JOMH Journal of Men's Health

J. Mens. Health **2022**; 18(8): 160
https://doi.org/10.31083/j.jomh1808160

Review

A Review about the Effectiveness of Virtual Therapy in the Recovery of Patients with Spinal Cord Injuries

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Submitted: 24 April 2022 Revised: 10 May 2022 Accepted: 19 May 2022 Published: 19 July 2022

Abstract

Background: A spinal cord injury usually results in a significant limitation in the functional outcomes implying a challenge to the performance of activities of daily living. The main aim of this study is to analyze the effectiveness of virtual reality to improve functional performance in patients with spinal cord injury. **Methods**: International virtual libraries such as ISI-Thomson Web of Science and Purpose have been accessed in this article. The search criteria selected were "title", "abstract" and "keywords". Within the platforms of the Scopus virtual library, the keywords in the search for articles were "Spinal Cord virtual reality". **Results**: Within this search, a number of 327 articles from 1996–2021 were identified. Within the platforms of the ISI Thomson Web of Science virtual library, the keywords in the search for articles were "Spinal cord virtual reality". Within this search, a number of seventy-seven articles from 2017–2021 were identified. In order to create the article, only the articles that had the direction of researching spinal cord injury rehabilitation using virtual reality were selected. The results were inconclusive for other results. **Conclusions**: Most of the studies analyzed did not confirm beneficial effects on functional performance compared to conventional physical therapy programs. The results showed that virtual reality does not prove to be more effective than conventional physical therapy programs in improving functional performance in patients with spinal cord injury, but taken together and acting as a complementary package the results are much more. As can be seen in the articles that tried to demonstrate the effectiveness of the product, the studies used a small number of patients, which is statistically irrelevant. The authors preferred to integrate these devices into the patient rehabilitation process but to use an irrelevant number of patients, so that they do not gain statistical relevance.

Keywords: virtual reality; spinal cord injury; rehabilitation; physical therapy

1. Introduction

Spinal cord injury is defined as any damage to any part of the spine due to trauma, tumor or infection. It can be traumatic in nature when the injury results from physical trauma (car accidents, work accidents, sports injuries) or non-traumatic in nature when it is caused by an underlying pathology such as an infection, tumors of any nature, musculoskeletal diseases [1]. Spinal cord injuries can be complete or incomplete. Incomplete lesions indicate the retention of functions that are still active. Complete lesions are characterized by a total functional deficit of a motor and sensory nature [2]. Depending on the level of the injury, there are different types of paralysis that can be grouped as follows: tetraplegia (upper limbs, torso, lower limbs and pelvic organs are affected) and paraplegia (torso, lower limbs and pelvic organs are affected). In conclusion, a crucial factor in determining the severity of spinal cord injury is the determination of the spinal cord segments affected by the injury, so the rehabilitation plan can be adapted to the needs of the patient [3].

Between 10 and 83 million people suffer from spinal cord injury every year, globally [4]. Statistics show that in Spain, annually, about 1000 cases of spinal cord injury occur due to injuries, half of which are due to traffic accidents, and the other half are due to sports accidents, falls and blows [5].

According to Kraus J.F.'s study, the incidence of spinal cord injury was much higher in males than in females (80.1 in males compared to 27.5 in females per million population, $p < 0.001$) [6]. In addition to a detailed incidence of spinal cord injury per year, the study by Kraus J.F. It also showed the annual average of deaths caused by spinal cord injury among males and females as well as race [6]. In addition to a detailed incidence of spinal cord injury per year, the study by Kraus J.F. It also showed the annual average of deaths caused by spinal cord injury among males and females as well as race [6] (Fig. 1).

Kraus J.F. identified that the most significant percentage of spinal cord injuries was due to external causes ($p < 0.0001$), and the fatality rate was significant in favor of external factors ($p < 0.0001$). The study included motor accidents, falls, firearms, recreation, etc. things that males do predominantly compared to females [6] (Table 1).

Another study by Fitzharris M. shows that in 2007 the incidence of traumatic spinal cord injury cases was 179,312, with a 95% confidence index (CIs). Fitzharris also states that the incidence of traumatic spinal cord injury can vary between 132967 and 225658 cases, with an overall rate of

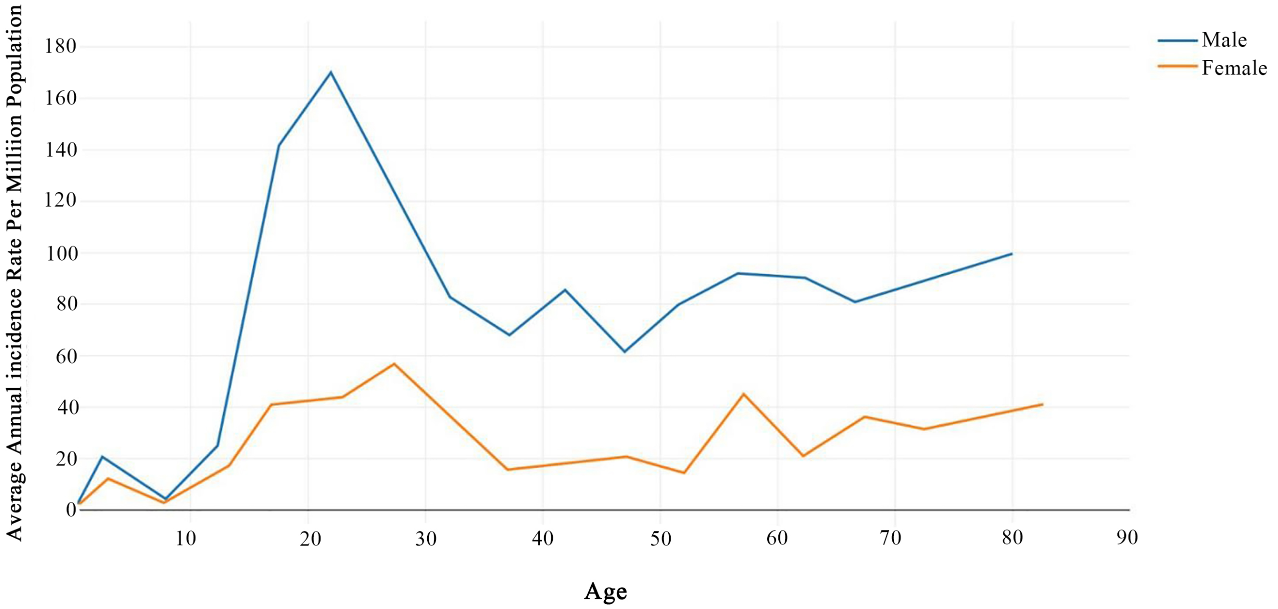

Fig. 1. The annual incidence of Kraus J.F. to Spinal cord injury for one million population from 1970–1971 on the 18 Northern California Counties [6].

Table 1. Annual average deaths by Kraus J.F. per million inhabitants and the fatality rate in the 18 Northern California Counties, 1970–1971 [6].

Race/ Etnic Group	Male			Female			Both Sexes		
	Number of deaths	Death rate	Case fatality Rate (%)	Number of deaths	Deat rate	Case fatality Rate (%)	Number of deaths	Deat rate	Case fatality Rate (%)
White	150	35.3	46	78	17.6	59	228	26.3	50
Mex-American	17	23.6	44	1	1.4	33	18	12.5	43
Black	36	86.5	52	12	27.9	63	48	56.7	55
Other	2	6.2	29	3	9.6	43	5	15.7	36
All groups	205	35.9	45	94	15.9	58	299	25.8	48

27.5 cases per million people (out of a population of 131 countries: 6.250 billion) [7]. According to Furlan J.C. in 2013, the incidence rate of spinal cord injury in America ranged from 20.7 to 83 people per million inhabitants according to Table 2 [8]. This is in line with the values offered by Kraus J.F. in 1975, but suggests a decrease in incidence compared to Kraus' time.

Furlan J.C. also shows in the study Global Incidence and Prevalence of Traumatic Spinal Cord Injury that the incidence rate of spinal cord injuries in Europe is lower ranging from 8.0 people in Spain to 130.6 people per million population in Bulgaria (Table 3) [8]. The incident was filed by Furlan J.C. in 2013 for Bucharest/Romania (period 1992–1993, hospitalized patients Dr. G. Marinescu Hospital) was 28.5/million inhabitants [8]. If we take into account the figures mentioned by Kraus J.F. (80.1 in males compared to 27.5 in females per million population, $p < 0.001$), means by the rule of three simple ones, the affectation of the male sex in a million population is (0.00801%), compared to the affectation of the female sex which is located at (0.00275%) [6].

Most patients suffer irreversible damage, in (96.9%) of cases they have difficulties and limitations in mobility, (81.1%) of cases have difficulties in self-care activities and (84.3%) have difficulties in performing domestic tasks. Another important aspect in the rehabilitation of patients with spinal cord injuries is the economic one, the associated costs being the higher the degree of damage to the patient. Also, the degree of disability with which the patient remains for a long time is a key aspect in the share of costs for rehabilitation [9]. Specialists suggest the implementation of technologies that involve low costs in order to improve the quality of life of patients with spinal cord injury.

The concept of virtual reality derives from the terms reality and virtual and can be translated as an imaginative reality, generated by the computer. In conclusion, virtual reality is able to generate a wide range of exciting user experiences. Virtual reality devices were used for the first time in the military industry, the latter using different sensory-motor stimulation devices in training but also different

Table 2. **Incidence of spinal cord injury in United States according to his Furlan J.C. study [8].**

Geographic Area	Inclusion and exclusion criteria	Incidence rates by year
Ontario, Canada	1994–1999 Hospital admissions for SCI in Ontario Trauma Registry.	37.2/million/year (1994/95) 46.2/million/year (1995/96)
London, Ontario, Canada	1997–2006 Admissions to hospital with SCI. Exclusion Criteria: Spine fracture without SCI; SCI unrelated to trauma; neurological deficit caused by peripheral nerve lesion; trauma occurring out of defined time.	40.8/ million/year (1997–2000) 21.0/million/year (1997) 26.0/million/year (1998) 44.0/million/year (1999) 49.0/million/year (2000)
Ontario, Canada	2003–2007 Data from Statistics Canada and the Canadian Institute for Health Information. All patients aged 18 years or older living in Ontario with SCI.	24.2/million/year (2003) 23.1/million/year (2006)
Manitoba, Canada	1981–1984 Manitoba Health Services Insurance Plan database.	40.0/million/year
Manitoba, Canada	1981–2007 Admission to hospital with SCI, or outpatient referral to an SCI rehabilitation specialist. Exclusion Criteria: congenital causes of paralysis such as spina bifida or cerebral palsy as well as acquired paralysis from multiple sclerosis or Guillain-Barrè syndrome.	17.1/million/year (1981–1985) 19.5/million/year (1998–2002) 25.6/million/year (2003–2007)
Alberta, Canada	1997–2000 Data from the Alberta Ministry of Health and Wellness, records from the Alberta Trauma Registry, and death certificates from the Office of the Medical Examiner.	52.5/million/year
Canada British Columbia, Canada	2010 Canadian population data multiplied by initial incidence rates previously published [8]. 1995–2004 Spinal Cord Unit at Vancouver General Hospital.	53/million/year (2010) 35.7/million/year (1995–2004)
Alaska, USA	1991–1993 SCI in Alaska Trauma Registry.	83/million/year
Arkansas, USA	1980–1989 Arkansas residents in Arkansas State Spinal Cord Commission registry.	28.5/million/year
Colorado, USA	1986–1991 SCI cases in Colorado and Wyoming Spinal Cord Injury Early Notification System (ENS); SCI cases in Colorado; Cases identified using retrospective ICD-9 reporting in 1989–990. Inclusion criteria not provided prior to this.	26.5/million/year (1986) 23.9/million/year (1987) 24.7/million/year (1988) 35.9/million/year (1989) 38.8/million/year (1990)
Oklahoma, USA	1988–1990 Oklahoma residents with SCI in Oklahoma statewide multilevel surveillance system. Exclusion Criteria: People who died at scene of injury; Injuries to nerve roots or spinal plexus.	51.0/million/year
Utah, USA	1989–1991 Statewide injury reporting system obtaining SCI cases from all state hospital and inpatient rehabilitation units and state death certificates.	47.0/million/year (age adjusted to 1980) 43/million/year (crude)
USA Kentucky and Indiana, USA Mississippi USA	1970–1977 Data from National Center for Health Statistics Hospital Discharge Survey. 1993–1998 University of Louisville Hospital SCI Trauma Registry and patient medical records. 1992–1994 All SCI cases that occurred in the state of Mississippi and to state residents.	40.1/million/year 25.2/million/year 77/million/year
San Diego, California, USA USA	1992–1997 Data from San Diego County Trauma Injury. National Model Spinal Cord Injury Data Base	40/million/year (1992) 40/million/year (1997) 30/million/year
Olmsted, Minnesota, USA	1935–1981 Medical records-linkage system of the Rochester Project at the Mayo Clinic, periodic multi-center surveys.	54.8/million/year (1935–1981) 22.2/million/year (1935–1944) 70.8/million/year (1975–1981)
West Virginia, USA	1985–1988 West Virginia residents with SCI in Statewide reporting system. Data collected during the West Virginia SCI Registry, includes only injured patients surviving until hospitalization.	25/million/year
USA New York State, USA	1974 National Head and Spinal Cord Injury Survey 1982–1988 All hospital discharges from acute-care facilities in New York State	50/million/year (1974) 43/million/year

Table 3. Incidence of spinal cord injury in Europe according to his Furlan J.C. study [8].

Geographic Area	Inclusion and exclusion criteria.	Incidence rates by year
Greenland	1965–1986 Admissions to rehabilitation hospital in Hornback with traumatic SCI.	26/million/year
Kingdom of Denmark	1975–1984 Admission to national specialized rehabilitation hospitals.	9.2/million/year
Iceland	1973–1989 Patients admitted to rehabilitation unit in Reykjavik.	24/million/year (1973–1982)
		18/million/year (1983–1989)
Iceland	1975–2009 Landspitali University Hospital, the single referral center for SCIs in Iceland.	30/million/year (1975–1979)
		12.5 million/year (1995–1999)
		33.5/million/year (2005–2009)
Estonia	1997–2007 Medical records from 22 Estonian hospitals.	39.7/million/year (1997–2007)
Plovdiv region, Bulgaria	1983–1992 Treatment for SCI at 2 clinics in Plovdiv region.	130.6/million/year
Ireland	2000 Patients admitted to National Rehabilitation Hospital.	13.1/ million/year
Netherlands	1994 Defined SCI cases within national registration system.	12.1/million/year
	Exclusion Criteria: Spinal contusions with no or temporary neurological symptoms.	
Anatolia, Turkey	1990–1999 Four hospitals that were major referral centers for trauma in South-eastern Anatolia.	12.1/million/year
Southeast Turkey	1994 Traumatic SCI in Southeast Turkey.	16.9/million/year
Istanbul, Turkey	1992 All new patients with SCI, including pediatrics.	20.8/million/year
Turkey	1992 Nation-wide survey of SCI admissions to medical institutions.	12.7/million/year
	Exclusion Criteria: Patients who died before hospitalization.	
Central Region of Portugal	1989–1992 Two hospitals that treat all SCI in the central region of Portugal. Including pediatric cases.	57.8/million/year
	Cases without neurological lesion, rehospitalization and vertebral lesions were excluded.	
Western Norway	1952–2001 Discharges from 8 hospitals in region with SCI.	6.2/million/year (1952–1956)
		26.3/million/year (1997–2001)
Norway	1952–2001 Individuals with SCI in the Hordaland and Sogn og Fjordane counties.	6.2/million/year (1952–1956)
		13.6/million/year (1972–1976)
		26.3/million/year (1997–2001)
Finland	1970–2004 All persons aged 50 or older admitted to Finnish hospitals for treatment of a fall induced severe cervical spine injury.	52.0/million/year (1970)
		120.0/million/year (2004)
Finland	1976–2005 Käpylä Rehabilitation Centre database.	13.8/million/year (1976–2005)
Bucharest, Romania	1992–1993 SCI patients admitted to Dr Gh. Marinescu Hospital.	28.5/million/year
Federal Republic of Germany	1983 Hospitalizations, Hamburg's Central Office for Paraplegic Patients, German Workmen's compensation, and General Local Health Insurance Cia.	36.0/million/year
Veneto, Italy	1994–1995 New cases of traumatic SCI and non-traumatic spinal cord disease treated in regional hospitals.	14.3/million/year
Spain	1984–11985 (Every traumatic and non-traumatic SCI patient in specialized Spanish hospitals).	8.0/million/year
Aragon, Spain	1972–2008 Hospital admission in Aragon.	8.2/million/year (1972–1980)
		13.8/million/year (1981–1990)
		12.9/million/year (1991–2000)
		13.4/million/year (2001–2008)
Spain	2000–2009 The National Hospital Discharge Register.	23.5/million/year (2000–2009)
France	2000 (Survey of rehab units in France Patients with SCI (! 15 yo) admitted for first stay.	19.4/million/year
	Exclusion Criteria: Non-traumatic SCI; neurological impairment due to peripheral nervous lesion; follow-up or readmissions to rehab unit).	

remote control procedures [10]. Adaptability is the main reason why virtual reality has attracted the attention of health experts. Virtual reality offers numerous clinical applications, independent of the user's location and health, provides a stimulating and interactive environment, partially comparable to real-life experiences [11–14]. Currently, different types of protocols are used to induce and facilitate neural regeneration processes [15]. Being a technology based on interaction, it increases the motivation and the degree of user involvement, which visibly improves the adherence to the treatment, especially in the case of recovery protocols that involve repetitive movements [16–20].

Studies have reported that virtual reality has promising effects in the clinical rehabilitation of many neurological disorders but also in improving physical and cognitive function caused by injuries caused by brain trauma [21,22]. It has been shown that virtual reality can improve balance and gait recovery after stroke, spinal cord injury and cerebral palsy [23–29]. Virtual reality has become a fairly attractive strategy for patients with spinal cord injury allowing patients to experience a high degree of body awareness, providing multisensory feedback [26]. Experimental studies emphasize the importance of combining multisensory stimulation for patients with spinal cord injury in both the acute and chronic stages of the disease [27]. Often, after spinal cord injury, patients become disconnected from the sensory information of congruent feedback and the treatment should reconnect them to this type of feedback. This multisensory feedback can induce changes in the sensory-motor network [19].

2. Materials and Methods

International virtual libraries such as ISI-Thomson Web of Science, Scopus and the (National Center for Biotechnology Information (NCBI) have been accessed in this article. In all of the international virtual libraries the search criteria selected were "title", "abstract" and "keywords". For all the virtual libraries the search engine was "Spinal Cord virtual reality" were we found:

• Scopus virtual library, a number of 327 articles from 1996–2021 were identified;

• ISI Thomson Web of Science virtual library a number of 77 articles from 2017–2021 were identified;

• NCBI (Pub MedCentral) a number of 994 articles from 2000–2022 were identified (Fig. 2).

In order to reproduce a quality review, we wanted to use only the most prestigious virtual libraries, where the selection criteria, the quality of the reviewers, the quality of the information, etc. are higher than in other virtual libraries.

In order to create the review, were selected just articles had as research direction the re-education of the spinal cord injuries using virtual reality tools, so that from all the articles identified in the 3 international databases, only those articles were selected that met the following criteria:

• to be in the medical field;
• to be in the field of medical recovery/rehabilitation;
• to be treated for spinal cord injury.

As we will see in the results, some years have not been beneficial for the re-education of spinal cord injuries using virtual reality tools, as there are no articles addressing spinal cord rehabilitation through virtual reality.

3. Results and Discussion

In 2000, Riva spoke about the flexibility of computer-generated programs through 3-D navigation, noting that this method offers therapists a variety of possibilities. In addition, he mentions that virtual reality offers a great ability to increase interaction with the environment in a controlled manner, but also with increased quality [30]. Schmidt presented in 2002 the benefits of using the conventional method of using the treadmill and the need for the therapist's effort in assisting the patient, comparable to a robotic device that allows the therapist to attach the device legs and sensors, to enter the necessary data in computer and to assist the patient only through coordination, guidance, motivation [31]. In 2003, in the Journal of Robotics, a study was published that conducted a comparative study on mice in which a physical treadmill was used with a virtual one generated by robots. The results were more impactful on the physical treadmill than on that generated by the robots [32].

A question raised in 2004 by Kushner, was on nervous influences, namely, whether this virtual reality technology influences our nervous system or whether movement in a virtual environment motivates the patient to perform [33]. In 2006, there were still discussions about innovative technologies that induce and perform passive movement to stimulate the motor efficiency of the spine, but also about technologies that stimulate voluntary patient movements, concluding that stronger evidence is needed to demonstrate the applicability of these technologies in rehabilitation [34].

Wellner wrote in 2007 that robots intended for rehabilitation during that period consisted of moving the lower limbs of patients on a predefined trajectory, not stimulating them enough because the device moves the lower limbs in the absence of patient effort, unable to observe their course. The attachment of an accrual, ventilator and audio system allows the patient to complete a route, thus increasing the recovery quality of the devices from that period [35].

A comparative study on the psychological effects offered by virtual reality vs. without virtual reality in cases of spinal cord heart injury was conducted in 2009 by Chen, where out of thirty patients, he formed two groups, a group where he used virtual reality and in a control group where he did not use virtual reality, he concluded that virtual reality helped to relax patients and induce a state of calm in them [24].

A review conducted in 2009 and presents the broad spectrum of virtual reality use in the rehabilitation of stroke, traumatic brain injuries, spinal cord injuries, intellectual

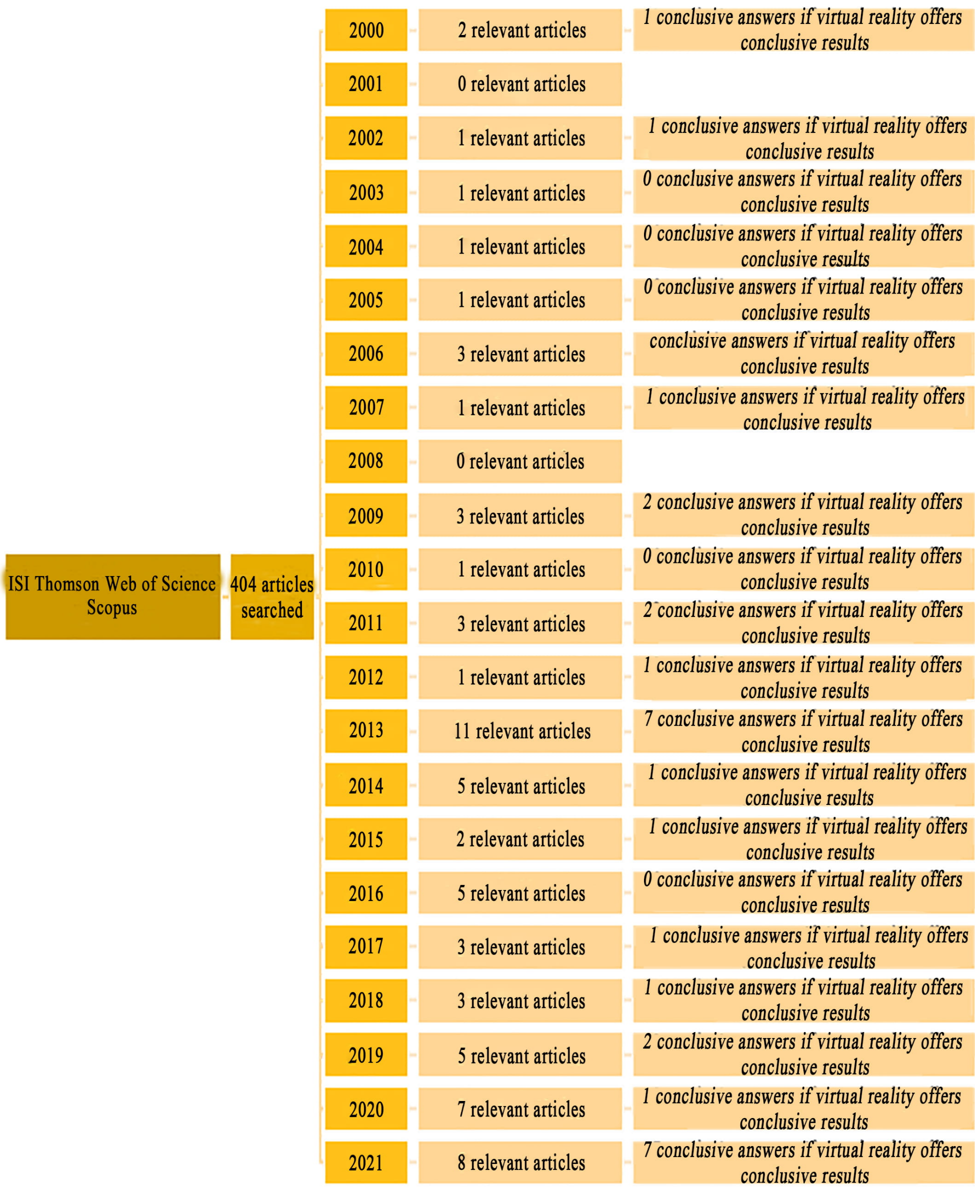

Fig. 2. Annual presentation of relevant study articles as well as the number of articles that provide accurate information on the benefits of using virtual reality in re-educating patients with spinal cord injuries.

disabilities and cerebral palsy and intellectual disabilities, but at the same time it highlights the beneficial effects that virtual reality has in such cases as: improves motor aspects, improves cognitive impairment and motivation [36].

Also, another review in 2010 found that most virtual reality articles contained a small number of patients and were intended to test and validate their own devices, rather than to demonstrate clinical efficacy in rehabilitation, concluding that virtual reality is a promising method for the future of neural rehabilitation, only studies should focus on demonstrating its effectiveness compared to traditional techniques [37].

De Mauro mentions in his study in 2011, about the benefits of using virtual reality in rehabilitating patients with spinal cord injuries, mentioning that it is a suitable technology due to its ability to stimulate real life, excludes monotony and at the same time motivating the patient [38].

Villiger points out in 2011 that intense sessions using virtual reality, can make possible the restoration of cortical networks, thus leading to a reduction of neuropathic pain and automatically improving motor function, applying a virtual water rehabilitation protocol to six patients, concluding that the protocol used can bring benefits in both reducing neuropathic pain and automatically improving motor function [39].

The year 2012 offered us an article that tried to rehabilitate through virtual reality the patients with spinal cord injury restoring their driving skills. Before 2012, no quality of life studies have been identified using virtual rehabilitation in regaining driving skills. The study was performed on a group of twelve patients with spinal cord injury and showed impressive results on regaining the driving skills of these patients [40]. Mazzone mentions that almost (70%) of spinal injury patients will develop shoulder pain at some point. He did a study on five patients with shoulder pain, a study in which patients performed shoulder exercises with and without virtual reality, not identifying major differences between the kinematics of the two, but muscle activation was similar or higher on exercises where reality was used virtual [41].

In 2013, Dimbwadyo argued that virtual reality is a system that induces motor activity and increased motor control, while promoting better cortical reorganization through mirror neurons system activation. To demonstrate this, he conducted a study of twelve patients trying to demonstrate the effectiveness of virtual reality through a system called Toyra®. The end of the study showed that patients who used the Toyra® system had improvements in parameters such as dexterity, coordination, grip, but also observed kinematic parameters [42,43]. Another virtual reality study called Toyra® on parameters such as range of motion, accuracy, repeatability and agility, showed that it can be used as an effective method in the motor assessment of the upper limb of patients with spinal cord injury [44]. In 2013 there is another study aimed at increasing the quality of life of patients, by using virtual reality to increase the performance of wheelchairs. The study was conducted on a group of ten people, regular users of wheelchairs. The results showed that the virtual driving simulator is a promising virtual reality tool to evaluate and increase the performance of wheelchair use [45].

In the same year there is a study that addresses virtual reality in terms of increasing quality of life, but also the reintegration of people in recreational and sports activities. The study used virtual reality in sailing simulators over a twelve-weeks period as a pilot treatment for the recovery of sailing enthusiasts. At the end of the twelve weeks all subjects demonstrated simple navigator skills, the ability to sail independently at moderate currents as well as speed as well as improved psychological health [46]. Villiger and colleagues demonstrated in 2013 that Augmented Virtual Reality has improved gait, balance, and strength in patients with spinal cord injury in lower limb cases, but in addition to that, the intensity and pain of neuropathy has decreased. A comparative study was conducted in 2014 on nine patients with spinal cord injury. One group used virtual reality using CyberTouch™ gloves, and the other group performed traditional rehabilitation, thirty minutes a day, twice a week, for two weeks [20]. The results obtained were not statistically significant, but the group where apparent virtual reality was used obtained better results in muscle balance, as well as in functional parameters such as dexterity, coordination and finite grips [47]. Mao Y. only praises the virtual reality used in rehabilitation, saying that when patients use virtual reality in prefrontal treatment sessions, parietal cortical areas and other motor cortical networks are activated, and this activation leads to the reconstruction of neurons in the cerebral cortex [48].

Another conclusion of Mao, emphasizes that virtual reality visibly improves neurological function in patients with spinal cord injury, cerebral palsy and other neurological disorders, this being possible by activating the cerebral cortex and improving the temporal-spatial orientation of patients, thus facilitating the control of the level balance and improving motor function [20]. A comparative study was conducted in 2015 between Lokomat (virtual reality) and passive pedaling; concluding that patients who benefited from Lokomat sessions had improvements in metabolic markers and those who benefited from passive pedaling sessions did not [49].

In 2016, nine patients participated in a spinal cord injury rehabilitation study using virtual reality combined with CyberTouch. The patients formed two groups where virtual reality was used with CyberTouch™ and the other group performed only the traditional rehabilitation, for a period of two weeks. The results did not show statistically significant changes, but the group that used virtual reality obtained changes in muscle balance, dexterity, coordination and finite grip [27]. Khurana conducted a comparative study on a group of thirty patients (twenty-eight men's and two woman's) with traumatic spinal cord injury. In order to conduct the study, patients were divided into two groups: group A benefited from balance training based on virtual reality play, and group B performed specific exercises for balance. The program lasted for four weeks, with five sessions lasting forty-five minutes each week. The results showed that group A, which performed balance training based on virtual reality play, performed better than group B. Another study compared the effectiveness of virtual reality using the Nintendo Wii system and conventional occupational therapy in improving upper limb function in patients with spinal cord injury [50]. The study involved twenty-two patients with spinal cord injury spinal cord injury, who were randomly assigned to two groups, group one received thirty minutes of virtual reality therapy and conventional occupational therapy for thirty minutes, at the same time the second group, for thirty minutes was subjected only to therapy conventional occupational. Both groups worked three times a week for six weeks and were evaluated at baseline and then at two weeks, four weeks, and six weeks from the start of therapy.

Evaluations performed after four weeks and after six weeks of treatment did not highlight significant differences between the two groups, in conclusion virtual reality has not been shown to be effective in improving upper limb function [51]. A study of a 60-year-old patient with spinal cord injury, incompletely affected cervix, wanted to assess cognitive and motor outcomes after a combined rehabilitation program, using the standard cognitive approach combined with virtual reality. The patient had a moderate tetra paresis that mainly affected the left side. It was first subjected to the standard treatment protocol and then to a combined therapeutic approach, traditional physiotherapy combined with virtual reality. The combined therapeutic approach has shown significant improvements in cognitive function, a significant reduction in symptoms of anxiety and depression but also improvements in motor performance and balance [52]. A pilot study was conducted to investigate the effects of rehabilitation therapy using a new device, iCycle. We analyzed eleven patients with incomplete spinal cord injury in different evolutionary stages, which underwent twelve trainings with iCycle. The functions were evaluated before the start of the trainings using the international standards described in the specialized literature. Improvements in the neurological classification for spinal cord injury motor score showed only two of the six patients with chronic injuries and four of the five patients with acute injuries. Five out of eleven participants showed moderate improvements in voluntary cycling Power output which did not correlate with changes in international standards for neurological classification for spinal cord injury motor score. At the end of the study, it was concluded that iCycle was not suitable for participants who were too weak to generate a detectable voluntary couple or whose effort led to a negative couple. Improved neurological classification for spinal cord injury motor score were associated with iCycle training in chronic participants. In sub-acute patients, changes due to iCycle training could not be distinguished [53].

In 2019, Chi [54] conducted a systematic review of spinal cord injury associated with neuropathic pain, concluding that the virtual reality applied in spinal cord injury -Associated neuropathic pain may reduce its effects, but the results on the analgesic effect are still unclear.

Porter *et al*. [55] presents in a study the use of a robot with a virtual reality platform in the rehabilitation of the upper limbs of patients with spinal cord injury spinal cord injury. The virtual reality platform consists of three different games, which offer the patient the opportunity to interact with the virtual scene using the upper limbs. During the therapy data are collected regarding the motor qualities, the system can be adapted according to the patient's needs. The efficiency of the system is proven by the collected data, which proves to be effective in the therapy of patients with spinal cord injury [55]. A study was conducted to analyze the results obtained in the case of conventional therapy combined with virtual reality and simple conventional therapy. The study included patients with spinal cord injury with upper limb involvement, the control group received sixty minutes of conventional therapy per day, four days per week for four weeks, the experimental group received thirty minutes of virtual reality and thirty minutes conventional therapy four days a week for four weeks. The measurements were performed using the specific tests described in the literature, these being performed at the beginning of the study and at the end of it. Clamping power and K-SCIM score improved significantly in the experimental group after intervention. When comparing the differences between the groups, elbow extensor, wrist extensor, ASIA-UEMS, clamping power, lateral clamping power and palmar clamping power were significantly improved [56].

In 2020, Sengupta *et al*. [57], conducted a study through which he wanted to evaluate the effects of a game-based virtual reality training program for torso balance and postural control in patients with spinal cord injury. Patients were divided into two groups, a control group and an experimental group, the groups being subjected to the conventional rehabilitation program. Five days a week for three weeks the experimental group underwent additional training with virtual reality therapy. The tests performed initially but also at the end of the treatment consisted of standard tests described by the specialized literature. The analysis of the tests performed did not show significant differences between the two groups, in terms of trunk mobility and patient posture. Also, no significant difference was observed in the analysis between groups depending on the severity of spinal cord injury spinal cord injury [57]. Another study investigated the effect of interaction with simulated virtual reality environments provided on the patient's mood and the effect of a higher number of virtual reality sessions over a period of one week on the depressive symptoms of people with spinal cord injury. During the week of therapy, the patients underwent three virtual reality sessions of twenty minutes each, three consecutive days. The state of control involved a regular practice of rehabilitation for a week. The evaluation was performed based on a standardized questionnaire at the beginning of therapy, after the first week, after the second week, respectively after the third week of treatment. Levels of happiness, relaxation and feeling of well-being were significantly higher after interacting with each virtual reality session. It was concluded that the interaction with simulated natural environments, provided by virtual reality can favorably influence the psycho-emotional health of people with spinal cord injury [58].

In 2020, Abou demonstrated the effectiveness of virtual therapy in rehabilitating sitting and orthostatic balance, as well as improving gait in patients with spinal cord injury [59]. Since 2020, Amaranta wrote in article: "Effectiveness of Virtual Reality on Functional Performance after Spinal Cord Injury: A Systematic Review and Meta-Analysis of Randomized Controlled Trials" that virtual reality is not as effective as conventional therapy in improving physical performance in cases of patients with spinal cord injury [60].

In 2021, Putrino conducted a study the purpose of this study was to investigate the effect of two different virtual reality protocols on pain intensity in people with spinal cord injury. Participants were recruited from the Burke Institute for Medical Research's spinal cord injury database from

2015 to 2016. Virtual reality was used as a pain management tool among people with acute, chronic, neuropathic pain and phantom limb pain. Virtual reality therapy also appears as a promising alternative treatment for people with spinal cord injury. The results indicated a mean decrease in pain after virtual reality intervention. The results obtained in the study were comparable with the results already existing in the literature, which once again confirms the effects of virtual reality therapy in pain therapy in patients with spinal cord injury [61].

Leemhuis *et al.* [62], describe the potential benefits of using virtual reality in patients with spinal cord injury to re-educate sensory-motor feedback. It was found that placing patients in a virtual environment enriches sensory perceptions and implicitly motor ones, through the processes of neuronal regeneration and plasticity [62]. The results showed that when virtual reality therapy is used concomitantly with conventional therapy the treatment results are visibly improved. In conclusion, virtual reality therapy combined with standard rehabilitation therapy could be an ideal rehabilitation tool for improving lower extremity function in patients with spinal cord injury. The study entitled Effectiveness of virtual reality-based exercise therapy in rehabilitation: A scoping review, tried to show the effectiveness of virtual reality in therapeutic physical exercises, thus fueling future research in this directive. Based on the information obtained, the authors concluded that virtual reality based on therapeutic physical exercises have a great potential in rehabilitation, but studies in this direction are still needed [63].

A study conducted in 2021 by Orsatti wanted to demonstrate the effectiveness of virtual reality intervention in the neuronal rehabilitation of patients with spinal cord injuries. This review was conducted over a period of ten years, from 2010–2020, which concluded with the conclusion that virtual reality is an effective therapy, but it is an effective complementary therapy, which tells us that it must come to the aid of conventional physical therapy [64]. Rutkowski also did a systematic review of virtual reality in upper limb, lower limb, gait and balance rehabilitation, but in the end concluded that virtual reality along with virtual games can bring considerable advantage in upper limb rehabilitation, but not for hand and walk. Virtual reality can also improve balance in cases of patients with neurological problems [65].

The same thing was identified by Lee in 2021 that the use of virtual reality can be a real tool in balance rehabilitation programs for patients with spinal cord injury. Min-Jae Lee conducted a study on twenty subjects with spinal cord injury, who were divided into two groups, a control group and an experimental group. Patients underwent a recovery program that included virtual reality, designed to improve balance. Each session lasts thirty minutes twice a week for eight weeks. Equilibrium functions were measured according to the protocols described in the literature [66].

4. Conclusions

Between ten and 83 million people suffer from spinal cord injury every year, globally. According to the results presented in our review we can conclude that the current evidence of virtual reality interventions to improve functional performance after spinal cord injury is limited. The articles analyzed in the review highlighted that virtual reality cannot be more effective than conventional therapy in improving functional performance in patients with spinal cord injury. In addition to the high costs of purchasing a virtual reality device, the purchase of software packages or various interactions depending on the specific needs of patients (age/sex/profession/hobby, etc.) should also be considered.

Although the real mechanisms underlying the therapeutic effects of virtual reality remain unclear, therapy is being approached to prove the effectiveness of a developed product and not to emphasize the mechanism of action on the condition and the patient. The evidence reported so far suggests that virtual reality procedures should be used in conjunction with standard/conventional rehabilitation so that the patient can benefit from both modern and conventional treatment, thus enhancing the quality of treatment provided. Recent evidence from the literature has shown that virtual reality may be useful as a therapeutic tool in patients with spinal cord injury to improve motor function or motor skills, to reduce pain perception and improve psychological/motivational outcomes by improving feedback physiologicaly.

As most articles have shown, the usefulness of virtual reality in people with spinal cord injury can be considered both in the acute phase and in the chronic phase of spinal cord injury treatment, which gives us a wide range of work with this tool. As specified above, most authors have attempted to demonstrate the efficacy of the product without regard to the clear mechanism of action and the medium- and long-term impact on patients' health/quality of life. Within a limited number of found authors, they tried to work on the patient's quality of life using virtual reality in the rehabilitation of daily activities, such as the reintegration of patients in recreational activities. These articles focused primarily on issues such as improving the patient's quality of life, promoting the activity prior to practicing a preferred trade/hobby, thus demonstrating their effectiveness in directions where conventional rehabilitation cannot be applied.

Author Contributions

The introduction was identified and edited by MI, the access to databases together with the design of the working methodology was performed by MT, the search in the virtual libraries and the browsing of all articles (relevant and irrelevant) was performed by to CI and IC. The entire review was supervised and guided by MR. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Department of Medical Biosciences, 'Gr.T.Popa' University of Medicine and Pharmacy, Iasi, Romania.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Bickenbach J, Officer A, Shakespeare T, Von Groote P. International Perspectives on Spinal Cord Injury: Summary. Publisher: ISCOS: Buckinghamshire. 2013.

[2] Stoica S, Tănase I, Onose G. Influences and consequences resulting in addictions in general and to chronic alcoholism, especially for patients with spinal cord injury. Balneo and PRM Research Journal. 2021; 12: 129–132.

[3] National Institute of Neurological Disorders and Stroke. Spinal Cord Injury Information Page. Available at: https://www.ninds.nih.gov/health-information/disorders/spinal-cord-injury (Accessed: 9 March 2021).

[4] Kirshblum SC, Burns SP, Biering-Sorensen F, Donovan W, Graves DE, Jha A, *et al.* The Journal of Spinal Cord Medicine. 2011; 34: 535–546.

[5] Wyndaele M, Wyndaele J. Incidence, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey? Spinal Cord. 2006; 44: 523–529.

[6] Kraus JF, Franti CE, Riggins RS, Richards D, Borhani NO. Incidence of traumatic spinal cord lesions. Journal of Chronic Diseases. 1975; 28: 471–492.

[7] Fitzharris M, Cripps RA, Lee BB. Estimating the global incidence of traumatic spinal cord injury. Spinal Cord. 2014; 52: 117–122.

[8] Furlan JC, Sakakibara BM, Miller WC, Krassioukov AV. Global Incidence and Prevalence of Traumatic Spinal Cord Injury. Canadian Journal of Neurological Sciences. 2013; 40: 456–464.

[9] DeVivo M, Biering-Sørensen F, Charlifue S, Noonan V, Post M, Stripling T, *et al*. International Spinal Cord Injury Core Data Set. Spinal Cord. 2006; 44: 535–540.

[10] Merritt CH, Taylor MA, Yelton CJ, Ray SK. Economic impact of traumatic spinal cord injuries in the United States. Neuroimmunol Neuroinflamm. 2019; 6: 9.

[11] Lele A. Virtual reality and its military utility. Journal of Ambient Intelligence and Humanized Computing. 2013; 4: 17–26.

[12] Rose T, Nam CS, Chen KB. Immersion of virtual reality for rehabilitation - Review. Applied Ergonomics. 2018; 69: 153–161.

[13] Trincado-Alonso F, Dimbwadyo-Terrer I, de los Reyes-Guzmán A, López-Monteagudo P, Bernal-Sahún A, Gil-Agudo A. Kinematic Metrics Based on the Virtual Reality System Toyra as an Assessment of the Upper Limb Rehabilitation in People with Spinal Cord Injury. BioMed Research International. 2014; 2014: 1–11.

[14] Kizony R, Raz L, Katz N, Weingarden H, Weiss PLT. Video-capture virtual reality system for patients with paraplegic spinal cord injury. The Journal of Rehabilitation Research and Development. 2005; 42: 595.

[15] Riva G, Wiederhold BK, Mantovani F. Neuroscience of Virtual Reality: from Virtual Exposure to Embodied Medicine. Cyberpsychology, Behavior, and Social Networking. 2019; 22: 82–96.

[16] Field-Fote EC. Spinal Cord Control of Movement: Implications for Locomotor Rehabilitation Following Spinal Cord Injury. Physical Therapy. 2000; 80: 477–484.

[17] Wall T, Feinn R, Chui K, Cheng MS. The effects of the Nintendo™ Wii Fit on gait, balance, and quality of life in individuals with incomplete spinal cord injury. The Journal of Spinal Cord Medicine. 2015; 38: 777–783.

[18] Carlozzi NE, Gade V, Rizzo A Tulsky DS. Using virtual reality driving simulators in persons with spinal cord injury: three screen display versus head mounted display. Disability and Rehabilitation: Assistive Technology. 2013; 8: 176–180.

[19] Dimbwadyo-Terrer I, Trincado-Alonso F, De los Reyes-Guzman A, Bernal-Sahun A, Lopez-Monteagudo P, Polonio-Lopez B, *et al*. 'Clinical, Functional and Kinematic Correlations using the Virtual Reality System Toyra (R) as Upper Limb Rehabilitation Tool in People with Spinal Cord Injury'. Proceedings of the Neurotechnix, International Congress on Neurotechnology, Electronics and Informatics. Algarve, Portugal. 2013.

[20] Villiger M, Bohli D, Kiper D, Pyk P, Spillmann J, Meilick B, *et al*. Virtual Reality–Augmented Neurorehabilitation Improves Motor Function and Reduces Neuropathic Pain in Patients with Incomplete Spinal Cord Injury. Neurorehabilitation and Neural Repair. 2013; 27: 675–683.

[21] Jordan M, Richardson EJ. Effects of Virtual Walking Treatment on Spinal Cord Injury–Related Neuropathic Pain: Pilot Results and Trends Related to Location of Pain and at-level Neuronal Hypersensitivity. American Journal of Physical Medicine & Rehabilitation. 2016; 95: 390–396.

[22] Roosink M, Robitaille N, Jackson PL, Bouyer LJ, Mercier C. Interactive virtual feedback improves gait motor imagery after spinal cord injury: an exploratory study. Restorative Neurology and Neuroscience. 2016; 34: 227–235.

[23] Pietrzak E, Pullman S, McGuire A. Using Virtual Reality and Videogames for Traumatic Brain Injury Rehabilitation: a Structured Literature Review. Games for Health Journal. 2014; 3: 202–214.

[24] Chen C, Jeng M, Fung C, Doong J, Chuang T. Psychological Benefits of Virtual Reality for Patients in Rehabilitation Therapy. Journal of Sport Rehabilitation. 2009; 18: 258–268.

[25] Li Z, Han X, Sheng J, Ma S. Virtual reality for improving balance in patients after stroke: a systematic review and meta-analysis. Clinical Rehabilitation. 2016; 30: 432–440.

[26] Ravi DK, Kumar N, Singhi P. Effectiveness of virtual reality rehabilitation for children and adolescents with cerebral palsy: an updated evidence-based systematic review. Physiotherapy. 2017; 103: 245–258.

[27] Dimbwadyo-Terrer I, Trincado-Alonso F, de los Reyes-Guzmán A, Aznar MA, Alcubilla C, Pérez-Nombela S, *et al*. Upper limb rehabilitation after spinal cord injury: a treatment based on a data glove and an immersive virtual reality environment. Disability and Rehabilitation: Assistive Technology. 2016; 11: 462–467.

[28] Pazzaglia M, Giannini AM, Federico F. Acquisition of Ownership Illusion with Self-Disownership in Neurological Patients. Brain Science. 2020; 10: 170.

[29] Pozeg P, Palluel E, Ronchi R, Solcà M, Al-Khodairy A, Jordan X, *et al*. Virtual reality improves embodiment and neuropathic pain caused by spinal cord injury. Neurology. 2017; 89: 1894–1903.

[30] Riva G. Virtual reality in rehabilitation of spinal cord injuries: A case report. Rehabilitation Psychology. 2000; 45: 81–88.

[31] Schmidt H, Sorowka D, Hesse S, Bernhardt R. 'Design of

a robotic walking simulator for neurological rehabilitation'. IEEE/RSJ International Conference on Intelligent Robots and Systems. Lausanne, Switzerland. 2002.

[32] Timoszyk WK, De Leon RD, London N, Joynes R, Minakata K, Roy RR, *et al*. Comparison of virtual and physical treadmill environments for training stepping after spinal cord injury. Robotica. 2003; 21: 25–32.

[33] Keshner EA. Virtual reality and physical rehabilitation: A new toy or a new research and rehabilitation tool? Journal of NeuroEngineering and Rehabilitation. 2004; 1: 8.

[34] Liebermann DG, Buchman AS, Franks IM. Enhancement of motor rehabilitation through the use of information technologies. Clinical Biomechanics. 2006; 21: 8–20.

[35] Wellner M, Duschau-Wicke A, von Zitzewitz J, Riener R. 'Stepping over Virtual Obstacles with an Actuated Gait Orthosis'. 2007 IEEE Virtual Reality Conference. Charlotte, North Carolina, USA. 2007.

[36] Weiss PL, Sveistrup H, Rand D, Kizony R. Video capture virtual reality: a decade of rehabilitation assessment and intervention. Physical Therapy Reviews. 2009; 14: 307–321.

[37] Peñasco-Martín B, de los Reyes-Guzmán A, Gil-Agudo Á, Bernal-Sahún A, Pérez-Aguilar B, de la Peña-González AI. Application of virtual reality in the motor aspects of neurorehabilitation. Revista de neurologia. 2010; 51: 481–488.

[38] De Mauro A, Ardanza A, Chen C, Carrasco E, Oyarzun D, Torricelli D, *et al*. Virtual Reality and Hybrid Technology for Neurorehabilitations. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 2011; 352: 582–591.

[39] Villiger M, Hepp-Reymond M, Pyk P, Kiper D, Eng K, Spillman J, *et al*. 'Virtual reality rehabilitation system for neuropathic pain and motor dysfunction in spinal cord injury patients'. 2011 International Conference on Virtual Rehabilitation. Zurich, Switzerland. 2011.

[40] Sung W, Chiu T, Tsai W, Cheng H, Chen J. The effect of virtual reality-enhanced driving protocol in patients following spinal cord injury. Journal of the Chinese Medical Association. 2012; 75: 600–605.

[41] Mazzone B, Haubert LL, Mulroy S, Requejo P, Gotsis M, Lympouridis V, *et al*. 'Intensity of shoulder muscle activation during resistive exercises performed with and without virtual reality games'. 2013 International Conference on Virtual Rehabilitation (ICVR). Philadelphia, USA. 2013.

[42] Dimbwadyo-Terrer I, de los Reyes-Guzmán A, Bernal-Sahún A, López-Monteagudo P, Trincado-Alonso F, Polonio-López B, *et al*. Virtual Reality System Toyra: a New Tool to Assess and Treatment for Upper Limb Motor Impairment in Patients with Spinal Cord Injury. Biosystems & Biorobotics. 2013; 119: 853–858.

[43] Dimbwadyo-Terrer I, Trincado-Alonso F, De Los Reyes-Guzman A, Bernal-Sahun A, Lopez-Monteagudo P, Polonio-Lopez B, *et al*. Clinical, functional and kinematic correlations using the Virtual Reality System toyra® as upper limb rehabilitation tool in people with spinal cord injury. NEUROTECHNIX 2013 - Proceedings of the International Congress on Neurotechnology, Electronics and Informatics. Vilamoura, Algarve, Portugal. 2013.

[44] Trincado-Alonso F, Bernal-Sahún A, López-Monteagudo P, Dimbwadyo-Terrer I, Peñasco-Martín B, Gil-Agudo A. Use of Virtual Reality System Toyra to Develop an Objective Set of Parameters to Evaluate the Motor Abilities of Upper Limbs in Patients with Spinal Cord Injury. Biosystems & Biorobotics. 2013; 24: 1025–1029.

[45] Mahajan HP, Dicianno BE, Cooper RA, Ding D. Assessment of wheelchair driving performance in a virtual reality-based simulator. The Journal of Spinal Cord Medicine. 2013; 36: 322–332.

[46] Recio AC, Becker D, Morgan M, Saunders NR, Schramm LP, McDonald JW. Use of a Virtual Reality Physical Ride-on Sailing Simulator as a Rehabilitation Tool for Recreational Sports and Community Reintegration: A Pilot Study. American Journal of Physical Medicine & Rehabilitation. 2014; 92: 1104–1109.

[47] de los Reyes-Guzman A, Dimbwadyo-Terrer I, Trincado-Alonso F, Aznar MA, Alcubilla C, Pérez-Nombela S, *et al*. A Data-Globe and Immersive Virtual Reality Environment for Upper Limb Rehabilitation after Spinal Cord Injury. IFMBE Proceedings. 2014; 41: 1759–1762.

[48] Huang D, Mao Y, Chen P, Li L. Virtual reality training improves balance function. Neural Regeneration Research. 2014; 9: 1628.

[49] Zeilig G, Weingarden H, Obuchov A, Bloch A, Gaides M, Reuveny R, *et al*. 'Lokomat walking results in increased metabolic markers in individuals with high spinal cord injury'. 2015 International Conference on Virtual Rehabilitation (ICVR). Valencia, Spain. 2015.

[50] Khurana M, Walia S, Noohu MM. Study on the Effectiveness of Virtual Reality Game-Based Training on Balance and Functional Performance in Individuals with Paraplegia. Topics in Spinal Cord Injury Rehabilitation. 2017; 23: 263–270.

[51] Prasad S, Aikat R, Labani S, Khanna N. Efficacy of Virtual Reality in Upper Limb Rehabilitation in Patients with Spinal Cord Injury: a Pilot Randomized Controlled Trial. Asian Spine Journal. 2018; 12: 927–934.

[52] Maresca G, Maggio MG, Buda A, La Rosa G, Manuli A, Bramanti P, *et al*. A novel use of virtual reality in the treatment of cognitive and motor deficit in spinal cord injury. A case report. Medicine. 2018; 97: e13559.

[53] Duffell LD, Paddison S, Alahmary AF, Donaldson N, Burridge J. The effects of FES cycling combined with virtual reality racing biofeedback on voluntary function after incomplete SCI: a pilot study. Journal of NeuroEngineering and Rehabilitation. 2019; 16: 149.

[54] Chi B, Chau B, Yeo E, Ta P. Virtual reality for spinal cord injury-associated neuropathic pain: Systematic review. Annals of Physical and Rehabilitation Medicine. 2019; 62: 49–57.

[55] Porter RR, Kopera KW, Trilk JL. Feasibility and Effectiveness of Community-Based Virtual Reality Group Exercise Training in Persons with Spinal Cord Injury. Medicine & Science in Sports & Exercise. 2019; 51: 167–167.

[56] Lim DY, Hwang DM, Cho KH, Moon CW, Ahn SY. A Fully Immersive Virtual Reality Method for Upper Limb Rehabilitation in Spinal Cord Injury. Annals of Rehabilitation Medicine. 2020; 44: 311–319.

[57] Sengupta M, Gupta A, Khanna M, Krishnan UKR, Chakrabarti D. Role of Virtual Reality in Balance Training in Patients with Spinal Cord Injury: a Prospective Comparative Pre-Post Study. Asian Spine Journal. 2020; 14: 51–58.

[58] Lakhani A, Martin K, Gray L, Mallison J, Grimbeek P, Hollins I, *et al*. What is the Impact of Engaging with Natural Environments Delivered via Virtual Reality on the Psycho-emotional Health of People with Spinal Cord Injury Receiving Rehabilitation in Hospital? Findings from a Pilot Randomized Controlled Trial. Archives of Physical Medicine and Rehabilitation. 2020; 101: 1532–1540.

[59] Abou L, Malala VD, Yarnot R, Alluri A, Rice LA. Effects of Virtual Reality Therapy on Gait and Balance among Individuals with Spinal Cord Injury: a Systematic Review and Meta-analysis. Neurorehabilitation and Neural Repair. 2020; 34: 375–388.

[60] Amaranta D M R, Dolores R, Salazar A, Camacho R, David LA. Efectiveness of Virtual Reality on Functional Performance after Spinal Cord Injury: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Journal of Clinical Medicine. 2020; 9: 2065.

[61] Putrino D, Tabacof L, Breyman E, Revis J, Soomro Z, Chopra D, *et al*. Pain Reduction after Short Exposure to Virtual Reality Environments in People with Spinal Cord Injury. International Journal of Environmental Research and Public Health. 2021; 18: 8923.
[62] Leemhuis E, Esposito RM, Gennaro L, Pazzaglia M. Go Virtual to Get Real: Virtual Reality as a Resource for Spinal Cord Treatment. International Journal of Environmental Research and Public Health. 2021; 18: 1819.
[63] Asadzadeh A, Samad-Soltani T, Salahzadeh Z, Rezaei-Hachesu P. Effectiveness of virtual reality-based exercise therapy in rehabilitation: a scoping review. Informatics in Medicine Unlocked. 2021; 24: 100562.
[64] Orsatti-Sanchez BA, Diaz-Hernandez O. Efficacy of Virtual Reality in Neurorehabilitation of Spinal Cord Injury Patients: A Systematic Review. Revista Mexicana de Inginieria Biomedica. 2021; 42: 90–113.
[65] Rutkowski S, Kiper P, Cacciante L, Cieślik B, Mazurek J, Turolla A, *et al*. Use of virtual reality-based training in different fields of rehabilitation: a systematic review and meta-analysis. Journal Rehabilitation Medicine. 2020; 52: jrm00121.
[66] Lee M J, Lee SM. The Effect of Virtual Reality Exercise Program on Sitting Balance Ability of Spinal Cord Injury Patients. Healthcare. 2021; 9: 183.