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Exergames for Motor Rehabilitation in Older Adults: An Umbrella Review

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Abstract

Background: Exergames have been used as an innovative motor rehabilitation method with the main aim of improving motivation and exercise. As research interest in exergaming for rehabilitation is rapidly growing, a review of existing systematic reviews is important to synthesize the available evidence and provide recommendations.

Objectives: In this article we systematically synthesized the information from reviews that have examined the effects of exergames on different body movement parameters in older adults with and without specific pathologies.

Method: Searches were conducted in Web of Science, Scopus, PsycARTICLES, PsycINFO, Psychology and Behavioural Sciences Collection, PubMed, SciELO, B-On and Google Scholar, articulating different terms and Boolean operators. Systematic reviews, meta-analysis and literature reviews published until May 2017 that investigated exergame interventions on physical outcomes, such as balance, gait, limb movements, muscle strength, in healthy and non-healthy older adults.

Results: Based on prior reviews, exergaming, as a standalone intervention, has a positive effect on balance, gait, muscle strength, upper limb function, and dexterity. When compared to traditional physiotherapy, exergaming has at least similar effects on these outcomes. Many of the investigated studies indicated low methodological quality for the evaluation of the effects of exergames on different outcomes related to motor rehabilitation.

Conclusions: Exergames could be used as a complement to traditional forms of motor rehabilitation, but future individual studies and reviews should follow more rigorous methodological standards in order to improve the quality of the evidence and provide guidelines for the use of exergames in motor rehabilitation.

Keywords: Motor Rehabilitation, Virtual Reality, Exergame, Older Adults

Word Count: 4784

Introduction

Regular physical activity has been suggested by the World Health Organization [1] as a preventive measure against disease and disability in older adults. Exergames (or active video games), which require physical activity beyond conventional hand-controlled games [2], have been suggested as an alternative or as a complementary tool to traditional physiotherapy or rehabilitation [3], providing new and engaging ways to improve physical condition, motivation and adherence to exercise [4,5]. Outcomes such as balance control [6–8], fall risk reduction [9,10], muscle strength [11] and gait [12,13] have been shown to improve after exercise with exergames. Moreover, many studies have not identified any negative effects of exergames [14]. Given the increasing interest in exergames and its applications for disease prevention and health promotion, many reviews published over the last decade have summarized the data regarding the impact of exergames on physical and cognitive functions, in healthy and clinical populations.

Given the substantial number of systematic reviews and meta-analysis that investigated the impact of exergames on different rehabilitation outcomes, a synthesis of their findings is important to inform about the available evidence on this topic, which may provide relevant information to decision-makers, physiotherapists, clinicians and system designers. Thus, using an Umbrella Review approach, our present work aims (i) to systematically synthesize the impact of exergame use on motor rehabilitation outcomes in older populations physiological parameters (i.e. balance, gait, muscle strength, upper limb function and dexterity); (ii) to synthesize the information about the methodology used and limitations; and (iii) to provide recommendations related to exergaming in older adults.

Material and Methods

A protocol for the present review was accepted in the PROSPERO platform (CRD42017059788) on March 28th, 2017. The Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 statement [15] guided the redaction of this review.

Data Sources and Searches

The main electronic databases searched were the Web of Science, Scopus, PsycARTICLES, PsycINFO, Psychology and Behavioural Sciences Collection, PubMed, SciELO, B-On, Google Scholar, Cochrane Library, and the Centre for Reviews and Dissemination database.

Searches in the databases were carried out in March 2017. Different terms related to the topics under investigation were used, using the Boolean operators “AND” or “OR”. The terms used were as follows: (*Gam* OR Virtual Reality OR Kinect) AND (Rehabilitation OR Physiotherapy OR Physical Therapy OR Kinesiotherapy) AND (Review OR Meta) AND/OR (Elder* OR Old*). The searches were performed using the same or a combination of the field tags “title”, “abstract”, “topics/subject”, “all text”, “all fields” for the keywords mentioned before. Manual searches in Google Scholar were conducted, as well as chain searching for other reviews through the citations of the reviews considered.

Study Selection

Following the PICO framework (Participants, Interventions, Comparators and Outcomes), the inclusion criteria for reviews to be considered were as follows: systematic reviews, meta-analyses and/or scoping reviews which have assessed the use of any single or combined exergames (Intervention); in a standalone condition or compared to a passive control or traditional physiotherapy (Comparators); to exclusively promote motor rehabilitation (Outcomes); in older adults over 60 years old,

regardless of the participant's health status (Participants). Additionally, only peer-reviewed articles published in English, Portuguese or Spanish published between January 2000 and May 2017 were considered. Reviews were excluded according to the following criteria: Reviews considering adults under 60 years old (Participants), interventions conducted without exergames (Intervention) and outcomes not exclusively related to motor rehabilitation (i.e. dual-task, cognitive rehabilitation). Specifically, findings on fall risk reduction were not considered since this outcome encompasses cognitive aspects that do not pertain to the scope of this review (Outcomes). In addition, articles published in languages other than English, Portuguese or Spanish were not considered.

Data Extraction and Quality Assessment

The collected articles were stored and managed through the reference managers *Mendeley* and *EndNote Web*. Microsoft Excel[®] and Word[®] forms were created containing an index of all the references collected by the database searched.

After collecting all the references, screening for the adequate reviews was performed independently by three reviewers: ER, GP, and LT. Articles were coded as adequate, inadequate, or needing further analysis, in each step of the selection process. The search results were screened in three levels: (1) title, (2) abstract, and (3) full-text. The articles coded as adequate and those requiring further analysis were screened in the following phase. After this process, the reviewers settled any disagreements, through a systematic consultation of the eligibility criteria. Only the articles considered adequate by all reviewers were then selected. The data extraction process was performed by ER and GP, and a form was created containing detailed information for each article.

The Assessment of Multiple Systematic Reviews (AMSTAR) measurement tool [16] was used to assess the methodological quality of the reviews. The AMSTAR

characterises quality in three levels: low (0 to 3), medium (4 to 7), and high (8 to 11). Two independent reviewers, ER and LT, evaluated the adequacy of the reviews and provided a final score. Discrepancies between the reviewer were settled by thoroughly consulting the reviews' characteristics and the AMSTAR assessment criteria. A final score was then attributed to each review. Five reviews did not meet the minimum requirements to be evaluated by the AMSTAR tool, and therefore no methodological score is presented for them.

Data Synthesis and Analysis

The considered reviews were analysed by taking into consideration the type of review in question, as well as the participants' and intervention characteristics. Additionally, each review's findings on motor rehabilitation outcomes were categorized using a classification system that included the following criteria: motor rehabilitation outcome (i.e. balance, gait, and muscle strength), intervention type (exergame only, or exergame combined with alternative condition), the participants' health status, injury or pathology, and exergame type.

Results

Review Selection, Quality Assessment and Characteristics

Search results. The Flow diagram presents the structure of the selection process following the PRISMA-P guidelines (Figure 1). The search in all databases yielded 1028 articles, with manual search retrieving an additional six articles. After crosschecking this list in *Mendeley* and *EndNote Web*, 71 duplicates were removed. Thus, 957 articles were screened by Title and Abstract, resulting in a list of 49 articles to be considered for full-text assessment. These 49 articles were thoroughly reviewed and screened against the eligibility criteria. A final list of 26 articles was considered for synthesis in the present review (see Table 1 for an Overview of the Included Reviews).

Methodological quality. Based on the AMSTAR [16] criteria, the mean review score was 4 ($Min = 1$; $Max = 7$). These results indicate low to medium methodological quality of the reviews selected, suggesting limitations of the findings reported (see Table 2 for an overview).

Intervention Protocols. Intervention duration ranged from 1 to 24 weeks, with 6 weeks or 12 weeks intervention being the most frequently reported. The average duration of the reported interventions was 8.42 ± 4.37 weeks, a value similar to those calculated in one previous review ($M = 8.2 \pm 4.7$ weeks [17]). By eliminating outliers (one qualitative 1-year study using Wii console [18]) the average value dropped to 5.43 ± 2.08 weeks. Most reports indicate 10-12 sessions of exergame per study ($M = 16.76 \pm 11.00$). The sessions were mainly 2-3 per week, each session lasted an average 34.63 ± 15.14 minutes (the majority were 30 minutes, ranging from 9 to 130 minutes). The total average time spent by participants in exergames was lower (707.08 ± 428.64 versus 1145 ± 547.5 minutes) than those reported in a previous review [19], even after eliminating outliers. Inclusion of only seven randomized controlled trials in [19] can explain the difference on training volume obtained in our review. Regarding participant follow-up, only six studies were identified [17], four of which applied a post-test at less than 6 weeks [7,20–22], another at six months [23] and lastly one at nine months post initial assessment [9]. Concerning the exergames, only one of the 26 reviews did not investigate the effects of the Nintendo Wii and the Wii Balance Board. Among the remaining reviews, most used either Dance Dance Revolution (an interactive dance mat), the Playstation EyeToy, or the Microsoft Kinect (both camera sensors) (Figure 2 presents the frequency of reviews by exergame type).

Outcomes and Interventions Effects

A summary of the findings is presented below, considering the intervention type (exergame only, or exergame combined with alternative condition), participants' health status and injury/pathology and the exergame type.

Balance. Regarding exergame-only interventions in older adults, without pathologies, improvements were reported on static and dynamic balance, standing ability and postural sway [24–33]. For older adults with pathologies in which one of the symptoms was impaired balance, the quality of evidence indicating improvements in balance was weak to moderate [14,31,32,34,35]. One review identified no negative impacts of the exergaming intervention [14]. Comparisons between exergaming interventions and alternative conditions in older adults without pathologies indicated that static and dynamic balance were slightly improved, or at least comparable with traditional exercise therapy, and significantly improved when compared to an inactive control condition when using the Nintendo Wii and/or its accessory the Nintendo Wii Balance Board [14,19,33,36–40]. Similarly to the effects found for the Nintendo Wii, most reviews also indicated that exergames (unspecified type) provide small or comparable improvements to traditional exercise therapy and inactive control conditions in older adults without specific pathologies [25,27,41,42]. Nevertheless, the data from one review highlights the limited validity of the evidence [24]. The data from two other reviews indicate that a combined intervention with exergames and traditional exercise was more effective than an intervention that just used exergames [28,43]. However, in one review two studies have been identified, in which no significant improvements or even worse results were reported for the exergame intervention when compared to traditional exercise [44]. The findings concerning exergame interventions in older adults with specific pathologies indicate that improvements in static and dynamic balance in comparison to an inactive control condition were found in individuals suffering from

stroke, multiple sclerosis and idiopathic Parkinson's disease [14,24,32,34,36,44]. When compared to traditional exercise for balance improvement, one review reported equal or augmented improvement in balance produced by exergames, even when the samples of analysed studies included both healthy and non-healthy older adults [17].

Gait. The evidence related to the exergames effects on gait is not as strong as those related to balance improvement. In standalone use of exergames as intervention for older adults without specific pathologies, the gait speed was improved [24,30]. In many studies with older adults having specific pathologies, the gait, walking speed and walking ability, were improved [31,32]. A review found weak evidence for improvements in walking performance [31]. In comparison with alternative therapies the exergames produced significant improvements in stepping executions in older adults without specific pathologies when compared to inactive control conditions [41] and small or similar effects when comparing to traditional exercise [26,42]. Increase in different walking parameters were also found [25,27]. Regarding older adults with specific pathologies, improvements were reported in gait not only when data on exergame intervention was reported, but also when the effect of exergames was compared with traditional exercise, or when intervention included exergames in conjunction with traditional exercise [24,26,44]. Increases were found in walking speed and walking ability when exergames were compared with an alternative condition in older adults [32]. Evidence regarding the effects of exergaming on different parameters of gait in samples of older adults with and without specific pathologies remains inconsistent [17,43].

Muscle Strength. In comparison with traditional exercise therapy, the impact of exergames on muscle strength was generally stronger in both healthy and in non-healthy older adults. When using an exergame only intervention, improvements in hand and

lower limb strength were found in older adults without specific pathologies [27,33]. Increases in muscle and hand grip strength were also reported in older adults with specific pathologies receiving exergames intervention [29,34]. Comparison of exergames intervention with passive control condition have shown improvements in lower limb strength and overall muscle strength for older adults, without [25,31,33,40,42] and with pathologies [24,36], respectively.

Upper Limbs. Although an increase in motor function in older adults with pathologies was reported [32,34,35] with exergaming-only interventions, no significant differences in range of motion was identified [45]. When comparing the exergaming intervention with traditional exercise therapy improvements in arm motion were found for older adults suffering from traumatic brain injury [33]. Stroke survivors using exergames reported improved arm speed, range of motion, force and decreased spasticity [36,45].

Dexterity. Improvements in finger range of motion, flexion speed, independence of finger motion, and hand function were reported in stroke survivors when using an exergames-only intervention [35,36].

Discussion

The impact of the use of exergames on health outcomes such as balance, gait, muscle strength, upper limb function and dexterity, in older adults with and without specific pathologies was investigated. We reviewed several meta-analyses, scoping and systematic reviews that met the eligibility criteria. Our findings were extracted from 26 reviews and categorized according to five motor-rehabilitation outcomes: balance, gait, muscle strength, upper limbs, and dexterity. Exergaming interventions used different devices, some non-commercial but most of them commercially available, with the Nintendo Wii being the most used, followed by the Dance Dance Revolution and

Playstation Eyetoy. Most exergaming interventions were considered effective in improving balance-related outcomes, and at least as effective as traditional exercise therapy, with only two reviews indicating a negative effect of exergame use. Positive effects on gait, muscle strength, upper limbs functionality and dexterity-related outcomes were also reported as most reviews identified an improvement following exergaming intervention, even when compared to traditional exercise therapy. Nevertheless, most of these findings are derived from low to medium quality evidence. Our analysis, using a standardized evaluation tool to measure the quality of evidence, identified different methodological limitations in a considerable number of studies.

Exergaming may be used as standalone intervention, or in conjunction with other physiotherapy interventions, to promote physical activity in older adults as a preventive measure against disease and disability [1]. Furthermore, our findings suggest that these technologies may be used as a complement to traditional forms of motor rehabilitation, but it cannot be assumed at this point that physiotherapy based solely on exergames is the solution for a complete and effective recovery. Compared with traditional exercise, exergaming interventions resulted in overall positive improvements in physical outcomes. However, in some studies the effect of exergames was not clearly demonstrated, since participants who underwent training with exergames also received physical training before or after the exergaming session. A combined intervention in which traditional physiotherapy is complemented with exergames seems to be more effective than each type separately and can have different impact depending on the health status of the elders. Tailored exercise routines, using adequate exergames and sensor devices that provide objective information on physiological parameters changes, should take the needs of the aged population into consideration to provide relevant physiological and performance metrics.

Since exergames are commonly seen as fun and motivating, these tools may be used to improve adherence to physical exercise [4,5]. Moreover, exergaming can be used in a home setting, played with friends or family [31]. The social interaction that game activities can provide has also been mentioned as a positive side-effect of exergaming [17,36,43]. Furthermore, these systems are relatively inexpensive (usually between \$100 and \$300) when compared with physical rehabilitation devices like force plates (\$6500), the Balance Master system (\$50,000), or the EquiTest (\$100,000) [29]. Tests on feasibility have generally shown that devices such as the Nintendo Wii Balance Board and the Microsoft Kinect have similar accuracy compared to more expensive alternatives when measuring centre-of-pressure (COP) and gross movements. However, further studies using low-cost measurement equipment for exergames are required to evaluate their accuracy during the performance of movements in different environments (e.g. measurement of different hand-arm angles using a Kinect device with different body postures).

Several drawbacks of systems for exergaming were also identified. Most commercially available gaming systems, like the Nintendo Wii or Dance Dance Revolution, do not allow for tailored and outcome specific exercise routines that fit patients' needs, which is often cited as a limitation to the rehabilitation process [43]. Furthermore, these commercially available exergames have interfaces, graphical representations and gameplay mechanics that are difficult for older people to understand and operate [17]. Consequently, some authors reported that older participants tend to drop out of exergaming experiences due to a lack of interest [46,47]. Exergame interventions developed for physical rehabilitation that consider the specific needs and functionalities of the individual, and that have the capacity to gradually adapt to the patients' requirements have greater chances of being effective [25].

Limitations

Several limitations must be acknowledged, which are related to: 1) the methodology chosen by the present review; 2) the methods and related findings of the analyzed papers; and 3) the limitations identified by the authors of the analyzed reviews.

The present study has included in the analysis only peer-reviewed full-texts, in English and Portuguese language publications, even though other publications in other languages may be available on the topic. Only outcomes related to balance, gait, muscle strength, upper limbs and dexterity were included but many other outcomes might be relevant for a comprehensive understanding of the exergaming effects in older adults (i.e., prevention and/or reduction of falls, improvements in cognitive functions, mood or quality of life). Heterogeneity in studied populations, heterogeneity in methods and findings in the analyzed reviews and heterogeneity of the estimated effects of exergaming in the analyzed outcomes prevented us from detecting significant differences produced by exergaming in older adults. The variety of technologies used, and intervention protocols also limits the ability to identify which game or technology, or which features of those games or technologies, are more useful for physical activity improvement in older adults.

Considering the nature of the reviews that synthesized the findings of other reviews on similar topics [48], the number of references that were cited across the different reviews was calculated. Of all the individual studies each review assessed, close to 42% of the individual studies were cited in at least two or more reviews. This percentage is a characteristic inherent to this type of review, although it has the advantage of comparing the consistency of data reporting between reviews, and summarizing their findings.

The reviews analysed in this paper had their own limitations. One limitation of the majority of the analyzed studies is the lack of clear differentiation between the outcomes measured during game play and those outside the game environment, defined by van Diest et al. [27] as internal and external outcome parameters. Eight out of 26 reviews presented some technical or technological problems that potentially affected the precision and consistency of the results related to internal or external outcome parameters (see Supplementary File), with half of these studies presenting problems related with accuracy of internal outcome parameters, such of the Nintendo Wii Fit center of pressure estimation or Microsoft Kinect motion estimation of shoulders or fingers. Moreover, the reviews analyzed do not clearly categorize the results of the analyzed studies for better understanding of evidence quality.

Another limitation is related to the instruments employed. Several reviews have used the PEDro scale [49] (7 out of 15 reviews), as an instrument for the analysis of risk of bias, and 11 of all analyzed reviews did not use any instrument for quality assessment (Table 2). The PEDro scale [49] is mainly used to analyze the quality of the reports on the physiotherapeutic interventions. Considering that many studies present data on the feasibility of the technologies for exergaming, more complex methods should be used. For instance, accuracy, sensitivity and reliability of the measurements included in the games should be considered, as well as the participation rate in different possible settings, the extent to which the intervention was delivered as intended, and the adaptation made. Other factors such as time and cost of intervention, impact of attrition on outcomes, the long-term effects of intervention, sustained delivery and modification of intervention should be contemplated. GRADE (Grading of Recommendations Assessment, Development and Evaluation) [50] and RE-AIM (Reach, Effectiveness, Adoption, Implementation and Maintenance) [51] guidelines should be adopted for

comprehensive and standardized reporting on quality of evidence related to exergaming. The QUADAS instrument [52] or STARD statement for reporting diagnostic accuracy studies [53,54] may be more adequate for study design and results report.

By using the GRADE guidelines, we organized the limitations presented by reviews in limitations related to study design and/or execution, imprecision and inconsistency of the results, publication bias and characteristics of technologies (see Supplementary File). The summarized data on limitations suggests that future studies should continue studying the effectiveness of exergaming, by comparing it with an alternative intervention and no intervention, and by improving the methodology. The instruments used to evaluate the effects of exergaming in postural control in older adults have also shown ceiling or floor effects which are not reliable to detect small changes in balance (see Supplementary File). Additionally, some design protocols did not allow clear differentiation of influence of learning or cognitive functions induced by exergaming on motor functions. Few data are related to the validation and accuracy of measurements executed by technologies of exergaming, in studies with population of older adult as participants. Moreover, methodological limitations do not allow the objective description of how game features may influence exergaming effectiveness in older adults, the dose-response relationship or specific components and parameters of exergaming in various contexts (i.e., in home or healthcare institutions).

Recommendations

The use of exergaming will likely play an important role in the future of the treatment and training of elderly people regardless of disability status. The present review may have implications for practice by showing the benefits of exergaming in motor rehabilitation context (see Table 3 for a summary). However, due to low to

moderate methodological quality of the analyzed studies only general recommendations can be presented.

Primary and secondary outcomes delineation. Research related to exergames for older adults should be initiated by designing primary and secondary outcomes: the short and long-term achievable goals. Meaningful outcomes for patients and clinicians should be clearly stated at the beginning of the research and in the research reports. In particular the evaluation of the exergaming effectiveness for motor rehabilitation should be in line with the International Classification of Functioning, Disability and Health [55]. This classification scheme requires the outcome measure to include those related to body functions and structures, and activity, participation and social determinants. The use of more sensitive and construct specific outcome measures, along with the overall outcome measures, would be valuable to determine the underlying mechanism through which exergames produce their individual effects. In-game score improvements or player experience should not be outcomes but potentially be analyzed as moderators.

Target behaviors description. The analyzed reviews indicate that there is no compelling evidence of an optimal exercise type, duration or intensity. Research planning and reports should include information on what movements users should do (i.e., type, intensity and frequency) and how to measure it (i.e., what user performance metrics should be collected, and which sensors or devices will provide the data). In designing exergaming or analyzing studies related to exergaming effectiveness for older adults, it is necessary to select appropriate movements or activities that offer meaningful and motivating exercise contexts for older subjects. In particular, theoretical frameworks for behavioral change (e.g., theory of reasoned action, theory of planned behavior, Fogg Behavior Model, self-efficacy, social learning and social cognitive theories) [56] should be considered when planning exergame intervention for motor

rehabilitation. Exergaming activities should be planned and examined considering the optimal putative transfer to real-world functional improvements. The results should emphasize how activity training using exergaming translates into activity performance in the real world. The metrics should also be used to adapt the intervention dose for the different rehabilitation purposes depending on health status, the stage of the disease or type of disability, combining challenges and support in the intervention.

Subjects, protocols and instruments. Among older adults with specific diseases and/or impairments, there is insufficient data for a comprehensive understanding of the effects of exergames on age, gender or baseline activity-level subgroups. In addition, little information is available concerning exergames use on very frail older adults, or those presenting loss of functional independence. Many studies only present feasibility and proof of concept details. Randomized controlled trials using sound methodological designs are necessary to evaluate exergaming effectiveness for older people. Power analysis should be conducted to estimate the optimal sample size for a planned study protocol. The methodological design must also describe the safeguards, the ease of use and accessibility conditions of the interventions, and consider long-term motivation and adherence to exergaming. Furthermore, it is necessary to be explicit in delineating the purpose and the use of any potential piece of technology. Detailed protocol description (e.g., length of each game session, frequency of administration, associated activities) and robust measurements, which take into account confounding variables, should be considered to increase the level of evidence related to exergaming impact on motor rehabilitation. Various instruments used for outcome measurements (in some cases, inadequate for the proposed measurements) suggest the need of guidelines and protocol standardization regarding proper use of instruments for each motor rehabilitation goal. For a better understanding of the rehabilitation benefits using exergaming, study

protocols should also include information about user experience, usability measurements in either a summative evaluation (e.g., metrics related to the elements of the game that facilitate high user engagement in the short and long term such as the ease in which the game can be understood, learned, used, and general attractiveness when used under specified conditions) or a formative evaluation (e.g., detection of usability problems; design of interventions to reduce or eliminate the impact of these usability limitations) [57].

Technology characterization. It is important to investigate which games are tailored specifically to older adults and which provide personalized exercises based on each individual's needs. Several guidelines for the development of accessible, traditional computer games for people with physical and non-physical disabilities have been previously compiled [58–60]. These guidelines are the product of experts in game design and accessibility standards. There are specific issues related to game design for older adults, in particular for those having motor disabilities. Additionally, data from user experience or usability studies of mobile technologies for older people should also be considered. Furthermore, the effectiveness of including social networking in exergaming interventions for various populations of older adults should be more comprehensively investigated. There are studies suggesting that older adults prefer to exercise alone rather than in group-based settings in which participants have significant age differences [61] or different fitness levels [62].

Policy recommendation. One potential advantage of older people using exergaming may be an increased accessibility to care and preventive health programs as the technologies for exergaming are generally low-cost, may be used without active supervision by healthcare professionals, permit remote communication between health professionals and users, and may be used in the home environment or in a group setting.

However, these interventions are generally not included in any reimbursement models, and many health systems lack the incentives for effective incorporation into clinical practice. Moreover, some studies suggest that increased co-option of technologies intended for the serious games into healthcare settings are dependent on various factors such as the role of digital, numeric and health literacy [63–65] as well as on health professionals' specialization [66]. It is also important to consider that interdisciplinary collaborations are key to better develop exergames and healthcare programs. The research process should be as transparent and accessible as possible, allowing for external researchers and stakeholders to consult game design protocols, research data, the exergames and their corresponding documentation. Sharing such information on platforms such as scientific repositories could provide new opportunities for feedback and collaborations that would benefit researchers and the end-user. Finally, policy makers and governments should support the creation of a sustainable knowledge ecosystems that will translate knowledge, provide tailored educational and training messages, and be alert for information that are of immediate relevance or benefit for large-scale implementation of exergames in healthcare programs.

Conclusions

The findings of the present Umbrella review suggest that exergames have a positive effect on balance, gait, muscle strength, upper limb functionality and dexterity outcomes in standalone interventions, with outcomes similar to traditional physiotherapy. However, these results should be interpreted in light of the low to moderate methodological quality of the studies included in the analyses and the high heterogeneity of populations, exergames and intervention types. Despite the limitations related to the methodological evaluation of exergames influence on body motor functions, exergaming has the potential to improve the recovery process of the patients,

the physiotherapists' workflow, and may be used as a complementary and tailored approach to traditional physiotherapy. Standardization of methodology for evaluating exergames effects in older adults is needed. Future studies should be conducted with methodological rigor to allow extrapolation of data and sound recommendations regarding the use of various exergame interventions for motor rehabilitation.

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Declaration of Interests

The authors declare no conflict of interest.

Biographical Notes

Eduardo Reis has a MSc. in Social and Organizational Psychology, and currently he is a PhD candidate in the Lisbon PhD in Social Psychology (LiSP). He has been involved in a project addressing the role of Virtual Reality-based Exergames for Physical Rehabilitation; currently, the goal of his PhD project is to investigate how intimate partner violence awareness campaigns can facilitate help-seeking among victimized men.

Gabriela Postolache is a researcher at the CBIOS, Universidade Lusófona and Telecommunications Institute. Her research focus on cardiovascular physiology and measurement instruments. She has collaborated in the development of several instruments and techniques for measuring vital signs and motor functions.

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Table 1. Overview of the included reviews

| Review | Aim | Exergames Investigated | Types of Interventions | Types of Studies Included | Nmber of Articles Included | Mean Number and Duration of Sessions (hrs) | Mean Number of Participants | Total Number of Participants | Main Outcomes |
|--|---|---|--|---|----------------------------|--|-----------------------------|------------------------------|--|
| Bleakley et al. (2015)[25] | Understand the physical and cognitive effects of interactive computer games on healthy older adults | Nintendo Wii Fit, Wii Balance Board, Cyber Walking, | Pre-post exergame only, exergame + control or traditional exercise | Observational, Controlled Trials and Randomized Controlled Trials | 12 | 18.66±11.09; 13.95±10.71 | 37.91±49.81 | 455 | Balance, Muscle Strength, Cognitive Function |
| Buck & Fink (2012) [29] | Investigate if the Wii is effective in decreasing fall risk in the elderly and to determine if it is comparable to other mechanical devices in assessing balance deficits | Nintendo Wii Fit and Wii Balance Board | Pre-post exergame only, exergame + control or traditional exercise | Case studies, Randomized Controlled Trials | 8 | 12±4.16; 6.42±2.81 | 15±10.63 | 120 | Fall Risk, Balance Control |
| Chao, Scherer & Montgomery (2015) [36] | Understand and summarize the impact of the Wii on physical function, cognition and psychosocial outcomes in older adults. | Nintendo Wii Fit and Wii Balance Board | Pre-post exergame only, exergame + control or traditional exercise | Case Studies, Controlled and Randomized Controlled Trials | 22 | 19.05±13.65; 11.91±8.06 | 22.04±14.02 | 551 | Balance, Fear of Falling, Upper Extremity Function, Cognitive function |
| Choi, Guo, Kang, & Xiong (2016) [24] | Synthesize the available research on exergame technology and interactive interventions for fall prevention in the older population. | Nintendo Wii Fit and Wii Balance Board, Microsoft Kinect, Dance Dance Revolution, SensBalance Board | Pre-post exergame only, exergame + control or traditional exercise | Quasi-experimental, Case study, Controlled and Randomized Controlled Trials | 25 | 19.92±12.03; 11.99±8.11 | 29.68±21.61 | 782 | Balance, Fall Prevention |
| Donath, Rossler & Faude (2016) [37] | Examine and classify the effects of exergames on fall-risk relevant balance performance and functional mobility in older adults without pathologies | Nintendo Wii Fit and Wii Balance Board, Dance Dance Revolution, Virtual Reality device | Exergame + control or traditional exercise | Controlled and Randomized Controlled Trials | 18 | 15.94±5.68; 11.22±6.29 | 32±10 | 619 | Standing Balance Performance, Functional Mobility |
| Goble, Cone & Fling (2014) [14] | Summarize the effects of Wii on balance outcomes, and provide insight into the system's use for the assessment and training of balance. | Nintendo Wii Fit and Wii Balance Board | Pre-post exergame only, Exergame + control or traditional exercise | Case study, Controlled and Randomized Controlled Trials | 19 | 18.16±12.45; 9.30±7.13 | 9.33±10.31 | 168 | Balance |

| Review | Aim | Exergames Investigated | Types of Interventions | Types of Studies Included | Number of Articles Included | Mean Number and Duration of Sessions (hrs) | Mean Number of Participants | Total Number of Participants | Main Outcomes |
|---|---|---|--|---|-----------------------------|--|-----------------------------|------------------------------|--|
| Harris, Rantalaine, Muthalib, Johnson & Teo (2015) [44] | Examine the effects of exergaming interventions on balance and postural control of older adults and people with idiopathic Parkinson's disease. | Nintendo Wii Fit and Wii Balance Board, Virtual Reality device | Exergame + control or traditional exercise | Randomized Controlled Trials | 11 | 15.27±5.78; 8.75±4.31 | 29.45±10.31 | 281 | Static and Dynamic Balance |
| Itakussu, Valenciano, Trelha & Marchiori (2015) [40] | Evaluate the effects of using the Wii on balance and functional capacity related outcomes of older adults. | Nintendo Wii Fit | Pre-post exergame only, Exergame + control or traditional exercise | Quasi-experimental, Controlled and Randomized Controlled Trials | 10 | 18.2±8.37; 10.52±7.98 | 23.8±16.45 | 238 | Static and Dynamic Balance, Functional Capacity, Muscle Strength |
| Kinne, Finch, Macken & Smoyer (2015) [38] | Evaluate the effectiveness of the Wii at improving balance in older adults without specific pathologies | Nintendo Wii Fit | Exergame + control or traditional exercise | Randomized Controlled Trials | 8 | 18.63±11.37; 13.06±8.62 | 34±21.65 | 272 | Postural Control |
| Klompstra, Jaarsma & Strömberg (2014) [30] | Investigate the feasibility and influence of exergames on physical activity in older adults | Nintendo Wii Fit, Wii Balance Board, CyberCycle, Cyber Walking IREX, Microsoft Kinect, Dance Dance Revolution, Playstation Eyetoy | Pre-post exergame only, Exergame + control or traditional exercise | Quasi-experimental, Controlled and Randomized Controlled Trials | 11 | 17.4±12.51; 12.94±7.90 | 32.3±21.06 | 323 | Balance, Cognitive function, Enjoyment, Quality of Life |
| Lange et al. (2010) [35] | Summarize and discuss approaches to improve independence in older adults using exergames and other technologies. | Nintendo Wii Fit, Cyberglove, Dance Dance Revolution, Playstation Eyetoy, GAME Wheels, GAMECycle | Pre-post exergame only, Exergame + control or traditional exercise | Quasi-experimental, Controlled Trials | 4 | 17.5±2.5; 17.5±2.5 | 6.25±5.80 | 25 | Balance, Sensorimotor and Cognitive Function, Dexterity |
| Larsen, Schou, Lund & Langberg (2013) [41] | Determine the effectiveness of exergames on validated quantitative physical outcomes in older adults without pathologies | Nintendo Wii Fit, Dance Dance Revolution, Cybercycle, Active Video Game | Exergame + control or traditional exercise | Randomized Controlled Trials | 7 | N/A | 41.14±16.29 | 288 | Balance Performance, Stepping Execution, Muscle Strength |

| Review | Aim | Exergames Investigated | Types of Interventions | Types of Studies Included | Number of Articles Included | Mean Number and Duration of Sessions (hrs) | Mean Number of Participants | Total Number of Participants | Main Outcomes |
|---|---|--|--|--|-----------------------------|--|-----------------------------|------------------------------|---|
| Laufer, Dar & Kodesh (2014) [19] | Determine the effects of Wii interventions on balance control and functional performance of older adults without specific pathologies | Nintendo Wii Fit and Wii Balance Board | Exergame + control or traditional exercise | Randomized Controlled Trials | 7 | 19.14±3.98; 19.08±9.1 | 40.71±8.73 | 285 | Balance Performance, Fitness, Muscle Strength |
| Lelard & Ahmaidi (2015) [28] | Review the effects of physical activity interventions on balance performance in older adults. | Nintendo Wii Balance Board | Pre-post exergame only | Controlled and Randomized Controlled Trials | 21 | 33.66±22.35; 33.77±31.58 | 34.57±43.75 | 726 | Balance, Muscle Strength |
| Miller et al. (2013) [31] | Summarize evidence on the effectiveness and feasibility of gaming systems utilisation by older adults at home to enable physical activity | Nintendo Wii Fit, IREX, Virtual Reality Device, Dance Dance Revolution, Playstation Eyetoy | Pre-post exergame only, Exergame + control or traditional exercise | Case Studies, Quasi-experimental, Controlled Trials and Randomized Controlled Trials | 14 | 19.64±9.03; 12.16±5.37 | 23.93±16.41 | 335 | Physical and Cognitive Function |
| Molina, Ricci, Moraes & Perracini (2014) [42] | Provide a summary of the effects of exergames in improving physical functioning in older adults | Nintendo Wii Fit and Wii Balance Board, Dance Dance Revolution | Exergame + control or traditional exercise | Randomized Controlled Trials | 13 | 16.42±6.16; 12.10±9.06 | 37.46±11.76 | 487 | Mobility, Posture Control, Muscle Strength, Reaction Time |
| Pichierri et al. (2011) [32] | Identify potentially promising methods that might be used in future intervention type studies in older adults. | Nintendo Wii Fit, Interactive Video Game, Virtual Reality Treadmill | Pre-post exergame only, Exergame + control or traditional exercise | Case Studies, Controlled Trials and Randomized Controlled Trials | 28 | 13.81±5.32; 9.81±5.81 | 27.93±23.13 | 782 | Physical and Cognitive Performance |
| Pietrzak, Cotea & Pullman (2014) [43] | Review the literature on the use of exergaming to prevent falls in older adults living in an assisted living community | Nintendo Wii Fit and Wii Balance Board, SensBalance Board, StepMania, Dancetown | Pre-post exergame only, Exergame + control or traditional exercise | Quasi-experimental, Controlled Trials and Randomized Controlled Trials | 21 | 18.26±9.54; 13.09±13.47 | 24.10±13.43 | 506 | Balance Control |

| Review | Aim | Exergames Investigated | Types of Interventions | Types of Studies Included | Number of Articles Included | Mean Number and Duration of Sessions (hrs) | Mean Number of Participants | Total Number of Participants | Main Outcomes |
|---|--|--|--|--|-----------------------------|--|-----------------------------|------------------------------|-------------------------------------|
| Ribeiro-Papa et al. (2016) [26] | Review the literature on motor learning with virtual reality use in older adults without specific pathologies | Nintendo Wii Fit, Cyber Walking | Exergame + control or traditional exercise | Quasi-experimental, Controlled Trial and Randomized Controlled Trial | 4 | 12.66±4.99; 7±7 | 33.5±7.43 | 134 | Motor Learning |
| Rodrigues, Valderramas, Rossetin & Gomes (2014) [67] | Evaluate the effects of exergaming on the musculoskeletal function of older adults without specific pathologies | Nintendo Wii Fit, Dance Dance Revolution, Playstation EyeToy | Exergame + control or traditional exercise | Quasi-experimental, Controlled Trial and Randomized Controlled Trials | 16 | N/A | 33.25±12.17 | 532 | Functional Mobility, Balance |
| Skjæret et al. (2016) [17] | Provide 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. | Nintendo Wii Fit, Playstation Eyetoy, Microsoft Kinect, Dance Dance Revolution | Pre-post exergame only, Exergame + control or traditional exercise | Case Studies, Quasi-experimental, Cohort Study, Controlled Trials and Randomized Controlled Trials | 60 | N/A | N/A | N/A | Physical Functions, Balance, Gait |
| Tahmosybat, Baker, Godfrey, Caplan & Barry (2017) [68] | Explore the outcome measures currently used to assess postural control in exergaming interventions targeting older adults without specific pathologies | Nintendo Wii Fit and Balance Board, Xavix Measured Step System, | Exergame + control or traditional exercise | Quasi-experimental and Randomized Controlled Trials | 12 | 18.25±9.45; 12.73±8.22 | 47.92±21.42 | 575 | Balance, Postural Control, Mobility |
| van Diest, Lamoth, Stegenga, Verkerke & Postema (2013) [27] | Review the effects of exergame training on postural control in older adults | Nintendo Wii Fit and Balance Board, Dance Mat, Interactive Video Game | Pre-post exergame only, Exergame + control or traditional exercise | Case Studies, Quasi-experimental, Cohort Study, Controlled Trials and Randomized Controlled Trials | 13 | 26.58±31.74; 10.88±12.86 | 18.85±16.04 | 245 | Postural Control, Balance |
| Webster & Celik (2014) [45] | Review Microsoft's Kinect applications in stroke rehabilitation of older adults. | Microsoft Kinect | Pre-post exergame only, Exergame + control or traditional exercise | Case Studies, Quasi-experimental, Controlled Trials and Randomized Controlled Trials | 48 | N/A | N/A | N/A | Balance, Gait, Fall Risk Reduction, |

| Review | Aim | Exergames Investigated | Types of Interventions | Types of Studies Included | Number of Articles Included | Mean Number and Duration of Sessions (hrs) | Mean Number of Participants | Total Number of Participants | Main Outcomes |
|-----------------------------------|--|--|--|---|-----------------------------|--|-----------------------------|------------------------------|--|
| Wiermeyer & Kliem (2012) [33] | Investigate the impact of serious games on prevention and rehabilitation of older adults. | Nintendo Wii Fit, Playstation EyeToy, Microsoft Kinect, Dance Dance Revolution | Pre-post exergame only, Exergame + control or traditional exercise | Case Studies, Quasi-experimental, Randomized Controlled Trials | 45 | 14.16±5.24; 4.16±3.12 | 17.4±13.65 | N/A | Physical Activity |
| Zeng, Pope, Lee & Gao (2017) [34] | Summarize findings and evaluate the effectiveness of exergames in improving physical, psychological and cognitive rehabilitative outcomes among older adults with chronic diseases | Nintendo Wii Fit and Balance Board, Playstation EyeToy, Microsoft Kinect | Pre-post exergame only, Exergame + control or traditional exercise | Case Studies, Quasi-experimental, Controlled and Randomized Controlled Trials | 19 | 16.21±14.03; 68.23±245.77 | 20.53±15.41 | 390 | Balance, Physical Functioning, Balance Confidence, Engagement, Quality of Life |

N/A = insufficient or not available data

Table 2. Assessing the Methodological Quality of Systematic Reviews (AMSTAR):
Criteria and sum of scores of the included reviews.

| Review and year | AMSTAR Criteria | | | | | | | | | | | Final Score |
|--|-----------------|---|---|---|---|---|--------|---|---|----|----|-------------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| Bleakley et al. (2015) [25] | 0 | 1 | 1 | 0 | 0 | 1 | 1(A) | 1 | 1 | 0 | 0 | 6 |
| Chao, Scherer & Montgomery (2015) [36] | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Choi et al. (2016) [24] | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Donath, Rössler & Faude (2016) [37] | 0 | 1 | 1 | 0 | 0 | 1 | 1(B) | 1 | 1 | 1 | 0 | 7 |
| Harris et al. (2015) [44] | 0 | 0 | 1 | 0 | 0 | 1 | 1(B) | 1 | 1 | 0 | 0 | 5 |
| Itakussu et al. (2015) [40] | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Kinne et al. (2015) [38] | 0 | 0 | 1 | 0 | 0 | 1 | 1(B) | 1 | 0 | 0 | 0 | 4 |
| Klompstra, Jaarsma & Strömberg (2014) [30] | 0 | 0 | 1 | 0 | 0 | 1 | 1(F) | 1 | 0 | 0 | 0 | 4 |
| Larsen et al. (2013) [41] | 0 | 0 | 1 | 0 | 0 | 1 | 1(A) | 1 | 0 | 0 | 0 | 4 |
| Laufer, Dar & Kodesh (2014) [19] | 0 | 1 | 1 | 0 | 0 | 1 | 1(B) | 1 | 1 | 0 | 0 | 6 |
| Miller et al. (2013) [31] | 0 | 1 | 0 | 0 | 0 | 1 | 1(A/C) | 1 | 1 | 0 | 0 | 5 |
| Molina et al. (2014) [42] | 0 | 0 | 1 | 0 | 0 | 1 | 1(B) | 1 | 0 | 0 | 0 | 4 |
| Pichierri et al. (2011) [32] | 0 | 0 | 1 | 0 | 0 | 1 | 1(C) | 1 | 0 | 0 | 0 | 4 |
| Pietrzak, Cotea & Pullman (2014) [43] | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| Ribeiro-Papa et al. (2016) [26] | 0 | 0 | 0 | 0 | 0 | 1 | 1(B) | 1 | 0 | 0 | 0 | 3 |
| Rodrigues et al. (2014) [67] | 0 | 1 | 0 | 0 | 0 | 1 | 1(D) | 1 | 1 | 0 | 0 | 5 |
| Skjaeret et al. (2016) [17] | 0 | 0 | 0 | 0 | 0 | 1 | 1(B) | 1 | 0 | 0 | 0 | 3 |
| Tahmosybayat et al. (2017) [68] | 0 | 0 | 1 | 0 | 0 | 1 | 1(E) | 1 | 1 | 0 | 0 | 5 |
| van Diest et al. (2013) [27] | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| Webster & Celik (2014) [45] | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Zeng et al. (2017) [34] | 0 | 1 | 1 | 0 | 0 | 1 | 1(G) | 1 | 1 | 0 | 0 | 6 |

Note. 1. A priori design; 2. Duplicate Study Selection and Data Extraction; 3. Comprehensive Literature Search; 4. Grey Literature; 5. List of Included and Excluded Studies; 6. Characteristics of Included Studies; 7. Methodological Quality Assessment (A. Cochrane Risk of Bias tool; B. PEDro scale; C. Downs and Black Quality Checklist D. JADDAD scale; E. Centre for Evidence-Based Medicine; F. Jovell & Navarro-Rubio (1995); G. Proprietary Developed Quality Assessment Tool.)); 8. Consideration of Methodological Quality for Conclusions; 9. Combination of Findings; 10. Publication Bias Assessment; 11. Conflict of Interest Statement.

Table 3. Summary of Recommendations

| Topic | Recommendations |
|--|--|
| Primary and secondary outcomes delineation | <ul style="list-style-type: none"> Decide on clearly established outcomes for patients and clinicians; Evaluate exergaming effectiveness considering the International Classification of Functioning, Disability and Health, by using specific and overall outcome measures; |
| Target behaviors description | <ul style="list-style-type: none"> Describe in detail the protocols for researchers, therapists and end-users of exergames, specifying the procedures and how the activity will be measured, considering appropriate movements, and potential contraindications. Use behavioral change theoretical frameworks to plan interventions, with the aim of estimating the optimal transfer to real-world functional improvements; |
| Subjects, protocols and instruments | <ul style="list-style-type: none"> Conduct methodological sound research designs with adequate power analysis to include adequate sample size; Conduct further research on the effects of exergames in older adults with specific health conditions and/or impairments, considering sociodemographic heterogeneity and baseline activity-level; Methodological designs must describe how to ensure safeguards, the ease of use of exergames in interventions, and how long-term motivation and adherence to exergaming can be evaluated; Develop guidelines and protocol standardization for responsible use of exergames and addressing exergames impact on physiological parameters; |

| | |
|--------------------------------|---|
| Technology characterization | <ul style="list-style-type: none">• Consider the specific needs of older adults during game design, and consult guidelines on the development of accessible games for people with and without disabilities;• Take into account data from usability studies, and contemplate the inclusion of social networking components in exergaming interventions; |
| Policy recommendation | <ul style="list-style-type: none">• Establish interdisciplinary collaboration during the game design process;• Share game design protocols, research data, exergames and correspondent documentation for researchers, therapists, and end-users, in scientific repositories;• Aim for the creation of a sustainable knowledge ecosystems that will translate knowledge, provide educational and training messages to promote healthy exergames for older users. |

Fig. 1 – Flow Diagram

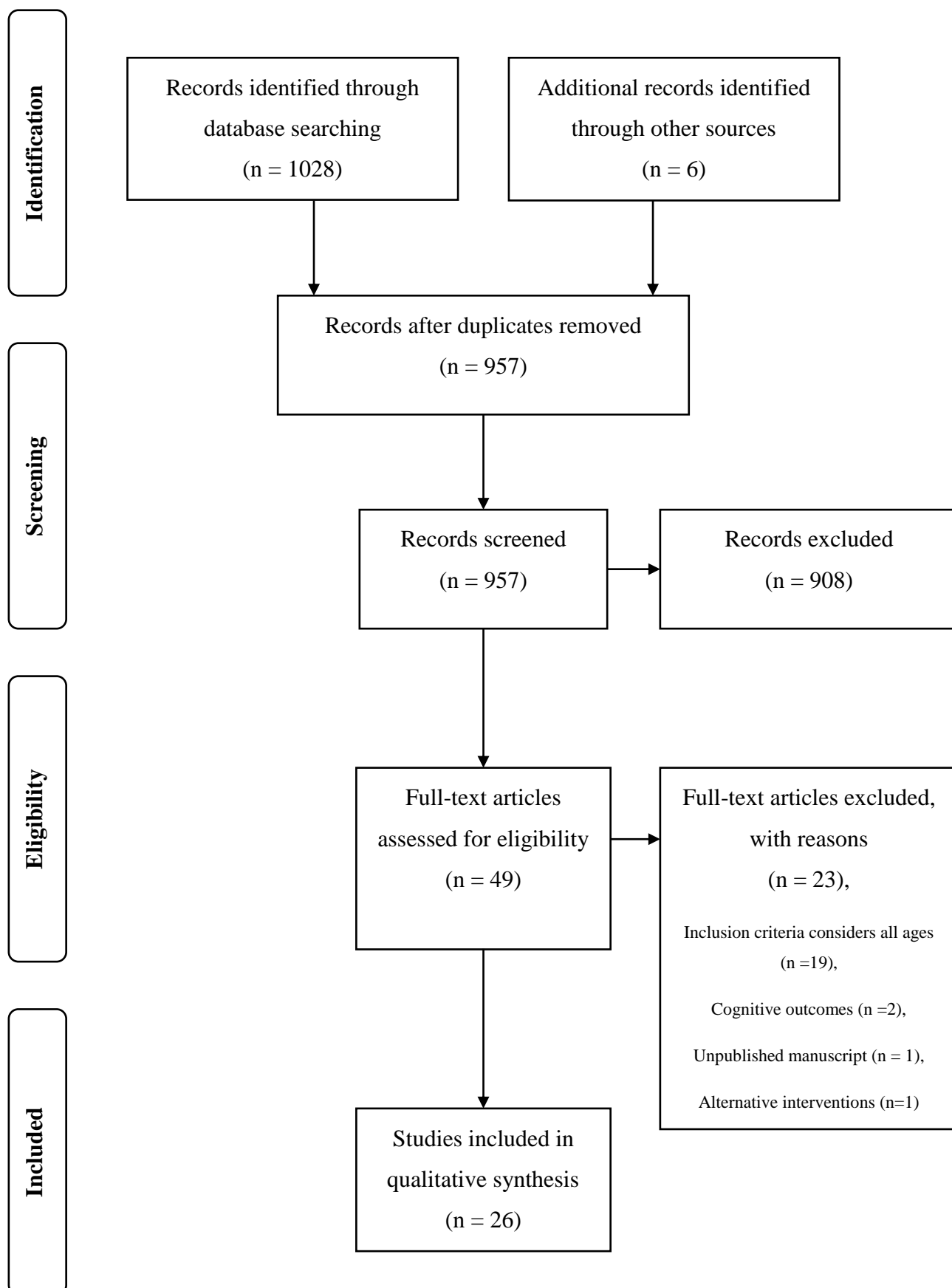
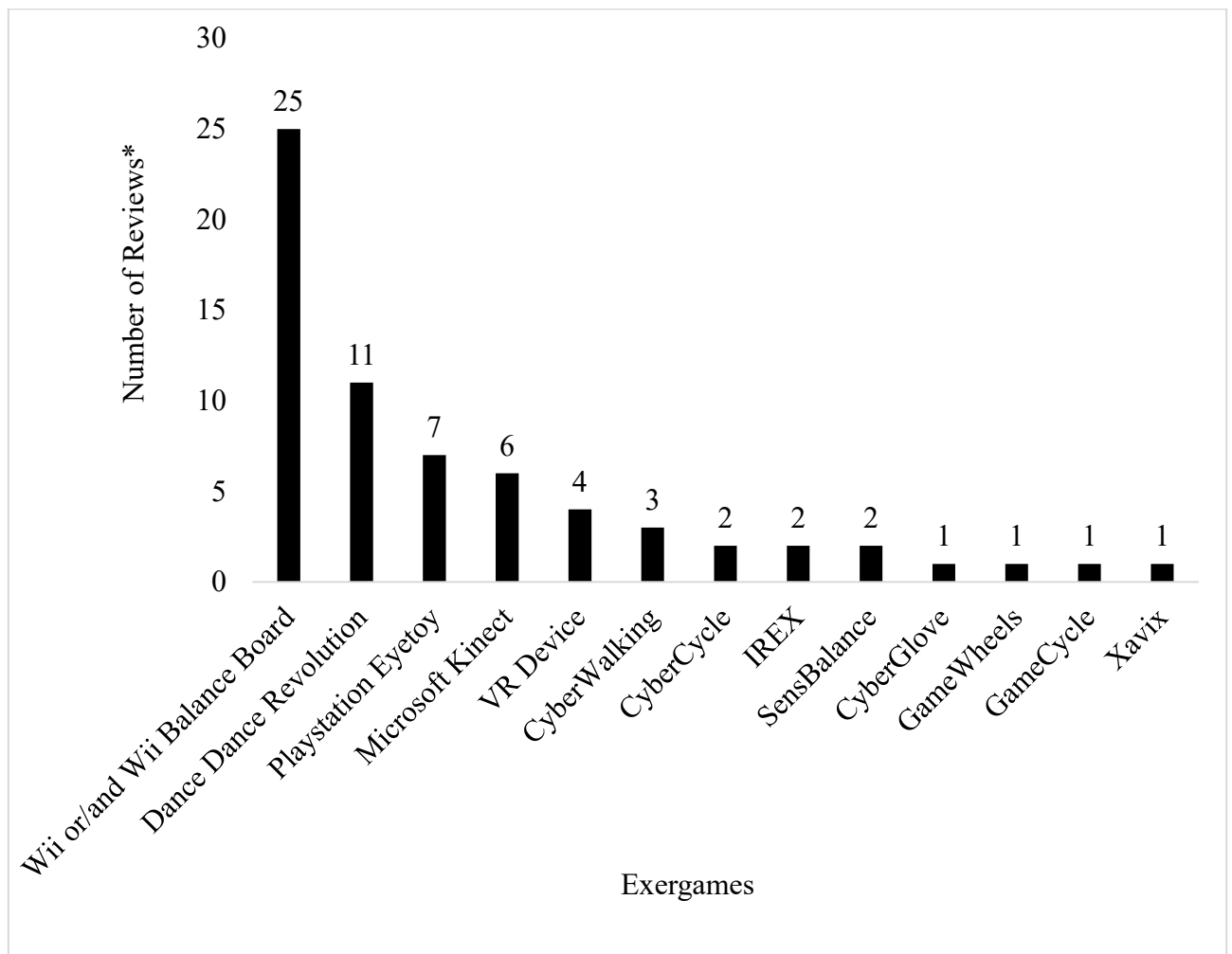


Fig. 2 – Frequency of Reviews by Exergame Type



*non-exclusively