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Short review

Low-Tech and High-Tech Assistive Tools for Occupational Therapy and Hand Rehabilitation in Patients with Upper-Extremity Sensorimotor Impairment and Disability

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Abstract

Hand rehabilitation, also known as hand therapy, is a critical aspect of Physical Medicine and Rehabilitation. Multimodal hand rehabilitation integrates interventions focused on preserving mobility and neuromuscular function and using hand training to enhance motor skills and overcome hand dysfunction. This is especially significant in patients with upper-limb disabilities resulting from sensorimotor impairments caused by neurovascular events or conditions affecting the brain, spinal cord, or upper limb peripheral nerves. Upper limb functional assessment and maximising hand functionality are the primary goals of hand rehabilitation. To achieve the best outcomes, a successful rehabilitative approach considers the entire upper limb, combining the mechanisms of various complementary conservative therapies, and could associate potential minimally invasive medical interventions intended to relieve severe neuromusculoskeletal intractable symptomatology. Occupational therapy plays a key role in comprehensive hand therapy programs, offering meaningful task-specific training, and using functional activities, facilitated by various assistive technologies and adaptive training tools, that can help increase movement control and functional independence. Continuous passive motion devices can help maintain soft tissue flexibility and mobility. Rehabilitative interventions using upper limb assistive tools can help prevent or mitigate mobility disabilities while enhancing or restoring hand motor skills, essential for optimising functional performance. This integrated approach fosters improved participation in daily activities across various life situations. Our main goal was to analyse relevant recent findings in the biomedical scientific literature and provide an updated, concise overview of the main categories of high-tech tools lately used in clinical research, that can assist, in hand rehabilitation settings, occupational and physical therapists working with individuals experiencing upper-limb sensorimotor impairments.

Keywords: Assistive Devices; Functional Training Tools; Hand Dysfunction; Hand Rehabilitation; Occupational Therapy; Sensorimotor Impairment; Upper Limb Disability

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Introduction

Hand rehabilitation, alternatively referred to as hand therapy, represents a critical aspect of therapeutic programs for patients with upper limb disabilities within Physical Medicine and Rehabilitation. Optimising hand fine motor skills and upper limb function, and enhancing functional capacity and occupational performance, are essential requirements for regaining functional independence and thoroughly engaging in meaningful tasks within activities of daily life.

Upper limb disabilities are particularly significant in patients with sensorimotor impairments resulting from acute neurovascular events or acquired neurological disorders and injuries affecting the brain, spinal cord, or upper limb peripheral nerves. Functional consequences of strokes, peripheral nerve injuries, spinal cord injuries, and traumatic brain injuries affecting motricity and sensibility in the extremities are among the most common reasons for admission to neurorehabilitation settings. Both upper and lower motor neuron syndromes are linked to disabling sensorimotor disturbances and limb paresis. Hemiplegia, quadriplegia, and monoplegia are the most severe forms involving the upper limb. Significant distal upper limb motor impairment is also linked to progressive muscle hypotonia, in genetically inherited neuromuscular disorders, such as limb-girdle muscular dystrophy affecting predominantly the proximal muscles within the shoulder region and upper arm. Perinatal cerebral palsy, which can be either flaccid-hypotonic or spastic-hypertonic, leading to delayed or abnormal development of motor behaviour, and obstetrical brachial plexus palsy, are common causes of paediatric non-progressive neuromuscular dysfunction affecting upper limb functioning. Carpal tunnel syndrome, cubital tunnel syndrome, cervical radiculopathy, and sensory or mixed peripheral neuropathies generally related to systemic autoimmune diseases, such as rheumatoid neuropathy and diabetes-related neuropathy, are common conditions involving moderate upper limb sensorimotor impairment. Special situations include upper extremity amputations, upper limb involvement in complex trauma, and post-combustion scar contractures and deformities in severe burn injuries involving cutaneous and deeper soft tissues. Degenerative joint diseases and other chronic musculoskeletal disorders, often associated with persistent pain and muscle weakness, also lead to hand dysfunction, the more important when combined with comorbid peripheral neuropathy, in chronic patients.

Upper limb disabilities can significantly negatively impact functioning and health-related quality of life. Without appropriate assistance, repetitive or demanding routine manual tasks can be difficult, overexerting or even impossible for people with impaired hand strength and dexterity. These challenges can hinder an individual's ability to perform everyday tasks autonomously, increasing the need for human and instrumental assistance.

Our primary goal was to analyse relevant recent findings in the biomedical scientific literature and provide an updated, concise overview of the main categories of high-tech training and assistive tools or systems lately used in hand rehabilitation and for clinical research in rehabilitation medicine. These tools could assist occupational and physical therapists in working more safely and efficiently with individuals experiencing significant sensorimotor impairments and upper-limb disability. Furthermore, we intended to highlight the significance of using multiple, integrated therapeutic interventions within hand therapy programs, supported by various appropriate available low-tech, mid-tech and high-tech assistive devices, in patients experiencing upper limb disabilities admitted for therapeutic management in Physical Medicine and Rehabilitation.

Multimodal Hand Rehabilitation: Employs a combination of various sequential personalised conservative interventions focused on enhancing neuromuscular function and hand training. Maintaining soft tissue flexibility and joint mobility through passive physiotherapy options, and improving impaired hand motor skills using different successive dynamic applications and combined methods for motor and functional training, are mandatory to overcome hand dysfunction and its consequences.

Primary objectives in hand rehabilitation include patient evaluation for clinical diagnosis and functional assessment of impaired upper limbs to establish the extent of physical disability and functional capacity status, and enhancing hand movement functionality through effective therapeutic management of upper limb impairment. Assessing the individual's physical mobility limitations affecting hand dexterity, manipulative skills, and occupational task performance, as well as identifying the determinants of hand dysfunction, are essential prerequisites for establishing achievable anticipated therapeutic goals, and realistic expected outcomes. A thorough clinical and functional assessment can help select and implement the most suitable therapeutic methods, techniques and tools, supported by available technology, and tailored to meet a patient's psychomotor potential, healthcare needs, and personal expectations.

To achieve the best outcomes, a successful approach must consider the entire upper limb, and the whole person, taking into account the personal physical, neurocognitive and emotional factors that influence an individual's motor behaviour, overall functioning, and adherence to therapy. Equally significant is identifying potential environmental and psychosocial barriers, as well as available and accessible facilitators that can help disabled individuals to surmount functional challenges.

Instrumental passive physiotherapy based on mechanical, thermal and electrophysical agent applications, along with manual therapy techniques and other forms of passive mobilisation—the main categories of physical therapy modalities—provide somatosensory stimulation and can help facilitate local tissue nutrition, alleviate symptoms, and maintain soft tissue flexibility, joint mobility and neuromuscular function until complete tissue recovery is achieved. Upper limb continuous passive motion devices assist in preserving joint range of motion until active movement is feasible or advised. Thus, passive physiotherapy methods offer alternative or combined, complementary therapeutic solutions and techniques within personalized rehabilitative programs to help prevent or minimise severe muscle contractures, joint stiffness and deformities—some of the main potential complications linked to hypertonia and hyperreflexia within upper motor neuron syndrome leading to spastic muscle overactivity, immobility and hand disuse. Rehabilitation program could associate potential minimally invasive medical interventions intended to relieve severe neuromusculoskeletal intractable symptomatology such as significant pain and spasticity. Neurogenic muscular atrophy, especially in sensorimotor impairments related to lower motor neuron syndrome, also benefits from various sensory stimulation methods and dynamic, passive and active rehabilitative techniques targeting muscle contractility and motor activity.

Somatosensory afferent peripheral electrical stimulation below the motor threshold, using higher frequencies of stimulation pulses or transcutaneous electrical stimulation to target enhanced hand motor recovery, activate sensory neurons, and provide repetitive somatosensory exteroceptive input that could help improve motor skill acquisition or consolidation, as well as motor performance and distal upper limb function. It noninvasively induces cortical neuro-modulatory effects, increasing sensorimotor integration within the contralateral hemisphere and connectivity between sensorimotor areas of the cerebral cortex responsible for hand function control, activating both hemispheres. Thus, somatosensory electrical stimulation applied over the impaired distal upper limb modulates adaptations in cortical synaptic plasticity and could induce neuroplasticity in hand neurorehabilitation, helping augment motor learning and neuromuscular recovery.

Neuromuscular electrical stimulation, which enables activation of both motor and sensory neurons at lower frequencies of stimulation, is applied for the excitation of peripheral nerves near to or above the motor threshold and consequent artificially-induced muscle contraction, also providing somatosensory proprioceptive input and enhancing motor function recovery. It can help improve gross motor function in disabled upper limbs, support axon growth during the posttraumatic nerve repair process, accelerate sensorimotor function improvement or recovery in the paretic hand, and increase functional use of the impaired arm.

Therapeutic exercises addressing the upper extremities, and physical activity involving the impaired upper limb, are imperatives for maximising hand-grip strength and optimising upper limb motor and functional performance. When performed following excitomotor-dynamic neuromuscular electrical stimulation, muscle-strengthening physical exercises can be more feasible and effective in controlling disuse muscle atrophy, and preventing muscle strength decline, especially in mild peripheral impairments without a severe neurological implication. Combined, dynamic, functional electrical stimulation applications provide enhanced motor and strength training, more cognitive engagement and real-time feedback, augmenting the effects of physical training programs.

Occupational Therapy: An essential component of the comprehensive rehabilitative hand therapy programs, is aimed at overcoming a patient's physical limitations and environmental and occupational challenges, physical overuse, psychological barriers, social disadvantages and disengagement, providing purpose for repetitive motor actions and increasing motivation and participation. Appropriate accommodations, ergonomic solutions, and adaptive, tailored equipment provide comfort, support, safety and efficiency, facilitating prehensile movements hand-grip and pinch-grip. Solving external constraints or obstacles that interfere with effective and safe self-reliant functioning in individuals with limited hand dexterity, occupational therapy enables the development of intrinsic compensatory mechanisms, promoting the efficient use of an individual's functional capacity and active upper limb rehabilitation. Appropriate upper limb assistive tools can help increase movement control and prevent strain, pain, discomfort, and overuse injuries, increasing an individual's engagement in normal day-to-day activities.

Furthermore, to the extent that the patient's hand prehensile strength allows it, occupational therapy tools and techniques enable purposeful task-specific training, using occupational activities as functional interventions that can help improve power and precision grasps, and restore hand and finger dexterity, increasing upper limb mobility and overall functioning, and promoting health in all its dimensions. Occupational therapy interventions can be facilitated by various simple and advanced assistive technologies and adaptive training tools, that can help increase movement control and regain functional independence in all areas of life. Rehabilitative interventions based on occupational therapy principles, and using assistive tools, can help prevent or alleviate mobility disabilities, while enhancing hand gross and fine motor skills, which are essential for optimising upper limb and functional performance. This integrated approach fosters improved participation in everyday occupational activities across various life situations. Additionally, rehabilitation programs include educational features, technical training and guidance for safely using assistive devices for the patient and its caregivers, and personalised specialised recommendations and support for the long term.

Assistive Technologies for Upper Limb Disabilities and Hand Therapy

Assistive technologies designed for upper limb disabilities serve as essential mobility facilitators for individuals who experience difficulties with hand movement control and limited manual dexterity, helping them to perform various tasks involving manual handling (manual tasks). Their accessible use facilitates interaction with the external environment and helps promote inclusion, bringing opportunities for maximally engaging in various aspects of life. Assistive technology input is particularly significant in cases where upper limb function is compromised by severe joint stiffness and deformities, decreased muscle strength resulting from disuse-induced or neurogenic skeletal muscle atrophy, abnormal muscle tone, hypermobility, uncontrolled movements, exercise-induced peripheral or central muscle fatigue, trauma-related complex regional pain syndrome, or disabling chronic neuropathic pain.

In 1998, assistive technology has been defined as *"technology designed to be used in an assistive technology device or assistive technology service"*. In this light, assistive technology devices are any items, equipment parts, or product systems—whether commercially acquired, custom-made or modified to fit—used to maintain or enhance the functional capabilities of people with disabilities [1]. Assistive devices can serve as adaptive compensatory, or stimulative, rehabilitative tools and systems, specifically designed to address the unique needs of individuals with disabilities, thereby enhancing their functional independence. These devices and accommodations facilitate adaptations to personal functional challenges, enabling engagement in everyday activities. The Act outlines related assisting services, that include evaluating and identifying the assistive technology requirements or needs of individuals with disabilities, selection and provision for the acquisition, designing and fitting (customising and adapting), maintenance, and providing physical and occupational rehabilitative interventions to optimise functioning. Additionally, it encompasses specialised training, and technical assistance for individuals with disabilities, their families and caregivers, employers, and for authorised representatives. In 2004, the Act was amended to include, among others, services that expand availability and access to electronic and information technology, for educational purposes and communication, in individuals with disabilities [2].

In order to select adequate, compatible and effective, advisable assistive tools, their specific functions, the individual's unique assistive and ergonomic needs and preferences, financial resources, accessibility of healthcare, and available technical and human assistance for the long-term are to be considered. The wide range of assistive technologies has been generally classified—based on complexity, functionality, availability, and affordability or cost-effectiveness—into low-tech, and high-tech. With the rapid pace of technological advancements and the increasing availability of technological innovations in the modern technological era, it has become increasingly difficult to classify nowadays different devices into these two main categories, based on initially considered criteria.

Upper extremity low-tech assistive tools for hand dexterity issues, more commonly available and accessible, are modified ergonomic equipment, tools, and appliances, with adaptive features, designed to assist individuals with limited hand mobility when dealing with challenging everyday routine tasks, adapting to their motor and functional impaired abilities. These simple tools enhance manual handling or manipulating objects by facilitating reaching movements and gripping, or prehensile hand function, and thus simplify occupational tasks and work processes, avoiding discomfort, fatigue and overuse injuries. Their general characteristics are listed in table 1.

• Simple to make, simple to use, standalone, basic assistive tools or accommodations (less complex)
• Non-electric, without electronic components (do not require a power source)
• Can have basic mechanical components (do not have complex electrical-mechanical parts)
• Provide limited customisation options, less versatile
• Usually lightweight and portable
• Do not require specialised user training (do not pose special health and safety risks)
• Practical, convenient to handle (user-friendly or easy-to-use, with minimal effort)
• Economically accessible to a broader range of end users (more widely available)

Table 1: General characteristics of low-tech assistive tools.

However, various terminologies have been used to describe contemporary technological innovations, such as modern, advanced, enhanced, smart, up-to-date, leading-edge, and intelligent technology.

State-of-the-art technology describes the highest level of technological advancements currently accessible, characterised by cutting-edge innovations that adhere to established output standards for specific processes. It facilitates the highest level of advancement in the development of occupational activities or professional endeavours by applying the best available, best-practicable, and most feasible techniques. It provides enhanced work efficiency, safety, and ergonomic support and enables robotic automation of repetitive, physically demanding or high-precision tasks, and safer industrial operations. It reduces manual tasks and potential hazards, avoids traumatic risks, minimises errors and enhances instrumental and work process accuracy. Furthermore, it can be cost-effective, maximising overall capabilities.

High technology supports the highest standards of modern clinical practice, high-performance medical devices for qualitative healthcare interventions, and qualitative scientific clinical research. Moreover, advanced technologies assist individuals with severe locomotor impairments in their usual occupational activities, helping maximise mobility and independence for self-care and other domestic tasks, and increasing participation in educational, professional, and community life, as well as in sports and other recreational activities.

A distinction must be made between current high-performance technologies, and other assistive devices once considered as such, but which, surpassed by recent advanced technological developments, have nowadays become much more accessible to the general public, being reasonably achievable from a social and economic perspective and widely available for various rehabilitation and healthcare settings. These devices can no longer be classified as high-tech, nor can they be deemed low-tech, falling into a unique category. This is how the concept of *mid-tech assistive technology* came about (Table 2). These devices are designed to be useful, safe and feasible for individual independent use in daily activities and minimise operational risks. Furthermore, the line between mid-tech and low-tech equipment is equally subjective, as one could consider some electronic assistive devices as low-tech compared to other technologies much more complex. The general characteristics of high-tech assistive tools are presented in table 3.

• More complex, specialised devices, with multiple features and functions
• Electronic devices – electrically powered
• Can be digital – allowing for the generation, storage and processing of data (hardware systems with software applications for specific functions)
• May include mechanical parts
• Some can be integrated within compatible computers and software applications
• Can often provide a wide range of functionality (versatile)
• Usually practical for independent use
• Could require some initial training, to lower operational health and safety risks
• Less expensive and more widely available compared to high-tech

Table 2: General characteristics of mid-tech assistive devices.

Low-Tech and Mid-Tech Assistive Tools for Limited Hand Function and Upper Limb Disabilities

These categories include a wide variety of alternative solutions to avoid demanding manual handling and various gripping aids—ergonomic, adaptive handles and specialised, adapted-handed tools and appliances, designed or modified to facilitate common manual tasks within daily living activities in individuals with limited range of motion, reduced grip-strength, abnormal muscle tone or impaired hand dexterity. They allow easy use of impaired hands, in neutral wrist and hand positions, minimising physical stress, pain and discomfort, and can be used in task-oriented occupational therapy, as training tools. To exemplify, adaptive alternative-ergonomic keyboards with wrist support, mini-keyboards for limited range of motion, extra-large keyboards for manual dexterity limitations, single-handed keyboards for unilateral impairment, adaptive-ergonomic mice and joysticks, can help facilitate hand and finger movements, increase dexterity and decrease fatigue, pain and discomfort in individuals with limited hand function.

• The most complex, advanced assistive devices, offering highly specialised features and functions
• Sophisticated electronic devices
• Typically computer-based, with advanced software applications
• May provide advanced integration of mechanical parts (mechatronics) and automation
• Provide the widest range of functionality and benefits for individuals with disabilities
• Much more difficult to use independently
• Require prior specialised training to lower operational health and safety risks
• Most expensive, not widely available or accessible

Table 3: General characteristics of high-tech assistive devices.

Basic upper limb orthotic devices such as splints or braces, with or without mechanical additions, provide support and protection for injured or impaired tissues of the locomotor system, prevent overuse, pain and fatigue due to repetitive tasks, and can limit or control unwanted motions. Support gloves can help reduce pressure in the distal upper limb during heavy work activities and physically demanding sports, or stabilise hand tremors, increasing joint stability and dexterity. Special gripping cuffs enable the use of conventional tools which normally require a superior grip strength. Portable carrying devices facilitate the manual transportation of heavy loads. Conventional, body-powered upper limb prostheses, more or less functional or cosmetic, structurally compensate for limb loss.

Speech-to-text software converting audio to text facilitates hands-free written communication. Self-care assistive tools, such as adaptive clothing, self-fasteners, long-handed reachers or grippers can help minimise physical dependence in individual activities. Adaptive non-electric and electric kitchen tools empower engagement in cooking activities and promote self-feeding independence. Adapted switches, electromagnetic and sensor-controlled switches based on motion or wave detection, and other environmental controllers enhance appliance control, using compatible interfaces, and successfully replace standard manual controls, allowing touchless and remote control of various smart home devices, and automated door and barrier systems. Adapted and powered mobility aids facilitate safe and effortless use and ambulation, increasing locomotor independence. Hand-grippers and finger grippers are assistive tools for hand-grip strengthening and fine hand motor skills training.

Mid-Tech and High-Tech Assistive Tools for Significant Upper Limb Disabilities

Mid-tech and high technologies designed to increase movement control in disabled upper limbs are advanced electronic, mechatronic and computer-based systems and devices, usually customisable (tailored to meet individual needs). Intelligent assistive technologies include advanced -computing capabilities, robotics and machine intelligence. Assistive and therapeutic rehabilitation technology can be stationary or wearable-portable, can encompass complex mechanical features, integrate electrical stimulation technology to enable functional electrical stimulation, and may associate brain control devices. Other advanced features include sensor-based systems, eye-tracking systems, augmentative and alternative communication based on voice and speech recognition software, virtual reality systems, brain-computer interfaces, closed-loop systems, and artificial intelligence.

Common examples of advanced assistive technologies are accessible gaming controllers for serious games, hydraulically powered arms, dynamic arm support devices, electrically actuated powered orthoses, myoelectric prostheses, advanced neuroprostheses, upper-body joint-based exoskeletal devices, activity-specific prostheses, robotic arm and hand training systems, functional electrical stimulation systems, wearable assistive soft-robotic gloves, hybrid systems, powered wheelchairs with advanced navigation systems. Emergent promising technologies are brain-controlled muscle stimulation systems and high-performance brain-computer interface technology applications integrating artificial intelligence, which goes beyond sensation and perception to higher-level cognition.

Advanced mid-tech and high-tech devices significantly improve the mobility of the impaired upper limbs, and the patient's motivation, satisfaction, and engagement in functional day-to-day activities, making rehabilitation training tasks more consistent with the patient's pre-morbid limb use habits.

We searched the PubMed database for the most recent clinical trials and observational research studies conducted on neurological patients with sensorimotor impairment and upper limb disabilities that analysed the therapeutic outcomes of using high-tech assistive devices for hand rehabilitation. These studies showed moderate improvements in upper limb function and functional activity performance. Below we present the main high-tech upper limb assistive devices and combined instrumental techniques for motor training in neurorehabilitation hand therapy that were used in selected clinical research studies from 2024. We briefly summarise the key findings and conclusions of these studies, which are generally positive, highlighting the potential advantages of employing advanced assistive technologies in neurorehabilitation for hand therapy.

- **Hand therapy video games** have not significantly improved hand dexterity, upper limb impairment, activity limitation and cognitive function in home-based hand rehabilitation after stroke, and led to technical problems in a home environment that negatively affected adherence; this approach may not be appropriate for unsupervised home-based training [3];
- **Mobile health applications for tablet app-based dexterity training** – used in home settings, were found to be effective in improving specific dimensions, such as finger movements and strength in individuals with multiple sclerosis [4];
- **Remodeled glove puppetry** significantly improved hand kinematics in children with developmental disabilities, and could help enhance hand performance and play behaviour [5];
- **Wheelchair-bound dynamic arm support** proved the potential to improve power wheelchair control in real-life contexts for individuals with upper limb disabilities; it could assist in daily activities accomplishment, but could require environmental accessibility for successful integration, to avoid adverse events and increase safety; long-term use could significantly improve wheelchair operating skills, and may lead to important positive psychosocial impact [6];
- **Virtual reality technology** proved to be a useful tool for upper limb post-stroke rehabilitation, providing motivating games for safe, intensive, individualised treatments in a playful environment, especially valuable for chronic patients with a lack of motivation; it could help improve grip strength, dexterity and motor function; satisfaction and adherence levels were very high following game training [7];
- **Virtual reality-based robot therapy** combined with **task-oriented therapy** is valuable for improving upper limb function and cerebral cortex activation in patients with stroke [8];
- **Semi-immersive virtual Reality Exercise Therapy** aimed to simulate a conducive training atmosphere for hand rehabilitation showed substantial enhancements in hand function, range of motion, and muscle power in a tetraplegic patient with spinal cord injury, also demonstrating commendable adherence and active participation [9];
- **Upper limb rehabilitation support robot combined with long-term task-oriented training** – improved motor function, active range of motion and functional capacity regarding self-care in severe bilateral upper limb paralysis after spinal cord infarction [10]; robot-assisted therapy followed by activities of daily living training could significantly improve upper limb motor function, passive joint movements, hand function, participation in daily living activities and quality of life in individuals with subacute stroke [11];
- **Upper limb robot-assisted training** proved to be superior to conventional training in terms of improving upper limb motor impairment, ability to perform daily living activities, and muscle tone, facilitating the functional recovery of stroke patients [12];
- **Unsupervised robot-assisted rehabilitation** with actuated devices for the upper limb was feasible for home use in post-stroke patients, complementing usual therapy and increasing therapy dose, helping promote sensorimotor recovery, with no adverse events and without requiring significant additional resources and manpower [13];
- **Ergonomic wearable glove for robotic-assisted repetitive and task-oriented hand training** improved upper limb motor function and manual dexterity in patients with multiple sclerosis [14];
- **Dyad motor learning in a wrist-robotic environment** – alternating between physical and observational practice, has the potential to improve therapeutic outcomes and increase care efficiency, and could significantly improve motor performance in complex motor tasks; it could reduce practice time compared to physical practice alone [15];

- **Grip-supporting wearable assistive soft-robotic gloves** – lightweight advanced assistive devices providing grip support for individuals with limited hand function, facilitating the performance of specific daily manual tasks, while stimulating active and highly functional movements within the user's possibilities. Can act as robot-assisted training tools during supervised therapy sessions, increasing grip and pinch strength and functional task performance, and can have a superior effect regarding improvement of motor function and dexterity compared to conventional therapy. Also, unsupervised assistive use in home environments for prolonged periods might have comparable results regarding grip strength and hand function [16];

- **Hybrid assistive limb–powered soft-bodied exoskeletons for the arms** operating on the principle of „interactive biofeedback", improved upper limb function and self-care abilities in a patient with severe neuropathy, in the chronic phase of Guillain-Barré syndrome at the end of intensive robot-assisted rehabilitation and self-training following hospital discharge [17];

- **Electromyography-driven soft robotic hand**, developed to assist task-oriented object-manipulation training effectively, significantly improved motor function, muscle coordination and upper limb function in chronic stroke survivors [18];

- **Myoelectric upper limb prostheses** are sophisticated electronic wearable alternatives to standard body-powered prostheses used for the replacement of amputated upper limb parts, providing greater pinch and grip force; performance may not be solely influenced by the design of the prosthesis, enabling users to achieve success with either type of device based on specific circumstances; prescription practices should prioritise individual needs and preferences over factors such as cost or prosthesis design; an increased emphasis on research in this domain would be advantageous for decision-making [19]; electromyographic feedback improves force control of a myoelectric hand prosthesis, which can be used in high-level amputations, despite the extent of the injury and non-intuitive control [20];

- **Myoelectric motor execution using virtual limbs and serious games combined with sensory training**, providing feedback, proved to be a potential rehabilitation treatment for individuals with highly impaired arms and hands; might also ameliorate chronic neuropathic pain [21];

- **Force feedback hand rehabilitation robot assisting conventional task-oriented training** – could improve hand performance in hemiplegic post-stroke patients, increasing training intensity. The sensory feedback function of fingers could help complete more accurate grasping movements [22];

- **Restrictive orthosis for constraint-induced movement therapy** – restriction of residual function of the paralysed fingers in post-stroke hemiparesis was found to be beneficial [23];

- **Upper-limb exoskeletons designed to facilitate task-specific training therapy**, assisting high-intensity repetitive arm and hand exercises, could help improve upper-limb motor functions and quality of life in post-stroke patients [24];

- **Shoulder elevation exoskeleton robot**, applying a novel optimization technique derived from the muscle synergy index, showed the possibility of safely improving the upper-extremity function in patients with severe stroke in the chronic phase [25];

- **Tenodesis-induced-grip exoskeleton robot with integrated assist-as-needed control mode** could improve both the upper limb function and activity level of the paretic limb in patients with chronic stroke, promoting patient active involvement, thereby fostering motor recovery [26];

- **Telerehabilitation using a 2-D planar arm rehabilitation robot** has been used for minimally supervised home-based upper-limb therapy for post-stroke hemiparesis; web-enabled telemonitored carer-supervised robotics-aided therapy could be feasible and safe for home-based upper limb rehabilitation, with increased acceptability, active training hours, clinical efficacy, and cost-effectiveness [27];

- **Brain-computer interfaces** – communication systems that can determine functional intent, translate brain signals into motor instructions, improve movement control and interaction, can further improve upper limb motor function based on traditional rehabilitation training in patients with ischemic stroke; adverse events were reported [28]; combining motor imagery with visual feedback and functional electrical stimulation, it might offer treatment alternatives for patients with severe upper limb paretic sensorimotor impairment in subacute stroke [29];

- **Neural interfaces** using selective peripheral nerve stimulation controlled by implanted intracortical microelectrode recordings from sensorimotor networks, along with restoration of tactile sensation of the hand using intracortical microstimulation has the potential to create bidirectional restoration of motor and sensory functions of the arm and hand after neurological injury and restore sensorimotor upper extremity function in tetraplegia [30];

- **360° immersive virtual reality-based mirror therapy** could be a promising approach for upper limb rehabilitation in stroke patients, improving functional outcomes and providing a more favourable experience and satisfaction for stroke patients [31]; as a valuable neurorehabilitation tool, immersive virtual reality can augment conventional treatment in subacute stroke patients [32] also holding the potential for personalised and intensive training within a telerehabilitation framework [27];

- **Virtual Reality and Functional Electrical Stimulation** demonstrated a notable increase in the strength and function of the upper extremities of children with Erb's [33];

- **Cathodal high-definition transcranial direct current stimulation** over the ipsilateral M1 cortex could potentiate cortical plasticity induced by intermittent theta burst stimulation and could enhance the after-effects, augmenting upper limb motor recovery and daily participation among subacute stroke patients [34];

- **Transcranial direct current stimulation combined with robot-assisted hand rehabilitation** – could improve the functional range of finger joint flexion in the affected upper limb in post-stroke patients [35];

- **Robotic resistance training for the upper limb** was more effective compared to active-assisted training in upper limb functional and structural improvement, and improved activity participation in patients with moderate post-stroke hemiparetic impairment [36];

- **Robot-assisted upper limb training combined with functional electrical stimulation** – effectiveness is to be explored in neuromuscular rehabilitation for post-stroke patients [37];

- **Repetitive Sensory Stimulation followed by Robot-Assisted Arm Training** – might be a promising approach for moderate paresis in post-stroke rehabilitation meant to improve sensorimotor function, as its sensorimotor effects could directly drive plasticity processes; feasibility was demonstrated for moderate to severe paresis [38];
- **Cluster needling at scalp points with retained needles** combined with **intelligent robot-assisted upper-limb training** improved upper limb motor function and the range of motion of the shoulder joint in subacute stroke patients [39].

Summary

Hand rehabilitation programmes combine in an integrated approach the mechanisms of action of various complementary therapeutic interventions and rehabilitative techniques, of which occupational therapy, with upper limb its tools and principles, provides an essential input for people with disabilities. Assistive technologies designed with ergonomic principles to exceed hand dexterity issues have become increasingly effective in expanding mobility and functioning. It can be generally accessible to people with physical disabilities and the general public, making manual manipulation tasks much easier in everyday activities.

Appropriate upper limb assistive devices and accommodations support and facilitate gross and fine hand use, increasing hand movement control and helping minimise the extent of disability. They are of utmost importance in hand therapy, assisting physical and occupational therapists in safely and effectively working with patients experiencing upper limb dysfunction. By promoting functional independence, assistive technologies can greatly impact the well-being and overall quality of life of individuals with severe upper limb disabilities, facilitating self-care and long-term assisted care in safer environments for those with chronic disabling conditions.

However, it is extremely challenging to classify upper limb assistive devices as low-tech or high-tech, according to old criteria, which are outdated in light of recent groundbreaking technological advancements. These innovations are revolutionising evolving modern healthcare and neuromotor rehabilitation, sustained by bioengineering-based musculoskeletal biomechanical laboratory investigation for clinical research in Physical Medicine and Rehabilitation.

Emerging assistive technologies need to be researched and validated in laboratory and clinical and occupational contexts to evaluate therapeutic effectiveness and identify new enhanced or combined functions that can support the development of novel improved therapeutic techniques and potential applications for long-term use in individuals with upper limb disabilities.

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