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Featured Article

Virtual reality exergames for improving physical function, cognition and depression among older nursing home residents: A systematic review and meta-analysis

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ABSTRACT

Objective: To explore the effectiveness of virtual reality (VR) exergames on physical function, cognition and depression among older nursing home residents.
Methods: A systematic review and meta-analysis were conducted. The PubMed, Ovid, Embase, Cochrane, CINAHL, and Web of Science databases were searched for relevant studies from inception until June 1, 2023. The reviewers independently completed the study selection, data extraction and quality assessment. Subgroup analyses were conducted to explore the sources of between-study heterogeneity and to determine whether participant or intervention characteristics influenced effect sizes.
Results: Eighteen studies met the inclusion criteria and were selected for qualitative and quantitative synthesis. The overall methodological quality was relatively high, and the overall evidence grade was moderate. VR exergames had a large effect on physical function, including mobility [SMD=-0.66, $P < 0.001$], balance [SMD=0.95, $P < 0.001$], and lower limb strength [SMD=0.53, $P = 0.0009$]; and a moderate effect on cognition [SMD=0.48, $P = 0.02$] and depression [SMD=-0.72, $P = 0.03$]. Subgroup analyses revealed that a training frequency of 2 sessions per week and coordinating with physiotherapists yielded greater improvements in mobility ($P = 0.009$; $P = 0.0001$). VR exergames had especially beneficial effects on balance for physically fit participants ($P = 0.03$) and on cognition for participants with cognitive impairment ($P = 0.01$). Additionally, regarding the improvement of depression, commercial VR exergames were superior to self-made systems ($P = 0.03$).
Conclusion: VR exergames can provide a positive impact on physical function, cognition and depression among older nursing home residents. The study also demonstrated the different benefits of exergames between participants who were physically fit and those with cognitive impairment, which is considered as an innovative, cost-efficient and sustainable approach. Specifically, commercial VR exergame programs with a frequency of 2 sessions per week and coordinating with physiotherapists may be the most appropriate and effective option.

Introduction

As the aging trend intensifies, the demands for primary medical care, assistance with activities of daily living, and measures to control the prevalence and severity of chronic conditions among older adults living in long-term care facilities and nursing homes (NHs) are also expected to increase. Aging is often associated with varying degrees of deterioration in gait performance, balance control and muscle strength, all of which are considered important risk factors for falls.[1,2] The 2020 World Health Organization (WHO) Global Report on Falls Prevention in Older Age indicated that approximately 30 %–50 % of older adults who live in NHs experience falls at least once annually, and 40 % of those individuals experience recurrent falls.[Anon., 3] According to statistical data, the number of falls among senior care facility residents was three times greater than that among community-dwelling older adults.[4] The main reason is that older NH residents are more likely to suffer from sarcopenia, which is

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characterized by a loss of muscle strength and decreased physical performance, triggering falling and fall-related injuries, such as fracture, hospitalization, multiple trauma, disability and even mortality.[5,6] Multiple adverse health outcomes are placing a substantial burden on the healthcare system.

According to the 2020 WHO Report on Mental Health of Older Adults, >20 % of older adults aged > 60 years suffer from mental health problems or neurologic disorders,Anon., 7 and age-related cognitive impairment has become a priority public health issue. Institutionalized older adults may exhibit a greater level of functional dependence due to cognitive decline than community-dwelling residents.[8] These issues could be attributed to the environmental stimulation provided by NHs. The conflicts and changes in the psychosocial environment experienced during relocation to NHs can result in impaired cognitive function, which is known as "transfer trauma" or "relocation stress syndrome".[9] Approximately 48 % of older adults experience a clear-cut cognitive decline after institutionalization, and the dependency rate for care is as high as 30 %.[10,11] Older NH residents are at greater risk of mild cognitive impairment (MCI), dementia, hospitalization and other complications, including urinary tract infections, pressure ulcers and pneumonia, due to a multidimensional decline in cognitive function.[12]

Depression is defined as a depressed mood and/or a loss of interest for at least 2 weeks, which might be accompanied by sleep disturbances (insomnia or lethargy), sensory disturbances (guilt or worthlessness), weight changes, irritability or psychomotor delay and fatigue.[13] It is estimated that the prevalence of depressive symptoms is approximately 29 % among older NH residents, of whom 10 % have severe depressive disorders.[14] The transition to institutionalization is an important stressor that may increase the risk of depression. Moreover, institutionalized older adults frequently feel lonely due to a lack of social interaction, and loneliness is also considered a major risk factor for depression.[15] From the perspectives of physical and cognitive function, falling is strongly tied to decreased physical performance, and those who experience falls report emotional disturbances due to the fear of falling and loss of confidence.[16] Cognitive decline frequently accompanies negative psychological problems,[17] and the three main factors together produce interactive effects.

Virtual reality (VR) is a computerized system that simulates an activity, and it has been employed to promote motor learning and transfer to real-world tasks. This complementary technology bridges the gap between exercise and games and is therefore commonly termed "exergames". Exergames combine physical activity with cognitively challenging tasks in a single session; they have the advantages of being acceptable, affordable and available and their use has become a trend in recent years.[18] Exergames can detect subtle changes in participants' activities and movements in the real world through wireless interface sensors; participants can receive instant feedback on their movements while immersed in the game's 3-dimensional (3D) world, which will stimulate motor, sensory and mental functions, thereby promoting a willingness to exercise consistently.[19] Moreover, various systems are available, such as Nintendo Wii Sports, Microsoft Xbox Kinect and Dance Revolution.[20] Exergames enable participants to engage in challenging tasks with visual and auditory stimuli, cues and feedback.[21] Immersion in the VR environment can effectively mitigate functional decline and promote cognitive rehabilitation.[22,23] Furthermore, virtual gaming is helpful for emotional regulation, real-time decision making, and social interaction to alleviate psychological symptoms.[24] Currently, the difficulty levels of VR exergames can be adapted based on users' conditions and abilities to increase their suitability for older NH residents.

A recent meta-analysis revealed that VR games can overcome the limitations of traditional exercise, improve physical function, enhance balance ability and minimize falls among older adults with impaired balance.[25] However, there is insufficient evidence to support the effects of VR games on older individuals residing in NHs. Compared with community-dwelling individuals, institutionalized older adults are more likely to suffer from multiple illnesses that result in worsening somatic and mental conditions. Previous research has shown the benefits of VR training on cognition, including memory, attention and executive function, and identified the different effects between clinical and nonclinical populations.[26] These findings suggest that the effects of exergames on cognitive function between different populations need to be further explored. Although a few studies have examined the effects of exergames on mental functioning,[13,14] the available evidence is inadequate to reach a consensus. No meta-analysis has summarized the effects of VR exergames on physical function, cognition and depression in older NH residents.

Therefore, the purpose of this systematic review and meta-analysis was to explore the effectiveness of VR exergames in promoting physical function and cognition as well as ameliorating depressive symptoms in older NH residents. Subgroup analyses were conducted based on participants' characteristics (age, basic physical condition) and intervention characteristics (duration, frequency and cycle, and various types of exergame systems and training formats) to optimize the selection of VR gaming programs.

Methods

This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Supplementary file 1). The study was registered at the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42023433984.

Search strategy

Relevant articles were retrieved from the PubMed, Ovid (MEDLINE), Embase, Cochrane Library, CINAHL (EBSCOhost), and Web of Science databases from inception until June 1, 2023, with the help of a health sciences librarian. Google Scholar was also searched to identify literature that may have been omitted in the other searches. The search was conducted using Medical Subject Headings (MeSH) and free text words, and language or publication year restrictions were not applied. The article types were restricted to randomized controlled trials (RCTs) and quasiexperimental studies. Moreover, we evaluated the gray literature, the reference lists of the screened studies, and the articles of forward citations for additional information. The search strategy details are presented in Supplementary file 2.

Inclusion and exclusion criteria

The Population, Intervention, Comparison, Outcome, Study Design (PICOS) framework was formulated as the selection criterion: (1) The population included individuals aged >60 years residing in NHs, senior centers, long-term care or assisted living facilities (residence duration ≥3 months); there were no restrictions on cognitive conditions, but participants must have been able to execute VR exergames. (2) The intervention comprised VR-based exergames or active video games, including commercial game systems or self-made game systems. There was no restriction regarding the VR environment displayed by the devices, such as television screens or 3D projectors. (3) The comparison groups performed exercises that were not in any way a form of VR exergames, received routine health care or did not undergo any intervention. (4) The primary outcomes included physical function-, cognition-, and depression-related targets. (5) The eligible study designs included randomized controlled trials (RCTs) and quasiexperimental studies.

The exclusion criteria were as follows: (1) VR exergames without exercise or the involvement of any body movements; (2) nonsynchronous controlled studies; (3) unable to access the full text; (4) mixed method design; (5) secondary analysis; (6) incomplete data for analysis; and (7) conference abstracts, case reports, commentaries, gray literature, study protocols and review literature.

Study selection and data extraction

Two researchers initially independently screened the literature by evaluating the titles and abstracts in accordance with the predesigned criteria. The literature that met the eligibility criteria was then selected for full-text reading and targeted analysis. Disagreements were resolved by consulting a third researcher to reach a consensus. The following data were extracted: (1) basic information (author names, publication year, country); (2) participant demographic data (characteristics, age, sample size and gender); (3) intervention characteristics (duration, frequency and cycle, types of exergame systems and training format); and (4) outcome measurements (physical function-, cognition- and depression-related indicators). All the data were cross-checked by the reviewers.

Quality assessment

The Cochrane risk of bias tool was used to evaluate the quality of the studies.[27] Two researchers independently completed the evaluation, and disagreements were resolved through discussion or by a third party. The following seven domains were assessed: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting and other bias. Each domain was rated as "high risk", "unclear risk" or "low risk". Studies that met all of the above criteria were considered high-quality studies. Furthermore, the level of evidence for outcome indicators was evaluated by the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach.[28] Each outcome was graded as very low, low, moderate or high level.

Statistical analysis

RevMan 5.3 (Cochrane Collaboration, Oxford, UK) statistical software was used to perform the meta-analysis. The standard mean difference (SMD) or mean difference (MD) was calculated for continuous data, relative risks (RRs) were calculated for counting data, and the effect size was assessed using 95 % confidence intervals (CIs). The Q value and I^2 value were used to determine heterogeneity among the studies. I^2 values of 25 %, 50 % and 75 % indicated low, medium and high heterogeneity, respectively. A fixed-effects model was applied if the heterogeneity among the results was not significant ($P \geq 0.1$, $I^2<50$ %); otherwise, a random-effects model was selected ($P < 0.1$, $I^2>50$ %). Stata 14.0 statistical software (StataCorp, LLC, College Station, TX, USA) was used to analyze potential publication bias, and the trim-and-fill methods were used for verification. In addition, subgroup analyses were conducted to explore between-study heterogeneity and sensitivity analyses were performed to test the reliability of the results. $P < 0.05$ was considered to indicate statistical significance.

Results

Study selection

A total of 2088 studies were initially selected via the predesigned retrieval strategy from the six selected databases and the Google Scholar search. After using EndNote software to remove 691 duplicate studies, the remaining 1397 studies were screened by title and abstract, and an additional 1328 studies were excluded because they did not meet the eligibility criteria. Then, 69 full-text studies were further screened, and 51 were subsequently excluded for several reasons: noncorrelation outcomes (n = 22); not RCTs or quasiexperimental studies (n = 9); mixed- method designs (n = 7); unable to access the full text (n = 6); secondary analysis of initial data (n = 2); and incomplete data for meta-analysis (n = 5). Ultimately, 18 studies[29-46] were included in the qualitative and quantitative synthesis. The PRISMA flow diagram of the study selection process is illustrated in Fig. 1.

Basic characteristics of the studies and participants

The 18 included studies were published from 2012 to 2023 and were conducted in Brazil (n = 2), Belgium (n = 2), China (n = 1), Iran (n = 1), Korea (n = 2), Lebanon (n = 1), the Netherlands (n = 1), Spain (n = 2), Switzerland (n = 1), Turkey (n = 2), the United States (n = 2) and the United Kingdom (n = 1). A total of 737 older adults met the eligibility criteria in the included studies, and the participants' mean (SD) age ranged from 67.71 (4.31)[42] to 87.50 (6.60)[39] years. The majority of participants were females (26.67 %–100 %); two studies did not report the sex distribution of the participants.[36,43] Three studies were conducted in long-term care or assisted living facilities,[33,37,46] four were performed at senior or residential care centers,[30,39,43,45] four were carried out in other social institutions,[34,36,38,42] and the remainder were conducted in NHs. Most of the participants were in good health condition, but one study involved pre-frail older adults,[45] two included older adults with mild cognitive impairments or mild Alzheimer's dementia,[39,46] and one mentioned major neurocognitive disorder (MNCD).[33] The participants' effective adherence rates ranged from 81.82 to 100 %. Seven studies reported that the reasons for loss to follow-up mainly included transfer (n = 5),[33] COVID-19 measures (n = 5),[33] severe cognitive impairment (n = 10),[35,37,44] becoming medically unfit (n = 7),[37] family issues (n = 3),[37] unwillingness to continue (n = 11),[37,40,42] and conducting other exercises (n = 1).[42] The methodological characteristics of the included studies are summarized in Table 1.

VR exergame features

Two main types of VR exergames were used as intervention measures. Fourteen study designs involved commercial VR game systems, which were characterized as acceptable, affordable and available, including Wii Fit, Kinect, X-BOX and other consoles. The remaining studies used self-made VR game systems, which were independently developed by the research team and focused on individualized exercise programs and timely feedback, such as GAMotion. Various games, such as Dance Central, Soccer Heading, Table Tilt and Balance Bubble, were included in the systems. The exergame training sessions mainly involved balance training, strength training and cognitive-motor dual tasking. Ten study designs reported that the training format was coordinated with physiotherapists, who designed, guided and supervised exergame sessions, helping the participants understand the program structure and ensuring the safety and comfort of the training. Eight studies employed health education, and exergame applications were introduced to the participants through course meetings and led by certified fitness professionals or volunteers. The duration of each training session ranged from 6 to 60 min, the training frequency was mainly 2 or 3 times per week, and the total intervention cycle lasted from 3 to 15 weeks. Most of the control groups received routine health care or no intervention, and the remaining studies were related to occupational therapy,[30,32] gymnastics sessions,[32] musicotherapy,[33] board games,[34] and OTAGO strength and balance exercises.[37] (Table 1)

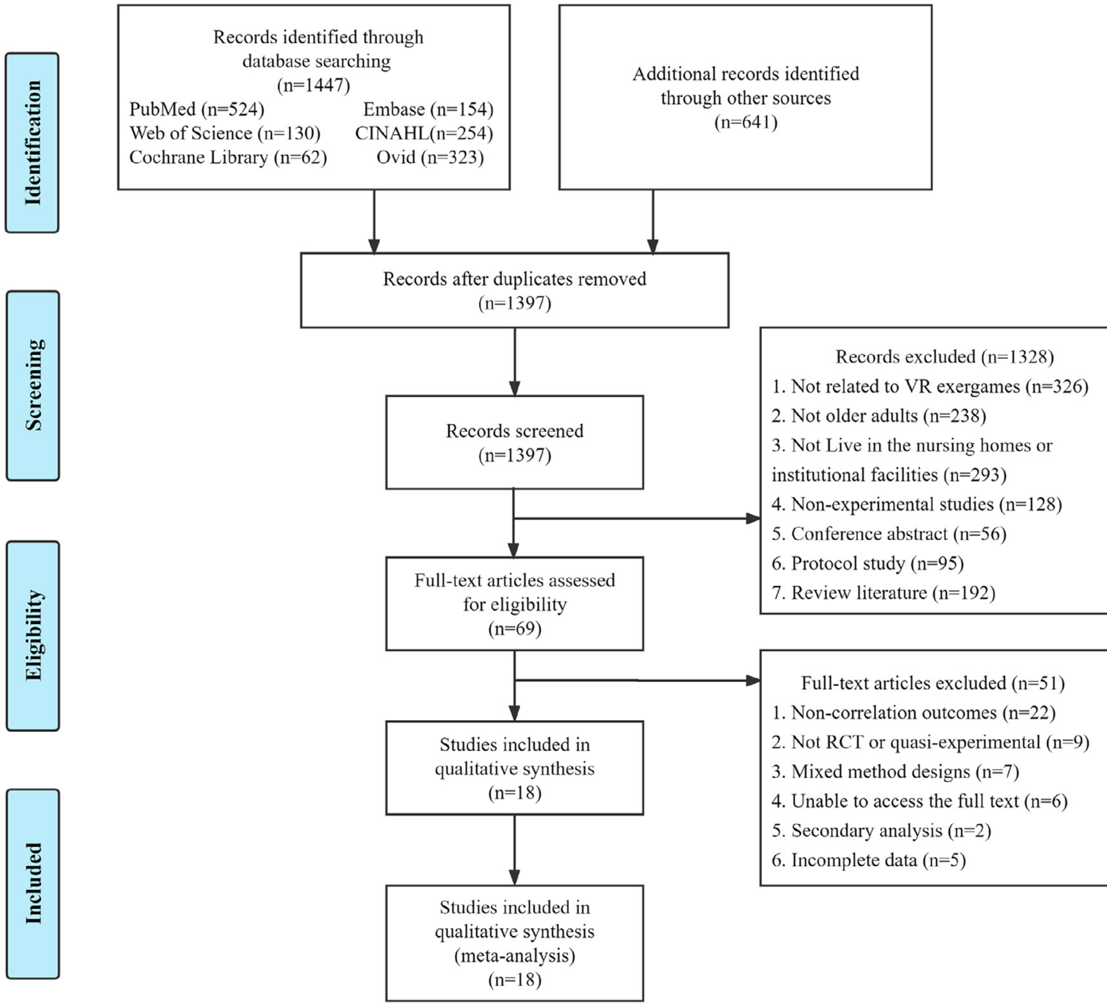

Fig. 1. PRISMA flow diagram of the study selection process.

Outcome measurements

The main outcome measures focused on physical function, cognition and depression. Farinatti illustrated that age-related physical function mainly included three aspects: mobility, balance and muscle strength.[47] The most common measurements were the timed up and go test (TUG) for mobility, the Berg Balance Scale (BBS) for balance, and the chair stand test (CST) for lower limb strength. The montreal cognitive assessment (MoCA) and mini mental status examination (MMSE) were the primary tools used to assess participants' cognitive function. The geriatric depression scale (GDS), Yesavage Scale for Geriatric Depression (EGD-15) and beck depression inventory (BDI) were selected for the evaluation of depression (Table 1). Finally, we extracted the different outcome measurement information according to similar structures and methods to create an outcome indicator that could be assessed.

Methodological quality

The included studies followed the principles of randomization allocation, reasonable control of the study design, and baseline comparison; follow-up loss and outcome measurement data were completely reported, and the overall quality was high. Among the 18 studies, 11 studies reported random sequence-generating methods that mainly included drawing lots, computerized random-number generators and block randomization. Four studies implemented procedures for allocation concealment. To ensure the successful completion of the exergame program, only three studies fulfilled the blinding of participants and interveners, but seven studies completed the assessor-blind methods. Almost all the studies reported complete data, indicating that there was a minimal possibility of selective reporting bias and other bias. The quality assessment of the included studies is summarized in Table 2. Levels of evidence for outcome indicators were assessed as moderate (n = 2) and low (n = 3). The low level of evidence was mainly attributed to the high heterogeneity and non-implementation of allocation concealment and blinding methods. The levels of evidence are illustrated in Supplementary file 3.

Meta-analysis of outcome measures

The primary indicators were physical function (mobility, balance and lower limb strength), cognition, and depression status.

Physical function

The physical function indicators included mobility, balance and lower limb strength. Thirteen studies were compared in terms of mobility, and three studies were excluded from this meta-analysis because they reported different calculation methods for the outcome indicators.[38,42,45] Twelve studies compared balance, and six studies compared lower limb strength between the VR exergame group and

Table 1
Characteristics of the included studies.

Author (year) Country	Participants		Interventions			Outcomes Measurement
	Characteristics Age (years)	Sample Size (Male/Female)	Experimental Group	Control Group	Duration, Frequency and Cycle	
Unver et al. (2023) Turkey	Older adults living in nursing homes EG/CG ≤ 75 (4/2) EG/CG > 76 (3/5)	Total=14 EG=7 (3/4) CG=7 (4/3)	• Design: VR Kinect exergame • Game: Dance Central • Mode: Health education (Introduced VR exercise)	No intervention	Minutes per session: 15 (morning and evening) Times per week: 3 Total: 3 weeks	• Depression: GDS
Campo-Prieto et al. (2022) Spain	Older adults living in a senior center EG: 85.08 ± 8.48 CG: 84.82 ± 8.10	Total=24 EG=13 (2/11) CG=11 (1/10)	• Design: BOX IVR game • Game: The Blue, Steam VR Home • Mode: Coordinated with physiotherapist (Individual guided and supervised sessions)	Usual care programs: occupational therapy and memory workshop	Minutes per session: 6 Times per week: 3 Total: 10 weeks	• Physical function • Mobility: TUG • Balance: Tinetti test
Zahedian-Nasab et al. (2021) Iran	Older nursing home residents EG: 69.67 ± 7.73 CG: 72.00 ± 7.81	Total=60 EG=30 (22/8) CG=30 (22/8) 26.67%	• Design: VR exercises games based on Xbox Kinect • Game: Penalty, goalkeeping, ski and darts. (Balance training) • Mode: Health education (Explained computer devices and exercises)	Routine programs: jogging, table tennis, and artistic activities	Minutes per session: 30-60 Times per week: 2 Total: 6 weeks	• Physical function • Mobility: TUG • Balance: BBS
Jahouh et al. (2021) Spain	Older adults living in a day care center or a mixed nursing home EG: 85.05 ± 8.63 CG: 83.25 ± 8.78	Total=80 EG=40 (18/22) CG=40(17/23)	• Design: Activities with the Nintendo Wii Fit® video game console • Game: "Step" (Aerobic training), "Nodding" (Attention, memory training) • Mode: Coordinated with physiotherapist (Guided and supervised sessions)	Routine therapies: physical therapy, occupational therapy and gymnastics sessions	Minutes per session: 40-45 Times per week: 2 Total: 8 weeks	• Cognitive function: MCE • Depression: EGD-15
Swinnen et al. (2021) Switzerland	Older adults with major neurocognitive disorder residing in long-term care facilities EG: 84.70 ± 5.60 CG: 85.30 ± 6.50	Total=45 EG=23 (5/18) CG=22 (5/17)	• Design: VR exergames were performed by "Dividat Senso" device • Mode: Coordinated with physiotherapist (Designed and supervised to ensure safety and comfort)	Routine care: watching and listening to music videos 15 min, walk to and back ward	Minutes per session: 15 Times per week: 3 Total: 8 weeks	• Cognitive function: MoCA • Depression: CSDD
Rica et al. (2020) Brazil	Older adults living in social institutions EG > 60 CG > 60	Total=50 EG=18 (0/18) CG=32 (0/32)	• Design: Kinect-based exercise used the X-BOX 360 console • Game: Kinect Sports Ultimate Collection Your Shape Fitness Evolved Dance Central Nike + Kinect Training • Mode: Health education	Played board games and normal daily activities	Minutes per session: 60 Times per week: 3 Total: 13 weeks	• Physical function • Balance: The time of permanence in a position • Lower limb strength: The sit-and-stand test • Depression: BDI
Buckinx et al. (2020) Belgium	Older nursing home residents EG: 66.00-73.00 CG: 78.50-88.80	Total=21 EG=11 (7/4) CG=10 (4/6)	• Design: GAMotion (a giant exercising board game) • Game: Activities including strength, flexibility, balance and endurance components • Mode: Coordinated with physiotherapist (Supervised the VR exergames program)	No intervention	Minutes per session: 30 Times per week: 1 Total: 4 weeks	• Physical function • Mobility: TUG • Balance: Tinetti test • Lower limb strength: Maximal isometric muscle strength • Depression: EQ-5D
Fakhro et al. (2020) Lebanon	Older adults living in social institutions EG ≥ 65 CG ≥ 65	Total=60 EG=30 CG=30	• Design: Wii fit BT exergames • Game: "Soccer Heading" (first 4 weeks), "Table Tilt" (remaining 4 weeks) • Mode: Health education	No intervention	Minutes per session: 30 Times per week: 3 Total: 8 weeks	• Physical function • Mobility: TUG
Stanmore et al. (2019) UK	Older adults residing in assisted living facilities EG: 77.9 (58-96) CG: 77.8 (58-101)	Total=106 EG=56 (11/45) CG=50(12/38)	• Design: The laptop and sensor set up exergame program • Mode: Coordinated with physiotherapist (Supervised the VR exergame programs)	OTAGO strength and balance exercise program	Minutes per session: 30 Times per week: 3 Total: 12 weeks	• Physical function • Mobility: TUG • Balance: BBS • Cognitive function: ACEII • Depression: 5-item GDS

(*continued on next page*)

Table 1 (*Continued*)

Author (year) Country	Participants		Interventions			Outcomes Measurement
	Characteristics Age (years)	Sample Size (Male/Female)	Experimental Group	Control Group	Duration, Frequency and Cycle	
Monteiro-Junior et al. (2017) Brazil	Institutionalized older adults EG: 85.00 ± 8.00 CG: 86.00 ± 5.00	Total=18 EG=9 (3/6) CG=9 (3/6)	• Design: VR-based physical exercises with exergames (PhysEx) • Mode: Health education (Introduced the devices and VR exergame programs)	Same exercises as PhysEx without VR stimulation	Minutes per session: 30-45 Times per week: 2 Total: 8 weeks	• Physical function • Mobility: 8FUGT • Lower limb strength: CST • Cognitive function: MMSE • Depression: GDS
Delbroek et al. (2017) Belgium	Older adults with mild cognitive impairment at the residential care center (MoCA<26) EG: 86.90 ± 5.60 CG: 87.50 ± 6.60	Total=20 EG=10 (2/8) CG=10 (5/5)	• Design: VR dual-task training using the BioRescue • Game: "Memory Exercise", "Avoidance Whilst", "Walking", "Hot Air Balloon", "Blackboard", "Space Shuttle", "Simple Maze" and "Tortoise" (Cognitive-motor dual tasking balance training) • Mode: Coordinated with physiotherapist	Routine health care	Minutes per session: 18-30 Times per week: 2 Total: 6 weeks	• Physical function • Mobility: iTUG • Balance: Tinetti-POMA • Cognitive function: MoCA
Yeşilyaprak et al. (2016) Turkey	Older adults living in nursing homes EG: 70.10 ± 4.00 CG: 73.10 ± 4.50	Total=18 EG=7 (4/3) CG=11 (2/9)	• Design: BTS NIRVANA VR Interactive System games • Game: Visual and audio feedback games (Balance training) • Mode: Coordinated with physiotherapist (Supervised the VR exergames program)	Conventional exercise	Minutes per session: 35-45 Times per week: 3 Total: 6 weeks	• Physical function • Mobility: TUG • Balance: BBS
Tsang et al. (2016) China	Older nursing home residents EG: 82.30 ± 3.80 CG: 82.00 ± 4.30	Total=79 EG=39 (16/23) CG=40(15/25)	• Design: Wii Fit balance training • Game: Soccer Heading, Table Tilt, Balance Bubble • Mode: Coordinated with physiotherapist (Led the VR exergame programs)	Conventional balance training	Minutes per session: 60 Times per week: 3 Total: 6 weeks	• Physical function • Mobility: TUG • Balance: BBS
Lee et al. (2015) Korea	Older adults living in social institutions EG: 68.77 ± 4.62 CG: 67.71 ± 4.31	Total=54 EG=26 (0/26) CG=28 (0/28)	• Design: Individualized feedback-based VR exercise program • Game: "Zen Energy" (Postural, balance, functional, lower body strength training) • Mode: Coordinated with physiotherapist (Led the VR exergames program)	No intervention	Minutes per session: 60 Times per week: 3 Total: 8 weeks	• Physical function • Mobility: 8FUGT • Lower limb strength: 30SCST
Jung et al. (2015) Korea	Older adults living in senior citizen centers EG1: 74.30 ± 2.10 EG2: 74.30 ± 3.50 CG: 73.60 ± 2.40	Total=24 EG1=8 EG2=8 CG=8	• Design: EG1: Nintendo Wii Sports EG2: Lumbar stabilization exercise • Game: Wakeboard, Frisbee dog, Jet ski and Canoe • Mode: Health education	No intervention	Minutes per session: 30 Times per week: 2 Total: 8 weeks	• Physical function • Mobility: TUG • Balance: BBS • Lower limb strength: FRT
Janssen et al. (2013) Netherland	Older nursing home residents EG: 81.50 ± 12.80 CG: 80.00 ± 8.50	Total=21 EG=8 (2/6) CG=13 (3/10)	• Design: Nintendo "Wii Fit Plus" sessions • Game: "Table Tilt Plus" balance and other two games. • Mode: Health education (Supervised by the researcher and the volunteer)	No intervention	Minutes per session: 60 Times per week: 2 Total: 12 weeks	• Physical function • Balance: BBS
Daniel (2012) USA	Pre-Frail older adults at senior centers and residential living centers EG1: 80.00 ± 3.37 EG1: 78.13 ± 5.50 CG: 72.60 ± 4.60	Total=21 EG1=8 (3/5) EG2=8 (3/5) CG=5 (3/2)	• Design: EG1: Nintendo Wii-fit exergames • Game: Bowling, tennis and boxing EG2: Seated exercise based on a traditional senior fitness program and a rigorous seated aerobics program • Mode: Health education (Led by a certified fitness professional)	No intervention	Minutes per session: 45 Times per week: 3 Total: 15 weeks	• Physical function • Mobility: 8FUGT • Balance: SRT • Lower limb strength: CST

(*continued on next page*)

Table 1 (*Continued*)

Author (year) Country	Participants		Interventions			Outcomes Measurement
	Characteristics Age (years)	Sample Size (Male/Female)	Experimental Group	Control Group	Duration, Frequency and Cycle	
Padala, et al. (2012) USA	Older adults with mild Alzheimer's dementia residing in an assisted living facility (MMSE ≥18) EG: 79.3 ± 9.8 CG: 81.6 ± 5.2	Total=22 EG=11 (3/8) CG=11 (3/8)	• Design: Wii Fit exergames • Game: Yoga, strength and balance games • Mode: Coordinated with physiotherapist (Led the VR exergames program)	Walking exercise	Minutes per session: 30 Times per week: 5 Total: 8 weeks	• Physical function • Mobility: TUG • Balance: BBS • Cognitive function: MMSE

Note: ACEII, Addenbrooke's Cognitive Examination III; BBS, Berg Balance Scale; BDI, Beck Depression Inventory; CG, control group; CST, Chair Stand Test; CSDD, Cornell Scale for Depression in Dementia; EG, experimental group; EGD-15, Yesavage scale for Geriatric Depression; EQ-5D, The EuroQol 5-dimension questionnaire; FRT, Functional Reach Test; GDS, Geriatric Depression Scale; MCE, Mini-Cognitive Examination; MoCA, Montréal Cognitive Assessment; MMSE, Mini Mental Status Examination; POMA, Performance-oriented Mobility Assessment scale; RCT, randomized controlled trial; SRT, Sit and Reach Test; TUG, Timed Up and Go Test; 8FUGT, 8-Foot Up-and-Go Test.

the control group. The results showed that mobility [SMD=−0.66, 95 % CI (−0.99, −0.33), Z = 3.90, $P < 0.001$], balance [SMD=0.95, 95 % CI (0.63, 1.28), Z = 5.72, $P < 0.001$] and lower limb strength [SMD=0.53, 95 % CI (0.22, 0.84), Z = 3.33, P = 0.0009] were significantly greater in the VR exergame group than in the control group (Fig. 2). Egger's tests revealed that there was no significant publication bias (P = 0.678; P = 0.807; P = 0.933), as shown in Table 3.

Cognitive function

Six studies assessed differences in cognitive function between the VR exergame group and the control group. The results showed that VR exergames significantly improved the cognition of older NH residents [SMD=0.48, 95 % CI (0.06, 0.90), Z = 2.25, P = 0.02] (Fig. 2). Due to the high heterogeneity among the studies, a sensitivity analysis was performed and showed that the study by Swinnen et al[33] was the main source of heterogeneity. Egger's test revealed that there was no potential publication bias (P = 0.284). The trim-and-fill method was used to impute three studies, and the results were subjected to trim-and-fill adjustment [SMD=1.165, 95 % CI (0.727, 1.866)], as shown in Table 3.

Depression status

Seven studies compared depression status among participants between the VR exergame group and the control group. The results showed that VR exergames significantly reduced depression of older NH residents [SMD=−0.72, 95 % CI (−1.38, −0.07), Z = 2.17, P = 0.03] (Fig. 2). Due to the high heterogeneity between studies, subgroup analysis was also conducted to explore the sources of heterogeneity. Egger's test revealed that there was no publication bias (P = 0.240), as shown in Table 3.

Moderator analysis of outcome measures

Subgroup analyses were also conducted to address between-study heterogeneity and determine whether participant or intervention characteristics influenced the effect size.

Subgroup analysis: physical function

Subgroup analyses revealed that a VR exergame frequency of ≤ 2 sessions per week resulted in a significantly greater improvement in mobility than did a frequency of > 2 sessions per week (P = 0.009). Moreover, ≤ 2 sessions per week also had greater improvement effects on lower limb strength [SMD=0.66, 95 % CI (0.10, 1.21)]. When the training format was coordinated with physiotherapists, the intervention was more effective than health education for improving mobility (P = 0.0001). Regarding participants' basic physical condition, VR exergames had significantly stronger beneficial effects on balance among participants who were physically fit than among participants with cognitive impairment (P = 0.03). Similarly, healthier individuals were shown to experience greater improvements in mobility and lower limb strength [SMD=−0.77, 95 % CI (−1.12, −0.41); SMD=0.58, 95 % CI (0.26, 0.91)]. However, the effects did not differ based on age, training duration, cycle, or VR exergame type. The results of the subgroup analysis are shown in Table 4.

Subgroup analysis: cognitive function

Regarding the participants' basic physical condition, the subgroup analysis revealed that VR exergames were more effective at improving cognition in participants who suffered from cognitive impairment than in healthy participants (P = 0.01). The subgroup analysis did not

Table 2
Quality assessment of the included studies.

Author (year)	Random sequence generation	Allocation conceal-ment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Unver et al (2023)	low risk	unclear risk	high risk	unclear risk	low risk	low risk	unclear risk
Campo-Prieto et al (2022)	low risk	unclear risk	unclear risk	unclear risk	low risk	low risk	low risk
Zahedian-Nasab et al (2021)	low risk	high risk	unclear risk	unclear risk	low risk	low risk	low risk
Jahouh et al (2021)	low risk	low risk	low risk	low risk	low risk	low risk	low risk
Swinnen et al (2021)	low risk	unclear risk	unclear risk	low risk	low risk	low risk	unclear risk
Rica et al (2020)	low risk	unclear risk	unclear risk	unclear risk	unclear risk	unclear risk	unclear risk
Buckinx et al (2020)	unclear risk	unclear risk	high risk	unclear risk	low risk	low risk	unclear risk
Fakhro et al (2020)	unclear risk	unclear risk	unclear risk	low risk	low risk	low risk	unclear risk
Stanmore et al (2019)	low risk	low risk	unclear risk	high risk	low risk	low risk	unclear risk
Monteiro-Junior et al (2017)	low risk	low risk	low risk	unclear risk	low risk	low risk	unclear risk
Delbroek et al (2017)	unclear risk	unclear risk	unclear risk	low risk	low risk	low risk	unclear risk
Yeşilyaprak et al (2016)	low risk	unclear risk	unclear risk	unclear risk	low risk	low risk	unclear risk
Tsang et al (2016)	unclear risk	unclear risk	unclear risk	low risk	low risk	low risk	low risk
Lee et al (2015)	low risk	low risk	low risk	low risk	low risk	low risk	low risk
Jung et al (2015)	unclear risk	unclear risk	high risk	unclear risk	low risk	low risk	low risk
Janssen et al (2013)	high risk	unclear risk	high risk	low risk	low risk	low risk	unclear risk
Daniel (2012)	unclear risk	unclear risk	unclear risk	unclear risk	low risk	low risk	unclear risk
Padala, et al (2012)	low risk	unclear risk	unclear risk	unclear risk	low risk	low risk	unclear risk

reveal any significant differences based on age or intervention characteristics, as shown in Table 4.

Subgroup analysis: depression status

Subgroup analysis revealed that commercial VR game systems were significantly superior to self-made systems for improving depression (P = 0.03). Furthermore, the effects of the VR exergames on depressive outcomes did not differ based on participant characteristics or training duration, frequency, cycle or format, as shown in Table 4.

Discussion

Given the intensification of population aging and the increasing demand for institutionalized facilities, there is an urgent need for an integrated, effective and sustainable option to provide physical, cognitive and psychological care and support to older adults. VR technology can provide a real environment for simulating exercise, allowing users to interact with multiple senses to improve their physical condition and receive real-time feedback.[19] This meta-analysis was conducted to explore the effectiveness of VR exergames for improving physical function, cognition and depression status among older NH residents. Eighteen studies reported that VR exergames had strong effects on physical function and moderate effects on cognition and depression among institutionalized older adults.

Effects of VR exergames on physical function

Age-related physical decline is particularly pronounced among older NH residents. The current meta-analysis revealed that VR exergames significantly improved the physical function of this population. The virtual environment focuses on guiding participants through a realistic experience, and immersive gaming can provide ecological and motivational treatments that promote physical rehabilitation.[48] Previous studies have indicated that virtual games can be used for rehabilitative purposes to improve flexibility and dynamic–static balance, strengthen lower limb muscles, and counteract age-related decreases in somatosensory functions.[19,49] The effects can be attributed to exergames require the players to produce physical body movements to complete set tasks or actions that integrate the vestibular, proprioceptive, auditory and visual systems, interactions with game scenarios and the imitation of movements, thereby improving sensorial perception and training coordination between the brain, muscles and nerves to maintain balance capacity.[50] Mobility is essential for maintaining postural control, transfers and gait speed. Virtual environments provide goal-oriented movements through motion-capture technologies or timely feedback that visualizes individualized movements,[22] which can improve the quality of motion and promote the recovery of executive functions to enhance gait ability and walking independence. Additionally, exergames are multicomponent exercises that involve strength and balance training components that can stimulate muscle protein synthesis and increase oxygen consumption, thereby increasing muscle mass and improving lower limb strength.[42] Other research has shown that, due to the participatory and interactive features of virtual games, participants are required to actively mobilize various body parts to maintain interaction, thereby stimulating intrinsic motivation and interest in exercise to minimize the impact of a sedentary lifestyle and further promote positive changes in physical function.[25]

Effects of VR exergames on cognitive function

Aging may be accompanied by varying degrees of cognitive decline, and the variability in cognitive performance is affected by multiple factors, which are mainly associated with poor stimulation of perceptive and executive functions.[32] A meta-analysis revealed that VR exergames had a moderate effect on cognitive function. Our result is consistent with previous findings that exergaming is a feasible and pleasant style with a positive impact on cognition and health status among older NH residents.[18,26] The mechanism underlying the effects of exergames involves a focus on attention, orientation, memory and construction tasks guided by a 3D landscape. This design can provide a stimulating environment that favors the activation of different sensory media to improve cognitive and executive functions, such as concentration, reaction time, short-term memory and information processing speed. Another explanation is that exergames combine physical and cognitive activities, which have positive effects on participants due to intertwined training.[39] These synergistic effects were derived from cognitive and motor networks that share common neural pathways, and improvements in physical function further enhanced cognition by inducing angiogenesis and neurogenesis and ameliorating brain-derived neurotrophic factors.[51]

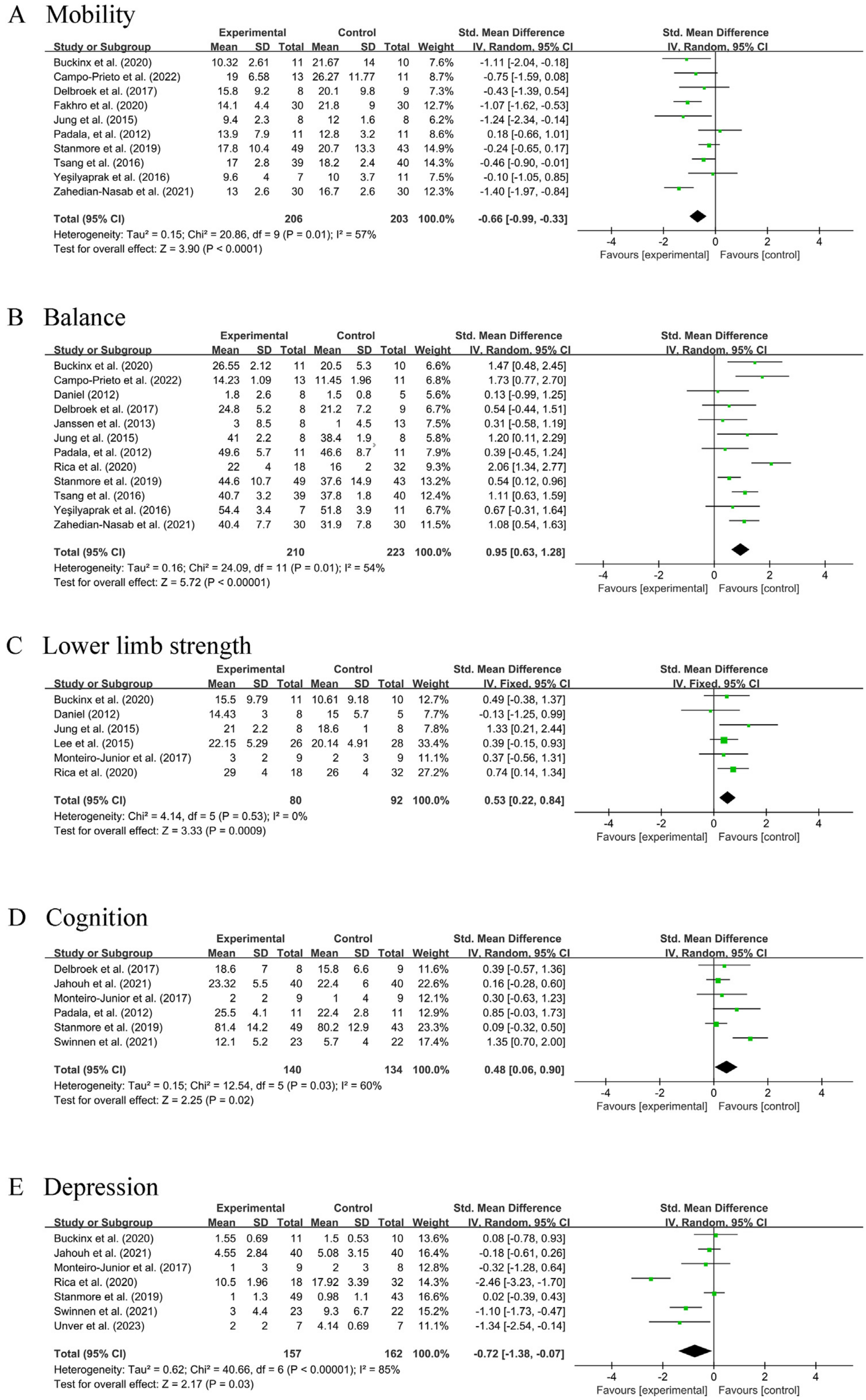

Fig. 2. Forest plots of main outcomes.

Effects of VR exergames on depression

Depression is considered the leading cause of disability among older adults, especially institutionalized adults, who are more likely to suffer from depressive symptoms due to transfer obstacles or feelings of loneliness caused by limited life space, with an incidence approximately four times greater than that of noninstitutionalized older adults.[13] The meta-analysis included in this study revealed that VR exergames had a moderate effect on depression. Our findings are in line with those of other studies reporting that exergames can improve psychosocial function and reduce emotional disturbance among aged-care residents.[32,52] The potential benefits can be

Table 3
Meta-analysis of outcome indicators included in the studies.

Outcome indicators	Study detail	Effect measure		Heterogeneity	Publication bias		
	Studies (n)	SMD (95 % CI)	P value	I^2(%)	Egger *P* value	Trim-and-fill imputed studies	Trim-and-fill adjusted SMD (95 % CI)
Physical function							
Mobility	10	−0.66 (−0.99, −0.33)	<0.001	57	0.678	0	–
Balance	12	0.95 (0.63, 1.28)	<0.001	54	0.807	0	–
Lower limb strength	6	0.53 (0.22, 0.84)	0.0009	0	0.933	0	–
Cognition	6	0.48 (0.06, 0.90)	0.02	60	0.284	3	1.165 (0.727, 1.866)
Depression	7	−0.72 (−1.38, −0.07)	0.03	85	0.240	0	–

ascribed to the communicative environment provided by virtual games. Exergames allow participants to engage in social interaction with other players or therapists in a real environment and to interact with virtual characters, animals or game elements in a virtual environment. These are beneficial methods for ameliorating depression, reducing loneliness and boredom, and improving mental health.[53] Moreover, technology-driven exergames were designed to require physical activity, which was proposed as a protective factor, and increase activity by an average of 100 steps/day to reduce the risk ratio of depression by 14 %.[54] The motivational character of exergames arouses interest and attention to exercise, further improving depressive symptoms.

Characteristics of participants

The moderation analyses revealed that the differences underlying the basic physical condition of the participants (i.e., physically fit or cognitively impaired) produced different effects on the outcome indicators, which could further explain the effectiveness of VR exergames.

Effects of basic conditions on physical function

The subgroup analysis showed that VR exergames resulted in a significantly greater improvement in balance among older NH residents who were physically fit than among those with cognitive impairment. Moreover, VR exergames exerted greater effects on mobility and lower limb strength among those who were physically fit. A previous meta-analysis among healthy older adults and patients with idiopathic Parkinson's disease (IPD) indicated that exergaming had more obvious improvements in static and dynamic balance and posture control among physically fit participants.[55] In our study, the BBS was included as the primary outcome measure for balance, which is prone to induce a learning effect, i.e., better scores on items with more complex tasks.[44] At present, most exergames require coordinated movement of the hips, knees and ankle joints and different muscle systems. The difficulty of training determines the frequency of employing them, and participants with favorable basic functions can perform more exercises to improve balance performance.[31] However, BBS tends to produce a ceiling effect, particularly in participants with higher levels of balance; therefore, these results should be interpreted with caution.

Effects of basic conditions on cognitive function

The subgroup analysis showed that VR exergames had a more significant and larger effect on cognition among older NH residents with cognitive impairment. This finding clarifies the potential mechanism for the high heterogeneity caused by the study of Swinnen et al,[33] which included participants with MNCD. Additionally, the above findings further validate the effectiveness of exergames for cognitively impaired patients. A previous meta-analysis demonstrated that combined cognitive-physical gaming triggered improvements in cognition among older adults with MCI or MNCD.[56] Another review considered exergaming to be a comprehensive rehabilitation approach for improving the multilevel cognitive impairment characterizing patients with PD.[57] The reason was that in addition to exergames helping to activate different sensory media, they also added the benefits of physical and cognitive activity. From a physiological perspective, exercise can alter the structure and function of the hippocampus to promote memory and cognition and modulate the prefrontal cortex, oxygenating or reorganizing neuronal networks to improve executive functions.[17]

Characteristics of the interventions

The moderation analyses revealed that the frequency, type and format of VR exergames had moderating effects on the improvement of physical condition among older NH residents. Therefore, in-depth analyses were performed to determine the optimal possible strategy.

Effects of VR exergame frequency on physical function

The subgroup analysis showed that the VR exergame frequency of approximately 2 sessions per week resulted in significantly greater improvement in mobility among older NH residents. Moreover, that frequency was associated with greater improvements in lower limb strength. The International Association of Gerontology and Geriatrics Global Aging Research Network (IAGG-GARN) guidelines recommend that institutionalized older adults engage in multicomponent exercise for 35 to 45 min, twice per week, to improve physical function and reduce the risk of chronic diseases.[10] Compared with community-dwelling older adults, NH residents are more likely to suffer from frailty, which can result in poor physical condition.[5] The design of virtual games emphasizes the adjustment of exercise intensity to individual tolerability levels to obtain the maximum benefits of training. For older adults with limited mobility, moderate-intensity training is considered feasible, effective and safe.[30] Therefore, we suggest that exergames performed with a frequency of approximately 2 sessions per week at an appropriately adjusted intensity represents an effective strategy for older NH residents.

Effects of the VR exergame format on physical function

To facilitate the implementation of exercise programs, the design of the training format must account for participants' personal preferences, goal expectations, attitudes and beliefs.[58] Our subgroup analysis showed that VR exergames coordinated with physiotherapists had a more significant effect on mobility than did health education. Although previous studies have confirmed the effectiveness of course conferences and guidance by certified fitness professionals,[38,45] these cannot replace physiotherapists who provide the following services: design individual programs that are adapted to the level of functionality; introduce and explain the movements to ensure correct execution; and guide and supervise the training process incrementally to foster autonomy.[32,33] The above measures could help participants

Table 4
Subgroup analysis of study participants and intervention characteristics.

Variables	Mobility				Balance				Lower limb strength				Cognition				Depression			
	N	SMD (95 % CI)	*p*[a]	*p*[b]	N	SMD (95 % CI)	*p*[a]	*p*[b]	N	SMD (95 % CI)	*p*[a]	*p*[b]	N	SMD (95 % CI)	p[a]	p[b]	N	SMD (95 % CI)	p[a]	p[b]
Characteristics of the participants																				
Mean age				0.14				0.58				0.73				0.12				0.60
≤ 80 yrs	6	−0.85 (−1.33, −0.36)	0.0007		7	1.03 (0.55, 1.51)	< 0.001		5	0.55 (0.22, 0.88)	0.001		1	0.09 (−0.32, 0.50)	0.68		4	−0.90 (−2.18, 0.37)	0.16	
> 80 yrs	4	−0.40 (−0.73, −0.07)	0.02		5	0.84 (0.36, 1.32)	0.0006		1	0.37 (−0.56, 1.31)	0.43		5	0.61 (0.10, 1.12)	0.02		3	−0.53 (−1.15, 0.10)	0.10	
Basic physical condition				0.07				0.03				0.23				0.01				0.38
Physically fit	8	−0.77 (−1.12, −0.41)	< 0.001		9	1.10 (0.73, 1.47)	< 0.001		5	0.58 (0.26, 0.91)	0.0004		3	0.14 (−0.15, 0.42)	0.34		6	−0.66 (−1.40, 0.08)	0.08	
Cognitive impairment	2	−0.08 (−0.72, 0.55)	0.80		3	0.38 (−0.18, 0.93)	0.18		1	−0.13 (−1.25, 0.99)	0.82		3	0.96 (0.40, 1.51)	0.0007		1	−1.10 (−1.73, −0.47)	0.0007	
Characteristics of the intervention																				
Duration				0.86				0.77				0.37				0.24				0.58
≤ 30 min	7	−0.63 (−1.02, −0.23)	0.002		6	0.88 (0.44, 1.32)	< 0.001		2	0.81 (0.12, 1.50)	0.02		4	0.65 (−0.01, 1.31)	0.05		4	−0.51 (−1.22, 0.19)	0.15	
> 30 min	3	−0.70 (−1.44, 0.04)	0.06		6	0.98 (0.49, 1.47)	< 0.001		4	0.46 (0.11, 0.81)	0.01		2	0.18 (−0.21, 0.58)	0.36		3	−0.98 (−2.46, 0.50)	0.19	
Frequency				0.009				0.92				0.58				0.28				0.09
≤ 2 sessions/wk	4	−1.16 (−1.56, −0.75)	< 0.001		5	0.94 (0.56, 1.31)	< 0.001		3	0.66 (0.10, 1.21)	0.02		3	0.21 (−0.15, 0.58)	0.25		3	−0.15 (−0.51, 0.21)	0.42	
> 2 sessions/wk	6	−0.45 (−0.79, −0.11)	0.009		7	0.97 (0.48, 1.46)	0.0001		3	0.47 (0.09, 0.85)	0.01		3	0.73 (−0.12, 1.58)	0.09		4	−1.19 (−2.34, −0.03)	0.04	
Cycle				0.22				0.98				0.94				0.12				0.59
≤ 8 wks	8	−0.73 (−1.12, −0.33)	0.0003		7	0.98 (0.70, 1.25)	< 0.001		4	0.52 (0.13, 0.91)	0.008		5	0.61 (0.10, 1.12)	0.02		5	−0.51 (−1.03, −0.00)	0.05	
> 8 wks	2	−0.36 (−0.79, 0.06)	0.09		5	0.97 (0.22, 1.72)	0.01		2	0.55 (0.02, 1.07)	0.04		1	0.09 (−0.32, 0.50)	0.68		2	−1.20(−3.63, 1.23)	0.33	
Type of VR game systems				0.79				0.87				0.38				0.14				0.03
Commercial VR game systems	8	−0.69 (−1.08, −0.31)	0.0004		10	0.97 (0.60, 1.34)	< 0.001		3	0.69 (0.21, 1.17)	0.005		4	0.67 (0.05, 1.29)	0.03		4	−1.24 (−2.28, −0.19)	0.02	
Self-made VR game systems	2	−0.57 (−1.39, 0.25)	0.17		2	0.89 (0.01, 1.77)	0.05		3	0.41 (−0.00, 0.82)	0.05		2	0.12 (−0.25, 0.50)	0.52		3	−0.02 (−0.36, 0.33)	0.92	
Training format				0.0001				0.72				0.52				0.69				0.13
Coordinated with physiotherapist	7	−1.23 (−1.60, −0.86)	< 0.001		7	0.87 (0.52, 1.22)	< 0.001		2	0.42 (−0.04, 0.88)	0.07		5	0.52 (0.03, 1.00)	0.04		4	−0.29 (−0.77, 0.19)	0.24	
Health education	3	−0.37 (−0.62, −0.13)	0.002		5	1.01 (0.35, 1.68)	0.003		4	0.62 (0.20, 1.05)	0.004		1	0.30 (−0.63, 1.23)	0.53		3	−1.40 (−2.76, −0.04)	0.04	

[a] Subgroup studies.
[b] Differences between subgroups; 95 % CI, 95 % confidence interval; yrs, years; wks, weeks; min, minute.

better understand the training structure and process to ensure safety and comfort while exergaming, effectively adjusting for personal exercise tolerance. Moreover, the supportive and encouraging atmosphere provided by therapists could improve participants' self-confidence and intrinsic motivation and relieve excessive tension in the cerebral cortex. Therefore, we recommend that the training format for exergames should be coordinated with that of physiotherapists.

Effects of VR exergame type on depression status

The types of VR exergames are manifold and varied, but the dominant systems are commercial systems and self-made systems. The differences between design types may produce different effects on outcome indicators. Unexpected anecdotal findings from the subgroup analysis showed that commercial VR game systems had a significantly greater effect on depression than self-made VR game systems. There are several potential mechanisms underlying this difference. For example, commercial systems, such as Nintendo Wii, Xbox Kinect and BTS NIRVANA, have the advantages of availability, amenity and affordability and could be applied in NHs, communities and families; therefore, these systems are extensively popular.[22] In addition, the interactive and communicative characteristics of commercial systems emphasize group-based training to strengthen social support, help create a relaxed and pleasant atmosphere, and reduce the level of depression among participants. Moreover, the acceptability of commercial systems is more likely to increase participants' willingness to participate, which could resolve the ethical concerns that may be encountered in the process of implementing exergame interventions. In contrast, while self-made exergames are more concerned with customized and personalized training programs based on individual exercise tolerance,[35] they ignore the importance of interactions and may cause participants to lose interest or feel lonely. Therefore, we suggest employing commercial exergame systems to further improve depression among older NH residents.

Strengths and limitations

This study systematically elucidated the effectiveness of VR exergames on physical function, cognition and depression among older NH residents. The optimal scheme was determined through in-depth analyses. Nevertheless, there are still some limitations to our study. First, the high proportion of female participants may have triggered sex-specific responses caused by the imbalance in the male–female ratio. Second, blinding is difficult to achieve because participants and interveners need to be aware of the exergame process and related precautions, which may limit the credibility of the results. Third, the BBS was included as our main outcome indicator of balance, which is prone to a ceiling effect. Future studies could control for the intensity of training by measuring perceived level, total number of exercises performed or distance traveled per session. In addition, laboratory or biomechanical assessments can detect subtle changes that cannot be measured by clinical tests to avoid ceiling effects. Fourth, because of the diversity of exergames, there may be bias in exercise intensity between different studies. Additionally, the interactivity of the game patterns and content are difficult to identify. Finally, high levels of depression are correlated with cognitive function degeneration,[13] and such interaction effects of betweenness might bias the results.

Conclusion

The current systematic review and meta-analysis demonstrated that VR exergames could improve physical function, cognition and depression among older NH residents. Our study also revealed that exergames are especially beneficial for participants who are physically fit and those who have cognitive impairment, thereby providing a reference for future research. The crucial findings were that administering commercial VR exergames at a frequency of 2 sessions per week and coordinating the intervention with physiotherapists may be the most appropriate and effective strategies for implementing exergaming in NH residents. Currently, VR exergames are promoted as an innovative, interesting and cost-efficient approach to improve physical and mental health in older adults. Future studies should include a multicenter study design and blinding procedures, precisely measured outcomes, and identification of the interaction effects between exercises to further elucidate the effectiveness of VR exergames among older NH residents.

Ethical approval

Not applicable.

Informed consent

Not applicable.

Data availability

The data utilized in this study are available in published articles.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Yu Peng: Writing – original draft, Visualization, Software, Methodology, Formal analysis, Conceptualization. **Ying Wang:** Validation, Methodology, Investigation, Formal analysis. **Lili Zhang:** Software, Resources, Data curation. **Yuhan Zhang:** Visualization, Resources. **Liyan Sha:** Writing – review & editing, Supervision, Methodology. **Jianli Dong:** Writing – review & editing, Supervision, Formal analysis. **Yang He:** Resources.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.gerinurse.2024.02.032.

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