe discomfort. All participants completed the sessions and continued participating in the following sessions until they were discharged. One participant (P6) experienced moderate dizziness during session 4, but it was noted that he suffered from general dizziness, thus not necessarily caused by VR. Another participant (P2) experiences that the headset was not properly tightened, causing it to bounce around during the exercise, which was *"uncomfortable and blurry when it (the headset) moved outside my field of view"* (P2). Comfortable seating was also an issue for two participants. One complained that the knee angle between the ergometer and the wheelchair was *"uncomfortable"* (P3). Another participant did not want to participate again because she sat uncomfortably on the chair (P1). She did, however, participate again in the following session.

3.4.4. *Finding 4: physical activity was perceived as somewhat beneficial*

P6 remarked that the VR added 'something extra' making him feel like he exerted more effort *"You get much more out of the exercise session... By wearing the VR headset"* (P6). The system encouraged him to work even harder in the final 5 minutes following an auditory notification about the remaining time. When the interviewer inquired whether he felt pressured to exert extra effort by the VR system, he responded: *"It was not the glasses* (VR-headset), *it was all me!"* (P6), later comparing it to a race where you sprint in "the final 100 meters". During sessions, it was observed that participants cycled at a steady pace and did not increase their effort in the final minutes.

3.4.5. *Finding 5: VR group exercise, as an activity, supported inpatient well-being and psychological needs*

> *"It's a sad place to be in. [. . .] Nothing is going on, you see? If I were to stay in this place, I would wither"* - (P6, about staying at the inpatient facility).

The use of VR and cycle ergometers as an activity provided individual excitement for the participants, helped with adherence during therapy, and reinforced inpatient well-being during admission. For P6, it seemingly maintained a level of normalcy during inpatient admission *"I couldn't dream of saying no. Getting to go out* (of the room) *and talk to you and the glasses* (VR-headset). *Amazing!"* (P6).

3.5. *Integrated findings*

There was a strong agreement between the quantitative and qualitative findings that the VR system was safe to use and that adverse events were infrequent and insignificant. Most participant responses (62%) gave the impression that it was a good experience to a large/great extent, which they would like to repeat again (76%). Only 10% responses indicated that the participant would not try the experience again. See an elaborate synthesis of results in Table 2.

4. Discussion

This study explored whether social interaction and PA could be combined through the novel use of immersive technology in a group exercise constellation. The underlying assumption was that if we supported the basic psychological needs, primarily relatedness, well-being would

Table 2
Summary of integrated findings in a mixed methods meta-matrix. Nomenclature: interview = int, Obs = observation, Open-ended questions = OE.

Themes	Quantitative findings	Qualitative findings	Data convergence and integration
1) VR instilled exercise enjoyment	**Experience quality:** Generally high ratings. 62% described that the experience was good to a large/great extent. **Activity persistence:** only 10% responded they would not try again	**INT:** it was described as "incredible". P6 compared it to "boring" normal exercise. **OBS:** participants were generally observed as being immersed. **OE:** P5 complained that the visual quality was "poor".	Description and interpretation converged in the findings. *Implications: IVR to support cycle ergometer exercise provided individual excitement and maintained psychical activity during therapy. Hence, it could apply to other older adults who may display low adherence and low well-being during hospital admission.*
2) Immersion inhibited social interaction	**Social meaningfulness:** The social elements were not perceived as meaningful. 85% responded either "not at all", "small extent," or "somewhat").	**INT:** Participants felt alone once they put on the headset. Participants could not cultivate social presence while being visually deprived or immersed. **OBS:** Except for a few remarks, participants did not interact much during the session.	Description and interpretation converge in the findings. *Implications: IVR may inhibit social interaction in games/experiences that do not support social presence through embodied avatars. Social interaction through co-action activities may require meaningful relationships and/or interactions with other patients, which is not cultivated among new relations.*
3) The VR cycling system was safe and feasible to use	The low incidence rate of dizziness (10%), with other factors likely being the cause. OE described incidences of discomfort affecting activity persistence negatively P1 in one instance.	**INT:** No dizziness mentioned **OBS:** No observed instances of participants stopping or describing severe discomfort during sessions. **OE:** Discomfort was described due to poor seating.	Description and interpretation converged yet with some incongruences in the findings. *Participants equated it with performing the activity without "visual stimuli" (IVR). Yet, therapists remarked that it was easier to keep them going with VR for longer periods of time.*
5) VR therapy, as an activity, supported inpatient well-being and psychological needs	**Activity persistence:** 90% responded that they would, to some extent, like to try again. Complete adherence during therapy (no withdrawals). Six participants completed several (2-5) sessions, and the rest completed a single session. There was an increasing tendency in activity persistence between sessions 1-3 (see Fig. 4).	**INT:** The experience provided excitement and supported adherence during therapy. Moreover, it offered volition and a sense of purpose in a "sad place" (P6). **OBS:** Therapy adherence was generally high, with no observed cases of participants stopping withdrawing. Participants. The ones who completed only single sessions expressed interest in trying again but were unable due to schedule conflicts or discharge.	Description and interpretation converged in the findings. *Implications: The VR group therapy offered the participants a novel activity, making it more "fun". ("It is fun. Instead of just sitting and grinding away on a bike", P6). The participants were seemingly autonomously motivated to engage in the PA. Although the PA was only perceived as somewhat beneficial compared to regular therapy (theme 4), it was still more engaging (theme 1). Presumably, it has the potential to counteract the low activity levels and loneliness of inpatients.*

likely be enhanced (Peters et al., 2018; Ryan & Deci, 2020). In this study, we sought to explore older adult inpatients' experience of, and attitude towards, engaging with the technology in this context, but also the feasibility of this type of setup integrated into physiotherapeutic inpatient regimens. The participants generally described the intervention as a fun and enjoyable experience. Most participants expressed a desire to pursue it continuously since it helped them with exercise adherence, i.e., the median activity persistence remained constant across several sessions. The experience also reinforced the well-being during the inpatient stay at least one participant (P6). Both findings indicate the autonomous motivation for this experience, which may positively influence patient well-being during hospitalization. These findings are in accordance with previous research that highlights exergames as a promising solution when promoting PA (Larsen et al., 2013; Marston et al., 2016; Mouatt et al., 2020; Høeg, Bruun-Pedersen & Serafin, 2021; Høeg, Bruun-Pedersen, Cheary, et al., 2021; Shah et al., 2022).

The participants perceived the exercise output as limited and beneficial. However, physiotherapists remarked that getting them to exercise with VR for longer durations was generally easier. Previous research suggests that older adults frequently find PA to be 'boring' (Costello et al., 2011). This contradiction may stem from the participants' inability to reconcile their enjoyment of the experience with their general perception of PA.

A major finding illustrates that the enclosing immersiveness of the headset hindered conversation during exercise. While the participants engaged in conversation before wearing the headset, the moment they put it on, the conversations fell silent. This could suggest that visual reliance is an important factor when trying to sustain social engagement. Still, it could also imply that the participants were too immersed in the experience to perform dual tasks. However, the exclusion of sight likely had a negative effect on forming relations between the participants, which conversely caused the participants not to experience cohesion and relatedness to the other participants. Several explanations could be derived from this. Not surprisingly, previous research has found that the sense of co-presence is greater when a visual representation is available (Oh et al., 2018). Roberts et al. found that similar VR systems (Samsung Gear VR) that did not directly facilitate social interaction led to inadequate social connectedness, with participants calling for greater social interaction (Roberts et al., 2019). Abeele et al. argue that shared experiences, including avatar customization and facial expressions, are an important design requirement for older adults (Abeele et al., 2021). These design considerations are supported by previous literature, which argues that social presence is contingent on intimacy and immediacy that is determined by both verbal and nonverbal cues (such as facial expressions) (Short et al., 1976). However, much of the previous research on exergames and rehabilitation games have utilized NVR solutions, where various social game modes are more easily integrated since the players can be co-located and see each other simultaneously (Anderson-Hanley et al., 2011; Feltz et al., 2014; Goršič, Cikajlo, Goljar, et al., 2017; Arlati et al., 2019; Kaos et al., 2019; Pereira et al., 2019).

The type of task likely influences social engagement as well. In a previous NVR study, it was found that collaboration promotes more social involvement than both competition and co-action (Pereira et al., 2019), and an IVR study likewise suggested that social interaction can be facilitated in co-located situations with low avatar fidelity when participants were required to perform a collaborative task (Høeg, Bruun-Pedersen, Cheary, et al., 2021). Our study relied on social presence as a modus through the co-located activity. Introducing more overt conjunctive tasks that utilize cooperation, collaboration or competition would likely lead to higher levels of interactivity and sense of coherence. Therefore, we cannot disregard that the type of game mode also most likely influences social engagement.

4.1. Safety and feasibility

Compared to previous VR solutions used in the unit, the therapists found the commercial solution to be easier to use Moreover, the study recorded a minimal amount of adverse events among the participants (see 3.3). Only two participants (P9 and P10) reported feeling dizzy during VR exposure in two sessions (1 and 4). However, it was not unpleasant enough for them to stop the experience. One participant (P1) complained about poor seating, and another participant (P3) experienced a poorly fitted headset. There were no other recorded issues with device weight or ergonomics.

However, it was difficult to synchronize the playback time of the different headsets since they had to be initiated manually. From a practical perspective, this would need to be centrally controlled, e.g., from a tablet, to be feasible in future therapeutic situations. Synchronization would also likely make the experience more coherent for older adults.

4.2. Strength and limitations

This study included several oldest-old participants, who are generally underrepresented in virtual rehabilitation interventions (Marston et al., 2016). We perceive this as an important step towards representing this population segment in literature and gaining a preliminary understanding of how older adults engage and experience VR-based therapy and how this may support well-being and healthy aging. Although social presence was not a facilitating feature of the experience, a co-located group setup is still practical for the therapist because multiple patients can exercise simultaneously while being monitored and assisted. Although there is no specific sample size estimation in qualitative or mixed methods research, it is generally suggested that saturation (Malterud et al., 2016; Creswell & Creswell, 2018) or information power (Malterud et al., 2016) is considered. In user experience research, it is suggested that as little as five participants are sufficient when uncovering system problems or gathering user insights. However, we cannot be certain that the sample (N = 10) was sufficient to reach saturation in all facets of the investigation. Although both observations and quantitative results indicate information power and saturation (results were consistent and did not spark new insights or reveal new properties), additional interviews could have uncovered variations in the reasons for self-reported or observed behavior. Credibility could have been improved by utilizing, e.g., member checking to determine the accuracy of the findings (Creswell & Creswell, 2018). However, we could no longer access study participants upon completing the analysis. Moreover, the interviewed participants both participated in multiple sessions (five and two), which may have affected their attitude towards the VR experience. Preferably, interviews should have been carried out with maximum variation in mind, i.e., also interviewing the ones who did not participate in multiple sessions.

4.3. Perspectives

During the COVID-19 pandemic, healthcare facilities worldwide faced unprecedented circumstances that forced them to introduce strict policies on social activities and access to common areas, television rooms, and exercise machinery (Kheirbek et al., 2021). Although intended to protect weakened individuals, it also left many inpatients frustrated with being deprived of interpersonal relations due to restricted visitor access and/or socializing with the other inpatients. VR-mediated group therapy may be a promising solution to existing physiotherapy practices if it incorporates a design that supports basic psychological needs. However, to achieve social engagement, a future system will need to afford a higher degree of social presence, e.g., through shared avatar embodiment (co-presence) (Oh et al., 2018; Roberts et al., 2019; Abeele et al., 2021) or beyond passive social interaction (co-action) (Marker & Staiano, 2015; Arlati et al., 2019; Kaos et al., 2019; Pereira et al., 2019; Høeg, Bruun-Pedersen, Cheary, et al., 2021) to facilitate social interaction through engaging game modes for older adults. Moreover, it will be necessary to conduct elaborate studies on the physiological efficacy of the intervention to determine if interventions can be considered as physiotherapy or as an additional offer to prevent sedentary behavior and improve inpatient well-being.

Several other authors have pointed out a dearth of research concerning the underlying psychological mechanisms of what constitutes a well-designed gaming experience (Reer et al., 2022; Peters et al., 2018). We would argue further that the context in which these gaming experiences are used is equally vital to their success. For instance, for older adults undergoing hospital treatment, engaging in exergaming activities may have the capacity to instigate greater enjoyment and adherence. Still, it could also risk isolating them if it is not carefully integrated into existing practices. In our case, a central premise was that the voluntary VR experience catalyzed increased PA and heightened social interaction between inpatients. The underlying assumption was that this combination of technology and context would be need-supportive (autonomy, competence, and relatedness) and (in the long term) improve inpatient well-being. This study does not confirm nor reject this hypothesis. However, we believe it is an important step towards increasing the knowledge of how exergames for older adults can promote sustained motivation and well-being through the support of basic psychological needs as a guiding principle.

Declaration of competing interest

Emil R. Høeg (ERH) became voluntarily involved with the company Syncsense LLC in the form of a Scientific Advisor after completing the study. The remaining authors have no conflicts of interest to declare.

Data availability

Data will be made available on request.

Acknowledgements

Partial funding for the study was provided by ERH's PhD research budget, funded by the Danish municipality of Frederiksberg. We wish to thank the company Syncsense LCC for changing their software architecture to fit the study.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.chbr.2023.100301.

References

Abeele, V. V., Schraepen, B., Huygelier, H., Gillebert, C., Gerling, K., & Van Ee, R. (2021). Immersive virtual reality for older adults: Empirically grounded design guidelines. *ACM Transactions on Accessible Computing*, *14*, 1–30. https://doi.org/10.1145/3470743.

Anderson-Hanley, C., Snyder, A. L., Nimon, J. P., & Arciero, P. J. (2011). Social facilitation in virtual reality-enhanced exercise: Competitiveness moderates exercise effort of older adults. *Clinical Interventions in Aging*, *6*, 275–280. https://doi.org/10.2147/cia.s25337.

Anderson-Hanley, C., Arciero, P. J., Brickman, A. M., Nimon, J. P., Okuma, N., Westen, S. C., Merz, M. E., Pence, B. D., Woods, J. A., Kramer, A. F., & Zimmerman, E. A. (2012). Exergaming and older adult cognition: A cluster randomized clinical trial. *American Journal of Preventive Medicine*, *42*, 109–119. https://doi.org/10.1016/j.amepre.2011.10.016.

Arlati, S., Colombo, V., Spoladore, D., Greci, L., Pedroli, E., Serino, S., Cipresso, P., Goulene, K., Stramba-Badiale, M., Riva, G., Gaggioli, A., Ferrigno, G., & Sacco, M. (2019). A social virtual reality-based application for the physical and cognitive training of the elderly at home. *Sensors (Switzerland)*, *19*. https://doi.org/10.3390/s19020261.

Bandura, A. (2006). Toward a psychology of human agency. *Perspectives on Psychological Science*, *1*, 164–180. https://doi.org/10.1111/j.1745-6916.2006.00011.x.

Bassett, S. F. (2003). The assessment of patient adherence to physiotherapy rehabilitation. *New Zealand Journal of Physiotherapy*, *31*, 60–66.

Bjørner, T. (2016). *Qualitative Methods for Consumer Research: The value of the qualitative approach in theory and practice*. Copenhagenn Denmark: Hans Reitzels Forlag.

Bogost, I. (2005). The rhetoric of exergaming. In *Proceedings of the Digital Arts and Cultures (DAC)* (p. 10).

Bouaziz, W., Schmitt, E., Kaltenbach, G., Geny, B., & Vogel, T. (2015). Health benefits of cycle ergometer training for older adults over 70: A review. *European Review on Aging and Physical Activity*, *12*. https://doi.org/10.1186/s11556-015-0152-9.

Bouillon, L. E., Sklenka, D. K., & Ver, A. C. (2009). Comparison of training between 2 cycle ergometers on dynamic balance for middle-aged women. *Journal of Sport Rehabilitation*, *18*, 316–326. https://doi.org/10.1123/jsr.18.2.316.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Bray, N. W., Smart, R. R., Jakobi, J. M., & Jones, G. R. (2016). Exercise prescription to reverse frailty. *Applied Physiology, Nutrition, and Metabolism*, *41*, 1112–1116. https://doi.org/10.1139/apnm-2016-0226.

Brown, C. J., Redden, D. T., Flood, K. L., & Allman, R. M. (2009). The underrecognized epidemic of low mobility during hospitalization of older adults. *Journal of the American Geriatrics Society*, *57*, 1660–1665. https://doi.org/10.1111/j.1532-5415.2009.02393.x.

Bruun-Pedersen, J. R., Serafin, S., & Kofoed, L. B. (2016a). Going outside while staying inside-exercise motivation with immersive vs. non-immersive recreational virtual environment augmentation for older adult nursing home residents. In *Proceedings - 2016 IEEE international conference on healthcare informatics*. Institute of Electrical and Electronics Engineers Inc. (pp. 216–226). https://doi.org/10.1109/ICHI.2016.31.

Bruun-Pedersen, J. R., Serafin, S., & Kofoed, L. B. (2016b). Motivating elderly to exercise - recreational virtual environment for indoor biking. In *2016 IEEE international conference on serious games and applications for health* (pp. 1–9). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/SEGAH.2016.7586265.

Bruun-Pedersen, J. R., Pedersen, K. S., Serafin, S., & Kofoed, L. B. (2014). Augmented exercise biking with virtual environments for elderly users: A preliminary study for retirement home physical therapy. In *2014 2nd workshop on virtual and augmented assistive technology, VAAT 2014; co-located with the 2014 virtual reality conference - proceedings*. IEEE Computer Society (pp. 23–27). https://doi.org/10.1109/VAAT.2014.6799464.

Buchner, D. M., Cress, M. E., De Lateur, B. J., Esselman, P. C., Margherita, A. J., Price, R., & Wagner, E. H. (1997). A comparison of the effects of three types of endurance training on balance and other fall risk factors in older adults. *Aging Clinical and Experimental Research*, *9*, 112–119. https://doi.org/10.1007/bf03340136.

Costello, E., Kafchinski, M., Vrazel, J., & Sullivan, P. (2011). Motivators, barriers, and beliefs regarding physical activity in an older adult population. *Journal of Geriatric Physical Therapy*, *34*, 138–147. https://doi.org/10.1519/JPT.0b013e31820e0e71.

Courtin, E., & Knapp, M. (2017). Social isolation, loneliness and health in old age: A scoping review. *Health & Social Care in the Community*, *25*, 799–812. https://doi.org/10.1111/hsc.12311.

Covinsky, K. E., Justice, A. C., Rosenthal, G. E., Palmer, R. M., & Landefeld, C. S. (1997). Measuring prognosis and case mix in hospitalized elders: The importance of functional status, https://doi.org/10.1046/j.1525-1497.1997.012004203.x.

Covinsky, K. E., Palmer, R. M., Counsell, S. R., Pine, Z. M., Walter, L. C., & Chren, M. M. (2000). Functional status before hospitalization in acutely ill older adults: Validity and clinical importance of retrospective reports. *Journal of the American Geriatrics Society*, *48*, 164–169. https://doi.org/10.1111/j.1532-5415.2000.tb03907.x.

Creswell, J. (2013). Qualitative, quantitative, and mixed methods approaches. In H. Salmon, C. Neve, M. O'Heffernan, D. C. Felts, & A. Marks (Eds.), *Research design* (5 ed.) (pp. 1–26). Thousand Oaks: SAGE Publications Inc.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative and mixed methods approaches* (5 ed.). Thousand Oaks, California: SAGE Publications Inc.

Creswell, J. W., & Poth, C. N. (2015). *Qualitative inquiry and research design: Choosing among five approaches, Vol. 16*. SAGE Publications. https://doi.org/10.1177/1524839915580941.

Deutsch, J. E., Myslinski, M. J., Kafri, M., Ranky, R., Sivak, M., Mavroidis, C., & Lewis, J. A. (2013). Feasibility of virtual reality augmented cycling for health promotion of people poststroke. *Journal of Neurologic Physical Therapy*, *37*, 118–124. https://doi.org/10.1097/NPT.0b013e3182a0a078.

Feltz, D. L., Kerr, N. L., & Irwin, B. C. (2011). Buddy up: The Köhler effect applied to health games. *Journal of Sport & Exercise Psychology*, *33*, 506–526. https://doi.org/10.1123/jsep.33.4.506.

Feltz, D. L., Forlenza, S. T., Winn, B., & Kerr, N. L. (2014). Cyber buddy is better than no buddy: A test of the Köhler motivation effect in exergames. *Games for Health Journal*, *3*, 98–105. https://doi.org/10.1089/g4h.2013.0088.

Genaro Motti, V., & Caine, K. (2014). Understanding the wearability of head-mounted devices from a human-centered perspective. In *Proceedings of the 2014 ACM international symposium on wearable computers* (pp. 83–86). New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/2634317.2634340.

Gill, D. L., Hammond, C. C., Reifsteck, E. J., Jehu, C. M., Williams, R. A., Adams, M. M., Lange, E. H., Becofsky, K., Rodriguez, E., & Shang, Y. T. (2013). Physical activity and quality of life, https://doi.org/10.3961/jpmph.2013.46.S.S28.

Goffman, E. (1966). *Behavior in public places*. Free Press.

Gopinath, B., Kifley, A., Flood, V. M., & Mitchell, P. (2018). Physical activity as a determinant of successful aging over ten years. *Scientific Reports*, *8*. https://doi.org/10.1038/s41598-018-28526-3.

Goršič, M., Cikajlo, I., & Novak, D. (2017). Competitive and cooperative arm rehabilitation games played by a patient and unimpaired person: Effects on motivation and exercise intensity. *Journal of NeuroEngineering and Rehabilitation*, *14*, 1–18. https://doi.org/10.1186/s12984-017-0231-4.

Goršič, M., Cikajlo, I., Goljar, N., & Novak, D. (2017). A multisession evaluation of an adaptive competitive arm rehabilitation game. *Journal of NeuroEngineering and Rehabilitation*, *14*, 128. https://doi.org/10.1186/s12984-017-0336-9.

Goršič, M., Cikajlo, I., Goljar, N., & Novak, D. (2020). A multisession evaluation of a collaborative virtual environment for arm rehabilitation. *Presence: Teleoperators & Virtual Environments*, *27*, 274–286. https://doi.org/10.1162/PRES_a_00331.

Grenade, L., & Boldy, D. (2008). Social isolation and loneliness among older people: Issues and future challenges in community and residential settings. *Australian Health Review*, *32*, 468–478. https://doi.org/10.1071/AH080468.

Halcomb, E. J., & Davidson, P. M. (2006). Is verbatim transcription of interview data always necessary? *Applied Nursing Research*, *19*, 38–42. https://doi.org/10.1016/j.apnr.2005.06.001.

Heikkinen, R. L., & Kauppinen, M. (2004). Depressive symptoms in late life: A 10-year follow-up. *Archives of Gerontology and Geriatrics*, *38*, 239–250. https://doi.org/10.1016/j.archger.2003.10.004.

Hespel, P., Eijnde, B. O. T., Van Leemputte, M., Ursø, B., Greenhaff, P. L., Labarque, V., Dymarkowski, S., Van Hecke, P., & Richter, E. A. (2001). Oral creatine supplementation facilitates the rehabilitation of disuse atrophy and alters the expression of muscle myogenic factors in human. *Journal of Physiology*, *536*, 625–633. https://doi.org/10.1111/j.1469-7793.2001.0625c.xd.

Hirzle, T., Cordts, M., Rukzio, E., Gugenheimer, J., & Bulling, A. (2021). A critical assessment of the use of SSQ as a measure of general discomfort in VR head-mounted displays. In *Proceedings of the 2021 CHI conference on human factors in computing systems* (pp. 1–14). New York, NY, USA: ACM. https://doi.org/10.1145/3411764.3445361.

Høeg, E. R., Bruun-Pedersen, J. R., Cheary, S., Andersen, L. K., Paisa, R., Serafin, S., & Lange, B. (2021). Buddy biking: A user study on social collaboration in a virtual reality exergame for rehabilitation. *Virtual Reality*, *1*, 1–18. https://doi.org/10.1007/s10055-021-00544-z.

Høeg, E. R., Bruun-Pedersen, J. R., & Serafin, S. (2021). Virtual reality-based high-intensity interval training for pulmonary rehabilitation: A feasibility and acceptability study. In *Proceedings - 2021 IEEE conference on virtual reality and 3D user interfaces abstracts and workshops* (pp. 242–249). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/VRW52623.2021.00052.

Høeg, E. R., Povlsen, T. M., Bruun-Pedersen, J. R., Lange, B., Nilsson, N. C., Haugaard, K. B., Faber, S. M., Hansen, S. W., Kimby, C. K., & Serafin, S. (2021). System immersion in virtual reality-based rehabilitation of motor function in older adults: A systematic review and meta-analysis. *Frontiers in Virtual Reality*, *2*, 30. https://doi.org/10.3389/frvir.2021.647993.

Holt-Lunstad, J., Smith, T. B., & Layton, J. B. (2010). Social relationships and mortality risk: A meta-analytic review. *PLoS Medicine*, *7*, Article e1000316. https://doi.org/10.1371/journal.pmed.1000316.

Johnson, D. A., Rushton, S., & Shaw, J. (1996). Virtual reality enriched environments, physical exercise and neuropsychological rehabilitation. In *European conference on disability, virtual reality and associated technologies (ECDVRAT)* (pp. 247–251).

Kaos, M. D., Rhodes, R. E., Hämäläinen, P., & Graham, T. N. (2019). Social play in an exergame: How the need to belong predicts adherence. In *Proceedings of the 2019 CHI conference on human factors in computing systems* (pp. 1–13). New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3290605.3300660.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, *3*, 203–220. https://doi.org/10.1207/s15327108ijap0303_3.

Keshner, E. A., Weiss, P. T., Geifman, D., & Raban, D. (2019). Tracking the evolution of virtual reality applications to rehabilitation as a field of study. *Journal of NeuroEngineering and Rehabilitation*, *16*, 76. https://doi.org/10.1186/s12984-019-0552-6.

Kheirbek, R. E., Gruber-Baldini, A., & Shulman, L. M. (2021). Family engagement for hospitalized Covid-19 patients: Policy with unintended consequences. *Quality Management in Health Care*, *30*, 78–79. https://doi.org/10.1097/QMH.0000000000000291.

Kim, N. G., Yoo, C. K., & Im, J. J. (1999). A new rehabilitation training system for postural balance control using virtual reality technology. *IEEE Transactions on Rehabilitation Engineering*, *7*, 482–485. https://doi.org/10.1109/86.808952.

Koivisto, J., & Malik, A. (2021). Gamification for older adults: A systematic literature review. *Gerontologist*, *61*, E345–E357. https://doi.org/10.1093/geront/gnaa047.

Kvale, S., & Brinkmann, S. (2009). *InterViews: Learning the craft of qualitative research interviewing* (2 ed.). Thousand Oaks, California: SAGE Publications Inc.

Larsen, L. H., Schou, L., Lund, H. H., & Langberg, H. (2013). The physical effect of exergames in healthy elderly—a systematic review. *Games for Health Journal*, *2*, 205–212. https://doi.org/10.1089/g4h.2013.0036.

Levac, D., Glegg, S., Colquhoun, H., Miller, P., & Noubary, F. (2017). Virtual reality and active videogame-based practice, learning needs, and preferences: A cross-Canada survey of physical therapists and occupational therapists. *Games for Health Journal*, *6*, 217–228. https://doi.org/10.1089/g4h.2016.0089.

Maclean, N., Pound, P., Wolfe, C., & Rudd, A. (2000). Qualitative analysis of stroke patients' motivation for rehabilitation. *British Medical Journal*, *321*, 1051–1054. https://doi.org/10.1136/bmj.321.7268.1051.

Malterud, K., Siersma, V. D., & Guassora, A. D. (2016). Sample size in qualitative interview studies: Guided by information power. *Qualitative Health Research*, *26*, 1753–1760. https://doi.org/10.1177/1049732315617444.

Marker, A. M., & Staiano, A. E. (2015). Better together: Outcomes of cooperation versus competition in social exergaming. *Games for Health Journal*, *4*, 25–30. https://doi.org/10.1089/g4h.2014.0066.

Marston, H. R., Freeman, S., Bishop, K. A., & Beech, C. L. (2016). A scoping review of digital gaming research involving older adults aged 85 and older. *Games for Health Journal*, *5*, 157–174. https://doi.org/10.1089/g4h.2015.0087.

Mouatt, B., Smith, A. E., Mellow, M. L., Parfitt, G., Smith, R. T., & Stanton, T. R. (2020). The use of virtual reality to influence motivation, affect, enjoyment, and engagement during exercise: A scoping review. *Frontiers in Virtual Reality*, *1*, Article 564664. https://doi.org/10.3389/frvir.2020.564664.

Mueller, F. F., Gibbs, M. R., & Vetere, F. (2008). Taxonomy of exertion games. In *Proceedings of the 20th Australasian conference on computer-human interaction: Designing for habitus and habitat* (pp. 263–266). New York, NY, USA: ACM. https://doi.org/10.1145/1517744.1517772.

Ng, J. Y., Ntoumanis, N., Thøgersen-Ntoumani, C., Deci, E. L., Ryan, R. M., Duda, J. L., & Williams, G. C. (2012). Self-determination theory applied to health contexts: A meta-analysis. *Perspectives on Psychological Science*, *7*, 325–340. https://doi.org/10.1177/1745691612447309.

Nilsson, N. C., Nordahl, R., & Serafin, S. (2016). Immersion revisited: A review of existing definitions of immersion and their relation to different theories of presence. *Human Technology*, *12*, 108–134. https://doi.org/10.17011/ht/urn.201611174652.

Oh, C. S., Bailenson, J. N., & Welch, G. F. (2018). A systematic review of social presence: Definition, antecedents, and implications. *Frontiers in Robotics and AI*, *5*, 114. https://doi.org/10.3389/frobt.2018.00114.

Oja, P., Titze, S., Bauman, A., de Geus, B., Krenn, P., Reger-Nash, B., & Kohlberger, T. (2011). Health benefits of cycling: A systematic review. *Scandinavian Journal of Medicine & Science in Sports*, *21*, 496–509. https://doi.org/10.1111/j.1600-0838.2011.01299.x.

Ortet, C. P., Veloso, A. I., & Vale Costa, L. (2022). Cycling through 360° virtual reality tourism for senior citizens: Empirical analysis of an assistive technology. *Sensors*, *22*, 6169. https://doi.org/10.3390/s22166169.

Pedersen, M. M., Bodilsen, A. C., Petersen, J., Beyer, N., Andersen, O., Lawson-Smith, L., Kehlet, H., & Bandholm, T. (2013). Twenty-four-hour mobility during acute hospitalization in older medical patients. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *68*, 331–337. https://doi.org/10.1093/gerona/gls165.

Pereira, F., Bermudez I Badia, S., Jorge, C., & Da Silva Cameirao, M. (2019). Impact of game mode on engagement and social involvement in multi-user serious games with stroke patients. In *International conference on virtual rehabilitation* (pp. 1–13). https://doi.org/10.1109/ICVR46560.2019.8994505.

Peters, D. (2022). Wellbeing supportive design-research-based guidelines for supporting psychological wellbeing in user experience. *International Journal of Human-Computer Interaction*. https://doi.org/10.1080/10447318.2022.2089812.

Peters, D., Calvo, R. A., & Ryan, R. M. (2018). Designing for motivation, engagement and wellbeing in digital experience. *Frontiers in Psychology*, *9*, 797. https://doi.org/10.3389/fpsyg.2018.00797.

Ranky, R., Sivak, M., Lewis, J., Gade, V., Deutsch, J. E., & Mavroidis, C. (2010). VRACK - virtual reality augmented cycling kit: Design and validation. In *Proceedings - IEEE virtual reality* (pp. 135–138). https://doi.org/10.1109/VR.2010.5444798.

Ranky, R. G., Sivak, M. L., Lewis, J. A., Gade, V. K., Deutsch, J. E., & Mavroidis, C. (2014). Modular mechatronic system for stationary bicycles interfaced with virtual environment for rehabilitation. *Journal of NeuroEngineering and Rehabilitation*, *11*. https://doi.org/10.1186/1743-0003-11-93.

Reer, F., Wehden, L. O., Janzik, R., Tang, W. Y., & Quandt, T. (2022). Virtual reality technology and game enjoyment: The contributions of natural mapping and need satisfaction. *Computers in Human Behavior*, *132*. https://doi.org/10.1016/j.chb.2022.107242.

Reis, E., Postolache, G., Teixeira, L., Arriaga, P., Lima, M. L., & Postolache, O. (2019). Exergames for motor rehabilitation in older adults: An umbrella review. *Physical Therapy Reviews*, 1–16. https://doi.org/10.1080/10833196.2019.1639012.

Roberts, A. R., De Schutter, B., Franks, K., & Radina, M. E. (2019). Older adults' experiences with audiovisual virtual reality: Perceived usefulness and other factors influencing technology acceptance. *Clinical Gerontologist*, *42*, 27–33. https://doi.org/10.1080/07317115.2018.1442380.

Rutkowski, S., Szary, P., Sacha, J., & Casaburi, R. (2021). Immersive virtual reality influences physiologic responses to submaximal exercise: A randomized, crossover trial. *Frontiers in Physiology*, *12*, 1679. https://doi.org/10.3389/fphys.2021.702266.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist*, *55*, 68–78. https://doi.org/10.1037/0003-066X.55.1.68.

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology*, *61*. https://doi.org/10.1016/j.cedpsych.2020.101860.

Ryan, R. M., Patrick, H., Deci, E. L., & Williams, G. C. (2008). Facilitating health behaviour change and its maintenance: Interventions based on self-determination theory. *The European Health Psychologist*, *10*, 2–5.

Shah, S. H. H., Hameed, I. A., Karlsen, A. S. T., & Solberg, M. (2022). Towards a social vr-based exergame for elderly users: An exploratory study of acceptance, experiences and design principles. In *International conference on human-computer interaction* (pp. 495–504). Springer.

Short, J., Williams, E., & Christie, B. (1976). *The social psychology of telecommunications*. London: Wiley.

Skinner, B. F. (1965). *Science and human behavior*. New York, New York, USA: The Free Press, Simon & Schuster Inc.

Slater, M., Sadagic, A., Usoh, M., & Schroeder, R. (2000). Small-group behavior in a virtual and real environment: A comparative study. *Presence*, *9*, 37–51.

Spradley, J. P. (2016). *Participant observation*. Long Grove, Illinois: Waveland Press, Inc.

Staiano, A. E., Abraham, A. A., & Calvert, S. L. (2012). Motivating effects of cooperative exergame play for overweight and obese adolescents. *Journal of Diabetes Science and Technology*, *6*, 812–819. https://doi.org/10.1177/193229681200600412.

Steed, A., Ortega, F. R., Williams, A. S., Kruijff, E., Stuerzlinger, W., Batmaz, A. U., Won, A. S., Rosenberg, E. S., Simeone, A. L., & Hayes, A. (2020). Evaluating immersive experiences during Covid-19 and beyond. *Interactions*, *27*, 62–67. https://doi.org/10.1145/3406098.

Steptoe, A., Shankar, A., Demakakos, P., & Wardle, J. (2013). Social isolation, loneliness, and all-cause mortality in older men and women. *Proceedings of the National Academy of Sciences of the United States of America*, *110*, 5797–5801. https://doi.org/10.1073/pnas.1219686110.

Stradford, J., Sakhare, A., Ravichandran, R., Schroeder, E. T., Michener, L. A., & Pa, J. (2021). Conducting a VR clinical trial in the era of Covid-19. *Frontiers in Virtual Reality*, *2*, 44. https://doi.org/10.3389/frvir.2021.639478.

Suryadinata, R. V., Wirjatmadi, B., Adriani, M., & Lorensia, A. (2020). Effect of age and weight on physical activity. *Journal of Public Health Research*, *9*, 187–190. https://doi.org/10.4081/jphr.2020.1840.

Szpak, A., Michalski, S. C., Saredakis, D., Chen, C. S., & Loetscher, T. (2019). Beyond feeling sick: The visual and cognitive aftereffects of virtual reality. *IEEE Access*, *7*, 130883–130892. https://doi.org/10.1109/ACCESS.2019.2940073.

Taylor, D. (2014). Physical activity is medicine for older adults. *Postgraduate Medical Journal*, *90*, 26–32. https://doi.org/10.1136/postgradmedj-2012-131366.

Teixeira, P. J., Carraça, E. V., Markland, D., Silva, M. N., & Ryan, R. M. (2012). Exercise, physical activity, and self-determination theory: A systematic review. *The International Journal of Behavioural Nutrition and Physical Activity*, *9*, 78. https://doi.org/10.1186/1479-5868-9-78.

Valenzuela, T., Okubo, Y., Woodbury, A., Lord, S. R., & Delbaere, K. (2018). Adherence to technology-based exercise programs in older adults: A systematic review. *Journal of Geriatric Physical Therapy*, *41*, 49–61. https://doi.org/10.1519/JPT.0000000000000095.

Vansteenkiste, M., Niemiec, C. P., & Soenens, B. (2010). The development of the five mini-theories of self-determination theory: An historical overview, emerging trends, and future directions. *Advances in Motivation and Achievement*, *16 PARTA*, 105–165. https://doi.org/10.1108/S0749-7423(2010)000016A007.

Wilson, R. S., Krueger, K. R., Arnold, S. E., Schneider, J. A., Kelly, J. F., Barnes, L. L., Tang, Y., & Bennett, D. A. (2007). Loneliness and risk of Alzheimer disease. *Archives of General Psychiatry*, *64*, 234–240. https://doi.org/10.1001/archpsyc.64.2.234.

Zisberg, A., Shadmi, E., Sinoff, G., Gur-Yaish, N., Srulovici, E., & Admi, H. (2011). low mobility during hospitalization and functional decline in older adults. *Journal of the American Geriatrics Society*, *59*, 266–273. https://doi.org/10.1111/j.1532-5415.2010.03276.x.