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Effects of Exergaming on Physical and Cognitive Outcomes of Older Adults Living in Long-Term Care Homes: A Systematic Review

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Keywords
Exergaming · Older adults · Aging · Long-term care

Abstract
Background: Aging is often associated with increasing functional decline as measured by deterioration in mobility and activities of daily living. Older adults (OAs) living in residential long-term care (LTC) homes in particular may not engage in regular physical exercise, significantly increasing their risk of further cognitive and functional decline. Exergaming may hold promise for OAs by combining exercise and technology-based gaming systems, but evidence for its use in LTC is unknown. ***Methods:*** A systematic review was conducted to summarize the effects of exergaming interventions on physical, cognitive, and quality of life (QoL) outcomes for OAs (>65 years of age) living in LTC. ***Results:*** Twenty-one studies involving 657 OAs living in LTC met the inclusion criteria. Most studies were associated with a high risk of bias and many used uncontrolled designs and small samples. Across studies, exergame interventions were associated with preliminary benefits relative to control conditions on standardized measures of physical outcomes (e.g., Timed Up & Go, 5-meter gait speed). No consistent effects were found for cognitive and QoL outcomes. ***Conclusions:*** Exergames might be a promising intervention to benefit the physical health of OAs (>65 years) living in LTC, but more research is required to determine the effects of exergaming on physical health, as well as cognitive and QoL outcomes. More specifically, larger and more methodologically robust evaluations are needed.

Background

As the global older adult (OA) population increases rapidly in the coming decades, the demand for residential long-term care (LTC) is expected to rise [1]. OAs residing in residential LTC homes (also called nursing homes) are characterized by increasing functional decline [2], often measured by deterioration in mobility and activities of daily living (ADLs). This population is complex, as functional decline can be brought on by a myriad of factors including physical aging, comorbidities [3, 4], cognitive impairment (e.g., dementia due to Alzheimer's or cerebrovascular disease) [5], and reductions in vision, hearing, and proprioceptive senses [6, 7]. The sedentary na-

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Table 1. Inclusion/exclusion criteria

PICOS component	Selection criteria
Population	Inclusion: OAs (>65 years of age) living in nursing homes, or LTC facilities
	Exclusion: younger adults (M age of <65); participants living in own home in the community, complex continuing care units, retirement homes/communities, assisted living homes
Intervention	Inclusion: exergaming, including physical exercise-based games applied using video game or virtual-reality technology
	Exclusion: noninteractive games or seated virtual-reality games that did not promote PA
Comparator	No restrictions
Outcome	Inclusion: quantitative measures of: Physical outcomes (e.g., balance, gait, center or pressure, and physical function; not vital signs or anthropometric measurements) Cognitive outcomes (e.g., global cognition, attention, memory, and executive function) QoL outcomes
Study type	Inclusion: quantitative studies including original research studies and pilot studies
	Exclusion: solely qualitative studies, reviews, case reports with a sample size of <2, presentation and conference abstracts
Date	No restrictions
Language	English

PICOS, Population, Intervention, Comparator, Outcome, and Study type.

ture of life in LTC homes [8] also significantly increases the likelihood of further declines in cognitive and functional abilities soon after admission [9]. The consequences of these declines are reflected in the experiences of OAs living in LTC, wherein poor quality of life (QoL) and neglect are often reported [10, 11].

Among various interventions that have been designed to address, maintain, and improve the physical and cognitive health of LTC residents, exergaming holds promise by harnessing novel technologies to improve activity levels [12]. Exergaming is described as interactive exercise-based games whereby players engage in physical and cognitive activities played on a technology-based gaming system. Current literature suggests that exergames have positive social, cognitive, and physical effects [13, 14], but vary markedly in intervention type and outcome data collected [15]. The mechanism of the benefits of exergaming is supported by the *Cognitive Enrichment* hypothesis [16] which states that the collective behaviors of an individual have a meaningful positive impact on cognitive and functional ability in old age. Another systematic review established the positive effects of exergaming on cognitive function among OAs living with mild cognitive impairment or dementia from a variety of settings, which include the community, hospitals, rehabilitation wards, and nursing homes [17]; however, it is unclear how exergaming interventions impact the physical and cognitive health of OAs residing in LTC. Thus, we conducted a systematic review of quantitative studies to summarize the effects of exergaming interventions on physical, cognitive, and QoL outcomes of OAs (>65 years of age) living in LTC.

Methods

Our systematic review was guided by the PRISMA statement [18].

Search Strategy

We searched six databases: CINAHL, PubMed, Web of Science, PsycINFO, ScienceDirect, and Cochrane. Searches were not limited by date, with the last search conducted in July 2020. The search strategy was developed for CINAHL in line with the Population, Intervention, Comparator, Outcome, and Study type framework; search terms were selected to capture four concepts: OAs, technology-based games or exergames, physical activity (PA), and LTC. The full CINAHL search strategy is included in the online supplementary material (see www.karger.com/doi/10.1159/000521832 for all online suppl. material). The search was translated into the other databases with the appropriate syntax and index terms for each database. Reference lists of included articles were hand-searched to identify additional records.

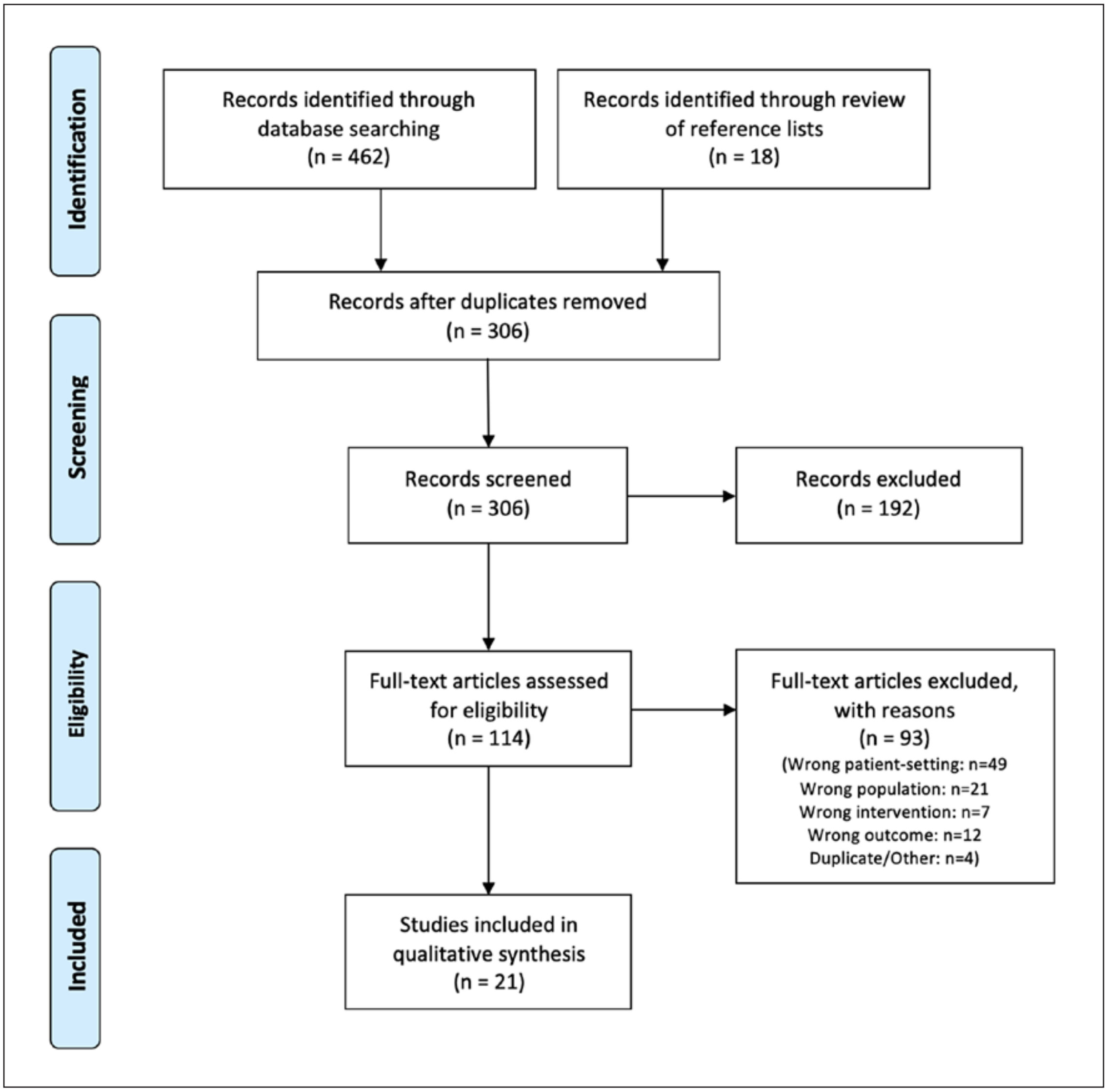

Fig. 1. PRISMA diagram of study selection process.

Selection of Studies

Inclusion and exclusion criteria were specified using the Population, Intervention, Comparator, Outcome, and Study type framework as outlined in Table 1. The results of our search were uploaded to Covidence, a web-based platform which facilitates the screening and data extraction process. Following exclusion of duplicate records, title and abstract screening were completed in duplicate (two teams of two) by 4 reviewers (A.Q., A.S., A.K., and A.Z.). Full-text review followed. Disagreements over inclusion of studies for data extraction were resolved through discussion or feedback from the senior author (C.C.).

Data Extraction and Management

The aforementioned reviewers (A.Q., A.S., A.K., and A.Z.) conducted data extraction independently using a predesigned data extraction form. Data were collected regarding study setting, country and design, participant characteristics, sample size, intervention characteristics (duration, frequency), gaming system used (e.g., Nintendo Wii, Xbox Kinect), adherence, physical and cognitive outcomes, and QoL. Data on comorbidities, namely cognitive disorders, were also collected.

Quality Assessment

The quality of the included studies was assessed using the appropriate tools based on study design: the Cochrane Risk of Bias tool (RoB-2) for randomized trials or the Risk of Bias in Non-randomized Studies (ROBINS-I) [19, 20]. Using the RoB-2 tool, risk of bias was classified as "high," "low," or "unclear" based on seven items: sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other biases. Similarly, the ROBINS-I tool assesses risk of bias based on seven items: confounding, selection bias, bias in classification of interventions, bias due to deviations from intended interventions, bias due to data missingness, bias in measurement of outcomes, and bias in selection of the reported results.

Data Synthesis

Given the heterogeneous nature of study designs and outcomes presented in the selected studies, a descriptive synthesis was conducted. Descriptive statistics across studies regarding age, number of sessions, and the volume of therapy (number of sessions × duration) were reported in terms of mean ± standard deviation. In addition, we report results of null hypothesis significance tests of within- and between-group differences and effect sizes where applicable.

Results

Study Selection and Characteristics

The database and reference list search produced 480 records (Fig. 1). One-hundred and seventy-four duplicate records were removed. After screening of the titles and abstracts of 306 records, 192 records were deemed to be irrelevant based on our inclusion and exclusion criteria. With the remaining 114 records, full-text screening was conducted to assess for eligibility, wherein 93 records were excluded. Twenty-one studies were ultimately included for data extraction. Interrater reliability of trial selection ranged from 0.85 to 1.0 across pairs of reviewers. The included studies were published between 2009 and 2020. Included studies were conducted in North America (n = 3), Europe (n = 10), Oceania (n = 3), South America (n = 1), and Asia (n = 4). With respect to study design, studies included nine randomized control trials [21–29], two nonrandomized control study [30, 31], four before-and-after studies [32–35], five quasi-experimental studies [36–40], and one interrupted time series study [41]. Details of the included studies are presented in Table 2, and summarized results from studies with a control group are provided in Table 3.

Participant Characteristics

A total of 657 OAs participated in the included 21 studies, of which 275 participants (42%) were controls. Group sample size ranged from 5 to 32 participants across studies. Both males and females were included across all studies. Not all studies reported on the gender composition of participants, however, the majority of studies (n = 17) had a higher proportion of women in comparison to men. The average age ranged from 70.1 to 90.4 years of age. Common study inclusion criteria were: (1) cognitive ability to understand the game and instructions given, (2) ability to stand or walk independently with or without aid, (3) ability to communicate based on researcher judgment, and (4) absence of cognitive impairment based on Mini-Mental Status Examination (MMSE) score [cutoffs differed across studies, with ≤15 being the lowest range point for cognitive impairment and ≤27 being the highest possible cutoff for cognitive impairment [32]. However, studies differed by the degree of functionality and assessment scores at baseline, as well as measures used to assess.

Participants generally were ambulatory. Baseline mobility characteristics of participants were reported in 52% (n = 11/21) of studies, with mobility challenges frequently reported, marked by the use of a walking aid, wheelchair, or falls in the last 6 months or year. Other physical characteristics were inconsistently reported between studies; e.g., separate studies reported on BMI [29] and hypertension [41]. Five studies identified included participants with cognitive impairment, with 3 studies noting inclusion of participants with cognitive impairment based on MMSE or Montreal Cognitive Assessment (MoCA) scores [21, 22, 37], and another 2 studies that enrolled participants with mild or moderate dementia [33, 36].

Participant withdrawal was only reported on in 11 of the 21 included studies; 6 studies reported withdrawal from both intervention and control groups [24, 29, 35, 37–39], 2 studies reported withdrawals from only the control group [25, 36], and 3 studies reported withdrawals from only the intervention group [23, 30, 31]. Overall, intervention adherence ranged from 55% to 100%. Most studies did not find pretest differences between the intervention and control groups. Eight studies reported on adverse events [21, 23–25, 30, 31, 35, 39] wherein adverse events were either reported to not have occurred or included medical conditions unrelated to the program, such as serious illness, osteoarthritis, hip fracture, musculoskeletal pain, and death; no studies reported exergaming-related adverse events.

Exergaming Intervention Characteristics

Intervention sessions occurred at least twice a week for 76% (n = 16/21) of studies (range 1–5 sessions per week), and most intervention durations were more than 4 weeks long (n = 13/21, 62%; range = 1–24 weeks). One study measured acute changes following a single session [26]. Length of exergaming sessions was variable across studies with the most common duration being approximately 30-min sessions (n = 7/21; 33%) ranging from 5 to 120 min. Eighty-one percent of studies (n = 17/21) used commercially available exergaming hardware (i.e., Nintendo Wii,

Table 2. Summary of included studies ($n = 21$)

Reference, country	Study characteristics	Intervention, duration and frequency	Groups	Physical outcome measures	Cognitive outcome measures	QoL measures
Cardoso et al. [32] Portugal	Before-and-after study *N* = 18 Female: 67% Mean age: 85.3 (±6)	Endurance, upper and lower limbs, balance, strength, and agility exercises through 5 exergames – Grape Stomping, Toboggan Ride, Rabelos VR, Exerpong and Exerfado One 90–120 min session per week for 3 months	Intervention group 1 (*N* = 6): participants with high levels of autonomy and functionality; able to perform exergaming while standing Intervention group 2 (*N* = 5): participants with more physical impairments Intervention group 3 (*N* = 7): performed exergames while seated	–	–	WHOQOL-BREF
Chiang et al. [36] Taiwan	Quasi-experimental design *N* = 53 Intervention group: 86% female, mean age 78.6 (±6.7) Control group: 58% female, mean age 80 (±7)	Xbox 360 Kinect Games: Mouse Mayhem, Follow the Arrow, Matchmaker in "Dr. Kawashima's Body and Brain Exercises" Three, 30-min sessions per week for 1 month	Intervention group (*N* = 22): somatosensory video game sessions (Xbox 360 Kinect Games) Control group (*N* = 31): usual care	Reaction time, hand-eye coordination	–	–
Cicek et al. [31] Turkey	Nonrandomized, controlled trial *N* = 44 Exergaming intervention group: 56.3% female, mean age 72.25 (±5.95) Physical activity intervention group: 57.1% female, mean age 75.14 (±5.50) Control group: 35.7% female, mean age 73.86 (±4.63)	Nintendo Wii Fit Plus games using Wii balance board Two, 30-min sessions per weeks for 8 weeks	Nintendo Wii Fit group (N = 16): Wii Fit Plus games (Step, Bird's Eye, Soccer Heading, Balance Bubble, and Tilt City) Physical activity group (*N* = 14): 30-min stationary cycling and treadmill walking program, twice weekly for 8 weeks Control group (N = 14): normal activities of daily living	BBS, TUG, 10MWT; SLST	–	WHOQOL-BREF
Delbroek et al. [21] Belgium	Randomized controlled trial *N* = 20 Intervention group: 80% female, mean age 86.9 (±5.6) Control group: 50% female, mean age 87.5 (±6.6)	BioRescue games: Dual tasking, weight-bearing transfer, weight-bearing transfer and stabilization Two, 18–30-min sessions per week for 6 weeks	Intervention group (*N* = 10): virtual-reality dual-task training using the BioRescue Control group (*N* = 10): usual care	iTUG, iTUG DT, Tinetti	MoCA	–
Eisapour et al. [33] Canada	Before-and-after study *N* = 8 Female: 83% Mean age: 86.8 (±6.2)	Oculus Rift HMD Farm, Oculus Rift HMD Gym and human-guided exercise Five, 20-min sessions per week for 3 weeks	Intervention group (*N* = 8): activities that required reaching overhead, reaching forward and straight, reaching forward and across body, and rowing using virtual-reality technology	Schlegel functional fitness assessment, shoulder circumduction, motion parameter	–	–
Ellmers et al. [34] UK	Before-and-after study *N* = 26 Female: 81% Mean age: 78.1 (±8.2)	PONG game using Nintendo Wii balance board Two, 5-min sessions per week for 4 weeks	Intervention group (*N* = 26): PONG games requiring participant balance to control paddle movement	COPE	–	–
Hsieh et al. [37] Taiwan	Quasi-experimental design *N* = 60 Intervention group: 77% female, mean age 76.4 (±7.6) Control group = 66% female, mean age 80 (±7.5)	Xbox 360 Kinect game Two, 60-min sessions per week for 6 months	Intervention group (*N* = 31): virtual-reality Tai Chi through "Your Shape Fitness Evolved 2012" Zen energy game Control group (*N* = 29): usual daily physical activities	6MWT, 30-s STS, 30-s AC, TUG, FR, sit-and-reach, drop ruler test, 5-m gait speed	CASI	–

Table 2 (continued)

Reference, country	Study characteristics	Intervention, duration and frequency	Groups	Physical outcome measures	Cognitive outcome measures	QoL measures
Janssen et al. [30] The Netherlands	Nonrandomized controlled trial *N* = 29 Intervention group 1: 50% female, 84.5 (±5.0) Intervention group 2: 75% female, 81.5 (±12.8) Control group: 77% female, 80 (±8.5)	Wii Fit Plus, games: Table Tilt Plus Two, 10–15 min sessions per week for 12 weeks	Intervention group 1 (*N* = 8): Individuals with regular Nintendo Wii Fit experience for at least 1 year Intervention group 2 (*N* = 8): novices to the Nintendo Wii Fit Plus Control group (*N* = 13): No experience with Nintendo Wii Fit, these participants maintained their usual daily physical activities	BBS, LAPAQ	–	–
Keogh et al. [39]	Quasi-randomized controlled trial *N* = 34 Intervention group: 89% female, mean age 81 (±7) Control group: 87% female, mean age 85 (±7)	Nintendo Wii Sports games 1–105 min (mean 30±24 min) per week for 8 weeks	Intervention group (*N* = 19): Nintendo Wii Sports (baseball, boxing, golf, tennis , and 10-pin bowling) Control group (*N* = 15): usual activities of daily living	Bicep curl, FSST, RAPA	–	WHOQOL-BREF
Keogh et al. [40] New Zealand	Quasi-experimental mixed-methods study *N* = 11 Female: 55% Mean age: 81 (±6)	Nintendo Wii Sports games Unstructured, self-report of game time resulted in an average of 28 min per week for 5 weeks	Intervention group (N = 11): unsupervised, Nintendo Wii Sports gaming (baseball, bowling, boxing, golf and tennis)	FSST	–	SF-36
Liu et al. [22] Taiwan	Randomized controlled trial *N* = 39 Female: unclear Intervention group: mean age 85.6 (±8.5) Control group: mean age 81.6 (±5.4)	Xbox 360 Kinect game: Fruit Ninja Three, 30-min sessions per week for 4 weeks	Intervention group (*N* = 20): Xbox 360 game in seated and standing position Control group (*N* = 19): sedentary activity, games: knitting, puzzles, tangram painting, etc	Grasping ruler test	–	SF-8
Monteiro-Junior et al. [26] Brazil	Randomized controlled trial *N* = 19 Intervention group: 90% female, mean age 86 (±7) Control group: 78% female, mean age 86 (±5)	Nintendo Wii Single 30–45 min session	Intervention group (*N* = 10): squat, postural displacements, dance and sports through Nintendo Wii games Control group (*N* = 9): same movements as the intervention group without virtual feedback from Nintendo Wii	–	VFT, DSF, DSB	–
Mugueta-Aguinaga et al. [25] Spain	Randomized controlled trial *N* = 40 Intervention group: 60% female, mean age 85.5 (±6.5) Control group: 60% female, mean age 83.1 (±9)	FRED exergame Three, 20-min sessions per week for 3 weeks	Intervention group (*N* = 20): using FRED, participants pass through different scenarios which require PA and attention, coordination of movement, balance, accuracy and spatial orientation Control group (*N* = 20): usual care	Barthel score, SPPB	–	–
Ogawa et al. [38] USA	Quasi-experimental study *N* = 35 Intervention group: 69% female, mean age 75.2 (±7.3) Control group: 69% female, mean age 78.9 (±7.1)	Microsoft Kinect-based versions of brain training programs Two, 1-h sessions per week for 8 weeks	Intervention group (*N* = 16): three exergames – target tracker, double decision, visual sweeps Control group (*N* = 19): lower-body resistance and balance training, and upper-body resistance training	Gait speed, stride length, stride width, swing time, double support, stride length CV, swing time CV, SPPB, Tinetti fall efficacy scale, SRT, CRT	MMSE, MoCA, TMT-A, TMT-B	–

Table 2 (continued)

Reference, country	Study characteristics	Intervention, duration and frequency	Groups	Physical outcome measures	Cognitive outcome measures	QoL measures
Pichierri et al. [29] Switzerland	Randomized controlled trial *N* = 22 Intervention group: 73% female, mean age 86.9 (±5.1) Control group: 91% female, mean age 85.6 (±4.2)	Motor exercise program and dance video game (StepMania) Two, 40-min sessions per week for 12 weeks	Intervention group (*N* = 11): progressive resistance training, postural balance program, and video game dancing program Control group (*N* = 11): progressive resistance training and postural balance program only	FES-I, FPA, gait analysis, gaze behavior	–	–
Portela et al. [27] Portugal	Cluster randomized controlled trial *N* = 65 Female: unclear Mean age: Intervention group 1: 80 Intervention group 2: 78 Control group: 79	Nintendo Wii, Wiitherapy, game: bowling Fifteen, 50-min sessions over a 4-month period	Intervention group 1 (*N* = 23): Wiitherapy with supervision (physiotherapist) Intervention group 2 (*N* = 20): use of Nintendo Wii unattended Control group (*N* = 22): geriatric gymnastics: upper and lower member's flexibility, balance, trunk and hip flexibility, coordination, and proprioception	Barthel score, BBS	MMSE	SF-36
Rogan et al. [28]	Randomized controlled trial *N* = 30 Intervention group: 63% female, mean age 90.4 (±6.9) Control group: 71% female, mean age 87.2 (±5)	Stochastic resonance whole-body vibration and a dance video game, five set program (base frequency 3–6 Hz) Three, 5-min sessions per week for 8 weeks	Intervention group (*N* = 16): combined stochastic resonance whole-body vibration and a dance video game Control group (*N* = 14): stochastic resonance whole-body vibration only	SPPB, IMVC, Fsub, IRFD, IRFDsub	–	–
Taylor et al. [24] New Zealand	Cluster randomized controlled trial *N* = 58 Intervention group: 77% female, mean age 86.8 Control group: 72% female, mean age 85.8	Xbox Kinect, "Your Shape Fitness Evolved, 2012 Aging With Grace" Two, 35-min sessions per week for 8 weeks	Intervention group (*N* = 26): Xbox Kinect exergames Control group (*N* = 32): usual care	DEMMI	–	–
Valiani et al. [41] USA	Interrupted time series *N* = 12 Female: 83% Mean age: 80.5 (±4.2)	Light intensity exercise (aerobic, strength, and balance) through Jintronix technology Two, 30-min sessions per week for 4 weeks	Intervention group (*N* = 12): light intensity exercise through exergaming technology	SPPB, RAPA	–	–
Wu et al. [35] Taiwan	Controlled, pre-post test pilot study *N* = 13 Intervention group: 0% female, 82.8 (±9.1) Control group: 43% female, mean age 80.3 (±6)	Xbox Kinect, moderate intensity exercise through Kinect Adventures, Sport Season II and Your Shape Fitness Evolved Two, 90-min sessions per week for 12 weeks	Intervention group (N = 7): moderate intensity exercise through exergames that focused on postural control training Control group (N = 6): usual activities of daily living	Muscle strength; 10MWT; 6MWT; TUG; BBS	–	–

Table 2 (continued)

Reference, country	Study characteristics	Intervention, duration and frequency	Groups	Physical outcome measures	Cognitive outcome measures	QoL measures
Yesilyaprak et al. [23] Turkey	Randomized controlled trial $N = 21$ Intervention group: 43% female, mean age 70.1 (±4) Control group: 82% female, 73.1 (±4.5)	BTS NIRVANA VR interactive system games Three, 45–55 min sessions per week for 6 weeks	Intervention group ($N = 10$): VR-based balance exercises Control group ($N = 11$): conventional balance exercise	BBS, TUG, FES-I, OLS-EO-R, OLS-EO-L, OLS-EC-R, OLS-EC-L, TS-EO, TS-EC	–	–

6MWT, 6-Min Walk Test; 10MWT, 10-Min Walk Test; 30-s STS, 30-s sit-to-stand test; AMTS, Abbreviated Mental Test Score; BBS, Berg Balance Scale; CASI, Cognitive Abilities Screening Instrument; COPE, Centre of Pressure Excursion; DEMMI, de Morton Mobility Index; DT, Dual Task; DSF, Digit Span Forward; DSB, Digit Span Backward; FPA, Foot Placement Accuracy test; FES-I, Falls Efficacy Scale; FSST, Four Square Step Test; 30-s AC, Arm Curl test; FR, Functional Reach test; IMVC, Isometric Maximal Voluntary Contraction; Fsub, Submaximal force; IRFD, Isometric Rate of Force Development; IRFDsub, Submaximal IRFD; iTUG, Instrumented Timed Up and Go; LAPAQ, LASA Physical Activity Questionnaire; MoCA, Montreal Cognitive Assessment; MMSE, Mini-Mental State Examination; OLS-EO-R, One Leg Stance-Eyes Open-Right; OLS-EO-L, One Leg Stance-Eyes Open-Left; OLS-EC-R, One Leg Stance-Eyes Closed-Right; OLS-EC-L, One Leg Stance-Eyes Closed-Left; RAPA, Rapid Assessment of Physical Activity; SF, Short Form Health Survey; SLST, Single Leg Stance Test; SPPB, short physical performance battery; SSSS, Satisfaction with Social Support Scale; TMT-A, Trail Making Test A; TMT-B, Trail Making Test B; TS-EO, Tandem Stance-Eyes Open; TS-EC, Tandem Stance-Eyes Closed; TUG, Timed Up and Go; VFT, verbal fluency test.

Table 3. Summarized results from studies with a control group ($N = 14$)

Citation	Summarized results		
	Physical outcome measures	Cognitive outcome measures	QoL outcome measures
Chiang et al. [36]	Significant difference ($p < 0.001$) for reaction time and hand-eye coordination for the exergaming compared to control group; post-intervention between-group effect size was 0.73	–	–
Cicek et al. [31]	Significant change of the primary outcome measures (BBS and TUG) between groups in favor of the Nintendo Wii Fit group. The difference in BBS was statistically significant in both exergaming (GI) and standard physical activity (GII) groups compared to the control group (GIII) (GI-GIII; $p = 0.001$, GII-GIII; $p = 0.002$). For TUG, there was a statistically significant improvement in the exergaming group (GI) compared to the other conditions (GI-GII; $p = 0.007$, GI-GIII; $p = 0.001$)	–	QoL was assessed using the WHOQOL-BREF. No statistically significant within-group and between-group differences observed
Delbroek et al. [21]	Group differences were not tested. iTUG improved significantly after 6 weeks training within the intervention group ($p = 0.02$), however no improvements in iTUG DT or Tinetti	Group differences were not tested. No changes were detected over time for both the control group and interventions group as measured by the MoCA	–

Table 3 (continued)

Citation	Summarized results		
	Physical outcome measures	Cognitive outcome measures	QoL outcome measures
Hsieh et al. [37]	Improvements in the exergaming relative to the control group found for the 6MWT, 30-s STS test, FR, 5-m speed, with medium to large improvement in the exergaming group ($d = 0.50–1.01$). No significant changes for 30-s AC, sit-and-reach, 5-m gait speed, TUG	No significant improvement in overall CASI relative to control group. Significant improvement in abstract thinking on the CASI ($d = 0.74$), but no other subscales. Average movement accuracy score at 3 months significantly predicted improvement in the total CASI score ($p = 0.023$)	–
Janssen et al. [30]	Improvement in reported physical activity on LAPAQ significantly higher in intervention groups ($p = 0.01$). No significant balance changes relative to control on BBS	–	–
Keogh et al. [39]	The exergaming group had a significantly greater increase in bicep curl repetitions ($p = 0.038$, $d = 0.65$) and self-reported PA on the RAPA ($p = 0.009$, $d = 1.19$) than the control group. No differences observed on the FSST	–	Significantly greater improvements in psychological QoL (as assessed by the WHOQOL-BREF) were observed for the exergaming group than the control group ($p = 0.012$, $d = 0.74$); no significant differences in physical, social, or environmental QoL
Liu et al. [22]	Differences between intervention and control group not tested. Reaction time on the grasping ruler test significantly improved ($p = 0.003$) within the intervention group but not the control group	–	Differences between intervention and control groups not tested. QoL on the SF-8 did not change in the intervention group, while OAs in the control group (sedentary activity) had better PCS ($p < 0.05$) and worse MCS ($p < 0.05$) at post-test
Monteiro-Junior et al. [26]	–	No differences between the exergaming and control group found for VFT, DSF, or DSB. VFT performance showed acute improvement immediately following a single session within the exergaming group ($p = 0.013$), with no other significant changes in cognitive measures in either group	–
Mugueta-Aguinaga et al. [25]	Significant improvements in SPPB in the exergame group from pre- to-post-test. Exergame group was more likely to show clinically relevant reductions in frailty compared to control group ($p < 0.001$), thus potentially modifying their risk profile	–	–
Ogawa et al. [38]	Significantly different changes in single-task measures of gait speed, stride length (cm), swing time, and double support observed favoring the exergame group. Effects reflected worse performance over time in control group, as pre-post changes were not significant in intervention group. No significant changes or between-group differences in stride width (cm), stride length CV, swing time CV, SRT, CRT, SPPB, or Tinetti falls efficacy scale. There were no statistically significant group differences in dual-task gait measurements except for swing time percentage and double support percentage, favoring the exergaming group	Modest improvements in MMSE score and TMT-B executive control within the exergaming group ($p < 0.01$) compared with baseline, but change was not significant compared to control group. Change scores from pre-to post-test on TMT-A psychomotor speed were significantly better in exergame than control group. No pre-post changes in either group for MoCA score	–

Table 3 (continued)

Citation	Summarized results		
	Physical outcome measures	Cognitive outcome measures	QoL outcome measures
Pichierri et al. [29]	No significant between-group differences were observed either in the FPA test or FESI-I. One measure of FPA showed significant pre-post improvement in exergame group. Gait analysis measures showed better performance in the exergame group relative to the control group ($p < 0.05$) and from pre- to post-test in a fast, dual-task condition. Gaze behavior measures were not analyzed due to incomplete data	–	–
Portela et al. [27]	Differences between intervention and control groups not tested. No significant improvements in activities of daily living within any group according to the Barthel index. Only the control group had statistically significant improvements in balance, as measured by the BBS	Differences between intervention and control groups not tested. No significant improvement in cognition by any group, as measured by the MMSE	QoL was assessed by the SF-36. No improvements in any of the SF-36 domains for the control group. Supervised exergaming group showed improvement from baseline on SF-36 domains of physical functioning and vitality but worse emotional performance. Unsupervised exergaming group showed significant improvement in the mental health and vitality components of SF-36. Differences between intervention and control groups not tested
Rogan et al. [28]	Between-group effect showed that exergaming had a significant effect after 4 weeks ($p = 0.014$) and after 8 weeks ($p = 0.001$) on physical performance, as indicated by the SPPB. Significant between-group effects were observed for lower extremity muscle function outcomes including IRFD, Fsub, IRFDsub, and IMVC	–	–
Taylor et al. [24]	DEMMI scores indicated that residents who played exergames had improved mobility, although this did not reach significance ($p = 0.06$). No significant difference between intervention and control groups in PA levels after the intervention period ($p = 0.42$) as measured by TUG	–	–
Wu et al. [35]	Statistically significant between-group difference ($p = 0.035$), in favor of the intervention group, as measured by TUG. No differences observed using other physical outcome measures – 6MWT, 10MWT, and BBS	–	–
Yesilyaprak et al. [23]	In both intervention group and control group, BBS, TUG duration, and left leg stance and tandem stance duration with eyes closed significantly improved with time ($p < 0.05$), but changes were similar in both groups ($p > 0.05$) after training. No changes in either group for other outcomes	–	–

BBS, Berg Balance Scale; CASI, Cognitive Abilities Screening Instrument; DEMMI, de Morton Mobility Index; DSF, Digit Span Forward; DSB, Digit Span Backward; FES-I, Falls Efficacy Scale-International; FPA, foot placement accuracy; IMVC, isometric maximal voluntary contraction; IRFD, isometric rate of force development; LAPAQ, LASA Physical Activity Questionnaire; MCS, Mental component summary; MMSE, Mini-Mental State Examination; PCS, Physical component summary; SF-36, 36-item Short Form Health Survey; SPPB, short physical performance battery; TMT-A, Trail Making Test parts A; TMT-B, Trail Making Test parts B; TUG, Timed-Up and Go; VFT, Verbal Fluency Test; 30-s STS, 30-s sit-to-stand.

Xbox Kinect). However, not all studies used the commercially available corresponding software (i.e., Wii Fit); some exergaming interventions involved noncommercially available games such as StepMania [29] and Jintronix [41] which were designed with OA end users in mind. Only 1 study used virtual-reality hardware and software [33]. All the intervention/exergaming sessions were supervised by either a member of the research staff ($n = 7$), a physical therapist ($n = 5$), an exercise therapist ($n = 3$), nursing staff ($n = 2$), or volunteer ($n = 1$).

Physical Outcomes

Twenty (95%) of the 21 included studies [21–25, 27–31, 33–41] cite reported physical outcome measures.

Mobility and Endurance

Eight of the included studies [21, 23, 24, 31, 35, 37, 40, 41] measured mobility and endurance. Across functional tests, a medium to large effect size ($d = 0.55–1.01$) was reported in favor of the exergaming intervention. These studies included Hsieh et al. [37] who reported significant improvements in the intervention compared to a control group for the 6-min walk test ($p = 0.01$, $d = 0.55$), measuring mobility and functionality, and the 30-s sit-to-stand test ($p = 0.002$), which measures endurance. Three studies reported statistically significant ($p < 0.05$) improvements in mobility in the exergaming group compared to a control group when using a standard clinical test – the timed up and go (TUG) test [23, 31, 35]. Two of these studies included conventional exercise comparison groups: Cicek et al. [31] noted mobility improvements for exergaming above the effects of conventional exercise, while Yesilprak et al. [23] reported moderate to large (0.69–1.03) within-group effect sizes for both types of exercise, which did not differ from each other. Delbroek et al. [21] also reported significant improvements within the intervention group for TUG duration and the turn-to-sit duration during single-task walking, indicating improved mobility ($p = 0.02$). In the interrupted time series study by Valiani et al. [41], there was a significant improvement ($p < 0.05$) in 4-meter walking speed and a reduction in time in completing the sit-to-stand test, indicating an improvement in mobility and endurance. Lastly, Taylor et al. [24] reported improved mobility among residents who played exergames, as measured by the de Morton Mobility Index (DEMMI), however this did not reach significance ($p = 0.06$).

Balance

Eight studies [23, 27, 30, 31, 34, 35, 37, 40] reported balance outcomes with mixed results. When administering the Berg Balance Scale, Cicek et al. [31] reported a statistically significant ($p < 0.05$) improvement among both exergaming and conventional exercise groups compared to a usual care control group. Yeşilyaprak et al. [23] reported improvements among both exergaming and conventional balance groups, thus, exergaming was not more effective at improving balance compared to the control group (see also Janssen et al. [30] for null findings compared to the control). Portela et al. [27] reported improved balance only in a control group with traditional exercise ($p = 0.006$), and Ellmers et al. [34] reported a stronger alignment between postural control and balance capabilities perceived by participants post-intervention ($p < 0.001$). Hsieh et al. [37] reported significantly improved ($p < 0.05$) functional reach among the exergaming group at the 3-month and 6-month time points; effect sizes of 0.5 (3-month) and 1.01 (6-month) favored the intervention over the control. Wu et al. [35] reported no difference in balance post-intervention, as indicated by Berg Balance Scale scores, and Keogh et al. [39] reported no significant quantitative improvements in dynamic balance as indicated by the Four Square Step Test.

Gait

Three of the included studies reported on gait [29, 37, 38], and significant improvements in gait characteristics were reported in each. Pichierri et al. [29] reported greater gait velocity and improved single support time during a fast walking dual-task condition for the intervention group relative to baseline and a control group. Ogawa et al. [38] reported modest, statistically significant ($p < 0.05$) improvements in single-task gait measures but not dual-task gait measures in the intervention group. Hsieh et al. [37] reported a significant improvement ($p < 0.05$) in 5-m gait speed of the exergaming group; effect sizes of 0.23 and 0.60 at 3- and 6-month timepoints represent improvement over time and favor the intervention group over the control group.

Reaction Time

Reaction time was evaluated using the Vienna test [36], and the Grasping ruler test [22]. Of these 2 studies, only Liu et al. [22] reported a significant improvement ($p < 0.05$) in reaction time among the exergaming intervention group but did not analyze whether this change was significant compared to the control group. Chiang et al. [36] found significantly better post-test reaction time scores in the intervention group.

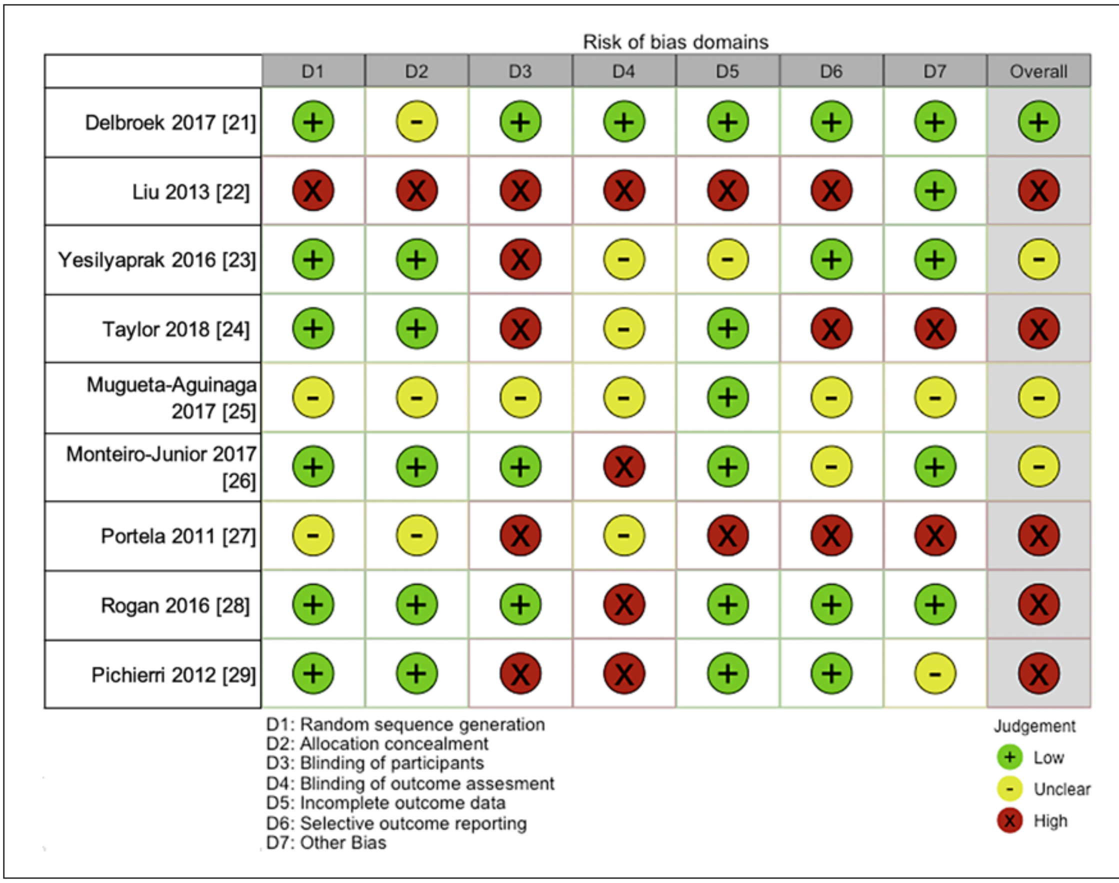

Fig. 2. Risk of bias assessment using the Cochrane RoB-2 tool presented as proportion of relevant studies ($n = 9$).

PA Levels

General level of PA was discussed in 5 of the included studies [25, 28, 30, 39, 41]. The studies collectively reported statistically significant improvements in physical well-being and PA levels according to questionnaire-based measures such as the Rapid Assessment of Physical Activity (RAPA) [39, 41], the LAPAQ (LASA Physical Activity Questionnaire) [30], and the Short Physical Performance Battery Test [25, 28, 41].

Cognitive Outcomes

Five of the 21 studies [21, 26, 27, 37, 38] reported on cognitive outcomes that were measured through validated measures such as MMSE, MoCA, the Verbal Fluency Test, Digit Span Forward, Digit Span Backward, Trail Making Test (TMT) A and B, and the Cognitive Abilities Screening Instrument (CASI). Ogawa et al. [38] reported better performance following exergaming for MMSE and TMT-B scores from pre-to post-test ($p < 0.05$), and change scores that favored the intervention group for TMT-A psychomotor speed. Hsieh et al. [37] reported no significant improvements in overall cognitive abilities as measured by the CASI or subscales examining specific cognitive abilities, with the exception of improvements on one abstract reasoning subscale ($p = 0.002$) at 6 months. Monteiro-Junior et al. [26] reported significant within-subject improvement on the Verbal Fluency Test after a single exergaming session, and effect size between groups ($d = 0.63$) indicated moderate effect of the exergame. Other studies found no significant group differences or pre-post changes in MMSE [27] or MoCA [21].

Quality of Life

QoL was reported on in 6 studies with varying results [22, 27, 31, 39, 40, 42]. The World Health Organization Quality of Life (WHOQOL) Instrument was used in 3 studies: one reported significant improvements in the intervention group compared to the control group for psychological QoL only [39], but another study reported no significant improvements in QoL in any of their three in-

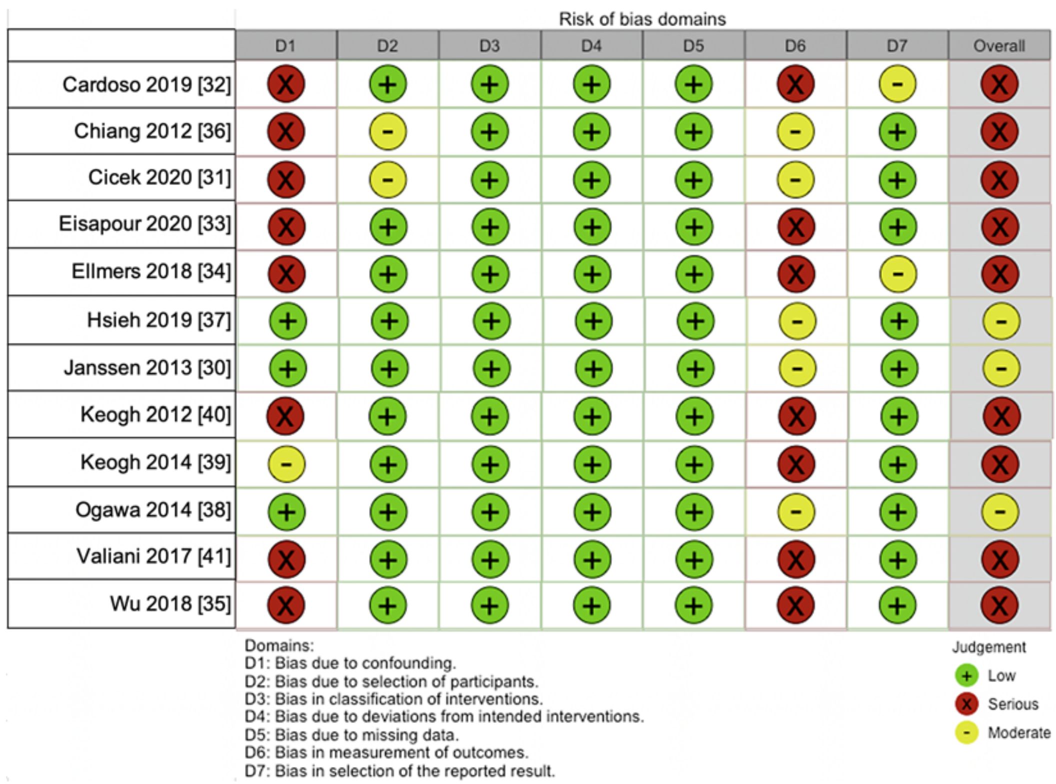

Fig. 3. Risk of bias assessment using the ROBINS-I tool presented as a proportion of relevant studies (n = 12).

tervention groups [32]. Similarly, Cicek et al. [31] administered the WHOQOL-BREF, and found no statistically significant within-group or between-group differences. Using the SF-8 health-related QoL questionnaire, Liu et al. [22] reported no significant improvements in health-related QoL in the exergaming intervention group. In contrast, Portela et al. [27] used the SF-36 health-related QoL questionnaire and observed significantly improved vitality (p = 0.007) and mental health-related QoL (p = 0.023) in the unsupervised exergaming group, as well as improved physical functioning (p = 0.024) in the supervised exergaming group. In contrast, Keogh et al. [40] found no significant within-group change in the SF-36 QOL scores.

Cost and Barriers to Implementation

Only 17% (n = 3) of studies mentioned cost of the exergaming intervention: these studies used commercially available products (i.e., Wii, Xbox Kinect, Oculus Rift products) and referred to such technology as "low cost" or "affordable" [21, 33, 39]. Cited barriers to the implementation of exergaming technology in LTC included a lack of space in the LTC home [23, 39] and the time required for staff to introduce a new activity to residents who are often unfamiliar with the technology [23, 41]. One study listed resident-reported barriers to participation in exergaming interventions which included: self-reported "laziness," lack of interest, feeling it was a "hassle," and physical health problems (p. 149) [35].

Risk of Bias Assessment

Nine studies were assessed using the RoB-2 tool [21–29]. Figure 2 provides details of each study's assessments by RoB domain. Generally, there was a low risk of bias for sequence generation, allocation concealment, and data missingness. Given the nature of exergaming interventions, there was a high risk of bias for blinding of study participants and outcomes assessors. There was also a high risk of bias due to selective outcome reporting by one-third of the evaluated studies.

Twelve studies were assessed using the ROBINS-I tool [30–41]. Figure 3 provides details of each study's assessment by ROBINS-I domain. In general, there was a low risk of bias for selection of study participants, classification of interventions, data missingness, and selection of the reported results. As expected, there was a moderate to serious risk of bias across all studies for measurement of outcomes as participants were not, and generally could not be, blinded due to the nature of exergaming interventions. The ROBINS-I tool detailed guide indicates that if the study is judged to be at serious risk of bias in at least one domain, the study's risk of bias overall should be judged as serious risk. As such, 75% of studies ($n = 9$ [31–36, 39–41] were judged as having an overall serious risk of bias.

Discussion

This systematic review aimed to summarize evidence regarding the effectiveness of exergaming interventions on the physical, cognitive, and QoL outcomes of OAs (>65 years of age) living in LTC. To the best of our knowledge, this systematic review is the first to consider the overall effect of exergaming interventions on the physical health, cognitive abilities, and QoL of this complex population. The analysis combined 21 studies involving a total of 657 participants. We observed wide variability of exergaming interventions, which promoted diverse types of PA (e.g., low intensity, coordination, dance) on different gaming systems. The majority (66%, $n = 14/21$) of studies were associated with a serious risk of bias due to lack of randomization, uncontrolled study designs, and lack of blinding due to the nature of the intervention. Only nine of the 21 studies included were randomized control trials, and four of the studies [32–34, 41] lacked a control group. The sample sizes within the studies were also relatively small (ranging from 8 to 65 participants). These limitations across research designs may be because many of the studies identified themselves as feasibility or pilot investigations mostly lasting 2 months or less (15/21 studies; 71%) with the goal of providing preliminary evidence. Taken together, the current research base lacks conclusive evidence of a positive benefit of exergaming on physical, cognitive, and QoL outcomes for OAs in LTC but does suggest promise in particular domains.

Preliminary evidence that supports possible physical health benefits of exergaming was found in 18 out of 21 studies [21, 22, 24, 25, 27–31, 33–41]: these included observational improvements within a group of exergamers (no control group) and between-group differences in favor of the exergaming group over a control group. Among the studies that measured mobility and endurance outcomes ($n = 8$), 88% reported statistically significant improvements within the exergaming group, indicating a potential effect of exergaming interventions on OA's mobility and endurance. In addition, all the included studies that measured gait ($n = 3$) also reported statistically significant improvements among the exergaming intervention group. This preliminary evidence for physical benefits of exergaming in LTC residents is consistent with stronger evidence of exergaming benefits among broader populations of OAs [42], but evidence from higher quality studies is needed.

Some additional caution is required to interpret the effects of exergaming on cognitive and QoL outcomes, which were more inconsistent across studies. Five studies with a control group included cognitive outcomes but only two reported improvements relative to the control group, and these benefits were limited to specific cognitive domains (i.e., psychomotor speed, abstract reasoning) [38]. In addition to high risk of bias across studies, the use of different cognitive measures (e.g., MMSE, CASI) hindered our ability to conclude the effect of exergaming on cognitive effects in this population. Effects on QoL were similarly inconsistent across studies and measures; of the 2 studies that tested between-group differences, one found improvements for exergaming relative to a control condition for psychological QoL only [40], and the other found no difference [23].

Despite incomplete evidence for positive improvements related to exergaming, it is notable that no exergaming-related adverse events and injuries were reported. Negative effects on an exergaming group were limited to a measure of QoL (Emotional Performance) in a single study at high risk of bias [27] and may have reflected decline over time that is often seen in this population [10]. No other studies reported negative impacts of exergaming on physical, cognitive, or QoL outcomes. Studies either reported no change or an improvement in physical and cognitive performance of residents, suggesting the potential for exergaming to mitigate cognitive and functional declines that are common after admission to LTC [9]. The safety of exergaming among OAs has been reported in other literature reviews [13, 43].

Based on the results of this review, it is evident that further investigation into the effects of exergaming on physical, cognitive, and QoL outcomes for LTC home residents is required. In order to reach more definitive conclusions, it is recommended that future studies employ research designs associated with reduced bias, including RCTs, and recruit large enough samples of residents to provide sufficient statistical power. Future research would benefit from the use of standardized tests and tools to evaluate physical (e.g., TUG, 3MWT, 5-meter gait speed), cognitive (e.g., MMSE), and QoL (e.g., WHOQoL) outcomes, which would permit quantitative synthesis of findings using meta-analysis. The addition of objective measures of PA levels, such as step counts based on a Fitbit activity tracker may also be useful to evaluate whether exergaming helps reduce sedentary time for LTC residents. In addition, evaluations of exergame interventions with longer sessions and increased frequency of sessions per week (i.e., more than 2 per week) may be beneficial to demonstrate more robust effects. Finally, it is recommended that future studies consider investigating moderators of exergame intervention efficacy on OAs (see also [44]). Loneliness and depression are highly prevalent among LTC residents [45], but these were not commonly included in the studies and were only measured by Hsieh et al. [37]. Loneliness, depression, and anxiety can negatively impact resident QoL and have been associated with poor physical functional ability [46]. Future studies should consider these conditions and how they may moderate the effect of exergaming on physical, cognitive, and QoL outcomes.

It is worth noting that the participants enrolled in the included studies were higher functioning physically and cognitively compared to the general population of OAs living in LTC. For example, in Ontario, Canada, 86% of OAs in LTC are dependent (e.g., require extensive help with activities of daily living such as getting out of bed, eating, or toileting) and 64% have dementia [47]. Therefore, results of exergame trials may not be generalizable to the broader population of LTC home residents and there may be issues related to the implementation and adoption of exergames with residents who have lower levels of mobility and cognitive function. Of the studies that reported adherence ($n = 12$), adherence ranged from 55% to 100%; 67% of these studies ($n = 8/12$) reported at least 75% adherence. Where reported, common reasons for missing exergaming sessions were tiredness, loss of interest, and conflicting schedules [24]. Poor adherence and attrition can lead to nongeneralizable conclusions because the participants did not receive the intended intensity or dose of the intervention [48]. Usability of exergames influences their implementation, but only 2 studies reported on system usability [32, 49]. Only 1 study reported, using the System Usability Scale, that users were satisfied with the usability of the system [32]. However, results from Gerling et al. [49] indicated a large difference in perceived usability between exergaming experienced and inexperienced groups, thus indicating that previous exergaming experience may influence LTC residents' willingness to participate in exergaming-delivered PA.

Enjoyable and motivating exergame platforms are important to increase transfer of results from exergaming studies into the LTC home context. There is a need to develop fun and engaging PA interventions since residents have reported negative perceptions and viewed exercise sessions as "boring" or "monotonous" with little interest in participating [50]. This suggests that currently available PA interventions do not take residents' interests and needs into consideration. Exergaming interventions provide the opportunity to implement engaging PA in LTC; user-centered design is important for the design of accepted, useable and thus successful products. Domains for consideration in the design process include user enjoyment, accessibility, and usability. In addition, the majority of studies included in this review used commercially available exergames (i.e., Nintendo Wii, Xbox Kinect) [51], and while these gaming systems were accessible for research study purposes, some of these systems are discontinued, no longer in production, or not widely commercially available. Future exergame interventions developed for this population should employ the principles of user centered design [52], an iterative process that would allow the needs of LTC residents to be captured throughout the design process, and use validated measures such as the System Usability Scale [53], to measure residents' perceptions of exergaming intervention usability. Systems developed through user centered design processes such as the MouvMat have been recently studied but are not yet commercially available [54].

This systematic literature review has some limitations. The studies included within this review were highly heterogeneous with respect to the console used, game software, impact of the exergame, and the outcomes assessed. For this reason, we were also unable to conduct meta-analyses. Therefore, conclusions reflect exergames for OAs in LTC more generally, and not a single exergaming intervention or training design.

Conclusion

Our review indicated that exergaming for residential LTC homes is a growing field of research, but existing evidence should be interpreted cautiously due to the heterogeneous nature of the interventions, uncontrolled designs, and small samples. Larger and more methodologically robust evaluations are required to mature the evidence base. Exergames might be a promising intervention to benefit the physical health of OAs (>65 years) living in LTC, but more research is required to determine the effects of exergaming on physical health, as well as cognitive and QoL outcomes. Cost-effectiveness analyses are also warranted as cost was identified as a barrier to exergaming systems implementation. There is also room for future co-design and development of exergaming technologies and systems that will consider the interests as well as the physical and cognitive needs of OAs to facilitate uptake and implementation.

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Statement of Ethics

An ethics statement was not required for this study type, no human or animal subjects or materials were used.

Conflict of Interest Statement

The authors have no conflicts of interest to disclose.

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Author Contributions

C.C., A.Q., and R.B. participated in all stages of this systematic literature review, from the design, extraction and interpretation of data, and final writing. A.S., A.K., and A.Q. extracted and analyzed the data. All authors participated in the writing and review of the final manuscript.

Data Availability Statement

All data generated or analyzed during this study are included in this article and/or its online supplementary material files. Further enquiries can be directed to the corresponding author.

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