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The effects of exergaming on individuals with limb loss: a systematic review

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ABSTRACT

Background: Losing a limb is a life-changing experience. Affected individuals (amputees) have to learn how to care for their amputated limb, how to walk, and how to cope and adjust with limb loss and prosthesis use. They also have reduced physical range of motion, poorer balance control, strength, and experience pain and fatigue. Exergaming is currently used in physical rehabilitation for Parkinson's disease, multiple sclerosis and post-stroke. There is currently no consensus on the efficacy of exergaming delivered to people with missing limbs.

AIM: The aim of this systematic review is to evaluate and summarize the current research on the effects of exergaming among individuals with missing limbs.

Method: Studies reporting on exergaming intervention delivered to individuals receiving prosthetic rehabilitation were included in the analysis. Ten electronic databases were searched. Twelve articles were identified. Data were extracted and assessed for quality.

Results: Three main categories of exergaming interventions comprised custom made exergames, Nintendo Wii games and exergames provided by the Computer Assisted Rehabilitation Environment (CAREN) system. Of these, seven interventions were delivered by research staff, four by a physiotherapist and one by a physiotherapist and an occupational therapist. Custom made exergames were used in five studies, of which four involved people with lower limb amputations and one involved people with upper limb amputations. The Nintendo Wii was used in five studies involving people with lower limb amputations, whilst the remaining two used the CAREN system, also involving people with lower limb amputations. All participants in the studies were adults except for one which evaluated exergaming in adolescents and children. Studies reported improvements in EMG muscle control, cognitive-motor ability, walking capacity, function, balance and reduced pain. Most participants enjoyed the exergaming intervention and found the experience to be positive. Results suggest that exergaming supports improvements in physical activity, balance, cognition, emotional states, quality of life and pain.

Conclusion: Exergaming interventions administered to people with missing limbs show heterogeneity in protocol, duration and gaming platform. Although there was evidence of improved outcomes in participants, the efficacy of exergaming is inconclusive due to varied differences in types of amputation, participant characteristics and assessed outcome measures. Nevertheless, reported enjoyment, acceptance and levels of motivation during exergaming appear to support the feasibility of exergaming for prosthetic training.

Keywords: *amputees, exergaming, active video games, rehabilitation*

BACKGROUND

Losing a limb is a life-changing experience and has negative impacts on the psychological and physical well-being of affected individuals (1). People with limb amputations experience decreased levels of physical activity and impaired balance (2,3). They may also experience phantom limb pain for the residual limb (4,5). Thus, rehabilitation through exercise may encourage physical functioning following amputation through the restoration of muscle strength, endurance, power and physical flexibility (6).

Using exergaming for therapeutic purposes is gaining interest (7). One of the most recent interventions currently used in physical rehabilitation is exergaming (8–10). Exergaming can be defined as physical exercise in a serious gaming environment enabled by digital technology (e.g. Nintendo Wii Fit) (11). It has been recommended as an appropriate form of rehabilitation for several clinical groups, including cerebral palsy related disabilities in paediatric patients and age-related disabilities in older people (12). Karahan and colleagues (13) reported significant improvements in pain, disease activity, functional capacity and quality of life in people with ankylosing spondylitis after exergaming. Another study that evaluated the effectiveness of exergaming on balance reported not only improved balance and gait amongst people with multiple sclerosis but also significantly higher improvements in gait whilst dual tasking after exergaming (14).

Despite potential health benefits of exergaming, there are differences in gaming pace and levels of cognitive complexity in certain exergames. For instance, people with Parkinson's disease have found difficulty in playing exergames that require fast physical movements (15). Therefore, using exergaming in rehabilitation must suit the therapeutic goal for which it was intended (16). Indeed, exergaming applications should support a wide range of physical exercises, allow the interventions to be personalized, involve the use of sensors that are comfortable to wear, and provide feedback to improve performance and encourage adherence without cognitive overload (17).

Exergaming is a relatively new intervention in the rehabilitation of people with missing limbs (i.e. amputees) (18). To fill this knowledge gap, the authors conducted a systematic review of the literature to look at exergaming interventions and related physical health outcomes from exergaming to provide a broad overview of exergaming effects in people with missing limbs, and to inform evidence-based clinical practice.

METHODS

Our systematic review is retrospectively registered with PROSPERO (19). The reporting of this review is consistent with PRISMA guidelines (20). In this review, the terms patient and participant are synonymous.

Search strategy

A systematic search was conducted in eight electronic databases from April 2019 and updated in August 2019. The following electronic databases were: CiNAHL, Google Scholar, Cochrane Library, MEDLINE, ScienceDirect, SPORTDiscus, PEDro, and Web of Science (science and social science citation index).

The titles, abstracts and keywords of publications resulting from the searches, where applicable, were searched with the following search terms: rehabilitation or ‘limb loss’ or amput* or telerehab* or physiotherapy or gam* or wii or digital or video gam* or prostheti* or ‘virtual reality’ or ‘augmented’. The references of included publications were also checked.

Screening process

The first author (JD) screened the initial 3,773 publications and removed duplicates from the initial search. All titles and abstracts were screened independently by the two authors (JD and IC). Any disagreements over publications were resolved through a discussion until a consensus was reached.

Study selection

Participants, intervention, comparisons (if any), outcomes and study design were used to identify the inclusion and exclusion criteria for the study.

Participants

We formulated our inclusion criteria to include individuals of all ages with missing limbs either due to surgical removal or traumatic disarticulation by injury or by surgical amputation. People awaiting diagnosis of amputation or surgery including individuals with congenital absence of limbs were excluded.

Intervention

Exergames must have encouraged physical movement or physical activity in order to interact with the game. They should have demonstrated at least some of the following characteristics: interactivity, cognitive-physical purpose, presence of an opponent or incentive to win points, exploration of a virtual environment by physical movement (e.g. walking in a virtual environment where the terrain is uneven which serves as "obstacles" or playing exergames by muscle activity) and the possibility of winning or losing.

Comparison

No comparative groups were required for inclusion.

Outcome measures

The outcomes were health related such as pain perception (i.e. phantom limb pain in amputees), balance, physical functioning and physical activity outcomes, including emotional states related to exergaming (i.e. motivation, acceptance of the exergaming intervention).

Study design

There were no limitations on trial design. However, reviews of the literature, articles from abstracts or summaries presented in a congress of conference were not included. Only articles available in English were included.

Data extraction

Data extraction was performed by one reviewer before being verified by the second reviewer. The following were extracted from selected studies: participant characteristics including type of amputation, details of intervention, equipment and setting, and clinical outcome measures. Two reviewers screened the articles independently. Any discrepancies were resolved through a discussion between the two reviewers. A third reviewer was consulted if there was a need for further resolve.

Risk of bias and quality of evidence

The Cochrane Collaboration Tool was used to assess risk of bias in randomized controlled trials (21). The Cochrane Collaboration tool assesses biases as a judgement (high, low, or unclear) for individual elements from five domains (selection, performance, attrition, reporting, and other). The assessment of observational studies was conducted using the Quality Checklist for Healthcare Intervention Studies (22). The Quality Checklist for Healthcare Intervention Studies comprises 27 questions covering five domains (study quality, external validity, study bias, confounding and selection bias and power). Any case reports, series or case studies were assessed using the IHE quality appraisal tool for case series studies (23,24). This quality appraisal tool is an 18-item questionnaire assessing the following: study objective, design, population, interventions, outcome measures, statistical analysis, results and conclusion, and competing interests and sources of support. Each article was assessed for risk of bias with the tools mentioned above by two reviewers working independently per study. Any disagreements were resolved through discussion between the reviewers.

Data analysis

A narrative synthesis of the findings from selected studies was provided. Selected studies were described following their research design, sample population characteristics, exergaming intervention, timing of intervention delivery, setting and outcome measures.

Statistical analysis

A meta-analysis would have been conducted if selected studies used the same type of intervention, sample population and reported the similar outcome measures.

RESULTS

Searches from eight electronic databases yielded a total of 3773 publications from which 236 were duplicates. After excluding 3506 publications based on titles and abstracts, 31 publications were assessed in full-text, and 12 publications were included in the review (see Figure 1). The 12 publications were published between 2010-2018 (2 in 2018, 3 in 2017, 1 in 2016, 2 in 2015, 1 in 2013, 2 in 2012 and 1 in 2010). Selected publications comprised 9 experimental intervention studies (2 RCTs (25,26), single-subject study =1 (27), case study = 2 (28,29), case reports = 3 (30–32) (30) and 4 feasibility studies (feasibility case series = 1 (33), feasibility single-subject study = 2 (34,35) and feasibility between-group study = 1 (36)). The exergaming research was conducted in two different environments, respectively: research laboratories (4 university laboratories, 1 military medical laboratory) and clinical facilities (6 interventions were administered in hospitals, and one study also provided home-based rehabilitation interventions for the control group).

Study quality assessment

Two randomized controlled trials (25,26) were included. When assessed for risk of bias using the Cochrane Collaboration's tool, no high risk of bias was detected for either study (see Table 1). Six publications (28–30,32) were assessed by the IHE quality appraisal tool for case series studies (23,24). These selected case reports, case series and case studies fulfilled most of the IHE checklist criteria (see Table 2). The remaining four feasibility studies were assessed using the Quality Checklist for Healthcare Intervention Studies (Table 3). They showed relatively good study quality with the lowest Downs and Black score being 19 (fair) and the highest being 24 (good), in consonance with scores previously reported (37).

Study populations

Participants

The studies included in the review enrolled a total number of 105 participants from Canada (79) (25,26,34–36), USA (18) (28,30–33), Austria (7) (27) and Sweden (1) (29) (see Table 4). Out of these, 88 were amputees and 17 were able bodied. The participant population comprised individuals presenting either one extremity amputation or double amputation. One extremity amputees included: 55 lower limb amputees (14 transtibial, 28 transtibial or transfemoral, 10 transfemoral, 3 Van Ness) and 23 upper limb amputees (21 transradial or transhumeral, 1 wrist, 1 transradial). Double amputees included 4 individuals presenting: 1 left transtibial with right midfoot, 1 left transtibial with right knee disarticulation, 2 bilateral transfemoral. With regard to attrition, 1 dropout (at follow-up after pre- and post-testing) and 4 withdrawals were reported across these studies (25). A dropout refers to a participant who voluntarily withdraws his participation from a study whereas a withdrawal refers to a well-weighed decision by research administrators to terminate participation of an individual, respectively. The reviewed studies included 16 children and adolescents, and 89 adults, within the age range of 8-78 years. The gender distribution was 28 male, 8 female and 70 non-specified. Only one study recorded participants’ level of education (high school 32%, college 42.9%, university 25%), employment status (32% employed) and cognitive functioning (mean 29 scored from MMSE, range 23-30). In addition, they also recorded socket comfort for their participants (8 median score, range 4-10) (25).

Study interventions

Five of the included interventions used computerized video games for their exergaming intervention (26–30) (see Table 5). The Nintendo Wii was used by five studies (25,31,34–36) and the remaining two studies used CAREN (32,33). The reported duration ranged from 20 to 45 minutes per session. Not all durations were reported as sessions depended on each individual’s adherence and motivation to persist. The duration of interventions ranged from one day to 8 weeks. Two studies included a comparison group of able-bodied individuals (26,36) whereas one also included a comparison group of amputees (25). Andrysek et al (36) presented the only study to use home-based exergaming for the experimental group (children with amputations). The study by Imam et al. (25) used the Nintendo WiiFit™ and Wii Big Brain Academy™, played with a handheld remote control. Their exergaming intervention was designed to receive training at the hospital before undertaking unsupervised home-based exergaming. Prahm et al (26) used computerized video games played by muscle control and the Myoboy, a standard rehabilitation tool designed for muscle activity and prosthetic training. Collectively, intervention delivery occurred within 5 months to 48 years post-surgery. Four studies took place within twelve months post-surgery (25,28,30,34). Andrysek et al. (36) carried out their study within 36 months post-surgery. In the study by Ortiz-Catalan et al., (29), their participant took part in the exergaming intervention 48 years post-surgery.

Outcome measures from exergaming interventions

Exergaming interventions were used to assess the following measures: pain (28–30,34), fatigue (34), physical functioning (25,32–35), muscle control (26,27) feasibility (25,36), acceptability (34), quality of life (35) and user experience (26,27).

Pain and fatigue

The Visual Analogue Scale (VAS) was used to assess pain (28–30). Imam et al (2013) (34) used the Numerical Rating Scale (NRS) whereas Chau et al (2017) (30) used three pain rating scales (the Visual Analogue Scale (VAS), the Short-form McGill Pain Questionnaire (SF-MPQ), and Wong-Baker FACES pain rating scale) to assess pain before and after the exergaming intervention. One study recorded fatigue scores by using a Short Feedback Questionnaire (SFQ-M) (34).

Physical functioning and mobility

The assessed outcomes were walking and step activity using the following: the 2 Minute Walk Test (2MWT) (25,34), L test (34,35) and computerized treadmill in combination with the Vicon motion capture system (32,33). Imam et al (2017) (25) assessed the number of steps taken each day for a week using the Modus Health Stepwatch^{TM} Activity Monitor (SAM), mounted on the prosthetic ankle. They also assessed self-reported physical activity by using the Physical Activity Scale for the Elderly (PASE). Cognitive-motor interaction was assessed using the Walking While Talking Test (WWT) (25), and locomotor activity was assessed using the Locomotor Capabilities Index in Amputees (LCI-5) (25). Tousignant et al (35) assessed functional mobility with a prosthesis using the Amputee Mobility Predictor (AMPPRO) questionnaire. Outcome measures for muscle control were levels of EMG control, fine muscle activation and electrode separation assessed by using recorded electromyographic (EMG) biofeedback via myoelectric signals (26,27). Miller et al. (2012) (31) was the only study to assess aerobic capacity whilst walking in older people with amputations.

The assessed outcomes for balance were balance confidence using a self-administered subjective questionnaire called the Activities-specific Balance Confidence (ABC) scale (25,31,34), centre of pressure (COP) displacements during quiet standing using the Nintendo Wii balance board (36), dynamic balance using the Biodex system (31) and functional balance using the Community Balance and Mobility Scale (CB&M) (36).

Feasibility and acceptability

Feasibility of the exergaming intervention was assessed using a customized questionnaire and a recorded logbook (36) whereas another study collectively assessed feasibility by considering outcome measures of safety and report of any adverse events from the exergaming intervention, post-intervention fatigue, pain levels, adherence and user acceptability of the exergaming intervention (34). User evaluation and acceptability of the games was assessed using a custom-made questionnaire (27), System Usability Scale [28] and the Short Feedback Questionnaire-modified (SFQ-M) (34).

Quality of life, motivation and user evaluation

One study assessed quality of life amongst amputees using the Trinity Amputation and Prosthesis Experience Scales (TAPES) (35). Motivation was assessed by using the Intrinsic Motivation Inventory (IMI) questionnaire (26,27) while another study used a custom made questionnaire to evaluate motivation by rating on a Visual Analogue Scale (VAS) and assessed patient satisfaction with health care services using the Health Care Satisfaction Questionnaire (HCSQ) (35).

Effects of the intervention

Two randomized controlled trials were included in this review. Imam et al (2017) (25) tested the effects of exergaming on walking capacity using the Nintento WiifFit^{TM} for 12 sessions (over 4 weeks) compared with cognitive games using the Big Brain Academy Degree^{TM} in older people with missing limbs. Their clinical outcome results were based on intention to treat analyses. Although there were no significant changes were in the other outcomes, their results on walking capacity at post-intervention and 3-week retention were comparable to those of an RCT with younger individuals (38). Improvements were observed in walking capacity and cognitive-motor tasks in favour of the exergaming intervention (Wii.n.Walk). The overall adherence to the exergaming intervention was high although in-home adherence was slightly lower than in-clinic adherence. Their patients preferred supervised group training and welcomed the convenience and accessibility of home-based exergaming.

Prahm et al (2018) (26) assessed short-term effects of exergaming on EMG muscle control in two patient groups and one control group comprising able-bodied participants. One of the patient groups served as a control, performing random EMG activations whereas the experimental and able-bodied group played exergames (computerized video games). They found significant increased maximum voluntary contractions in the groups that played the exergames, indicating stronger muscle contraction and improved muscle control. Improved proportional precision control was also observed in these groups for all EMG target intensities. The patient control group however, showed significant improvement for the middle intensity target. Although there was overall improvement in muscle separation in almost every instance, these results were not always significant. Only the groups that played exergames showed significant decreases of involuntary activation of the opposing electrode for the first to third measurements for low goal intensity levels. Improved endurance and muscle isolation was also found in favour of exergaming. Their patients significantly enjoyed playing the exergames and perceived the MyoBoy to be a useful EMG training tool. In terms of exergame evaluation, they preferred rhythm and racing games. Racing games scored slightly higher motivational scores.

Three of the twelve studies evaluated whether pain improved after an exergaming intervention (28–30). All three reported reductions in pain intensity. Ambron et al. (2018) (28) found lower pain intensity ratings at post-intervention but were not able to establish the association between pain and level of fatigue. The patient in Chau et al (2017) (30) reported significant pain relief taking effect approximately 24 hours after each exergaming session. There was also a decrease in pain lasting progressively longer for several days after each exergaming session. Follow-up feedback on pain one week post-intervention reported continued pain relief over five days after the last exergaming session and an overall decrease in baseline pain levels. At six weeks follow-up, the patient reported that the pain was still present but generally decreased in severity and was much more tolerable. This indicates longer lasting benefits retained after exergaming. The results of Ortiz-Catalan et al. (2014) (29) were especially interesting where the patient experienced an increment of pain at the beginning of the exergaming intervention, followed by reduced pain intensity after 4 weeks and pain-free periods after 10 weeks, which then developed into completely pain-free periods a couple of sessions later. Although pain was not their primary clinical outcome, Imam et al (2013) reported post-intervention pain and fatigue scores which ranged less than 6 on a scale of 0 to 10 (0 = no pain; 10 = extreme pain and 0 = no fatigue, 10 = extreme fatigue). They also reported high adherence (80%) to their reported median scores for pain and fatigue, suggesting beneficial effects on phantom limb pain from exergaming in amputees.

The studies that used CAREN to evaluate clinical outcomes found improvements in walking, gait, physical functioning and balance, including progression of level walking to more challenging terrain (32,33). One of the studies demonstrated evidence of retaining benefits in gait at least 5 weeks after the final exergaming session (32) The other reviewed studies found improvements favouring the exergaming group in some of the outcomes assessed, such as better muscle control (27), dynamic balance (31) and balance confidence (25,31,34). One study (36) showed differences in functional balance and mobility between patient groups where patients with transfemoral amputations scored lower than those of the Van Ness group despite overall improvement in functional balance and mobility (CB&M) scores between baseline, at post-intervention and follow-up. Another study found high levels of motivation after exergaming amongst their patients (35). Study participants demonstrated positive responses in terms of acceptability of exergaming (34).

DISCUSSION

This is the first systematic review to evaluate and summarize current literature concerning the effects from exergaming on individuals with missing limbs. The interventions we found through this review showed variability from one another in terms of clinical and methodological diversity. Hence, it is difficult to conclude which method of delivery would prove to be the most advantageous.

Exergaming interventions in the reviewed studies had different therapeutic targets and varied in terms of participants, duration, gaming design and strategies, whether it was to improve balance and stability responses through repeated practice (32), to provide treatment for phantom limb pain (28) or to improve muscle control (26,26). The Nintendo WiiFit^{TM} was the most used intervention in studies involving people with lower extremity amputations whereas computerized video games were used in the studies involving people with upper extremity amputations. Only one study using computerized video games involved two individuals with lower extremity amputations whereby one patient (with left transtibial amputation) reported reduced pain severity after exergaming and a progressive decrease in phantom limb pain across the exergaming sessions (28). This suggests the suitability of exergaming interventions across different types of amputations in individuals.

In terms of clinical benefit, exergaming was seen to improve mobility and balance (25,31–36) when assessed through the current review, showing alignment with previous exergaming studies involving able-bodied clinical groups (9,13,39). The studies that used CAREN found improved outcomes in their participants individually, particularly in walking and balance (32,33).

Pain was assessed in three studies in this review (28–30), showing improvements following the exergaming intervention. These findings are consistent with those of Pekyavas and Ergun (2017) (40) who compared the Wii with home exercise programme provided to people with patients with subacromial impingement syndrome (SAIS). They found that the exergaming group demonstrated significantly better improvements in range of movement in the shoulder, and scapular rotation and retraction compared to the home exercise group despite improvements in pain in both groups after exergaming.

The current review was unable to find strong evidence of long term benefits from exergaming. However, from the studies assessed, exergaming interventions appear to confer at least short term benefits to people with amputations, where one study demonstrated evidence in the retainment of improved gait at least five weeks after the last exergaming session (32). This is similar to a study by Sims et al (2013) (41) which evaluated the effects of exergaming on static postural control in able-bodied people with a history of lower limb injury. In addition to improved static postural control after exergaming, they found significant improvement in self-reported function at four weeks post-intervention.

Patient motivation and adherence to rehabilitation encourages recovery and improved health outcomes in patients (42). Findings from the studies reviewed showed increased motivation amongst their patients after exergaming (25–27). For instance, rhythm and racing games were perceived to be more enjoyable than dexterity games and motivation scores were rated higher in racing games when compared to rhythm games (25). The single participant in the study of Sheehan et al (2016) (32) attributed the benefits of exergaming to which, he believed that interacting with the exergaming intervention had challenged him to focus to the surroundings and to make necessary gait and posture changes in order to play the exergames. The participants in Miller et al (2012) (31) found exergaming to be challenging and enjoyable. Participants in the Tousignant et al (2015) (35) demonstrated high motivation and adherence to the exergaming intervention and were satisfied with the service provided. They also scored highly on the Health Care Satisfaction Questionnaire (97%, 100% and 84%, respectively).

Because the included studies showed wide heterogeneity, it is difficult to draw firm conclusions in the delivery of interventions and the clinical outcome measures assessed within the selected studies. Nevertheless, exergaming interventions appear to be feasible and favourably received by individuals with missing limbs. A high degree of adherence and low level of dropouts from the reviewed studies indicated high acceptance regarding the proposed exergaming interventions, including both immersive and nonimmersive virtual reality designs. Of all the included studies, there was one in which had the only lost to follow-up participant (25). The participant developed complications with preexisting lung disease, unrelated to the study. In spite of this, adherence to the study was 83.4% (25).

With regards to feasibility, the exergaming sessions were well accepted and received positive feedback from participants (30). Participants in Andrysek et al (2102) (36) perceived the exergames to be fun and easy to play. Furthermore, participants in Prahm et al (2018) (26) significantly enjoyed exergaming, even though the required physical movements put more pressure on them. Participants in Imam et al (2017) (25) were willing to exert more physical effort to play the exergames in comparison to using the MyoBoy. They perceived the exergaming intervention to be useful for improving their walking abilities and intended to continue using the equipment at home on a regular basis (25). Usability of exergaming interventions also received favourable ratings in Ambron et al (2018) (28) where majority of ratings by way of the System Usability Scale questionnaire fell within the acceptable range of above 50 out of 100, where scores of 70+ mean good prospective usability for a information technology-based application in development (43). Nevertheless, there was also report of low ratings in usability for one of the exergames called Quest for Fire by one participant, reflecting the frustration encountered whilst learning to move the avatar around the labyrinth (28). With regard to safety, 4 near-fall incidents while exergaming with lower limb prosthesis were recorded in Andrysek et al (2012) (36). Nonetheless, there was no report of adverse effects relating to the exergaming interventions.

With respect to quality of life, one of the domains of life classified by the International Classification of Functioning, Disability and Health (ICF) is mobility (44). In fact, the benefits of exergaming derived from the variety of exergames and complex challenges presented to the user are not limited to improved functional parameters, but instead, also encompass domains directly influencing the quality of life of the participants. For instance, reducing pain at phantom limb level, improving prosthesis control, self confidence and outdoor environment ambulation management as related by participants in the reviewed studies (28,32). One participant in Ambron et al (2018) (28) reported dramatic improvements in his physical activity over the course of the exergaming intervention. After two exergaming sessions, he successfully walked to the local grocery store using a lower-limb prosthesis for the first time after amputation. The participant attributed his improved physical activity as a result of exergaming training. Feedback from the participant in Chau et al (2017) (30) was also promising. He stated that playing the exergames made him forget the pain, move as if the pain was not there and he felt normal. His remark of *"I feel like my hand is back*" is an especially important response to exergaming as this reflects the potential therapeutic benefit from exergaming on physical recovery and movements on a residual limb.

The current review is not without its limitations. The selected studies showed great heterogeneity. Study protocols differed in terms of exergaming intervention and length of therapy sessions. Furthermore, exergaming interventions from the reviewed studies differed in frequency, duration, gaming elements, and physical and cognitive user tasks. The actual power of the studies is also limited by the low number of participants enrolled. Outcome measures also differed in assessment methods. Due to the scarcity of literature for exergaming in people with amputations, more research should be conducted to explore common clinical outcomes from exergaming interventions, suitable for individuals with different types of amputations. Future research should also assess longer follow-ups post-intervention in order to assess the effects of exergaming over time.

CONCLUSION

In conclusion, there was a wide variability in the studies assessed. Due to the heterogeneity in the included studies, we were unable to conclude its effectiveness. However, there was evidence of improved health outcomes after exergaming, feasibility and acceptance of the exergaming interventions to suggest that exergaming may be potentially therapeutic for people with missing limbs.

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REFERENCES

1. Senra H, Oliveira RA, Leal I, et al. (2012). Beyond the body image: a qualitative study on how adults experience lower limb amputation. *Clin Rehabil*. 26:180–91.

2. Gaunaurd I, Gailey R, Hafner BJ, et al. (2011). Postural asymmetries in transfemoral amputees. *Prosthet Orthot Int*. 35:171–80.

3. Ku PX, Osman NAA, Abas WABW (2014). Balance control in lower extremity amputees during quiet standing: a systematic review. *Gait Posture*. 2014;39:672–82.

4. Kooijman CM, Dijkstra PU, Geertzen JH et al. (2000). Phantom pain and phantom sensations in upper limb amputees: an epidemiological study. *Pain* 87:33–41.

5. Nikolajsen L, Jensen TS (2001). Phantom limb pain. *Br J Anaesth*. 87:107–16.

6. Vestering MM, Schoppen T, Dekker R, et al. (2005). Development of an exercise testing protocol for patients with a lower limb amputation: results of a pilot study. *Int J Rehabil Res*. 28:237–44.

7. Van Diest M, Lamoth CJ, Stegenga J, et al. (2013). Exergaming for balance training of elderly: state of the art and future developments. *J Neuroengineering Rehabil*. 2013;10:101.

8. Barry G, Galna B, Rochester L (2014). The role of exergaming in Parkinson's disease rehabilitation: a systematic review of the evidence. *J Neuroengineering Rehabil*. 11:33.

9. Robinson J, Dixon J, Macsween A, et al. (2015). The effects of exergaming on balance, gait, technology acceptance and flow experience in people with multiple sclerosis: a randomized controlled trial. *BMC Sports Sci Med Rehabil*. 7:8.

10. Tough D, Robinson J, Gowling S, et al. (2018). The feasibility, acceptability and outcomes of exergaming among individuals with cancer: a systematic review. *BMC Cancer*. 18:1151.

11. Oh Y, Yang S (2010). Defining exergames & exergaming. *Proceedings of Meaningful Play,* p. 1–17.

12. Goble DJ, Cone BL, Fling BW (2014). Using the Wii Fit as a tool for balance assessment and neurorehabilitation: the first half decade of "Wii-search." *J Neuroengineering Rehabil.* 11:12.

13. Karahan AY, Tok F, Yildirim P, et al. (2016). The effectiveness of exergames in patients with ankylosing spondylitis: A randomized controlled trial. *Adv Clin Exp Med.* 25:931–6.

14. Kramer A, Dettmers C, Gruber M (2014). Exergaming with additional postural demands improves balance and gait in patients with multiple sclerosis as much as conventional balance training and leads to high adherence to home-based balance training. *Arch Phys Med Rehabil*. 95:1803–9.

15. dos Santos Mendes FA, Pompeu JE, Lobo AM, et al. (2012). Motor learning, retention and transfer after virtual-reality-based training in Parkinson's disease–effect of motor and cognitive demands of games: a longitudinal, controlled clinical study. *Physiotherapy* 98:217–23.

16. Pirovano M, Surer E, Mainetti R, et al. (2016). Exergaming and rehabilitation: A methodology for the design of effective and safe therapeutic exergames. *Entertain Comput.* 14:55–65.

17. Doyle J, Kelly D, Caulfield B (2011). Design considerations in therapeutic exergaming. IEEE p. 389–93.

18. Imam B, Miller WC, Finlayson HC, et al. (2018). A clinical survey about commercial games in lower limb prosthetic rehabilitation. *Prosthet Orthot Int Sage Publ Ltd*. 42:311–7. doi:10.1177/0309364617740238.

19. PROSPERO (2011). International prospective register of systematic reviews. https://www.crd.york.ac.uk/prospero/.

20. Liberati A, Altman DG, Tetzlaff J, et al. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med*. 6:e1000100.

21. Higgins JP, Altman DG, Gøtzsche PC, et al. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *Bmj*. 343:d5928.

22. Downs SH, Black N (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 52:377–84.

23. Guo B, Moga C, Harstall C, et al. (2016). A principal component analysis is conducted for a case series quality appraisal checklist. *J Clin Epidemiol.* 69:199-207.e2. doi:10.1016/j.jclinepi.2015.07.010.

24. Moga C, Guo B, Schopflocher D, et al. (2012). Development of a quality appraisal tool for case series studies using a modified Delphi technique. *Edmont AB Inst Health Econ*.

25. Critical Appraisal Skills Programme (2014). CASP checklists. Crit Apprais Ski Programme CASP Mak Sense Evid.

26. Imam B, Miller WC, Finlayson H, et al. (2017). A randomized controlled trial to evaluate the feasibility of the Wii Fit for improving walking in older adults with lower limb amputation*.* *Clin Rehabil*. 31:82–92.

27. Prahm C, Kayali F, Sturma A, et al. (2018). PlayBionic: Game-Based Interventions to Encourage Patient Engagement and Performance in Prosthetic Motor Rehabilitation. *PM&R*. 10:1252–60. doi:10.1016/j.pmrj.2018.09.027.

28. Prahm C, Kayali F, Vujaklija I, et al. (2017). Increasing motivation, effort and performance through game-based rehabilitation for upper limb myoelectric prosthesis control. IEEE p. 1–6.

29. Ambron E, Miller A, Kuchenbecker KJ, et al. (2018). Immersive low-cost virtual reality treatment for phantom limb pain: Evidence from two cases. *Front Neurol*. 9:67.

30. Ortiz-Catalan M, Sander N, Kristoffersen MB, H et al. (2014). Treatment of phantom limb pain (PLP) based on augmented reality and gaming controlled by myoelectric pattern recognition: a case study of a chronic PLP patient. *Front Neurosci*. 8:24.

31. Chau B, Phelan I, Ta P, et al. (2017). Immersive Virtual Reality Therapy with Myoelectric Control for Treatment-resistant Phantom Limb Pain: Case Report*.* *Innov Clin Neurosci.* 14:3–7.

32. Miller CA, Hayes DM, Dye K, et al. (2012). Using the Nintendo Wii Fit and Body Weight Support to Improve Aerobic Capacity, Balance, Gait Ability, and Fear of Falling: Two Case Reports. *J Geriatr Phys Ther.* 35:95–104. doi:10.1519/JPT.0b013e318224aa38.

33. Sheehan RC, Rábago CA, Rylander JH, et al. (2016). Use of perturbation-based gait training in a virtual environment to address mediolateral instability in an individual with unilateral transfemoral amputation. *Phys Ther.* 96:1896–904.

34. Kruger S (2011). A virtual reality approach to gait training in service members with lower extremity amputations. *Int J Disabil Hum Dev.* 10:313–6.

35. Imam B, Miller WC, McLaren L, et al. (2012). Feasibility of the Nintendo WiiFit^{TM} for improving walking in individuals with a lower limb amputation. *SAGE Open Med.* 1:2050312113497942.

36. Tousignant M, Milton-McSween E, Michaud K, et al. (2015). Assessment of the Feasibility of the nintendo wii balance board as an intervention method for balance rehabilitation with lower-limb amputees. *J Nov Physiother*. 5:1–7.

37. Andrysek J, Klejman S, Steinnagel B, et al. (2012). Preliminary Evaluation of a Commercially Available Videogame System as an Adjunct Therapeutic Intervention for Improving Balance Among Children and Adolescents With Lower Limb Amputations. *Arch Phys Med Rehabil.* 93:358–66. doi:10.1016/j.apmr.2011.08.031.

38. Hooper P, Jutai JW, Strong G, et al. (2008). Age-related macular degeneration and low-vision rehabilitation: a systematic review. *Can J Ophthalmol.* 43:180–7. doi:10.3129/i08-001.

39. Rau B, Bonvin F, De Bie R (2007). Short-term effect of physiotherapy rehabilitation on functional performance of lower limb amputees. *Prosthet Orthot Int.* 31:258–70.

40. Hung J-W, Chou C-X, Hsieh Y-W, et al. (2014). Randomized comparison trial of balance training by using exergaming and conventional weight-shift therapy in patients with chronic stroke. *Arch Phys Med Rehabil.* 95:1629–37.

41. Pekyavas NO, Ergun N, (2017). Comparison of virtual reality exergaming and home exercise programs in patients with subacromial impingement syndrome and scapular dyskinesis: Short term effect. *Acta Orthop Traumatol Turc*. 51:238–42. doi:10.1016/j.aott.2017.03.008.

42. Sims J, Cosby N, Saliba EN, et al. (2013). Exergaming and static postural control in individuals with a history of lower limb injury [with consumer summary]. *J Athl Train.* 48:314–25.

43. Maclean N, Pound P (2000). A critical review of the concept of patient motivation in the literature on physical rehabilitation. *Soc Sci Med.* 50:495–506.

44. Sauro J, (2012). Measuring usability with the system usability scale. URL: Http://www.measuringusability.com/sus.php and procedure 9.4 2012 (2011

45. WHO (2000). World Health Organization Disability Assessment Schedule (WHODAS II). 2000.