Review

Design Considerations for Immersive Virtual Reality Applications for Older Adults: A Scoping Review

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Abstract: Immersive virtual reality (iVR) has gained considerable attention recently with increasing affordability and accessibility of the hardware. iVR applications for older adults present tremendous potential for diverse interventions and innovations. The iVR literature, however, provides a limited understanding of guiding design considerations and evaluations pertaining to user experience (UX). To address this gap, we present a state-of-the-art scoping review of literature on iVR applications developed for older adults over 65 years. We performed a search in ACM Digital Library, IEEE Xplore, Scopus, and PubMed (1 January 2010–15 December 2019) and found 36 out of 3874 papers met the inclusion criteria. We identified 10 distinct sets of design considerations that guided target users and physical configuration, hardware use, and software design. Most studies carried episodic UX where only 2 captured anticipated UX and 7 measured longitudinal experiences. We discuss the interplay between our findings and future directions to design effective, safe, and engaging iVR applications for older adults.

Keywords: immersive virtual reality; older adults; user experience; design considerations

1. Introduction

The world population is ageing at a faster pace than in previous decades. According to the world population ageing report [1], there are 703 million older adults of age above 65 and this trend is set to increase to 1.5 billion by 2050. This rapid increase demands to identify the needs of changing population, provide timely services to meet their needs and support their wellbeing. This must be done with an understanding that older adults are a diverse group with varied physical and cognitive capabilities and technical literacy. If designed well, technology can become a great aid to fulfill older adults' needs and foster wellbeing goals [2,3].

Emerging technologies such as virtual reality (VR) have seen a growing number of applications in various domains: entertainment, medicine, training and education, rehabilitation, architecture, and engineering. In health research, VR terminology has been interchangeably used to describe a range of displays and environments, e.g., screen projections. VR systems, however, are broadly categorized as [4]: *less immersive* that show 3D environment on desktop or tablet with limited interactivity; *moderately immersive* that project on screen or support interactivity through body-tracking cameras, e.g., Xbox Kinect;

and *highly immersive* ones such as CAVE projection system and head-mounted display (HMD). In this work, we focus on HMD-based highly immersive systems and refer to them as immersive virtual reality (iVR). Commercially available iVR encompasses a diverse range varying in cost, types of experiences offered, and possible configuration. One set of devices are PC-based high-end iVR, such as HTC Vive, Oculus Rift, and Sony PlayStation VR, which are highly immersive systems with a wide field of view. Other variants like Samsung Gear and Google Cardboard HMDs are more affordable and operate using mobile devices. Comparatively, nowadays HMDs offer accessibility, a wide field of view and better tracking while costing less than their past counterparts [5]. This diversity in both end users' capabilities and available iVR technology not only offers a variety of design choices but also raises several challenges.

Best practices and guidelines to design iVR applications for older adults are scarce, and despite the variability of abilities and interests, they are greatly needed. Such guidelines can help designers take into account the whole spectrum, increasing accessibility to those who might otherwise be left out. iVR community has recently begun to explore how design choices in iVR systems impact vulnerable users' capabilities, including older adult users [6]. iVR applications provide a highly immersive user experience with compelling levels of presence [7] due to the wider field of view and efficient tracking capabilities that enable engaging experiences. However, iVR systems still pose various challenges for older adults before we reap any potential benefits, despite the advancements made in recent years. These include technology-related challenges such as cybersickness, discomforts, and heavy HMDs. Moreover, novelty or unfamiliarity with emerging technology may also undermine the value it can bring for users who may be technology averse. To leverage potential benefits, iVR designers need to minimize the challenges and offer experiences that resonate well with older adults' needs and desires. However, to achieve the desired outcomes, the involvement of various stakeholders and users in the design process can be supported by a better understanding of specific User Experience, system and interaction requirements of older adults and techniques suitable to involve older adults in User-Centered Design and the participatory design process. We aim to address this gap through a review of existing evidence.

Recent review papers have examined the usability and UX of VR for older adults. For example, Tuena and colleagues conducted a systematic review of usability-specific issues in VR; however, their scope was specific to clinical applications of all types of VR [8]. Kim and colleagues reviewed the literature on VR UX and challenges for young adults [9]. However, the needs of older and younger adults may not be identical. Others reviewed a wide spectrum of displays labelled as VR for older adults, lacking focus on HMDs [10,11], thus the design recommendations provided were limited in scope. Closer to our work is [12]. However, the presented design guidelines were based on a limited number of papers (13) reviewed from only two databases. We maintain that a wider review of the recent literature is imminent for a comprehensive set of guidelines. Due to this gap in the literature, we aim to provide an understanding of existing evidence relevant to the experiences of older adults to guide future design choices and processes in HMD-based iVR specifically.

Through a scoping review, this research aims to develop a picture of iVR UX design considerations for older adults and identify trends, gaps, and future directions relevant to iVR design processes and assessments. Our study is motivated by a gap in useful design guidelines. As such, we address the following research questions:

1. What are the design considerations that guide the design and development of immersive VR systems for older adults?
2. What characterizes the design processes followed to develop iVR systems specific for older adults?
3. How to evaluate the user experience of immersive VR for older adults, and what type of studies and methods are used for evaluation?
4. What are the reported usability challenges of immersive VR systems for older adults?

2. Background

In the context of designing for older adults, this section reviews existing literature pertaining to each research question (RQ). Specifically, older adults' acceptance of iVR technology (RQ1), the involvement of older adults in the design process (RQ2), and iVR user experience design for older adults (RQ3 and RQ4).

2.1. Older Adults' Acceptance of iVR Technology

Age-related changes are often linked with cognitive decline [13], functional limitations [14], barriers to physical activity [15], and mobility issues [16]. Older adults increasingly interact with technology in their homes, at work, and in applications related to healthcare and quality of life. Functional independence is an important goal for the aged population to maintain their daily activities [17]. Many technology solutions are explored to support this goal and aid users to enhance their capabilities as they age [18]. Technology-based interventions, such as video games, chat rooms, 3D virtual environments, robots, and social networks, were found to be effective in reducing loneliness and social isolation in older adults [19]. Older adults are increasingly aware of various digital platforms, some of which offer mental health support [2]. In addition, it was argued [20] the technology gap among young and older adults would reduce as future ageing populations have better technology exposure as they grow in the age of the internet.

In recent years, iVR as an emerging technology has been increasingly explored for a variety of therapeutic and enrichment purposes among the ageing population. In clinical settings, the technology has been utilized for clinical conditions such as cognitive impairment [21], mental disorders [22], and movement disorders [23]. Regarding the quality of life, iVR can contribute to the elderly's emotional, social and physical well-being [24–27]. Compared to other types of VR (e.g., computer monitor, large projection screen, CAVE), iVR offers a fully immersive experience and, to a great extent, supports natural sensorimotor contingencies for perception [28]. Moreover, consumer-grade VR HMDs have become more affordable and powerful than their predecessors, bringing iVR experiences out of research labs and into the hands of a broader audience. Standalone VR systems such as Facebook Oculus Quest also have an uncomplicated setup and a wireless experience. These advances make HMD-based VR an ideal system to be used in hospitals, care centers, seniors' residences, and even at homes.

Older adults, who are well versed in internet usage, are reported to show a willingness to use iVR technology. iVR experiences are positively reviewed by elderly users in terms of enjoyment and satisfaction [29–33] despite the hesitations and negative preconceptions before actual usage, e.g., "virtual reality was a frivolous undertaking that held little benefit" [31]. Nevertheless, iVR as an immature technology also comes with various usability issues pertaining to hardware and software that must be addressed for optimal user experience [29–33]. Furthermore, older adults with clinical conditions may require a more sensitive approach in experience design, with careful considerations in the physical design of systems, shared experiences, multisensory stimulation, personalization, and active participation [25].

As technologies become more readily available, guiding principles and insights also emerge. Age-related characteristics and human factors such as vision, hearing, speech, memory, and physical coordination are most likely to impact UX [34–37]. Additionally, [34] highlighted the need for understanding technology literacy and mental models of older adults to minimize typical usability problems. To a large extent, these guidelines can be applied to the design of iVR experiences for older adults. However, the fact that they were formulated based on popular ICT devices, such as smartphones, tablets, and personal computers, indicates a lack of specificity to the nature of iVR as an emerging technology. Therefore, for iVR to appeal to elderly users, a comprehensive review of various design aspects from development to implementation is needed to generate insights on overcoming the aforementioned challenges.

2.2. Technology Design with and for Older Adults

Human–Computer Interaction (HCI) research focusing on technology design *for* older adults is usually categorized under or together with accessibility studies [38], partly because accessibility issues are more prevalent among older adults. However, addressing these accessibility issues should not be the only item on the research agenda. Older adults should not be considered a homogenous group; rather, research must acknowledge them rightly as complex individuals [39], with highly diverse demographics [38]. Individual differences in educational level, income, living arrangement, health status, values, and life experiences [34] contribute to the varying needs and desires of older adults and, therefore, should be factored into the design process.

Design approaches, such as human-centered design, participatory design, and co-design enable design *with* older adults to actively capture their unique experiences as well as accessibility perspectives, such as cognitive impairment [40]. A number of considerations are noted in the literature in relation to engaging with older adults in participatory processes. Long discussions may hinder engagement, and particularly in relation to technology, some find it hard to articulate reflections as well as to picture new technologies [39]. If technologies are not deemed useful, older adult participants may disengage from the process [41]. Older people's trust in their ability to use a prototype can also be low due to unfamiliarity with technology; hence, their confidence could easily be shattered by a usability issue [42], or they might not feel comfortable being mixed with younger participants in the same study session [34].

While the above challenges are by no means exhaustive, they emphasize the complications associated with involving older adults with varying abilities in the design process. We postulate that these difficulties may be exacerbated in the context of iVR. For example, the ergonomic issues of HMD and its fully immersive quality might lead to probable physical and psychological impacts beyond researchers' control, raising the need for the engagement of relevant stakeholders such as family members, carers, and therapists. In this paper, we critically review existing design processes followed to develop iVR systems for older adults and synthesize lessons learnt.

2.3. User Experience of iVR for Older Adults

The term User Experience (UX) has been used by researchers and practitioners to refer to different things [43]. In this paper, we adopted the international standard on ergonomics of human–system interaction, ISO 9241-210, in which user experience is defined as "*a person's perceptions and responses that result from the use or anticipated use of a product, system or service*" [44]. UX is multi-dimensional, concerning user perceptions of both the pragmatic and hedonic aspects of interactive products [45]. Since the cornerstone of VR technology is its powerfully stimulated experiences, these facets of UX are inherently important to consider in the process of designing, developing, and evaluating iVR applications [46] proposed and validated a model of user experience in an immersive virtual environment that consisted of 10 components, namely: presence, engagement, immersion, flow, usability, skill, emotion, experience consequence, judgement, and technology adoption. Each component can be measured using either objective or subjective methods or a combination of the two. This paper examines which facets or aspects of iVR UX for older adults are typically evaluated and the measurements used.

Good UX is often linked to positive emotional outcomes while considering the dynamic, temporal, and situatedness of the experience [47]. The novelty of the iVR technology, coupled with its seemingly complicated hardware and various side effects, may hinder the experiences of older adult users. Therefore, to maximize the potential of iVR to improve the quality of life among older adult users, it is essential to consider iVR UX holistically, e.g., deliver practice sessions at the beginning, consider how assistance may be provided during the session, and minimize physiological consequences at the end [48]. We argue that crafting an end-to-end experience will improve the usability of the system and support

long-term use. For that reason, the analysis also investigates which period of experience was evaluated in the reviewed studies and key challenges faced by older adults.

3. Method

3.1. Scoping Review Protocol

In this study, we undertook a scoping review in accordance with the guidelines proposed by [49]. The database searched included the ACM Digital Library, IEEE Xplore Digital Library, Elsevier's Scopus, and PubMed. We selected these databases due to their peer-review literature focusing on computing, information technology, and biomedical topics.

We tested different combinations of "virtual reality" and "older adults" keywords (as well as their synonyms) before deciding on the following search string ("virtual reality" OR "immersive virtual reality" OR "immersive VR") AND ("older adults" OR "seniors" OR "elderly"). This query was used consistently throughout the four selected databases. To search for UX and design in VR, we considered adding "user experience," "UX," "design", and "frameworks" to the "virtual reality" and "older adults" terms. However, the results became too narrow since many biomedical or health-focused studies do not explicitly mention design-related keywords. Therefore, we picked a broader query and invested more effort in the manual scanning of papers for UX and design aspects. We include the details of our search strategy in the supplementary material (Supplementary Information S1).

3.2. Selection Criteria

We chose peer-reviewed papers published in English language at conference proceedings or journals based on the following criteria.

Inclusion: Papers were included if they satisfied the following criteria:

- Papers presenting systems that were specifically designed for or evaluated with older adults (65 years old or over), with recent HMDs (introduced after 2010) covering any range of physical and cognitive capabilities.
- Papers that involve mixed user groups of young and older adults with the intention to capture any specific measures tailored for the older adult user group.

Exclusion: We excluded any study that did not meet the inclusion criteria. Specifically, we excluded:

- Papers in which the systems were designed for or evaluated with a general population of various age groups.
- Papers that report the use of HMD models developed prior to 2010 and mixed reality HMDs.
- Papers that use non-HMD VR setups, such as CAVE systems, were excluded because we were interested to understand characteristics of research in HMD-based setups.
- Review papers, perspective, or opinion papers.
- Literature on the effectiveness of VR health interventions that focused on primary or secondary intervention outcomes, sustainability, and intervention adherence, without examining the impact of VR.
- Papers without evaluation and reporting of results, such as demo papers or studies that focused on just the design phase.
- Papers that were published in languages other than English.

3.3. Study Selection

Identification: In two searches conducted in July 2018 and December 2019, we identified a total of 3874 papers from ACM Digital Library (n = 528), IEEE Xplore (n = 532), Scopus (n = 2523), and PubMed (n = 291). Duplicates (n = 54) across the databases were removed in Mendeley Desktop for MacOS.

Screening: Initial screening involved reading the paper titles and abstracts to eliminate those not meeting the selection criteria. 425 papers were selected.

Eligibility: The first round of eligibility assessment involved reading full-text papers to eliminate those not meeting the selection criteria. 65 papers were then selected.

Next, we considered a working definition of 'design consideration' as considerations relevant to the development of VR applications for older adults with specifications relevant to people, physical configurations, hardware, and software. Our definition state that "*a design consideration must be something the authors deliberately implemented with a clearly explained purpose and rationale behind it with specifications relevant to people, physical configurations, hardware and software.*" In the second round, 29 papers were eliminated, if offered no evaluation, not focused on the older adults' population, and did not provide design information of the system. For instance, [50] was excluded as they offered no design-related information and mixed user groups. We examined the selected papers more carefully in a second round and finalized a set of 36 papers) to be included in the review. Supplementary Information S2 in the supplementary material contains a list of all extracted design considerations in their original words.

Two reviewers worked on the identification, screening, and the first round of eligibility assessment (KI and TT), and four reviewers (KI, TT, NA, BK) worked on the second round to finalize the selection and resolve disagreements. The screening process and the total number of selected papers in each review stage are shown in a PRISMA flow diagram (Figure 1).
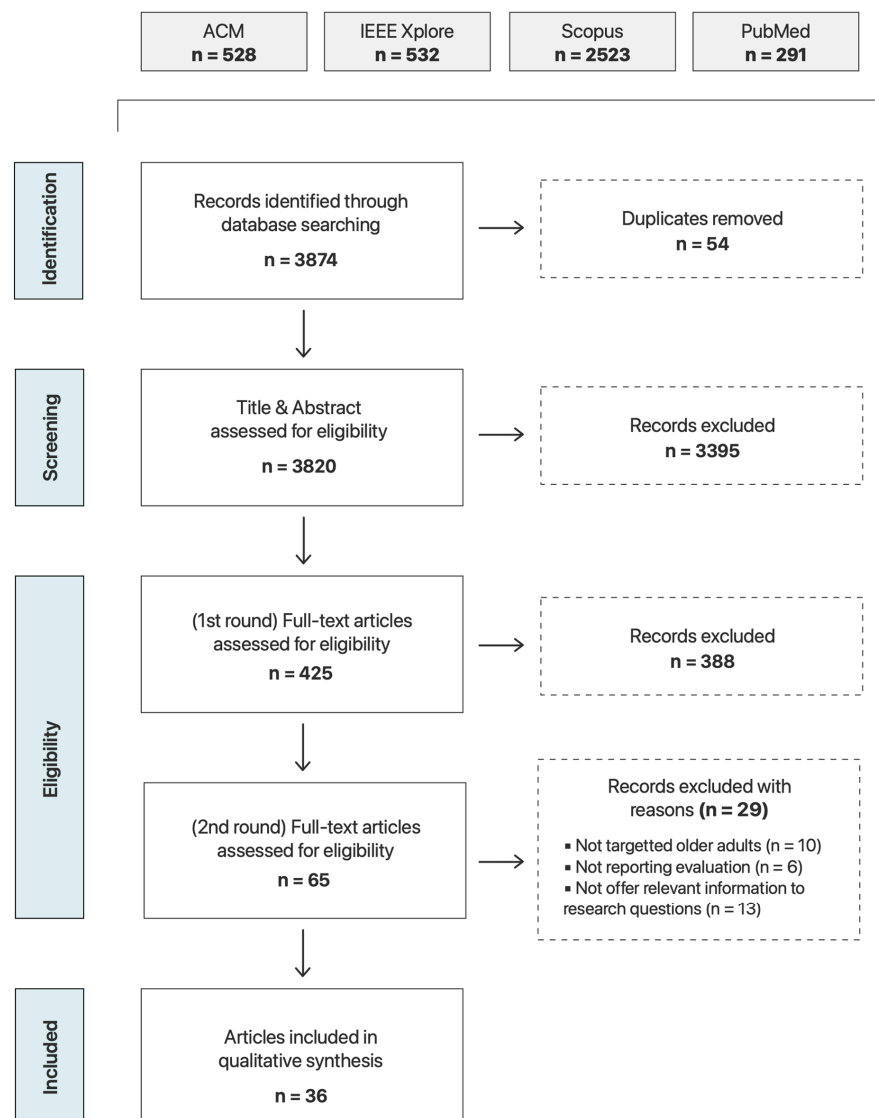

Figure 1. PRISMA flow diagram.

3.4. Evaluation

For each of the 36 selected papers, we recorded the following details: author, year, title, paper summary, hardware (type of HMD and other equipment used), commercial product or bespoke design, narrative of the VR app (e.g., game narrative, tasks, activities), visual/audio content, physical interactions, postures, embodiment, design considerations, design process, study method, assessment tools, sample size, age range, gender distribution, clinical condition (if applicable), study outcome, and reported UX issues.

4. Results

In this section, we present an overview of our analysis corresponding to each research question.

4.1. Overview

4.1.1. Study Objective and Context

We classified the 36 selected papers according to the study objectives and contexts, as shown in Figure 2. A number of objectives emerged, with wellbeing topics being most frequent (7), followed by usability-related topics (5) and therapy (5). In terms of context, 22 studies were experimental and conducted in a lab, while others were launched in care or nursing home facilities (7), community centers (4), homes (1), and participants' preferred places (1). One study did not specify its context.
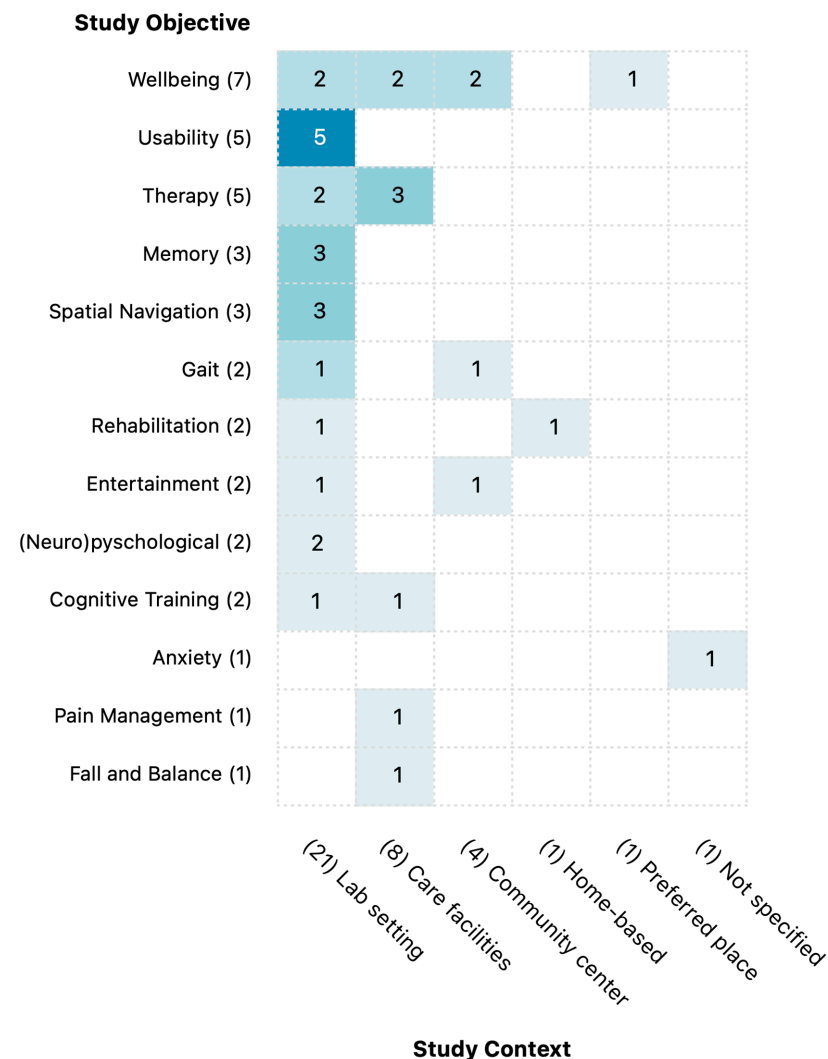

Figure 2. Studies classified based on objective and context.

4.1.2. Study Participants

The majority of the studies (22) were evaluated with older adults. However, there were 11 papers where young adults were recruited for comparison with older adults. In 4 papers, experts were recruited, which involved therapists [6,22], care facility staff members [51], and older adult carers [25].

The reported age range of the participants in the selected papers was 18 to 101 years; however, all papers included older adult participants (=> 65 years). The majority of studies recruited healthy participants (25), while 8 papers included patients with health problems. Of note, 3 papers evaluated iVR experiences with both groups; patients diagnosed with psychological conditions and healthy population with no clinical condition reported [33,52,53]. The female representation in the older adult sample size ranged from 40% [51] to 100% [54], as shown in Figure 3a.
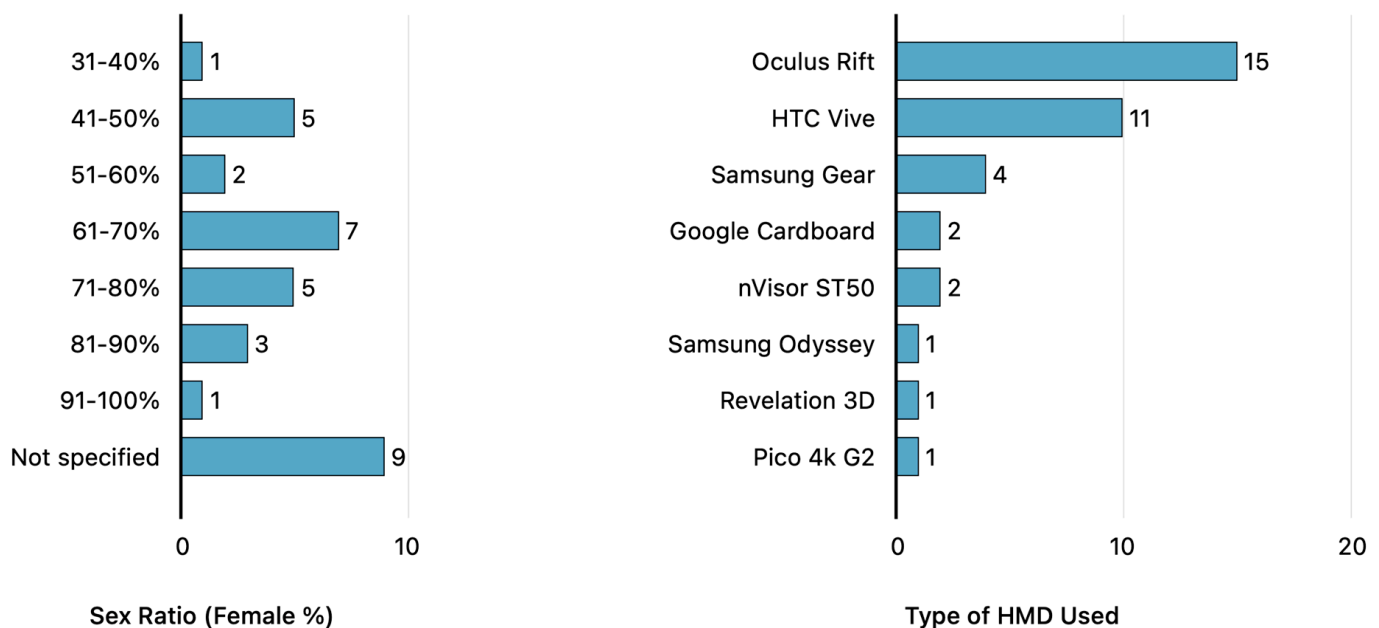

Figure 3. Studies classified based on sex ratio in sample size (**a**) and HMD type (**b**).

4.1.3. HMD Type

Various consumer HMDs were used in the selected papers (Figure 3b), including Oculus Rift (15), HTC Vive (11), Samsung Gear (4) or Odyssey (1), Google Cardboard (2), nVisor ST50 (2), Revelation 3D (1), Pico 4k G2 (1), indicating Oculus Rift and HTC Vive were the two most widely used HMDs.

4.1.4. Application Content

In terms of iVR environment, 27 papers designed bespoke experiences where the remaining (9) used off-the-shelf commercially available content. Most popular visual content was 3D rendered virtual environment (VE), VR games, and 360 videos. However, a few papers designed photorealistic imagery [55] and 3D augmented virtual [56] environments by mapping real-world objects in iVR. 3D VE mostly facilitated task-based narrative, while iVR games had an element of fun to engage players. 360-degree videos were also used to simulate relatable scenarios (See Table 1 for more details of the visual content, narrative, and audio offered).

Table 1. Summary of 36 reviewed papers (OA: older adults, YA: young adults, en dash "–": Not specified). The papers were arranged alphabetically by the first author's surname and divided into three sections: A, B, and C.

Section A

References	Objectives	Context	Hardware	Type of Application	Narrative	Visual	Audio	Cohort	OA Sample Size (Female)	OA Age Range	OA Clinical Condition
Ahmed et al. (2018)	Psychological disorders	Lab setting	Oculus Rift	Bespoke	(1) Wrist and arm exercise for physical fitness and (2) navigation practice for memorization	VR game	–	OA	20 (15F)	55–84	Both
Andringa et al. (2019)	Cognitive training	Day care centre	HTC Vive	Bespoke	Play VR balloon pricking game	VR game	–	OA	10 (7F)	–	Both
Baker, Kelly et al. (2019)	Wellbeing	Lab setting	HTC Vive and Oculus Rift	Bespoke	Sit around a reflective pond and talk to each other	3D VE	–	OA	22 (11F)	70–81	Healthy
Baker, Waycott et al. (2019)	Wellbeing	Resident facilities	Oculus Rift	Commercial	Play games such as Quil (drawing), Ocean Rift (discovery), ToyBox, and Power Solitaire	VR game	–	OA, Staff	5 (2F)	74–88	Patient
Banville et al. (2018)	Neuropsychological	Lab setting	Oculus Rift	Bespoke	Perform several tasks alone based on daily life	3D VE	–	OA, YA	11 (8F)	63–72	Healthy
Baqai et al. (2019)	Physiotherapy	Lab setting	Oculus Rift	Bespoke	Collect fruits hanging from a tree	VR game	Audio feedback	OA, YA	2 (1F)	58–68	Patient
Benham et al. (2019)	Pain management	Senior day centre	HTC Vive	Commercial	Play popular games (engagement with pets, interactive music, travel)	VR game	–	OA	12 (8F)	Mean 70.2	Patient
Brown (2019)	Usability, Preferences, Application	Lab setting	Samsung Gear VR	Bespoke	Watch a series of 6 videos consisted of walks and drives around the town of the participants	360° video	–	OA	10 (8F)	63–89	Healthy
Bruun-Pedersen et al. (2016)	Physiothrepapy	Nursing home	Oculus Rift	Bespoke	Bike through nature-based trails	3D VE	Bird tweets	OA	9 (9F)	69–101	Healthy
Coldham and Cook (2017)	Usability	Lab setting	HTC Vive	Commercial	Navigate to any point in Google Earth and find their way home	3D VE	Background noise	OA	19	> 65	Healthy
Eisapour et al. (2018a)	Physiotherapy	Long-term care, retirement home	Oculus Rift	Bespoke	Do activities focusing on upper body motions	VR game	Audio instruction	OA, Therapists	3	–	Patient
Eisapour et al. (2018b)	Physiotherapy	Long-term care, retirement home	Oculus Rift	Bespoke	Do five motions related to neck, shoulders, and arms	VR game	Audio instruction	OA, Therapists	6 (5F)	Mean 86.8	Patient

Table 1. *Cont.*

Section B

References	Objectives	Context	Hardware	Type of Application	Narrative	Visual	Audio	Cohort	OA Sample Size, Female	OA Age Range	OA Clinical Condition
Hodge et al., (2018)	Entertainment	Community centre	Google Cardboard; Unspecified HMD	Bespoke	Explore and navigate through VR environments	3D VE	Ambient sound	OA, Carers	4	53–83	Patient
Howes et al. (2019)	Fall & Balance	Day centre	Oculus Rift	Bespoke	Do four mini-exergames (a) knee bends; (b) leg abduction; (c) sideways walking; (d) one leg stand.	VR game	–	OA	4	> 65	Healthy
Huang (2019)	Cognitive training	Lab setting	Oculus Rift	Commercial	Play Fruit Ninja game	VR game	–	OA	16	–	Healthy
Huygelier et al. (2019)	Usability (Acceptance)	Lab setting	Oculus Rift	Commercial	Experience the VR application Perfect of nDreams	3D VE	–	OA	38 (19F)	60–92	Healthy
Ijaz et al. (2016)	Wellbeing	Community centre	Oculus Rift	Bespoke	Experience a virtual tour or beat the previous players by finding more landmarks in competetive game	VR game	Audio feedback	OA, YA	20	60–92	Healthy
Ijaz et al. (2019)	Spatial navigation	Lab setting	Oculus Rift	Bespoke	Take a landmark recall test	Immersive photoreal-istic imagery	Audio in-struction	OA	22	50–89	Healthy
Janeh et al. (2018)	Gait	Lab setting	HTC Vive	Bespoke	Walk at a normal pace along the virtual walkway	3D VE	–	OA, YA	21 (12F)	45–83	Healthy
Kim et al. (2017)	Neuro-rehabilitation	Lab setting	Oculus Rift	Bespoke	Walk forward in a virtual city on a pedestrian path for 800m, on a treadmill	3D VE	–	OA, YA	22 (16F)	Mean: 65	Both
Korsgaard et al. (2019)	Wellbeing	Lab setting	Oculus Rift CV1	Bespoke	Talk to older friends while eating a solitary meal in augmented virtuality.	3D aug-mented VE	–	OA	27 (20F)	> 65	Healthy
Kovar (2019)	Anxiety	–	Samsung Gear VR	Bespoke	Watch 360° video that gradually simulated similar but easier traumatic event as he overcame in the past	360° video	Environment sound	OA	4 (2F)	61–77	Patient
Lai et al. (2019)	Entertainment	Lab setting	HTC Vive Pro	Commercial	Play one of the three different VR applications, i.e., The Blu, Fruit Ninja, and Tilt Brush	VR game	–	OA	14 (9F)	54–82	Healthy
Lecavalier et al. (2018)	Memory assessment	Lab setting	Nvisor ST50	Bespoke	Memorise a shopping list and then fetch the items in the store	3D VE	Ambient sound	OA, YA	57 (47F)	Mean: 67.77	Healthy

Table 1. *Cont.*

Section C

References	Objectives	Context	Hardware	Type of Application	Narrative	Visual	Audio	Cohort	OA Sample Size, Female	OA Age Range	OA Clinical Condition
Liao et al. (2019)	Gait	Community centre	HTC Vive	Bespoke	Imitate the virtual character and adjust their movements based on the simultaneous visual and auditory feedback	3D VE	Audio feedback	OA	18 (11F)	>65	Patient
Lin et al. (2018)	Wellbeing	Assisted living communities	Samsung Gear VR	Commercial	Watch videos, Google Street View, and guided tours	360° video	–	OA	Pre: 35 (23F), Post: 31 (21F)	68–99	Healthy
Liu et al. (2018)	Wellbeing	Community centre	Pico 4K G2	Commercial	Watch video contained China's sceneries	360° video	–	OA, YA	58 (36F)	60–91	Healthy
Micarelli et al. (2019)	Rehabilitation	Home-based setting	Revelation 3D	Bespoke	Play the Track Speed Racing 3D game by tilting the head	VR game	–	OA	47 (26F)	Mean 76.3	Patient
Mol et al. (2019)	Wellbeing	Participants' preferred places	Google Cardboard	Bespoke	Dance an old song (Y.M.C.A.) inside the living room	VR game	Ambient sound	OA	10 (8F)	60–77	Healthy
Ouellet et al. (2019)	Memory assessment	Lab setting	Nvisor ST50	Bespoke	Participants memorize shopping list and later have to "buy" these same items	3D VE	Ambient sound	OA, YA	54 (44F)	Mean 68 Mean 67.20	Both
Plechatá et al. (2019)	Memory assessment	Lab setting	HTC Vive	Bespoke	Memorize a shopping list and later find and collect recalled items in the virtual grocery store	3D VE	–	OA, YA	36 (23F)	60–91	Healthy
Roberts et al. (2019)	Usability (Acceptance)	Lab setting	Samsung Gear VR	Commercial	View two audio-visual VR simulations ("Jurassic World" and "Cirque du Soleil")	3D VE	–	OA	41 (31F)	50–99	Both
Sakhare et al. (2019)	Spatial navigation	Lab setting	HTC Vive Pro	Bespoke	Bike 0.5 miles to a fountain landmark	3D VE	Music	OA, YA	20 (10F)	52–70	Healthy
Seo et al. (2019)	Usability (Experience)	Lab setting	Samsung Odyssey	Bespoke	Evacuate the subway station	3D VE	–	OA, YA	5 (4F)	65–77	Healthy
Süzer and Olguntürk (2018)	Spatial navigation	Lab setting	HTC Vive	Bespoke	Take route replication task and picture classification test	3D VR	–	OA	90 (45F)	65–80	Healthy
Yang (2019)	Therapy	Lab setting	HTC Vive	Bespoke	Help Little Red Riding Hood to navigate through the game	VR game	Audio feedback, Music	OA	6	65–70	Healthy

4.2. Design Considerations

We identified and categorized design considerations in the selected papers in two ways. In a top-down approach, we structured the design considerations based on our definition across three layers of interactions between the participants and the iVR systems. The first layer is *Physical and People Configuration*, specifying how the participants engaged with the study environment setup and the researchers involved. The second layer characterizes the *Hardware*, comprising iVR HMD, controllers, and other equipment involved. The last layer is *Software*, interfacing the features and allowing the user to experience the virtual world. In a bottom-up approach, we then identified design considerations in the selected papers and categorized them thematically using the affinity diagramming method [57].

We identified ten categories of design considerations that guided the target users and physical configuration, hardware use, and design (or selection) of iVR software: onboarding and assistance, safety, embodiment, environment, sound, realism, personalization, usability, engagement, and consequences. Details of individual design consideration are visualized in Figure 4 and summarized in the following sub-sections. Note that these categories are not mutually exclusive, and papers may appear under multiple design considerations if they had considered UX as a complex and multi-faceted concept that entails various considerations.
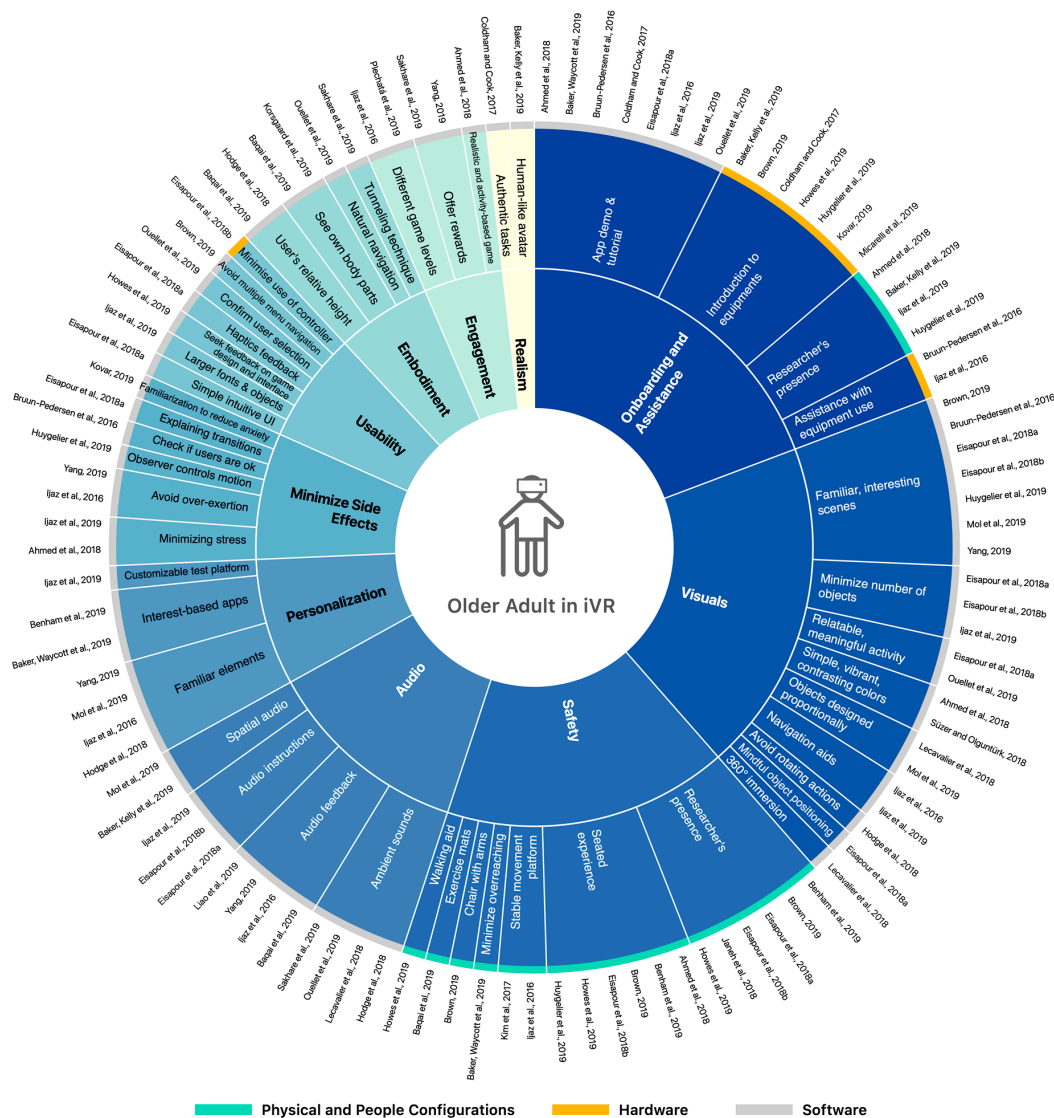

Figure 4. Design considerations grouped by themes and clusters.

4.2.1. Onboarding and Assistance

In total, 14 papers considered creating opportunities for onboarding to help older adults become accustomed to novel iVR apps and receive assistance and support when needed. A number of papers entailed multiple considerations in this area. These included having researchers present throughout the session to assist with [24,32,55,58], introduction to the equipment [24,30–32,59–61], assistance with the equipment use [26,54], and providing application tutorials. The latter was achieved in a number of ways: in-person training [58], through a demo with mini-tasks [26,53,54], a demo of commercial applications, e.g., Oculus First Contact [51] or Steam VR [31], reading or listening to instructions [6,55,58].

4.2.2. Safety

Safety of older adult users while using iVR was addressed in relation to people and physical configuration in 12 papers. To ensure safety, 6 papers considered people configuration such as the presence of a researcher or expert therapists [22], 6 papers used seated physical configuration such as cushioned swivel chair [22,30,32,58,59,62], 2 papers used platforms that provide stable movement such as stable recumbent exercise tricycle [26] and treadmill with a controlled speed [52]. Other considerations included positioning the participants' wheelchairs at the center of the tracking space to ensure that they do not need to extend their arms too far to reach out [51], using a chair with arms to support stability [30], using an exercise mat to prevent falls [63], and utilizing hand aid [59].

4.2.3. Embodiment

Embodiment, defined as a person's self-perception of their bodily ownership, was considered through people and physical configuration and VR software in 5 papers [53] demonstrated how navigation in VR can be paralleled with natural walking (physical configuration) in order to enhance the user's experience of presence (i.e., feeling as if they are there in the virtual world). Other considerations were linked to software design. The user's relative height was adjusted (e.g., relative to other objects such as trees) to provide a correct altitude in the iVR environment and field of view [25,63]. Two papers used avatars to represent the user's body [56,63], ensuring visibility of various body parts and any immediate interactions. One study used the tunneling technique during locomotion to reduce motion sickness on sharp turns while the user was on a virtual bicycle [64].

4.2.4. Visuals

The visual design of iVR spans across several software elements like landscape, buildings, virtual objects, and avatars/characters This aspect was addressed in 13 papers, with considerations extending across multiple areas. Two papers considered providing meaningful and relatable activities [6,53] to enhance engagement. Designing familiar scenes in iVR was considered in 7 papers, which included the following environments: farm or rural [6,22], nature [32,54,65], living room with classic furniture [66]. Considerations for simple, vibrant, and contrasting colors were demonstrated in 2 papers to assist the visual functioning that declines with age [58,67]. To avoid cognitive load and distraction, 3 papers limited the number of virtual objects in the environment [6,22,55].

Object design was addressed in 2 papers, with one providing proportional geometry [66] and the other a sense of spatial stability using dimensions as the real assessment room [68]. Additionally, two papers provided assistance with orientation and locomotion in VR using navigation aids, such as a compass and map [26,55]. Other considerations that were mentioned in just one paper each were: avoiding moving objects and rotating actions that may cause motion sickness while maintaining high-quality rendering and frame rate [25], mindful positioning of objects in the field of view to match user's physical capabilities [6], and using 360-degree head movements to allow natural visual affordances to enhance immersion [68].

4.2.5. Audio

Sound and audio experience were considered in 13 papers. Spatial audio was used in 2 papers to give a directional cue in the 3D environment [24,66], although some participants were unsuccessful in detecting the direction of the voice. Ambient sounds were used in 4 papers in forms of natural sound of waves, wind, and birds to complement the environment [25], background noise for realistic effect [53,68], and music for enjoyment [64]. Audio feedback was used in 4 papers to indicate scores and successful actions [63], navigation cues [26], situational awareness [65], as well as to provide feedback on participants' movement [21]. Audio instructions were used in 3 papers to transition users into the VR scenes [6] and deliver task instructions [22,55].

4.2.6. Realism

Maximizing realism of virtual experiences was only considered in 2 papers. One demonstrated realism through authentic tasks and scenarios [31]. Another embedded human-like avatars that speak and act like a human [24] to achieve a sense of realism. While not explicitly categorized as realism, some studies demonstrated visual elements and ambient sounds that may be described as contributing to a sense of realism. However, those papers are listed in Sections 4.2.4 and 4.2.5 and are not repeated under this section.

4.2.7. Personalization

Personalized hardware and software were considered in 8 papers to fulfill older adults' capability needs. This included personalizing the narratives in 4 papers to have familiar elements and places known to users and reduce their cognitive load [25,26,65,66]. Allowing users to select iVR apps that meet their preferences (e.g., power solitaire, painting game Quill) was considered in 2 papers [51,62]. Lastly, one study used customizable hardware to accommodate additional tasks while allowing the use of equipment that is known to users to provide less demanding interaction modes (e.g., using a joystick instead of a conventional VR controller, which offers smoother movement) [55].

4.2.8. Usability

Usability considerations spanned across the hardware and software levels in 6 papers [22] limited the use of controllers and button presses during iVR interaction to aid user learning and reduce cognitive load. In relation to software design, [6] used a simple and intuitive iVR user interface [55] used large fonts and objects with clear signage to guide users while repeating instructions and task reminders on the iVR interface [59] considered the use of colors and enhancing clarity and ease of reading the text in the iVR [6] used haptic feedback, such as controller vibration, to trigger user tasks or actions [53] used a two-step response process (e.g., select and validate) to confirm user selection and avoid any errors or unintentional button presses [30] simplified menu navigation.

4.2.9. Engagement

A few design considerations aimed to capture user attention and provide a sense of value in iVR experience through relatable or gamified tasks. Engagement-related design considerations were identified in 5 papers. Using game rewards was considered in 2 papers [64,65], pointing to the importance of maintaining a simple design to foster a sense of accomplishment [65]. Gamification in the form of different game levels or leaderboards to engage users in competition [26,69] was used in 2 papers. One paper considered a realistic activity-based design with clear actions, tools, and aims [58].

4.2.10. Minimize Side Effects

We identified 8 papers that considered minimizing the iVR side effects, predominantly in relation to hardware and software. Reducing users' anxiety was considered in one paper by providing extra familiarization time with iVR devices [60]. Another paper considered clear instructions on tasks to put users at ease, specifically while transitioning from one

scene to another [6]. Additionally, one paper considered maintaining communication with users to ensure they are not feeling sick while maintaining low-latency tracking and using a high frame rate [54]. Another paper considered giving users full control of their motion in the environment to reduce symptoms of motion sickness [32]. Minimizing stress was considered in another 2 papers through eliminating task completion time limits [55,58]. Finally, 2 papers considered avoiding over-exertion through reducing the interaction time [26] and allowing users to take regular breaks [65].

4.3. Design Process

We identified 12 papers that reported, in detail, the process of designing iVR experiences for older adults. A human-centered design approach was employed in 7 papers [6,22,25,56,59,60,65], whereby user needs and requirements were identified and user feedback was collected throughout the process (e.g., interviews) [27] followed a similar process for selecting commercial applications, specifically focusing on users' social relationships, daily activities, physical and cognitive abilities, as well as emotional needs. Moreover, participatory action research with iterative cycles of planning, action, and reflection was considered in one paper [24]. Apart from users, other stakeholders were involved in a number of studies, including kinesiologists [6,22], therapists [6,22], clinicians [59], developers [59], psychologists [55], and carers [25]. Finally, design requirements were generated from existing literature in 4 papers [25,58,65,66].

4.4. Evaluation

Out of the 36 papers, 35 used UX research methods which can be classified into quantitative, qualitative, and mixed methods, as summarized in Table 2. One study did not report a typical UX evaluation [21] and instead focused on measuring executive functions and dual-task gait performance.

Table 2. Research methods used.

UX Research Methods	Number of Articles (%)	References	Type of Methods
None	1 (2.8%)	Liao et al. (2019)	
Qualitative	9 (25%)	Baker, Kelly et al. (2019), Benham et al. (2019), Brown (2019), Coldham and Cook (2017), Eisapour et al. (2018a), Hodge et al. (2018), Korsgaard et al. (2019), Seo et al. (2019), Yang (2019)	Focus groups, interviews, observations, audio, and video recordings.
Quantitative	15 (41.7%)	Ahmed et al. (2018), Banville et al. (2018), Eisapour et al. (2018b), Huang (2019), Huygelier et al. (2019), Janeh et al. (2018), Kim et al. (2017), Kovar (2019), Lai et al. (2019), Lecavalier et al. (2018), Micarelli et al. (2019), Ouellet et al. (2019), Plechatá et al. (2019), Sakhare et al. (2019), Süzer and Olguntürk (2018)	Physiological data, task performance data, standardised and custom questionnaires.
Mixed methods	11 (30.5%)	Andringa et al. (2019), Baker, Waycott et al. (2019), Baqai et al. (2019), Bruun-Pedersen et al. (2016), Howes et al. (2019), Ijaz et al. (2016), Ijaz et al. (2019), Lin et al. (2018), Liu et al. (2019), Mol et al. (2019), Roberts et al. (2019)	

The evaluated aspects of UX varied across the studies, as shown in Table 3. Overall, UX [70] was addressed in 13 papers, mainly using qualitative techniques such as interviews. Standardized questionnaires were frequently used to measure cybersickness (8), e.g., Simulator Sickness Questionnaire [71], and presence (12), e.g., Slater-Usoh-Steed Presence Questionnaire [72]. Other types of standardized questionnaires included the Intrinsic Moti-

vation Inventory [73] to assess user acceptance [32] and the International Test Commission Sense of Presence Inventory [74] to develop an assessment of enjoyment and immersion.

Table 3. Evaluated UX aspects.

UX Aspects	Number of Articles (%)	References
Generic	13 (36.1%)	Andringa et al. (2019), Baker, Kelly et al. (2019), Baker, Waycott et al. (2019), Brown (2019), Bruun-Pedersen et al. (2016), Eisapour et al. (2018a), Hodge et al. (2018), Howes et al. (2019), Ijaz et al. (2016), Ijaz et al. (2019), Korsgaard et al. (2019), Mol et al. (2019), Yang (2019)
Presence/Immersion	12 (33.3%)	Banville et al. (2018), Bruun-Pedersen et al. (2016), Eisapour et al. (2018a), Huang (2019), Huygelier et al. (2019), Janeh et al. (2018), Kim et al. (2017), Lecavalier et al. (2018), Liu et al. (2019), Roberts et al. (2019), Sakhare et al. (2019), Süzer and Olguntürk (2018)
Performance	10 (27.8%)	Ahmed et al. (2018), Andringa et al. (2019), Banville et al. (2018), Baqai et al. (2019), Ijaz et al. (2019), Lecavalier et al. (2018), Ouellet et al. (2019), Plechatá et al. (2019), Sakhare et al. (2019), Süzer and Olguntürk (2018)
Others *	9 (25.0%)	Andringa et al. (2019), Baqai et al. (2019), Brown (2019), Eisapour et al. (2018b), Ijaz et al. (2016), Howes et al. (2019), Roberts et al. (2019), Sakhare et al. (2019), Seo et al. (2019)
Cybersickness/Discomfort/Challenges	8 (22.2%)	Banville et al. (2018), Huygelier et al. (2019), Janeh et al. (2018), Kim et al. (2017), Lecavalier et al. (2018), Micarelli et al. (2019), Sakhare et al. (2019), Seo et al. (2019)
Experience	7 (19.4%)	Baker, Kelly et al. (2019), Baker, Waycott et al. (2019), Baqai et al. (2019), Benham et al. (2019), Bruun-Pedersen et al. (2016), Coldham and Cook (2017), Mol et al. (2019)
Motivation	7 (19.4%)	Andringa et al. (2019), Baker, Kelly et al. (2019), Bruun-Pedersen et al. (2016), Huygelier et al. (2019), Ijaz et al. (2016), Ijaz et al. (2019), Lecavalier et al. (2018)
Usability/Applicability/Acceptability/Perceived Usefulness/Desirability	7 (19.4%)	Baker, Waycott et al. (2019), Bruun-Pedersen et al. (2016), Howes et al. (2019), Huygelier et al. (2019), Lin et al. (2018), Plechatá et al. (2019), Roberts et al. (2019)
Affect/Emotion/Feeling	6 (16.7%)	Lai et al. (2019), Lin et al. (2018), Liu et al. (2019), Mol et al. (2019), Roberts et al. (2019), Seo et al. (2019)
Attitude/Perception	6 (16.7%)	Brown (2019), Huygelier et al. (2019), Lai et al. (2019), Lin et al. (2018), Liu et al. (2019), Mol et al. (2019)
Anxiety/Stress	5 (13.9%)	Andringa et al. (2019), Ijaz et al. (2019), Kim et al. (2017), Kovar (2019), Sakhare et al. (2019)
Enjoyment	4 (11.1%)	Andringa et al. (2019), Eisapour et al. (2018b), Huygelier et al. (2019), Ijaz et al. (2016)
Satisfaction/Likely to recommend	3 (8.3%)	Eisapour et al. (2018b), Ijaz et al. (2019), Lin et al. (2018)

* Other aspects include: Safety, Competence, Connectedness, Preferences, Comfort, Engagement, Exertion, Task understanding, Familarity.

Episodic UX, which involves assessing user experience post-interaction, was evaluated in almost all the papers (34), except for a study by [62]. Meanwhile, 13 papers involved real-time UX evaluations using physiological data [27,55,60,63], experience sampling during the interaction [26,54], observation notes or video recordings [2,6,29,51,56,59,66]. Anticipated UX was evaluated in 2 papers [32,75] to capture user expectations prior to interaction.

Only 7 papers involved longitudinal evaluation of UX; two papers gathered participants' feedback at the end of the intervention period using an open-ended questionnaire [62] and interviews [75], another had daily and weekly evaluation of physical activity [22]. Meanwhile, UX data were collected after each session over a number of sessions in other papers [51,58,60,61].

4.5. Reported Usability Challenges

User challenges reported in the selected papers were linked to HMD, controllers, visual content, audio, and physical motion. As shown in Figure 5, the largest number of issues was reported in relation to hardware (75), followed by visual content (16). A UX trade-off can be identified between compact devices and high-quality rendering; for example, most standalone VR HMDs are light and non-tethered (supporting good UX) but lack processing power (diminishing UX). However, the gap between these all-in-one headsets and those with wired connections is gradually narrowing as the new generation of devices are commercialized.
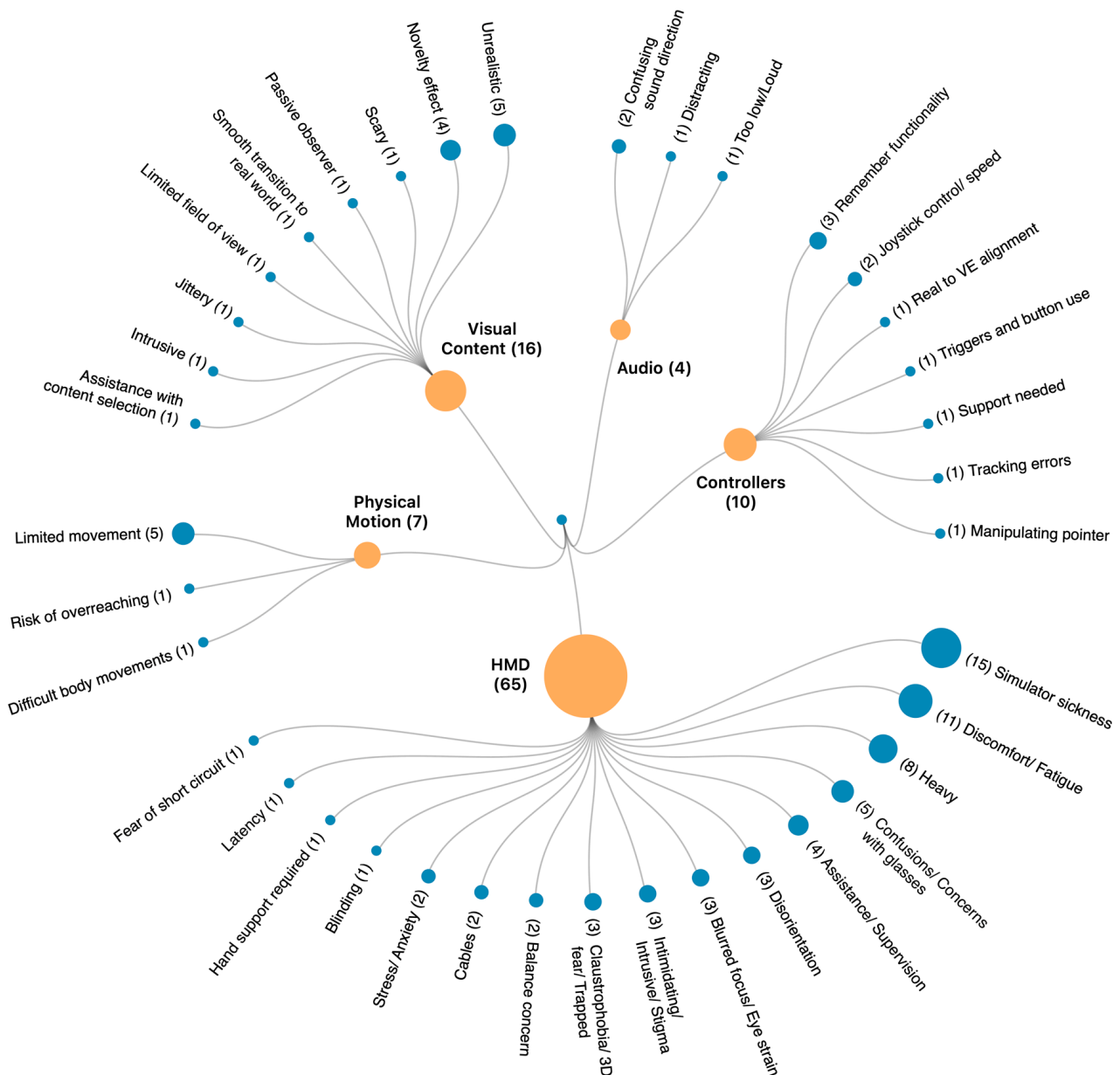

Figure 5. Challenges reported for older adults in iVR.

In relation to HMD, 15 papers reported simulator sickness (e.g., dizziness, nausea, headaches), 11 reported fatigue and discomfort, and 8 reported complaints about the HMD weight. Older adult users voiced challenges in remembering how to operate controllers in 3 papers. Visual content was perceived as unrealistic in 5 papers. The novelty of iVR introduced further challenges for older adults in 4 papers. Audio and sound direction was reported as a challenge in 2 papers [24,33]. Age-related changes, such as limited physical movement, caused frustration and made some visual content inaccessible in 5 papers. Other challenges included claustrophobia, stress, fear of short circuits, alignment with the real world, feeling like a passive observer, dislike of low lighting visuals, hearing issues due to both low or loud audio, and risk of fall.

4.6. Summary

To summarize: (1) software design considerations currently dominate the literature; (2) however, physical configuration received less attention; (4) human-centered design and engagement with stakeholders are considered best practices in iVR design; (5) UX evaluation is dominated by momentary and episodic assessments and there may be an opportunity to further investigate anticipated and longitudinal UX evaluation; (6) here may also be an opportunity to further examine the impact of older adults' stress, enjoyment, psychological needs, preferences and comfort with iVR UX; (7) clear opportunities exist in resolving the reported usability challenges, such as motion sickness, lack of comfort due to HMD design and weight, learnability of hardware interaction (e.g., controller), balancing the novelty impact (e.g., by enhancing realism), and improving accessibility both in terms of sensory experience (e.g., audio) and physical interactions.

5. Discussion

In this review, we identified 10 categories of iVR design considerations for older adult users and investigated existing trends in design processes, UX evaluation, as well as usability challenges, which can inform the design of future iVR applications. In this section, we reflect on our findings and discuss the limitations of our study. The first section discusses design considerations to address RQ1, followed by a section on the design process to address RQ2, the evaluation to address RQ3, and finally, a section on usability challenges to address RQ4.

5.1. Design Considerations

The following categories of iVR design concerns were derived from empirical research published in 36 papers to explore RQ1: Onboarding and Assistance, Safety, Embodiment, Visuals, Audio, Realism, Personalization, Usability, Engagement, and Minimizing Side Effects. Because study aims, the complexity of iVR systems, and sample characteristics varied across research, we viewed the synthesized design considerations as comprehensive but preliminary, prompting future work to determine their effectiveness and generalizability to a larger audience. Additionally, our detailed analysis uncovered key challenges and tensions identified in multiple studies but not addressed that merit further discussion.

5.1.1. Tension between "Familiar" vs. "New" experiences

Of the design considerations identified, onboarding and assistance were mentioned most frequently. Older adult users were found to experience anxiety when interacting with less familiar technologies [60,76]. Supporting familiarization with novel iVR configuration, hardware, and software at the beginning of the interaction is therefore essential to older adults' UX.

Cultivating familiar narratives in software and experiences with configuration and hardware during the interaction was found to provide better UX to older adults due to alignment with their mental models. Existing literature does not provide much guidance as to what makes software familiar [77] suggested that virtual environments can appear more familiar, despite the novelty of the experience, if they trigger previously known

scenes. Similarly, [25] suggested blending the aspects of old and familiar experiences in new settings, particularly for users with cognitive decline [30] suggested that making familiar environments accessible to older adults (e.g., through a virtual tour) is enjoyable for those who may not be able to visit or easily navigate the old places. Familiar environments and contexts have emotional values that older adult users find enjoyable [10]. Importantly, users over 60 years of age are found susceptible to cybersickness effects when exposed to unfamiliar content in iVR [78]. Therefore, initial onboarding appears to be useful for non-tech savvy users to gain familiarity and reach a comfortable interaction. Using the new iVR medium and yet providing familiar experiences demands careful and balanced design strategies for older adults; however, future research should uncover expectations of adults who grow old in the age of the internet, are more familiar with iVR, and are open to experiencing novel interactions.

While familiarity may facilitate interaction, [30] noted that familiar content in iVR may have emotional consequences and aggravate the disconnect, loneliness, and anxiety in older adults. For example, [23] found that viewing one's own images in immersive 360-degree videos resulted in various reactions in users with Parkinson's disease due to the depiction of their frailty, with some users finding it distressing and losing motivation for physiotherapy activities. The authors also suggested that preparation and onboarding could mitigate this impact.

Choices made in relation to iVR configuration, software, and hardware have ethical consequences; however, more evidence and guidelines are needed to inform future developments.

5.1.2. Transition between Virtual to Real World

A considerable number of design considerations identified in the 36 selected papers focus on supporting users in discrete phases, especially prior to (onboarding) and during the interaction with iVR. However, we did not find much information about user transitions from the real to the virtual world, the internal transition(s) within iVR, or the final transition from the virtual to the real world, which is important as immersed iVR users experience a reduced sense of real world during their interaction [79]. This may be considered an opportunity for future research as this transition was not mentioned in any of the studies reviewed. To maintain UX continuity, a smooth transition from one virtual scene to another is deemed important [80] Transition to the real world involves both mental and physical awareness of exiting the iVR boundary [30] reported that older adults face balance issues when removing iVR HMD. Providing a smooth exit transition is, therefore, vital to prevent spatial disorientation [81] suggested designing virtual worlds with a sense of realism that offers a smooth transition to and from the virtual world. In a qualitative study, [82] explored UX across space, control, sociality, time, and sensory adaption as users transitioned out of iVR, which may guide future research in this area. We suggest future research should consider holistic studies that address transitions across the iVR experience.

5.1.3. Active vs. Passive User Participation in Immersive Experiences

Our review suggests that iVR designed for older adults considers users as either passive observers (e.g., watching a 360-degree video) or active players (e.g., interactive games). Older adults seem to prefer fully immersive virtual environments that appear realistic over video-based VR content [83]. Active iVR participation offers interactive experiences and provides a higher sense of agency and presence [84], which can lead to more engaging experiences. In terms of realistic environments, [85] showed that active exploration of the environment and object structure can enhance recognizability, compared to passive observation. In the health domain, active iVR engagement is found to be particularly effective and sufficiently distracting in managing pain [86,87] while providing opportunities for personal growth [88].

Our review uncovers a broad range of applications designed for older adults, including 360-degree videos, 3D interactive environments, and gameplay. The choice of iVR content and hardware for older adults should provide personalization opportunities to meet their

physical and cognitive abilities [26] suggested keeping a relaxed interaction pace during an active exergame play to avoid over-exertion of older adult users. Similarly, [65] designed a temporary meditation room and kept game time limited to allow rest time. Therefore, design considerations often vary for these experiences depending on the type and range of interaction intended, as well as safety concerns.

5.2. Design Process

In addition to design considerations found, we regard the design process followed as critical for experiences catering to older audience needs. Thus, we investigated the characteristics of the design process followed in the included papers. While it is evident that the inclusion of older adults into the design process results in highly relevant insights, the number of papers reporting the use of a human-centered design or participatory approaches to create bespoke iVR experiences was relatively small. Some notable challenges found in our review include recruitment difficulties (especially with people with dementia) [25,51], limited time spent with the participants [25], and the inability or unwillingness of the participants to travel to a research center [59]. Nonetheless, building an extended engagement with a few participants still helped to inform the development of a tailored environment [25]. Conversations that take place in care or community centers also benefit from a familiar and friendly atmosphere. For example, [25] integrated workshops and interviews into an existing schedule, i.e., afternoon tea sessions, at the community centers. In these engagements, HMD-VR systems and existing VR programs were often introduced early to gauge older adults' opinions and experiences [6,59], helping to resolve the difficulties envisioning new technology—an issue that was previously raised by [39,89].

Apart from end-users, involving other stakeholders in the design process adds unique and pertinent viewpoints that contribute to the overall quality of iVR programs. For instance, [6] consulted with kinesiologists and exercise therapists to select motions and virtual environments for a VR exergame [55] refined a cognitive assessment tool using inputs and feedback from clinical neuropsychologists who are subject-matter experts. The companion of caregivers, as in the study by [25], allowed researchers to understand the social context around the person with dementia. Besides, it was the shared experiences with family members that enabled easy conversations with the patients and reduced their hesitation in using a novel system. Staff members of residential aged care facilities who have good knowledge about the resident's capacities could support shortlisting potential participants and provide feedback for the VR system based on their experience organizing lifestyle activities [51]. In the study by [59], care center managers provided insight into the services and service users. Previous research suggested that staff participation in the design process is critical not just for developing useful and accessible iVR experiences but also for addressing their concerns about the suitability of iVR for older adults, hence increasing their readiness to employ the technology.

5.3. Evaluation

Our review highlighted the lack of longitudinal studies, specifically in relation to evaluating iVR design for older adults [90] discussed the concept of temporality in UX and considered three UX phases: orientation, incorporation, and identification. Over time, as familiarity increases, so does functional dependency and emotional attachment. Increased familiarity with the technology may reduce frustration, while the novelty of the experience wears off slowly. This can be extended to the iVR UX, where understanding the changes in UX through longitudinal studies with older adults might generate valuable design insights. Furthermore, the effectiveness of iVR in many areas is linked to its potential to blur the boundaries of real vs. virtual world. The latest tracking technologies and improvements in iVR graphics offer highly immersive UX, but may pose several physical and psychological risks [91] listed six possible issues when using iVR as a research tool: limited experimental environments, informed consent related to long-lasting psychological effects, possible risks in clinical applications, malicious use of research outcomes, online exposure, and

limited code of conduct available for iVR research itself. As such, they noted that it is hard to fully realize all the associated risks unless longitudinal studies are conducted, which, consequently, raises concerns around maleficence. We note this is an important direction for future research.

It is also worth noting that only 8 of the 36 reviewed studies assessed motion sickness, whereas 12 assessed presence. Both aspects deserve more attention, given that older adults, even in a controlled environment, are prone to psychological and physical harm that may undermine the benefits of iVR. Motion sickness and related complaints, reported in the reviewed papers, have been previously discussed in the literature [92–94]. With the latest advancements in iVR, motion sickness has been improved; however, a number of studies suggested minimizing time pressure [55] while maintaining communication with the user to check their condition [54]. Similarly, presence in iVR can potentially pose several safety challenges, such as falling or attempting actions not possible in the real world (e.g., trying to sit on a virtual chair). Furthermore, there is still no guideline as to the optimal iVR exposure time, particularly for older adults, mainly due to the lack of longitudinal studies [95] outlined that older adults felt 6 min was a suitable duration, while some who were more engaged with iVR used it for up to 20 min.

5.4. Usability Challenges

Identified usability challenges of current iVR designs for older adults posed in RQ4 need to be overcome for safe and useful future experiences. A major theme identified in our review is the numerous issues related to iVR hardware systems, including the headset and hand controllers. Nevertheless, we postulate that rising consumer demand and more investment in VR hardware will quickly bring about a paradigm shift in form factors for iVR devices. Current HMDs that lack aesthetics and physical comfort are yet to evolve into more socially acceptable and user-friendly wearables. The recently-debuted all-in-one VR platforms represent a huge leap forward compared to the exorbitantly expensive and cumbersome tethered systems that were popular many years ago [96].

While almost half of our reviewed papers reported the use of Oculus Rift, the model is now discontinued as a result of the new standalone VR headsets [97]. These changes indicate a trend toward resolving technical challenges; however, the evolving UX is yet to be fully examined to account for this transformation. With regards to usability, we suggest that the role of caregivers and residential aged care staff should be considered to ensure safe and effective deployments of iVR programs. One example is that a wheelchair should be positioned at the center of the tracking space to minimize user overreaching [51]. In another case, older adults needed help moving the wheelchair to access particular virtual objects [98]. Since it is apparent that facilitator competency is critical, [11] advised that training be offered to both aged care personnel and family members.

5.5. Limitations

Our review study is limited in several ways. The selected papers were identified based on the keywords employed in our search strategy and other combinations may potentially yield a wider range of papers. The search terms "virtual reality" OR "immersive virtual reality" were used to find more relevant results, though "immersive VR" could be a good alternative. To maintain a focus on HCI literature, we searched the ACM Digital Library, IEEE Xplore Digital Library, Elsevier's Scopus, and PubMed databases; however, other databases may address additional UX design considerations or evaluation methods. The selected papers include diverse iVR setups using a range of HMDs, affording different aesthetics and tracking quality. In addition, some of the iVR apps offered off-the-shelf commercial content, while others were designed specifically for older adults. Additionally, some of the studies recruited young participants in addition to older adults. Studies concerning designed and bespoke iVR apps did not necessarily examine the effectiveness of their design, while those which used commercial apps undermined the impact of custom design on the study outcomes. Study designs also varied in terms of contexts, aims, and

outcomes. Therefore, some level of contextualization is needed in generalizing our findings. The diversity in hardware, software, and configuration may have affected some of the reported results, reducing our ability to compare the design decisions made.

6. Conclusions

In this paper, we reviewed 36 papers published between 2010 and 2019, whereby iVR applications were developed for older adult users in the context of clinical, entertainment, and wellbeing. Our research was motivated by the gap in useful design guidelines, aiming to develop effective and enjoyable UX in safe iVR applications for older adults. We identified 10 categories of design considerations that were explicitly applied in the studies. Design considerations were extended beyond software development to consider people and physical configuration as well as hardware use. Taken together, these support discrete phases like onboarding or visual iVR experience. The review also highlighted a general lack of guidelines to best support older adults' safe iVR experiences and smooth transition to/from the real world. Limited evidence suggests the use of participatory design approaches and inclusion of various stakeholders; however, recruitment challenges in several studies were reported. Most attention was given to overall UX evaluation in current literature, where several usability challenges were reported, but the need for longitudinal UX remains. Moreover, further research is needed on the effectiveness of the 10 design considerations categories we identified, their effectiveness in a given context and links to UX evaluations. Overall, this study emphasizes the need to develop guidelines that inform the design and choice of UX evaluation methods in iVR for older adults.

The unprecedented growth rate of the world's elderly population, together with the emergence of the metaverse age, underscore the importance of iVR research for older individuals. We call for future research to engage closely with older adults as active participants in the design process to better capture their needs and strategically extend the 10 proposed design considerations. These should encompass ethical considerations across the boundaries of the user's physical and psychological needs, iVR hardware and software, and UX.

References

1. United Nations. World Population Ageing 2019. In *Economic and Social Affairs, Population Division*; United Nations: New York, NY, USA, 2019.
2. A Andrews, J.; Brown, L.J.; Hawley, M.S.; Astell, A.J. Older Adults' Perspectives on Using Digital Technology to Maintain Good Mental Health: Interactive Group Study. *J. Med. Internet Res.* **2019**, *21*, e11694. [CrossRef] [PubMed]

3. Peek, S.T.; Luijkx, K.G.; Rijnaard, M.D.; Nieboer, M.E.; van der Voort, C.S.; Aarts, S.; van Hoof, J.; Vrijhoef, H.J.; Wouters, E.J. Older Adults' Reasons for Using Technology while Aging in Place. *Gerontology* **2015**, *62*, 226–237. [CrossRef] [PubMed]
4. Mujber, T.; Szecsi, T.; Hashmi, M. Virtual reality applications in manufacturing process simulation. *J. Mater. Process. Technol.* **2004**, *155*, 1834–1838. [CrossRef]
5. Slater, M. Immersion and the illusion of presence in virtual reality. *Br. J. Psychol.* **2018**, *109*, 431–433. [CrossRef] [PubMed]
6. Eisapour, M.; Cao, S.; Domenicucci, L.; Boger, J. Participatory Design of a Virtual Reality Exercise for People with Mild Cognitive Impairment. In Proceedings of the Conference on Human Factors in Computing Systems, 2018a. Montreal, QC, Canada, 25–27 April 2018; p. CS15. [CrossRef]
7. Slater, M.; Lotto, B.; Arnold, M.M.; Sanchez-Vives, M.V. How we experience immersive virtual environments: The concept of presence and its measurement. *Anu. Psicol.* **2009**, *40*, 193–210.
8. Tuena, C.; Pedroli, E.; Trimarchi, P.D.; Gallucci, A.; Chiappini, M.; Goulene, K.; Gaggioli, A.; Riva, G.; Lattanzio, F.; Giunco, F.; et al. Usability Issues of Clinical and Research Applications of Virtual Reality in Older People: A Systematic Review. *Front. Hum. Neurosci.* **2020**, *14*, 93. [CrossRef]
9. Kim, Y.M.; Rhiu, I.; Yun, M.H. A Systematic Review of a Virtual Reality System from the Perspective of User Experience. *Int. J. Hum.-Comput. Interact.* **2019**, *36*, 893–910. [CrossRef]
10. Silva, R.S.; Mol, A.M.; Ishitani, L. Virtual reality for older users: A systematic literature review. *Int. J. Virtual Real.* **2019**, *19*, 11–25. [CrossRef]
11. Thach, K.S.; Lederman, R.; Waycott, J. How older adults respond to the use of Virtual Reality for enrichment: A systematic review. In Proceedings of the 32nd Australian Conference on Human-Computer Interaction, Sydney, Australia, 2–4 December 2020. [CrossRef]
12. Abeele, V.V.; Schraepen, B.; Huygelier, H.; Gillebert, C.; Gerling, K.; Van Ee, R. Immersive Virtual Reality for Older Adults: Emperically Grounded Design Guidelines. *ACM Trans. Access. Comput.* **2021**, *14*, 1–30. [CrossRef]
13. Murman, D.L. The Impact of Age on Cognition. *Semin. Heart* **2015**, *36*, 111–121. [CrossRef]
14. McGrath, R.P.; Ottenbacher, K.J.; Vincent, B.; Kraemer, W.J.; Peterson, M. Muscle weakness and functional limitations in an ethnically diverse sample of older adults. *Ethn. Health* **2017**, *25*, 342–353. [CrossRef] [PubMed]
15. Lim, K.; Ec, B.; Stat, M.; ATaylor, L. Factors associated with physical activity among older people—A population-based study. *Prev. Med.* **2005**, *40*, 33–40. [CrossRef] [PubMed]
16. Webber, M.S.C.; Porter, M.M.; Menec, V.H. Mobility in Older Adults: A Comprehensive Framework. *Gerontology* **2010**, *50*, 443–450. [CrossRef] [PubMed]
17. Ahmadpour, N.; Keirnan, A. Design for Ageing-in-place: Evidence from Australia. In *DRS2016: Future-Focused Thinking*; Lloyd, P., Bohemia, E., Eds.; Design Research Society: London, UK, 2016; Volume 4.
18. Mynatt, E.D.; Rogers, W.A. Developing technology to support the functional independence of older adults. *Ageing Int.* **2001**, *27*, 24–41. [CrossRef]
19. Khosravi, P.; Rezvani, A.; Wiewiora, A. The impact of technology on older adults' social isolation. *Comput. Hum. Behav.* **2016**, *63*, 594–603. [CrossRef]
20. Charness, N.; Boot, W.R. Aging and Information Technology Use: Potential and Barriers. *Curr. Dir. Psychol. Sci.* **2009**, *18*, 253–258. [CrossRef]
21. Liao, Y.-Y.; Chen, I.-H.; Lin, Y.-J.; Chen, Y.; Hsu, W.-C. Effects of Virtual Reality-Based Physical and Cognitive Training on Executive Function and Dual-Task Gait Performance in Older Adults With Mild Cognitive Impairment: A Randomized Control Trial. *Front. Aging Neurosci.* **2019**, *11*, 162. [CrossRef]
22. Eisapour, M.; Cao, S.; Domenicucci, L.; Boger, J. Virtual Reality Exergames for People Living with Dementia Based on Exercise Therapy Best Practices. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* **2018b**, *62*, 528–532. [CrossRef]
23. Goh, L.; E Allen, N.; Ahmadpour, N.; Martens, K.A.E.; Song, J.; Clemson, L.; Lewis, S.J.G.; MacDougall, H.G.; Canning, C.G. A Video Self-Modeling Intervention Using Virtual Reality Plus Physical Practice for Freezing of Gait in Parkinson Disease: Feasibility and Acceptability Study. *JMIR Form. Res.* **2021**, *5*, e28315. [CrossRef]
24. Baker, S.; Kelly, R.M.; Waycott, J.; Carrasco, R.; Hoang, T.; Batchelor, F.; Ozanne, E.; Dow, B.; Warburton, J.; Vetere, F. Interrogating Social Virtual Reality as a Communication Medium for Older Adults. *Proc. ACM Hum.-Comput. Interact.* **2019**, *3*, 1–24. [CrossRef]
25. Hodge, J.; Balaam, M.; Hastings, S.; Morrissey, K. Exploring the Design of Tailored Virtual Reality Experiences for People with Dementia. In Proceedings of the Conference on Human Factors in Computing Systems, Montreal, QC, Canada, 1–13 April 2018; p. 514. [CrossRef]
26. Ijaz, K.; Wang, Y.; Milne, D.; Calvo, R.A. Competitive vs Affiliative Design of Immersive VR Exergames. In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*; Springer: Berlin/Heidelberg, Germany, 2016; Volume 9894, pp. 140–150. [CrossRef]
27. Lai, X.; Lei, X.; Chen, X.; Rau, P.-L.P. Can Virtual Reality Satisfy Entertainment Needs of the Elderly? The Application of a VR Headset in Elderly Care. In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 159–172. [CrossRef]
28. O'Regan, J.K.; Noë, A. A sensorimotor account of vision and visual consciousness. *Behav. Brain Sci.* **2001**, *24*, 939–973. [CrossRef] [PubMed]

29. Andringa, G.; Nuijten, P.L.; Macville, M.M.; Mertens, E.G.A.; Kaptein, J.J.; Bauer, A.C.M.; Doel, L.R.V.D.; Roos, A.G. *Feasibility of Virtual Reality in Elderly with Dementia*; Springer: Cham, Switzerland, 2019; pp. 146–149. [CrossRef]

30. Brown, J.A. An Exploration of Virtual Reality Use and Application Among Older Adult Populations. *Gerontol. Geriatr. Med.* **2019**, *5*. [CrossRef] [PubMed]

31. Coldham, G.; Cook, D.M. VR usability from elderly cohorts: Preparatory challenges in overcoming technology rejection. In Proceedings of the 2017 National Information Technology Conference (NITC), Colombo, Sri Lanka, 13–15 September 2017; pp. 131–135. [CrossRef]

32. Huygelier, H.; Schraepen, B.; Van Ee, R.; Abeele, V.V.; Gillebert, C.R. Acceptance of immersive head-mounted virtual reality in older adults. *Sci. Rep.* **2019**, *9*, 4519. [CrossRef] [PubMed]

33. Roberts, A.R.; De Schutter, B.; Franks, K.; Radina, M.E. Older Adults' Experiences with Audiovisual Virtual Reality: Perceived Usefulness and Other Factors Influencing Technology Acceptance. *Clin. Gerontol.* **2018**, *42*, 27–33. [CrossRef] [PubMed]

34. Czaja, S.J.; Boot, W.R.; Charness, N.; Rogers, W.A. *Designing for Older Adults: Principles and Creative Human Factors Approaches*; CRC Press: Boca Raton, FL, USA, 2019. [CrossRef]

35. Farage, M.A.; Miller, K.W.; Ajayi, F.; Hutchins, D. Design Principles to Accommodate Older Adults. *Glob. J. Health Sci.* **2012**, *4*, 2–25. [CrossRef]

36. Johnson, J.; Finn, K. *Designing User Interfaces for an Aging Population: Towards Universal Design*; Morgan Kaufmann Publishers: Burlington, MA, USA, 2019.

37. Kurniawan, S.; Zaphiris, P. Research-derived web design guidelines for older people. In Proceedings of the 7th International ACM SIGACCESS Conference on Computers and Accessibility, Baltimore, MD, USA, 9–12 October 2005; pp. 129–135. [CrossRef]

38. Knowles, B.; Hanson, V.L.; Rogers, Y.; Piper, A.M.; Waycott, J.; Davies, N. HCI and Aging: Beyond Accessibility. In Proceedings of the Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems, Glasgow, Scotland, 4–9 May 2019; pp. 1–8.

39. Lindsay, S.; Jackson, D.; Schofield, G.; Olivier, P. Engaging older people using participatory design. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, TX, USA, 5–10 May 2012; pp. 1199–1208.

40. Lazar, A.; Edasis, C.; Piper, A.M. A Critical Lens on Dementia and Design in HCI. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, Denver, CO, USA, 6–11 May 2017; pp. 2175–2188. [CrossRef]

41. Coleman, G.W.; Gibson, L.; Hanson, V.L.; Bobrowicz, A.; McKay, A. Engaging the disengaged: How do we design technology for digitally excluded older adults? In Proceedings of the 8th ACM Conference on Designing Interactive Systems, Aarhus, Denmark, 16–20 August 2010; pp. 175–178.

42. Newell, A.; Arnott, J.; Carmichael, A.; Morgan, M. Methodologies for involving older adults in the design process. In Proceedings of the International Conference on Universal Access in Human-Computer Interaction, Beijing, China, 22–27 July 2007; pp. 982–989.

43. Forlizzi, J.; Battarbee, K. Understanding experience in interactive systems. In Proceedings of the 5th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, Cambridge, MA, USA, 1–4 August 2004; pp. 261–268. [CrossRef]

44. *ISO DIS, 9241-210*; Ergonomics of Human System Interaction—Part 210: Human-Centred Design for Interactive Systems. Ergonomics of human-system interaction: New York, NY, USA, 2010.

45. Hassenzahl, M. The Thing and I: Understanding the Relationship Between User and Product. In *Funology: From Usability to Enjoyment*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2003; pp. 31–42. [CrossRef]

46. Tcha-Tokey, K.; Christmann, O.; Loup-Escande, E.; Loup, G.; Richir, S. Towards a model of user experience in im-mersive virtual environments. *Adv. Hum.-Comput. Interact.* **2018**, *2018*, 7827286. [CrossRef]

47. Hassenzahl, M.; Tractinsky, N. User experience—A research agenda. *Behav. Inf. Technol.* **2006**, *25*, 91–97. [CrossRef]

48. Stanney, K.M.; Mollaghasemi, M.; Reeves, L.; Breaux, R.; Graeber, D.A. Usability engineering of virtual environ-ments (VEs): Identifying multiple criteria that drive effective VE system design. *Int. J. Hum.-Comput. Stud.* **2003**, *58*, 447–481. [CrossRef]

49. Arksey, H.; O'Malley, L. Scoping studies: Towards a methodological framework. *Int. J. Soc. Res. Methodol.* **2005**, *8*, 19–32. [CrossRef]

50. Amin, A.M.; Tong, X.; Gromala, D.; Shaw, C.D. Cardboard Mobile Virtual Reality as an Approach for Pain Distraction in Clinical Settings. In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems—CHI EA '2017, Denver, CO, USA, 6–11 May 2017; pp. 2345–2351. [CrossRef]

51. Baker, S.; Waycott, J.; Robertson, E.; Carrasco, R.; Neves, B.B.; Hampson, R.; Vetere, F. Evaluating the use of interactive virtual reality technology with older adults living in residential aged care. *Inf. Process. Manag.* **2019**, *57*, 102105. [CrossRef]

52. Kim, A.; Darakjian, N.; Finley, J.M. Walking in fully immersive virtual environments: An evaluation of potential adverse effects in older adults and individuals with Parkinson's disease. *J. Neuroeng. Rehabil.* **2017**, *14*, 1–12. [CrossRef] [PubMed]

53. Ouellet, E.; Boller, B.; Corriveau-Lecavalier, N.; Cloutier, S.; Belleville, S. The Virtual Shop: A new immersive virtual reality environment and scenario for the assessment of everyday memory. *J. Neurosci. Methods* **2018**, *303*, 126–135. [CrossRef] [PubMed]

54. Bruun-Pedersen, J.R.; Serafin, S.; Kofoed, L.B. Going Outside While Staying Inside—Exercise Motivation with Immersive vs. Non–immersive Recreational Virtual Environment Augmentation for Older Adult Nursing Home Residents. In Proceedings of the 2016 IEEE International Conference on Healthcare Informatics, Chicago, IL, USA, 4–7 October 2016; pp. 216–226. [CrossRef]

55. Ijaz, K.; Ahmadpour, N.; Naismith, S.L.; A Calvo, R. An Immersive Virtual Reality Platform for Assessing Spatial Navigation Memory in Predementia Screening: Feasibility and Usability Study. *JMIR Ment. Health* **2019**, *6*, e13887. [CrossRef] [PubMed]

56. Korsgaard, D.; Bjørner, T.; Sørensen, P.K.; Bruun-Pedersen, J.R. Older adults eating together in a virtual living room: Opportunities and limitations of eating in augmented virtuality. In Proceedings of the ECCE 2019—31st European Conference on Cognitive Ergonomics: "'Design for Cognition", Belfast, UK, 10–13 September 2019; pp. 168–176. [CrossRef]

57. Tomitsch, M.; Wrigley, C.; Borthwick, M.; Ahmadpour, N.; Frawley, J.; Kocaballi, A.B.; Nunez-Pacheco, C.; Straker, K. *Design. Think. Make. Break. Repeat. A Handbook of Methods*; BIS Publishing: Pretoria, South Africa, 2020.

58. Ahmed, B.; Kim, D.H.; Hwang, Y.; Park, S.-J. Treatment of Alzheimer's, Cognitive, Chronic Pain Rehabilitation, Depression and Anxiety disorders in One System for Elderly Using VR. In Proceedings of the 2018 15th International Conference on Ubiquitous Robots, UR, Jeju, Korea, June 28–July 1 2018; pp. 483–488. [CrossRef]

59. Howes, S.; Charles, D.; Pedlow, K.; Wilson, I.M.; Holmes, D.; McDonough, S. User-centred design of an active computer gaming system for strength and balance exercises for older adults. *J. Enabling Technol.* **2019**, *13*, 101–111. [CrossRef]

60. Kovar, I. Use of Virtual Reality as a Tool to Overcome the Post-Traumatic Stress Disorder of Pensioners. *Int. J. Adv. Sci. Eng. Inf. Technol.* **2019**, *9*, 841. [CrossRef]

61. Micarelli, A.; Viziano, A.; Micarelli, B.; Augimeri, I.; Alessandrini, M. Vestibular rehabilitation in older adults with and without mild cognitive impairment: Effects of virtual reality using a head-mounted display. *Arch. Gerontol. Geriatr.* **2019**, *83*, 246–256. [CrossRef]

62. Benham, S.; Kang, M.; Grampurohit, N. Immersive Virtual Reality for the Management of Pain in Community-Dwelling Older Adults. *OTJR Occup. Particip. Health* **2018**, *39*, 90–96. [CrossRef]

63. Baqai, A.; Memon, K.; Memon, A.R.; Shah, S.M.Z.A. Interactive Physiotherapy: An Application Based on Virtual Reality and Bio-feedback. *Wirel. Pers. Commun.* **2018**, *106*, 1719–1741. [CrossRef]

64. Sakhare, A.R.; Yang, V.; Stradford, J.; Tsang, I.; Ravichandran, R.; Pa, J. Cycling and Spatial Navigation in an Enriched, Immersive 3D Virtual Park Environment: A Feasibility Study in Younger and Older Adults. *Front. Aging Neurosci.* **2019**, *11*, 218. [CrossRef]

65. Yang, Y.-C. Role-play in Virtual Reality Game for the Senior. In *ACM International Conference Proceeding Series Part F1483(982)*; ACM: New York, NY, USA, 2019; pp. 31–35. [CrossRef]

66. Mol, A.M.; Silva, R.S.; Ishitani, L. Design recommendations for the development of virtual reality focusing on the elderly. In Proceedings of the Iberian Conference on Information Systems and Technologies, CISTI, Coimbra, Portugal, 19–22 June 2019. [CrossRef]

67. Süzer, K.; Olguntürk, N. The aid of colour on visuospatial navigation of elderly people in a virtual polyclinic environment. *Color Res. Appl.* **2018**, *43*, 872–884. [CrossRef]

68. Lecavalier, N.C.; Ouellet, É; Boller, B.; Belleville, S. Use of immersive virtual reality to assess episodic memory: A validation study in older adults. *Neuropsychol. Rehabil.* **2018**, *30*, 462–480. [CrossRef] [PubMed]

69. Plechatá, A.; Sahula, V.; Fayette, D.; Fajnerová, I. Age-Related Differences With Immersive and Non-immersive Virtual Reality in Memory Assessment. *Front. Psychol.* **2019**, *10*, 1330. [CrossRef] [PubMed]

70. Bargas-Avila, J.A.; Hornbæk, K. Old wine in new bottles or novel challenges: A critical analysis of empirical studies of user experience. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Vancober, BC, Canada, 11–15 June 2011; pp. 2689–2698.

71. Kennedy, R.S.; Lane, N.E.; Berbaum, K.S.; Lilienthal, M.G. Simulator sickness questionnaire: An enhanced meth-od for quantifying simulator sickness. *Int. J. Aviat. Psychol.* **1993**, *3*, 203–220. [CrossRef]

72. Slater, M.; Usoh, M.; Steed, A. Depth of presence in virtual environments. *Presence Teleoperators Virtual Environ.* **1994**, *3*, 130–144. [CrossRef]

73. McAuley, E.; Duncan, T.; Tammen, V.V. Psychometric properties of the Intrinsic Motivation Inventory in a com-petitive sport setting: A confirmatory factor analysis. *Res. Q. Exerc. Sport* **1989**, *60*, 48–58. [CrossRef]

74. Lessiter, J.; Freeman, J.; Keogh, E.; Davidoff, J.B. A Cross-Media Presence Questionnaire: The ITC-Sense of Presence Inventory. *Presence: Teleoperators Virtual Environ.* **2001**, *10*, 282–297. [CrossRef]

75. Lin, C.X.; Lee, C.; Lally, D.; Coughlin, J.F. Impact of Virtual Reality (VR) Experience on Older Adults' Well-Being. In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 10927 LNCS*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 89–100. [CrossRef]

76. Turner, P.; Turner, S.; Van De Walle, G. How older people account for their experiences with interactive technology. *Behav. Inf. Technol.* **2007**, *26*, 287–296. [CrossRef]

77. Cleary, A.M.; Brown, A.S.; Sawyer, B.D.; Nomi, J.S.; Ajoku, A.C.; Ryals, A.J. Familiarity from the configuration of objects in 3-dimensional space and its relation to déjà vu: A virtual reality investigation. *Conscious. Cogn.* **2012**, *21*, 969–975. [CrossRef]

78. Petri, K.; Feuerstein, K.; Folster, S.; Bariszlovich, F.; Witte, K. Effects of Age, Gender, Familiarity with the Content, and Exposure Time on Cybersickness in Immersive Head-mounted Display Based Virtual Reality. *Am. J. Biomed. Sci.* **2020**, 107–121. [CrossRef]

79. Steed, A.; Slater, M. A virtual presence counter. *Presence Teleoperators Virtual Environ.* **2000**, *9*, 413–434.

80. Men, L.; Bryan-Kinns, N.; Hassard, A.S.; Ma, Z. The impact of transitions on user experience in virtual reality. *IEEE Virtual Reality* **2017**, 285–286. [CrossRef]

81. Slater, M.; Steed, A.; Mccarthy, J.; Marinelli, F. The Virtual Ante-Room: Assessing Presence through Expectation and Surprise. 1996. Available online: https://www.researchgate.net/publication/2499466_The_Virtual_Ante-Room_Assessing_Presence_through_Expectation_and_Surprise (accessed on 9 June 2022).

82. Knibbe, J.; Schjerlund, J.; Petraeus, M.; Hornbæk, K. The Dream is Collapsing: The Experience of Exiting VR. In Proceedings of the Conference on Human Factors in Computing Systems, Montreal, QC, Canada, 25–27 April 2018; pp. 1–13. [CrossRef]

83. Huber, T.; Paschold, M.; Hansen, C.; Lang, H.; Kneist, W. Artificial Versus Video-Based Immersive Virtual Surroundings: Analysis of Performance and User's Preference. *Surg. Innov.* **2018**, *25*, 280–285. [CrossRef] [PubMed]

84. Piccione, J.; Collett, J.; De Foe, A. Virtual skills training: The role of presence and agency. *Heliyon* **2019**, *5*, e02583. [CrossRef] [PubMed]

85. James, K.H.; Humphrey, G.K.; Vilis, T.; Al, J.E.T. "Active" and "passive" learning of three- dimensional object structure within an immersive virtual reality environment. *Behav. Res. Methods Instrum. Comput.* **2002**, *34*, 383–390. [CrossRef] [PubMed]

86. Phelan, I.; Furness, P.J.; Fehily, O.; Thompson, A.R.; Babiker, N.T.; A Lamb, M.; A Lindley, S. A Mixed-Methods Investigation Into the Acceptability, Usability, and Perceived Effectiveness of Active and Passive Virtual Reality Scenarios in Managing Pain Under Experimental Conditions. *J. Burn Care Res.* **2018**, *40*, 85–90. [CrossRef] [PubMed]

87. Ahmadpour, N.; Keep, M.; Janssen, A.; Rouf, A.S.; Marthick, M. Design Strategies for Virtual Reality Interventions for Managing Pain and Anxiety in Children and Adolescents: Scoping Review. *JMIR Serious Games* **2020**, *8*, e14565. [CrossRef]

88. Ahmadpour, N.; Randall, H.; Choksi, H.; Gao, A.; Vaughan, C.; Poronnik, P. Virtual Reality interventions for acute and chronic pain management. *Int. J. Biochem. Cell Biol.* **2019**, *114*, 105568. [CrossRef]

89. Massimi, M.; Baecker, R. Participatory design process with older users. In Proceedings of the UbiCoomp2006 Workshop on Future Media, Irvine, CA, USA, 12–16 June 2006.

90. Karapanos, E.; Zimmerman, J.; Forlizzi, J.; Martens, J.-B. User experience over time: An initial framework. In Proceedings of the Conference on Human Factors in Computing Systems, Boston, MA, USA, 4–9 April 2009; pp. 729–738. [CrossRef]

91. Madary, M.; Metzinger, T.K. Real virtuality: A code of ethical conduct. Recommendations for Good Scientific Practice and the Consumers of VR-Technology. *Front. Robot. AI* **2016**, *3*. [CrossRef]

92. Munafo, J.; Diedrick, M.; Stoffregen, T.A. The virtual reality head-mounted display Oculus Rift induces motion sickness and is sexist in its effects. *Exp. Brain Res.* **2016**, *235*, 889–901. [CrossRef]

93. Saredakis, D.; Szpak, A.; Birckhead, B.; Keage, H.A.D.; Rizzo, A.; Loetscher, T. Factors Associated with Virtual Reality Sickness in Head-Mounted Displays: A Systematic Review and Meta-Analysis. *Front. Hum. Neurosci.* **2020**, *14*, 96. [CrossRef]

94. Sharples, S.; Cobb, S.; Moody, A.; Wilson, J.R. Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop and projection display systems. *Displays* **2008**, *29*, 58–69. [CrossRef]

95. Appel, L.; Appel, E.; Bogler, O.; Wiseman, M.; Cohen, L.; Ein, N.; Abrams, H.B.; Campos, J.L. Older Adults With Cognitive and/or Physical Impairments Can Benefit FROM Immersive Virtual Reality Experiences: A Feasibility Study. *Front. Med.* **2020**, *6*, 329. [CrossRef] [PubMed]

96. Kugler, L. The state of virtual reality hardware. *Commun. ACM* **2021**, *64*, 15–16. [CrossRef]

97. Oculus. Oculus Rift S. Available online: https://www.oculus.com/rift-s/ (accessed on 10 June 2022).

98. Zhao, W.; Baker, S.; Waycott, J. Challenges of Deploying VR in Aged Care: A Two-Phase Exploration Study. In Proceedings of the 32nd Australian Conference on Human-Computer Interaction, Sydney, Australia, 2–4 December 2020. [CrossRef]