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 ≥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 ≥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 ≥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.
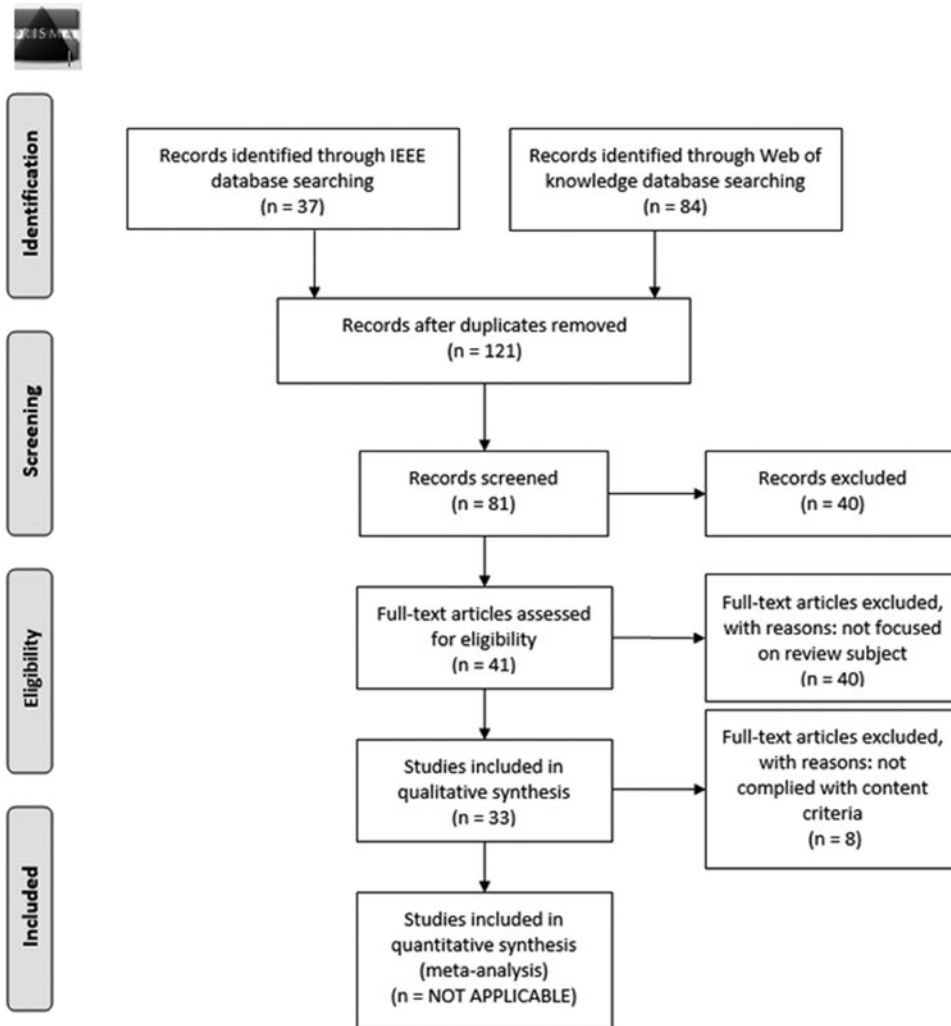(b) Complementary vision systems: this category refers to systems using a camera and other sensors to obtain

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] FLAR-ToolKit,[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	—	41 Affected users	Medical scale evaluation	—	Yes	—	Yes	—
2017	Esfahlani et al.[107]	81	Kinect; Myo Armband	Neuromuscular disorders	Hips; 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	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 García-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	—	—	—	—	—
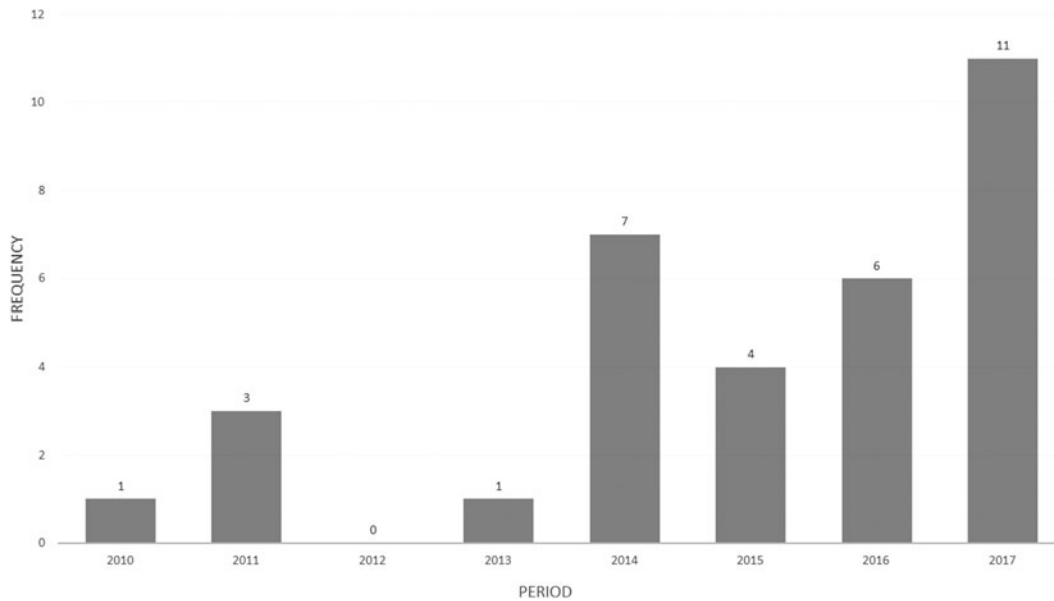
FIG. 2. Publications histogram.

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 exer-

FIG. 3. Body parts for rehabilitation.

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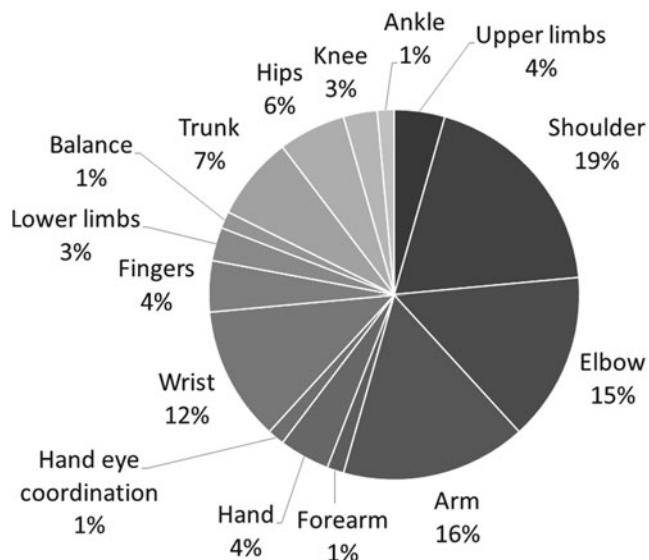
the game was commercial or was implemented by the authors.[95,96,100,104–106,108,110–112,114,116,117,121,122]

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.

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