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REVIEW
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A Scoping Review of Augmented/Virtual Reality Health and Wellbeing Interventions for Older Adults: Redefining Immersive Virtual Reality

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Augmented and virtual reality (AR/VR) technologies are regularly used in psychology research to complement psychological interventions and to enable an individual to feel as if they are in an environment other than that of their immediate surroundings. A scoping review was performed to identify how AR/VR was being used with older adult populations to impact their physical and mental health. The review also sought to determine whether the terminology used in AR/VR research was consistent. The results show that 65 studies have been published in the last 20 years that meet the inclusion criteria (virtual/augmented reality) technology to impact older adults' physical/mental health and wellbeing. Participants included healthy, physically, and cognitively impaired, and emotionally vulnerable older adults. We argue that over 70% of the studies included in this review were mislabeled as VR and only six papers included fully immersive VR/AR. The remaining studies use less immersive variants of virtual reality with their populations, and only one study made use of AR, which prompted the suggestion of a new definition for virtual reality. This paper also calls for an updated taxonomy of augmented and virtual reality definitions to address the lack of consistency found in studies that identify themselves as AR/VR when they are using less immersive technical set-ups, including displaying non-interactive videos on 2D screens.

Keywords: virtual reality, augmented reality, older adults, physical/mental health, scoping review, psychology

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BACKGROUND

The development and impact of virtual and augmented technologies has been examined since the early 60s (Eckert et al., 2019, p. 2). In their current evolution, they provide digital interaction in space. There are many complementary definitions of both terms though the most comprehensive are from McCoy and Stone (2001) and Botella et al. (2015). Virtual reality is "a collection of technologies that allow people to interact efficiently with 3D computerized databases in real time using their natural senses and skills" (McCoy and Stone, 2001, p. 912), whereas augmented reality "combines the real world with virtual elements, using computer graphics mixed with the real world in real time" (Botella et al., 2015, p. 2). Both definitions emphasize the importance of real-time interaction while also establishing their fundamental differences. Virtual reality immerses the user in a digital environment whereas augmented reality enhances the world around the user. Virtual technologies (hereafter referred to as AR/VR), have been incorporated into many areas of psychological research including exposure therapy (Riva et al., 2019, p. 82), pain management (Wiederhold, 2016, p. 577), and even diagnostic proficiency (Tarnanas et al., 2015, p. 12).

The use of AR/VR in older adult populations is often used as a form of Positive technology. This is the application of creative technologies for the benefit of personal experience (Botella et al., 2012, p. 78) through its structuring, augmentation and/or replacement" (Kitson et al., 2018, p. 3). When used to support user engagement, it enhances the environment and supports a person in new ways that better reflect their needs (Graffigna et al., 2013, p. 1). Functions of positive technologies include, encouraging positive emotions, promoting engagement and self-empowerment, and increasing social integration and connectedness (Wiederhold and Riva, 2012, p. 67). Each area can be promoted, affected, and facilitated by AR/VR and, the more interesting or compelling the virtual environment, the greater the enjoyment which can lead directly to increase motivation (Rizzo and Kim, 2005). Given that the population of adults over 65 in the EU27 (member states of the European Union) is expected to increase by 8.9% (Eurostat, 2020) by 2050, new and innovative ways to use AR/VR has become a tenet of research to support older adults to live independently at home for as long as possible (Wiederhold, 2020, p. 141). AR/VR physical activity programs have been successful in terms of increasing physical activity and strength and by influencing the motivations that drive these positive behaviors (Ng et al., 2019, p. 280). These interventions, underpinned by social cognitive theory, can effectively act as supplementary supports to physical actions. Through the observation of "others" or "oneself" in the digital environment, the user can learn and reinforce behaviors. Further research of the effects of intrinsic and extrinsic motivations in AR/VR interventions, is needed. While there are many studies that use AR/VR to impact physical and social factors in varied populations (Tarnanas et al., 2015, p. 2; Wiederhold, 2016; Riva et al., 2019, p. 82, p. 577), there is very little standardization or consistency in the terminology used to describe the technology. This has led to a call to unify definitions by (Kardong-Edgren et al., 2019, p. 29) and this review aims to address some of the gaps highlighted by the researchers.

"Virtual" Behavior Change Theory

Over the last decade virtual reality research has made the leap from "toy" to serious research tool (Stadler et al., 2019, p. 207). Several theories (Riva et al., 2016, p. 2–3) can be used to justify the inclusion and success of virtual interventions and this is important as many interventions have been found to provide inadequate theoretical support for their behavior change interventions (Michie et al., 2014). Perceptual Control Theory (Parker et al., 2020, p. 616) argues that participants occupied with a goal state interact with a digital environment and receive perceptual updates of their progress. Until their current perceptual state matches their goal state, they will receive "error" feedback, prompting them to continue until congruence is achieved. Self-affirmation theory (Velez and Hanus, 2016, p. 721–722) also supports the effectiveness of virtual interventions. During a virtual intervention, participants are often faced with negative information relevant to themselves. Researchers will prompt participants to change these behaviors in response to the intervention, but this can threaten the positive aspects of self-identity so virtual interventions often include positive encouragement to bolster important aspects of self-identity. This positive reinforcement facilitated by the virtual environment (e.g., gaining points in a virtual game) allows participants to fully engage with, and internalize the purpose of, the intervention. The Transtheoretical Model of Behavior Change (Yu-Leung et al., 2019, p. 287) states that there are six stages of health-related behavior change that hold true in both physical and virtual settings. These shifts in attitude are a useful indicator to researchers developing virtual interventions when compared to participants' prior experience and interest. Finally, Transformative Learning Theory (Huth et al., 2020, p. 1026), unlike self-affirmation theory, suggests that a pre-existing view evolves in response to a conflicting situation. The participant can reflect and engage with the situation in the virtual environment and experience a fundamental shift in perspective.

Rationale for Scoping Review

To date, approximately 19 meta-analyses and systematic reviews (See **Supplementary Table S1**) have examined the effects of VR on older populations, yet none have investigated the impact of AR in this population. Smart health technologies can benefit the cognitive, emotional, physical, and social domains of day-to-day living (Guisado-Fernández et al., 2019, p. 7–8). As such, illuminating the relationship between AR/VR, older adults and physical and mental health is essential.

Two research questions were posed in this scoping review.

1. How is AR/VR technology currently used in research with older adults to assess and/or improve physical and mental health and general wellbeing?
2. Is consistent terminology used across these studies and if not, what are the inconsistencies, and can this evaluation identify (or construct) a definition that will advance or improve understanding?

METHODS

Protocol

The PRISMA Extension for Scoping Reviews (Tricco et al., 2018, p. 4) was guides this review. We selected this framework given the variety of AR/VR technologies in research use, the numerous ways the technology is described, and the need to establish what and how research is conducted to enable appropriate systematic reviews to take place. Our aim is to create a resource for researchers interested in conducting AR/VR research with older adult populations in physical and mental health settings. As AR/VR terminology is multi-varied and (often) used interchangeably, this paper will summarize how these terms are being used and offer a rationale for why they are/are not being used correctly.

TABLE 1 | Academic Search Complete + CINAHL Complete + MEDLINE + PsychArticles + PsychINFO – 24/03/2020

#	Search Term	Results	Year
S1	Virtual Reality OR VR OR Augmented Reality OR AR, OR Augment* AND Reality OR Interreality OR Heads-Up* AND VIRTUAL REALITY or AUGMENTED REALITY Marker* AND virtual reality OR Augmented Reality OR Projection* AND virtual reality OR Augmented Reality OR Superimposition AND virtual reality OR Augmented Reality OR Holo* AND virtual reality OR Augmented Reality OR Tangible AND virtual reality OR Augmented Reality OR Mixed AND virtual reality OR Augmented AND Reality	437,212	1806 - 2020
S2	Older adults OR elderly OR geriatric OR geriatrics OR aging OR senior OR seniors OR older people OR aged 65 OR 65+ OR age related OR old age OR elder OR mature adult OR oldest old OR aged adult OR Late Life OR Retirement OR retired OR End of life* OR Older people OR older population OR OAP or OAPs OR Pensioner OR pensioners OR vulnerable elderly	3,200,549	1597 – 2021
S3	Physical health or physical wellbeing or health OR Physical activity or exercise or fitness or physical exercise OR physical therapy or physiotherapy or rehabilitation OR Balance OR Posture OR Fall prevention OR Mental Health OR Wellbeing or well-being or well being or wellness OR Mindfulness Dementia or alzheimers or Parkinson or cognitive impairment or memory or mild cognitive impairment OR emotional health OR Psychological Health OR depression or anxiety OR Psychiatr* OR Psychol*	20,291,326	1597 – 2021
S4	S1 AND S2 AND S3	3,061	1926 – 2020
S5	S4 limited by year	2,789	2000 – 2020
S6	S5 limited by age: aged: 65+years. Aged, 80 and over Aged (65yrs & older) Very old (85 yrs. & older) Aged, 80 & over	1,1014	2000 – 2020
S7	S6 Limited to Scholarly (Peer Reviewed) Journals only	984	2000 – 2020
	Duplicates Removed	74	
Title/Abstract Screening	YES	91	
	NO	721	
	C1 (Diagnostic)	24	
	C3 (AR/VR used tool / not intervention	42	
	R (Review)	32	
	Total	910	

Search Keywords and Databases

A comprehensive list of search terms was created to address the three areas of interest in this review: AR/VR, older adults, physical/mental health, and wellbeing. The literature search was conducted on March 24th, 2020 across the following licenced databases: Academic Search Complete, CINAHL, PsycINFO, PsycArticles and Medline. Primary studies with all types of designs were included along with all types of reviews. **Table 1** illustrates the key and related search terms used. Terms were combined using the Boolean Operators.

Inclusion and Exclusion Criteria

Articles were included if the target group were aged 60+°years, a common threshold for research in this field. If a study had participants of various ages, data relating to the older adults must have been presented separately to be included. All articles using terms such as "virtual," "augmented" and/or "mixed" reality where included. Finally, articles were only included if they investigated physical/mental health, wellbeing and AR/VR was used as part of their intervention. Articles were excluded if they did not meet the above criteria, if they did not include an active intervention or if they were published abstracts (where no paper was submitted), book reviews, opinion articles, commentaries, letters, editorials, interviews, lectures, legal cases, newspaper articles, or patient education handouts. Articles published from January 1999 to March 2020 were considered so that the review would not only contain recent studies, but also those from the early 2000s (the emergence of modern 3D virtual and augmented reality technologies) and the 00s (when Virtools VR Pack was released, which supported development of virtual environments in immersive spaces such as CAVE's and HMD's such as the Oculus Rift). Finally, only articles published in English were included as accurate translation would not be possible in the review timeframe.

Data Sorting and Analysis

Two reviewers screened for title and abstract, and full text reviews. Each reviewer conducted their screening individually, conflicts were discussed, and a final decision made. If any articles were not agreed upon, they were sent to a third party for arbitration. Data from full-text review was charted using the following headings: Title, citation, hypothesis, research question, aim, study design, participant details, methodology, procedure, country, results, conclusions, hardware used, software used, classification of AR/VR and, definitions used. Following the same procedure, reviewers also classified each article as: 1) Immersive VR; 2) Non-Immersive VR; 3) 2D VR; or 4) AR. Classifications were determined separately and a consensus was achieved through discussion.

Results

The literature revealed 984 studies. From this, 74 duplicates were removed. After screening titles and abstracts of the remaining 910

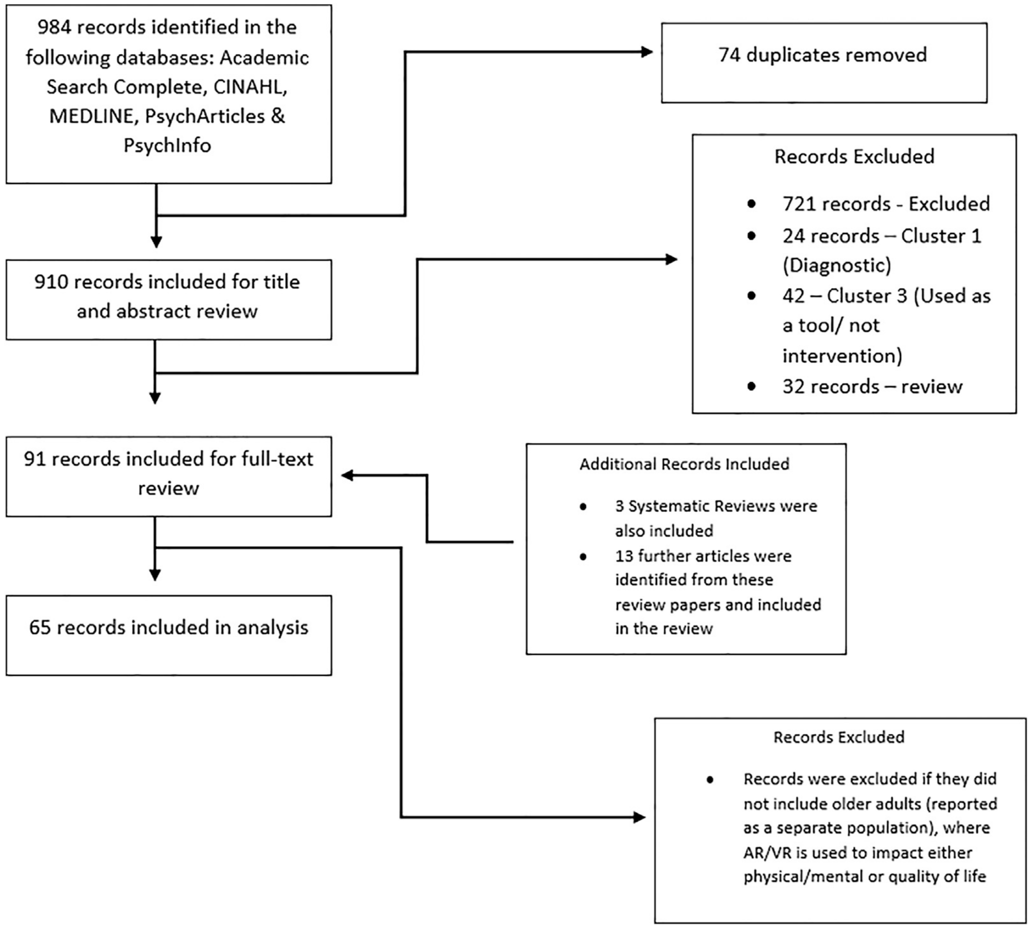

FIGURE 1 | Scoping Review-Augmented/Virtual Interventions - Study Flow Chart.

articles, 91 articles were brought forward for full-text review. After review, 52 studies were included in this study (See **Figure 1**). A further 13 articles were incorporated into this study based on a review of the references included in three systematic reviews identified in our search. The final number of articles included in this review was 65. The most common reasons for exclusion were participants under the age of 60 and studies that did not include an active intervention. Two reviewers screened results at all stages of screening and disagreements were found in approximately 7.5% of cases on average.

Characteristics of the Participants

For a detailed overview of the virtual and augmented reality characteristics included in the 65 studies, please see **Table 2**. Across the 65 studies identified, there was an average of 65 participants (Range 7–664) with a mean age of 67.63 (SD 8.45). Each study investigated older populations except three that compared older and younger adults. Four studies provided a participant age range (60–90+) and just one study specified a population over 60. Most studies included male and female participants however 13 investigated only male ($N = 1$), female ($N = 5$) populations or, did not specify participant gender ($N = 7$). The majority of studies included healthy participants however others included participants prone to falling ($N = 5$), participants in hospital ($N = 2$) or long-term living facilities ($N = 3$), participants with osteopenia ($N = 2$), neurological issues ($N = 15$), PTSD ($N = 1$) or diabetes ($N = 1$), participants who had experienced a stroke ($N = 1$) or persistent dizziness ($N = 2$), veterans ($N = 2$), those who were recently bereaved ($N = 1$) and those with depression ($N = 1$). Finally, three studies were systematic reviews containing multiple populations.

Study Designs

Of the included studies, 24 were randomized controlled trials, four were non-randomized controlled trials one was an exploratory study, two were observational two were qualitative, and one was an open label trail. The remaining studies were quasi-experimental (see **Table 2**).

Research Focus (Measures)

The measures used across the 65 studies were categorized into seven main themes, with most research examining two or more (See **Table 3**). Themes included physical activity, general health, balance and falls, cognition, affect, wellbeing and user experience

TABLE 2 | Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Agmon et al. (2011)	*N* = 7 Mean Age = 84.0 Gender: 3 M:4 F	Healthy	Quasi-Experiment	Non-Immersive VR	Wii Balance Board	Nintendo Wii Fit exergames with balance board to improve balance in older adults Played for an average of 50, half hour sessions
Anderson-Hanley et al. (2011)	*N* = 14 Mean Age = 78.1 Gender: 1 M:13 F	Healthy	RCT	2D VR	Stationary Bicycle	Cybercycle over 1 month period with virtual competitors to examine the effect of social facilitation and competitiveness on exercise in exergaming
Anderson-Hanley et al. (2012)	*N* = 63 Mean Age = 78.69 Gender: 17 M: 62 F	Healthy	RCT	2D VR	Stationary Bicycle	Cybercycle and stationary bicycle groups: 1 month familiarization period. Participants asked to gradually increase their exercise frequency to 45 min per session, five-times/week for an additional 3 months
Anderson-Hanley et al. (2014)	*N* = 30 Mean Age = 79.5 Gender: 17 M: 46 F	Healthy	Quasi-Experiment	2D VR	Stationary Bicycle	Cybercycle and stationary bicycle groups: gradually increase exercise to 45 min, 5 days/week for 3 months
Bacha et al. (2018)	*N* = 46 Mean Age = 69.3 Gender: 12 M: 34 F	Healthy	Non Randomized Pilot Trial	Non-Immersive VR	Xbox Console and Kinect Camera	Xbox 360 and Kinect Camera Kinect Adventures Games and Conventional physical therapy groups: 14 1 h training sessions, twice/week
Barbosa et al. (2019)	*N* = 12 Mean Age = 70.1 Gender: 4 M: 8 F	Dizziness + Unilateral Vestibular Hypo-function	RCT	Non-Immersive VR	Xbox Console and Kinect Camera	Xbox 360 and Kinect camera VR and Control Group: Three times/ week over a 5 week period
Bell et al. (2011)	*N* = 21 Age: 60–90+ Gender: 5 M: 16 F	Assisted Living Facility	Repeated Measures Design	Non-Immersive VR	Wii Consoles	Nintendo Wii Console over an 8 week period, playing one bowling game on each weekly session to examine effects on quality of life, social relationships and confidence in ability to prevent falls
Benoit et al. (2015)	*N* = 18 Mean Age = 68.2 Gender: 11 M: 7 F	MCI	Quasi-Experiment	2D VR	BARCO	BARCO iSpace VR system with projectors to display a familiar image-based virtual environment. Participants spent a maximum in 15 min in two VR conditions (7 min each) and after each condition were asked whether they recognized the environment they saw
Bisson et al. (2007)	*N* = 24 Mean Age = 74.4 Gender: 10 M: 14 F	Healthy	RCT	Non-Immersive VR	IREX	IREX 3D VR displayed on 3D screen VR and Biofeedback Training Groups: Two 30 min sessions/week for 10 weeks
Blackman et al. (2007)	*N* = 38 Age: 71–84 Gender: 19 M: 19 F	Dementia	Quasi-Experiment	2D VR	Joystick/Controller	Images of a town center on a PC projected onto a large 6 × 2 m screen with ambient street sounds. Participants interacted with the environment using a joystick
Cacciata et al. (2019)	*N* = 614 Mean Age = 73.6 Gender: 204 M: 413 F	Not Specified	Systematic Review			RCT's that evaluated the effect of exergaming on health-related QoL in older adults and published between 2007 and 2017
Chan et al. (2010)	*N* = 27 Mean Age = 66.1 Gender: 18 M: 9 F	Long-Term Care	RCT	Non-Immersive VR	IREX	IREX 3D VE displayed on a 2D screen Ten, 15 min long sessions of two VR activities over a period of 5 weeks

(Continued on following page)

TABLE 2 | (*Continued*) Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Choi and Lee (2019)	*N* = 60 Mean Age = 76.3 Gender: 9 M: 51 F	Mild Cognitive Impairment	Quasi-Experiment	2D VR	Custom Scenario: 2D Display Screen	1st person video recorded and viewed on a projector screen VKP Group: Two 60 min sessions/week for 6 weeks Control Group: Performed home exercises for the same time period
Corno et al. (2014)	*N* = 10 Age: Over 60 years Gender: 6 M: 5 F	Healthy	Exploratory Study	VR	Joystick/Controller and HMD	HMD with tracker and wand for interaction. Participants interacted with a VR apartment and were required to achieve eight tasks as part of the virtual memory training program
Coyle et al. (2015)	*N* = 664 Mean Age = 76 Gender: Not Specified	MCI and Dementia	Systematic Review			Search included computerized training and interventions for older adults with memory impairment between 2000 and 2014
Eggenberger et al. (2015)	*N* = 71 Mean Age = 78.9 Gender: 25 M: 46 F	Healthy	Quasi-Experiment	2D VR	Dance Platform	Dance Platform–2D VE displayed on screen Two 1 h training sessions/week with at least 1 day between sessions for recovery over a 6 month period, leading to a total of 52 sessions for all three groups (Dance, Memory, and Phys)
Fasilis et al. (2018)	*N* = 10 Mean Age 73.6 Gender: Not Specified	Mild Dementia	Study Design	2D VR	Joystick/Controller	3D VE displayed on a 2D screen Three training sessions for 1 h each No Control Group
Felnhofer et al. (2014)	*N* = 124 Mean Age = 46.2 Gender: 62 M: 62 F	Healthy younger and older adults	Quasi-Experiment	VR	Joystick/Controller and HMD	HMD with smart phone controller, displaying a virtual café Participants completed a set list of tasks in the VE
Franco et al. (2012)	*N* = 23 Mean Age = 78.2 Gender: 7 M: 25 F	Healthy	RCT	Non-Immersive VR	Wii Balance Board	Wii Fit and Balance Board Participants met for individual sessions twice/week for three weeks. Each exercise session lasted 10–15 min and participants played 5 different games Matter of Balance program. Participants attended group exercise sessions (30–45 min) twice/week for 3 weeks
Gamito et al. (2010)	*N* = 10 Mean Age = 63.5 Gender: Male Only	PTSD War Vets	Quasi-Experiment	VR	HMD	3D VE in HMD. VRET and EI Group: 12 sessions
Gamito et al. (2019)	*N* = 25 Mean Age: 65–74 Gender: 4 M: 21 F	Healthy	Quasi-Experiment	2D VR	Keyboard/Mouse	3D VE displayed on a 2D monitor with mouse and keyboard Intervention performed twice a week for a total of twelve 30 min sessions No Control Group
Glännfjord et al. (2017)	*N* = 8 Mean Age: 78.0 Gender: 6 M: 2 F	Healthy	Observation and Qualitative Interview	Non-Immersive VR	Wii Consoles and Wii Remote	Wii Sport Bowling Participants met with the researcher on nine occasions over a 17 week period for an approximate total time of 15.5 h
Gomes et al. (2018)	*N* = 30 Mean Age: 84.0 Gender: 2 M: 28 F	Frail and Pre-frail	RCT	Non-Immersive VR	Wii Consoles and Wii Remote	Wii Fit Plus Participants attended 14 training sessions, lasting 50 min each, twice/week. In each session, participants played five of 10 selected games, with two attempts at each game

(Continued on following page)

TABLE 2 | (*Continued*) Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Hsieh et al. (2018)	*N* = 60 Mean Age = 78.2 Gender: 17 M: 43 F	Cognitive Impairment	Non-Randomised Control Trial	Non-Immersive VR	Xbox Console and Kinect Camera	Xbox 360 and Kinect camera VRTC Group: 50 min group sessions, twice/week for 24 weeks Control Group: Maintain usual daily physical activities for the 6 month period
Kahlbaugh et al. (2011)	*N* = 35 Mean Age = 82.0 Gender: 4 M: 32 F	Healthy	RCT	Non-Immersive VR	Wii Remote	Wii Console and Wii Remote Wii and TV Group: 1 h/week for 10 weeks Control Group: maintained current lifestyle
Karahan et al. (2015)	*N* = 52 Mean Age = 70.2 Gender: Female Only	Healthy	Non-RCT	Non-Immersive VR	Xbox Console and Kinect Camera	Xbox 360 and Kinect Motion Sensor, Dance Central Participants attended three dance training sessions per week for 12 weeks
Kizony et al. (2006)	*N* = 16 Mean Age = 70.6 Gender: 5 M:7 F:4 Not specified	Healthy and Neurological Deficits	Quasi-Experiment	Non-Immersive VR	IREX	PC with webcam. Java based visual interaction system Healthy participants interacted with the system for one 20–30 min session. After training, participants played two games for 5 min each Participants with neurological symptoms also interacted with the system for one 30 min session with an occupational therapist and they played 3 different games For one participant who suffered a stroke, the system was installed at home and his wife trained to use the system. They recorded what games/how long he played for
Kizony et al. (2010)	*N* = 22 Mean Age = 69.2 Gender: 11 M: 11 F	Healthy and Post Stroke	Observation	2D VR	Treadmill	VE of a grocery store aisle with a custom built treadmill using a computer assisted rehabilitation environment system (CAREN) to synchronize treadmill speed and scene progression Participants we provide with instructions (how many items to collect) in various ways (listed together, sequentially etc.)
Korsgaard et al. (2019)	*N* = 7 Mean Age = 80.2 Gender: 1 M:6 F	Mobility Problems	Qualitative	AR	Augmented Reality Environment	Oculus Rift HMD with a GoPro helmet mount connected to a VRREeady PC, a green table cloth used to help the software separate the table elements from the surrounding environment. Virtual elements created in Unity and librealsense API used to align real world color and depth images Participants were provided with three desserts and ate them while interacting with the mixed reality environment

(Continued on following page)

TABLE 2 | (*Continued*) Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Knowles et al. (2017)	*N* = 27 Mean Age = 67.2 Gender: 9 M: 21 F	Recently Bereaved	Quasi-Experiment	2D VR	Keyboard/Mouse and MMORPG	3D VE displayed on a 2D screen with mouse and keyboard VR Support Group: 1 h, twice/week on non-consecutive days for 8 weeks (16 sessions) Control Group: One reading on grief/ week approx. 1 page in length. Time online was tracked
Laver et al. (2012)	*N* = 44 Mean Age = 85.0 Gender: 9 M:35 F	Acute Care Patients Currently Hospitalized	RCT	Non-Immersive VR	Wii Balance Board	Wii Fit and Balance Board Gaming Participants: Played games using the Wii console for 25 min each day, 5 days per week during their hospital stay Control Participants: took part in conventional physiotherapy throughout their hospital stay
Lee and Shin (2013)	*N* = 55 Mean Age = 74.3 Gender: 16 M: 39 F	Diabetes Mellitus	RCT	Non-Immersive VR	PlayStation and EyeToy Camera	PlayStation 2 and EyeToy Exercise Group: 50 min twice/week for 10 weeks Exercise and Control Group: Received health education throughout this time
Lee et al. (2015)	*N* = 47 Mean Age = 68.24 Gender: Female Only	Healthy	RCT	Non-Immersive VR	Xbox Console and Kinect Camera	Xbox 360 and Kinect Camera Individualized feedback-based VR and Group-based Exercise Groups: 60 min intervention, 3 times/week for 8 weeks
Levy et al. (2016)	*N* = 16 Mean Age = 70.53 Gender: 6 M: 10 F	Healthy	RCT	Non-Immersive VR	PlayStation and EyeToy Camera	PlayStation 2 and EyeToy Treatment Group: Twelve, 40 min sessions, once/week Control Group: Waiting List
Lee et al. (2017)	*N* = 40 Mean Age = 75.93 Gender: 17 M: 23 F	Healthy	Open Label Trial	Non-Immersive VR	Joystick/Controller; Treadmill and Wii Balance Board	Wii Console, Balance Board and Joystick Experimental Group: Two, 60 min training sessions/week for 6 weeks Experimental Group and Control Group: Three sessions of fall prevention education during weeks 1, 3, and 5
Liu (2010)	*N* = 128 Mean Age = 69.5 Gender: 64 M: 64 F	Healthy	Quasi-Experiment	2D VR	Keyboard/Mouse	Virtual shop displayed on a 19" LCD TV. The shop contained four show-rooms, with 144 goods displayed and each showroom had approx. 36 pieced. Objects were displayed as either 2D or 3D

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TABLE 2 | (*Continued*) Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Lokka et al. (2018)	*N* = 81 Mean Age = 48.5 Gender: 41 M: 40 F	Healthy Younger and Older Adults	Controlled Experiment	2D VR	Videos	Large Projection screen 2.2 m from participants Participants were shown a representative image from each of the three VE (displaying various routes) and asked to rate their preference for hypothetical route learning tasks. Next, participants were given a scenario where someone takes them to a market in an unfamiliar neighborhood and they were told to memorize the route as they would need to navigate the same route themselves unsupervized. This initial session took approx. 1–1 h 40 min. Later participants were brought back for a second session approx. 40 min–1 h
Man et al. (2012)	*N* = 44 Mean Age = 80.29 Gender: 5 M: 39 F	Questionable Dementia	RCT	2D VR	Joystick/Controller	3D VE displayed on 2D screen with keyboard and joystick VR-based and therapist-led memory training groups: 10 individual sessions for 30 min each, two–three times/ week
Manera et al. (2016)	*N* = 57 Mean Age = 75.65 Gender: 32 M: 25 F	MCI and Dementia	Quasi-Experiment	2D VR	BARCO	Barco OverView full HD 3D stereoscopic LED video wall 1.55 × 1.74 m Participants were asked to identify target characters in a series of increasingly complex levels. Participants were only allowed to progress in levels after the initial five targets are found Participants sat at a distance of 1.9 m while wearing 3D LCD shutter glasses and interacted with the VE using a wireless mouse
Marivan et al. (2016)	*N* = 8 Mean Age = 87.4 Gender: 4 M: 4 F	Healthy	Experiment	Non-Immersive VR	Joystick/Controller	PC, video projector and joystick Participants were asked to get their avatar to walk in a straight line along a corridor over a period of 1 week including 3–5 sessions day
Matas et al. (2015)	*N* = 88 Mean Age = 72.8 Gender: 54 M: 34 F	Post-Fall Rehabilitation	Cohort Survey	2D VR	Joystick/Controller and Driving Simulator	3D VE displayed on 2D screen with gaming wheel and peddles Participants sat at a desk chair and controlled a virtual car using a small gaming wheel and pedals Practice drive of 10 min.Drive 1: 15 min Drive 2: 15 min with additional attention tasks
Merriman et al. (2015)	*N* = 76 Mean Age = 74.18 Gender: 16 M: 60 F	Fall-Prone + Healthy	RCT	Non-Immersive VR	Wii Balance Board	Wii Console and Balance Board Intervention Group: Two, 30 min sessions of balance training/week for 5 weeks Control Group: Keep a diary of daily light, moderate and heavy physical activities

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TABLE 2 | (*Continued*) Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Merriman et al. (2018)	*N* = 56 Mean Age = 71.8 Gender: 21 M: 35 F	Healthy and Fall-Prone	RCT	Non-Immersive VR	Wii Balance Board	Nintendo Wii Balance Board with waist high support frame. Software: CityQuest Participants took part in two pre-training sessions followed by 10 training sessions with an average of two sessions/week over 5 weeks. Sessions lasted approx. 60 min
Miller et al. (2014)	*N* = 355 Mean Age = 82.28 Gender: Not Specified	Healthy and Neurologically Impaired	Systematic Review			Search for gaming and virtual reality with older adults between 2000 and 2012
Mirelman et al. (2011)	*N* = 20 Mean Age = 67.1 Gender: 14 M: 6 F	Parkinson's Disease	RCT	2D VR	Treadmill	3D VE on a 2D screen with treadmill Intervention: Three sessions/week for 6 weeks No Control Group
Monteiro-Junior et al. (2017)	*N* = 19 Mean Age = 86.0 Gender: 3 M: 16 F	Long-Term Care	Quasi-Experiment	Non-Immersive VR	Wii Consoles	Wii Console Wii Group: 1 h of exergaming with resting periods included Control Group: 30–45 min of exercising
Morone et al. (2016)	*N* = 38 Mean Age = 68.9 Gender: Female Only	Bone Loss	Quasi-Experimental	Non-Immersive VR	Wii Balance Board	Wii Fit and Balance Board Participants in both the Wii group and the control group took part in 1 h training exercises, 2 days/week for 8 weeks. Exercises were supervised by two physiotherapists
Optale et al. (2010)	*N* = 36 Mean Age = 80.0 Gender: 12 M: 24 F	Memory Impaired	RCT	VR	Joystick/Controller and HMD	HMD with PC and joystick VRMT: 6 months of virtual reality memory training including auditory stimulation and VR experiences in path finding. 3 months initial training, with 3 auditory and 3 VR sessions every 2 weeks) and 3 months booster training (1 auditory and 1 VR session per week) Control Group 6 months face-to-face music therapy
Padala et al. (2012)	*N* = 22 Mean Age = 80.4 Gender: 6 M: 16 F	Alzheimer's Dementia	Prospective Randomized Pilot Study	Non-Immersive VR	Wii Consoles	Wii Console Nintendo Wii Fit and Walking group: 30 min' activity/day, five times/week, for 8 weeks
Padala et al. (2017a)	*N* = 30 Mean Age = 68.0 Gender: 26 M: 4 F	Veterans	Prospective Randomized Pilot Study	Non-Immersive VR	Wii Consoles	Wii Console Wii Fit Group: 45 min, 3 days/week for, 8 weeks Control Group: A computer-based cognitive program for 45 min, 3 days/week, for 8 weeks
Padala et al. (2017b)	*N* = 30 Mean Age = 73.0 Gender: 38 M: 22 F	Mild Alzheimer's Disease	Quasi-Experimental	Non-Immersive VR	Wii Consoles	Wii Console Wii and Walking Groups: 30 min, 5 days/week for 8 weeks

(Continued on following page)

TABLE 2 | (*Continued*) Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Parijat et al. (2014)	*N* = 24 Mean Age = 72.35 Gender: 12 M: 12 F	Healthy	Quasi-Experimental	VR	Treadmill and HMD	HMD with treadmill where virtual slips are created by tilts in pitch plane of the VR scene at random intervals Baseline Measure: Walk approx. 10 min to gather slip data Training acquisition: Control group, normal walking for 10–15 min. Training group, 5 min walking with harness on treadmill, 15 min with HDM on treadmill where virtual slips may occur Transfer of Training: 1 day later, participants returned to the baseline measure location and matched walking pace to the first meeting. A final slip trial was conducted
Rodrigues et al. (2018)	*N* = 47 Mean Age = 70.2 Gender: Female Only	Fallers vs. non-fallers	RCT	Non-Immersive VR	Xbox Console and Kinect Camera	Xbox 360 and Kinect Camera Intervention Group: 12 weeks of video game dance training. 40 min sessions, three times/week Control Group: Maintained their current lifestyle
Rosenberg et al. (2010)	*N* = 19 Mean Age = 78.7 Gender: 6 M: 13 F	Subsyndromal Depression	Quasi-Experimental	Non-Immersive VR	Wii Consoles	Wii Console Participants completed a 12 weeks intervention, playing Wii Sports for 35 min, three times per week
dos Santos Mendes et al. (2012)	*N* = 27 Mean Age = 68.65 Gender: Not Specified	Parkinson's and Healthy	Longitudinal Controlled Clinical Study	Non-Immersive VR	Wii Consoles and Wii Remote	Wii Console and Wii Fit Participants took part in 14 twice-weekly individual training sessions overseen by a physiotherapist. Sessions included 30 min warm-up. Afterward, participants played five games, twice. At the end of the 14 week period, participants received two attempts at 10 Wii Fit games
Sápi et al. (2019)	*N* = 75 Mean Age = 68.62 Gender: 6 M: 70 F	Healthy	RCT	Non-Immersive VR	Xbox Console and Kinect Camera	Xbox 360 and Kinect Camera Kinect and Conventional Balance Groups: 30 min training, three times/ week for 6 weeks
Sauzéon et al. (2016)	*N* = 60 Mean Age 44.4 Gender: Not Specified	University (Younger) Community Leisure Institutions	RCT	2D VR	Keyboard/Mouse	3D VE displayed on 2D screen with mouse and keyboard There were two learning trials were participants were participants watched a target version of the apartment (which is presented twice) Each participant was asked to complete a free recall task immediately after each presentation The same instructions were repeated before the presentation of the second version
Smaerup et al. (2016)	*N* = 57 Mean Age = 70.21 Gender: 21 M: 36 F	Chronic Dizziness	RCT	2D VR	Webcam. Keyboard/ Mouse	PC with webcam Software: "Move It to Improve It" Participants played a series of individual games each day for 20–30 min for 12 weeks
Studenski et al. (2010)	*N* = 25 Mean Age = 80.2 Gender: 5 M: 20 F	Healthy	Quasi-Experimental	2D VR	Xbox Console and Kinect Camera and Dance Platfrom	TV and DanceTown™. Participants took part in supervised dance sessions with the aim of completing 24 sessions in a three-month period. Sessions two place twice per week for 30 min each

(Continued on following page)

TABLE 2 | (*Continued*) Study details.

Article	Participants	Population	Design	AR/VR Category	AR/VR Equipment	Protocol
Sun et al. (2019)	*N* = 29 Mean Age = 77.5 Gender: Female Only	Osteopenia or Osteoporosis	Quasi-Experimental	2D VR	Xbox Console and Kinect Camera	Kinect Camera, PC and 2D screen Participants took part in a series of fall risk assessments with FRAAn (a fall risk assessment avatar) guiding each session. Each session lasted approx. 20 min
Tsuda et al. (2016)	*N* = 16 Mean Age = 66.81 Gender: 10 M: 6 F	Hematologic Malignancies receiving Chemotherapy	Quasi-Experimental	Non-Immersive VR	Wii Balance Board	Nintendo Wii Fit and Balance Board Participants took part in two physical activities one-on-one with a physical therapist for approx. 20 min, each day, five times/week from the beginning of chemotherapy until hospital discharge
Vallejo et al. (2014)	*N* = 36 Mean Age = 70.5 Gender: 22 M: 14 F	Healthy	Quasi-Experimental	Non-Immersive VR	Joystick/Controller	PC, TV screen, joystick, touchpad and game controllers. Software: 3D Memory Island Participants tried out four different interfaces. Their task was to guide an avatar through a pathway to reach a goal by following the navigation signs along the way
De Vries et al. (2018)	*N* = 30 Mean Age = 69.62 Gender: 10 M: 20 F	Healthy	Quasi-Experimental	Non-Immersive VR	Xbox Console and Kinect Came and Wii Consoles	Wii Console (two games), Xbox Kinect (four games), Dynstable (two games) Participants in all three conditions, played each game three times except for two games in the Xbox condition which were longer so were only played once
Williams et al. (2011)	*N* = 22 Mean Age = 83.86 Gender: 4 M: 18 F	Healthy	Quasi-Experimental	Non-Immersive VR	Wii Balance Board	Wii Fit and Balance Board Over 4 weeks participants completed 12, 20 min sessions using different games in the Wii Fit package
Yeh et al. (2019)	*N* = 294 Age = 61–76+ Gender: Not Specified	Healthy	Quasi-Experimental	Non-Immersive VR	Wii Consoles	Wii Console Participants played Wii Fit games for 10 weeks with an average 10 opportunities to play with the system and 2–4 people playing each game at the same time. A new group took over if the first became tired

VR, a virtual environment which envelops the user often through HMD's; Non-Immersive VR, a virtual environment where the user can see themselves or an avatar representing themselves within a virtual world; 2D VR, where the user interacts with a 3D virtual environment using a 2D monitor display but does not see themselves or an avatar representing themselves.

(UX). One measure looked at a person's motivations within a natural or therapeutic environment and was categorized as other.

AR/VR Equipment

The 65 studies included a combination of custom-made and commercially available virtual technologies. Custom systems usually consisted of a specially designed virtual environment displayed on a monitor or projector and interacted with using keyboard/mouse (*N* = 5), joystick/controller (*N* = 10) or, exercise equipment such as treadmills (*N* = 4) or stationary bicycles (*N* = 3). Other customized equipment included the BARCO™ (*N* = 2) and IREX™ (*N* = 3) systems. Commercially available systems included use of Xbox Console™ and Kinect Cameras™ (*N* = 10), PlayStation™ and EyeToy™ Cameras (*N* = 2) or, Wii Console™ (*N* = 11) with Wii Remote™ (*N* = 4) and Wii Balance Board™ (*N* = 9). Only six studies used HMDs to immerse users in a virtual (*N* = 5) or augmented (*N* = 1) environment. Alternate set-ups included: 1) a two custom scenarios where participants "rowed" along with a first person video displayed on screen (*N* = 1) or where participants memories a route (*N* = 1), 2) a bereavement study where the participants interacted with each other through "Second Life," a massively multiplayer online roleplaying game (MMORPG) (*N* = 1); 3), studies that looked at the impact of using dance platforms (*N* = 2); and 4) a study that looked at cybersickness and drop-out rates in a driving simulator (*N* = 1).

Virtual Reality Characteristics

This scoping review aimed to identify AR/VR technology used to support older adults' physical and/or mental health. However, only one augmented reality study (Korsgaard et al., 2019) was identified. As described earlier this paper categorized the technology used in each study as either: 1) 2D VR, 2)

TABLE 3 | Areas of research interest across 65 studies.

Study	Phys. Activity	General Health	Balance/ Falls	Cognitive	Affect	Quality of Life	UX	Other
Agmon et al. (2011)	✓		✓					
Anderson-Hanley et al. (2011)					✓		✓*	
Anderson-Hanley et al. (2012)				✓				
Anderson-Hanley et al. (2014)>	✓	✓		✓			✓	
Bacha et al. (2018)	✓		✓	✓				
Barbosa et al. (2019)	✓	✓	✓					
Bell et al. (2011)			✓			✓		
Benoit et al. (2015)				✓	✓		✓*	
Bisson et al. (2007)			✓					
Blackman et al. (2007)				✓		✓	✓*	
Cacciata et al. (2019)								✓**
Chan et al. (2010)				✓			✓	✓***
Choi and Lee (2019)	✓		✓	✓				
Corno et al. (2014)				✓			✓	
Coyle et al. (2015)								✓**
Eggenberger et al. (2015)				✓				
Fasilis et al. (2018)				✓				
Felnhofer et al. (2014)				✓			✓	
Franco et al. (2012)		✓	✓				✓	
Gamito et al. (2010)					✓	✓	✓	
Gamito et al. (2019)				✓	✓	✓		
Glännfjord et al. (2017)							✓*	
Gomes et al. (2018)	✓		✓	✓	✓		✓*	
Hsieh et al. (2018)	✓			✓	✓			
Kahlbaugh et al. (2011)	✓	✓			✓	✓		
Karahan et al. (2015)	✓		✓	✓	✓	✓		
Kizony et al. (2006)							✓*	
Kizony et al. (2010)				✓			✓*	
Korsgaard et al. (2019)							✓*	
Knowles et al. (2017)		✓			✓			
Laver et al. (2012)	✓		✓			✓		
Lee and Shin (2013)	✓		✓					
Lee et al. (2015)	✓	✓						
Levy et al. (2016)		✓	✓		✓			
Lee et al. (2017)	✓		✓					
Liu (2010)							✓*	
Lokka et al. (2018)				✓			✓*	
Man et al. (2012)				✓	✓	✓		
Manera et al. (2016)				✓	✓		✓*	
Marivan et al. (2016)				✓			✓*	
Matas et al. (2015)		✓					✓	
Merriman et al. (2015)			✓	✓				
Merriman et al. (2018)			✓				✓	
Miller et al. (2014)								✓**
Mirelman et al. (2011)		✓		✓		✓		
Monteiro-Junior et al. (2017)				✓				
Morone et al. (2016)		✓	✓		✓			
Optale et al. (2010)				✓	✓	✓		
Padala et al. (2012)	✓		✓	✓		✓		
Padala et al. (2017a)	✓	✓	✓	✓				
Padala et al. (2017b)			✓	✓		✓		
Parijat et al. (2014)			✓				✓*	
Rodrigues et al. (2018)	✓		✓		✓			
Rosenberg et al. (2010)		✓		✓	✓			
dos Santos Mendes et al. (2012)				✓	✓		✓*	
Sápi et al. (2019)	✓		✓					
Sauzéon et al. (2016)				✓			✓*	
Smaerup et al. (2016)	✓		✓			✓		
Studenski et al. (2010)	✓	✓	✓	✓				
Sun et al. (2019)	✓		✓				✓	
Tsuda et al. (2016)	✓				✓	✓	✓*	
Vallejo et al. (2014)							✓	
De Vries et al. (2018)				✓	✓		✓*	

(Continued on following page)

TABLE 3 | (*Continued*) Areas of research interest across 65 studies.

Study	Phys. Activity	General Health	Balance/ Falls	Cognitive	Affect	Quality of Life	UX	Other
Williams et al. (2011)			✓					
Yeh et al. (2019)							✓*	

**Studies that include UX questions, but not standardized measures.*
***Systematic Reviews.*
****Study uses the Volitional Questionnaire, which does not fit into the above categories.*

TABLE 4 | Virtual reality definitions.

Article	Definition
Bacha et al. (2018)	"VR is defined as the simulation, in real time, of an environment, scenario, or activity where the individual can interact"
Barbosa et al. (2019)	"Virtual reality is defined as the human-machine connection, where situations occur that can be compared to those experienced during daily life, thus, the individual experiences a considerable number of stimuli through interaction with the proposed scenario."
Benoit et al. (2015)	VR "a computer-simulated environment that can provide the sensation of physical presence in places representing real or imagined worlds"
Bisson et al. (2007)	Virtual Reality is defined as "a computerized simulation in two or three dimensions that is in real time and interactive."
Chan et al. (2010)	"VR entails the use of advanced technologies, including computers and various multimedia peripherals, to produce a relatively lifelike situation that users perceive as comparable with real-world objects and events."
Choi and Lee (2019)	Virtual reality is "a computer-simulated environment and interaction of computer-generated experience used to enhance physical or psychological function in another place"
Glännfjord et al. (2017)	Virtual Reality is a "computer-generated simulation that creates a realistic looking world."
Hsieh et al. (2018)	"A type of user-computer interface that implements real-time simulation of an activity or environment that allows user interaction *via* multiple sensory modalities"
Kizony et al. (2010)	Virtual Reality: "the use of interactive simulations created with computer hardware and software to introduce users to opportunities to interact in environments that seem and feel similar to the real world."
Korsgaard et al. (2019)	Mixed Reality: the concept of experiencing the real and virtual world at the same time as a coherent and perceivable merged reality
Levy et al. (2016)	Virtual Reality "involves the creation of an interactive computer-generated, three-dimensional (3D) environment"
Marivan et al. (2016)	VR "interactive simulations that create environments that appear and feel similar to real world objects and events."
Optale et al. (2010)	VR is an experiential interface in which the components of perception (visual, tactile, and kinaesthetic) are the bases for interactivity, encouraging a sense of "being there"–that is, the sensation of being actually inside the virtual environment
Parijat et al. (2014)	VR "an approach to generate simulated, interactive, and multidimensional environments on a head-mounted display (HMD) or on a computer monitor."
dos Santos Mendes et al. (2012)	Virtual Reality "A computer-based technology providing a multisensorial environment with which the user can interact."
Yeh et al. (2019)	VR "a computer-generated reality that allows users to enter a virtual world through a computer interface"

Non-Immersive VR, 3) Immersive VR and 4) AR. Despite self-identifying as Immersive VR, 16 of 21 studies were in fact 2D VR. The remaining five studies correctly identified themselves as either a "virtual environment" (Liu, 2010; Fasilis et al., 2018; Lokka et al., 2018), a video game (Studenski et al., 2010) and a virtual avatar (Sun et al., 2019). This review categorized 35 studies as non-immersive VR but, only seven of these studies did not include the phrasing "Immersive VR" or "virtual reality" in their interventions. Five papers described themselves as "exergames" (Rosenberg et al., 2010; Franco et al., 2012; Karahan et al., 2015; Padala et al., 2017a; Padala et al., 2017b), one as a videogame (Laver et al., 2012), one as a "virtual environment" (Merriman et al., 2015) and one only described the type of console used (Padala et al., 2012). Finally, five studies can be categorized as "Immersive VR" (Gamito et al., 2010; Optale et al., 2010; Corno et al., 2014; Parijat et al., 2014; Lokka et al., 2018) and each study accurately described itself as such. Despite the large number of studies included in this review, only 16 provided a definition for virtual reality (See **Table 4**), one offered a definition for virtual reality exposure therapy (Barbosa et al., 2019) and one described "mixed reality" (Korsgaard et al., 2019).

Usability and Virtual/Augmented Technologies

Over a third of the studies included in this review directly investigated the usability and feasibility of various AR/VR systems for use with older populations to support physical and mental health and wellbeing. However, only ten of these studies used standardized questionnaires (see **Table 3**) to evaluate participants' sense of presence and the usability of each system. The remaining studies that included evaluations of usability or design provided their participants with bespoke questionnaires tailored to fit their purpose. Key findings from this group of studies indicated that there were no age differences (between older and younger users) in physical and social presence (Felnhofer et al., 2014), or in experience of cybersickness (Sauzéon et al., 2016). One study demonstrated a reduction in

TABLE 5 | Usability, Feasibility & Tailored Design.

Table 5: Usability, Feasibility & Tailored Design

	Factors	Anderson-Hanley et al., (2011)	Anderson-Hanley et al., (2014)	Benoit et al., (2015)	Blackman et al., (2017)	Chan et al., (2010)	Corno et al., (2014)	Felnhofer et al., (2014)	Franco et al., (2012)	Gamito et al., (2010)	Glännfjord et al., (2017)	Gomes et al., (2018)	Kizony et al., (2006)	Kizony et al., (2010)	Korsgaard et al., (2019)	Liu (2010)	Lokka et al., (2018)	Manera et al., (2016)	Marivan et al., (2016)	Matas et al., (2015)	Merriman et al., (2018)	Parijat et al., (2014)	Dos Santos Mendes et al., (2012)	Sauzéon et al., (2019)	Sun et al., (2019)	Tsuda et al., (2016)	Vallejo et al., (2014)	De Vries et al., (2018)	Yeh et al., (2019
Usability Factors	Accessibility																												
	Challenge																				✓								
	Choice		✓																								✓		
	Clear & Simple Design & Instructions				✓		✓									✓	✓												
	Combining UI																										✓		
	Comfort	✓													✓														
	Consistency of Virtual Environment						✓																						
	Ease of Use										✓															✓			
	Engagement																	✓											
	Enjoyment								✓		✓	✓							✓		✓					✓		✓	✓
	Matching			✓								✓			✓														
	Motivation																	✓	✓		✓						✓	✓	✓
	Simple UI						✓																						
	Social Interaction										✓																		
	Value																											✓	✓
Feasibility	Feasibility									✓			✓	✓								✓			✓				
	Gender Differences																			✓									
	Participant Ability																										✓		
	Safety	✓				✓																				✓			
	Tasks Designed to Population																												
	Understanding														✓														
Tailored Design	Active Navigation																							✓					
	Education & Interaction with Technology							✓																					
	Equipment Training						✓																						
	Immersion						✓											✓											
	PPI																												
	Realism																✓		✓										
	Transfer/Retention of Skills																						✓						

cybersickness with older adults with schizophrenia (Chan et al., 2010), another indicated that most of their PTSD patients reported no negative effects after exposure to a virtual environment displayed in an HMD. Despite this, research still maintains that older adults are a high-risk group for cybersickness (Matas et al., 2015). One study did find a gender difference in level of presence, where men were more likely to experience a greater sense of presence (Felnhofer et al., 2014).

Analysis of the 28 studies that considered UX design of AR/VR environments (See **Table 5**), and the technologies used has established three main categories, each with further sub-categories, to describe the factors by. These include usability, feasibility, and tailored design.

Usability

Enjoyment ($N = 8$) and Motivation ($N = 6$) are the most common themes with researchers identifying them as vital to user engagement. Additional themes included, clear and simple design/instructions ($N = 4$), Matching ($N = 3$), Value ($N = 2$), Ease of Use ($N = 2$), Comfort ($N = 2$) and Choice ($N = 2$). The remaining themes within the category of Usability each had one mention and they included, Accessibility, Challenge, Combining UI,

TABLE 6 | Theories supporting AR/VR methodologies.

Article	Theory	Domain	Summary
Anderson-Hanley et al., (2011)	Social Facilitation Theory (Allport, 1955)	Social	"behavior in simple tasks is improved in the presence of others" (pp. 275–276)
	Generalized Drive Hypothesis (Zajonc, 1965)	Social	"social facilitation increases one's innate internal drive and activation levels, which are found to be elevated in competitive environments." (p. 276)
Anderson-Hanley et al., (2014)	Theory of Planned Behavior (Ajzen, 1991)	Social	"people's attitudes and beliefs about objects and themselves influence their participation in health-relevant behaviors" (p. 2)
	Temporal Self-Regulation Theory (Hall and Fong, 2007)	Biopsychosocial	"people decide to engage in immediate behaviors that yield later, but not immediate, effects." (p. 2)
Fasilis et al., (2018)	Theory of Interactive Cognitive Complexity (Tennyson and Breuer, 1997)	Cognitive	"simulation games are more effective than other instructional methods, because they simultaneously engage trainees' affective and cognitive processes." (p. 43)
	Decomposition Hypothesis (Anderson, 2002)	Cognitive	"the daily presented tasks that we face in our life, complex and non-complex, can be degraded, decomposed, into equally fundamental actions, and by training ourselves in those actions/operations, we can get improved overall." (p. 47)
Felnhofer et al., (2014)	Social Influence Theory (Kelman, 1958)	Social	"to explain why people, tend to react to virtual characters as if they were real: (i) agency as the user's belief that the avatar is being controlled by a human in contrast to a computer, (ii) communicative realism as the believability of the avatar's communicative behavior." (p. 273)
Glännfjord et al., (2017)	Social Interaction Theory (Vygotsky, 1978)	Social	"keeping an active life is important when growing older." (p. 334)
	Activity Theory (Havighurst, 1961)	Social	"it is important to keep active while growing older and to socially interact with others." (p. 334)
Kahlbaugh et al., (2011)	Theory of Active Engagement (Rowe and Kahn, 1997)	Social	The "positive role of activity in supporting a sense of purpose or place *via* role support." (p. 332)
Lokka et al., (2018)	Dual Channel Theory (Mayer and Moreno, 2003)	Cognitive	"people do not rely *only* on visuospatial memory systems for key executive functions such as the encoding, storage and recall of information." (p. 2)
Merriman et al., (2018)	Theory of Planned Behavior (Ajzen, 1991)	Social	"beliefs and attitudes can predict intentions and behavior."
	Cognitive Load Theory (Sweller, 1980)	Cognitive	"If too much cognitive load is present in a complex learning environment, performance may be hindered due to insufficient working memory resources available to complete the task at hand ." (p. 552)
De Vries et al., (2018)	Means-End Theory	Cognitive	"consumers or players in this case will prefer one game to another because of how certain attributes or game mechanics lead to certain benefits, or desired consequences, or ultimately tailor to the goals or values a player seeks." (p. 2)

Consistency of Virtual Environment, Engagement, Simple UI and Social Interaction.

Feasibility

Feasibility (N = 5), Safety (N = 3), Gender Differences (N = 1), Participants Ability (N = 1), Tasks Designed to Population (N = 1) and Understanding (N = 1) were sub-categories identified across the research studies.

Tailored Design

Finally, there were seven suggestion/outcome sub-categories identified. These included, Realism (N = 2), Active Navigation (N = 1), Education and Interaction with Technology (N = 1), Equipment Training (N = 1), Immersion (N = 1), Public and Patient Involvement (PPI) (N = 1), and Transfer/Retention of Skills (N = 1).

Intervention-Based Theories

This paper outlines four popular theories that can be applied to AR/VR research; perceptual control theory, Self-affirmation theory, the transtheoretical model of behavior change and the transformative learning theory. However, none of these theories were considered by the studies included in review. Instead, 13 additional theories were used to support the AR/VR methodologies used in those papers (See **Table 6**) and only the theory of planned behavior (Anderson-Hanley et al., 2012; Merriman et al., 2018) was cited twice. Overall, the theories that were cited focused on either the impact of the surrounding environment (Anderson-Hanley et al., 2011; Felnhofer et al., 2014; Glännfjord et al., 2017)' the intrinsic motivations of the individual (Anderson-Hanley et al., 2011; Kahlbaugh et al., 2011; Anderson-Hanley et al., 2014; Glännfjord et al., 2017; De Vries et al., 2018) or the complex cognitive processes occurring in the unconscious (Fasilis et al., 2018; Lokka et al., 2018; Merriman et al., 2018).

DISCUSSION

This scoping review was undertaken to assess the variety and scale of AR/VR in use with older adults in relation to physical and mental health and wellbeing. As this study was completed in the first half of 2020, it includes the most recent relevant articles from 2019. Findings from this review, indicate that AR is not readily being used with this population in a health setting. More studies are using non-immersive VR (53%) compared to 2D VR (32%), but research of this kind is less likely to define VR before including it in the methodology.

TABLE 7 | Usability, feasibility and design considerations.

Study	Measures	Key Elements	Detailed Description of Usability, Feasibility and Design Considerations
Anderson-Hanley et al. (2011)	No standardized UX measures	• Safety • Comfort	This study uses an exercise bike. Design considerations included ensure the safety and comfort of older adult participants to help reverse negative thinking about exercise
Anderson-Hanley et al. (2014)	Cybercycling Attitudes Test (CAT)–1 Item Likert	• Choice	Giving participants choice to continue in whatever group they choose after the RCT is completed is a good way to continue to engage participants in research
Benoit et al. (2015)	Cybersickness Questionnaire–22 Items) Spatial Presence Questionnaire	• Virtual/Real World Matching	Using physical apparatus (e.g., chair) as part of the immersive experience may help to ground older users in the virtual environment and reduce cybersickness (i.e., the user is sitting in the VE, the user is also seated in real life)
Blackman et al. (2007)	No standardized UX measures	• Clear and Simple Design/ Instructions	No discussion regarding usability, feasibility or design considerations for technology used, however the study does discuss the importance clear and simple of building design so those with cognitive impairment can navigate the space with ease
Chan et al. (2010)	Simulator Sickness Questionnaire–16 items	• Safety	The researchers discuss the safety of virtual environment to older adult participants with schizophrenia based on a lack of simulator sickness. Factors which contribute to this low score include immersion in a 2D space and the use of projector screens instead on HMD's
Corno et al. (2014)	System Usability Scale–10 items	• Clear and Simple Design/ Instructions • Simple User Interface • Consistency of Virtual Environment • Equipment Training • Tasks designed to population • PPI	Three factors • Task related issues–where instructions are too long or complex • Hardware related issues–where participants had difficult using the input devices (e.g., wand) • Difficulties with the HMD directly (i.e., perception of the environment is inconsistent with expectations–colors are too bright etc. General suggestions • Dedicate more time to training participants how to use the environment/technology so they do not become distracted with learning how to do a task during the intervention • Re-design tasks and instructions for the sample population • Test the environment with the users to identify and resolve any technical problems as a direct result of the technology. This may include modifying the sensitivity and response interactions of the input devices
Felnhofer et al. (2014)	Social Presence Survey (SPS)–five items iGroup Presence Questionnaire (IPQ–14 items	• Education and Interaction with Technology	In terms of usability, the older adults in this study were highly educated. In conjunction with research that suggests a link between education and increase technology-related computer self-efficacy, the authors suggest that higher education level in older adults can explain a lack of age-related differences in experience of presence It is vital that older adults are willing to interact with the technology as this is a key factor in the experience of presence
Franco et al. (2012)	Wii Fit Enjoyment Questionnaire	• Enjoyment	Wii Fit exercise program is both feasible and enjoyable for older adults. This is important as enjoyment may result in continued engagement in research and exercise interventions
Gamito et al. (2010)	ITC SOPI	• Feasibility	No discussion regarding usability, feasibility or design considerations for technology used, however the study did consider the feasibility of using VR to treat PTSD in retired veterans
Glännfjord et al. (2017)	No standardized UX measures	• Enjoyment • Ease of Use • Social Interaction	Enjoyment was discussed as an important factor for continued engagement in the study. Also, many participants noted it was easier to play bowling using the Wii Console as there was no extra equipment required. The social component also factored into their continued attendance
Gomes et al. (2018)	No standardized UX measures	• Enjoyment• • Motion Matching	Enjoyment was mentioned as a factor in acceptable of the technology. Noted that games which included a stationary gait while taking quick steps, could result in adverse events, but they do not make recommendations to prevent or circumvent these risks

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TABLE 7 | (*Continued*) Usability, feasibility and design considerations.

Study	Measures	Key Elements	Detailed Description of Usability, Feasibility and Design Considerations
Kizony et al. (2006)	No standardized UX measures	• Feasibility	The equipment tested in this study can be used with older adults' post-stroke, however it is likely they will need assistance when the system is installed in their own home
Kizony et al. (2010)	No standardized UX measures	• Feasibility	As feasibility of the set-up was assessed in this study, no surface manipulations were made which facilitated participants attention on the specific tasks
Korsgaard et al. (2019)	No standardized UX measures	• User Interface–Comfort • Environment Matching • Understanding	Suggestions • Participants who wore glasses could use the HMD, but only if the glasses did not exceed dimensions • Potential for environmental factors to influence participant opinion (i.e., easting out-side in a VR may be more enjoyable if the real-life weather is cold outside) • Participants had difficulties understanding the ability to eat "anywhere" in mixed reality even after immersion in the MR environment
Liu (2010)	No standardized UX measures	• Clear and Simple Design/ Instructions	Suggestions • "Landmarks" are an important feature for older adults immersed in environments depicting a virtual shop
Lokka et al. (2018)	No standardized UX measures	• Clear and Simple Design/ Instructions • Realism	Suggestions • Route recall accuracy improves in mixed VR (image is a combination of abstract and photorealistic structures)–too much or too little information can negatively affect recall performance • A smaller number of older participants (compared with younger participants) initially preferred the realistic VE before the experiment, but still switched to the mixed VR afterward (38%), however unlike the younger participants, 54% continued to prefer the realistic environment
Manera et al. (2016)	No standardized UX measures	• Immersion • Engagement • Motivation	Noted that participants with Alzheimer's and Dementia preferred the VR condition due to immersion, engagement, and motivation to continue
Marivan et al. (2016)	No standardized UX measures	• Enjoyment • Realism • Motivation	Researchers noted the impact and importance of enjoyment, realism, and motivation to continue using the system
Matas et al. (2015)	Useful Field of View (UFOV) Divided Attention Subtest Simulator Sickness Questionnaire–16 items	• Gender Differences	SSQ can be used to predict dropout in older adults and females were more likely to drop-out than men; supporting research which suggests that women are more susceptible to both motion and simulator sickness.–Suggests drivers with a history of motion sickness not take part in immersive driving simulation studies
Merriman et al. (2018)	Game Experience Questionnaire (GEQ)	• Challenge • Motivation • Enjoyment	Evaluation of acceptability and game experience in health and fall-prone older adults. Both groups reported high acceptability scores though on average, fall-prone adults reported higher acceptability rates. Participants noted that the challenge of the games were their primary motivation to continue playing. Game enjoyment was also discussed, thought there was little difference between the population groups
Parijat et al. (2014)	No standardized UX measures	• Feasibility	No discussion regarding usability, feasibility or design considerations for technology used, however the study did consider the suitability of VR perturbation as a means of improving motor skills in older adults
dos Santos Mendes et al. (2012)	No standardized UX measures	• Transfer/Retention of Skills	People with Parkinson's disease may experience grater motor difficulties (compared with cognitively impaired and healthy older adult populations) while playing most Wii Fit games but, this does not impact their ability to learn and improve with practice nor, their ability to retain any benefits of training In contrast, those with cognitive impairments (particularly, difficulties with decision-making and working memory) were at greater risk of impeded learning in certain Wii games. This study adds credibility to the concept that effects of VR training is transferable and retained in Parkinson's patients

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TABLE 7 | (*Continued*) Usability, feasibility and design considerations.

Study	Measures	Key Elements	Detailed Description of Usability, Feasibility and Design Considerations
Sauzéon et al. (2016)	No standardized UX measures	• Active Navigation	No discussion regarding usability, feasibility or design considerations for technology used, however the study did note some interesting results based on active or passive navigation. Regardless of age, active navigation can benefit recognition hits in a navigation task, compared to passive navigation. However, active navigation also increases the number of false recognition hits made by older adults (compared with younger adults)
Sun et al. (2019)	System Usability Scale–10 item scale	• Feasibility	The FRAAn system can be used effectively to assess fall risk in older adults. Over 80% of participants reported high usability
Tsuda et al. (2016)	No standardized UX measures	• Safety • Enjoyment • Ease of Use • Accessibility (Financial) • Accessibility (Environmental)	The authors did not include any standardized UX measures but claim that the Wii Fit is feasible, safe with high efficacy. The reasons they provide for this increased usability include the enjoyment and ease of use for fragile patients, the accessibility it provides for patients who are isolated in clean rooms and the reduced cost compared with full VR systems (approx. $200 at time of publication)
Vallejo et al. (2014)	System Usability Scale–10 item scale	• Choice • Combining UI • Participant Ability • Motivation	Preference of user interface is dependent of the task to be completed and the abilities of the users. Combining several user interfaces provides increased interaction opportunities in line with the tasks and users abilities. When creating a serious game intervention, it is paramount to consider the types of devices in use, the patients' abilities, and their motivation to play
De Vries et al. (2018)	No standardized UX measures	• Motivation • Enjoyment • Value	Older adults were motivated to play VR balance games, and this was also linked with high enjoyment and value scores indicating that motivation was correlated with enjoyment of the game and the perceived value of the exercise
Yeh et al. (2019)	No standardized UX measures	• Value • Enjoyment • Motivation	No discussion regarding usability, feasibility or design considerations for technology used however, the researchers did discuss factors which impact willingness to participant/use VR interventions. These factors included perceiving the value of the intervention, and the use of enjoyment/fun to increase motivation

Designing AR/VR Environments

As described in the results above, over a third of papers identified in this review are investigating the usability, feasibility, and design considerations important for AR/VR environments aimed at assisting older adults in their physical/mental health and general wellbeing. Despite the large number of papers investigating this area, very few used standardized measures. This impedes reviews such as this as comparisons and developments are more difficult to evaluate. However, three primary categories were identified including usability, feasibility, and tailored design (See **Table 7**). Within those categories there were many themes, which will now be discussed.

Usability

The most common factors identified as vital to usability were enjoyment and motivation. Many of the articles noted that participants reported either feeling enjoyment or a need to enjoy the activity to continue with the interventions. Similarly, motivation was identified as essential to continued engagement with the interventions over time. The remaining themes were not identified as often but were nonetheless important. Usability was dependent on participants receiving clear and simple instructions (Corno et al., 2014) and/or taking part in environments that were designed with clear and simple layouts (Blackman et al., 2007; Liu, 2010; Lokka et al., 2018). The concept of "matching" came up in three separate studies, though each with a different emphasis. Benoit et al. (2015) identified the importance of creating an environment where both the virtual and the real-world mirror each other (e.g., sitting at a table in a virtual environment, and sitting a table of similar height in the real-world) to help reduce the symptoms of cybersickness. Gomes et al. (2018) discusses the impact of games where the user/avatar appears stationary, but the user is required to take quick steps in the real-world and how this could result in adverse effects for the user. However, despite identifying this concern, they made no attempt to prevent or propose solutions. Finally, Korsgaard et al. (2019) considered the potential to increase use and willingness to use VR technology and applications through weather matching, or rather "miss-matching." The ability of VR environments to provide a warm comfortable outside environment for exercise and other activities may entice older adult users into engaging with the technology on cold, wet days when they are unable to leave their homes. Perceived value of an intervention also had an impact on the usability of a piece of technology or virtual environment. Participants who could see how the exercise would help them were more likely to continue an intervention to the end and they were more likely to link it with their motivation to continue. How easy the technology was to use (Tsuda et al., 2016; Glännfjord et al., 2017) also played a part in the usability of the system; however, it was surprising that this factor was not mentioned more across the identified studies. Participant comfort considered both the equipment being used (Anderson-Hanley et al., 2011) and the features of users (e.g., eyeglasses) (Korsgaard et al., 2019), though again, not many findings or observations were identified. Other factors which played a part in the overall usability of a system included providing participants with a challenge (Merriman et al., 2018), choice of different user interfaces (Vallejo et al., 2014) so their motions/interactions are identified/picked-up, providing an environment that is consistent (Corno et al., 2014) with expectations (e.g., colors are not too bright etc.), easy to engage with (Manera et al., 2016), using simple user interfaces (Corno et al., 2014) and social interaction (Glännfjord et al., 2017) where the ability to compete and take part with others influenced participants decisions to continue engaging with the interventions.

Feasibility

Three studies considered the importance of safety in regards to the feasibility of their intervention. One study considered how the intervention itself provided additional safety to its participants when compared to completing a similar intervention in a real-world setting (Anderson-Hanley et al., 2011), another considered the impact simulator sickness may have on individuals with schizophrenia and determined there set-up was a safe alternative to HMD's (Chan et al., 2010) and another considered the increased safety VR systems could provide to chemotherapy patients required to remain in clean-rooms (Tsuda et al., 2016). One study noted gender differences as a feasibility consideration (Matas et al., 2015); women were more prone to both motion and simulator sickness and the authors went on to suggest that drivers with a history of motion sickness should not take part in any immersive driving simulations. Participants inherent abilities should also be taken into consideration of the feasibility of a AR/VR set-up (Vallejo et al., 2014) as overly mismatching their ability to the task could pre-dispose participants to reduced motivation and incompletion of the intervention. This is in-line with research that argues that tasks themselves be tailored to the population (Corno et al., 2014). The final theme identified in this category related to older adults ability to understand the combining of virtual and real aspects of a mixed reality setting; for example, understanding that they could eat "anywhere" within the virtual environment even though no tables were visible despite having spent time in that environment while seated at their own table (Korsgaard et al., 2019). This is of particular importance as older adults and those with cognitive impairment must understand the environments they are immersed in so as to avoid any upset or negative effects on the participant.

Tailored Design

The final category could be broken into seven themes. Realism was identified as an important factor in continued use of a system (Marivan et al., 2016) but it was also worth noting that the level of realism was important for older adult populations (Lokka et al., 2018). Older adults initially preferred the realistic environment and a small percentage switched to using a mixed reality environment. However, despite the switch, over 50% of the older adults' participants continued to prefer the realistic environment compared with a younger population. This is interesting as this research suggests that the mixed environment produced better recall (both long and short-term) in younger and older adult populations. This poses an interesting ethical dilemma that merits further examination; if personal choice and preference is important in establishing and retaining participant trust, comfort, and engagement until the end of an intervention, but researcher selected equipment and environments are expected to demonstrate greater efficacies, is it justifiable to remove those choices? Are the potential results, the expected savings in study finance, resources, and time acceptable reasons for limiting interventions with these vulnerable populations?

Many studies using AR/VR use navigation tasks to assess memory and attention in cognitively impaired populations. Active navigation is an interesting factor to consider as it requires the participant to navigate a virtual environment themselves using some form of UI, whereas passive navigation typically demonstrates a route or direction through pre-recorded video. Active navigation increases recognition hits in older adults, however it also increases false positives in older adult populations (Sauzéon et al., 2016). Often it is both necessary and preferred that participants actively engage in a virtual intervention, but if there is a possibility that the subsequent results are Type 1 errors, then checks and controls should be built into the intervention procedures. An interesting interaction between education level and computer self-efficacy was also reported (Felnhofer et al., 2014). Older adults with higher education were better able and more confident in using the virtual environments. Many current older adults may have missed educational opportunities due to historic circumstance, however as education levels in the global aging population increase, progressively more and more older adults will be proficient technology users. Researchers should no longer assume older populations are technologically illiterate. Older adults are more capable than ever at interacting with complex technology, but there is still a learning curve. It has been suggested that when instructing participants on the procedure of an intervention or task, they should first be introduced to the technology and allowed to interact with it (Corno et al., 2014). Adjustment periods ensure that participants do not become distracted by the technology during the data collection period. The level of immersion is also an important factor to consider for Alzheimer's and Dementia populations. There may be an assumption that these populations can become confused with high levels of immersion or through the use of 3D glasses but Manera et al. (2016) found that participants preferred the 3D environment when compared with a 2D paper task. Similarly, research with Parkinson's patients (dos Santos Mendes et al., 2012) has noted that also they can have difficulty with virtual games due to increased motor difficulties, this does not prevent them from learning, improving and retaining the positive effects of exergaming. In contrast, those with cognitive impairment are more likely to experience inhibited learning.

The key take home message across these studies is the importance of positive user experience influencing the usability and feasibility of AR/VR environments and technologies (Vallejo et al., 2014, p. 24; Yeh et al., 2019, p. 10).

Increasingly, research is being conducted with the assistance of experts by experience (public, patient involvement; PPI). The is an important paradigm shift for researchers. By asking living experts to help design (make suggestions), and evaluate virtual environments as they are created you increase the likelihood that your intervention will meet the needs and requirements necessary for that population group (Corno et al., 2014). By including PPI researchers will address two vital factors for feasibility of AR/VR research interventions, designing tasks with a population in mind and matching the abilities of the participants to the task.

The Lack of Augmented Reality

This review indicates that AR is rarely being used as a form of digital intervention. There are many reasons for this. When the original articles were screened for title and abstract two main clusters of articles were identified that closely matched the current search but were different enough to warrant exclusion. These included articles where AR/VR were used as either a means of diagnosis or studies that used virtual technology as a convenient alternative to a potentially dangerous real-world setting; the effects of the virtual environment or equipment was not itself examined. A greater number of AR papers may have fallen into these alternate categories. Another reason AR technology may have been absent from these results is the current focus of AR studies. Much of the research employs smart-phone applications (such as Pokémon Go), which older adults are less likely to engage with. AR also features in research in the areas of education, tourism, and advertising; areas where digital interventions are not always targeted toward older adults. In comparison to VR, many AR studies may still be in their infancy and while they would suit an older population, research tends not to be directed to those 60˚years and above. Finally, several studies in this review include samples where younger participants were present, but where older adults' results were reported separately. AR research may not yet categorize their samples to the degree required by this review.

VR-Based Interventions

This review has identified several sub-populations and areas of interest where virtual reality technology is being used to affect the physical/mental health and wellbeing of older adults. Populations include healthy, physically, and cognitively impaired, and emotionally vulnerable older adults (Tarnanas et al., 2015, p. 3; Wiederhold, 2016, p. 577–578; Riva et al., 2019, p. 82–88). VR technology has demonstrated its positive impacts using immersive environments that can display games, exercises and true-to-life digitally created surroundings. The environments in the 65 studies in this review were used to increase physical activity, improve balance, memory, attention, and quality of life, and to reduce falls, anxiety, and depression. The most common limitations described included small sample sizes not representative of the larger populations (including limited gender balances), a lack of control groups, limited access to technical (gameplay) data and short intervention periods often due to a lack of time/resources. Future research in this area should look at large scale studies with interventions capable of being personalized and meeting the recommended length of time for behavior change (12 weeks). Participants should be more representative of the general population with gender, education level, ethnicity and socioeconomic status all taken into consideration. Technical interventions should include neurobiological assessments as control measures to further support physical and cognitive change assessments. Areas needing further exploration include, active identify of older adults and its role in influencing VR related exercise behavior (Anderson-Hanley et al., 2011), acceptance of VR supported interventions in hospital-bound populations (Korsgaard et al., 2019), the experience of immersion and flow in 3D VR training (Lee et al., 2017), and investigating natural user interfaces to allow for simultaneous dual motion input (Vallejo et al., 2014).

Theories in Practice

This review drew attention to four well known theories (Riva et al., 2016) that can be applied to AR/VR research. The authors expected to find these theories being used to support the methodologies used by the identified articles but only nine papers used psychological theory to support their intervention. Unexpectedly, none of the theories put forth by Riva and colleagues (2016) were used. However, the 13 theories adopted by researchers to support AR/VR research (see **Table 6** above) were also based on social, cognitive, and biopsychosocial frameworks. Most of the theories were social, and a common theme included the influence of others of behavior (38%). Other areas of effect included impact of the surrounding environment (23%), intrinsic motivation of the individual (7%) and interaction with cognitive processes (38%). These studies clearly demonstrate the psychological underpinnings related to and influencing the effects of AR/VR methodological design. However, most studies evaluated in this review offered no theoretical support for their experimental design. Behavior change research is complex and often interventions designed to effect change are activating many interconnected components that work together to produce a response. Even when an intervention is successful, the lack of appropriate theoretical supports means there is no way to accurately determine what underpinned this success (Michie et al., 2014). Future researchers must reconsider incorporating psychological theory to provide strong foundations from which to develop effective, lasting and, impactful AR/VR interventions.

Specific Domains

Within the social domain, the theories addressed the impact of others on the behaviors of the individual during interventions. The transformative Learning Theory model was also based in a social framework and while it was not referenced specifically, common aspects of this theory included, recognition of the self and revision of beliefs leading to behavior change. The cognitive domain was more prominent in the theories presented by Riva et al. (2016) but these theories were less frequent in the identified literature. However, these theories are similar in that the place the self at the forefront and behavior change is influenced by our perceptions. Socio-cognitive and biopsychosocial models were presented as explanations for behavior change and while these models were the least incorporated, they are the most complex supporting explanations for behavior changes because of complex interconnections between the environment, cognition, social influences, biological predispositions, and psychological health.

Defining Virtual and Augmented Reality

When searching the literature for virtual and augmented reality research it became clear that there was no single definition in use. Many studies used terms like virtual, augmented, and mixed reality to describe 3D virtual environments displayed onto 2D desktop environments. The "reality-virtuality continuum" (Eckert et al., 2019, p. 2) suggests that terms like "virtual environment" and "virtual reality" can be used to describe these two-dimensional displays. However, AR/VR technologies have advanced beyond the systems available in the 1990s and the continuum does not accurately differentiate digitally created environments. A desktop environment like Sims™ or Second Life™ can be called a "virtual environment" but so too can an immersive display in a HMD like the Oculus Rift™. Only 16 of 65 papers in this review provided a definition of VR. All 16 definitions considered the digitally created environment and real-time interaction, but only seven also mentioned the user (See **Table 4**) and only one defined "mixed reality;" a term often used to describe the combination of virtual and augmented reality technology elements. The remaining definitions described only the technical elements (e.g., computer simulated environment, interaction of computer-generated experience) required to create VR. This illustrates an interesting distinction between papers that focus solely on the technical components (50%) and those that consider the human interaction as a vital step in the virtuality process. There is no clear way to determine which approach is more successful in terms of reaching the objectives of the planned intervention however, future research could set out to identify the definitions/descriptions used in quantitative AR/VR research and complete a meta-analysis comparing the outcomes of the studies. In general, these findings support those of Kardong-Edgren et al. (2019), (p. 33) who identified 14 different VR definitions and six different AR definitions in their review. These combinations of ambiguity and opposing perspectives contributes to the complexity of true AR/VR and clearly demonstrates the need for a more robust taxonomy. This review also aimed to determine if consistent terminology was being used in AR/VR research. Only five studies using the term VR involved a fully immersive virtual environment. The remaining 57 studies used variations of "virtual reality" and "virtual environments" to describe their technology. Over 70% of studies in this analysis mislabeled themselves as "virtual reality" and this may be attributed to two main factors. First, very few studies provided an operational definition of virtual reality and this leads to ambiguities and misunderstandings as readers attempt to ascribe a label to the technology used. Second, while virtual (Milgram and Kishino, 1994, p. 8–12) and augmented reality (Grubert et al., 2017, p. 1711–1715; Hugues et al., 2011, p. 5–15) taxonomies exist, they do not accurately describe the modern technologies available (e.g., describing analogue or digital monitors), which adds further confusion to an already complex and quickly evolving area.

These inconsistent terms and definitions emphasize the need for more sophisticated terminology to describe virtual designs. In addition, one study described their set-up as a virtual reality, referring to a video they had taken as a virtual environment (Choi and Lee, 2019, p. 862). Under the "reality-virtuality continuum" (Eckert et al., 2019, p. 2) this identification is legitimate, but it is inaccurate. Asking participants to watch a video and follow along with the motions is not the same as a participant interacting in real-time within a 3D virtual environment that can track movement and provide an immersive user experience. While the definitions of McCloy and Stone (2001), (p. 912) Botella et al. (2015), (p. 2) used in planning this review are the most acceptable definitions that are currently available, greater nuance is required to convey fully the degree and level of immersion required in a virtual reality system. Based on the definitions identified in this review and those identified in the call for unification of virtual reality theories (Kardong-Edgren et al., 2019, p. 30–31), we have identified the following elements which are required to formulate a more complete definition. There must be reference to 3D graphics displayed in either 2-or-3 dimensions. This should include everything from projector screens, television sets, computer monitors and HMD's. The second element of a new definition should address the level of interaction available to the users including multimodal systems combining the senses to create full-body experiences and increasing levels of user interfaces ranging from controllers and joysticks to motion control, position tracking and multi-modal interface in-puts. Finally, a new definition should include the ability to view the environment and any avatars in either first or third person perspective. This is a complicated task as even with these factors there are many levels of technology included. To fully address the insufficient language and terminology in this complex area, an updated taxonomy classifying virtual and augmented technologies is urgently required.

Strengths and Limitations

This review evaluated many studies to determine how AR/VR is used when aiming to improve physical/mental health and general wellbeing of older adults. The analysis clearly demonstrates the assortment of technologies available, but also the insufficient terminology available to categorize and identify them. Two researchers conducted the screening for this review ensuring consensus was reached on all points. Finally, three systematic reviews (Hugues et al., 2011; Miller et al., 2014; Coyle et al., 2015) identified in the screening process were used to supplement the initial search and an additional 13 studies were included in this review.

Two branches of AR/VR research were not included in this review (use as a diagnostic tool and use as a methodology rather than the factor under investigation) due to time constraints. Both areas are large enough to warrant their own review. Another limitation to this study is the lack of AR research found. This may be due to the focus on older adults in this review, or that AR research may not report the older participants as an individual group. Another factor may be the availability of AR technology. Newer models of smart phones and tablets may be AR compatible, but these may not be used to the same extent in an older population.

CONCLUSION

This scoping review aimed to identify how AR/VR technology was used within an older adult population to influence their physical, mental health and wellbeing. Only five studies were objectively classified as VR and only one study used AR. However, these studies encompassed a wide range of domains including improving physical activity, balance, memory, attention, and quality of life, and reducing falls, anxiety, and depression. A secondary aim of this study was to identify whether the terminology used across the studies was consistent. Findings have demonstrated that terms such as virtual reality and virtual environments are used to describe many levels of technology. Many of the papers discussed in this review provide no definition of virtual reality and those that do, lack consensus. Further, half of these definitions fail to include the user despite the user being central to the intervention being conducted. This review has proposed the elements necessary to construct an alternative definition. It also urgently calls for an updated taxonomy to address the varying levels of technology and immersion used in today's virtual reality research. Similarly, there are many useful theories that can bring focus to the factors influencing behavior change. When designing these interventions, the authors urge researchers to do so with a strong theoretical foundation.

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The main body of research was conducted by JC supported by LH and AF. Contributors to the paper include, RL-V, PB, and EK.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2021.655338/full#supplementary-material

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.