Chapter 6
Virtual Reality-Based Rehabilitation Gaming System

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Abstract Many human motor function impairments are caused due to a variety of neurodegenerative diseases, motor dysfunction disabilities and age-related issues. As the geriatric population progresses, the need for novel solutions to manage age-related diseases increases. To combat this, intensive rehabilitation treatment is instituted repetitively. However, the traditional rehabilitation treatment regimes, involving tedious and monotonous activity with numerous repetitions, lacking active patient participation are of boring and strenuous nature. This ultimately leads to suboptimal treatment outcomes necessitating long-term care. To overcome this, a range of interactive and easy measuring technology-based innovative solutions fused with the rehabilitation process is being investigated to ameliorate the effectiveness and productivity of rehabilitation programs and escalate the independence of patients and empower them to administer their treatment. Recently, game-based Virtual Reality (VR) rehabilitation protocol has turned out to be a promising therapeutic alternative, amalgamating Brain-Computer Interface (BCI) with VR to activate neuro-motor functions, sustain motivation and reach rehabilitation goals to improve the quality of life of patients. Virtual rehabilitation is a computer-generated interactive patient-centred simulation system combining computers, special interfaces, and simulation exercises that imitates reality and provides an artificial environment mimicking real-world experience. The architecture of the system is designed in such a way that it can remotely track the patients, obtain data, and tailor the rehabilitation sessions

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according to the current needs of the patients. VR improves both motor skills and confidence for daily living and in numerous situations to enhance functional results, improving the clinical and social benefits of surgery. Thus, game-based VR is being developed to allow clinicians to create game-based VR tasks and this will serve to drive advances in rehabilitation interventions.

Keywords Exercise training · Game-based rehabilitation · Physiotherapy · Stroke rehabilitation · Virtual reality

Abbreviations

3D	3-Dimensional
AI	Artificial intelligence
ALP	Amyotrophic lateral sclerosis
AR	Augmented reality
ARAT	Action-research-arm-test
ASD	Autism disorder
BBT	Box-and-block-test
BWS	Body weight system
BCI	Brain-computer interface
CAREX	Cable-driven upper arm exoskeleton
CGBT	Computer game-based therapy
CIMT	Constraint-induced movement therapy
CP	Cerebral palsy
DALYs	Disability adjusted life years
ECG	Electrocardiograph
EEG	Electroencephalograph
EMG	Electromyograph
FES	Functional electrical stimulation
FIM	Functional-independence-measure score
FMA	Fugl-Meyer-assessment
GBD	Global burden of disease
HMD	Head mounted display
Hz	Hertz
IMU	Inertial measurement unit
IoT	Internet of things
IR	Infra-red
LED	Light emitting diode
LIS	Locked-in syndrome
MATLAB	Matrix Laboratory
MEG	Magnetoencephalography
MSD	Musculoskeletal Disorder
MSI	Musculoskeletal Injury

MVF	Mirror Visual Feedback
NASDAQ	National Association of Securities Dealers Automated Quotations
NEPSER	Neuroplasticity Principle-Based Sensory Rehabilitation
NLP	Natural Language Processing
NW	Nintendo Wii
OSD	Osgood schlatter disease
PPG	Photoplethysmography
RTP	Return to Play
SCI	Spinal Cord Injury
SMA	Shape Memory Alloy
SMR	Sensor Motor Rhythms
SSVEP	Somatosensory Visual Evoked Potentials
TIA	Transient Ischemic Attack
VR	Virtual Reality
VRC	Virtual Reality control
VRML	Virtual Reality Markup Language
WHO	World Health Organisation
WMFT	Wolf-Motor-Function-Test
XR	Extended Reality

6.1 Introduction

Rehabilitation works on the ideology that every person has got the fundamental policy to be a master in maintaining one's health. There is a marked difference between acute care and rehabilitation, where acute care refers to one's survival, while rehabilitation refers to personal care and autonomy. It is one of the prominent health care strategies which aids in the up-gradation, prevention, therapy and end-of-life care.

6.1.1 Rehabilitation

Rehabilitation is a set of interventions developed to advance optimal functioning and to minimize disability in people with impaired health conditions to improve a better interaction with their surroundings as defined according to the World Health Organization (WHO). The rehabilitation process is sketched to meet each one's definite needs to attain the maximum level of activity, autonomy and status of life but will not alter or revert the damage undergone due to an illness or trauma rather restores the well-being of an individual [1].

The general components for rehabilitation include the following:

- To treat disease and to prevent the problems associated with it

Table 6.1 Areas of rehabilitation

Patient requirements	Examples
Personal care skills	Eating, grooming
Physical health	Medication
Household support	Lifestyle and financial concerns and their adaptability
Emotional hold	Behavioral issues
Pain and stress relief	Medications to overcome pain
Job training	Vocational skills
Interaction skills	Socialising among others
Learning skills	Analytical skills
Oratory skills	Different methods of communication
Breathing care	Treatments to improve lung physiology
Portability skills	Mobility to different environments
Awareness and education	Family awareness and use of techniques to train

- To overcome disability by increasing activity
- To establish tools to adapt and alter the surroundings
- To create awareness among people to improve lifestyle.

Rehabilitation can extend its support in any one of the patient-centric areas and is depicted in Table 6.1.

6.1.1.1 Elements of Rehabilitation

The various elements of rehabilitation utilized to improve the lifestyle of people are

(A) Preventive rehabilitation

It is one of the common methods of rehabilitation occurring in people with chronic disease conditions aimed to ward off or slow down the onset of impairments and to improve self-management in cancer patients.

(B) Restorative rehabilitation

It concentrates on procedures to ameliorate impairments usually in people following a surgery or an acute disease namely stroke.

(C) Supportive rehabilitation

It is also termed adaptive rehabilitation where it can improve an individual's care features through the help of assistive technology.

(D) Palliative rehabilitation

It helps to improve functional autonomy and to relieve symptoms in people with life-threatening conditions to lead a good quality life with utmost comfort and dignity [2].

6.1.1.2 Objectives of Rehabilitation

The objectives outlined in rehabilitation are

- Preventing functional loss
- Retarding the rate of functional loss
- Restoring function to its maximum
- Compensating functional loss
- Conserving current functional ability

6.1.1.3 Outcomes of Rehabilitation

The various benefits rendered by rehabilitation overtime includes the following

- Reduced demand for health services out of hospitals
- Improved autonomy
- Increased self-care conditions
- Reduced independence
- Better recovery to working conditions
- Finally improved value of life and well-being.

6.1.1.4 Scope of Rehabilitation

It is an umbrella with a wide spectrum to support communication, improve health, well-being and combat acute illness like trauma and thus requires support in the following areas

(i) Development of supplementary skills to overcome hurdles
(ii) Establishment of independence in conditions like dementia
(iii) Improves performance in athletes
(iv) Retrieve from sudden acute illness like stroke
(v) Recover from crucial shock to regain back the usual skills after an accident
(vi) Govern chronic problems through rehabilitation interventions to maximise function
(vii) Self-care to avoid secondary complications in people with depression
(viii) Acquire advocacy in vulnerable individuals [3].

6.1.1.5 Benefits of Rehabilitation

At the outset, the use of assistive technology and its various benefits are listed in Table 6.2.

Table 6.2 Benefits of rehabilitation

Physical benefits of rehabilitation	Enhances	• Strength and flexibility • Balance and coordination • Gait and posture
	Reduces	• Pain and risk of falls • Inflammation • Unexpected complications • Continuous support and dependence
Psychological benefits of rehabilitation	Enhances	• Self-esteem • Independence and wellbeing
	Reduces	• Complication rates
Lifestyle benefits of rehabilitation	Enhances	• Social participation • Return to working conditions • Quality of life
	Reduces	• Dependence
Economic benefits of rehabilitation	Enhances	• Earning ability • Potential of children
	Reduces	• Associated Hospital costs • Hospital Readmissions • Length of stay • Number of appointments

6.1.1.6 Types of Rehabilitation

1. Orthopaedic and musculoskeletal rehabilitation

   It follows therapeutic interventions to improve recovery and pain management in patients with musculoskeletal disorders by framing personalised therapy regimes to enhance physical strength and mobility. E.g. Aerobics and other exercises performed individually or in groups to strengthen muscles.
2. Neurological rehabilitation

   This approach involves simulation of the brain in patients with stroke. Along with pharmacological treatments, the use of assistive devices, physiotherapy, safety training and occupational therapy can strengthen muscles, overcome weakness, improve balance, coordination and cognition. These patients can recover in phases of early and late stages of the disease to carry out regular household chores [4]. E.g. Fitness exercise, physiotherapy.
3. Cardiac rehabilitation

   This is an advanced rehabilitation protocol to be adapted in patients with severe cardiovascular abnormalities like heart attack, which includes health education, simple physical exercises and management of stress to alleviate risk for sudden demise and control symptoms [5]. E.g. Hand exercise, breathing exercises.

4. Pulmonary rehabilitation

   Pulmonary rehabilitation practices procedures based on an assessment to optimize respiratory functions in patients having moderate to severe chronic pulmonary diseases.

5. Geriatric rehabilitation

   Older patients show chronic diseases and comorbidities making them carry out a sedentary lifestyle due to aging. Thus, improving their physical activity regularly can enhance their active life expectancy and bring down the risk of progressive chronic conditions. E.g. Home-based multimodal exercise and nutrition.

6. Renal rehabilitation

   This type of rehabilitation is found to be most efficient in people with chronic kidney diseases following dialysis and can improve the quality of life through increased cardiopulmonary functions and ventilation efficiency. Chronic kidney disease can end up in secondary sarcopenia which can also be managed with supervised rehabilitation and strengthening exercises. E.g. Intradialytic exercises.

7. Burn rehabilitation

   Various rehabilitation methods have assisted to improve pain management, anxiety, gait functions, limb movements, mental satisfaction and lessened muscle tension in patients who have sustained burn injuries [6]. E.g. Robotics, music therapy, behavioural therapy.

The global concept of rehabilitation explained that over 15% of the global population lives with some form of disability and according to a recent survey, 2.41 billion people live with impairments and need rehabilitation services to overcome their disease or injury. The life expectancy has gone above 60 years of age but, people living with chronic diseases experiencing disability are increasing leading to the need for rehabilitation regimes, especially amidst susceptible populations all over the world [7].

Though rehabilitation is a requisite health service crucial among children, adults and the elderly, the highest contributors to the global need for rehabilitation depends on stroke and musculoskeletal disorders.

6.1.2 Stroke

Stroke is a crucial medical emergency condition and needs prompt and early treatment action to avoid damage to brain tissues and related complications. Either a rupture or bleeding of a blood vessel in the brain or a block in the blood vessel to the brain causes a stroke. This is due to the poor blood flow resulting in reduced oxygen and nutrients supply to the brain tissue causing brain cells to die within minutes. People who have had strokes live less than a year and it predominantly affects people over 65 years of age. In 2020, according to the information from the Centre for Disease Control and Prevention, stroke was considered the leading cause of mortality behind neurological reasons and ranked 5th among all diseases in the world.

6.1.2.1 Signs and Symptoms

The onset of symptoms is very rapid over seconds to minutes and depends on the portion of the brain tissue affected. The right identification of a stroke episode can be found by detecting face weakness, a drift of one arm downward and slurred speech. The signs and symptoms appear very soon after the occurrence of stroke.

- Inability to move leading to loss of balance and coordination
- Numbness in one side of the body leading to unilateral paralysis
- Speaking trouble and slurred speech
- Dizziness
- Vision loss
- Altered consciousness
- Lack of responsiveness and understanding
- Increased agitation or seizures
- Sudden severe headache.

The other common chronic secondary complications include pneumonia and bladder control loss. Early and prompt treatment is required to reduce brain damage, long-term disability and mortality in stroke survivors [8].

6.1.2.2 Classification

(i) Ischemic stroke

It is the most common form of stroke and 87% of strokes are ischemic strokes due to a blocked artery either by a clot or a plague resulting in severe ischemia. Symptoms of this form of stroke usually last longer or sometimes become permanent. Hemorrhagic transformation can also occur when there is bleeding in the areas of ischemia.

Blood supply to brain tissue can be decreased due to obstruction by a blood clot or an embolus or when there is a total blood volume reduction. Sometimes the cause of stroke is unknown and termed cryptogenic and accounts for nearly 30 to 40%. Ischemic stroke can be treated if detected within 3–4 h using clot-dissolving medicines.

(ii) Hemorrhagic stroke

Hemorrhagic stroke results from bleeding of a blood vessel due to a leak or burst and blood seeps into the brain tissue. This may occur due to unregulated high blood pressure, overuse of anticoagulants, aneurysms, trauma or ischemic stroke. The two subtypes of hemorrhagic strokes are

- Intracerebral haemorrhage—It is the most common type of hemorrhagic stroke where bleeding occurs within brain tissue due to the burst of an artery flooding the neighbouring tissue which can be either intraparenchymal or intraventricular.
- Subarachnoid haemorrhage—It is the less common type of hemorrhagic stroke where bleeding occurs outside the brain tissue but within the skull exactly between the arachnoid and pia mater.

The most common symptom is a severe headache popularly termed thunderclap. Sometimes people may experience a Transient Ischemic Attack (TIA) referred to as a mini-stroke when there is a temporary reduction of blood supply to the brain tissue which reverses on its own. The symptom lasts for less than 1–2 h and it's not permanent. But people having a TIA have an increased risk for stroke later.

6.1.2.3 Causes

Stroke episodes can be due to any one of the following

- Thrombosis occurs either in a large or a small blood vessel
- Embolism in the artery
- Cerebral hypoperfusion is usually due to cardiac arrest
- Cerebral venous sinus thrombosis
- Intracerebral haemorrhage.

6.1.2.4 Risk Factors

The risk factors associated are

- Sedentary lifestyle
- Use of drugs and smoking
- Obesity
- Unhealthy diet
- Increased blood pressure
- Cardiovascular disease
- Elevated blood lipid profile
- Diabetes
- Kidney disease
- Family history of stroke
- COVID-19 disease.

Also, men and people aged 55 years are more prone to the risk of stroke attack.

6.1.3 *Musculoskeletal Disorders (MSDs)*

Musculoskeletal disorders constitute nearly 150 medical conditions affecting the human musculoskeletal system causing injury and pain which ranges from sudden and severe acute problems such as a fracture to irreversible chronic injuries such as arthritis. It can arise due to a sudden exertion, repetitive strain or continuous exposure to strain, vibration or wrong posture and can affect the spine, extremities, neck and shoulders. It constitutes the biggest category of workplace disorders [9].

According to the Global Burden of Disease (GBD), these disorders affect approximately 1.71 billion people worldwide and is ranked second among the various disabilities affecting mankind. The highest burden is due to low back pain which is prevalent among 568 million people. These conditions predominantly reduce movements and thereby cause early retirements, lower well-being and lessen societal participation [10].

The musculoskeletal disorder affects

- bones causing osteoporosis, fractures
- joints causing rheumatoid arthritis, spondylitis, stiffness, dislocation
- ligaments causing inflammation
- muscles causing spasms, cramps, sarcopenia
- tendons causing sprains, strains
- skeleton causing poor posture problems
- cartilage causing overuse injuries.

6.1.3.1 Causes

MSDs can arise due to the following factors

(i) Biomechanical or ergonomic
(ii) Physical
(iii) Psychological
(iv) Occupational factors [11].

6.1.3.2 Symptoms

Common symptoms of MSDs include

- Severe ache on movements
- Stiffness of joints
- Muscle burning sensation
- Tiredness
- Muscle twitches
- Sleep disturbances [12].

Examples of MSDs include

- Carpal tunnel syndrome
- Epicondylitis
- Tendonitis
- Back Pain
- Tension neck syndrome
- Hand-arm vibration syndrome
- Ligament sprain
- Thoracic outlet compression
- Digital neuritis
- Dequervain's syndrome
- Mechanical back syndrome
- Degenerative disc disease
- Ruptured/Herniated Disc.

6.2 Classical Treatment Approaches

Thus with the increasing geriatric population, disabilities related to human motor dysfunction predominantly due to stroke and musculoskeletal disorders also progress eliciting the need for customized rehabilitation treatments to improve autonomy in stroke and disabled persons. The methods and procedures for treating stroke and musculoskeletal disorders are discussed in the following section.

6.2.1 Methods and Procedures for Stroke Treatment

In low and middle-income countries there is a steady increase in the number of new stroke cases recording more than one crore accounting for a mortality rate of 75% and 80% of disability-adjusted life years (DALYs). Among the stroke survivors only 5–20% show complete recovery while the majority possess Upper Limb functional deficits with no better protocol for therapy. The duration of practice, intensity and frequency of rehabilitation is directly related to the recovery rate after stroke [13].

1. Treatment of stroke follows three stages
2. Prevention

   This can be done by considering the risk factors like high blood pressure, cardiovascular disease, and diabetes and treating people to prevent the first or subsequent stroke episodes.
3. Acute stroke therapy

   Acute treatments are carried out to cease a stroke during the episode by either dissolving the clot or stopping the bleeding using drug therapy which is the most common treatment method.

4. Post-stroke rehabilitation

Rehabilitation after stroke provides novel ways for patients to regain and relearn skills that were lost due to brain damage. The main aim of stroke rehabilitation is to increase independence and to provide the best possible quality of life by improving physical, mental, social and spiritual health after a stroke to restore functional well-being. Research has shown that the functions associated with the specific area of damage earlier, restore to other parts of the brain after a stroke and hence practising can improve rewiring of neurons.

Post-stroke rehabilitation programs are customized to meet patient-specific needs which are carefully planned, well-focused, involve repetitive practice and should be initiated within 48 h after stroke in the hospital itself. Reaching the rehabilitation goal relies on various variables including the pathophysiology and severity of the stroke, type and extent of disability, general health of the patient and their family support.

6.2.1.1 Stroke Management

Stroke recovery focuses on various major areas including

- Upper Limb functional rehabilitation

  The latest research focus is on observation of action in enhancing the motor function and dependence of using upper limb activities in day-to-day living. This therapy improves better arm and hand coordination with fewer adverse effects. Constraint-Induced Movement Therapy (CIMT) and mirror therapy with repetitive practice was found to be effective in upper limb functionality [14].
- Cognitive rehabilitation

  To improve attention deficits in stroke patients, cognitive rehabilitation is found to be effective and research is going on to check for the sustained effects in daily tasks.
- Gait rehabilitation

  Research on improving motor functions and walking speed in patients encountered with stroke is in progress and seems to enhance walking endurance and personal assistance.
- Physical and occupational rehabilitation

  Physical therapy concentrates on improving joint motions and their strengthening through exercises and repeated learning of tasks namely bed mobility, walking and other motor functions, especially on the hemiplegic side employing CIMT [15].
- Speech and language rehabilitation

  This therapy is recommended as a part of post-stroke rehabilitation to improve communication impairments and speech production disorders thereby the overall communication, writing practice, reading style and expressive language are improved over long periods.

- Physical fitness improvement

  The general fitness and health of a person have usually reduced following a stroke which can also, in turn, affect the extent of rehabilitation. Thus physical exercises prove to be beneficial in improving permanent health status.

- Use of assistive devices

  Assistive Technology can improve mobility in patients with the use of devices namely wheelchairs, canes, ankle–foot orthosis, Walkers, etc.

- Yoga

  Practicing yoga can elevate stress-related anxiety by improving pain management, endurance mental health and overcoming disability to lead a peaceful life.

The different approaches to stroke rehabilitation depend on the body part affected or the type of impairment caused due to a stroke episode and includes.

(i) Physical activities
(ii) Motor skill exercise to rejuvenate muscle strength and coordination. E.g. During swallowing.
(iii) Mobility training to better make use of mobility aids like a walker, wheelchairs or an ankle brace. E.g. During walking.
(iv) Constraint-induced therapy also called forced-use therapy involves movement and functioning of the affected limb to its fullest without restraining the unaffected limb.
(v) Range of motion therapy employs exercises to decrease spasticity and improve range of motion [16].

Technology augmented physical activities include

- Electrical stimulation to re-educate the muscular contraction
- Robotic technology to strengthen impaired limbs
- Wireless technology to monitor post-stroke tasks
- Virtual reality to make patients interact with the virtual real-time environment.

(ii) Cognitive and emotional activities

- Cognitive therapy overcomes the lost abilities of cognition through occupational and speech therapy.
- Communication or speech therapy helps overcome communication disorders so that a patient could regain speaking and listening skills.
- Psychological therapy sets right the emotional disturbances and improves mental health through counselling and group participation activities.
- Drug therapy improves alertness and settles agitation with the prescription of antidepressants.

Experimental therapies namely non-invasive brain stimulation involving Transcranial Magnetic Stimulation, biological stem cell therapy and alternative medicine employing massage, herbal treatments and acupuncture are being investigated in post-stroke patients.

6.2.2 Treatment Approaches for Musculoskeletal Disorders

Maintaining good bone strength and joints is important for preventing musculoskeletal pain and this can be achieved by limiting repetitive movements, maintaining the right posture, practising the perfect lifting procedures and performing stretching exercises regularly. But in the worst case, the common treatment approaches for MSDs include:

- Drug therapies
- Use of orthopaedic devices
- Acupuncture
- Chiropractic medicine
- Rehabilitation therapies.

6.2.3 Limitations in Traditional Approaches

- Implementation of high-intensity training in a real-time setting
- The quick loss of interest in repetitive training and exercises
- Lack of motivation, feasibility and safety towards the tedious medical regime
- Lack of encouragement in patient skill upgradation
- Poor adherence and annoyance due to long hours of workouts
- Lack of availability of therapist and equipment
- Low level of commitment in-home rehabilitation regime
- Poor patient compliance and Long term care
- Suboptimal treatment outcomes
- No creativity and customized treatment methods
- Less interaction and non-availability of techniques to measure recovery rate
- Limited entertainment and less diversity of content in gaming.

Thus, to promote patient's compliance and activate neuro-motor activities to their fullest towards rehabilitation therapy lacking in traditional approaches, various modern rehabilitation technologies have come up as a tool to increase motivation and reach rehabilitation goals.

6.3 Modern Rehabilitation Technologies

Rehabilitation plays an important role among human beings from childhood till the end of their life. Both healthy and unhealthy people can also use this rehabilitation practice. Gait analysis helps us to study the issues in the kinematics of human motion. Rehabilitation supports the people in various ways as follows

- Fast recovery from an unexpected illness. E.g. Stroke, Trauma
- Speedy recovery from surgery. E.g. Knee replacement
- Aggressive people who need support. E.g. Mental Illness
- Reduce anxiety and depression in individuals. E.g. Psychosis.

Orthopaedic and neurological rehabilitation involves the use of orthotics and prosthetics to replace a limb or to maintain the anatomical position of the human body that is impaired or missing. As traditional prosthetics were too heavy, people couldn't wear them for long periods and were also not comfortable for children. Classical orthosis, namely hand-on-thigh gait devices used by polio-affected children were difficult to carry. It was then replaced by modern prosthetic technology namely knee ankle foot orthosis made up of thermoplastics or carbon fibre material to keep their knees from dragging [17]. Modern prosthetics are having a very huge growth and development so that people have started using advanced limbs nowadays. They offer a variety of advantages like lightweight, comfortability and high functioning which allows disabled persons to live an independent and normal life.

6.3.1 Physical Prosthetics

Over a decade, prosthetics have been made through plaster casting of the affected or missing limb. Depending on the comfort level of the individual, it is simple to incorporate into their everyday routines such as driving, walking, and so on. Recent prostheses designs have increased strength while reducing weight employing pioneer materials such as kevlar, titanium and carbon fibre, which are robust, durable and assist us in designing lightweight prostheses [18].

6.3.1.1 Classification of Prosthesis

(i) Based on the level of amputation

   (a) Upper Limb Prosthetics are mainly used during upper limb amputation or deficiency. One of the important prostheses in the upper limb is a myoelectric prosthesis which is based on the study of muscle activity of the hand using EMG pattern. In recent techniques, pattern recognition controlled myoelectric hands are in use which does multiple axis movements instead of opening and closing hands. E.g. Transradial, Transhumeral, shoulder disarticulation.

(b) Lower Limb Prosthetics are mainly used during lower limb amputation such as Transtibial which needs artificial foot, ankle and shank, whereas a transfemoral amputation needs replacement of the missing part of the thigh and artificial knee as a prosthetic [19]. E.g. Knee and Hip Disarticulation, Foot Amputation.

(ii) Based on the construction design

(a) Exoskeletal Prosthesis is the covering that is present outside, supporting the total body weight. Outer covering sockets are made up of resin over foam or wood as a filler material. E.g. People affected with Spinal Cord Injury (SCI), major trauma like stroke and cerebral palsy.

(b) Endoskeletal prostheses are present inside the skin layer called pylon, constructed using lightweight carbon fibre and metal. Endoskeletal prosthesis offers easy alignment and replacement of components. E.g. Transfemoral and Transtibial Prosthesis.

6.3.1.2 Components of Prosthesis

- Body of prosthesis-Outer structure made up of durable, lightweight material
- Socket-Holder in which residual limb is present.
- Control system-Signals from the sensor are converted into electrical signals.
- Harness/suspension system-Harnesses are made out of a socket fit attached to a residual limb and dacron straps.
- Terminal device-Bionic hand, Gloves, Hook.

Another key recent innovation in physical prosthetics is the development of targeted muscle reinnervation work on powerful prostheses that are resilient, integrated, self-determined and adaptable. Another cost-effective and low-budget physical prosthesis is a customized, hardware-specified 3D printing limb specially designed for kids. Customized 3D printing is an open-source platform and the user can design it by themselves in low-income families. Also, experts can design various implants and anatomical models using 3D prosthetics [20].

6.3.2 Sensory Prosthetics

Traditional prosthetic devices are unable to acquire general sensory information while a person is moving or interacting with an object. They are experiencing trouble while managing the force required to move the prosthetic hand, which could lead to medical complications. The feedback system can be utilized to collect sensory information from the prosthesis and convey it to the brain or neurological system which then sends a receptor signal to the skin, muscle and joint [21]. There are various sensory prosthetic devices used for a variety of rehabilitation purposes and are shown in Table 6.3.

Apart from the above said sensory prosthetics, there are still a few more to be addressed namely,

- 3D printed wearable module- Facial Rehabilitation (Impersonate and activate the facial muscle movement). E.g. facial paralysis.
- Hybrid vibrotactile stimulator -Sensor Rehabilitation (Parallel sensing streams delivered to a patient at one point). E.g. Upper extremities.
- Prosthetic leg—Natural sensation of touch and proprioception.
- Stroke sensory rehabilitation—Fast recovery due to sensory feedback.
- Sensory enabled neural prosthesis—Amputee for processing regular activities in-home. E.g. spinal cord injury and mental illness.

6.3.3 Robotics Rehabilitation

Robotics is the design and construction of machines to perform human tasks. As illustrated in Fig. 6.1, robotics are now used in various fields. Robotic precision and artificial intelligence (AI) techniques are used to perform repetitive tasks and to work in hazardous environments where humans are unable to work. It is capable of performing difficult tasks that humans are incapable of performing. They are becoming even smarter as AI advances. Overall, robots have the potential to be the ideal assistant for humans in resolving a wide range of problems in a variety of industries.

In recent years, incredible progress has been made in robotics applications such as moving objects or devices using multi-programmed software to complete tasks in bionic components. The ability to offer more dosage and higher-level instruction for patients with disorders such as stroke and tetraplegia (spinal cord abnormalities) is a major benefit of using robotics in rehabilitation.

6.3.3.1 Classification of Rehabilitation Robotics

(i) Therapeutic Robotics- Exoskeleton and Immunoregulatory type devices are utilized to provide user-defined training. Exoskeletons are more expensive to build than immunoregulatory devices. E.g., Direct control of joints by robots that can provide mechanical stress on the distal limbs.
(ii) Assistive Robotics—Utilized for compensatory purposes, such as treatment with the help of robots. E.g. Stroke rehabilitation [29].

Robotics systems based on the Internet of Things (IoT) are employed in upper limb prostheses, orthotics and people with motor disabilities such as stroke, tremor and brain injury and are depicted in Table 6.4. Patients, rehabilitation specialists and physiotherapists can all be found under one roof using IoT-based rehabilitation. The

Table 6.3 Various sensory prosthetics with their applications and limitations

S. No.	References	Methodology	Advantages and application	Limitations
1	Peripheral nerve stimulation [22]	• Sensory feedback • Revokes somatotopic and permits haptic feedback	• Enhanced high sensitivity during touching, vibration • Induce exhaustive feedback such as textures and so on. E.g., Prosthetic hand	• Less spatial resolution • The coupling of feedback with sensitivity is irresolvable due to the size of the stimulator
2	Myoelectric prosthetic hand [23]	• Vibration stimulator • Vibration sheets made up of shape memory actuators are used	• Low-cost • Efficient • Non-invasive sensory prosthetics • E.g., Hand, arm and knee controlled prosthetic hand	• Prolonged vibration and changes inaccuracy
3	Vibrotactile stimulator for gait analysis [24]	• Used for Lower prosthesis • Produces low-intensity vibrations when gait transitions change • The individual's gait phase can be maintained as a result of this training	• Low-cost gait analysis • Speed recovery without cognitive burn • E.g., an Elderly patient having a transfemoral amputation	• The sample size is very low • Follow-up time is very low • No possibility of extension
4	Wearable feedback prosthetics [25]	• Ambulation feedback • The gadget for lower extremity amputees stretches the skin on the lateral surface	• Optimal accuracy of 98% is achieved • E.g., Lower limb amputee due to trauma and congenital defect	• Conjunctival irritation on the skin surface
5	Waist wearable feedback prosthetics [26]	• The wearable feedback prosthetic device can emit mild vibrations in the wrist when there is a walking phase change	• The symmetry index of gait was increasing • E.g. Irregularities in the spatiotemporal gait phase	• Concurrent compression on the trunk and pelvis will increase
6	Neuroplasticity principle-based sensory rehabilitation (NEPSER) [27]	• Motor and sensory recovery-NEPSER • Significant training using sensory modalities such as visuoperceptual, motor functional task for 8 week	• Not only enhancing sensory recovery it also enhances the motor and functional recovery • E.g., Poststroke hemiparetic patients	• Heterogeneity in the study the brain activities • Modality of sensory defects

(continued)

Table 6.3 (continued)

S. No.	References	Methodology	Advantages and application	Limitations
7	Sensory attenuation in rehabilitation [28]	• Basal ganglia task-related sensory information has been studied	• Easy navigation and interaction with the environment • E.g., Parkinson''s disease	• Sensory input for exercise programs is not enough

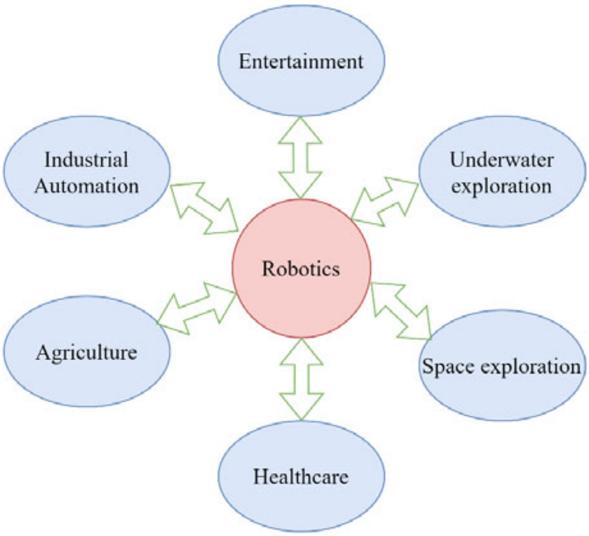

Fig. 6.1 Application of robotics in various fields

doctor can keep an eye on the patient from afar and patients can be trained in the comfort of their own homes, where they can undertake simple and repeated therapies [30]. The ROBIN is a rehabilitation robot that not only stabilizes body positions but also allows patients to perform simple hand movements including grasping and reaching for objects. This robot encourages individuals to exercise through video games, which can lead to more rehabilitation activities and improved motor function in the patient, resulting in a faster recovery. ROBIN is highly valuable for patients who are unable to visit their physician or therapist regularly [31]. It also incorporates artificial intelligence and results in breakthroughs in neurological rehabilitation. This brain rehabilitation program can teach a non-technical individual how to change the programming and neural robotics set up to ensure that the patient participates actively [32].

Key factors of Robotics Rehabilitation

- Self-executing systems make the user walk fast and also maintain their normal gait phase.

Table 6.4 Robotics applications in rehabilitation

S. No.	Prosthetics	Technology	Applications
1	Bionic glove	• Wearable robotic hand • SMA actuators assist pressure in the fingertip sensors • Information sent from robots to users	• Restore grip strength after stroke or accident
2	Robot-assisted gait analysis	• Joint trajectory to entire gait cycle and provide the stiffness • Replacement for wheelchair technology • Implantable therapies	• Stroke and spinal cord injury
3	Ankle Bot	• Exoskeleton robot • Apply the appropriate force to the ankle and train it to improve both walking style and balance	• Amputation • Muscular dystrophy • Cerebral palsy
4	CAREX (Cable-driven upper arm exoskeleton)	• Novel robots arm made up of robot-controlled prosthesis • 10 times lighter than arms • Assist the muscle and motor pattern	• Lightweight prosthetic hand
5	Genium Knee	• Microprocessor-controlled knee joint • Made up of the latest sensor and computer technology • Able to walk or stand on a slope • Able to optimize the wing phase	• Osgood schlatter disease (OSD)
6	MIT manus	• Simple video game for sensory-motor interfacing • People need to draw a shape or need to move along the point	• Post-stroke upper limb amputee
7	FLOAT	• Multidirectional overhead BWS (Body weight system) • Safe gait training for the person in a 3D environment • Computer-assisted robots	• Gait rehabilitation for paediatrics

- It is a mind-controlled device.
- It reduces physical stress as well as complications.
- High comfort and mobility in amputee life.

Limitations

- A complete report on the employment of robotics in rehabilitation has yet to be obtained.
- There is a substantial ethical and methodological constraint when robot-assisted rehabilitation is used for stroke victims.
- Simple movement patterns are utilized mainly for amusement, not for functional purposes.
- This therapy is out of reach for the poor or cannot be used by the general community due to its exorbitant cost.

6.3.4 Brain-Computer Interface (BCI)

For proper movement and motor control, neuronal interaction between the muscle and the brain is essential. If there is a medical issue, communication gets disrupted and the brain is unable to communicate, which may result in paralysis or neuronal damage. A Brain-Computer Interface can then be used to reawaken the brain that has been silenced by diseases such as amyotrophic lateral sclerosis (ALP), multiple sclerosis and brainstem stroke. BCI is a collection of basic software tools that employ an algorithm to convert brain impulses into actions. The operation of the BCI is shown in Fig. 6.2.

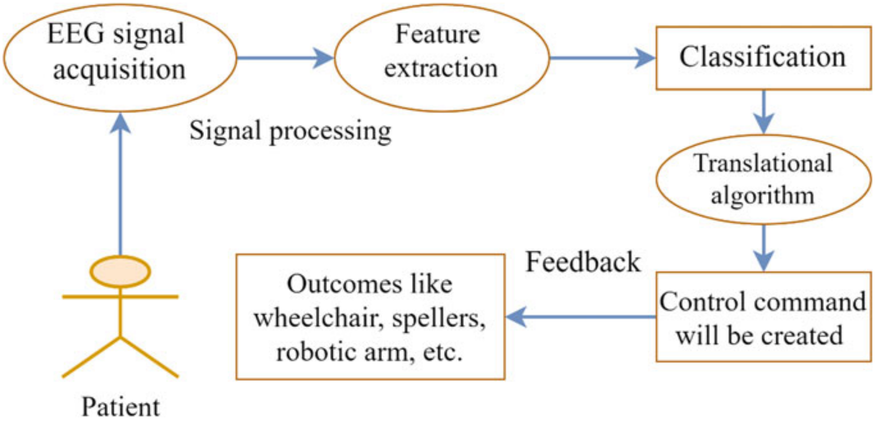

Fig. 6.2 Workflow diagram of brain-computer interface

Table 6.5 Physiological signals for BCI applications

S. No.	Physiological signals	Advantages	Limitations
1	Scalp EEG—scalp Recording of the electrical activity of the brain	• Easy • Safe • Less expensive	• Intracranial Information can't be gathered from the outside surface like the skull and scalp • Some information may be lost
2	Micro EEG—implantation of microarray in the cortex Individual neuron action potential is measured	• For a deep understanding of neurons and synapses	• Complex Neurosurgical procedure • The long-term functional stability is questionable
3	Intracortical BCI—microelectrode measurement from ventricles. Recording of intracranial scale pressure	• Larger area recording • More information can be acquired	• Neurosurgical implantation • Long-term electrode stability is unanswerable
4	Magnetoencephalography (MEG)—magnetic field generated due to an electrical activity from the cell axon Detection of (mu) rhythm	• Satisfactory control on BCI	• Difficult to conduct the experiment and obtain the result • Expensive
5	fMRI-functional MRI—various brain lobes Measures the activity level of oxygen	• Human brain-controlled robotic arm	• Cumbersome • Expensive

Dr J. Vidal discovered the brain-computer interface in 1970 while studying Electroencephalography (EEG) analysis and cerebral activity. BCI enables users to establish a direct link between their brain and external technologies which can lead to a variety of applications for disabled people, one of the most well-known of which is the human brain-controlled wheelchair. The analysis of brain signals utilising electrodes on the cortical surface, cortex and scalp is the most important aspect of the BCI interface and the technologies are named as follows in Table 6.5 [33].

6.3.4.1 BCI Components

As shown in Fig. 6.2, the following are the components of BCI:

- Signal acquisition unit—The EEG brain signal is obtained using scalp electrodes, then the electrical signals are transformed into digital signals and supplied to the computer.
- Signal processing unit- Utilizing captured EEG signal and a large amount of data, features such as alpha (8–12 Hz), beta (12–35 Hz), gamma (greater than 35 Hz),

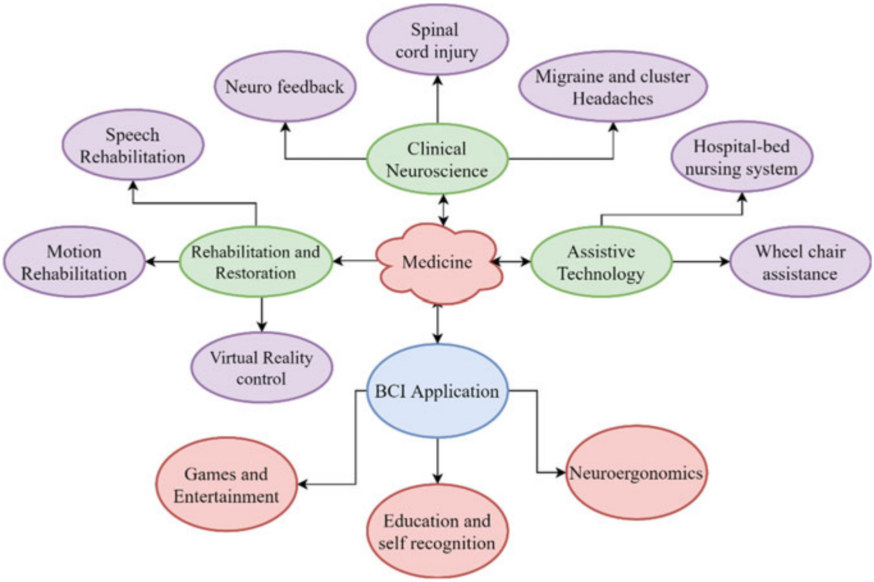

Fig. 6.3 BCI applications

delta (0.5–4 Hz), and Theta (4–8 Hz) waveforms can be extracted and can be converted into the control commands using translational techniques.

- Computer System- The algorithm's control command could be sent to output devices such as a wheelchair, robotic arm, spellers and cursor control.

BCI has applications in a variety of sectors as shown in Fig. 6.3 explained as follows [34].

The various applications of rehabilitation are

1. Rehabilitation and restoration—BCI has a wide range of applications in rehabilitation, as illustrated below

   a. Speech Rehabilitation—BCI is primarily used to help persons with speech disabilities, such as aphasia, improve communication. The disabled person selects one letter on a monitor and asks to build words to improve their speech capacity. E.g., Amyotrophic lateral sclerosis, locked-in syndrome (LIS).
   b. Motion Rehabilitation—The major goal of BCI is to improve the motor movement of impaired limbs, which will be categorized as.

   Lower limb-based on the frequency of visual stimuli from P300, determination movement direction can regulate wheelchair movement.

   Upper limb-major BCI's goal is to eliminate upper limb limitations by employing P300 or Somatosensory Visual Evoked Potentials (SSVEP). Using the above-mentioned potential, it can control the robotic arm's movement using a gripper. E.g. stroke rehabilitation and cerebral palsy.

   c. Virtual Reality control (VRC)—The basic purpose of a BCI system is to improve communication between a disabled person and an external device. The person using brain patterns can move or touch the virtual object on the monitor, and the computer can then identify the event and communicate the elevated command prompt to the device. E.g. spinal cord injury and amyotrophic lateral sclerosis (ALS).

2. Clinical Neuroscience—The study of the nerve system is identified as clinical neuroscience and anyone can control the rehabilitation gadget using this. The following are some of the other applications of BCI-based rehabilitation in clinical neuroscience.

   a. Neurofeedback—The use of BCI in Neurofeedback aids people in achieving a faster recovery and improving their overall quality of life. By employing neurofeedback to target brain activity, it is possible to increase brain performance. The expert can gather the individual's reaction by indulging in personal interaction with them. E.g. ALS, cerebral palsy, brainstem stroke.
   b. Spinal cord injury—For examining the motor action improvement in spinal cord injury patients, Pfurtschellar combined multiple systems such as BCI, Functional Electric Stimulation (FES), and Sensor motor rhythms (SMR). This, in turn, improves peripheral nerve and motor neuron function. E.g. Spinal cord injury.
   c. Migraine and cluster headaches—BCI is also utilized in the treatment of migraines, headaches, and depression. To detect migraines, EEG-based categorization methods are used. In the visual evoked potential environment, there is a general change in EEG complexity for migraine and head discomfort patients. Physical therapy can be provided by BCI to relieve tension in the cervical spine and muscular stiffness, hence reducing discomfort due to headaches and migraine.

3. Assistive technology—some examples of BCI's use in assistive devices include:

   a. Hospital bed nursing system—LED stimulation is used to elicit the user's SSVEP as an input signal. The programmable gate array is then produced by the filter, amplifier circuit, and SSVEP processor to acquire and process the subject demand utilizing SSVEP. A specific drive circuit known as an H-bridge DC (Direct Current) motor is used to control the attitude of the hospital bed. E.g. spinal cord injury, muscular dystrophies, chronic peripheral neuropathies.
   b. Wheelchair system—The P300 controlled wheelchair may receive direct commands from an EEG signal and deliver them to the wheelchair as control. The majority of disabled people are requesting this controlled wheelchair. E.g. Paralyzed and stroke rehabilitation.

      - Neuroergonomics- The study of the human brain during daily activities and at work is known as neuroeconomics. Places of work, transportation, and home automation can all benefit from using a brain-computer interface to enhance safety, comfort, and physiological control over our daily activities. BCI has recently been integrated with IoT, which has enhanced the study and safety of individuals.

- Educational and self-recognition-using neurofeedback from functional MRI (fMRI), BCI can improve education and self-recognition in the following ways.
  (i) It is used to offer training to combat depression and other psychiatric diseases.
  (ii) It also helps to manage stress during sports competitions.

4. Games and Entertainment—Nonmedical BCI has a wide range of applications in gaming and entertainment, including the following:

(i) Brain Arena is a football game in which two BCIs are used. Goals can be scored by just moving your left or right hand.
(ii) The user simply needs to move the ball from side to side, which will relax the folks. The game's eventual result is a stress reduction.

6.4 Virtual-Reality (VR)

The user's interaction with the simulated environment is maintained with Virtual Reality (VR) where it allows users to interact with and experience real-world environments and may be utilised for both educational and entertaining purposes. Virtual reality in 3D portrays a physical and mental sense of being in the actual world.

6.4.1 Classification of Virtual Reality Based on Experience

- Fully Immersive simulations—It is capable of providing a fully immersive experience, including sound, vision and sense. Individuals have the impression that they are in the actual world. E.g. Gaming and Entertainment purposes like 3D filming.
- Semi-Immersive simulations- It provides a partial realistic experience where the complete vision of the virtual environment will be unavailable. It is used mainly for education and training purposes. E.g. aircraft simulators, medical surgery simulators.
- Non-Immersive simulations—No realistic experience in a virtual environment. A person knows we are in a physical place and interacting with the virtual one. E.g. Basic level of gaming.

The milestones in virtual reality are examined in Table 6.6.

Table 6.6 Milestones in virtual reality

Timeline	Scientist/inventor	Technology development	Applications
1838	Sir Charles Wheatstone	Mirror stereoscope	Photo or image gave the user a sense of immersion and depth
1890	Thomas Edison	Kinetoscope and kinetograph	Early motion picture
1935	Stanley Weinbaum	Fictional model for VR	Story over how, with the help of a pair of glasses, we can enter a fictional world
1929	Edwin link	Link trainer	Mechanical aeroplane simulator for training purposes
1956	Morton Heilig	Sensorama	First VR machine with Vibrating chair, smell and 3D screen
1961	C. Comeau & J. Bryan	Headsight	First head mount display used for motion tracking
1965	Sutherland	Sketchpad	Computer hardware for the interaction of the user in the virtual world
1965	Robert Mann	VR training environment for orthopaedics	Helps to learn various surgery techniques
1966	Thomas Furness	First flight stimulator	Military purpose
1968	Bob Sproull	Sword of damocles	Head mount display connected with a computer instead of a camera
1969	Myron Krueger	Artificial reality –Video place	It allows people who are thousands of miles apart to communicate with each other in a computer-generated environment
1975	Krueger's	Video place	Large room with big screen, Innovation of virtual communication
1977	Dan sandin	Sayre Glove	Light sensors with a light source on one side and a photocell on the other end of a flexible tube are used to measure finger flexon, lightweight and inexpensive
1979	Mc Donell-Douglas	Head tracker vital helmet	Military purpose
1980	Robert Mann	Wearable HMD	Visualization of medicine

(continued)

Table 6.6 (continued)

Timeline	Scientist/inventor	Technology development	Applications
1985	Jaron lanier and Thomas Zimmerman	Registered VR company	For selling VR goggles and data glove
1987	British aerospace	Virtual cockpit with the speech recognition system	Training simulator
1989	Scott foster	VIEW- astronaut stimulator	Astronaut stimulator
1991	Antonio Medina	Computer simulated teleoperation-from the Earth to mass robot rover design 3D gaming	3D gaming
1994	Dav Raggett	VRML (Virtual reality markup language)	File format for representing a 3D image
1997	Georgia Tech	Virtual Vietnam -VR based war zone	VR based war zone
2001	Maurice Benayoun	SAS cube	PC based cubic room
2007	Google	Street view map	Navigation purpose
2015	Wall street journal	VR roller coaster	For following the NASDAQ market
2021	Facebook	Horizon workroom	VR based conference rooms

6.4.2 *Virtual Reality Devices*

Virtual reality mostly deals with the sensory feedback of human beings and some of the common sensory-based devices used in virtual reality as shown in Fig. 6.4 are follows:

1. Head Mount Display
    - Pair of goggles over your eyes.
    - Provides 3D imaging virtual environment.
    - Includes headphones, sensors and blindfolds.
    - Very heavy, not able to use for long term.
    - The operation involves two screens with different stereoscopic images to create a 3D Effect.
2. Immersive Rooms
    - Due to discomfort in the head mount, an immersive room concept is introduced.
    - The changing stereoscopic image is displayed on the wall of the room.
    - This immersive room is helpful, especially in a simulation environment.

Fig. 6.4 Basic components of virtual reality

3. Hand Gloves

- It is a normal glove made up of various types of sensors for the detection of hand movements.
- Some of the sensors used in hand gloves are accelerometer (orientation of hand), hand bend sensors and gyros (Measuring the hand rotation).

VR is an emerging field with various types of applications in different fields is as shown in Fig. 6.5.

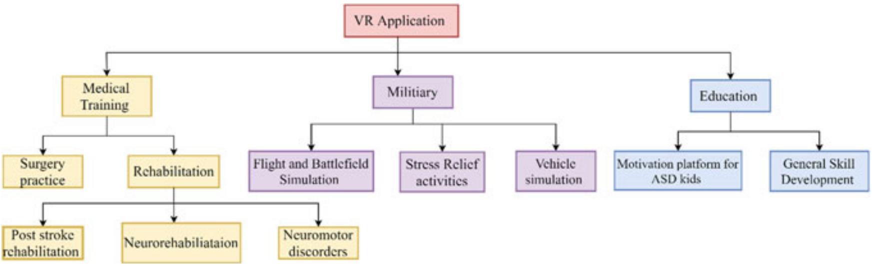

Fig. 6.5 Application of virtual reality in various fields

6.4.3 VR in Rehabilitation

The new method with improved intensity, frequency and time of the exercise without any stress is VR. It is a forefront technology ready to face recent therapeutic challenges, train people in a motivational way and boost the people's performance in a better way in a live environment. VR can work out real-life tasks as rehabilitation therapy [35].

Key Features of VR in Rehabilitation:

- It is easily adopted by all types of patients under therapy and the treatment is specific. E.g. Stroke survivors.
- VR provides a realistic environment so that the patient can take therapy in different scenarios and also in various phases.
- VR will make rehabilitation therapy an interesting and most interactive one with different types of games.
- VR will join hands with a human–computer interface for monitoring day-to-day life training activities and makes VR a safe and immersive training method which is not possible with other rehabilitation techniques. E.g. Autism patients.
- Interactive tools like tactile interfaces, mice, joypads make VR an entertaining and interactive one to track motions, especially for kids having Cerebral Palsy.

6.4.4 Game-Based VR Rehabilitation

No universal protocols are available to treat the upper limbs affected by stroke. The traditional treatment procedures are mostly repetitive training that is been given to motors causing a poor recovery rate. As discussed in Sect. 6.4, the VR based system is being used for various commercial applications and also as an assistive device for medical applications. For the past two decades, VR has been used in the healthcare ecosystem as a computer-interactive simulation that helps out disabled people to feel and practice the real-world experience in a virtual environment. If the post-therapy training is suggested through gaming than the conventional physiotherapy treatment plans, the patient's motor performance would exhibit greater improvement. Commercially available low-cost consoles have increased the attention of researchers and clinicians to recommend gaming-based therapy to patients. The observations by the clinicians after recommending VR based gaming rehabilitation has proved that there are significant improvements in movements, power and velocity. The most important elements of game-based interactive rehabilitation VR systems are illustrated in Fig. 6.6.

Some of the studies reveal that the treatment should be exciting, task-specific, interactive, encouraging, and intensive for neural disorders to recover at a faster rate. VR-based game therapy offers goal-oriented training to the patients to enhance motor, cognitive and learning skills. Many treatment plans recommend the patients to take up

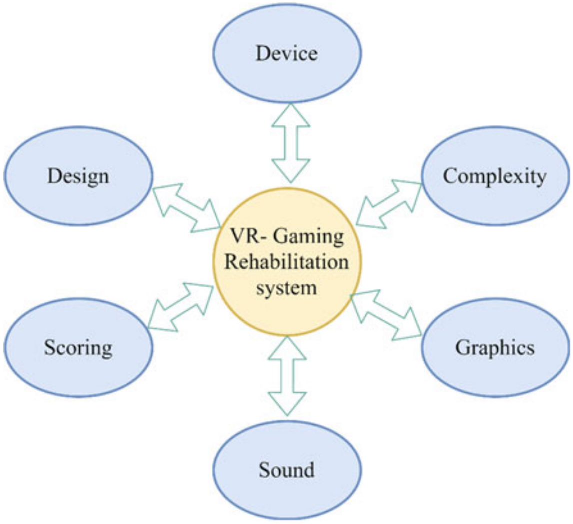

Fig. 6.6 Elements of game-based interactive rehabilitation VR systems

a task about an average of 30–45 min per day five times per week. Apart, constraint-induced movement therapy (CIMT) suggested for upper-limb rehabilitation for post-stroke requires 3–6 h of walking per day lasting up to 4–5 months. Such repetitive tasks lead to poor outcomes due to frustration among patients and caregivers. Though many gaming based systems are proposed by the researchers, still there are some limitations in them.

Limitations of Game-based rehabilitation without VR.

1. The integration of traditional rehabilitation treatment procedures into gaming-based systems.
2. Issues in solving neuromotor and cognitive disabilities simultaneously.
3. Lack of platform to integrate all game-based rehabilitation systems for various causes.
4. Lack of an alert system to avoid risky situations for the patients.
5. Lack of monitoring, controlling and evolution of patients using data observed.

As illustrated in Fig. 6.6, a tailor-made VR-Gaming rehabilitation system consisting of devices like accelerometers, gyroscopes, depth sensors, robotic gloves, VR head mounts, and other immersive components support the entire system. Many scoring methods have been proposed since January 2000. They are Fugl-Meyer-assessment (FMA), Wolf-motor-function-test (WMFT), Box-and-block-test (BBT), Action-research-arm-test (ARAT) and functional-independence-measure score (FIM). Based on the recent studies of rehabilitation, a gaming experience for the patients improves their interest and involvement in taking up long-duration training. Such approaches involve an intelligent system to get the feedback of the patients' response during the training, thereby optimal training is possible. To propose an approach for any treatment plans, two different approaches are followed. They are (i) user-centric approach and (ii) System-centric approach.

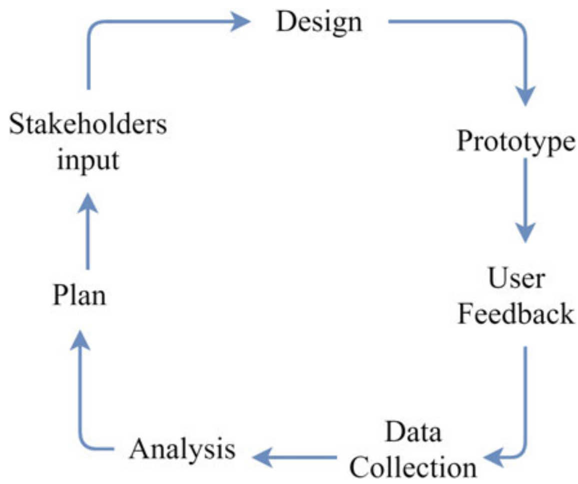

Fig. 6.7 User-centric VR-gaming plan

6.4.4.1 User-Centric VR-Gaming Rehabilitation System

User-centred gaming is an iterative process that is usually designed, based on the interviews with stakeholders and the results derived from other gaming activities carried out before the design plan. The interviews are made with various stakeholders who explain their conventional game-based rehabilitation experiences and detailed information is gathered based on the interaction. The challenges, opportunities, and possible risks are assessed from the questionnaire. Based on these inputs, a preliminary design plan is proposed. The essential resources like software and other hardware components are recommended for the prototype by the team in consultation with the expert members like game developers, clinicians, therapists and sports personalities. A brainstorming session is planned with the stakeholders to collect the issues that are faced. Till the team agrees to implement and validate the results, the process is repeated (brainstorming, expanding, and refining) as illustrated in Fig. 6.7.

6.4.4.2 System-Centric VR-Gaming Rehabilitation System

Many systems have been proposed to provide self-training to post-stroke patients at the chronic stage. Hardware-based solutions are used to estimate the patients' health status during joint movements. Goniometers or protractors are used to find the range of motion, joint velocity, torque, and reaching time. However, such instruments provide very low accuracy and are dependent on the evaluators.

6.4.5 System Requirements

Different hardware-based sensors are used to measure the conditions of the patients for physical rehabilitation. They are:

- Accelerometer—Patients' movements are observed by force sensors.
- Smart haptic gloves—Joint angle and grasping forces are measured.
- Xbox one—A Kinect camera to observe the gesture of the participants.
- Mirror—A mirror is placed in the patient's midsagittal plane with one limb behind the mirror. Mirror visual feedback (MVF) is a favourable technique to improve the performance of neurorehabilitation without training.
- Wearable sensors—To measure ECG, temperature, glucose, blood pressure, PPG, and respiration rate.
- Inertial sensors and force sensors—Gait analysis and measurements of knee angle, and foot planar pressure. An inertial measurement unit (IMU) is used to record the fall detection and posture monitoring for elderly.
- Leap motion sensor—Hand movements are tracked.

Fusion of multiple sensors like Kinect camera, bioelectric sensors, inertial sensors, pressure sensors, and motion sensors (IR, ultrasound, depth sensor, and camera with multi-array microphones) are used to observe the patients with upper and lower limb palsy, Parkinson's disease, stroke, multiple sclerosis, brain injury, and an autism spectrum disorder.

6.4.6 System Architecture

As mentioned in Sects. 6.4.4.1 and 6.4.4.2, the VR-based gaming rehabilitation system consists of two important interfacing components. They are (i) Patient interface and (ii) Therapists console. The patient interface has NLP interfacing elements to feel, hear and speak to the interactive rehabilitation system (Fig. 6.8).

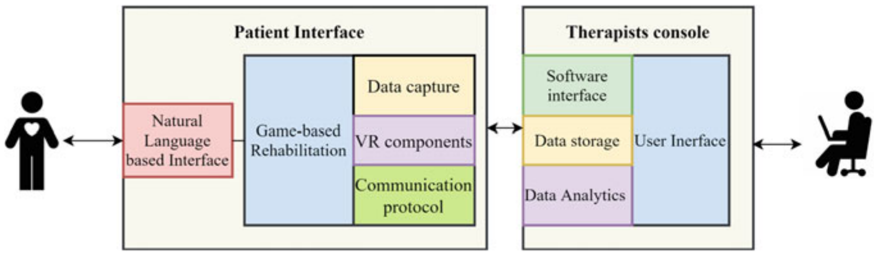

Fig. 6.8 System architecture

The various sensors and interactive elements (VR components) support the patients to train in a sporty environment with external commands towards a task-oriented ecosystem. Simultaneously, the vital parameters are also observed by the wearable systems. The primary objective of the system is to make the patients participate and be self-motivated. The therapists from the user interface observe and assess the patient's physiological and psychological parameters analysing large amounts of data that are being recorded. Such data is interpreted and visualised from different perspectives. This supports therapists in making well-defined decisions for futuristic exercise and rehabilitation training procedures.

6.5 VR Applications for Rehabilitation

In the past decade, the rehabilitation process helps to treat and slow down the disorder in various fields such as cardiology, oncology, neurology, and orthopaedics. Nowadays, it has witnessed burgeoning attention by implementing virtual reality (VR) technology for diagnosis and giving therapy for rehabilitation patients.

Importantly, VR presents an opportunity to assess various rehabilitation scenarios that are more challenging and are highly relevant to deal with real-world applications. Virtual reality is a key technology that provides feedback to patients during the rehabilitation process on a preferred schedule. In most of the VR applications outcome was delivered through sensory modalities including visual (eye) and auditory (ear) senses. Various real-world environment applications targeting various specific disorders like traumatic brain injury and learning disabilities are very useful for monitoring [36]. The simple structure of the VR system is designed in such a way that it can remotely track the patient's date, and initiate the rehabilitation sessions according to the current needs of the patients. Extended Reality (XR) is another science-based revolutionizing technology in Industry 4.0. It is more of mimicking real-life situations and scenarios.

This section covers different VR techniques in the field of mental rehabilitation for post-stroke treatments, cerebral palsy and autism disorders, also the role of VR in upper limb prosthetic training and the impact of sports rehabilitation. The two important categories of Virtual Reality in the healthcare field are simulation and interactive tools. Most doctors mainly prefer VR as a simulation tool before planning for surgery. The advantage of the technology is that surgeons can make mistakes during the process and learn from them without taking any risks to the patients.

6.5.1 Virtual Reality in Mental Rehabilitation

The virtual mode of the rehabilitation process for patients with mental disorders has been proven to be effective in modern-day healthcare delivery [37]. According to the authors, patients treated with virtual reality-based rehabilitation processes for mental health disorders, have reported to experience lower levels of depression, anxiety, and other negative symptoms than the standard treatment and also the recovery time is faster than the conventional method. VR in stroke rehabilitation helps patients to regain their muscle control [38]. Dementia is an abnormality with persons with loss of thinking and remembering ability can be addressed efficiently using VR technology. Psychiatric illness is termed as emotional and behavioural disorders in patients undergoing mental stress. VR treatment has the chance for patients with psychiatric illnesses to deal with a sudden changing phobia, anxiety, mental depression and cognition. Cerebral palsy (CP) is an abnormality that causes variations in the patient's tone of muscle, stance and limb movements, it requires rehabilitation techniques to support and cure the patient. The physicians face difficulties in performing physical and cognitive tasks using the VR technique for patients with CP. VR training is given to children affected by CP disorder to improve their interaction with other individuals. There are only a reduced number of randomized trials implemented using the VR technique, this is the key area that needs to be improved shortly.

6.5.1.1 Virtual Reality in Post-Stroke Treatments

According to statistics in India, the number of patients diagnosed with stroke is increasing in recent years. Recent research in the year 2022 suggests that the prevalence of stroke in countries like India ranges from 105 and 152 cases per 100,000 people per year [39]. Also according to the National Institutes of Health, there is a global alarm for increased cases of stroke patients annually. It is challenging to devise innovative rehabilitation programs for patients other than the conventional treatments. Hence, exploring VR in the rehabilitation process provides effective behavioural recovery and positive patient feedback.

6.5.1.2 The Computer-Based Desktop VR System

A VR system was designed with help of a computer for stroke patients with upper arm impairment by rehabilitating hand function. It consists of input–output gloves to make them suited for hand rehabilitation exercises. Input glove is a user glove with a pressure sensor and is advised to be worn on the patient's hand. Output glove is a feedback glove designed to be an exoskeleton biomechanical device used to measure force using implanted sensors in it.

User-glove is embedded with 18 pressure sensors, preferably strain-gauge sensors. It is designed to measure angles of the metacarpophalangeal joints and proximal interphalangeal of fingers. Each angle is calculated when the patient is allowed to do wrist flexion during rehabilitation exercises. During the VR rehabilitation process, every hand joint angle is converted into glove-sensor voltage as an output.

Feedback-glove is an output exoskeleton device that applies force to the user's fingertips. Pneumatic actuators with less weight are placed at the tips of each finger.

Fig. 6.9 Designed output exoskeleton system for VR rehabilitation system

An actuator is a sensor that converts applied energy in the form of force or pressure into mechanical motion. In the VR system around 16 N of force is slowly applied and displacement inside the glove (fingertip) is measured concerning their angle. The joint angles of all fingers are estimated as shown in Fig. 6.9.

Those two data are considered as sensor data and acquired data are filtered and taken for evaluation of patient's improvement in VR rehabilitation process in regular trials for a few weeks. The performance evaluation is very helpful for physiotherapists and patients to know their improvement in the post-stroke treatments.

The rehabilitation exercises with the implementation of the VR technique along with user and feedback gloves is illustrated in Fig. 6.10. The VR simulations tool needs to evaluate using four exercises for analyzing one particular parameter of the hand movement. The performance is calculated based on the range of hand movement, asking the patient to move one hand at a time, speed and strength of hand movement. During each trial, the patient is instructed to flex each finger one by one as much as possible and then open them to the maximum possible angle possible. The workout is performed separately for four fingers (ring, middle, index and thumb) excluding the little finger because of negligible movement from it. Different combinations of finger exercises are executed to obtain and evaluate all ranges of motion. The filtered data is stored in a database for future reference and for setting up a target for the next visit for rehabilitation. Based on the performance, a new target is calculated and assigned for a patient and taken as a new trial. Implementing target-based exercises in VR simulation requires a previous target to evaluate the patient's movement. Each time the same set of a VR rehabilitation process is continued and applied to the patient.

6.5.1.3 Application: Computer Game-Based Therapy for Post-stroke Therapy

In this section, the author identifies the various applications for post-stroke treatment both in VR and CGBT.

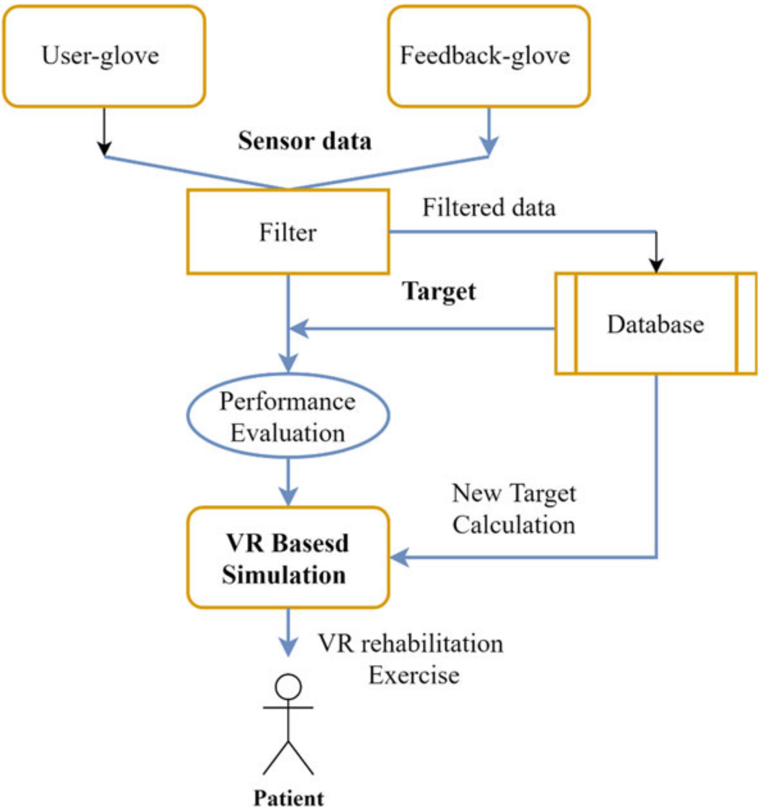

Fig. 6.10 Block diagram of a computer-based desktop VR rehabilitation system

- Virtual Underwater fire CGBT game was designed to study the patient's upper extremity movement and hand–eye coordination.
- Virtual Goalkeeper games is one of the CGBT games expected to analyze the upper extremity parameters like speed controlling, stamina, precision, and various motion range.
- Bug hunter is a CGBT game that efficiently improves upper limb impairments and studies the capability of the hand to react to all challenges given to patients in the stroke group.
- The rollercoaster virtual game was designed to increase the speed of upper Extremities and trunk movements.
- Nintendo Wii (NW)—Type of CGBT video games brings some fun for stroke patients in their post-treatment for the recovery process and help patients to regain the lost strength and core motor skills.
- XaviX Tennis Racket—Type of CGBT tennis in video games mode where the user can control the game using a tennis racket. It is very interactive and fun to

play. The user can play tennis action by putting serve, volley at baseline of court, charging the net and pitching the ball with wireless XaviX Technology.

- Sony Playstation MOVE—High-Velocity Bowling is one of the virtual games available in the playstation network developed by Sony Entertainment. The patients undergoing upper hand stroke treatment can use this CGBT tool for recovery.
- The other games available in the CGBT environment using the above tool are Nintendo Wii bowling, boxing, goalkeeper game, XaviX bowling, bird hunter, shooting, etc.

In the investigation done through these commercial video games for improving upper extremity function after stroke on 24 patients with first-time stroke, results are effective in CGBT based recovery process compared with conventional rehabilitating treatment. Assessment of motor function was done, results are efficient in XaviX tennis application compared to conventional physical exercise [33].

6.5.1.4 Limitations

The software interface used in various video games and system setup is in other languages like Japanese and it is not easy to understand by the users. The software response time of the game is too fast and not easy for patients to play. In some CGBT processes with haptic devices to control a non-immersive environment, some patients may have difficulty handling it. During the study, some patients felt that games were too difficult. The difficulty levels of the games may be increased/decreased considering the patient post-treatment process.

6.5.2 Autism

Autism is a neuro disorder identified for the patient with difficulty with social interaction, behavioural changes, and lack of communication and has restrictions without emotional ties. In the reported case, children with the autistic disorder will have noticeable stereotypical movements, such as coordinated hand clapping or arm flapping whenever the child is getting excited or upset. It is characterized by childhood. More cases are reported recently worldwide and identified as a developmental disabilities.

Very simple VR activity-based training practice was given to children like reading social signals helps them to express socially appropriate behaviours. Training in a virtual outdoor environment, children with autism disorder were seen interacting with faster recovery [40]. Various virtual reality systems are implemented to identify the moving and walking pattern of ASD children. One such VR-based system is discussed in this section to capture the acceleration speed and moving gestures of the children affected with autism. In this study, 5 children with autism have taken

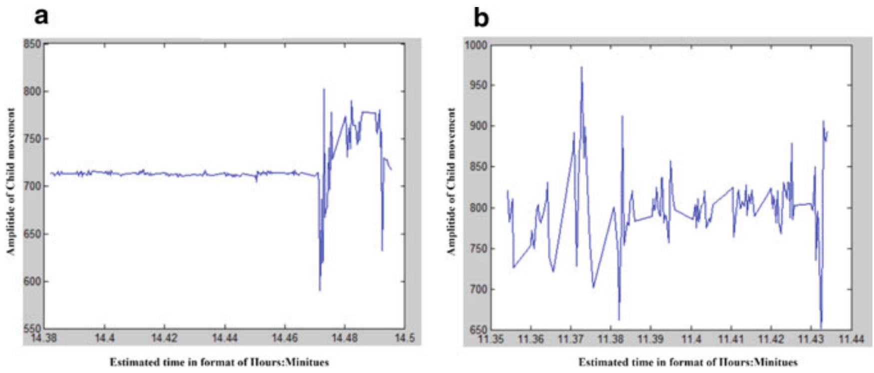

Fig. 6.11 Plotted graph of **a** normal child, **b** an autistic child

part in analysis and the average age of autistic children undergone in the study was 5–15. The VR task was to identify the various walking gestures and speed of the child. The obtained output is evaluated by plotting the graph (Time vs. Amplitude of child movement) using MATLAB software as shown in Fig. 6.11. The analysis using the VR system clearly shows the difference in the pattern of movement for normal children and autistic children. Each of the autistic children has different walking movements and speeds. The child affected with autism disorder's walking speed differs from a healthy person is monitored and evaluated by the physician and physiotherapist. This analysis will be very helpful for the doctors to analyze the walking speed and conclude the disorder to the children is hyper or hypo.

Results of the certain investigation by evaluating the capability of the VR system during the rehabilitation process are encouraging. But still, there are some restrictions of the current study to proceed with children with the disorder. Additionally, a fundamental challenge in designing VR and XR systems is the accuracy in interactions, and the need for a robust device in the VR platform.

6.5.3 Cerebral Palsy

Cerebral palsy (CP) is termed to be a disorder with the movement of any person due to muscle stiffness and reported in early childhood where the babies won't be able to crawl or sit, walk initially as other children of the same age group because of preterm birth or low weight during birth. According to recent statistics, one to nearly four per thousand children reported with cerebral palsy around the world. In a recent study conducted in the year 2010, 58.9% of CP-affected children can walk on their own, 7.8% of children need hand-held assistive devices to walk, and 33.3% of them cannot walk [41].

Giving early treatment to CP patients with the assistance of VR techniques is very helpful for paediatricians, neurologists and parents to handle them better during treatment procedures. Therapeutic tools were introduced by various physiotherapists and physicians with some virtual reality games, this ambience helps to cure neurological disorders in a faster and more interactive manner [42]. For CP patients, VR technology motivates the patients through the rehabilitation process by offering more security, flexibility exercises, attracting patients towards given tasks and increasing social interface.

6.5.3.1 Application: Virtual Game System for Cerebral Palsy

According to the studies and surveys of authors, one of the most popular VR gaming is the 'Wii game' is a motion-detecting video game platform bringing physical activity into gameplay. It provides good results for CP patients by helping children to improve hand function. Players are CP patients, they swing a handheld remote device that interacts with on-screen activities to deliver a more productive physical gaming experience. According to the author [43] the CP patients were separated into two groups:

- The first group received a standard conventional method of neurodevelopmental rehabilitation treatment for patients with cerebral palsy.
- The second group of CP patients was given VR therapy by allowing them to play 3 games of virtual tennis, boxing and baseball using a Wii game-pad and treatment was given to the patients continuously for 6 weeks.

Check Limit Game: In this game-based VR system, two methods are followed. The first one is by connecting the Kinect sensor used for motion capture by attaching it to the patient's body and the second method of motion capture is done using the touchscreen. The response through these interfaces to the game is recorded. The game-based analysis system was established by the Information Systems Laboratory at the University of Sao Paulo [44]. After the analysis of motion capture in two systems of VR games, the Kinect system gives better performance than the Touchscreen method [45].

6.5.3.2 Outcomes and Limitations

The physician then evaluated the independence of each patient and the arm-hand mobility of each child. As expected, the second group that had been playing video games in VR systems for several weeks scored ominously higher in tests that measured for identifying the abilities of a patient's arm movement. Wii-fit VR video games system for CP patients is a promising sign by giving better evaluation results in both static and performance parameters when combined with regular treatment in children with mild CP [46]. Although there are still very few clinical trials and real-time studies are carried out, there are still more unaddressed problems while implementing virtual reality on humans.

6.5.4 Upper Limb Prosthetic Training

Nowadays amputation cases have increased drastically because of road accidents and in severe cases, they have to face the fate of amputation. Upper arm training is considered one of the therapeutic procedures in neuro-rehabilitation for patients with paralyzed upper extremities. Artificial prosthetic hands are the best possible choice if the patient loses their upper limb. In recent years 3D printing has become a handy tool to design and print artificial upper limbs. CURA is popular software used to design the prosthetic model named Bionic arm and output is uploaded in the 3D printer for printing artificial limbs [47].

To provide training to the prosthetic upper limb, micro servo motors are connected using fishing lines. An electromyogram (EMG) signal is acquired to train the Bionic arm as shown in Fig. 6.12 using a clamp electrode attached with micro servo motors. The EMG signal for both muscle contraction and relaxation is obtained and transmitted to the Arduino board for training purposes. After receiving the signal from the EMG regarding muscle contraction and relaxation of the Bionic arm, evaluation is made to observe the performance of the upper prosthetic limb. Based on the evaluation, the real-time prosthetic arm is designed and used for amputee patients.

6.5.4.1 Application: Serious Gaming VR System

Serious gaming is a VR tool used recently in clinical practice that has gained more attention in treating motor dysfunctions in the upper extremity.

- Various categories of game types are incorporated in serious gaming tools like virtual reality (VR), augmented reality (AR), video games, e-board games, and mobile health games [48].
- Serious gaming is simulated in the real world in 3D virtual environments using computer graphics.

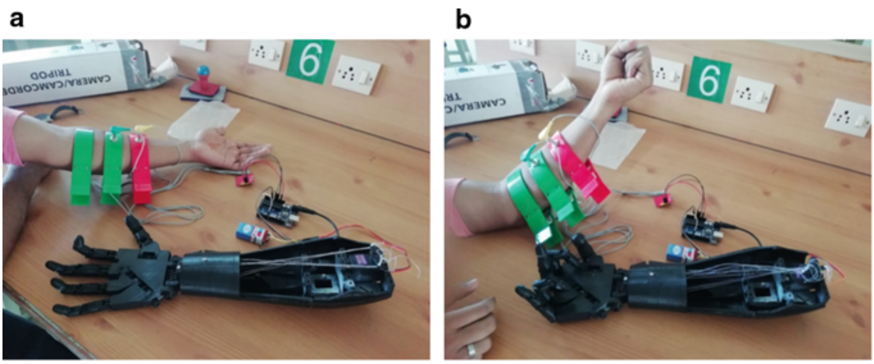

Fig. 6.12 **a** During contraction and **b** relaxation of Bionic arm

- Kinect depth sensors are used to capture body parts and follow their movements in VR systems and analyze the performance of the upper extremity. It can be combined with EMG and other biosignals during gaming.
- The Kinect sensors were positioned on upper limb measuring areas to track the coordinates of the arm movement and hand movement.
- IDLE RACING GO is a gaming platform using video gaming techniques that bring a unique idle clicking experience for the user and can be analysed based on their performance in the gaming levels.

6.5.5 Sports Rehabilitation Exercises

In sports, many indoor and outdoor athletes are prone to physical or internal injuries due to various reasons like an increase in athlete's workload. Because of the demands of competitive sport, the inability to manage player workload results in excessive wear and tear of muscle/bone. An immediate and effective rehabilitation exercise program helps the players to regain their physical strength, flexibility, and stamina quickly after an injury, empowering them to resume their athletic activities. Sports Rehabilitation is a key process for a player's sports life that helps to decide the return of injured players safely to practice or competition. Physiotherapists in the healthcare field work closely with injured players to undergo the rehabilitation phase for recovery by giving wide-ranging training, especially in the musculoskeletal system.

6.5.5.1 Case Study: The Pattern of Common Musculoskeletal Injuries in Male Basketball Players

Musculoskeletal Injury (MSI) is the possible sports injury commonly registered in any person participating in sports like basketball and volleyball. In these types of sports, heavy complex movement was given to muscles and joints like jumps, sudden turns and rapid changes in direction of the person. According to the muscle study conducted [49], the injury site at the right knee is in high danger with 40.17% because of the heavy workload compared to the left knee. The lowest possible injury site in basketball is the right thigh with an injury range of 0.71–0.87%.

6.5.5.2 Sports Rehabilitation Protocol Findings

The most common injury in the musculoskeletal system of any sportsperson is hamstring injury and it is considered complex for any individual. The occurrence of hamstring injury is widely seen in athletes involving fast sprinting, hurdling and water-skiing. Hamstring muscles are stabilized in the hip and knee joint region during an excessive contraction while playing and doing exercises. According to recent literature, severe hamstring injuries should undergo surgery and be followed by rehabilitation protocols to slow return of play (RTP). The sportsperson diagnosed with this type of injury is very challenging because of the complexity in anatomy surrounding the tissue. The VR based assistive devices support sportspersons with a lower extremity injury to stabilise both the foot and ankle.

During COVID–19 pandemic, many sports personalities have been affected by continuous lockdowns. The global sports calendar has been impacted, so lack of sports activities in lockdown time results in loss of performance for a player in their respective field [50]. Globally, most athletes are almost stuck indoors due to this novel disease affecting their mental health and overcoming this situation is a major challenge for any player and the physiotherapist. VR based gaming solution is an alternate and best approach to make them be in practice forever.

6.5.5.3 Guidelines for Sports Rehabilitation

Various guidelines to be followed during VR rehabilitation are-

- Based on the medical needs and resources, sports rehabilitation programs are to be modified and customised to access VR devices.
- Keeping patients interested while attending the program and undergoing a gaming system.
- Robust gaming platform: gaming tool to be user friendly and it should be used at any time and any place, especially in the comfort zone of the patient.
- Utmost care is to be taken to ensure the privacy of patients attending the rehabilitation program.
- Ability to record and communicate the progress of patients during rehabilitation games to the caretakers and patients. Patient gaming profile should be maintained properly.

6.6 Summary and Conclusion

The aim of this chapter proposed by the authors expressed their views on the use of modern rehabilitation technologies in terms of VR techniques. The role of Virtual Reality and its application discussed in this chapter have significant potential and positive impact on individual lives and in the healthcare field. The challenges behind the conventional rehabilitation processes were explored and a user-centric VR-Gaming rehabilitation system for the comfort zone of the patient during post-treatment has been proposed. Implementation of a VR-gaming rehabilitation system recommended to patients with stroke, cerebral palsy and autism disorders employing upper limb prosthetics and sports rehabilitation can have a major role to be played by engineers and physiotherapists. There is a wide range of virtual reality applications in modern rehabilitation treatments that were summarized in this chapter. The VR system not only helps for better therapy for patients but keeps them interested while performing the rehabilitation program in a robust environment. The use of VR in association with post-therapy patients has shown encouraging results. In this chapter, the role of virtual games in faster recovery during post-therapy was discussed. The various applications of the rehabilitation process were illustrated in all sections for better quality patient care with faster recovery time. Case studies on sports rehabilitation exercises provided a systematic review for various musculoskeletal injuries to athletes and guidelines for them to return to play (RTP).

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