The use of the computer assisted rehabilitation environment in assessment and rehabilitation

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Authors’ Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

DOI: https://doi.org/10.34142/HSR.2023.09.02.09

Abstract

Purpose. The purpose of this review article was to review and analyze the available literature regarding one of the most advanced virtual reality technologies. We reviewed and analyzed the use of the computer-assisted rehabilitation environment system in assessment and rehabilitation.

Materials and methods. PubMed, Web of Science, Cochrane Library, Scopus, and Physiotherapy Evidence Database databases were searched from inception to October 2021. We used the search term "Computer Assisted Rehabilitation Environment" and included articles which directly or indirectly addressed the use of the computer assisted rehabilitation environment system in assessment, rehabilitation and on healthy people. We excluded articles not published in the English language, conference proceedings, reports of abstracts only, and duplicated articles. Also, articles addressing the use of other virtual reality technologies whether they used fully immersive, semi-immersive, or non-immersive interfaces or virtual reality devices such as the Wii or Xbox gaming technologies were also excluded. The relevant studies were collected and critically analyzed.

Results. Our search retrieved 205 articles, with 119 duplicates identified and removed. Following screening 86 articles, we included 50 relevant articles which directly or indirectly addressed the computer-assisted rehabilitation environment system and were published in scientific journals. Twenty-two articles used the computer assisted rehabilitation environment for biomechanical analysis, 15 articles used the computer assisted rehabilitation environment for rehabilitation, 4 articles were reviews, and 9 articles addressed the computer assisted rehabilitation environment in other ways.

Conclusion. The computer assisted rehabilitation environment system is a promising tool for assessment and rehabilitation. It can be used with different concepts to assist in diagnosis and treatment, can be used for healthy individuals and with patients, and basically follows biomechanical principles in operating. The high cost and complex infrastructure, however, may be the restriction to its use for research purposes and in clinical practice.

Key words: the computer assisted rehabilitation environment, virtual reality, rehabilitation, medicine
Anotação

Mohamed Abdelmeged, Hossni Elkhawaga. Використання комп’ютерного реабілітаційного середовища в оцінці та реабілітації

Мета. Мета цієї оглядової статті полягала в огляді та аналізі доступної літератури щодо однієї з найпередовіших технологій віртуальної реальності. Ми розглянули та проаналізували використання системи комп’ютерного реабілітаційного середовища в оцінці та реабілітації.


Результати. Наш пошук знайшов 205 статей, 119 дублікатів виявлено та видалено. Після перевірки 86 статей ми включили 50 відповідних статей, які прямо чи опосередковано стосувалися системи комп’ютерного реабілітаційного середовища та були опубліковані в наукових журналах. Двадцять дві статті використовували комп’ютерне реабілітаційне середовище для біомеханічного аналізу, 15 статей використовували комп’ютерне реабілітаційне середовище для реабілітації, 4 статті були оглядами, а 9 статей розглядали комп’ютерне реабілітаційне середовище іншими способами.

Висновок. Комп’ютерна система реабілітаційного середовища є перспективним інструментом оцінки та реабілітації. Він може використовуватися з різними концепціями для допомоги в діагностиці та лікуванні, може використовуватися для здорових людей і пацієнтів, і в основному дотримується біомеханічних принципів у роботі. Однак висока вартість і складна інфраструктура можуть бути обмеженнями для його використання в дослідницьких цілях і в клінічній практиці.

Ключові слова: комп’ютерне реабілітаційне середовище, віртуальна реальність, реабілітація, медицина
Introduction

In the field of medicine and rehabilitation, the search for innovation is a dynamic process for the sake of finding tools to help diagnose and treat different bodily conditions. The use of virtual reality in medicine and rehabilitation has a promising and effective influence although most of these technologies are expensive and are not ubiquitously available [1,2]. Virtual reality has been studied as an assessment and rehabilitative tool [3–5]. A systematic review by Lee et al [6] concluded that virtual reality training was effective in improving function in patients with chronic stroke. Similarly, Gumaa and Rehan [7] found the current evidence in support of virtual reality as an effective tool in orthopedic rehabilitation. Moreover, several systematic reviews have suggested the use of virtual reality in rehabilitation of different conditions, such as Parkinson’s disease [8,9], multiple sclerosis [10,11], burn [12], low back pain [13], total knee arthroplasty [14,15], functional ankle instability [16] and breast cancer [17]. Additionally, a recent study by Rodrigues et al [18] concluded that a single session of virtual reality could improve shortness of breath, tiredness, and anxiety in patients hospitalized with Coronavirus Disease-2019.

One of the most advanced virtual reality technologies is the computer-assisted rehabilitation environment. Created by Motek Medical (Motekforce Link, Amsterdam, the Netherlands) in the early 2000, the computer-assisted rehabilitation environment system is a fully immersive type of virtual reality that has been used for assessment, rehabilitation, and research purposes for healthy populations and different orthopedic, psychological, neurological, and vestibular conditions [19]. The creator of the computer-assisted rehabilitation environment system called it “the world most advanced biomechanics lab”. The computer-assisted rehabilitation environment system is a result of the integration of many modalities in one system, such as virtual reality, treadmill, biomechanical and physiological biofeedback. In addition to performing functional activities in a fully immersive virtual reality environment, the computer-assisted rehabilitation environment system allows real-time feedback to analyse these activities. It provides a controlled environment that maintains patient safety and can be customised to patients’ needs [20].

A motion capture system, with base platform and force plate describe the basic components of the computer-assisted rehabilitation environment system. The base platform is operated through a hydraulic and mechanical mechanism that allows the base to move up to six degrees of freedom. A three-dimensional motion capture system with around 12 cameras captures the subject’s performance. The patient can be situated in front of a big flat, curved panoramic screen, or inside a dome. The operator can provide perturbation to the platform according to the complexity of the task. There are various modifications and additions to the basic when needed. Treadmill can be incorporated into the system and the degree of virtual reality immersion can be modified with different gaming applications depending on the target treatment goals. Real-time movement tracking is available to show subjects’ performance and provide immediate feedback.

A safety harness is also available to provide the necessary support. A customized D-flow software operating the system enables the operator to adjust and change specification of the gaming applications used. Although biofeedback-driven equipment is many, when the concept of biofeedback is incorporated into an upscale technology such as the computer-assisted rehabilitation environment system, the result can be very promising. The force plate in the computer-assisted rehabilitation environment system can provide real-time feedback to both the patient and the operator and can also show postural control strategies the patient is using during the task [20]. The purpose of this study was to review and analyze the available literature regarding the use of the computer-assisted rehabilitation environment system in assessment and rehabilitation.

Materials and methods

Search strategy and selection criteria

In this review, we searched PubMed, Web of Science, Cochrane Library, Scopus, and Physiotherapy Evidence Database databases from inception to October 2021. We used the search term “computer assisted rehabilitation environment”. Mendeley was used to identify and exclude duplicate articles. Then, title, abstract and full-text screening was performed. Articles addressing the computer-assisted rehabilitation environment system in any way were included in this review. Conference proceedings, reports of abstracts only and papers in languages other than English were excluded.
Results

Our search retrieved 205 articles, with 119 duplicates identified and removed. After screening 86 articles and excluding irrelevant results and conference proceedings, we included 50 relevant articles which directly or indirectly addresses the computer-assisted rehabilitation environment system and were published in scientific journals. Twenty-two articles used the computer-assisted rehabilitation environment system for biomechanical analysis [21–42], 15 articles used the computer-assisted rehabilitation environment system for rehabilitation [43–57], 4 articles were reviews [19,20,58,59] and 9 articles addressed the computer-assisted rehabilitation environment system in other ways [60–68]. A flow chart summarizing study selection is shown in figure 1.

Figure 1. Flow chart summarizing study selection

Regarding the use of the computer-assisted rehabilitation environment system in biomechanical analysis, six studies were performed on healthy population [21–26]. These studies investigated the effect of different types of physical, visual and cognitive perturbations during walking on dynamic postural stability and gait parameters such as margins of stability, walking speed, step length, step frequency and step width. Summary of the studies is shown in Table 1.
Summary of the studies used the computer-assisted rehabilitation environment system in biomechanical analysis of the effect of different perturbations during walking on healthy participants

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Type of the computer-assisted rehabilitation environment system</th>
<th>Type of perturbation</th>
<th>Perturbation conditions</th>
<th>Outcomes</th>
<th>Major findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al, 2012 [21]</td>
<td>Healthy young adult participants n=12</td>
<td>The computer-assisted rehabilitation environment system (Motek, Amsterdam, The Netherlands) with 24-camera Vicon motion capture system (Oxford Metrics, Oxford, UK). Kinematic data were collected using 22 reflective markers at 60Hz.</td>
<td>Physical and Visual</td>
<td>No perturbation, AP platform oscillations, AP visual oscillations, ML platform oscillations and ML visual oscillations</td>
<td>- AP MOS - ML MOS</td>
<td>AP MOS for AP platform oscillations, ML platform oscillations and ML visual oscillations were smaller than during no perturbation. ML MOS was larger during all perturbation conditions than during no perturbation.</td>
</tr>
<tr>
<td>Hak et al, 2012 [22]</td>
<td>Healthy adult participants n=9 Male/Female=4/5</td>
<td>The computer-assisted rehabilitation environment system (Motek Medical by, Amsterdam, The Netherlands) with 12 high resolution infra-red cameras (Vicon, Oxford, UK). Kinematic data were collected using vicon Lower Body Plug-in-Gait marker set. Motek Medicals D-flow software was used.</td>
<td>Physical</td>
<td>ML translations of the walking surface at four different intensities.</td>
<td>- Walking speed - Step length - Step frequency - Step width - Local dynamic stability - AP MOS - ML MOS</td>
<td>Walking speed did not change after ML</td>
</tr>
<tr>
<td>Study</td>
<td>Participants</td>
<td>Environment</td>
<td>Physical</td>
<td>Physical Tests</td>
<td>Effects</td>
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<tr>
<td>Hak et al, 2013 [23]</td>
<td>Healthy young participants n=10 Male/Female=8/2</td>
<td>The computer-assisted rehabilitation environment system (Motek Medical by, Amsterdam, The Netherlands) with 12 high resolution infra-red cameras (Vicon, Oxford, UK). Kinematic data were collected using vicon Lower Body Plug-in-Gait marker set. D-flow software was used.</td>
<td>Four trials of 4 min walking conditions (unperturbed walking, unperturbed walking and hitting virtual targets with markers guided by knee, ML perturbed walking and ML perturbed walking and hitting virtual targets with markers guided by knee)</td>
<td>- Walking speed - Step length - Step frequency - Step width - AP MOS - ML MOS</td>
<td>Step length decreased and step width increased during walking conditions requiring a high level of both adaptability and stability</td>
<td></td>
</tr>
<tr>
<td>Gholizadeh et al, 2020 [25]</td>
<td>Healthy young participants n=15 Male/Female=8/7</td>
<td>The extended System (Motek Medical, Amsterdam, Netherlands) with 12-camera Vicon motion capture system (Vicon, Oxford, UK). Kinematic data were collected using 57 reflective markers at 100 Hz. Ground reaction force data were collected at 1000 Hz.</td>
<td>AP trip perturbations during symmetric (treadmill speed=1.2 m/s for both legs) or asymmetric (left leg=1.2 m/s, right leg =0.96 m/s) walking condition with three arm conditions: Normal, Bound and Released</td>
<td>- Step width - Stance time - Whole-body angular momentum - Trunk angular velocities - COM</td>
<td>AP trip perturbation, arm conditions and Walking conditions had an influence on dynamic postural stability by affecting various gait parameters. Arm movements could help in recovering after perturbations</td>
<td></td>
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<tr>
<td>Jeschkea, et al, 2019 [24]</td>
<td>Healthy young participants n=13 Male/Female=1/12</td>
<td>The computer-assisted rehabilitation environment system (Motek Medical by, Amsterdam, The Netherlands) with motion capture system (VICON Bonita 10, Oxford, UK). Kinematic data were collected using 4 markers on the pelvis. D-flow software (version 3.28) was used.</td>
<td>Cognitive and Visual</td>
<td>Seven different intervention conditions (IC (original color-word Stroop task (IC original), slower version of IC original, IC original where optic flow was still present, audio Stroop task and a pane directing the gaze of the participants low in the virtual reality environment, at the original Stroop task height and higher).</td>
<td>- Walking speed increased when performing color-word Stroop task, slower version of IC original and when gaze was directed at the original Stroop task height and higher.</td>
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<td>Mokhtarzadeh et al, 2021 [26]</td>
<td>Healthy young male participants n=20</td>
<td>The computer-assisted rehabilitation environment system -Extended System (Motek Medical, Amsterdam, Netherlands) with 12-camera Vicon motion capture system (Vicon, Oxford, UK). Kinematic data were collected using 46 markers at 100 Hz. Ground reaction force data were collected at 2000 Hz.</td>
<td>Cognitive and Visual</td>
<td>Cognitive task (visual search). Participants were instructed to search and shot at targets while walking at three different speeds (0.56, 1.11, 1.67 m/s). The targets were in the form of friend/foe or red/green colors randomly appeared on the screen</td>
<td>- AP MOS - ML MOS - Visual performance - Cost of Visuo Motor Targeting Task</td>
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<td>ML MOS improved during the visual search task and with increased gait speed. AP MOS was only affected by gait speed. Visual performance and Cost of Visuo Motor Targeting Task were enhanced during walking versus standing up to 25%.</td>
<td></td>
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</table>

Abbreviations: AP: Anterior-Posterior; ML: Mediolateral; MOS: Margins of Stability; COM: Center of Mass
As used for healthy people, the computer-assisted rehabilitation environment system was also used for biomechanical analysis of different cases: individuals with lower limb amputation [27–35], stroke [36,37], cerebral palsy [38,39], osteoporotic vertebral compression fractures [40,41] and fibula aplasia [42]. Most of these studies did not only assess the cases but also compared them to healthy control groups.

The computer-assisted rehabilitation environment system was used in different types of rehabilitation: neurological [43–46] vestibular [47–50], psychological [51,52], amputation [53], Cognitive [54] and visual rehabilitation [55]. We also identified two randomized controlled trial protocols: one was for the use of the computer-assisted rehabilitation environment system in improving balance and reducing falls in older adults [56] and the other was for the use of the computer-assisted rehabilitation environment system in military members with combat-related treatment-resistant posttraumatic stress disorder [57]. Additionally, we found 4 review articles [19,20,58,59], one of them was systematic review [19]. Moreover, 9 articles addressing the computer-assisted rehabilitation environment system in other ways were found [60–68].

**Discussion**

In this review article, we reviewed the available literature to find out how the computer-assisted rehabilitation environment system was used in assessment and rehabilitation. Although the computer-assisted rehabilitation environment system technology is expensive and usually found in big rehabilitation centers, hospitals, research, and military facilities, this technology helps in assessment and rehabilitation of different bodily conditions thanks to the innovations and the accessories attached to the machines [19,59]. Although we found 50 studies addressing the computer-assisted rehabilitation environment system, research is still lacking. This may be due to the lack of availability of the computer-assisted rehabilitation environment system due to the high cost and the bulky infrastructure required for the system.

When a subject uses the computer-assisted rehabilitation environment system for assessment or treatment, their performance can be challenged through the movement of the movable platform in six degrees of freedom, incorporating additional accessories to the main setup of the system, or through increasing the complexity of the task by the operator through changing the speed of the task or the surface platform parameters (speed, perturbation, inclination, etc.). After the patient’s performance is fed to the computer and simulated on a human body model, performance accuracy, errors and parameters can be calculated and fed back to the big screen for real-time feedback [20].

Challenging patient’s performance can also be performed by adding a second task in addition to the primary targeted task. Kizony et al. [69] used a gaming application which allows the patient to virtually shop for groceries while virtually walking to select their shopping items. They investigated what effect a single task such as walking or dual tasks such as walking and selecting the grocery items have on gait parameters in patients with stroke as compared to healthy controls. As expected, there was variability in gait parameters between the two groups with the stroke group walked slower with dual tasking which had more cognitive demands.

A systematic review by Collins et al [19] was conducted on the use of the computer-assisted rehabilitation environment system in research and rehabilitation. They found 31 articles published on the computer-assisted rehabilitation environment system from 1999 to 2013, 9 of them were conference proceedings. Less than half of them (12 papers) studied the use of the computer-assisted rehabilitation environment system in rehabilitation. The published studies included subjects with amputations, cerebral palsy, traumatic brain injuries, stroke, vestibular dysfunctions, gait, and balance abnormalities. Since the technology is primarily found in military facilities, a lot of studies have been conducted on active service member, off duty military personnel with or without medical conditions.

*The use of computer-assisted rehabilitation environment system in biomechanical analysis*

Understanding human strategies to control dynamic postural stability during walking when exposed to perturbations is the key to understanding how falls occur and how to prevent them [21]. The computer-assisted rehabilitation environment system was used for biomechanical analysis in studies that investigated the effect of different types of physical, visual and cognitive perturbations during walking.
on dynamic postural stability and gait parameters in healthy participants [21–26], individuals with lower limb amputation [27–33] and stroke [36,37]. Additionally, the computer-assisted rehabilitation environment system was used for gait analysis in cerebral palsy [38,39], osteoporotic vertebral compression fractures [40,41] and fibula aplasia [42].

Young et al. [21] attempted to identify how humans control dynamic walking stability when exposed to platform and visual anteroposterior and mediolateral oscillations. Participants walked in the computer-assisted rehabilitation environment system with a 7-meter diameter dome and a virtual scene of 300° field of view. Six-degrees of freedom platform with treadmill was embedded in the bottom of the dome. The computer-assisted rehabilitation environment system was used to produce physical or visual oscillations during walking and to measure their effect on margins of stability. A 24-camera Vicon motion capture system at 60 Hz and 22 reflective markers were used for data collection. The study concluded that anteroposterior margin of stability for anteroposterior platform oscillations, Mediolateral platform oscillations and mediolateral visual oscillations were smaller than during no perturbation. Mediolateral margin of stability was larger during all perturbation conditions than during no perturbation.

Gholizadeh et al. [25] used the computer-assisted rehabilitation environment system to assess dynamic postural stability when recovering from sudden anteroposterior trip perturbations during walking. Center of Mass, peak trunk angular velocities, Whole-body angular momentum, step width, and stance time were measured during walking in different arm and walking conditions. Healthy young participants walked on the computer-assisted rehabilitation environment system treadmill in symmetric and asymmetric walking conditions simultaneously with three different arm swings conditions: normal arm motion, arms were bound at their sides and participants were instructed to walk without arm swing. Treadmill speed was 1.2 m/s speed for both legs in the symmetric condition and 1.2 m/s for left leg and 0.96 m/s for right leg in the asymmetric condition. A set of 57 reflective markers was used to analyze gait parameters before and after recovering from perturbations. This study indicated that anteroposterior trip perturbation, arm conditions and Walking conditions had an influence on dynamic postural stability by affecting various gait parameters. Arm movements could help in recovering after perturbations.

Shafelty et al. [35] used the computer-assisted rehabilitation environment system as an assessment tool to measure ground reaction force and angle range of motion in two versions of the 3D printed Compliant and Articulating Prosthetic Ankle and to compare them to two other types of prostheses: the Solid Ankle Cushioned Heel foot and the Renegade® all terrain prosthetic foot. Ten able-bodied participants wear a transfemoral prosthetic simulator and walked the the computer-assisted rehabilitation environment system treadmill system for gait analysis. Shafelty et al. concluded that the ground reaction forces and ankle angles of the Compliant and Articulating Prosthetic Ankle foot during gait cycle were greater and more closely to normal gait than the solid ankle cushioned heel foot and Renegade® all terrain prosthetic foot.

The use of computer-assisted rehabilitation environment system in rehabilitation

Although several studies concluded that virtual reality is an effective rehabilitative tool [6–18], only a limited number of studies have addressed the use of the computer-assisted rehabilitation environment system in different types of rehabilitation: neurological [43–46] vestibular [47–50], psychological [51,52], amputation [53], cognitive [54] and visual rehabilitation [55].

Streicher et al. [35] reported that the computer-assisted rehabilitation environment system is a safe and effective tool for gait and balance training in multiple sclerosis patients. They compared the use of the computer-assisted rehabilitation environment system with traditional physical therapy on Berg Balance Scale, Timed Up and Go test, 6-Minute Walk Test and Timed 25-Foot Walk. While the computer-assisted rehabilitation environment system group showed significant improvements for all outcome measures, traditional physical therapy group showed significant only in Berg Balance Scale. Further, in a case study by Rábago et al. [46], the computer-assisted rehabilitation environment system was used for assessment and rehabilitation of a case with mild traumatic brain injury who successfully returned to full duty and training for combat deployment. Another case report by De Luca et al. [46] showed the efficacy of the computer-assisted rehabilitation environment system in improving cognitive and...
A personal experience with the computer-assisted rehabilitation environment system

The first author of this review had a chance to work among a team of healthcare providers and used the computer-assisted rehabilitation environment system in rehabilitation of patients with different pathologies. Out of a personal experience, I can say that the computer-assisted rehabilitation environment system is an interesting, engaging, and motivating tool of rehabilitation. Usually, when we see a fancy technology, we are intrigued to see what it can do. When we explained what the computer-assisted rehabilitation environment system technology can do to patients, they were encouraged to try it out. One patient with a stroke said, “I want to focus and accomplish one task in the the computer-assisted rehabilitation environment system so I can be a stroke survivor rather than a stroke victim”. This pushed the patient to do her best to get high scores in one of the physically challenging gaming applications.

Another patient with scoliosis wanted to see if she can activate her back muscles to correct the scoliotic curve using the “Maze” gaming application. We used a therapeutic bag filled with water called “aqua bag” and asked the patient to carry it over her shoulder, hold it with both hands and navigate through the maze she sees in the big screen in front of her. We adjusted the game difficulty to selectively activate the stretched back muscles, hoping that with repetitive activations, the patient will get into the habit of activating the desired muscles in normal daily activities. The fact that the computer-assisted rehabilitation environment system allows the use of different rehabilitative tools either installed on the machine or even attached to the patients, this can make the exercise performed more creative.

There are many ways to increase the difficulty of the task using the computer-assisted rehabilitation environment system which makes the computer-assisted rehabilitation environment system effective also in the athletic population. We used it with weightlifters, runners, golfers, and tennis players. Of course, those population has different goals in rehabilitation, and we had to be creative in individualizing the exercise tasks. For example, we incorporated the use of an ankle destabilizing device for an athlete recovering from an ankle sprain and asked the patient to use the “car racing” gaming application. Using this application, the patient had to virtually race with a car and avoid being hit from other cars in the track. By balancing on the injured ankle with a destabilizing device while we control
the difficulty level of the platform movement while trying to get high scores in the application, we can achieve the rehabilitation goals and prepare the athlete for sports participation.

**Conclusion**

The computer-assisted rehabilitation environment system provides an excellent assessment and rehabilitation environment. The high cost and the bulky infrastructure, however, may be the restriction to use in research purposes and clinical practice.

**References**


**Conflict of interests**

The authors declare that they have no competing interests.

**Funding information**

No funds were available for this study.

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Received: 2022-08-10   Accepted: 2022-09-20   Preprint 2022-09-28   Published: 2023-06-25

©Abdelmegeed M, Elkhawaga H., 2023
https://doi.org/10.34142/HSR.2023.09.02.09

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