Interaction Modalities Used on Serious Games for Upper Limb Rehabilitation: A Systematic Review

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Abstract

This systematic review aims to analyze the state-of-the-art regarding interaction modalities used on serious games for upper limb rehabilitation. A systematic search was performed in IEEE Xplore and Web of Science databases. PRISMA and QualSyst protocols were used to filter and assess the articles. Articles must meet the following inclusion criteria: they must be written in English; be at least four pages in length; use or develop serious games; focus on upper limb rehabilitation; and be published between 2007 and 2017. Of 121 articles initially retrieved, 33 articles met the inclusion criteria. Three interaction modalities were found: vision systems (42.4%), complementary vision systems (30.3%), and no-vision systems (27.2%). Vision systems and no-vision systems obtained a similar mean QualSyst (86%) followed by complementary vision systems (85.7%). Almost half of the studies used vision systems as the interaction modality (42.4%) and used the Kinect sensor to collect the body movements (48.48%). The shoulder was the most treated body part in the studies (19%). A key limitation of vision systems and complementary vision systems is that their device performances might be affected by lighting conditions. A main limitation of the no-vision systems is that the range-of-motion in angles of the body movement might not be measured accurately. Due to a limited number of studies, fruitful areas for further research could be the following: serious games focused on finger rehabilitation and trauma injuries, game difficulty adaptation based on user's muscle strength and posture, and multisensor data fusion on interaction modalities.

Keywords: Interaction modality, Serious game, Upper limb rehabilitation

Introduction

Accidents and medical conditions could affect the mobility in certain body parts; therefore, patients should perform rehabilitation exercises to recover the mobility. However, these exercises are executed in a repetitive manner without motivating the patient.

Serious games have been developed to assist people in the rehabilitation process. A serious game could be defined as "an experience that allows to the player to archive a specific purpose using the entertainment and engagement component provided by the game."[1] As a result, patients could execute their rehabilitation exercises by playing a serious game.

Moreover, there are sensors capable of recognizing body movements in the market. Consequently, these sensors have been used to interact with videogames (interaction modalities). Specifically, this systematic review found three interaction modalities used on serious games for upper limb rehabilitation: vision systems, complementary vision systems, and no-vision systems.

Contribution

The main contribution of this systematic review is to analyze the state-of-the-art regarding the interaction modalities used on serious games for upper limb rehabilitation. These interaction modalities were proposed based on the device(s) used to control the game in the studies. Furthermore, key details regarding rehabilitation were obtained per article (e.g., target disease, body parts to be rehabilitated, and metric used to assess the participant's performance).

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Method

Evidence acquisition

This systematic review was performed following the guidelines of the PRISMA[2] protocol. First, our question of research was defined as follows: What is the state-of-the-art regarding serious games and interaction devices? Second, the searching parameter was defined based on the question of research. This was composed of the sentence: "serious games rehabilitation." This sentence was searched in IEEE Xplore and Web of Science (WoS) databases. Third, the articles were filtered using the following criteria: they must be written in English, be at least four pages in length, use or develop serious games, focus on upper limb rehabilitation, and be published between 2007 and 2017.

Quality of reporting

This review includes a quantitative analysis per article, which is performed using the QualSyst standard.[3] This standard is composed of 14 assessing points. Our review uses 13 points, which are related to research design, robust measurement, and conclusions supported by the results.

According to the QualSyst standard, each assessing point can be assigned to the following values depending on the degree of meeting the criterion: two points (fully met), one point (partially met), or zero points (not met). The total score is divided by the number of assessing points. Finally, this score is expressed in terms of percentage, that is, it ranges from 0% to 100%.

Evidence synthesis

The following features were obtained per article meeting the inclusion criteria and having a QualSyst score $\geq 70\%$:

- QualSyst score: this is obtained using the QualSyst standard to assess the quality of the article.
- Device: this provides information regarding the sensors or devices used to control the game or to obtain the position of the player.
- Target disease: this corresponds to the diseases faced in the articles.
- Body parts: this refers to the body parts requiring rehabilitation. This feature involves diseases that affect the body's functions and lead to a rehabilitation process. These diseases might be classified into neurological, neurodegenerative, autoimmune, and trauma. Neurological diseases involve the following medical conditions: apoplexy, cerebral palsy, dysplasia, hand impairment, hemineglect, hemiparesis, hemiplegia, motor disabilities as a result of neurological disease, motor function impairments, and musculoskeletal and neuromuscular disorders. Chronic pain, mild stroke, natural maturation declines of motor control, Parkinson, stroke, and subacromial impingement syndrome correspond to neurodegenerative diseases. Guillain-Barré syndrome can be classified as an autoimmune condition, whereas wrist injuries can be categorized as a trauma.
- Commercial game/Game engine: authors use a commercial game or specify the game engine used to develop the game.
- Users: users participating in the experiments, which can be healthy users or users suffering a medical condition.
- Metrics: parameters used to assess the user's progress (e.g., specialist evaluation, medical scale evaluation, range-of-motion comparison at the beginning and at the end of the treatment, and game score).
- Classification algorithm: this is related to the algorithms used to recognize user's movements (e.g., kinematic analysis, device's Software Development Kits [SDK], and computer vision).
- User's motivation: authors included the user's motivation on the serious game design or they found a relationship between the use of serious games and the user's motivation during rehabilitation.
- Remote rehabilitation: the serious game can be played online; therefore, rehabilitation can be performed remotely.
- Assistance: this implies that the serious game aims to assist the physiotherapist during the rehabilitation of the user.
- Replacement: this implies that the serious game aims to replace the physiotherapist in the future.

Results

It can be seen from Figure 1 that our initial search retrieved 121 articles (37 from IEEE Xplore and 84 from WoS). After removing duplicates, 80 articles were obtained. Only 41 articles met the criteria explained earlier. Conversely, 80 articles did not meet the criteria because they (i) focus on rehabilitation on body parts different to upper limbs[4–24] or focus on other types of rehabilitation[25–44]; (ii) have purposes different to rehabilitation[45–51] (e.g., measurement of personal performance and development of musical skills); (iii) are editorial notes, reviews, and guidelines to develop serious games[1,52–73]; (iv) are incomplete articles[74]; (v) are up to three pages in length[75–78]; (vi) are not written in English[79–81]; and (vii) are out of the scope of this review.[82]

This review includes articles with QualSyst percentages $\geq 70\%$. This percentage was obtained calculating the mean score of the 41 articles meeting the inclusion criteria. Then, standard deviation was subtracted resulting in 66.48% and rounded to 70%. As a result, 33 articles were included in this review for further analysis, whereas the remaining 8 articles[83–90] were excluded because their percentages were below 70% (i.e., between 37% and 66%). The QualSyst score was low in some studies because the assessing points 2, 10, 12, and 13 of the QualSyst standard were partially or not covered.

The 33 articles having a QualSyst score $\geq 70\%$ (assessing criterion) were classified according to the interaction modality. In this review, an interaction modality is defined as the sensor(s) used to collect data, which will be processed to provide commands to the game, or control the game directly. Three interaction modalities were obtained:

(a) Vision systems: this category is related to systems only using one sensor based on a camera to obtain the data.
(b) Complementary vision systems: this category refers to systems using a camera and other sensors to obtain

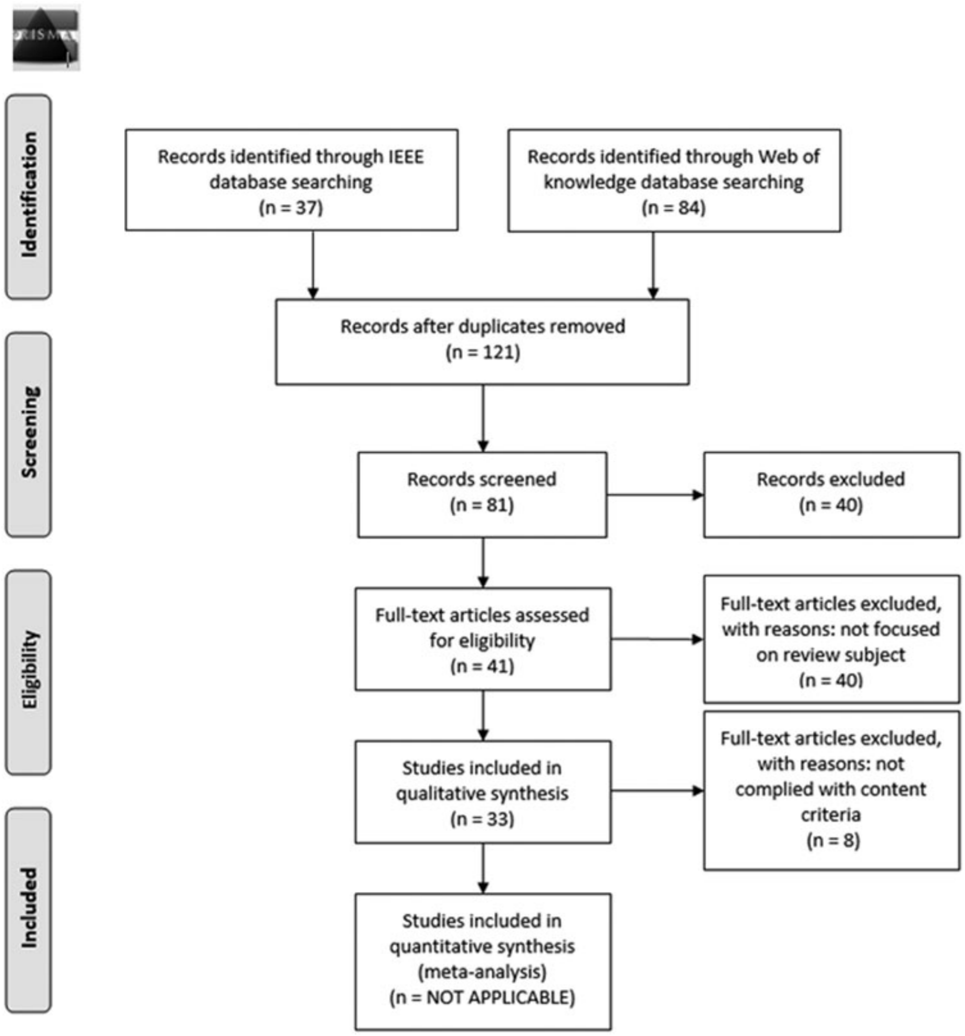

FIG. 1. PRISMA flow diagram.

the data, for example, Myo Armband, Wii Balance Board, and Leap Motion.

(c) No-vision systems: this category involves studies using devices different to a camera to control the game or to measure users' movements. These devices could be biosignal sensors, robotic systems, haptic interfaces, game consoles, and PC components.

Vision systems

This category represents 42.4% of the articles meeting the QualSyst score criterion (i.e., 14 of 33 articles). The mean QualSyst score is $86.42 \pm 7.65\%$. Furthermore, 2017 reported the highest number of published articles (seven articles[91–97]).

Moreover, Kinect is the most widely used device in this category for controlling the serious games or measuring the user's positions (i.e., 78% of the articles). The remaining studies use other devices, for example, Leap Motion,[98] PrimseSense,[99] and web cameras.[100]

In addition, 50% of the diseases treated in the articles belong to neurological diseases,[91,94,97,98,100–102] whereas 42% belong to neurodegenerative diseases.[92,93,95,99,103,104] Conversely, 7% of the articles do not report the medical condition that could be treated with the serious game.[96]

Regarding the body parts treated in the articles, the majority of studies focus on the shoulder,[91,92,95–97,101,104] arms,[91,93,97,99,102] and elbows.[91,92,96,100,101] Conversely, few studies focus on finger[98] and wrist[92,98] rehabilitation.

Unity 3D is used as the game engine in 35% of the studies.[93,97–99,102] Other studies use Blender Game Engine,[97] XNA Game Studio,[94] commercial games,[91,103] and SecondLife[101] as the game engine. These represent 35%, whereas 28% of the studies do not report the game engine used to develop the serious game.[95,96,100,104]

The studies analyzed in this review use several methods to measure the patient's progress during rehabilitation through serious games. Some of these methods are as follows: game score[94,95,97,100]; comparison of the range-of-motion[96,98,99,101] and medical scales[91,100,103]; evaluation from a physiotherapist[92,94,102]; and continuity and proper execution of the movement, as well as speed and time in performing the movement.[104] Only one study does not report the method used to assess the patient's progress.[93]

The majority of the studies of this category (85%) find a relationship between the use of serious games and the user's

Table 1. Vision Systems

Year	Author	QualSyst score	Device	Target population	Body parts	Commercial game/ game engine	Users	Metrics	Classification techniques	User's motivation	Remote rehabilitation	Assistance to the physiotherapist	Replacement of the physiotherapist
2017	Trombetta et al.[92]	95	Kinect	Mild stroke	Shoulder Elbow Wrist Knee	Unity 3D	10 Healthy users	Physiotherapist evaluation	—	Yes	—	Yes	—
2017	Eckert et al.[97]	95	Kinect	Motor function impairments	Shoulder Arm	Blender Game Engine	8 Affected children 3 Affected adults 8 Healthy children	Game score	Kinect SDK	Yes	—	Yes	—
2017	Türkbey et al.[91]	92	Kinect	Apoplexy	Shoulder Elbow Arm	Commercial game	20 Affected users	Medical scale evaluations	—	Yes	—	—	—
2017	Bonnechère et al.[95]	91	Kinect	Natural maturation declines of motor control	Shoulder Hips Trunk	—	81 Healthy users	Game score	—	—	—	—	—
2017	Idriss et al.[94]	90	Kinect	Musculoskeletal disorders	Balance	XNA Game Studio	10 Healthy users 20 Affected users	Game score Physiotherapist evaluation	—	Yes	—	Yes	—
2017	Bonnechère et al.[96]	90	Kinect	—	Shoulder Elbow Hips Knee	—	10 Healthy adults 19 Healthy children	Range-of-motion comparison	Model-based approach	—	—	—	—
2017	Shiratuddin et al.[93]	77	Kinect	Stroke	Arm	Unity 3D	—	—	—	Yes	Yes	—	Yes
2016	Elnaggar and Reichardt[98]	85	Leap motion	Hand disabilities	Fingers Wrist	Unity 3D	3 Healthy users 3 Affected users	Range-of-motion comparison	Law of sines	Yes	Yes	Yes	—
2015	Bower et al.[99]	90	Prime-Sense	Stroke	Arm Trunk	Unity 3D	40 Affected users	Range-of-motion comparison	PrimeSense SDK	Yes	—	—	—
2014	d'Ornellas et al.[102]	91	Kinect	Hemiplegia	Arm	Unity 3D	—	Physiotherapist evaluation	—	Yes	—	Yes	—
2014	Jaume-I-Capó et al.[100]	86	Webcam	Cerebral palsy	Trunk Shoulder Elbow	—	10 Affected users	Game score Medical scale evaluations	Computer vision–continuously adaptive mean shift	Yes	—	Yes	—
2014	Pompeu et al.[103]	83	Kinect	Parkinson	Upper limbs Lower limbs Trunk	Commercial games	7 Affected users	Medical scale evaluations	—	Yes	—	Yes	—
2015	Rahman[101]	70	Kinect	Hemiplegia	Shoulder Elbow Hips Ankle	SecondLife engine	8 Healthy users	Range-of-motion comparison	Kinematic analysis	Yes	—	Yes	—
2013	Fikar et al.[104]	75	Kinect	Subacromial impingement syndrome	Shoulder	—	—	Continuity of the movement Performed speed and timing of the movement Proper execution of the movement	—	Yes	Yes	Yes	—

SDK, Software Development Kit.

motivation during rehabilitation.[91–94,97–104] Moreover, three studies offer rehabilitation through serious games remotely.[93,98,104]

The assistance to the physiotherapist is not a priority in the minority of these studies (35%).[91,93,95,96,99] On the contrary, one study aims to replace the physiotherapist in the future.[93]

Further details are summarized in Table 1.

Complementary vision systems

This interaction modality represents 30.3% of the articles meeting the QualSyst score criterion (i.e., 10 of 33 articles). Its mean QualSyst score is 85.7 ± 8.99%. The highest number of articles was published in 2017[105–107] and 2011.[108–110]

Similar to vision systems, the most widely used device in the complementary vision systems is the Kinect, which is used with other systems such as Leap Motion,[111] Myo Armband,[107] Wii Balance Controller,[106] Vicon system,[112] MoCap,[109] IOtracker,[109] G.tec g.MOBiLab,[109] and TMSI Mobi.[109]

Other studies use the following combinations of devices: an Optitrack v120 and a haptic interface[105]; accelerometers, vibrotactile interfaces, and a Microsoft live cam v3[113]; a web camera and a thermal vision camera[110]; and a web camera with a robotic system.[114]

The medical conditions treated in the studies of this category correspond to neurological[105,107,111–113] (50%), neurodegenerative[106,109,110,114] (40%), and autoimmune[113] (10%) diseases. The most treated body part in these studies is the wrist,[107,108,111] followed by the elbow,[107,112,114] shoulder,[107,112,114] fingers,[105,111] and hand.[108,110,113]

It can be seen that the studies of this category use Unity 3D,[107,109] 3D webGL,[111] ArtoolKit,[113] Chai3D,[113] FLARToolKit,[108] NyARToolKit,[108] and XNA Game Studio[110] to develop the serious games. Conversely, 40% of the studies do not report the game engine used to develop the serious game.[105,106,112,114]

In this category, the following methods are used to assess the patient's progress: medical scales,[105,106,109,114] evaluation from a physiotherapist,[113] and time in finishing the exercise.[113] Conversely, 50% do not mention the method used to evaluate the patient's progress.[107,108,110–112]

The majority of the studies of this category (80%) find a positive relationship between the use of serious games and patient's motivation during rehabilitation.[105–110,112–114] In this interaction modality, 40% of the studies propose remote rehabilitation systems.[107–109,111] On the contrary, 70% of the studies aim to assist the physiotherapist.[105,106,110–114] Conversely, 10% of the studies aim to replace the physiotherapist in the future.[107]

Table 2 summarizes these studies.

No-vision systems

This interaction modality is composed of nine articles (i.e., 27.2%). Its mean QualSyst score is 84.66 ± 9.2%. The years reporting the highest number of publications were 2014[115–117] and 2016.[118–120]

These studies use a wide variety of devices, for example, Lego robot,[119] Myo Armband,[119] commercial joysticks,[121] mouse,[122] gyroscope,[117] magnetometer,[117] and Nintendo®.[123] Moreover, the most treated medical condition in the studies of this interaction modality (66.6%) is the neurodegenerative disease.[115,116,118,120,122,123] One study focuses on trauma injuries.[117] Conversely, one study does not provide information regarding the medical condition that is treated.[121] In addition, the body parts treated in this interaction modality are the arm,[119–123] elbow,[122,123] shoulder,[122,123] wrist,[115–117] and hand.[120]

Regarding the game engine, 44.4% of the studies of this interaction modality do not report the game engine used to develop the serious game. On the contrary, 22.2% of the studies use commercial games[118,123] as serious games, whereas 11.1% of the studies use Unity 3D[115] to implement the serious game.

In this interaction modality, the following methods are used to assess the patient's performance during the game: game score,[115,122] medical scales,[123] comparison of the range-of-motion,[118,120] limp distance from the target,[116] heart rate,[119] "motion jerk,"[116] respiratory rate,[121] and energy consumption from the assistive robot.[116]

The majority of the studies (55.5%) find a relationship between the patient's motivation during rehabilitation and the use of serious games.[115,117,119–123] Moreover, 33.3% of the studies aim to provide remote rehabilitation,[117,119,120] whereas 11.1% of the studies aim to assist the physiotherapist.[122]

Table 3 provides details of these studies.

Discussion

The search time period of this review was established from 2007 to 2017. Figure 2 shows the histogram of the number of publications per year. Note that the oldest publication meeting the inclusion criteria is from Saposnik et al.[123] Furthermore, 2017 reported the highest number of publications (11 articles).

Regarding the QualSyst score, the three interaction modalities presented in this review obtained a mean QualSyst score of 85.72 ± 8.27%. Moreover, vision systems corresponded to 42% of the publications included in this review, followed by no-vision systems (30%) and complementary vision systems (27%). In terms of the devices used to collect the body movements, the most widely used device was the Kinect sensor, which was used in 16 of the 33 publications included in this review. Only two studies reported the accuracy levels of Kinect: 70% and 89% of recognition on gross and fine motor movements of users,[95] and 91.9% of recognition on the user's movement.[112] Only one study[109] concluded that Kinect is not suitable as a medical evaluation device.

Regarding the medical conditions, neurodegenerative diseases were the most treated diseases reported in the articles (48%). Specifically, 75% of these studies related to neurodegenerative diseases focused on strokes. Neurological diseases were treated in 36% of the articles. Furthermore, autoimmune and trauma conditions were addressed in 9% of the articles. Conversely, 8% of the articles did not report the medical condition that was addressed.

In addition, the studies presented in this review mainly focused on the rehabilitation of the following body parts: the shoulder (19%), arm (16%), and elbow (15%). The percentages of the remaining body parts are presented

Table 2. Complementary Vision Systems

Year	Author	QualSyst score	Device	Target population	Body parts	Commercial game/game engine	Users	Metrics	Classification techniques	User's motivation	Remote rehabilitation	Assistance to the physiotherapist	Replacement of the physiotherapist
2017	Bortone et al.[105]	100	Optitrack V120 Wearable haptic devices	Cerebral palsy Dyspraxia	Fingers	—	4 Healthy users 4 Affected users	Medical scale evaluation	Computer vision	Yes	—	Yes	—
2017	Bonnechère et al.[106]	90	Wii Balance Board Kinect	Stroke	Arm Hips	—	41 Affected users	Medical scale evaluation	—	Yes	—	Yes	—
2017	Esfahlani et al.[107]	81	Kinect Myo Armband	Neuromuscular disorders	Shoulder Elbow Wrist	Unity 3D	—	—	Inverse kinematics	Yes	Yes	—	Yes
2016	Rahman[111]	85	Kinect Leap Motion	Hemiplegia	Fingers Wrist Forearm	3D WebGL	1 Affected user	—	Inverse kinematics	—	Yes	Yes	—
2016	Omelina et al.[112]	72	Kinect Vicon system	Cerebral palsy	Elbow Shoulder Trunk	—	—	—	Facial recognition–local binary patterns	—	—	Yes	—
2015	Prange et al.[114]	100	ArmeoBoom Webcam	Stroke	Shoulder Elbow	—	70 Affected users	Medical scale evaluation	Computer vision with markers	Yes	—	Yes	—
2016	Hossain et al.[113]	81	Accelerometer Vibrotactile interface Microsoft life cam v3	Stroke Guillain-Barré	Hand–eye coordination	AR toolkit Chai3D	25 Healthy users 10 Stroke users 1 Guillain-Barré user	Physiotherapist evaluation Time to complete the exercise	—	Yes	—	Yes	—
2011	Cheng[108]	87	Mouse Webcam markers	—	Hand Wrist	NyARToolKit FLARToolKit	—	—	Computer vision with markers	Yes	Yes	—	—
2011	Schönauer et al.[109]	83	MoCap IOTracker Kinect Gtec g.MOBIlab TMSI Mobi	Chronic pain	Upper limbs Lower limbs	Unity 3D	6 Affected users	Medical scale evaluation	Computer vision with markers	Yes	Yes	—	—
2011	Evett et al.[110]	78	Webcam Thermal camera	Stroke	Hand	XNA game studio	—	—	Computer vision–color segmentation	Yes	—	Yes	—

Table 3. No-Vision Systems

Year	*Author*	*QualSyst Score*	*Device*	*Target population*	*Body parts*	*Commercial game/game engine*	*Users*	*Metrics*	*Classification techniques*	*User's motivation*	*Remote rehabilitation*	*Assistance to the physiotherapist*	*Replacement of the physiotherapist*
2017	Darzi et al.[121]	80	Haptic master Standard commercial joystick G.tec respiration airflow sensor	—	Arm	—	12 Healthy users	Respiration rate	—	Yes	—	—	—
2016	Saposnik et al.[118]	92	Nintendo Wii	Stroke	Upper limbs	Commercial games	141 Affected users 70 Wii users 71 Other activities	Range-of-motion comparison	—	—	—	—	—
2016	Lopez-Samaniego and Garcia-Zapirain[119]	87	Microsoft band 2 Lego robot Myo armband	Physical and cognitive rehabilitation	Arm	Xcode software development kit	7 Affected users	Hearth rate	MicrosoftBandKit_IOS MyoKit	—	Yes	—	—
2016	House et al.[120]	79	BrightArm duo systems	Stroke	Arm Hand	BrightArm custom games	7 Affected users	Range-of-motion comparison	—	Yes	Yes	—	—
2015	Hocine et al.[122]	86	Mouse	Stroke	Arm Stroke Elbow	—	7 Affected users	Game score	Digital pheromone-based algorithm	Yes	—	Yes	—
2014	Andrade et al.[115]	100	Rehabilitation robot	Stroke	Wrist	Unity 3D	4 Healthy users	Game Score	Q-learning Reinforcement learning	Yes	—	—	—
2014	Moretti et al.[116]	75	Inmotion arm	Stroke	Wrist	—	1 Affected user	Distance from target Robot power motion jerk	Neural networks Principal components analysis	—	—	—	—
2015	Baranyi et al.[117]	71	Gyroscope Motion sensor Magnetometer	Wrist injuries	Wrist	—	—	—	—	Yes	Yes	—	—
2010	Saposnik et al.[123]	92	Nintendo Wii	Stroke	Arm Shoulder Elbow	Commercial games	22 Users 11 Serious game treatment 11 Common treatment	Medical scale evaluation	—	—	—	—	—

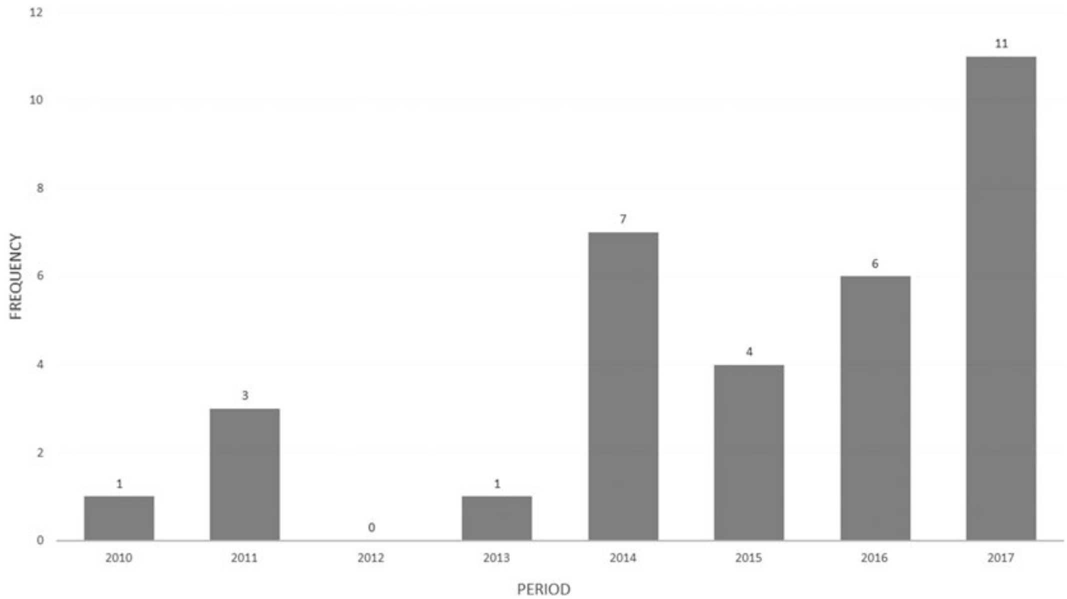

FIG. 2. Publications histogram.

in Figure 3. Regarding the game engine, XNA Game Studio, Blender Game Engine, and Unity 3D were used to develop the serious games. Other studies used commercial games.

Several metrics to assess the patient's performance during the playing were proposed in the articles. The main metrics used in the studies were medical scale evaluation (24.24%), range-of-motion comparison (18.18%), game score (18.18%), and physiotherapist evaluation (12.12%). The most used algorithms to recognize user's movement were computer vision (21.21%), device's SDK (12.12%), and inverse kinematics (6.06%).

Moreover, one of the key objectives of a serious game is to maintain the patient's motivation to finish the exercises. The majority of the articles (75%) included in this review reported a positive relationship between patient's motivation and the use of serious games. These studies identified the user's motivation as follows: using custom-designed serious game or commercial games as a motivational factor[92–94,97–107,109,110,113,115,117,118,121,122]; adding competitive elements, for example, multiplayer, tournaments[102,120]; or using surveys on user's feedback.[91,93,94,97–99,105,106,109,110,113,114,118,120,122]

In addition, serious games might permit the rehabilitation to be remotely. It can be seen that 30.3% of the articles considered offering rehabilitation remotely through serious games. These remote serious games provided the following data to the specialist: tracking and session IDs, date, time, start and end times, left limb angle, joint data (orientation, position, and angular velocity), muscle data (eight surface EMG channels), and range-of-motion score.[93,107] Furthermore, 51.5% of the articles aimed to assist the physiotherapist by providing information regarding the patient's progress.

Three studies aimed to replace the physiotherapist in the future. Two of these studies proposed a dynamic adaptive system, in which a virtual therapist supervises and assesses the user's performance based on parameters previously given by a specialist.[93,107]

Regarding limitations per interaction modality, vision systems and complementary vision systems present two main limitations: environmental conditions might affect the device's performance (e.g., lighting conditions and occlusion of body parts)[97,100,106–113]; and interaction modalities based on Kinect cannot detect finger positions using its SDK.[91–97,101–103] Regarding the no-vision systems, its main limitation is that the range-of-motion in angles of the body movement might not be measured accurately.[117,118,120,122,123] Other limitations irrespective of the interaction modality are as follows: the games were not specifically designed for rehabilitation[91,98,103,118,123] and some studies did not report whether

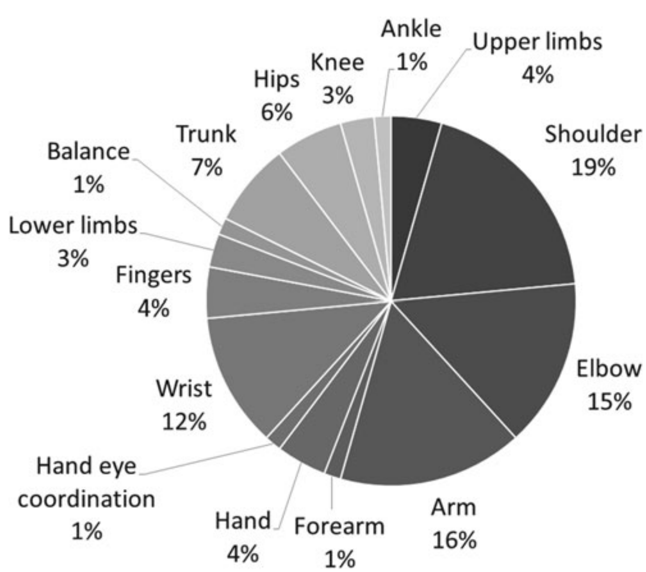

FIG. 3. Body parts for rehabilitation.

the game was commercial or was implemented by the authors.[95,96,100,104–106,108,110–112,114,116,117,121,122]

In addition, some trends regarding the interaction modalities are to provide remote rehabilitation,[93,98,104,107–109,111,117,119,120] to assist the specialist during the session,[92,94,97,98,100–106,110–114,122] and to design games focused on rehabilitation following the advice of the specialist.[94,96,97,99,100,104,106,107,110,115,120]

Finally, due to a limited number of studies, it can be concluded that fruitful areas for further research could be serious games focused on finger rehabilitation and trauma injuries, remote rehabilitation through a serious game, game difficulty adaptation based on user's muscle strength and posture, multisensor data fusion on interaction modalities, biosignals as interaction modality, and biosignals to measure user's motivation.

Conclusions

In this review, interaction modalities used on serious games for upper limb rehabilitation are presented. Only 33 articles of 121 articles initially retrieved met the inclusion criteria (27.3%). Specifically, three interaction modalities were identified in the articles: vision systems (42.4%), complementary vision systems (30.3%), and no-vision systems (27.3%). Moreover, vision systems and complementary vision systems obtained a similar mean QualSyst score (i.e., ∼86%) followed by no-vision systems (84.6%).

It can be seen that almost half of the studies (48.48%) used the Kinect sensor to obtain the body movements. Similarly, almost half of the studies (48.48%) focused on neurodegenerative diseases. On the contrary, Unity was the most widely used game engine (24.24%), whereas the shoulder was the most treated body part in the studies (19%) in terms of upper limb rehabilitation.

Regarding the technique used to assess the patient's performance, the most widely used technique in the studies was a comparison of the degrees of the user's movement obtained through medical scales before and after performing rehabilitation exercises.

Acknowledgments

The author C.A.A.-L. thanks Consejo Nacional de Ciencia y Tecnología (CONACYT) for funding his studies under a scholarship (550372). The author E.J.R.-R. thanks PRODEP-SEP for supporting this research under the program ''Grant for incorporation of new Professors (Apoyo a la Incorporación de Nuevos Profesores de Tiempo Completo).''

Author Disclosure Statement

No competing financial interests exist.

References

1. Rego P, Moreira PM, Reis LP. Serious games for rehabilitation a survey and a classification towards a taxonomy. 5th Iberian Conference on Information Systems and Technologies, Santiago de Compostela, Spain; June 16–19, 2010:1–6.
2. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med 2009; 6:e1000097.
3. Kmet LM, Cook LS, Lee RC. *Standard Quality Assessment Criteria for Evaluating Primary Research from a Variety of Fields*. Edmonton, Canada: Alberta Heritage Foundation Medical Research AHFMR-HTA Initiat #13; 2004:1–28.
4. Pérez-Ibarra JC, Siqueira AAG. Comparison of kinematic and EMG parameters between unassisted, fixed- and adaptive-stiffness robotic-assisted ankle movements in post-stroke subjects. 2017 International Conference on Rehabilitation Robotics (ICORR), London, Uk; July 17–20, 2017:461–466.
5. Dao TT, Tannous H, Pouletaut P, et al. Interactive and connected rehabilitation systems for E-health. IRBM 2016; 37:289–296.
6. Cho KH, Lee KJ, Song CH. Virtual-reality balance training with a video-game system improves dynamic balance in chronic stroke patients. Tohoku J Exp Med 2012; 228:69–74.
7. Baranyi R, Willinger R, Lederer N, et al. Chances for serious games in rehabilitation of stroke patients on the example of utilizing the Wii Fit Balance Board. IEEE 2nd International Conference on Serious Games and Applications for Health (SeGAH), Vilamoura, Portugal; May 2–3, 2013:6.
8. Thomas S, Fazakarley L, Thomas PW, et al. Mii-vitaliSe: A pilot randomised controlled trial of a home gaming system (Nintendo Wii) to increase activity levels, vitality and well-being in people with multiple sclerosis. BMJ Open 2017; 7:e016966.
9. Gonçalves ACBF, Dos Santos WM, Consoni LJ, Siqueira AAG. Serious games for assessment and rehabilitation of ankle movements. IEEE 3rd International Conference on Serious Games Applications and Health, Rio de Janein Brazil; May 14–16, 2014.
10. Máximo-Bocanegra N, Martín-Ruiz ML. An innovative serious game for the detection and rehabilitation of oral-facial malfunction in children: A pilot study. J Sensors 2017; 2017:Article ID 8745437.
11. Leblong E, Fraudet B, Dandois M, et al. A 4 weeks home training program using a biofeedback serious game and sensors for Parkinson's disease: A pilot study on a new and completely autonomous solution. International Conference Congress of Virtual Rehabilitation ICVR, Montreal, QC, Canada; June 19–22, 2017; pp 1–2.
12. Labruyère R, Gerber CN, Birrer-Brütsch K, et al. Requirements for and impact of a serious game for neuro-pediatric robot-assisted gait training. Res Dev Disabil 2013; 34:3906–3915.
13. Jaarsma T, Klompstra L, Ben Gal T, et al. Increasing exercise capacity and quality of life of patients with heart failure through Wii gaming: The rationale, design and methodology of the HF-Wii study; A multicentre randomized controlled trial. Eur J Heart Fail 2015; 17:743–748.
14. Tannous H, Istrate D, Benlarbi-Delai A, et al. A new multi-sensor fusion scheme to improve the accuracy of knee flexion kinematics for functional rehabilitation movements. Sensors (Switzerland) 2016; 16:pii:E1914.
15. Naumann T, Kindermann S, Joch M, et al. No transfer between conditions in balance training regimes relying on tasks with different postural demands: Specificity effects of two different serious games. Gait Posture 2015; 41:774–779.
16. Jansen-Kosterink SM, Huis in't Veld RMHA, Schönauer C, et al. A serious exergame for patients suffering from chronic musculoskeletal back and neck pain: A pilot study. Games Health J 2013; 2:299–307.
17. Girardin-Vignola G, Michaud B, Begon M, Roussel P. A serious game for gait rehabilitation with the Lokomat. IEEE Conference. August 2017, pp. 3–4. doi: 10.1109/ICVR.2017.8007482

18. Martín-Ruiz ML, Máximo-Bocanegra N, Luna-Oliva L. A virtual environment to improve the detection of oral-facial malfunction in children with cerebral palsy. Sensors (Switzerland) 2016; 16:444.
19. Kontadakis G, Chasiouras D, Proimaki D, Mania K. Gamified 3D orthopaedic rehabilitation using low cost and portable inertial sensors. 2017 9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games), Athens, Greece; September 6–8, 2017:165–168.
20. Páez-Ardila DR, Parra-Navarro LM, Salinas SA. Serious game for rehabilitation of meniscus injury using a prototype of orthosis. Conference: Health Care Exchanges (PAHCE), 2013 Pan American, Medellin, Colombia; April 29–May 4, 2013:1–6.
21. Tannous H, Istrate D, Benlarbi-delai A, et al. Exploring various orientation measurement approaches applied to a serious game system for functional rehabilitation. In Conference Proceedings: Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Orlando, FL; August 16–20, 2016:1987–1990.
22. Tannous H, Dao TT, Istrate D. Tho MCHB. Serious game for functional rehabilitation. 2015 International Conference on Advances in Biomedical Engineering ICABME 2015, Beirut, Lebanon; September 16–18, 2015:242–245.
23. Bonnechère B, Omelina L, Jansen B, Van Sint Jan S. Balance improvement after physical therapy training using specially developed serious games for cerebral palsy children: Preliminary results. Disabil Rehabil 2017; 39:403–406.
24. Velasco MA, Raya R, Muzzioli L, et al. Evaluation of cervical posture improvement of children with cerebral palsy after physical therapy based on head movements and serious games. Biomed Eng Online 2017; 16:157–169.
25. Elaklouk AM, Mat Zin NA, Shapii A. Investigating therapists' intention to use serious games for acquired brain injury cognitive rehabilitation. J King Saud Univ Comput Inf Sci 2015; 27:160–169.
26. Bottiroli S, Tassorelli C, Lamonica M, et al. Smart aging platform for evaluating cognitive functions in aging: A comparison with the MoCA in a normal population. Front Aging Neurosci 2017; 9:1–14.
27. Burdea G, Polistico K, Krishnamoorthy A, et al. Feasibility Study of the *Bright Brainer*™ integrative cognitive rehabilitation system for elderly with dementia. Disabil Rehabil Assist Technol 2016; 10:421–432.
28. Mondéjar T, Hervás R, Johnson E, et al. Correlation between videogame mechanics and executive functions through EEG analysis. J Biomed Inform 2016; 63:131–140.
29. Lv Z, Esteve C, Chirivella J, Gagliardo P. Serious game based personalized healthcare system for dysphonia rehabilitation. Pervasive Mob Comput 2017; 41:504–519.
30. Amado I, Brénugat-Herné L, Orriols E, et al. A serious game to improve cognitive functions in schizophrenia: A pilot study. Front Psychiatry 2016; 7:1–11.
31. Liu XD, Jin HZ, Ng BHP, et al. Therapeutic effects of qigong in patients with COPD: A randomized controlled trial. Hong Kong J Occup Ther 2012; 22:38–46.
32. Fernández-Aranda F, Jiménez-Murcia S, Santamaría JJ, et al. Video games as a complementary therapy tool in mental disorders: PlayMancer, a European multicentre study. J Ment Health 2012; 21:364–374.
33. Gamito P, Oliveira J, Coelho C, et al. Cognitive training on stroke patients via virtual reality-based serious games. Disabil Rehabil 2017; 39:385–388.
34. Lv Z, Chirivella J, Gagliardo P. Bigdata oriented multimedia mobile health applications. J Med Syst 2016; 40:120.
35. Rego PA, Rocha R, Faria BM, et al. A serious games platform for cognitive rehabilitation with preliminary evaluation. J Med Syst 2017; 41:1–15.
36. Aresti-Bartolome N, Garcia-Zapirain B. Cognitive rehabilitation system for children with autism spectrum disorder using serious games: A pilot study. Biomed Mater Eng 2015; 26:S811–S824.
37. Manera V, Petit P-D, Derreumaux A, et al. ''Kitchen and cooking,'' a serious game for mild cognitive impairment and Alzheimer's disease: A pilot study. Front Aging Neurosci 2015; 7:24.
38. Reynolds LM, Davies JP, Mann B, et al. StreetWise: Developing a serious game to support forensic mental health service users' preparation for discharge: A feasibility study. J Psychiatr Ment Health Nurs 2017; 24:185–193.
39. Rico-Olarte C, López DM, Narváez S, et al. Haphopphysio: A computer game to support cognitive therapies in children. Psychol Res Behav Manag 2017; 10:209–217.
40. Muhammad G, Masud M, Alelaiwi A, et al. Spectrotemporal directional derivative based automatic speech recognition for a serious game scenario. Multimed Tools Appl 2015; 74:5313–5327.
41. Politis Y, Robb N, Yakkundi A, et al. People with disabilities leading the design of serious games and virtual worlds. Int J Serious Games 2017; 4:63–73.
42. Alloni A, Sinforiani E, Zucchella C, et al. Computer-based cognitive rehabilitation: The CoRe system. Disabil Rehabil 2017; 39:407–417.
43. Vallejo V, Wyss P, Chesham A, et al. Evaluation of a new serious game based multitasking assessment tool for cognition and activities of daily living: Comparison with a real cooking task. Comput Hum Behav 2017; 70:500–506.
44. Gamito P, Oliveira J, Lopes P, et al. Executive functioning in alcoholics following an mhealth cognitive stimulation program: Randomized controlled trial. J Med Internet Res 2014; 16:1–13.
45. Borghese NA, Pirovano M, Mainetti R, Lanzi PL. IGER: An intelligent game engine for rehabilitation. Biosyst Biorobot 2013; 1:947–950.
46. Duvinage M, Castermans T, Petieau M, et al. Performance of the Emotiv Epoc headset for P300-based applications. Biomed Eng Online 2013; 12:1–15.
47. Prahm C, Vujaklija I, Kayali F, et al. Game-based rehabilitation for myoelectric prosthesis control. JMIR Serious Games 2017; 5:e3.
48. Ferracani A, Pezzatini D, Seidenari L, Del Bimbo A. Natural and virtual environments for the training of emergency medicine personnel. Univ Access Inf Soc 2015; 14:351–362.
49. Manera V, Ben-Sadoun G, Aalbers T, et al. Recommendations for the use of serious games in neurodegenerative disorders: 2016 Delphi Panel. Front Physiol 2017; 8:1–10.
50. Bégel V, Di Loreto I, Seilles A, Dalla Bella S. Music games: Potential application and considerations for rhythmic training. Front Hum Neurosci 2017; 11:1–7.
51. van Riel W, Post J, Langeveld J, et al. A gaming approach to networked infrastructure management. Struct Infrastruct Eng 2017; 13:855–868.

52. Wiederhold BK. Virtual reality in healthcare: Medical simulation and experiential interface. Annual Review of Cybertherapy and Telemedicine, IOS Press BV, Amsterdam, Netherlands, 2015: pp 1–240.
53. Binder JC, Zöllig J, Eschen A, et al. Multi-domain training in healthy old age: Hotel Plastisse as an iPad-based serious game to systematically compare multi-domain and single-domain training. Front Aging Neurosci 2015; 7:137.
54. Åberg AC, Halvorsen K, From I, et al. A study protocol for applying user participation and co-learning—lessons learned from the ebalance project. Int J Environ Res Public Health 2017; 14:1–17.
55. Lawrence H, Hills S, Kline N, et al. Effectiveness of exercise on functional mobility in adults with cerebral palsy: A systematic review. Physiother Canada 2016; 68:398–407.
56. Bamparopoulos G, Konstantinidis E, Bratsas C, Bamidis PD. Towards exergaming commons: Composing the exergame ontology for publishing open game data. J Biomed Semantics 2016; 7:1–15.
57. Horne-Moyer HL, Moyer BH, Messer DC, Messer ES. The use of electronic games in therapy: A review with clinical implications. Curr Psychiatry Rep 2014; 16: 520.
58. Karray F, Alemzadeh M, Saleh JA, Arab MN. Human-computer interaction: Overview on state of the art. Int J Smart Sens Intell Syst 2008; 1:137–159.
59. Frutos-Pascual M, Zapirain BG. Review of the use of AI techniques in serious games: Decision-making and machine learning. IEEE Trans Comput Intell AI Games 2015:133–152.
60. Abdulkader SN, Atia A, Mostafa MSM. Brain computer interfacing: Applications and challenges. Egypt Informatics J 2015; 16:213–230.
61. Eichenberg C, Schott M. Serious games for psychotherapy: A systematic review. Games Health J 2017; 6:127–135.
62. Pirovano M, Surer E, Mainetti R, et al. Exergaming and rehabilitation: A methodology for the design of effective and safe therapeutic exergames. Entertain Comput 2016; 14:55–65.
63. Muscio C, Tiraboschi P, Guerra UP, et al. Clinical trial design of serious gaming in mild cognitive impairment. Front Aging Neurosci 2015; 7:26.
64. Skjæret N, Nawaz A, Morat T, et al. Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy. Int J Med Inform 2016; 85:1–16.
65. Laura MC, Andrea AM. Emotion recognition techniques using physiological signals and video games-systematic review. Rev Fac Ing 2017; 26:19–28.
66. Bonnechère B, Jansen B, Omelina L, et al. Can serious games be incorporated with conventional treatment of children with cerebral palsy? A review. Res Dev Disabil 2014; 35:1899–1913.
67. Robert P, Leroi I, Manera V. Editorial: ICT for assessment and rehabilitation in alzheimer's disease and related disorders. Front Aging Neurosci 2016; 8:6–8.
68. Wiemeyer J, Kliem A. Serious games in prevention and rehabilitation-a new panacea for elderly people? Eur Rev Aging Phys Act 2012; 9:41–50.
69. Yáñez-Gómez R, Cascado-Caballero D, Sevillano JL. Academic methods for usability evaluation of serious games: A systematic review. Multimed Tools Appl 2017; 76:5755–5784.
70. Webster D, Celik O. Systematic review of Kinect applications in elderly care and stroke rehabilitation. J Neuroeng Rehabil 2014; 11:108.
71. Nawaz A, Skjæret N, Helbostad JL, et al. Usability and acceptability of balance exergames in older adults: A scoping review. Health Informatics J 2016; 22:911–931.
72. Rego PA, Moreira PM, Reis LP. Natural user interfaces in serious games for rehabilitation. 6th Iberian Conference on Information Systems and Technologies (CISTI 2011), Chaves, Portugal; June 15–18, 2011:1–4.
73. Sardi L, Idri A, Fernández-Alemán JL. A systematic review of gamification in e-Health. J Biomed Inform 2017; 71:31–48.
74. Laver K, George S, Ratcliffe J, et al. Use of an interactive video gaming program compared with conventional physiotherapy for hospitalised older adults: A feasibility trial. Disabil Rehabil 2012; 34:1802–1808.
75. Abellard P, Abellard A. Virtual reality and serious games for rehabilitation. 2015 International Conference on Virtual Rehabilitation, Valencia, Spain; June 9–12, 2015:117–118.
76. Bertrand J, Dukes LC, Dukes P, et al. Serious games for training, rehabilitation and workforce development. Proceedings IEEE Virtual Reality. 2013:195–196.
77. Fernandez-Cervantes V, Stroulia E, Castillo C, et al. Serious rehabilitation games with Kinect. 2015 IEEE Games Entertainment Media Conference GEM, Toronto, ON, Canada; October 14–16, 2015. 2016:199769.
78. Jaume-I-Capó A, Samčović A. Vision-based interaction as an input of serious game for motor rehabilitation. 2014 22nd Telecommunication Forum, TELFOR 2014-Proceedings Paper. 2014:854–857.
79. Noveletto F, Bertemes Filho P, Da Silva Hounsell M, Vinicius Soares A. Biomedical control interface for a physical rehabilitation serious game. IEEE Latin America Transactions 2016; 14:38–44.
80. Peron GC, Santos LIB, Brasil LM, et al. Serious games in cognitive rehabilitation. Pan American Health Care Proceedings 2011:94–95.
81. Rocha R, Reis LP, Rego PA, Moreira PM. Serious games for cognitive rehabilitation: Forms of interaction and social dimension. 2015 10th Iberian Conference on Information Systems and Technologies, Aveiro, Portugal; June 17–20, 2015:1–6.
82. Petrov NV. Katyń: The Kremlin's double game. East Eur Polit Soc 2015; 29:775–783.
83. Rahman MA, Ahmed M, Qamar A, et al. Modeling therapy rehabilitation sessions using non-invasive serious games. Conference: 2014 IEEE International Symposium on Medical Measurements and Applications (MeMeA), Lisboa, Portugal; June 11–12, 2014:1–4.
84. Qamar A, Rahman MA, Basalamah S. Adding inverse kinematics for providing live feedback in a serious game-based rehabilitation system. Proceedings on Fifth International Conference on Intelligent Systems, Modelling and Simulation, Langkawi, Malaysia; January 27–29, 2014:215–220.
85. Afyouni I, Rehman FU, Qamar AM, et al. A therapy-driven gamification framework for hand rehabilitation. User Model User Adapt Interact 2017; 27:215–265.
86. Martins T, Carvalho V, Soares F. A serious game for rehabilitation of neurological disabilities: Preliminary study. Proceedings on 2015 IEEE 4th Portuguese Meeting on Bioenginering ENBENG 2015, Porto, Portugal; February 26–28, 2015:94–98.

87. Dehem S, Lejeune T, Stoquart G, et al. Robotic-assisted serious game for motor and cognitive post-stroke rehabilitation. 2017 IEEE 5th International Conference on Serious Games and Applications for Health SeGAH, Perth, WA, Australia; April 2–4, 2017:ii.
88. Sucar LE, Orihuela-Espina F, Velazquez RL, et al. Gesture therapy: An upper limb virtual reality-based motor rehabilitation platform. IEEE Trans Neural Syst Rehabil Eng 2014; 22:634–643.
89. Andrade KDO, Fernandes G, Martins J, et al. Rehabilitation robotics and serious games: An initial architecture for simultaneous players. ISSNIP Biosignals and Biorobotics Conference, Rio de Janeiro, Brazil; February 18–20, 2013: 1–6.
90. Postolache O, Lourenco F, Dias Pereira JM, Girao PS. Serious game for physical rehabilitation: Measuring the effectiveness of virtual and real training environments. I2MTC 2017-2017 IEEE International Instrumentation and Measurement Technology Conference Proceedings, Turin, Italy; May 22–25, 2017:1–6.
91. Türkbey T, Kutlay S, Gök H. Clinical feasibility of Xbox KinectTM training for stroke rehabilitation: A single-blind randomized controlled pilot study. J Rehabil Med 2017; 49:22–29.
92. Trombetta M, Henrique BPP, Brum MR, et al. Motion rehab AVE 3D: A VR-based exergame for post-stroke rehabilitation. Comput Methods Programs Biomed 2017; 151:15–20.
93. Shiratuddin MF, Rail S, Murali G, et al. A usability evaluation of Neuromender's upper limb game-based rehabilitation system for stroke survivors. 2017 IEEE International Conference on Serious Games and Applications for Health, Perth, WA, Australia; April 2–4, 2017:1–8.
94. Idriss M, Tannous H, Istrate D, et al. Rehabilitation-oriented serious game development and evaluation guidelines for musculoskeletal disorders. JMIR Serious Games 2017; 5:e14.
95. Bonnechère B, Sholukha V, Omelina L, et al. Suitability of functional evaluation embedded in serious game rehabilitation exercises to assess motor development across lifespan. Gait Posture 2017; 57:35–39.
96. Bonnechère B, Jansen B, Omelina L, et al. Patients' follow-up using biomechanical analysis of rehabilitation exercises. Int J Serious Games 2017; 4:3–13.
97. Eckert M, Gómez-Martinho I, Meneses J, Martínez JF. New approaches to exciting exergame-experiences for people with motor function impairments. Sensors (Switzerland) 2017; 17:pii:E354.
98. Elnaggar A, Reichardt D. Digitizing the hand rehabilitation using the serious games methodology with a user-centered design approach. 2016 International Conference on Computational Science and Computational Intelligence (CSCI'16), Las Vegas, NV, USA; December 15–17, 2016.
99. Bower KJ, Louie J, Landesrocha Y, et al. Clinical feasibility of interactive motion-controlled games for stroke rehabilitation. J Neuroeng Rehabil 2015; 12: 1–12.
100. Jaume-I-Capó A, Martinez-Bueso P, Moya-Alcover B, Varona J. Interactive rehabilitation system for improvement of balance therapies in people with cerebral palsy. IEEE Trans Neural Syst Rehabil Eng 2014; 22:419–427.
101. Rahman MA. Multimedia environment toward analyzing and visualizing live kinematic data for children with Hemiplegia. Multimed Tools Appl 2015; 74: 5463–5487.
102. D'Ornellas MC, Cargnin DJ, Prado ALC. Thoroughly approach to upper limb rehabilitation using serious games for intensive group physical therapy or individual biofeedback training. Brazilian Symposium Games Digit Entertainment SBGAMES 2014. 2014:140–147.
103. Pompeu JE, Arduini LA, Botelho AR, et al. Feasibility, safety and outcomes of playing Kinect Adventures! TM for people with Parkinson's disease: A pilot study. Physiotherapy 2014; 100:162–168.
104. Fikar P, Schönauer C, Kaufmann H. The Sorcerer's apprentice: A serious game aiding rehabilitation in the context of subacromial impingement syndrome. Proceedings on ICTs Improving Patients Rehabilitation Research Techniques 2013:327–330.
105. Bortone I, Leonardis D, Solazzi M, et al. Integration of serious games and wearable haptic interfaces for neuro rehabilitation of children with movement disorders: A feasibility study. IEEE International Conference on Rehabilitation Robotics, London, UK; July 17–20, 2017: 1094–1099.
106. Bonnechère B, Melissa VV, Christophe B, et al. A preliminary study of the integration of specially developed serious games in the treatment of hospitalized elderly patients. 2017 International Conference on Virtual Rehabilitation, Montreal, QC, Canada; June 19–22, 2017:1–6.
107. Esfahlani SS, Cirstea S, Sanaei A, Wilson G. An adaptive self-organizing fuzzy logic controller in a serious game for motor impairment rehabilitation. IEEE International Symposium on Industrial Electronics, Edinburgh, UK; June 19–21, 2017:1311–1318.
108. Cheng P-H. Augmented reality serious game framework for rehabilitation with personal health records. 2011 IEEE 13th International Conference on e-Health Networking Applications and Services, Columbia, MO, USA; June 13–15, 2011:197–200.
109. Schönauer C, Pintaric T, Kaufmann H, et al. Chronic pain rehabilitation with a serious game using multimodal input. 2011 International Conference on Virtual Rehabilitation ICVR, Zurich, Switzerland; June 27–29, 2011:1–8.
110. Evett L, Burton A, Battersby S, et al. Dual camera motion capture for serious games in stroke rehabilitation. 2011 IEEE 1st International Conference on Serious Games and Applications for Health (SeGAH), Braga, Portugal; November 16–18, 2011:1–4.
111. Rahman MA. Web-based multimedia hand-therapy framework for measuring forward and inverse kinematic data. Multimed Tools Appl 2016; 76:8227–8255.
112. Omelina L, Jansen B, Bonnechère B, et al. Interaction detection with depth sensing and body tracking cameras in physical rehabilitation. Methods Inf Med 2016; 55: 70–78.
113. Hossain MS, Hardy S, Alamri A, et al. AR-based serious game framework for post-stroke rehabilitation. Multimed Syst 2016; 22:659–674.
114. Prange GB, Kottink AIR, Buurke JH, et al. The effect of arm support combined with rehabilitation games on upper-extremity function in subacute stroke: A randomized controlled trial. Neurorehabil Neural Repair 2015; 29:174–182.
115. Andrade KDO, Fernandes G, Caurin GAP, et al. Dynamic player modelling in serious games applied to rehabilita-

tion robotics. Robotics: SBR-LARS Robotics Symposium and Robocontrol (SBR LARS Robocontrol), 2014 Joint Conference, Sao Carlos, Brazil; October 18–23, 2014: 211–216.
116. Moretti CB, Joaquim RC, Caurin GAP, et al. Knowledge discovery, rehabilitation robotics, and serious games: Examining training data. 2014 5th IEEE RAS EMBS International Biomedical Robotics and Biomechatronics 2014; 21201:567–572.
117. Baranyi R, Reisecker F, Lederer N, et al. WristDroid-A serious game to support and motivate patients throughout their wrist rehabilitation. 2014 IEEE Conference on Biomedical Engineering and Science IECBES, Kuala Lumpur, Malaysia; December 8–10, 2014. 2015:786–791.
118. Saposnik G, Cohen LG, Mamdani M, et al. Efficacy and safety of non-immersive virtual reality exercising in stroke rehabilitation (EVREST): A randomised, multicentre, single-blind, controlled trial. Lancet Neurol 2016; 15:1019–1027.
119. Lopez-Samaniego L, Garcia-Zapirain B. A robot-based tool for physical and cognitive rehabilitation of elderly people using biofeedback. Int J Environ Res Public Health 2016; 13:1176.
120. House G, Burdea G, Polistico K, et al. A Rehabilitation First—Tournament Between Teams of Nursing Home Residents with Chronic Stroke. Games Health J 2016; 5: 75–83.
121. Darzi A, Goršič M, Novak D. Difficulty adaptation in a competitive arm rehabilitation game using real-time control of arm electromyogram and respiration. IEEE International Conference on Rehabilitation Robotics (Proccedings), London, UK; July 17–20, 2017:857–862.
122. Hocine N, Gouaïch A, Cerri SA, et al. Adaptation in serious games for upper-limb rehabilitation: An approach to improve training outcomes. User Model User Adapt Interact 2015; 25:65–98.
123. Saposnik G, Teasell R, Mamdani M, et al. Effectiveness of virtual reality using wii gaming technology in stroke rehabilitation: A pilot randomized clinical trial and proof of principle. Stroke 2010; 41:1477–1484.

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