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Effectiveness and feasibility of virtual reality and gaming system use at home by older adults for enabling physical activity to improve health-related domains: a systematic review

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Abstract

Background: use of virtual reality and commercial gaming systems (VR/gaming) at home by older adults is receiving attention as a means of enabling physical activity.
Objective: to summarise evidence for the effectiveness and feasibility of VR/gaming system utilisation by older adults at home for enabling physical activity to improve impairments, activity limitations or participation.
Methods: a systematic review searching 12 electronic databases from 1 January 2000–10 July 2012 using key search terms. Two independent reviewers screened yield articles using pre-determined selection criteria, extracted data using customised forms and applied the Cochrane Collaboration Risk of Bias Tool and the Downs and Black Checklist to rate study quality.
Results: fourteen studies investigating the effects of VR/gaming system use by healthy older adults and people with neurological conditions on activity limitations, body functions and physical impairments and cognitive and emotional well-being met the selection criteria. Study quality ratings were low and, therefore, evidence was not strong enough to conclude that interventions were effective. Feasibility was inconsistently reported in studies. Where feasibility was discussed, strong retention (≥70%) and adherence (≥64%) was reported. Initial assistance to use the technologies, and the need for monitoring exertion, aggravation of musculoskeletal symptoms and falls risk were reported.
Conclusions: existing evidence to support the feasibility and effectiveness VR/gaming systems use by older adults at home to enable physical activity to address impairments, activity limitations and participation is weak with a high risk of bias. The findings of this review may inform future, more rigorous research.

Keywords: *older people, virtual reality, gaming, physical activity, effectiveness, systematic review*

Introduction

The use of virtual reality and commercial gaming systems (VR/gaming) has received attention for enabling physical activity and engagement in healthy individuals and for rehabilitation in clinical populations [1–4]. Definitions of virtual reality describe 'immersive' environments responsive to the actions of the user, providing opportunities for repetitive, contextual practice and feedback consistent with conditions for successful motor skill acquisition [1, 5]. Particularly when coupled with popular, commercially available gaming systems, the engaging nature of these activities can provide a motivating and enjoyable means of adhering to exercise and increasing physical activity [3, 4] in the comfort and convenience of home.

The World Health Organization has provided recommendations for regular physical activity in older individuals as an important preventative measure against disease and disability [6]. The application of VR/gaming systems to promote physical activity has been termed *exer-gaming* or *active/activity promoting gaming* [4]. These technologies are increasingly being adopted by older individuals; one survey reporting that almost a third of Americans who played video and computer games were over 50 years of age [7]. To date, most reviews relating to the effectiveness of these technologies have included studies undertaken in a range of locations; the majority completed in clinical and laboratory settings for the convenience of researchers and clinical participants [1–4]. These findings cannot necessarily be generalised to home environments where the individuals potentially receive far less supervision and encouragement to adhere to the gaming activities or programmes.

The primary research question addressed by the systematic review was:

- What is the effectiveness of VR/gaming systems undertaken for enabling physical activity in a home setting to improve impairments, activity limitations and participation in people aged over 45 years old?

The secondary question addressed was:

- Is there evidence to support the feasibility of using VR/gaming systems for enabling physical activity in a home setting in terms of safety, training and supervision required, and the cost and acceptability in terms of recruitment, adherence, retention and take up for people aged over 45 years?

Method

Search strategy and selection criteria

Operational definitions of virtual reality and gaming technologies obtained through MeSH thesauruses and non-MeSH terms were used to establish the search strategy for this review. These terms were then applied to search 12 electronic databases from health, social sciences and engineering related disciplines: Scopus, Web of Science, TROVE, MEDLINE, CINAHL, Rehabilitation Reference Centre, Nursing Reference Centre, Inspec, Compendex, SocIndex, PsycINFO and Sociological Abstracts from 1 January 2000 to 8 November 2011. The search was updated in July 2012 and included additional studies published up to this point. Examples of search terms utilised in MeSH and non-MeSH databases can be found in Supplementary data are available in *Age and Ageing* online Appendix S1. Gaming and virtual reality is a rapidly evolving field, and technologies introduced prior to 2000 were likely to be superseded and no longer commercially available or compatible with current technologies.

Peer-reviewed intervention studies with pre- and post-intervention measurements including randomised controlled trials (RCT), comparative studies with/without concurrent controls, and case series published in English were included in the review. Conference proceedings, poster abstracts, theses, books and review articles were excluded. A broad definition of 'older' to take into account lifespan variations associated with different socioeconomic, cultural and ethnic groups [8] was adopted; publications including participants with a mean or age range of participants 45 years and older, defined by the MESH terms 'middle-aged' (aged 45–64 years), 'aged' (65–79 years) and 'aged 80+ years' were selected. Studies set in retirement villages, aged care facilities providing low-level care services, service-integrated housing and supported accommodation were considered consistent with the Merriam-Webster Dictionary definition of a 'home' setting and were selected for inclusion [5], while interventions undertaken in a hospital, laboratory, community or nursing home environments were excluded. Applications specific to cognitive, arm and hand re-training, and where VR/gaming were combined with robotic/mechanical assistance were also excluded. The applications of robotics and smart-home technologies to assist older individuals to live at home were reviewed separately by this research group [9, 10].

Data extraction and quality assessment

Throughout this review the application of the selection criteria, data extraction and quality assessment were performed by two independent, trained reviewers. Lack of agreement regarding the included articles, data extracted or quality assessment was reconciled by mutual agreement. Data extraction was conducted using customised data extraction forms which included information regarding the study design and aims, setting, sample characteristics and outcome information, feasibility and results of the study (Supplementary data are available in *Age and Ageing* online, Appendix S2). Meta-analysis was not feasible because dependent variables were heterogeneous between studies; therefore, results were synthesised and summarised. The primary dependent variable for each study was broadly classified in accordance with The World Health Organization's International Classification of Functioning Disability and Health (ICF) as body structures and functions, activities or participation [11]. Details relating to the interventions included: technologies used, target and recorded dosages, and feasibility with respect to recruitment, retention, adherence, take up, the training and assistance required and safety concerns associated with use of the technologies.

Risk of bias (high, low or not applicable) in the selection, performance, detection, attrition and reporting in the individual studies was assessed using the Cochrane Collaboration Risk of Bias Tool [12]. In addition, the Downs and Black quality checklist was used to evaluate the overall methodological quality [13]. The Downs and Black checklist, unlike the Risk of Bias tool, was developed to evaluate randomised and non-randomised study designs. It scores 27 items (generally rated 1, 'yes' or 0, 'no' or 'unable to determine') reflecting the interventions, potential confounders and outcome elements of the studies. Higher summed scores for this checklist are indicative of greater study quality and confidence in conclusions relating to intervention effectiveness. As the final item in the Downs and Black Checklist was found to be ambiguous, quality assessment was rated according to 26 items for this review, with a maximum total score of 27.

Results

Study selection

Figure 1 illustrates the flow of studies through the systematic review process. The initial search yielded 2,220 publications; 1,087 of these records were excluded as they failed to meet selection criteria or were duplicates. The titles and abstracts of the remaining 1,133 articles and 15 additional records identified through a targeted search were screened to yield 122 articles. In the final phase of the screening, 111 publications were excluded following examination of the full text. The most common reasons for exclusion were because the study had not been undertaken in a home setting ($n = 39$), the articles were narrative reviews of a topic ($n = 38$), the participants were younger than 45 years ($n = 14$) or the interventions were specifically directed at regaining hand dexterity ($n = 5$). The agreement rate between the two reviewers in selection of studies was \sim96%. An updated search in 2012 identified 311 new publications, 278 of these were excluded on review of the

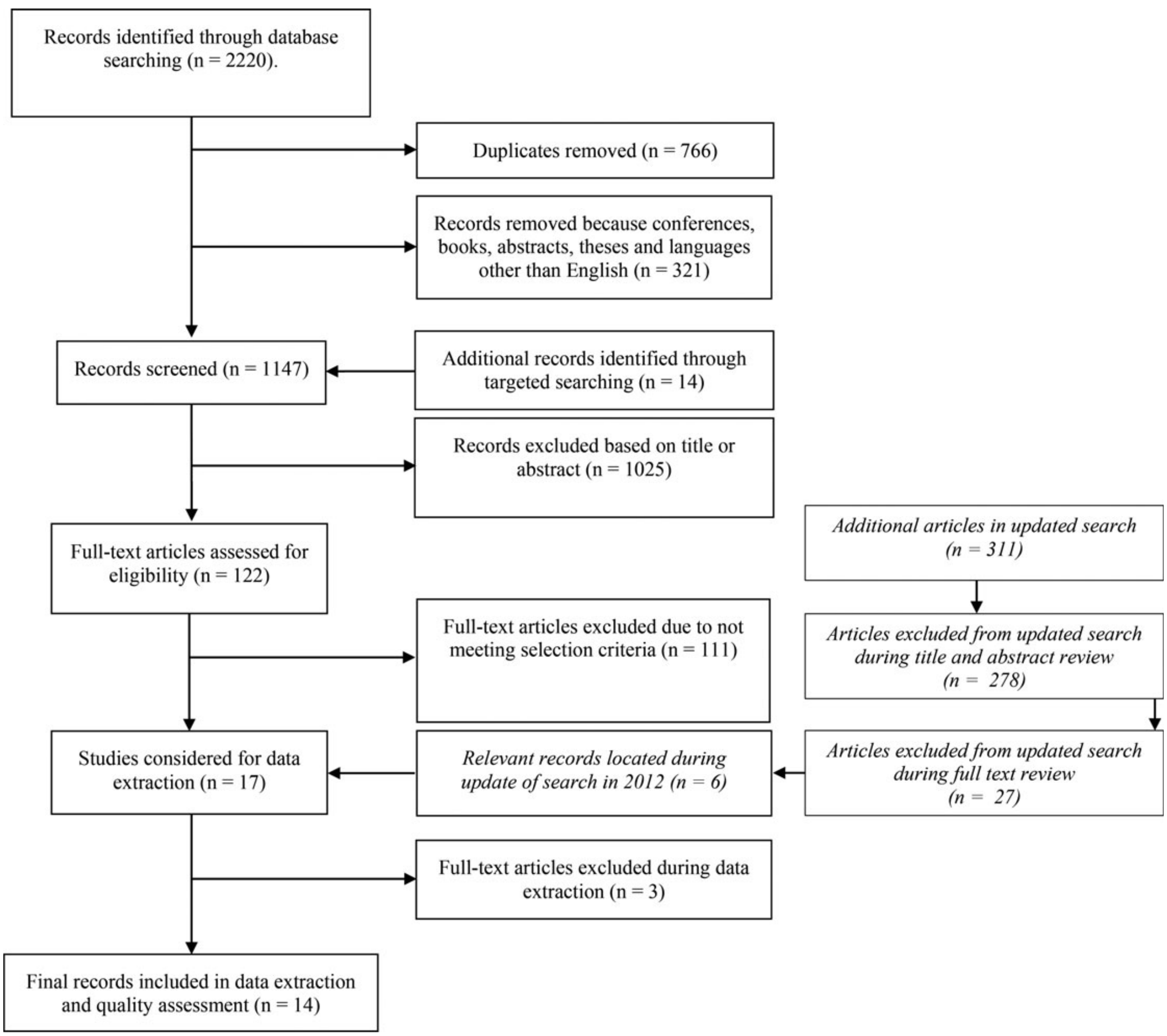

Figure 1. Yield of articles for the virtual reality and gaming literature.

Table 1. Risk of bias as established for reviewed studies

	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other potential bias
Esculier *et al.* 2012 [24]	+	+	+	+	−	−	
Agmon *et al.* (2011) [17]	+	+	+	+	−	−	
Bell *et al.* (2011) [25]	+	+	+	+	−	−	
Kahlbaugh *et al.* (2011) [15]	?	?	+	?	−	−	
Williams *et al.* (2011) [16]	+	+	+	+	−	−	
Yuen *et al.* (2011) [22]	+	+	+	+	−	−	
Lotan *et al.* (2010) [14]	+	+	+	+	−	−	Primary outcome (heart rate) measure not consistently reliable
Nitz *et al.* (2010) [19]	+	+	+	+	−	−	
Rosenberg *et al.* (2010) [20]	+	+	+	+	−	−	Five participants withdrew from baseline to follow-up
Sohnsmeyer *et al.* (2010) [27]	+	+	+	+	−	−	
Studenski *et al.* (2010) [21]	+	+	+	+	+	+	11/36 withdrew from the study; reported outcome measures not consistent with stated study aims
Lotan *et al.* (2009) [23]	+	+	+	+	−	−	
Flynn *et al.* (2007) [18]	+	+	+	+	−	−	
Kaminsky *et al.* (2007) [26]	+	+	+	+	−	−	

+, high risk of bias; ?, unclear risk of bias; −, low risk of bias as established applying the Cochrane Collaboration tool for assessing risk of bias [12].

title or abstract, 27 were excluded following review of the full texts, yielding an additional six articles that were relevant to this review.

Study characteristics

The study characteristics for the 14 included studies are presented in Supplementary data are available in *Age and Ageing* online, Appendix Table S1. Only 2 of the 14 studies utilised a RCT design [14, 15]. The majority of the studies (7/14) were case studies [16–22], considered the weakest level of evidence (grade IV) according to National Health and Medical Research Council (NHMRC) of Australia guidelines. The remaining studies were comparative studies with (three studies, NHMRC grade III.2) [23–25] or without (one study, NHMRC grade III.3) [26] concurrent control subjects or pseudo-randomised designs (one study, NHMRC grade III.1) [27]. A high-risk bias was identified for the majority of studies on the Cochrane Collaboration Risk of Bias Tool (Table 1).

The primary aim of the reviewed studies was to evaluate the potential effect of gaming/VR on activities or activity limitations [16–19, 21, 23, 24], or physical body functions or impairments [14, 22, 26, 27]. Three studies investigated the impact of gaming/VR on cognitive and emotional well-being including loneliness and quality of life, attributes that spanned mental and emotional functioning, activity and participation ICF domains [15, 20, 25]. Most studies were undertaken in homes or retirement villages in North America [16, 18, 20–22, 24, 26].

Participant characteristics

Participants were predominantly healthy older individuals [16, 17, 19, 21, 25] or people with neurological conditions such as stroke, Parkinson's disease, developmental or intellectual disabilities (Supplementary data are available in *Age and Ageing* online, Appendix Table S1) [14, 18, 23, 24, 26]. Two articles provided minimal information about participants [15, 27]. Sample sizes (1–60) and the mean participant age (47–84 years) varied considerably between studies. Sampling strategies were either not described or utilised a convenience sample.

Utilisation of gaming and virtual reality technologies

Popular, commercially available gaming technologies were used to encourage physical activity in all but one of the reviewed studies (Supplementary data are available in *Age and Ageing* online, Appendix Table S1). The Nintendo™ *Wii* (Nintendo; Redmond, WA, USA) was the most commonly employed technology. Four studies used some or all games in the *Wii Sports* package with the associated handheld remotes [15, 20, 25, 27], while five studies used the balance, fitness and strength games in the *Wii Fit* package with the accompanying *Wii* balance board [16, 17, 19, 22, 24]. Other gaming systems employed were the *Dancetown* dance mat™ (Cobalt Flux, Inc., Salt Lake City, UT, USA) and gesture recognition systems developed for the Sony Playstation® II *EyeToy* (Sony Computer Entertainment, Foster City, CA, USA) and the GestureTek IREX videocapture system™ (Toronto, ON, Canada) [14, 18, 23, 26]. Virtual cueing spectacles (Human

Interface Technology Laboratory, University of Washington, Seattle, WA, USA and HMD Therapeutics, San Anselmo, CA, USA) were employed to improve walking in the final study [26].

Supplementary data are available in *Age and Ageing* online, Appendix Table S1 provide a summary of the target and recorded dosage (where available) of technology use. Target sessions varied from 20 to 75 min in length, one to five times per week for durations of 10 days to 3 months.

Feasibility of gaming and virtual reality technologies

Results for the effectiveness and feasibility of VR/gaming used to enable physical activity in a home setting to address impairments, activity limitations, and personal factors are provided in Supplementary data are available in *Age and Ageing* online, Appendix Table S3.

Feasibility was generally poorly described in the reviewed studies. Many studies provided limited information about participant recruitment, retention or adherence to the study protocol. Where reported, 37% of screened individuals were enrolled in the studies, retention varied from 70 to 100% and adherence varied from 63 to 100%. Training was conducted through orientation sessions, user manuals or supervised sessions at the beginning of half of the reviewed studies, to familiarise the participants with the set-up and use of the gaming/VR technology [14, 17, 20, 22–24]. Many studies indicated that standby assistance and monitoring was required to assure safety, at least initially, during the VR/gaming activities [14, 20, 23], and home visits were needed to assess and progress participants [17]. Many studies reported that the participants enjoyed the VR/gaming activity [16–18, 20, 24, 25]; however, none described the take up of the technology post-study. Safety concerns were identified in three studies. Four participants withdrew complaining of lower extremity, weight bearing pain when they played *Dancetown* [21]. Minor musculoskeletal pain was associated with using the Nintendo™ *Wii* gaming technologies, but participants did not withdraw from these studies [17, 20]. Modifications of *Wii Fit* Balance Board activities, including the use of supports, were necessary to accommodate participants with poor balance [17]. Only one study described the cost of the VR/gaming technology [18].

Effectiveness of gaming and virtual reality technologies

Quality assessment

As most studies in this review were pilot or feasibility studies employing case series or comparative study designs, their methodological quality scores were relatively low, with a median (IQR) of 13 (2) out a total score of 27. Insufficient detail was provided by many studies regarding sampling methodology and recruitment, principle confounders, and adverse events. Some comparative group studies, including one of the two RCTs [14] reported within-group comparisons only, and statistical significance was reported without change scores or effect sizes. Therefore, the results presented are derived from relatively weak supporting evidence.

Activity limitations and participation. While no studies evaluated the effectiveness of physical activity associated with VR/gaming in addressing participation restrictions; balance and walking activities were the focus of many studies. The majority of these employed weaker NHMRC Level IV case series designs (Supplementary data are available in *Age and Ageing* online, Appendix Tables S1 and S3). In healthy older individuals improvements in balance, including Berg Balance Scale performance (mean change scores beyond the 95% confidence interval for minimal detectable change [28]) [16, 17], single leg stance time [19] and Community Balance and Mobility scale (CBM) scores [24] were reported following Nintendo™ *Wii Fit* use 20–40 min, two to three times/week over 6–10 weeks. Improvements in self-perceived balance efficacy on the Activities-specific Balance scale and overall mobility on the Timed Up and Go (TUG) following VR/gaming use were inconsistent between studies [19, 21, 24]. Similarly, weak evidence (NHMRC Levels IV and III.2) was found for balance and walking performance improvements following VR/gaming use in a home setting by people with neurological conditions (Supplementary data are available in *Age and Ageing* online, Appendix Table S3). In individuals with Parkinson's disease 4–6 weeks of Nintendo™ *Wii Fit* balance board use was associated with significant improvements in TUG times, CBM and Tinetti's Performance-Oriented Mobility Assessment scores [24]. However, the median reduction in TUG time was less than the mean detectable change established specific to this population [29]. Two case studies/series reported improvements in Dynamic Gait Index in an individual following stroke [18] and walking distance over 12 min in participants with developmental disabilities [23] following 4–6 weeks of Sony Playstation® II *EyeToy* use.

Physical body functions or impairments. Four studies examined the effects of physical activity associated with VR/gaming on body functions or physical impairments. One of the two reviewed RCTs reported reduced resting heart rate in individuals with developmental disabilities following an 8-week fitness programme using the GestureTek IREX video capture VR system™ [14]. However, within- but not between-groups statistical comparisons were reported in this study. Between-groups comparisons were reported in a quasi-experimental design study, finding improved quadriceps strength in older participants compared with inactive controls after 6 weeks of Nintendo™ *Wii* use for 20–30 min, 2–3 days/week [27]. A similar intensity of Nintendo™ *Wii* use over 10 weeks was associated with reduced fatigue on the Fatigue Severity Scale, weight and waist circumference in a case series of individuals with systemic lupus erythematosus [22]. Finally, a case series found the use of virtual cueing spectacles did not consistently reduce the frequency of gait freezing episodes in participants with Parkinson's disease [26].

Cognitive and emotional well-being. Three relatively low-quality studies investigated the use of VR/gaming by older adults to improve cognitive and emotional well-being in Kahlbaugh *et al.* [15, 20, 25] (Supplementary data are available in *Age and Ageing* online, Appendix Table S3). The second of two RCT studies in this review reported improvements in loneliness (UCLA Loneliness Scale), but not mood, in participants from an independent living facility who engaged in a 10-week program of playing Nintendo™ *Wii* bowling once/week with a companion, compared with watching television with a companion [15]. A comparative study with concurrent controls, using a similar programme of Nintendo™ *Wii* bowling game play, reported no between-group differences in perceived social support or quality of life [25]. In contrast, weaker evidence from a case series was found supporting improved mood and quality of life following a 12-week period of Nintendo™ *Wii* use by older individuals in a retirement village [20].

Discussion

Previous systematic and narrative reviews have not focused on the application of VR/gaming systems specific to a home setting. This is an important distinction, given the intended applications to facilitate independent physical activity recommended for successful, healthy ageing and intensive, goal-oriented repetitive practice for rehabilitative purposes in clinical populations [1, 3]. The findings of this systematic review indicate that evidence to date supporting the feasibility and effectiveness of VR/gaming systems undertaken for enabling physical activity in a home setting to address impairments, activity limitations and participation in people aged over 45 years old is relatively weak with a high risk of bias in this emerging area, and, therefore, insufficient to provide sound recommendations for clinical practice. The findings of this review may be used in planning future studies.

This review identified a number of feasibility issues. There was inconsistent reporting of recruitment, retention, the target and recorded dosage of exercises, adherence, training, assistance, safety, cost, acceptability and take up of the technologies, despite their importance in implementing the technologies safely and effectively in a home setting. In studies where recruitment was thoroughly described, a comparatively small percentage of participants met the screening criteria, potentially reflecting the higher level of function required to undertake the gaming activities safely at home. Relatively strong retention and adherence rates were reported, consistent with previous reviews highlighting the potential benefits of the engaging and motivating elements of VR/game-based activities [3, 4]; nonetheless, none of the studies discussed carryover of physical activity through take up of VR/gaming following completion of the studies. Training and assistance was required, at least initially, for participants to use the technologies. Safety concerns associated with monitoring vital signs and preventing falls and the aggravation of musculoskeletal symptoms were reported in some studies, highlighting the importance of considering and monitoring safety with the implementation of VR/gaming in a home setting. Finally, the technology costs were discussed in only one study. While commercially available gaming systems are relatively modest in cost, accessibility of these technologies coupled with appropriate viewing platforms (e.g. televisions) for those with limited incomes is also an important consideration for implementation. Future studies should carefully explore these important feasibility issues.

The effects of physical activity associated with VR/gaming on balance and walking activities, physical body functions and impairments and cognitive and emotional well-being have been investigated in older people and individuals with neurological conditions. However, as most studies employed case series or comparative study designs, these findings are at high risk of bias. While the evidence is insufficient to make clinical recommendations, changes reported in muscle strength and fitness, balance, gait speed and performance of more complex mobility activities may assist in establishing sample size requirements and potential effect sizes for future investigations [14, 16–19, 21, 24]. The results of one reviewed RCT provide stronger preliminary support for the potential benefits of playing weekly VR/gaming activities with others to reduce loneliness in individuals living in supported care communities. Exercise is known to be associated with improved mood in older adults [30]; the social engagement of playing games with others may provide additive benefits for emotional well-being. There is a need for high-quality research incorporating strong research designs in this area.

There are several limitations to the current review. Reviewed studies were limited to those published in English and applications of technologies in a home environment. Given the focus on physical activity associated with VR/gaming use, studies in which VR/gaming was used for specific purposes of cognitive retraining or regaining isolated hand dexterity were not included. Separate analyses were undertaken to review evidence for the use of robotics [10] and the use of smart-home technologies in home environments [9]. Finally, VR/gaming technologies are a rapidly evolving field. The Sony Playstation® II *EyeToy* discussed in this review has since been superseded by the PlayStation® *Move* and X-Box™ *Kinect* (Microsoft X, Redmond, WA, USA) incorporating more sophisticated motion sensing devices. Future studies are likely to utilise these newer systems.

Conclusions

While potentially an important preventative measure against disease and disability, the existing evidence to support the feasibility and effectiveness of VR/gaming systems use by older adults at home to enable physical activity to address impairments, activity limitations and participation is weak with a high risk of bias. The findings of this review may inform future, more rigorous research and therapies directed towards individual goals.

Key points

- The current evidence for the effectiveness of home-based VR/gaming for improving health-related domains in older adults is relatively weak with a high risk of bias and therefore insufficient to provide sound recommendations for clinical practice.
- Feasibility was inconsistently reported. Where addressed, strong retention and adherence with exercise, and the need for assistance, training and monitoring to ensure safety was identified.
- Future studies should not only address the effectiveness of VR/gaming exercise programs for particular older populations, but also the feasibility issues specific to the implementation in a home environment using more rigorous research designs.

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Conflicts of interest

None declared.

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Supplementary data

Supplementary data mentioned in the text is available to subscribers in *Age and Ageing* online.

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