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Review article

Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy

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ABSTRACT

Background: There has been a rapid increase in research on the use of virtual reality (VR) and gaming technology as a complementary tool in exercise and rehabilitation in the elderly population. Although a few recent studies have evaluated their efficacy, there is currently no in-depth description and discussion of different game technologies, physical functions targeted, and safety issues related to older adults playing exergames.
Objectives: This integrative review provides an overview of the technologies and games used, progression, safety measurements and associated adverse events, adherence to exergaming, outcome measures used, and their effect on physical function. Methods: We undertook systematic searches of SCOPUS and PubMed databases. Key search terms included “game”, “exercise”, and “aged”, and were adapted to each database. To be included, studies had to involve older adults aged 65 years or above, have a pre-post training or intervention design, include ICT-implemented games with weight-bearing exercises, and have outcome measures that included physical activity variables and/or clinical tests of physical function.
Results: Sixty studies fulfilled the inclusion criteria. The studies had a broad range of aims and intervention designs and mostly focused on community-dwelling healthy older adults. The majority of the studies used commercially available gaming technologies that targeted a number of different physical functions. Most studies reported that they had used some form of safety measure during intervention. None of the studies reported serious adverse events. However, only 21 studies (35%) reported on whether adverse events occurred. Twenty-four studies reported on adherence, but only seven studies (12%) compared adherence to exergaming with other forms of exercise. Clinical measures of balance were the most frequently used outcome measures. PEDro scores indicated that most studies had several methodological problems, with only 4 studies fulfilling 6 or more criteria out of 10. Several studies found positive effects of exergaming on balance and gait, while none reported negative effects.
Conclusion: Exergames show promise as an intervention to improve physical function in older adults, with few reported adverse events. As there is large variability between studies in terms of intervention protocols and outcome measures, as well as several methodological limitations, recommendations for both practice and further research are provided in order to successfully establish exergames as an exercise and rehabilitation tool for older adults.

Contents

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1. Introduction

During the last decade, there has been a rapid increase in research on the use of virtual reality (VR) and gaming technology in the elderly population [1,2]. Exercise through video games, so-called exergames, is used progressively more to increase physical activity and improve health and physical function in older adults [1,3–5], and there is growing interest in using exergames as a potential rehabilitation tool to facilitate specific exercises in different clinical groups [6–8]. Studies suggest that exergaming promotes improvements in mobility [9,10], muscular strength of the lower limbs [11], balance control [2,12,13], and cognition [14] in older adults.

In line with this increased research interest, several reviews on exergaming have recently appeared. A Cochrane review from Laver et al. [8] evaluated the effects of VR and interactive video gaming in stroke rehabilitation. The authors concluded that exergaming is a promising rehabilitation approach for stroke recovery. Furthermore, few adverse events were reported across studies, and those that were reported (transient dizziness, headache, pain) were mild, indicating that the interventions were relatively safe for this patient population. However, interventions varied greatly with regards to which technology and games were used, leading to uncertainty about which characteristics of the interventions, such as technology, game consoles and game activity, may have been most important.

Similarly, Barry et al. [15] evaluated the evidence for the safety, feasibility, and effectiveness of exergaming as a rehabilitation tool in people with Parkinson's disease. They commented that commercial exergames that required fast decision making and rapid movements to avoid virtual obstacles, might be too difficult to use for many patient populations. Furthermore, only two of the included studies addressed patient safety, and neither objective (such as falls or near falls) nor subjective (participant perceptions) measures of safety were reported in any of the studies [15].

Likewise, Verheijden Klompstra et al. [16] conducted a scoping review that focused on the feasibility and influence of exergames on physical activity in different groups of older adults, to assess whether exergames increased physical activity in patients with heart failure. Even though they concluded that exergames could be feasible to increase physical activity in patients with heart failure, they also highlighted that it would be challenging to find the most suitable exergame for any specific patient group as both the demands of games and the ability of the patients vary considerably [16].

In sum, these reviews indicate that exergames seem to be a feasible exercise tool for older adults with an acquired disease. Exergaming is also increasingly offered to elderly in general as a means of maintaining physical function, health, and, as a result, independence. Several reviews indicate that engaging older adults living in the community in an exergaming program is safe and feasible, and may enhance the participants' balance capabilities [5,17–20]. Laufer and colleagues [17] concluded that exergame programs may be an alternative to more conventional forms of exercise aimed at improving balance control. However, research on exergaming varies greatly in methodological quality as well as in intervention protocols and outcome measures used [17,19]. These factors make the evidence to support the effectiveness of using exergames for improving physical functioning in older adults inconclusive [19].

Exergames may have fundamental advantages compared to traditional exercise, as they easily allow for task-specific exercises to be delivered across a range of difficulty levels. This allows each user to begin at an appropriately challenging level that is attainable and comfortable, and then proceed with a gradual progression of difficulty that can be based on the individual's performance in real time [21]. However, commercial games that are readily available on the market are primarily designed for entertainment and recreation for younger populations, and tend to have colorful and visually busy game interactions, unsuitable music, and demanding navigation through the user interface. No easy one-touch interface is yet available, making the exergaming technology less feasible for many older people [21–23]. Furthermore, commercially available games are mostly designed for enjoyment and not based on basic exercise principles. In order for the games to be effective, they need to elicit specific movement characteristics in the players that are considered relevant for the function being trained. As falls and fall-related injuries are the leading cause for institutionalization and loss of independence amongst senior citizens [24,25], key components in exercise for older adults should focus on elements shown to reduce fall risk, i.e., weight-bearing exercise with elements that challenge balance and improve strength [26–28].

As technology continues to become more accessible and affordable, exergames may become more widely used in rehabilitation settings, in-patient hospital care, retirement homes, and home settings. It is therefore, important to evaluate not only the effectiveness of these games on physical performance and health outcomes, but also which type of technology and games to use in order to ensure high adherence and safety for older adults in different settings.

Existing reviews concerning exergames and VR have revealed that there is a large variety of study designs, technologies and exergames, and there is a notable lack of high quality studies with regard to methodology. However, previous reviews have mainly been systematic, focusing on the effect of exergaming, often in specific patient groups, and typically with few included studies. Also missing is an extensive overview of the technologies and games used in interventions with older adults, safety measurements and associated adverse events, adherence to exergames compared to other forms of exercise, and how game features may influence effectiveness. If exergames are to be employed safely and effectively as an exercise and rehabilitation tool for senior citizens there is a need to obtain not only evidence about efficacy and effectiveness, but also a broader understanding of the potential usefulness as a training tool, as well as the qualities of the commercial games and gaming consoles that are being used.

The aim of the current paper is to fill these gaps by providing a systematic overview, in-depth description, and discussion of the literature on exergames used for the elderly population, including the different game technologies, physical functions targeted, and safety issues related to older adults playing exergames. Specifically, the following research questions will be addressed using an integrative review approach: [1] which game technologies and exergames have been used in studies with older adults, which games provided exercise progression, and how was the adherence to the exergaming exercise? [2] What safety measures were used and have adverse events been reported? [3] Which physical functions have been targeted, and which outcome measures have been used? [4] Was there a change in physical function following exergame intervention?

2. Methods

2.1. Search strategy and selection criteria

A systematic literature search was performed with a preplanned review protocol specifying inclusion and exclusion criteria for the revealed studies and subsequent data analysis. Only original research, peer-reviewed, English-language studies were considered, excluding review articles and short conference abstracts. Inclusion criteria were as follows: (1) median or mean age of the study sample(s) had to be 65 years or above; (2) the study had to have an intervention design with pre- and post-measurements; (3) ICT-implemented games had to include weight-bearing exercises; and (4) outcome measures had to include physical activity variables and/or clinical tests of physical function. Papers were excluded when exercises were limited to the upper extremities, wheelchair activities, or cognitive function only.

Electronic searches were performed on July 10th 2013 in PubMed and SCOPUS. The searches consisted of combinations of controlled terminology and free-text terms expressing the concepts game, exercise, and aged, and were adapted to each database. Detailed search criteria are presented as supplementary material. The search was updated on February 22nd 2015.

2.2. Selection process

Prior to the extraction of data, two reviewers assessed a random sample of 50 studies to ensure that the selection criteria were unambiguous. All identified records were screened for duplicates and non-English papers by the first author. The abstracts of the remaining records were each screened independently by two reviewers and in case of uncertainty or disagreement, the paper was screened in full-text. Subsequently, included studies were each independently assessed in full-text by two reviewers. Disagreement about eligibility of a study was resolved by a third reviewer's assessment of the study.

2.3. Data extraction

Data from included studies were extracted using a custom-made, pre-piloted electronic form using Microsoft Excel 2010. Data on study design, participants, interventions, games and game technologies, outcome variables, and study findings were extracted. Details relating to the interventions included: intervention setting; length, frequency, and duration of intervention; and time of testing. Details relating to the games and game technologies included: game system; exercises and exercise order; game progression during intervention; safety measures to prevent falls; and adverse events.

2.4. Data analysis

For the purpose of this review, *physical function* refers to any physical performance or patient-reported outcome (e.g. balance, gait, quality-of-life) that is self-reported, observed, and/or objectively tested. Furthermore, game exercises were divided into categories based on which activity they targeted. Sport games such as bowling and golf were classified as a separate subgroup in accordance with the definitions in Nintendo Wii Fit games [29]. In sum, the categories included: balance, strength training, aerobic exercise, flexibility, dance, yoga, walking/stepping, and general sports. Study design is reported based on information from the papers and classified as experimental studies with or without random allocation, or analytical observational studies such as case-control and cohort studies. Regarding classification of outcome variables, physical tests refer to all clinical and objective tests of e.g. mobility, strength, and flexibility. Regarding intervention effect, we selected the studies that compared exergaming against at least one other active control group for analysis. Two reviewers independently assessed the methodological quality of these studies using the 10-point PEDro checklist [30,31]. Incongruities between the two reviewers were discussed and resolved by consensus.

3. Results

The results are presented in the subsequent sections: study selection, characteristics of the included studies and participants, gaming intervention, adherence, safety measures, outcome measures, and exergaming effects.

3.1. Study selection

Fig. 1 illustrates the flow of papers through the review process. The database search identified 706 records of possible interest. After removing duplicates, titles and abstracts of the remaining papers were screened against the selection criteria. Eighty papers were assessed in full-text review, yielding 47 studies for final data analysis. The most common reasons for exclusion were (1) median or mean age below 65 years; (2) focus on the upper extremities; (3)

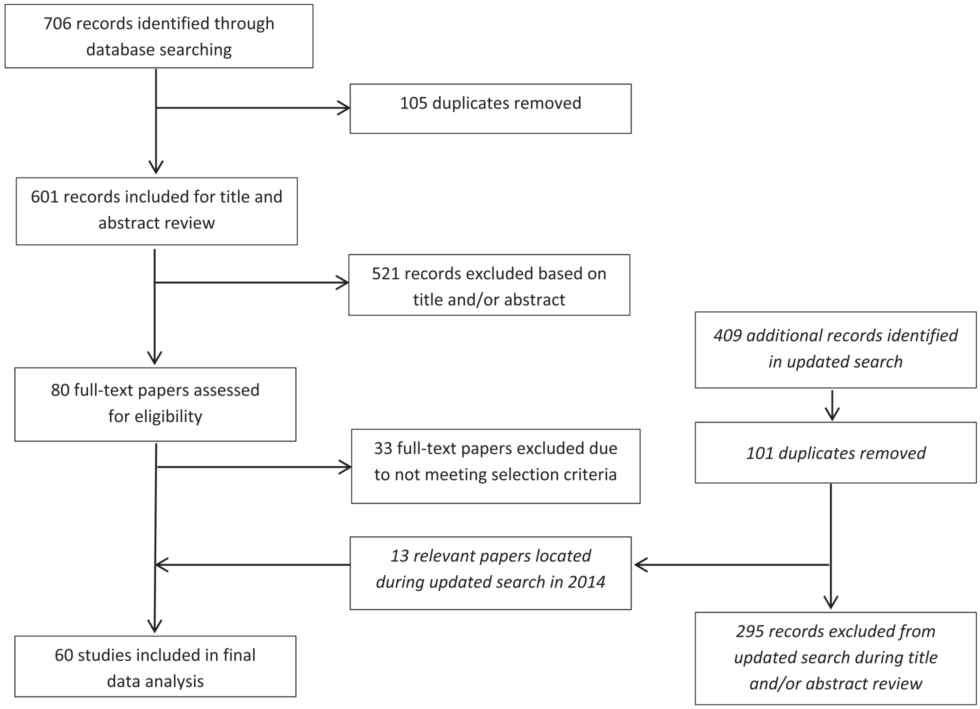

Fig. 1. Flow chart over study selection through the different phases.

Table 1
Study design of included studies.

Study design	Number of studies	References
Experimental with random allocation	27	[10–13,32,33,38,41–43,46–49,53,55,57,61,62,64–66,69,72,78,80,81]
Experimental with non-randomized allocation	6	[9,44,50,56,73,74]
Single group intervention	14	[35–37,39,40,51,52,54,68,70,76,77,79,85]
Case-control	2	[60,67]
Single group repeated measures	1	[63]
Feasibility study with single group	1	[75]
Prospective cohort study	1	[58]
Mixed methods	3	[59,71,82]
Case reports	5	[34,45,83,84,86]

Table 2
Exercise design in included studies.

Exercise design	Number of studies	References
Group exercise	11	[40,51,55,58,65,66,69,71,72,75,82]
Exercising in pairs	5	[10,11,50,74,77]
Individual exercise	24	[9,12,13,32–35,38,39,43,45,49,54,56,57,59,60,63,67,68,73,80,81,86]
Individual exercise at home	7	[52,62,70,78,79,83,84]
Exercise individually or in pairs	1	[76]
Not mentioned	12	[36,37,41,42,44,46–48,53,61,64,85]

Table 3
Study population in included studies.

Study population	Number of studies	References
Community-dwelling healthy older adults	22	[9–11,13,32,36–38,41,42,44,47,48,51,54,59,61,62,67,69,78,79]
Healthy older adults living in-care[a]	14	[12,35,39,40,55–57,65,66,71,72,74,76,77]
Non-healthy[b] older adults living at home	10	[33,45,49,58,60,68,70,75,83,84]
Non-healthy[b] older adults living in-care[b]	3	[34,52,85]
In-hospital patients	4	[64,80,81,86]
Both healthy and non-healthy[b] living at home or in-care	2	[46,82]
Both healthy and non-healthy[b] older adults without specification of residency	5	[43,50,53,63,73]

[a] Older adults living in retirement homes, nursing homes, or senior living centers.
[b] Older adults with Parkinson's disease, diabetes, heart failure, balance disorders, chronic obstructive pulmonary disease, or chronic stroke.

cognitive training only; and (4) method development studies without pre-post exercise design. An updated search in February 2015 identified 409 additional records. After excluding papers based on the selection criteria, 13 additional studies were included. Thus, a total of 60 studies were included in the final data analysis.

3.2. Study characteristics

Of the 60 included studies, the majority (53, >85%) were published between 2011 and February 2015, while the oldest published study was from 2007, reflecting that research on exergaming is a young field of science with rapidly increasing activity. The primary aim of the reviewed studies was to evaluate the potential effect of gaming/VR exercise on balance, either alone [9,12,32–46], in combination with other physical abilities such as strength or mobility [11,13,47–51], or in combination with falls or fear of falling, cognition, quality of life, or user experience [52–62]. Seven studies investigated the effect of gaming/VR exercise on gait parameters [63–69], and six studies examined the effectiveness with regard to different physical functions and associated fall risk [10,70–74]. The remaining 12 studies investigated the feasibility of using gaming/VR exercise to increase physical activity in healthy older adults [75–79], in hospitalized older adults [80,81], or in a patient population [82–86].

This broad range in study aims was reflected in the study designs as well. As can be seen in Table 1, 33 studies used an experimental design with either random or non-random allocation. The remaining studies were single group intervention studies, case-control studies, single group repeated measures studies, single group feasibility studies, prospective cohort studies, or mixed methods studies. The last five studies were case reports (see Table 1 for references).

The gaming interventions were carried out either in a clinical setting, in a laboratory setting, or at home. How participants performed the exercises differed between studies and could consist of group exercises, exercising in pairs, or individual exercises (see Table 2 for details). In one study, participants could choose whether to exercise individually or in pairs. Twelve studies did not mention how exercises were performed (see Table 2 for references).

The interaction time with each game within the intervention period was extremely variable. Across the included studies, the length of the VR intervention ranged from 1 to 24 weeks, with a median of 8 (mean: 8.2 ± 4.7) weeks. The frequency of the intervention ranged from 1 to 7 times per week, with a median of 3 (mean: 2.8 ± 1.3), and a median duration of each session of 32.5 (mean: 40.9 ± 20.0) minutes with a range of 15–120 min. Two studies reported that length of intervention was determined by either the individual participant's physical therapy treatment [49], or phase of dopaminergic medication [85]. Three studies did not report on intervention frequency [49,51,62], and three studies did not report on intervention duration [44,62,79]. Finally, one study had optional duration [60], and one study had self-regulated duration and frequency of each exercise session [71].

3.3. Participant characteristics

Mean participant age across the 60 studies was 76.1 (±6.7) years, with a range of 44–98 years. Except for one study that included only female participants [75], all studies included both genders, with a higher average number of female participants (66.2%). Excluding the case-reports, the sample size varied between 6 and 104 participants, with a median of 25 participants.

As can be seen in Table 3, the majority of participants in the included studies were older adults who were community-dwelling or living in retirement homes, nursing homes, or senior living centers. The remaining studies included different patient groups living at home, in nursing or retirement homes, or in-hospital patients, either as the only study sample or in combination with healthy older adults (Table 3).

3.4. Gaming technology and game exercises

The majority of the included studies (43 of 60) used commercially available gaming technologies. The Nintendo Wii game console (Nintendo; Redmond, WA, USA) was the most commonly used technology (35 studies). Six studies used some or all the games in the Wii sport package with the handheld remotes [34,55,71,72,75,83], 22 studies used the balance, fitness, and strength games in the Wii Fit package with the accompanying Wii balance board [11–13,32,35,37,40,42–45,47,49,52,56–58,60,73,74,77,86], and the remaining seven studies used both the handheld remotes and the balance board [10,53,69,70,80–82]. Other gaming systems utilized were the gesture recognition system Eye Toy developed for Sony PlayStation II (Sony Computer Entertainment, Foster City, CA, US) [50,84], the motion-detecting camera system Kinect for X-Box360 (Microsoft Corporation, One Microsoft Way, Redmond, WA, US) [48,85], and DanceDanceRevolution (DDR), either as the Dancetown™ (Cobalt Flux Inc., Salt Lake City, Utah, US) [76], or an open-source DDR game (www.stepmania.com) [65,66,78]. The last 17 studies used custom-designed games. Of these, nine games were designed to target balance and consisted of GestureTek's Interactive Rehabilitation and Exercise System (IREX®) (GestureTek Health, Toronto, Ontario, Canada) [9], the SensBalance Fitness Board Sensamove (SensBalance Fitness Board; Sensamove®, the Netherlands) [36,39,54], the Balance Rehabilitation Unit (BRU™, Medicaa™, Montevideo, Uruguay) [38], virtual environments created using Virtools 4.0 (Dassault Systems) software with Wii Balance board [46], an interactive game-based virtual interface designed in MatLab® 2007a and Psych toolbox V2.54 with 5 wearable inertial sensors (LegSys™, BioSensics LLC, MA, USA) [61], and different pressure mats or force platforms [33,59]. Five of the custom-designed games targeted walking and stepping movements and used either a treadmill with a VR simulation [63,64,68], the Xavix Measured Step System (The Xavix Measured Step System, SPECTRUM9000MB-500system, UIS Co., Japan) [41], or developed inertial motion sensors to facilitate interaction with the exergames on a laptop computer (Toshiba Satellite L855; Intel Core i5 processor; 4 GB RAM; AMD Radeon dedicated graphics card) [62]. Two studies targeted several physical functions and utilized either modular interactive tiles (Entertainment Robotics, Odense, Denmark) [51] or the OGRE 3D graphics library together with a Kinect camera [79]. Finally, one study targeted strength with fast sit-to-stand movements using a set of uni-axial force plates, so called lower limb power rehabilitation [67]. The distribution of game technologies used across publication years is displayed in Fig. 2.

As with the game technology used, there was a wide variety in exercise games. For the 35 studies using Nintendo Wii, two studies used only the Wii Sports bowling game [34,55], while the remaining 33 studies used two or more games during the intervention. Furthermore, 11 of the Nintendo Wii studies used games that targeted balance only [11,35,37,42–44,47,57,58,73,82], while 16 used a combination of games that targeted different physical functions in addition to balance, such as strength, endurance, and mobility [10,13,32,40,45,49,52,56,60,69,70,74,77,80,81,86]. For those studies that did not utilize Nintendo Wii, only three studies [51,79,84] aimed to have an effect on more than one physical function. As can be seen in Table 4, the studies utilizing commercially available exergames targeted a wide variety of physical functions and activities, with balance being the main target of improvement (see

Table 4
Physical functions targeted using commercially available game consoles.

	Nintendo Wii balance board	Nintendo Wii handheld controller	Wii both	PlayStation EyeToy	Xbox Kinect	DDR
Balance	[11,13,32,35,37,40,42–45,47,49,52,56–58,60,73,74,77,86]		[10,69,70,80–82]	[50,84]	[85]	
Strength	[12,45,52,74,77,86]		[80,81]	[84]		
Aerobics	[40,56,60,74,77]		[70,80]	[84]		
Dance						[65,66,76,78]
Yoga	[13,32,49,56,60,74,77]		[80]		[48]	
Sports	[45]	[34,55,71,72,75,83]	[10,53,69]			
Walking				[84]		

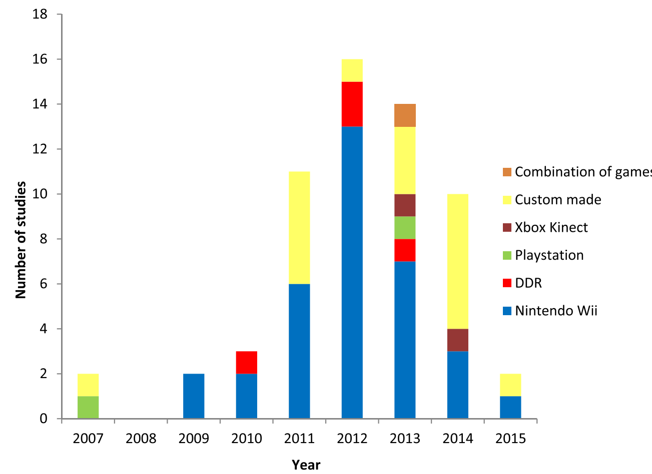

Fig. 2. Distribution of game consoles in exergame studies until February 2015.

Table 4 for references). For the custom-designed games three functions were mainly targeted; balance [9,33,36,38,39,46,54,59,61], walking/stepping [41,51,62–64,68], and strength [67,79].

3.5. Exercise progression

Thirty-two studies reported that they applied some kind of exercise progression during the intervention. The progression varied from increasing exercise duration [45,77], proceeding to the next level of the same game or to other games [10,13,32,38,39,43,46,49,50,52,54,57,61,65,66,73,74,78,85], adding more load in e.g. weight vests worn by the participants [53,69,72], and/or manipulating speed, orientation, size, frequency or shape of obstacles on the screen [33,45,59,60,63–68,76,78]. Two studies reported not having any form of progression during the intervention [56,86], while the remaining twenty-six studies did not report whether progression mechanisms were implemented during the intervention.

3.6. Adherence

Six of the included studies did not report the number of participants that completed the study [36,38,51,53,54,69]. Across the 54 studies that did include information about exercise completion, 88.8% of the participants completed the intervention on average, with a range of 56 to 100% of the participants. However, 24 of the studies did not report on the number of completed training sessions during the intervention [9,12,13,33,35,37,39,41,42,44–46,49,51,53,54,67,69,73–75,79,82, 85]. For the studies that reported on number of completed training sessions the methods varied between reporting adherence as a percentage of the maximum number of training sessions, compliance as the degree of accuracy with the prescribed intervention, or as the number of exercise sessions completed. Seven studies reported on adherence for both the intervention and the control group(s). Four of these showed no difference in adherence between the control exercise group and the group having an exergame intervention [57,72,80,81] while Pichierri et al. [65], Portela et al. [55], and Uzor and Baillie [62] showed better adherence in the exergaming group than in the control group(s).

3.7. Safety measures and adverse events

Forty-two studies reported that a safety measure was applied during the intervention. Of these, three interventions were conducted in a home environment

[52,83,84], while the others were performed in a laboratory setting or at a rehabilitation or community center [10–12,32,34,35,38–40,43–47,49,50,53–56,58–61,63–68,72–74,76,77,80–82,86]. Of the 42 studies that reported on safety measures, 17 interventions were supervised by a physical therapist, researcher, trainer, or nursing staff [10,11,34,38–40,43,44,47,54,55,59,64,72,73,76, 84]. Eleven studies placed a chair, walker, or walking frame near the participants, or used a gait belt or harness to ensure safety among the participants during game play [32,46,49,52,53,56,60,63,65,66,68]. Twelve studies had both a safety aid and supervised exercise [12,35,45,58,61,67,74,77,80–82,86]. The remaining two studies reported that they provided the participants with safety guidelines or a consultation with an exercise trainer before conducting the exercises [50,83].

Regarding adverse events, only 21 of the 60 included studies (<35%) reported whether adverse events occurred in the course of the intervention period. None of the studies reported any serious adverse events during the intervention, but four studies informed about adverse events occurring outside the intervention. In these four studies participants either withdrew with complaints about pain or discomfort after playing [76,81,83], or had a fall between the initial screening session and the first group exercise session [58].

3.8. Outcome measures

As can be seen in Table 5, a plethora of different outcome measures have been utilized to assess potential effects of gaming/VR exercise. Main outcomes were measures targeting balance, gait, center of pressure (CoP), other physical function tests, patient-reported outcome measures using different questionnaires, and disease-specific measures. The most commonly used tests employed were clinical measures of balance, such as the Berg Balance Scale (BBS) and the Functional Reach test (FR), measures of gait such as walking a set distance, and measures of physical functions such as the Timed Up & Go test (TUG), and Sit-to-Stand test. Alternatively, some studies employed more complex assessments of balance ability such as computerized stepping tests and CoP-measurements on force platforms. A wide range of different patient-reported outcome measures such as fear of falling, quality of life (QoL), and motivational questionnaires have been utilized as well. In addition to a wide variety of outcomes, there were also variations within measures based on differences in study protocols across the included studies.

With respect to assessment schedule, outcome measurements were typically performed at baseline and immediately after or shortly following the intervention. Four studies had a time interval until post-test follow-up of less than 6 weeks [41,56,63,80]. Only two studies involved longer follow-up, one at six months post intervention [84] and one at nine months post-initial assessments [38].

3.9. Methodological quality

Of the 29 studies that used a RCT or pre-posttest design, 21 studies included an exercise control intervention [9,13,32,33,38,43,44,47,49,53,55,57,60,64,65,67,69,72,73,80,81]. The methodological quality of these 21 studies according to the PEDro classification scale is presented in Table 6. The PEDro scores show that most of the studies had several methodological weaknesses, with only four studies achieving more than 5 of the 10 criteria [33,38,64,81]. Most studies fulfilled the criteria "random allocation" and "point estimates and variability". In approximately half of the studies, "baseline comparability", "key outcomes", and "between group comparisons" were fulfilled. In contrast, only six studies used blinded assessors [33,38,64,73,80,81]. Furthermore, "concealed allocation" was fulfilled in six studies only [13,33,38,64,65,81], and "intention to treat analysis" in three studies only [32,49,81]. None of the 21 studies could achieve a perfect score of 10 as the nature of the intervention (exercise) precludes blinding of the participants and the therapists.

3.10. Changes in physical function

None of the studies that compared an exergaming group with an active control group reported any negative effect of exergaming (see Table 6). In seven studies, no between-group effects were reported [32,44,55,60,67,72,80], and five studies had no observed differences between the exergaming and active control groups [9,13,49,57,73]. The remaining studies demonstrated improvements favoring the exergame group in one or more of the outcome measures evaluated [33,38,43,47,53,64,65,69,81].

For the Timed Up & Go test, four studies indicated improvements in favor of the exergame group [43,53,64,81], while the other four studies did not observe this [13,33,47,73]. With regard to the Berg Balance Scale, four studies obtained significant improvement after exergaming in comparison with an exercise control group [33,43,64,81], while Franco et al. [57] did not find any between-group effects. Szturm et al. [33] found positive between-group effects of the Clinical Test of Sensory Interaction and Balance. Furthermore, positive effects on postural sway measures were noted in two studies [38,53].

With respect to spatiotemporal gait parameters, there were no consistent findings across the five studies that used these outcome measures. Pichierri et al. [65] found that a few of the gait parameters, mainly single support time in different conditions, improved more in the exergaming group than in the exercise control group. On the other hand, Lee et al. [69] found positive effects with regard to double support time and swing time, while Cho and Lee [64] observed an advantage for the exergaming group with regard to gait velocity and cadence. Two studies [33,38] did not find any significant improvements in spatiotemporal gait parameters from exergaming compared to other exercise control groups.

Finally, patient-reported outcome measures indicated less fear of falling in one study only [38], and improved scores on the Activity-specific Balance Confidence scale in another [33]. The study by Duque et al. [38] was the only one reporting on fall incidence, which was significantly lower in the exergaming group than in the exercise control group nine months after initial assessments.

4. Discussion

The current integrative review aimed to provide an overview of the use of exergaming/VR games, and to explore whether this technology is a safe and effective exercise and rehabilitation tool for older adults. The review included 60 studies that used ICT-implemented weight-bearing games in an elderly population above the age of 65 years. Most of the studies included healthy older adults with a wide range of number of participants, duration of intervention, game technologies, and interaction time with each game. The majority of included studies were published in 2011 or later, reflecting that exergaming as a method of exercise and rehabilitation for older adults is still in its infancy. In addition, the studies used a variety of outcome measures and study designs, making it challenging to compare them and draw conclusions regarding the effect of interventions. However, several studies found an effect of improved balance and gait parameters, and one study reported improvement in incidence of falls.

Table 5
Outcome measures.

	Outcome measures	*n*	References
Balance	FRT, Tinetti POMA, BBS, One-leg stance, 4-square step test, computerized stepping testes, CTSIB, SOT, alternate step test, figure-8-test, tandem, FAB, Romberg, balance board, game task, bubble test in Wii	40	[13,32–37,39–41,43–46,50,52–61,63,64,66,67,71,73,74,77–82,85,86]
Gait	Tinetti POMA, 4 meter timed walk test, Spatiotemporal gait variables, single/dual task, 6-min walk test, DGI, 2 min walk test, 10 meter walk test, Endurance Shuttle Walk test	29	[10,13,33,34,38,47,49–53,57–59,62–65,68–70,73,74,76,77,82–85]
Center of pressure	Sway, Area, mean (SD) ML+AP, velocity, excursion, Dynamic Motion Analysis score, Tetrax stability score, optokinetic stimuli, GRF on stepping task, Wii Fit CoP test	16	[9,11,13,32,37,38,42,43,45,48,54,58,59,61,78,86]
Physical function tests	TUG, SPPB, PPA, Sit-to-stand, Grip strength, Heartrate, arm lifts, arm curls, back scratch, ramp walk power test, obstacle course, Gallon-jug shelf transfer test, medicine ball chest press throw test, knee extension and flexion strength test, muscle strength, MVC, rate of force development, LEFS, SFT, Timed IADL, FIM, Barthel index, tri-axial (RT3) accelerometers, MET, Wii Fit Age, ROM, Kinect posture estimation	41	[10–13,33–35,38,41,43,45,47–51,53,55,56,59–62,64,67,68,70–82,84,86]
Patient-reported outcomes (QoL, Falls, physical activity, balance, motivation, cognition)	FES-I, fall risk for older people in community setting, SAFFE, ABC-scale, SF-36, upper extremity functional index, CHAMPS, LLFDI, Health-related quality of life EQ-5D, numeric pain rating scale, WHO quality of life, PACES, AFRIS, self-regulation questionnaire for exercising, SFQ, RAPA, activity log, SEE, OEE, level of enjoyment on Likert scale, GDS, Beck depression inventory, Montreal Cognitive Assessment, Trail Making Test, digit symbol substitution test, MMSE, Self-efficacy for Exercise scale, VAS	33	[9,11–13,33–36,38,41,45,46,49,50,52,55,57,58,60–63,65,67,71,72,74,76–78,81,83,84]
Disease specific	UPDRS, PDQ-39, Chronic respiratory questionnaire, Fugl-Meyer scale, modified Ashworth scale, The community balance and mobility scale	5	[9,63,70,84,85]

n: number of studies looking at one or more of the mentioned outcomes.
FRT: Functional Reach test; Tinneti POMA: Tinetti Performance Oriented Mobility Assessment; BBS: Bergs Balance Scale; CTSIB: Clinical Test of Sensory Interaction and Balance; SOT: Sensory Organization Test; FAB: Fullerton Advanced Balance Scale; DGI: Dynamic Gait Index; TUG: Timed Up & Go; SPPB: Short Physical Performance Battery; PPA: Physiological Profile Assessment score; MVC: maximal voluntary contraction; LEFS: Lower Extremity Functional Scale; SFT: Senior Fitness Test; IADL: instrumented activities of daily living; FIM: Functional Independent Measure; MET: Melbourne Edge Test; ROM: Range of motion; FES-I: Falls Efficacy Scale International; SAFFE: Survey of Activities and Fear of Falling in the Elderly; ABC: Activity-specific Balance Confidence scale; SF-36: The Short Form [36] Health Survey; CHAMPS: Community Healthy Activities Model Program for Seniors; LLFDI: Late Life Function and Disability Index; PACES: Physical Activity Enjoyment Scale; AFRIS: Attitude to Falls-Related Interventions Scale; SFQ: Short Feedback Questionnaire; RAPA: Rapid Assessment of Physical Activity; SEE: Self-Efficacy for Exercise scale; OEE: Outcome Expectations for Exercise scale; GDS: Geriatric Depression Scale; MMSE: Mini Mental Status Evaluation; VAS: Visual Analogue Scale; UPDRS: Unified Parkinson's Disease Rating Scale; PDQ-39: The Parkinson's Disease Quality of life questionnaire.

Table 6
Study characteristics, PEDro score, and effect on physical function of 21 intervention trials comparing exergaming with other forms of exercise.

Study; design; sample size; intervention dose	PEDro score	Sample characteristics	Exergaming group(s) (E)	Other exercise group(s) (O)	Progression	Between group change in physical function
Laver et al., [81]; RCT-pilot; $N=42$; stay at rehab unit, 5×/week, 25 min	8	Hospitalized; age 84.9 (±4.5)	E: Nintendo Wii	O: Conventional PT focused on functional mobility	NR	**POS** TUG $p=.048$; modified BBS $p=.042$ **NO** SPPB, Timed IADL, ABC, HQoL EQ5D
Cho & Lee [64]; RCT; $N=14$; 6weeks, 3×/week, 30 min	7	Chronic stroke (rehab); E:64.6 (±4.4), O:65.1 (±4.7)	E: Virtual walking training program using a real-world video recording, and therapeutic exercise, occupational therapy, functional electrical stimulation	O: Therapeutic exercise, occupational therapy, functional electrical stimulation, treadmill gait training	E: Speed was increased by 5% if the subject could maintain the training speed while feeling safe for 20secs O: NR	**POS** BBS $p=.011$; TUG $p=.013$; gait velocity $p=.013$; cadence $p=.035$ **NO** Step length, stride length, single limb support%
Duque et al., [38]; RCT; $N=68$; 6weeks, 2×/week, 30 min	6	Community-dwelling with balance impairment (home); E:79.3 (±10), O:75 (±8)	E: Balance Rehabilitation Unit	O: Invitation to join an exercise program (Otago protocol), medication review, home visit by occupational therapist (if more than 60% of the falls occurred at home), hearing and visual assessment, nutritional supplements, vitamin D supplementation, education materials on falls prevention	E: Increasing levels of complexity (maximum 15 levels) O: NR	**POS** (after 9 months) limits of stability cm^2 $p<.01$; optokinetic stimuli $p<.01$; vertical VVC $p<.01$; horizontal VVC $p<.01$; SAFFE $p<.01$; falls $p<.01$ **NO** (after 9 months) sway (eyes open on floor), sway (eyes closed on floor and foam), gait velocity, cadence, stride length, double support time, Grip strength, GDS
Szturm et al., [33]; RCT; $N=27$; 8weeks, 2×/week, 45 min	6	Independently living; E:80.5, O:81	E: Built COP-game with pressure mat	O: Rehab program with strength and balance exercises in sitting and standing	E: Increasing sensitivity of COP movements, speed, precision and duration O: NR	**POS** BBS $p<.001$; ABC scale $p<.02$; CTSIB $p<.007$ **NO** TUG, avg. gait speed, spatiotemporal gait variables
Pichierri et al., [65]; RCT; $N=22$; 12 weeks, 2×/week, 40 min	5	Community dwelling (hostels for older adults); 86.2 (±4.6)	E: Modified version of DDR (Stepmania) + progressive resistance and postural balance training	O: Progressive resistance and postural balance training	E: Through the beats per minute and the difficulty level O: number of repetitions and load were progressively increased with weight vests	**POS** foot placement accuracy (condition 2) $p=.03$; velocity (fast with cognitive task) $p=.041$; single support time (fast with cognitive task) $p=.029$; single support time (normal dual task) $p=.05$; single support time (fast dual task) $p=.04$ **NO** foot placement accuracy (distance errors, walking velocity condition3, quality evaluation); temporal-spatial parameters (normal, fast and normal with cognitive task: velocity, cadence, step time, cycle time, stance time, single support time, double support time, step length); temporal-spatial parameters (fast with cognitive task: cadence, step time, cycle time, stance time, double support time, step length); relative dual task costs (normal and fast: velocity, cadence, step time, cycle time, stance time, double support time, step length); FES-I
Cho et al., [43]; RCT; $N=22$; 6weeks, 3×/week, 30 min	5	Chronic stroke at outpatient department of rehabilitation hospital; 64.2 (±7.6)	E: Nintendo Wii + standard rehabilitation program	O: Standard rehabilitation program with physical therapy, occupational therapy and speech-language therapy	E: Encouraged to increase level O: NR	**POS** BBS $p<.001$; TUG $p<.01$ **NO** Postural Sway Velocity AP and ML with eyes open and closed

Table 6 (*Continued*)

Study; design; sample size; intervention dose	PEDro score	Sample characteristics	Exergaming group(s) (E)	Other exercise group(s) (O)	Progression	Between group change in physical function
Lee et al. [69]; RCT; $N = 82$; 10weeks, 3×/week, 45 min	5	Community-dwelling (senior center); 75.2(±6.6)	E: Nintendo Wii	O: Traditional group fitness with walking, strength and stretching	E: Weight vest with 2 pounds and adding 2 additional pounds every 2 weeks O: Modifications (e.g. deeper lunges and stiffer bands)	**POS** double support time% $p = .013$; swing time% $p = .010$ **NO** gait velocity, stride length, cadence, CV stride length, CV swing time, balance efficacy scale
Pluchino et al., [13]; RCT; $N = 27$; 8weeks, 2×/week, 60 min	5	Independently living; 72.5 (±8.4)	E: Nintendo Wii	O1: Standard balance exercise program O2:Tai Chi	E: 3 levels within each game, progress as soon as max score was attained O1: E.g. closing eyes, reducing base of support O2:NR	**NO** TUG, one-leg-stance, FR, POMA, FROP-Com, FES, sway, dynamic posturography
Fung et al., [49]; RCT; $N = 50$; length of stay in physical therapy service, 15 min	5	Outpatients following total knee replacement; 68 (±11)	E: Nintendo Wii	O: Lower extremity exercises that addressed balance, posture, weight shifting and strengthening	E: Other games once demonstrating a plateau in scoring O: Progressed to next level when similar exercises was performed successfully	**NO** active knee flexion, active knee extension, 2minute walk test, numeric pain rating scale, ABC-scale, LEFS
Reed-Jones et al., [47]; RCT; $N = 45$; 12 weeks, 2/week, 90 min	4	Community dwelling (retirement home); 67.5 (±5.9)	E: Nintendo Wii	O1: ACSM exercise recommendations for elderly O2: Agility drills	NR	**POS** obstacle course (hits) $p < .001$ (.212) **NO** grip strength, STS, arm curl, 6-min walk test, FR, TUG, ramp walk power test (long), ramp walk power test (short), Gallon-Jug shelf-transfer test, medicine ball chest press throw test, obstacle course (time), obstacle course (time + hits)
Franco et al., [57]; RCT; $N = 32$; 3 weeks, 2×/week, 10–15 min	4	Community dwelling (independent living senior housing); 78.3 (±6)	E: Nintendo Wii + supplemental home exercises	O1: Completed exercises from the MOB Program O2: No intervention	E: Introduced to different games O1: Regular MOB protocol O2: -	**NO** Tinetti, BBS, SF-36
Toulotte et al., [32]; RCT; $N = 36$; 20weeks, 1×/week, 60 min	4	Independently living; 75.1 (±10.3)	E1: Nintendo Wii E2: Nintendo Wii + Adapted physical activities	O: Adapted physical activities	E1: Based on different levels in each video game E2: Levels of game + increased numbers of repetitions and difficulty O: Increased numbers of repetitions and difficulty	**NR**
Crotty et al., [80]; RCT-pilot; $N = 44$; stay at rehab unit, 5×/week, 25 min	4	Acute care hospital inpatients; E:85.2 (±4.7), O:84.6 (±4.4)	E: Nintendo Wii	O: Conventional therapy designed to improve balance, strength and aerobic capacity	E: NR O: NR	**NR**
Ray et al. [53]; RCT; $N = 87$; 15weeks, 3×/week, 45 min	3	Community dwelling; 75	E: Nintendo Wii	O1: Group fitness with strength exercises sitting and standing O2: Control group	E: Weighted vest of 2 pounds, 2-pound increase every 2nd week until 10 pounds O1: Progressively increasing intensity routine	**POS** SOT $p = .007$; 8-foot TUG $p = .017$ (main effect) **NO** SOT strategy, 6-min walk, arm curls, chair stands, shoulder stretch

Singh et al. [73]; pre-post controlled; N = 28; 6weeks, 2×/week, 120 min	3	Community stroke rehabilitation centers; E:65.4 (±9.8), O:67.0 (±8.4)	E: Nintendo Wii and Xbox Kinect	O: Standard group therapy conducted by PT, stretch, strengthening, balance, coordination, endurance	E: Increasing difficulty level based on performance O: NR	**NO** TUG, 30 sec STS, 10 min walk test, 6 min walk test, Static balance, Barthel index
Daniel [72]; RCT pilot; N = 21; 15 weeks, 3×/week, 45 min	3	Community dwelling (residential living centers); 77 (±5.3)	E: Nintendo Wii	O1: Traditional senior fitness program, and rigorous seated aerobics program O2: Control asked to continue usual exercise	E: 2% of body weight added to weight vest every 2 weeks O1: increasing intensity O2: NR	**NR**
Bisson et al., [9]; pre-post intervention; N = 24; 10weeks, 28/week, 30 min	2	Independently living; E:74.4 (±3.7), O:74.4 (±4.9)	E: IREX	O: Dynamic balance training with visual biofeedback	E: NR O: NR	**NO** AP displacement, ML displacements reaction time, community balance and mobility
Portela et al., [55]; RCT; N=58; length NR, 20sessions, 50min	2	Community dwelling (nursing home); 79	E1: Nintendo Wii with supervision E2: Nintendo Wii unattended	O: Geriatric gymnastics	E1: NR E2: NR O: NR	**NR**
Bateni [44]; quasi-experimental; N = 17; 4weeks, 3×/week, no information on duration	2	Independently living; 73 (±13)	E1: Nintendo Wii E2: Nintendo Wii+ physical therapy	O: PT training to increase strength, and improve posture and balance.	E1: NR E2: NR O: NR	**NR**
Chen et al., [67]; case-control; N = 40; 6 weeks, 2×/week, 30 min	2	Independently living; E:76.4 (±7.4), O:75.4 (±8.5)	E: LLPR (video-game-based rehabilitation device)	O: Home exercise with sit-to-stand movements, knee extension, one leg stance	E: Increased target power threshold O: NR	**NR**
Williams et al. [60]; case-control; N = 17; 12 weeks, 2×/week, optional duration	1	Community-dwelling fallers (home); E:76.8 (±5.2), O:76.5 (±4.8)	E: Nintendo Wii	O: Exercise/education program supervised by PT	E: Modified at weeks 4 and 8 O: NR	**NR**

N = number of participants completed; intervention dose = length, frequency, duration; NR = not reported; E = exergaming group; O = control group; PT = physiotherapy; POS = significant positive group effect in favor of exergame; NO = no significant group effect. Effects are presented as: outcome variable (condition) p-value (effect size, if reported). Note: No studies reported a significant negative group effect of exergaming.

4.1. Game technologies and exergames

The review revealed a variety of game technologies and exergames being used. The Nintendo Wii console was the most frequently used, with variations depending on the package and accessories used. However, other commercial game consoles such as the Xbox 360 with Kinect and PlayStation II with EyeToy have been brought into play in recent years. Even though most studies have used games that are available on commercial consoles, several custom-designed consoles and games have also been utilized. However, these latter exergames tend to be characterized by fairly simple designs and exercises. Some of the custom-designed systems, such as the balance rehabilitation unit, require specific training before implementation, have a high cost compared to commercial systems, and depend on access to sufficient playing space and safety accessories. In addition, custom-designed games are usually employed by a single research group only. Although exergaming technology developed within the context of research addresses several of the problems that commercial exergames represent for an older age group, it remains to be seen to what extent these custom-designed systems can be widely disseminated.

Although several of the exergames were found to have a positive effect on balance and gait parameters among older adults, we know from previous research [22,87] that some games are rather demanding in terms of game interfaces that can be colorful, visually busy, and accompanied by unsuitable music, noises, and running commentary. To ensure that exergames reach the same acceptance as other exercise tools and methods, the games need to offer accessible and enjoyable activities for older adults in the same manner as more traditional forms of exercise. This might be important to consider when implementing or testing certain exergames in the elderly population. However, it will still be a challenge to find the most suitable exergame for older adults as they are a heterogeneous group, and physical and mental health status should be taken into consideration before implementing exergames as an exercise or rehabilitation tool.

About half of the included studies in this review reported having some kind of progression in exercise during the intervention. However, how progression was attained differed between studies, ranging from increasing the difficulty of the game to adding additional cognitive challenges or increasing the weight of a vest worn by the participants while playing. Studies also differed in how progression was achieved, often requiring a manual action by the researcher or participant. If exergames are to be used widely as an individual exercise tool, progression should be implemented within the game design itself, automatically adapting the level of challenge for each individual player based on their current performance [23]. The use of implemented standardized tests that have to be performed in regular intervals may also provide individual adjustments in loading and difficulty level. The games should set clear goals and both record and display progression so that the users feel that they are achieving their goals and managing to improve their physical function.

As exergames are typically reported to be fun and motivating, it has been claimed that they may increase adherence and compliance to exercise. Nonetheless, this has rarely been examined quantitatively and compared with appropriate control groups. Studies included in the current review generally revealed high attendance to exergaming. However, as most of the studies were conducted in a laboratory or clinical setting with supervision, there is little evidence to conclude that exergaming in general provides better adherence than standard exercise. Even though Miller et al. [88] reported strong retention and adherence rates in their systematic review concerning effectiveness and feasibility of VR/exergaming systems in a home setting, little is known about long-term participation in this form of activity. User characteristics and personality are likely to influence the types of exergames that seniors like to play and a "one-size fits-all" approach may result in low or even non-adherence. Likewise, exergaming has the potential to include a social context where older adults can chat with each other while exercising, play together with other people, or against each other in a competition. In addition, through use of new technologies people have the possibility to play together remotely through the internet without both players needing to be at the same location. However, the social aspects of exergaming and how these might influence adherence have not been studied thoroughly. Furthermore, even though the multi-player option is generally perceived as social and fun, we lack empirical data about whether playing together remotely is an equally enjoyable possibility as actually being in the same room.

4.2. Safety measures and adverse events

There is only limited evidence available to assess whether exergaming is safe for older adults as only one third of the studies included in this review presented information regarding the occurrence of adverse events during the interventions. The few adverse events that were reported ranged from mild discomfort to musculoskeletal pain and none of the studies reported any serious adverse events during exergaming, suggesting that exergaming interventions might be safe for older adults. However, most studies were conducted in a laboratory, rehabilitation, or community center setting and applied extra safety measures such as supervision, walking frames, or gait belts. One of the potential benefits of exergaming interventions is that they can be administered at home as individual exercise. Home-based exercise has been shown to be effective in reducing mortality, injuries, and falls, as well as being more cost-effective than other interventions [27,89]. However, few studies have assessed the safety of administering exergaming in the homes of older adults. In the current review, the five studies with a home-based intervention reported that there were no adverse events during the exergaming intervention [52,70,78,84,90]. However, as some of the latter studies applied extra safety measures and generally had few participants, it is premature to conclude that exergaming is equally safe as other, more conventional forms of home-based exercise.

Importantly, half of the 60 studies we reviewed used the Nintendo Wii and Wii fit balance board, and an additional six studies used pressure mats or force platforms. Both the Wii fit balance board and the step mat for DDR are elevated platforms that the player has to stand on in order to perform the exercises. They may therefore present a risk of tripping and falling, particularly when attention is focused on the television screen. Newer commercial exergaming systems such as the Microsoft Kinect do not require the player to stand on an elevated surface, and may therefore provide a safer alternative of exergaming for older adults. However, at the moment few studies have been published on these newer commercial systems, so the improved safety aspect of these games remains to be established.

4.3. Measures of physical function

Studies on exergaming for older adults have focused on a wide range of physical functions, but the most common focus has been to establish whether exergaming has an effect on balance.

The general recommendations to stay active and healthy for adults above 65 years are to carry out moderate-intensity aerobic physical activity, in addition to balance and strength training [28]. However, only a few studies using commercially available exergames, and none of the custom-designed games, have used games that target more than one physical function. Future studies should include games that target multiple physical functions in order to establish the extent to which exergaming can contribute to keeping older adults active and healthy.

Finally, the plethora of different assessment tests and outcome measures makes it difficult to do a comprehensive meta-analysis on the effectiveness of exergaming. This will be further discussed below.

4.4. Changes in physical function

The studies that compared exergame-based training with other exercise programs found that exergames showed comparable or slightly better changes in physical function in several outcome measures. Interestingly, none of the studies included in this review showed a negative effect of exergaming when compared to other exercise interventions. This might indicate that exergaming is an effective alternative to conventional exercise or rehabilitation for older adults. Nevertheless, a generalized conclusion must be regarded with caution as only two of the included studies had a long-term follow-up of at least six months. However, the results of both these studies are encouraging. Duque et al. [38] reported a significant improvement in limits of stability as well as in the incidence of falls and in levels of fear of falling nine months after initial assessment. In addition, Flynn et al. [84] found a sustained or improved function for all outcome measures in their case report at six-month follow-up.

Another point to be taken into consideration is that positive effects were often limited to specific functions trained during exergaming, without generalizing to other functions not specifically trained. In addition, it should be noted that in some studies reporting improvements in favor of the exergame group, participants took part in additional balance and strength exercises [43,64,65]. Finally, these results are mostly obtained from fairly healthy, community-dwelling older adults as most samples were based on convenience sampling rather than strictly population samples. Hence, generalizability of results to community-dwelling older people in general and at-risk groups in particular may be problematic and requires further investigation.

Results regarding the methodological quality indicated a general lack of concealed allocation and use of intention-to-treat analysis in most of the included studies. Only four of 21 studies attained a score of 6 or above (of 10) on the PEDro scale. As a consequence, this restricts the capacity of these studies to generate reliable evidence regarding the effectiveness of exergame interventions. Previously published reviews on exergaming/VR-interventions report similar problems [5,16,19,88].

4.5. Strengths and limitations

The main strength of this review lies in its extensive search strategy, covering a broad range of search terms and databases in the fields of medicine, social sciences, health care, and technology. This systematic and multidisciplinary approach is also reflected in the inclusion of all types of pre-post intervention studies, regardless of research design. Another strength is the use of the PEDro scale to evaluate the methodological quality of studies that compared exergaming against at least one other active control group in order to investigate the potential effect of exergaming.

Nevertheless, there are some limitations to our review. First of all, although we conducted an extensive search, it was not complete in the sense that we limited our search to original research with a pre-post intervention and English language publications only. Furthermore, aspects such as social potential and user perspectives were not included in this review as they fell outside the main objective. However, these aspects have relevance for long-term engagement in exergaming (cf. [91]) and should be included in future research.

5. Recommendations and conclusion

In general, exergames show good potential as an exercise or rehabilitation tool for older adults. It is encouraging to note that only a few studies reported on, relatively mild, adverse events and that all studies reported exergaming to be as effective as or more effective than conventional forms of exercise. Based on the findings in the current review, we provide the following recommendations for both research and practice to successfully establish exergames as an exercise and rehabilitation tool for older adults.

1) Exergames need to be personalized to goals and performance level

A "one-size fits all" approach is not the best solution to engage older adults in exergaming. Before implementing an exergame in a home, community center, or rehabilitation center, the needs, wishes, and motivation of the intended user should be assessed, for example by use of focus interviews, workshops or user-centered design methods, and further taken into account to increase engagement in the exergame. Progression should be ensured by automatically adapting the level of challenge (difficulty and load) to the current performance level, making games more challenging when the user achieves consistently good performance and less challenging when performance drops.

2) Exergames should address multiple physical functions when used as an exercise tool

Future studies should include games that can target multiple physical functions to establish the extent to which exergaming can contribute to keeping older adults active and healthy. New technologies such as the Microsoft Kinect have the potential to incorporate complex and continually adaptive exercises requiring specific movements and track the extent to which these movements are indeed performed by the players. By way of example, exergames that only require an individual to repeatedly reach for an object do not exploit this potential and therefore, do not utilize the full potential of exergaming as an exercise and rehabilitation tool.

3) Exergames need to be safe for players without the need for additional safety measures

If exergames are to be used by healthy older adults at home, in frail older adults, or in older adults with an acquired disease, the safety of playing needs to be established more firmly. Ideally, no extra equipment such as harnesses and frames should be required in order to play. However, for frail older adults a walking aid can be useful in the initial phase of playing exergames. To establish safety, objective and subjective measures of this should be reported, as well as the participants' ability to play the games.

4) Adherence to exergaming should be included in study methods

Even though exergaming is largely purported to be fun and motivating, there is little evidence of whether exergames achieve higher adherence than conventional forms of exercise. Future studies should include outcomes on adherence for both exergaming interventions and exercising control groups. Here as well, new technology provides great opportunities as one can save and store large amount of information from an exergaming session. Information about which games have been played, how much they have been played, and how the players moved during the gaming session can be obtained from the technology. This information can give insight into exercising routines that traditional exercise logs

Summary points

What was known before this study?

- Exergames are used progressively more to increase physical activity and improve health and physical function in older adults.
- Previous reviews have mainly focused on the effect of exergaming in specific populations.

What did this study add to our body of knowledge?

- The current review contributes with an extensive overview of game technologies and exergames, physical functions targeted, outcome measures, and safety measures used in intervention studies.
- Results of the review indicate similar or better effects of exergaming compared to traditional forms of exercise, with few and relatively minor adverse events.
- The review points out several areas that are in need of more research, including adherence to the exergaming and tailored progression of exercises.
- Based on the results, the review provides recommendations for both practice and further research in order to successfully establish exergames as an exercise and rehabilitation tool for older adults.

typically do not. Exploiting the information given by the technology can provide insight not only into adherence, but also enable personalized feedback on how movements should be performed and adjusting and adapting the games to each player. Although social aspects of exergaming were not part of the objectives in this review, exergaming and exergaming technology have an important but under-exploited potential that should be explored further. Having the possibility to play together with, or against, one or several people might be a way to keep older adults involved and engaged in exercise. Furthermore, including one or more social components into the gaming sessions such as a chat function or a multiplayer function might contribute to keeping older adults more socially active and less isolated.

5) Studies with longer follow-up should be conducted to establish long-term effects

To establish the long-term exercise effect of exergaming, we recommend that randomized controlled trials should be conducted with a longer follow-up, including larger group sizes, follow-up assessments, and more standardized protocols and outcome measures.

Exergaming has great potential to become a crucial part of future personalized medical technology and a significant tool for health professionals such as physiotherapists and occupational therapists. This requires the use of appropriate games that are tailored specifically to older adults, provide personalized exercises based on each individual's needs, and ensure long term follow-up. Furthermore, as many elderly increasingly become tied to their homes with age and disease, they are at risk of decreasing levels of social and physical activity, as well as increased isolation. In these situations, exergames have the potential not only to be a fun and motivating way to exercise, but also to engage older adults in social activities. In order to realize the full potential of exergaming as an exercise and rehabilitation tool for older adults, research is needed to establish whether the games are safe, which technology to use for which purpose, how to ensure ease of use for the older adults, and how to achieve long-term adherence to the games.

Author's contributions

Nina Skjæret and Beatrix Vereijken managed the review process with input from Ather Nawaz, Tobias Morat, Daniel Schoene, and Jorunn L. Helbostad. Nina Skjæret and Beatrix Vereijken reviewed the full papers. Beatrix Vereijken and Tobias Morat assessed the methodological quality of the included studies. All authors critically revised the paper for publication.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijmedinf.2015.10.008.

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