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REVIEW ARTICLE (META-ANALYSIS)

Systematic Review on the Effects of Serious Games and Wearable Technology Used in Rehabilitation of Patients With Traumatic Bone and Soft Tissue Injuries

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Abstract

Objective: To assess the effects on functional outcomes and treatment adherence of wearable technology and serious games (ie, interactive computer applications with specific purposes useful in the "real world") currently used in physical rehabilitation of patients after traumatic bone and soft tissue injuries.

Data Sources: PubMed, EMBASE, Cochrane Library, and Current Index to Nursing and Allied Health Literature were searched without publication date restrictions for the terms *wearable*, *serious game*, *videogame* or *mobile application*, and *rehabilitation*, *exercise therapy*, and *physiotherapy*.

Study Selection: The search yielded 2704 eligible articles, which were screened by 2 independent reviewers. Studies comparing serious games to standard therapy were included.

Data Extraction: Methodology and results of the studies were critically appraised in conformity with Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

Data Synthesis: Twelve articles were included, all of which tested "off-the-shelf" games. No studies on "wearable-controlled" games or games specifically developed for rehabilitation could be included. Medical conditions included postoperative rehabilitation and acute traumatic injuries. All studies were of low to moderate quality. Only 2 studies found beneficial effects of serious games compared to conventional therapy. One of 3 studies reporting pain scores found beneficial effects of serious games compared to physiotherapy. One of 5 trials reporting treatment adherence found a statistically significant advantage in the game group compared to conventional physiotherapy. Because of heterogeneity in study design and outcome measures, pooling of data was not possible.

Conclusions: Serious games seem a safe alternative or addition to conventional physiotherapy after traumatic bone and soft tissue injuries. Future research should determine their validity and effectiveness in rehabilitation therapy, next to their cost-effectiveness and effect on treatment adherence.

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Physiotherapy and rehabilitation are considered essential for the recovery of patients suffering from traumatic bone and soft tissue injuries. Research[1] has shown, though, that only 35% to 76% of patients perform exercise regimens as prescribed. Reasons for low compliance include costs, logistical reasons, and, most importantly, lack of patient motivation.[2,3] New rehabilitation techniques that stimulate patient motivation are therefore much needed to improve treatment outcomes and decrease overall costs to society. Games or gamification techniques, derived from the video game industry, present as cheap and promising alternatives to regular physiotherapy or home-based rehabilitation exercises.

Serious games are "interactive computer applications, with or without a significant hardware component, that have a challenging goal, are fun to play and engaging, incorporate some concept of scoring, and impart to the user a skill, knowledge, or attitude that can be of use in the real world."[4(p.xvii)] Earlier studies have already

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shown beneficial effects of serious games in chronic disease, such as on upper limb rehabilitation,[5] as well as on activities of daily living functioning after stroke and in elderly patients.[5-7] In these studies,[5-7] games were used both as an adjunct to regular rehabilitation therapy and as a stand-alone alternative treatment with highly similar outcomes.

Recently, a great interest has arisen in combining games and wearable technology.[1,8,9] *Wearable technology* refers to electronic devices worn on the body, which are nonobtrusive and contain sensors for recording and storage of data. Wearable devices track the "connected self" and send data to a smartphone, network, or database.[10,11] Combining digital games and wearable technology could make physiotherapy more engaging and immersive than standard therapy regimens[5,12-16] while objectively measuring physical improvements. Wearable devices can thus be used to refine personal treatment and to monitor individual progress.[10] Combining serious games and wearable technology thus offers a powerful combination to improve treatment adherence and potentially lower treatment costs.[7]

Despite the proven potential of serious games in neurorehabilitation or for elderly patients,[5,6] little is known about their overall effectiveness in rehabilitation after traumatic bone and soft tissue injuries, which is of a shorter duration than that in the techniques applied in previous studies.[14,17-19] Moreover, few serious game−based interventions have previously applied validation research strategies during their development, despite the importance of determining validity, as shown in therapeutic and training interventions.[20,21] This systematic review aims to provide an overview of serious games, with or without wearable technology, that are currently used in rehabilitation of patients suffering from traumatic bone and soft tissue injuries. We aim to assess their effects on treatment duration and functional outcomes, treatment adherence, and adverse events compared to conventional rehabilitation treatment.

Methods

Search strategy

A systematic literature search in the peer-reviewed literature on the effects of serious games and/or wearable technology used in rehabilitation was carried out. PubMed, EMBASE, Cochrane Library, and Current Index to Nursing and Allied Health Literature were searched without publication date restrictions for the following key terms: ("Mobile Applications"[MeSH] OR wearable OR serious gam* OR videogam* OR video gam* OR gaming OR game-based) AND ("Rehabilitation"[MeSH] OR "Exercise Therapy"[MeSH] OR rehabilitat* OR physiotherapy* OR physical therap* OR exercise therap*), where MeSH stands for Medical Subject Headings. The last search date was September 8, 2017. In addition, the reference lists of relevant articles were screened for any other eligible articles to include for review. The systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist. The protocol for this systematic review was registered in the International Prospective Register of Systematic Reviews database under registration number CRD42015025596.

List of abbreviations:

MeSH Medical Subject Headings

Inclusion criteria

Two independent reviewers screened articles on title and abstract. Articles deemed "relevant," "dubious," or "unknown" were included for full-text review. Original peer-reviewed articles were included, evaluating any type of wearable device or serious game for the purpose of physical rehabilitation of traumatic bone and soft tissue injuries in patients of all ages. All experimental studies were considered for inclusion, including randomized controlled trials, prospective cohort studies, and case-control studies, whereas studies without control groups were excluded.

The different types of serious games were recorded, as well as the effects on patient motivation and treatment outcomes compared to the outcomes after standard rehabilitation treatment. For this study, physical rehabilitation was formally defined as treatment aimed at restoring health or normal life after illness by training and therapy[22] through discussion until a consensus was reached by the authors. Studies on psychiatric rehabilitation, neurorehabilitation, and rehabilitation of chronic conditions were excluded, as well as studies on e-learning or robotics.

Data extraction

Randomized studies were critically appraised for their methodological quality and risk of bias according to the *Cochrane Handbook for Systematic Reviews*[23] using Review Manager (RevMan version 5.3.5).[a] The Methodological Index for Non-Randomized Studies tool[24] was used to determine the risk of bias in nonrandomized studies. Basic information on the type of game and device used, study methodology, and study population was recorded. The interventions were evaluated for the type of validity measured (ie, face, content, construct, concurrent, and predictive validity).[20,21] Primary outcomes were functional outcomes, pain, and reported treatment adherence. If patients were treated until full recovery, the time until recovery was registered as a primary outcome. Adverse events were recorded as secondary outcomes.

Synthesis and analysis

The different types of interventions and patient populations were qualitatively evaluated and structured in groups according to the type of illness or condition. The quality of different reports on the interventions studied was determined by the risk of bias combined with the population size and effect sizes. If not reported, Cohen's d was calculated to determine the effect size using mean and SD or an estimation of these values based on the reported median and interquartile range. Studies were regarded to be of high quality when they had a low risk of bias, had a large sample size, and found a medium or large effect size (defined by Cohen's d of 0.5 or 0.8, respectively). The validity steps tested and those achieved are reported according to the previously reported framework by Graafland et al.[20] Because of the large heterogeneity in study design and methodology, data pooling and meta-analyses could not be performed.

Results

From a total of 2704 articles screened on title and abstract, 12 articles were considered eligible for inclusion (fig 1 and table 1).

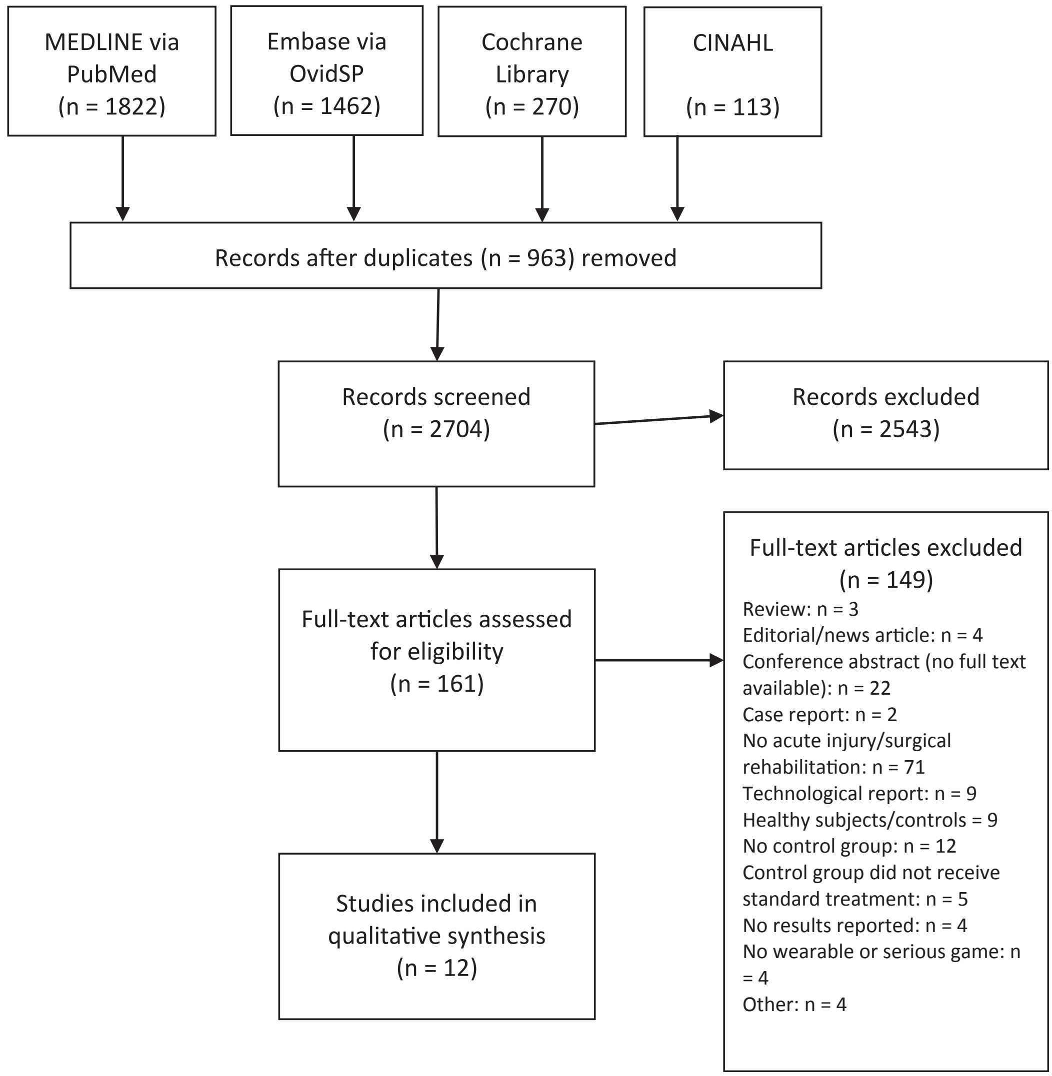

Fig 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart. Abbreviation: CINAHL, Current Index to Nursing and Allied Health Literature.

The included studies[25-36] all focused on “off-the-shelf” serious games operated on commercial gaming consoles. No trials focusing on “wearable-controlled” serious games were eligible for inclusion in this review. An overview of all studies and interventions is given in table 1, and study outcomes and validity steps are presented in table 2.

Nine[25-33] of 12 included studies had a population size between 17 and 32 patients. The 3 largest included studies had population sizes of 50[35] to 90[29,34] patients (see table 1). Risk of performance and detection bias was high overall, because of lack of blinding of participants and outcome assessments (figs 2 and 3). Considering the difficulty of participants blinding with the investigated types of interventions, 4 trials[28,29,31,36] had an otherwise low risk of bias, 1 trial[30] had a high risk of bias, and the 7 remaining trials[25-27,32-35] had an unclear risk of bias (see table 2).

“Off-the-shelf” serious games for rehabilitation

All 12 included studies investigated the effects of commercially available video games on patients recovering from both operatively treated and nonoperatively treated traumatic bone and soft tissue injuries. All but 1 study described games played on commercially available gaming consoles, such as Wii,[25-29,33-36,b] PlayStation EyeToy,[30,c] and Xbox Kinect.[31,d] One study[32] described a stand-alone cognitive game, *Dr. Kawashima’s Brain Training: How Old Is Your Brain?*,[b] to improve physical performance after total hip arthroplasty. Details of these interventions are given in table 1.

Functional outcomes

Two of 12 included studies found statistically significant differences in functional outcomes between control groups receiving regular rehabilitation exercises and intervention groups using either Wii in geriatric patients after a fall or femur fracture[34] or the cognitive game *Dr. Kawashima’s Brain Training* in patients after total hip arthroplasty[32] (see table 2). A large study by Chan et al[34] found a significantly greater improvement in the Wii serious game group (n=30) than in the historical control group (n=60) recovering with regular physiotherapy only (FIM improved by 8.7±2.5 vs 6.0±3.6; $d=.87$; $P<.05$). Treatment adherence was not reported, whereas no adverse events occurred during the trial.

Table 1 Design of studies

Study	Study Type	Population: Condition	Population: Groups (n)	Population: Age (y)	Intervention	Control	Duration, Frequency	Aim
Baltaci et al (2013)[27]	RCT	ACL reconstruction	Serious game (n=15) Control (n=15)	29±7	Balance exercises using Wii Fit	Standard physiotherapy	3mo, 3 sessions/wk	Improve functional outcomes after ACL reconstruction
Chan et al (2012)[34]	Clinical trial with matched historical controls	Geriatric disorder (diagnosis: falls [n=7, 23%], femur fracture [n=6, 20%], or stroke, Parkinson disease)	Serious game (n=30) Historical control (n=60)	Serious game group: 80.1±7.1 Historical control group: 80.0±7.0	Balance and physical exercises using Wii and Wii Fit	Standard physiotherapy	5–8wk, 2 sessions/wk	Improve physical and functional independence
Ficklscherer et al (2016)[25]	RCT (pilot)	ACL reconstruction, total knee arthroplasty	Serious game (n=17) Control (n=13)	Serious game group: 54±19 Control group: 52±18	Standard physiotherapy with Wii	Standard physiotherapy	Daily exercises plus 3.2±1.38 serious game sessions in the intervention group	Test feasibility and safety and improve functional outcomes of the knee
Fung et al (2012)[35]	RCT	Total knee arthroplasty	Serious game (n=27) Control (n=23)	Serious game group: 67.9±9.5 Control group: 68.2±12.8	Balance and mobility exercises using Wii Fit	Standard physiotherapy	On average 2mo, but as long as needed	Improve functional outcomes including balance and strength and decrease total rehabilitation time
Imam et al (2015)[28]	RCT	Lower limb amputation	Serious game (n=14) Control (n=14)	61.5 (range, 50–78)	Wii Fit	Cognitive games using Wii	4wk, 3 times/wk	Improve endurance and walking ability
Lehrl et al (2012)[32]	RCT	Total hip arthroplasty	Serious game (n=16) Control (n=16)	Serious game group: 66.1±9.3 Control group: 68.9±13.9	*Dr. Kawashima's Brain Training: How Old Is Your Brain?* in addition to regular physiotherapy exercises	Standard physiotherapy	~12wk/d	Improve hip function and strength
McPhail et al (2016)[33]	RCT (pilot)	Lower limb fracture	Serious game (n=9) Control (n=9)	Serious game group: 37 (IQR, 23–52) Control group: 43 (IQR, 30–53)	Wii Fit in addition to regular physiotherapy exercises	Standard physiotherapy	6 sessions, 20min of an additional game exercise in the serious game group	Test feasibility and safety and determine power for complete RCT

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Table 1 (*continued*)

		Population						
Study	Study Type	Condition	Groups (n)	Age (y)	Intervention	Control	Duration, Frequency	Aim
Parker et al (2016)[36]	RCT	Burn injury	Serious game (n=12) Control (n=10)	26 (range, 16.75–35.00)	Wii Balance Board in addition to regular physiotherapy exercise	Individualized physiotherapy exercises	1wk, 5 sessions in total	Decrease pain scores and anxiety and improve range of motion in upper and lower limbs
Parry et al (2015)[30]	RCT (pilot)	Burn injury	Serious game (n=9) Control (n=8)	Serious game group: 10.6±4.5 Standard therapy group: 12.3±4.4	Physiotherapy exercises for upper extremity and trunk movements using PlayStation EyeToy	Standard physiotherapy consisting of upper extremity active and active assistive range of motion exercises	3wk of intensive treatment, 10 sessions/wk; 6mo of home-based exercise, 5 times/wk	Improve range of motion, increase compliance and enjoyment, and decrease pain scores
Punt et al (2016)[29]	RCT	Acute ankle sprains	Serious game (n=30) Standard physiotherapy (n=30) No treatment (n=30)	34.7±11.3	Wii Balance Board	The standard physiotherapy group received mobilization and strengthening exercises, the second control group did not receive any physiotherapy or other treatment	6wk, 2–3 sessions/wk	Improve physical function of the ankle and decrease pain
Voon et al (2016)[31]	RCT	Burn injury	Serious game (n=15) Control (n=15)	Game group: 31 (IQR, 25–39) Control group: 29 (IQR, 23–40)	Physiotherapy exercises using Xbox Kinect	Regular physiotherapy exercises	2wk, 2 sessions/d	Improve range of motion and improve treatment adherence
Yohannan et al (2012)[26]	RCT	Burn injury	Serious game (n=11) Control (n=12)	Game group: 42.1 (SE, 5.3) Control group: 32.1 (SE, 2.6)	Motion exercises using Wii Balance Board	Standard range of motion exercises	3 consecutive sessions of 15min	Decrease pain scores and anxiety and improve active range of motion in upper and lower limbs

Abbreviations: ACL, anterior cruciate ligament; IQR, interquartile range; RCT, randomized controlled trial.

Table 2 Outcomes of studies

Study	Intervention: Game or Wearable	Primary Outcome Score (Range)	Intervention Group	Control Group	Effect Size (d)	P	Risk of Bias	Validity Steps Tested	Achieved Validity
Baltaci et al (2013)[27]	Wii Fit	Modified star excursion balance test (dynamic balance [in centimeters] at 12wk):					Unclear risk of bias (Cochrane tool)	Concurrent	NA
		Anterior	4.7±7.03	6.5±5.2	0.29	NR			
		Posteromedial	3.1±6.9	5.5±5.3	0.39	NR			
		Posterolateral	−0.3±4.3	2.9±4.3	0.74	NR			
Chan et al (2012)[34]	Wii and Wii Fi	FIM	Improved 8.7±2.5	Improved 6.0±3.6	0.87	<.05	12/24 (MINORS)	Face, concurrent	Face, concurrent
		Borg's perceived exertion scale (score range, 6–20)	7.9±2.3	7.3±1.5	0.31	0.11			
Ficklscherer et al (2016)[25]	Wii	International Knee Documentation Committee functional score (score range, 0–100)	Improved from 31.16±13.36 to 42.6±19.37	Improved from 28.82±7.79 to 39.08±15.4	0.20	0.67	Unclear risk of bias (Cochrane tool)	Face, concurrent	Face
Fung et al (2012)[35]	Wii Fit	Active range of motion of the knee	Flexion: improved 17.18% Extension: improved 0.55%	Flexion: improved 17.51% Extension: improved 1.15%	Not enough data	0.951 0.492	Unclear risk of bias (Cochrane tool)	Concurrent	NA
Imam et al (2015)[28]	Wii Fit	2-minute walk test	148.5±47.4	133.3±42.0	0.60	NR (sample size calculation)	Low risk of bias (Cochrane tool)	Concurrent	NA
Lehrl et al (2012)[32]	*Dr. Kawashima's Brain Training: How Old Is Your Brain?*	Harris Hip score (score range, 0–100, with 100 being the best functional score)	Difference: −37.6±14.0	Difference: −28.6±12.4	0.68	.041	Unclear risk of bias (Cochrane tool)	Face	Face
McPhail et al (2016)[33]	Wii Fit	Adverse events	None	None	±0.22	NR (sample size calculation)	17/24 (MINORS)	Face, concurrent	NA
		Lower Extremity Functional Score (score range, 0–80, with 80 being the best functional score)	Improved from 43 (IQR, 35–46) to 51 (IQR, 46–56)	Improved from 40 (IQR, 22–46) to 48 (IQR, 44–70)					
Parker et al (2016)[36]	Wii Balance Board	Pain scores (VAS)	17% more improved than the control group, improved with a 95% CI of −0.584 to −0.298	NR	r^2=1.18	.019	Low risk of bias (Cochrane tool)	Concurrent	Concurrent
Parry et al (2015)[30]	PlayStation EyeToy	Shoulder range of motion (in degrees)	Flexion: improved 44% Abduction: improved 13% (range, NR)	Flexion: improved 35% Abduction: decreased 29% (range, NR)	Not enough data	NR NR	High risk of bias (Cochrane tool)	Concurrent	NA
Punt et al (2016)[29]	Wii Balance Board	Foot and Ankle Ability Measure (physical ability questionnaire, score range, 0–100): Sports subscale	Improved from 49.1±31.9 to 73.7±25.5	Group a: improved from 37.1±25.8 to 64.0±25.5	0.38	All 3 groups improved, <.001	Low risk of bias (Cochrane tool)	Concurrent	NA
				Group b: improved from 52.6±25.6 to 70.0±26.4	0.14				
		ADL subscale	Improved from 80.2±16.3 to 90.7±13.8	Group a: improved from 70.8±20.3 to 86.8±15.2	0.27	No significant difference between any of the groups, ≥.344			
				Group b: improved from 82.8±13.7 to 88.6±13.3	0.15				

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Table 2 *(continued)*

Study	Intervention: Game or Wearable	Primary Outcome Score (Range)	Intervention Group	Control Group	Effect Size (*d*)	*P*	Risk of Bias	Validity Steps Tested	Achieved Validity
Voon et al (2016)[31]	Xbox Kinect	Self-reported exercise duration (in minutes)	49.37	26.7	Not enough data	<.0001	Low risk of bias (Cochrane tool)	Face, concurrent	Face
		QuickDASH (Disabilities of the Arm, Shoulder and Hand Score) questionnaire (score range, 0–100, with lower scores indicating better function)	Improved from 40 (IQR, 30.6–54.7) to 38 (IQR, NR)	Improved from 54.5 (IQR, 25–68) to 43.7 (IQR, NR)		No significant difference between groups at the end of the study			
Yohannan et al (2012)[26]	Wii Balance Board	Pain (VAS)	Change score: −0.32 (SE, 0.33)	Change score: 0.65 (SE, 0.37)	0.83	0.07	Unclear risk of bias (Cochrane tool)	Concurrent	–
		Anxiety (VAS)	Change score: 0.12 (SE, 0.27)	Change score: 0.23 (SE, 0.24)	0.13	0.77			
		Active range of motion (in degrees)	Change score: 2.26 (SE, 1.57)	Change score: 1.71 (SE, 1.52)	0.10	0.81			

Abbreviations: ADL, activities of daily living; IQR, interquartile range; MINORS, Methodological Index for Non-Randomized Studies; NA, not applicable; NR, not reported; VAS, visual analog scale.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)
Baltaci 2013	+	?	?	?	+	?
Ficklscherer 2016	+	?	−	?	?	?
Fung 2012	+	?	−	?	−	+
Imam 2015	+	+	−	+	?	?
Lehrl 2012	?	?	−	−	?	?
Parker 2016	+	?	−	−	+	+
Parry 2015	?	−	−	−	?	?
Punt 2016	+	?	−	?	+	+
Voon 2016	+	+	−	−	+	?
Yohannan 2012	?	?	−	+	−	?

Fig 2 Risk of bias assessment in randomized studies.

The cognitive game *Dr. Kawashima's Brain Training* had a statistically significant effect on functional outcomes in patients after total hip arthroplasty in a randomized controlled trial.[32] The trial compared an intervention group (n=16) exercising using a cognitive game in addition to the regular physiotherapy regimen with a control group (n=16) receiving physiotherapy only. The game group showed a significantly greater improvement in functional outcomes than did the control group (Harris Hip Score,

	1. Clearly stated aim	2. Inclusion of consecutive patients	3. Prospective collection of data	4. Endpoints appropriate to the aim of the study	5. Unbiased assessment of the study endpoint	6. Follow-up period appropriate to the aim of the study	7. Loss to follow-up less than 5%	8. Prospective calculation of sample size	9. An adequate control group	10. Contemporary groups	11. Baseline equivalence of groups	12. Adequate statistical analysis
Chan 2012	+	−	?	+	?	−	?	?	−	−	+	+
McPhail 2016	+	?	+	+	?	?	−	−	+	+	+	+

Fig 3 Risk of bias assessment in nonrandomized studies (Methodological Index for Non-Randomized Studies).

−37.6±14.0 out of 100 vs −28.6±12.4 out of 100; d=.68; P=.041).[32]

Ten[25-31,33,35,36] of 12 included studies found no significant effects on functional outcomes between the intervention and control groups, although all showed clinical improvements in intervention and control groups. Punt et al[29] compared functional outcomes after acute ankle sprains in a large randomized controlled trial with a low risk of bias. One group recovered using the Wii Balance Board,[c] 1 group received regular physiotherapy, and 1 group received no therapy at all. This trial[29] found similar functional results in all 3 groups, yet found no statistically significant differences between the 3 groups (within-group pre- and postintervention differences: P<.001; between-group postintervention differences: P≥.344).

Effects on pain scores

Three studies,[33,35,36] together including a total of 91 patients, examined the effects of games on pain outcomes. Parker et al[36] performed a randomized controlled trial with a low risk of bias on the effect of Wii compared to regular physiotherapy exercise on pain outcomes after acute minor burn injury. This trial[36] found a statistically significant decrease in pain in the game group (n=12) compared with the control group (n=10) receiving standard physiotherapy (r^2=1.18; 95% confidence interval, −.584 to −.298; P=.019). This trial focused on inpatient rehabilitation and therefore did not evaluate treatment adherence. No adverse events were reported.

Two other studies reporting pain outcomes also compared Wii exercises to regular physiotherapy after total knee replacement[35] and lower limb fracture,[33] and they were of moderate quality because of an unclear risk of bias[35] and a small sample size.[33] These trials[33,35] found no between-group differences in pain improvement.

Treatment adherence

Five trials reported treatment adherence data, with 1 trial[30] having a low quality because of a small sample size and a high risk of bias and 4 trials[28,31,35,36] being of moderate quality because of an unclear risk of bias and a small sample size. Only the trial by Voon et al[31] focused specifically on treatment adherence. This study[31] included 30 patients and showed a significantly longer self-reported exercise duration (in minutes) in the game group than in the control group receiving regular physiotherapy (49.37min vs 26.7min; 95% confidence interval, 20.9−34.4min; P<.0001). The other 4 trials[28,30,35,36] reporting treatment adherence found no statistically significant differences between the groups. One other study[37] reported that overall exercise compliance in both the intervention and control groups was 100%, yet it did not evaluate adherence as an outcome measure.

Because all trials treated patients for a fixed time period, rather than until full recovery, the effects of serious games on the duration of recovery could not be analyzed. The validity steps tested and the achieved levels of validity for each intervention are presented in table 2.

Discussion

This is the first systematic review that gives an overview of serious games in rehabilitation of patients with traumatic bone and soft tissue injuries. Thus far, only off-the-shelf commercially available serious games have been researched. The results from this review indicate that these serious games may have effects on functional outcome and pain scores comparable to that of regular physiotherapy alone in rehabilitation after traumatic bone and soft tissue injuries. Because of the lack of larger, higher-quality randomized studies, no definite conclusions can be drawn on the effectiveness of serious games as "stand-alone" therapy. This review found no reports on games developed specifically for rehabilitation after traumatic bone and soft tissue injuries. Also, none of the included serious games used wearable devices to monitor progress or give direct feedback to patients. Furthermore, the results indicate that serious games had few adverse effects and can therefore be regarded as a safe form of rehabilitation therapy, although sample sizes are too small for definitive conclusions.

Only 5 of 12 studies reported treatment adherence as an outcome measure, with 4 studies[28,30,35,36] showing a comparable and 1 study[31] showing an improved treatment adherence in serious game−driven rehabilitation than in regular rehabilitation. Although this supports our hypothesis of treatment adherence being an important factor contributing to the effects of serious games, the evidence remains insufficient for definite conclusions.

The findings of our systematic review are in line with previous studies examining the effects of games used in rehabilitation after stroke or in general rehabilitation. These previously published studies[5,7,12,38-40] found that commercial video games may be beneficial in rehabilitation therapy or are at least no less effective than conventional rehabilitation techniques. A Cochrane review[5] on virtual reality games for stroke rehabilitation found that serious games may be beneficial in addition to usual care but also concluded that evidence is still of too low quality to draw any specific conclusions, warranting more uniform studies with larger sample sizes.

Support for the possible effect on treatment adherence comes from a systematic review by Kairy et al[41] on telerehabilitation, which comprises home-based rehabilitation using information and communication technologies to increase accessibility of care. This study[41] found a higher patient satisfaction, next to an improved adherence to treatment, positively influencing treatment outcomes in patients recovering with telerehabilitation compared to standard care. Serious games used in a home-based setting can most certainly be regarded as an extended form of telerehabilitation. Other telerehabilitation applications, such as smartphone applications (apps) and games, also showed their potential as home-based hand therapy interventions.[42] These interventions are promising in the current age of rapidly developing technology, in combination with the aging population and rising health care costs, as they may provide an opportunity for more optimal use of health care resources and can facilitate patient self-management and independence.[43]

Telerehabilitation interventions and serious games, however, face challenges in accurately monitoring patients and providing direct feedback. Therefore, this review proposes further examination of serious games combined with wearable technology. Wearable sensors allow personal monitoring over larger time frames to measure activity, range of motion, and other parameters.[43] This monitoring provides personal guidance and feedback on the basis of the measurements using wearables while potentially being more time efficient and cost-effective for both therapists and patients. A cost-effectiveness analysis is needed in future studies to investigate this hypothesis.

Studies in this review reveal little information on the validity of the tested interventions. The validity of an instrument defines whether it measures what it is supposed to measure or trains what it is supposed to train. Validity comprises not only the clinical effectiveness of serious games as interventions in rehabilitation but also the rigor and acceptability of their internal structure and physical appearance as treatment tools. A complete scientific validation process determines the perceived acceptability of the serious game as a treatment tool (face validity), the completeness and correctness of its content (content validity), the reliability of its measurement system (construct validity), its effectiveness compared to that of other instruments that are believed to measure or train the same trait (concurrent validity), and its effectiveness in terms of objective clinical outcome measures (predictive validity).[20]

Although most studies included in this review test the concurrent validity of serious games, there is a general lack of established construct and face validity of the treatment tools. This may lead to overestimation of their effect in the test setting. The application of newly developed serious games needs to be preceded by rigorous validity research during their development so as to make reliable applications in health care and rehabilitation.

Study limitations

In this systematic review, most of the included studies are of low to moderate quality, with only a minority showing significant effects of using games over regular therapy. Several studies have small sample sizes, leading to questioning their statistical power.

A second limitation is the lack of uniform outcome measures for patients after bone and soft tissue injuries. Although most studies report their own functional outcome scores, no universal conclusion can be derived from these scores and pooling of data is not possible. Examples of universal outcome scores that could be used for this purpose are pain scores, range of motion (eg, in percentage improvement), and quality of life.

In line with this, it can be regarded as a limitation that all types of traumatic bone and soft tissue injuries in patients of all ages have been analyzed as if they were the same medical condition, but this is a heterogeneous group of patients. There may be a difference in the effects of serious games in simple rehabilitation, for example, in younger patients after a single injury, compared to complex rehabilitation of older patients suffering from multiple injuries. This comprehensive review serves to provide an overview of clinically researched serious games in the rehabilitation of traumatic bone and soft tissue injuries, because no systematic review on these types of injuries has been published to date.

Conclusions

This review concludes that serious games seem a safe rehabilitation modality for patients recovering from traumatic bone and soft tissue injuries. The results indicate that the effectiveness of off-the-shelf commercially available serious games may be comparable to that of regular physical therapy. Yet, because of the lack of solid evidence, no definite conclusions can be drawn. Moreover, future studies should determine their effectiveness in randomized controlled trials and require measurements of treatment adherence and cost-effectiveness. Furthermore, the overall heterogeneity in research strategies found in this review suggests the development of universal testing protocols for telerehabilitation programs, including newly developed serious games and wearable technology.

Suppliers

a. Review Manager, RevMan version 5.3.5; The Cochrane Collaboration.
b. Wii, *Dr. Kawashima's Brain Training: How Old Is Your Brain?*, Wii Balance Board; Nintendo.
c. PlayStation EyeToy; Sony.
d. Xbox Kinect; Microsoft.

Keywords

Orthopedics; Rehabilitation; Telemedicine; Video games; Wearable electronic devices; Wounds and injuries

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