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A review of upper limb robot assisted therapy techniques and virtual reality applications

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ABSTRACT

Impairments in the sensorimotor system negatively impact the ability of individuals to perform daily activities autonomously. Upper limb rehabilitation for stroke survivors and cerebral palsy (CP) children is essential to enhance independence and quality of life. Robot assisted therapy has been a bright solution in the last two decades to promote the recovery process for neurological disorders patients. Nevertheless, defining the optimum intervention of robot assisted therapy (RAT) in different cases is not clear yet. With this aim, the presented study reviewed the current literature on RAT protocols for upper limb impairments and the effects of RAT on recovery outcomes. A literature search was conducted using different search engines, reviews, and studies. This study presents an overview of fourteen robotic devices used in the rehabilitation field and seventeen clinical trials using commercially available devices during the last three years. A discussion about reaching an efficient rehabilitation process based on different aspects such as clinical setting and training modes has been introduced. This review identifies the limitations of RAT to lay the foundation for more effective neuromotor disorders rehabilitation. Finally, using virtual reality (VR) as an assisting feature in RAT improves the whole process of recovering motor functionality.

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1. INTRODUCTION

The enormous dynamic development in the robotics field made it possible for the robots to be used in sensitive aspects such the medical practice. The first robot-assisted rehabilitation process was introduced in 1970. The process included applying continuous passive motion (CPM) trials to induce the generation and healing of articular tissues [1]. However, the trials were performed on rabbits, the idea then was the key for more research on promoting joint healing and tissue regeneration through motor treatment [2]. Robot-assisted therapy (RAT) is defined as the use of a mechatronic system to perform specific tasks through following therapeutic protocols to promote different neuromotor disorders [2]. Robots used in the rehabilitation field rely on demonstrating repetitive tasks and assist the patient with the aid of virtual reality (VR) and serious games [3]. The implementation of VR in RAT provides more focus, engagement, fun, and novelty to the rehabilitation process which results in better active participation [4]. The repetitive nature of using robots for the rehabilitation process was proven to enhance motor functions along with providing more flexible therapy sessions [5]. In fact, different studies showed how active engagement through either desktop games or repetitive engaging tasks can promote sensorimotor recovery as it increases movement control and muscle activation [6]–[8].

Pursuing the optimal rehabilitation process for neurological patients, the RAT research field became an emerging topic in most the research areas. Figure 1 shows the statistics generated by th Scopus database relating RAT to subject areas such as medicine, engineering, and computer science. The essential phase of physical rehabilitation is the evaluation process for patients' recovery. Upper/lower limb activities evaluation is done based on objective assessments during the recovery phase. Following those assessments and protocols manually can result in multiple errors and significant costs [9]. Overcoming this challenge, artificial intelligence (AI) has been introduced to the area of medical recovery. AI is defined as the machine intelligence presented by robots with which they can enhance their performance based on specific measures and conditions. AI is used as an analytical estimation tool for several aspects such as diagnosis, evaluating error of trajectory function, joint angles, and joint angular velocity during recovery assessments [10]. AI was proven very useful in the robotic rehabilitation domain as it can be used in movement assistant robot development, VR-based rehabilitation, and motor function evaluations for stroke patients via different machine learning algorithms [11], [12]. AI can be also used to predict the appropriate exercises and recognize the performed ones based on each patient's case as illustrated in [13], where the scholar applied convolutional neural network (CNN) in exercise recognition. Another importance for AI in the rehabilitation sector is the ability to create a personalized treatment plan that can be used clinically. According to the review study [14], AI contribution to the medical sector can be in form of; disability evaluation, electrodiagnosis, speeding up clinical trials, and many other potential uses.

Neuromotor and sensorimotor disorders include cerebral palsy (CP), strokes, and acquired brain injuries (ABI), categorized based on their impact and their suitability to be treated through RAT [2], [8]. CP is defined as mental and physical dysfunctionality caused by motor deficiency. CP is a neurological condition caused by brain injury during the brain development process during the first two years of life. According to [15] a study conducted in 2020, around 80% of CP cases result in limbs spasticity and CP occurs in two to three out of 1,000 births. Children and patients with CP suffer from difficulties in maintaining postures and performing basic movements. The term CP is always accompanied by motor disorders causing disturbances in cognition, sensation, communication, tone, and perception [16]. CP diagnosis uses different neurological assessments, recognition and observation of clinical risk factors, and neuroimaging findings in the first five months of life. Due to the recent technological advances, the diagnosis became more accurate and conducted in the early stages of the disease which results in better long-term outcomes. The following tools are proved to have the highest sensitivity in CP detection during the first 5 months of life: prechtl qualitative assessment of general movements (GMA) with 98% sensitivity, the hammersmith infant neurologic examination (HINE) with 90% sensitivity, and neonatal magnetic resonance imaging (MRI) with an average sensitivity of 87.5% [17]. Another cause of CP in infants is the strokes that happen during the first 8 weeks of life due to blood vessel blockage or brain bleeding [15]. ABI occurs after birth, yet they are not caused by congenital factors, and they are often caused by traumatic damage of the brain. The traumatic accident causes sensorimotor damage that results in weak muscles, loss of motor control, and in severe cases, spasticity [18]. Those sensorimotor disorders affect different body parts accordingly as they can cause different levels of paralysis in either lower or upper limbs. Losing the ability to perform daily life activities and being dependent on others to accomplish basic tasks are the major negative effects of those disorders [19]. This research focused on motor disorders rehabilitation affecting the upper limb by conducting a thorough study on the currently used robotic devices in this field.

Robot-assisted rehabilitation is performed through two main robotic categories; end-effector robotic arm and exoskeleton. The end-effector type functions while attached to the patient's body part, yet the exoskeleton type is a motorized worn version of orthotic rehabilitation devices [20], [21]. Both categories are aided with virtual designed environments and games that simulate daily tasks to be done by the patients. The designed tasks can be performed through desktop games or through virtual environments based on the type of the used device [22], [23]. However, various studies showed that providing an interacting virtual environment during the rehabilitation process accelerates the healing process and prevents the progression of the disease [24], [25]. Performing therapeutic training in VR stimulates the organization of neural structures and the generation of new neural connections that promotes the recovery from sensorimotor damage along with providing objective information about characteristics of motor control [26]–[28]. Measuring the improvement in motor functions and evaluating the effect of rehabilitation techniques are done through validated clinical scales such as the following [29]: the modified ashworth scale (MAS) for evaluating upper limb spasticity degree, the quality of upper extremity skills test (QUEST) for hand movement and function evaluation, the fugl-meyer assessment (FMA) for measuring sensorimotor impairments, the Melbourne assessment of unilateral upper limb function (MAUULF) for quality of upper limb movement evaluation, the assisting hand assessment (AHA) specialized for children to evaluate the ability of their defected hand movements during bimanual activities, the box and block test (BBT) for gross manual dexterity measurement, and motor activity log for measuring involvement in life situations [30]–[32]. In conclusion, robot-assisted rehabilitation is still an emerging field. It requires intensive research and creative approaches to reach optimum neuroplasticity and sensorimotor recovery for patients with neurologic disorders [33].

In this study, a comprehensive review collecting the different used technologies in the RAT field focusing on upper limb rehabilitation is introduced. Section 2 discusses the followed research methodology. Section 3 states the review search outcomes. Sections 4 and 5 provide a detailed description of RAT motion approaches and related clinical protocols, respectively. Concluding the review study, section 6 provides an overview of RAT feasibility, motor learning challenges, and current design limitations.

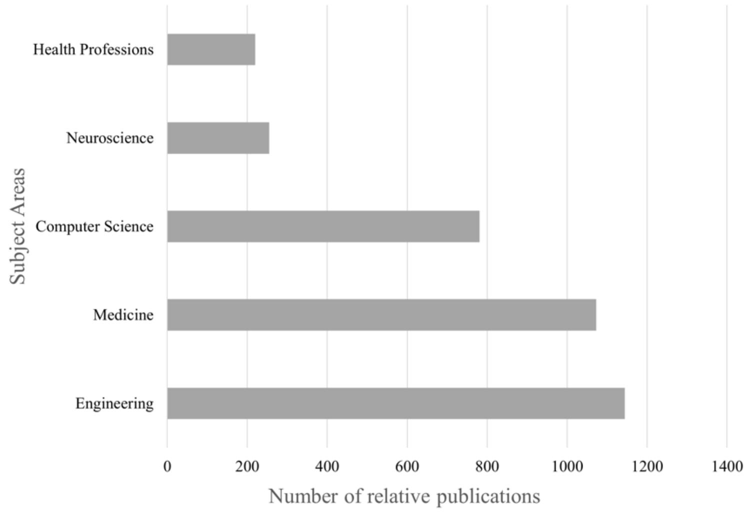

Figure 1. RAT research area

2. SEARCH METHODOLOGY

A scientific literature survey was conducted in ScienceDirect, Scopus, Google Scholar, and Egyptian Knowledge Bank (EKB), using the following keywords or titles: upper limb, upper limb spasticity, CP, Stroke patients, neuromotor disorders, sensorimotor disorders, RAT, rehabilitation, CPM, and robotic therapy. The studies were filtered to be up to 2017. The next step was to investigate each research to ensure they met the following inclusion criteria: they include robotic devices for upper limb rehabilitation, the device was tested on different subjects, the aim of it was to treat the selected neurologic disorders. The flow chart in Figure 2 shows the followed methodology to conduct this review research. In order to conduct the review study, inclusion criteria were selected and applied. The inclusion criteria were: i) robot-assisted therapy and/or assisting robot for upper limb, ii) recent used devices for children and/or adults with motor dysfunctionality, iii) the studies include approved clinical trials, iv) the studies are written in English. The research was performed through primary and secondary literature databases such as PubMed, Cochrane Library, Web of Science, Scopus, and Educational Resources Information Centre (ERIC). The rejection process of certain studies was based on exclusion criteria that included the following: the rehabilitation included any type of invasive surgeries, and the devices were proposed and tested only on healthy subjects.

3. SEARCH RESULTS

Based on the selected keywords, primary literature databases such as PubMed, and secondary literature databases such as Cochrane Library returned 106 articles that fit the wide scope of the research and the specifically applied search filters. Investigating the research results and applying the inclusion criteria, forty articles were selected and categorized by: 9 articles include systematic reviews, 14 articles present devices structures, and 17 articles include clinical trials. Algorithm 1 shows the followed search strategy to reach the mentioned results. The review studies presented investigations for different rehabilitation devices categorized based on effectiveness, VR usage, their mechanisms, and the used clinical protocols. In this study, a wider approach was followed to review the most recent rehabilitation devices. Those devices may include VR and can be improved to be adjusted to suit children and adult patients (CP, strokes, ABI). The present work will address the current limitations in the commonly used devices and proposed solutions.

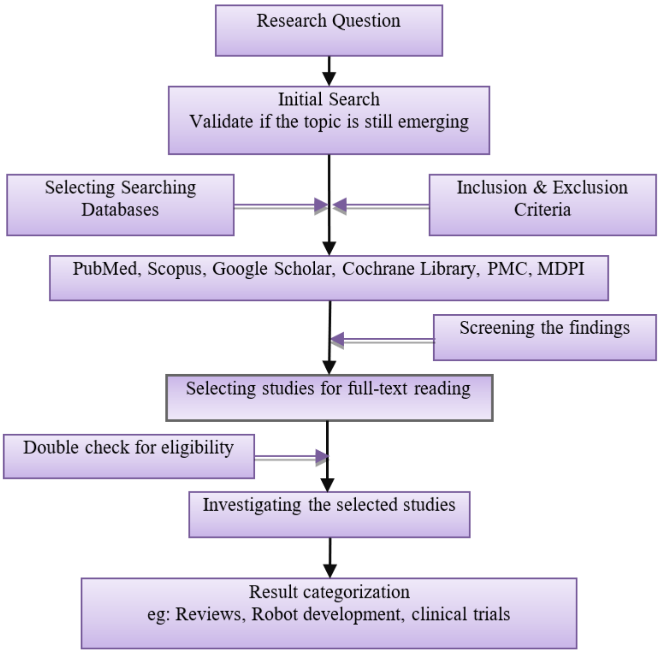

Figure 2. Followed research methodology

Algorithm 1: Search Strategy

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Result: Research categorization
initialization;
validate topic importance;
create inclusion& exclusion criteria;
select relevant research databases;
screen the findings (n);
if: inclusion criteria are met
then: categorize research results (n-i);
else: exclude the search results (i);
end
```

4. RAT MOTION APPROACH

Reviewing the included studies, a moderate number of fourteen robotic devices were found. All the included were developed beyond the proof-of-concept stage and approved to be tested on patients with neurological disorders. Throughout this subsection, each device will be analyzed, and a comparative analysis is conducted for the selected devices. Through investigating each of the mentioned devices, a conclusion about their operation methodology is reached as shown in Figure 3. The process starts with ROM diagnosis to decide the appropriate motion for each patient, and the signal of the motion is measured and recorded using electromyography (EMG) sensors. The signals are then sent to the next step that includes VR simulation and actuation of the device accordingly. To ensure accurate motion paths, feedback signals are generated using EMG sensors back to the processing unit. Table 1 presents a systematic comparison of the characteristic features of the selected devices. Following is an overview describing each device:

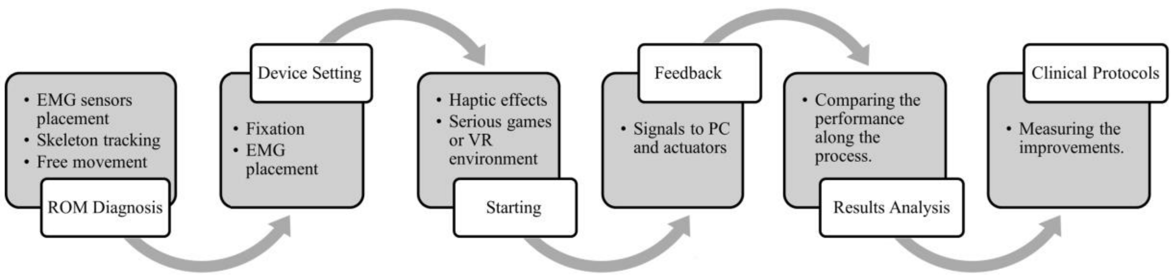

Figure 3. RAT operation methodology

Table 1. Characteristic features of selected robotic devices

Robotic Device	Type	DOFs	Targeted Joint	Measured Output	Use of VR	Feedback	Availability in Market
ArmAssist (AA) [34]	End effector	2	Shoulder, Elbow	Kinematics		Haptic, Visual	
ArmeoSpring [35]	Exoskeleton	5	Shoulder, Elbow, Forearm, Fingers, Wrist	Kinematics		Visual, Auditory	✓
REAPlan [36]	End effector	2	Shoulder, Elbow	End effector Kinematics		Visual, Haptic, Auditory	✓
HAL-SJ [37]	Exoskeleton	2	Elbow	RoM		Visual, Auditory	
Gloreha-hand [38]	Exoskeleton (Glove)		Wrist, Fingers	RoM		Visual	✓
InMotion 2 [39], [40]	End-effector	2	Shoulder, Elbow	Kinematics		Visual, Haptic, Auditory	✓
InMotion 3 [41]	End-effector	3	Shoulder, Elbow, Wrist	Kinematics RoM		Visual, Haptic, Auditory	
Cyber Grasp [42]	Exoskeleton		Wrist, Fingers	Kinematics		Haptic	✓
Novint Falcon [43]	End-effector	3	Shoulder, Elbow, Forearm	Kinematics		Visual, Haptic, Auditory	✓
NJIT-RAVR [44]	End-effector	6	Shoulder, Elbow, Forearm	Kinematics, RoM	✓	Visual, Haptic, Auditory	
CHARMin [45]	Exoskeleton	6	Shoulder, Forearm, Wrist	Arm, Kinematics		Visual, Haptic, Auditory	
YouGrabber [46]	Exoskeleton		Wrist, Fingers	Kinematics	✓	Visual, Haptic	
Dexo-hand [47]	Exoskeleton		Fingers	Kinematics, RoM		Haptic	
MyPam [48]	End-effector	2	Shoulder, Elbow	Kinematics		Visual, Haptic	

4.1. Kinematics-based designs

ArmAssist (AA) [34] is a low-cost end-effector that enables movement in the 2D plan. AA is designed for shoulder and elbow rehabilitation for post-stroke patients. The system offers shoulder support on the table with interactive games that include different tasks operated on a web-based platform. The system does not perform the active motion, yet it produces haptic effects such as gravity as well as taking feedback based on the movement of the arm. The feedback taken is represented in 2D position, force, and forearm angle.

ArmeoSpring [35] is an exoskeleton rehabilitation device that includes a suspension system that supports the weight of the arm and connects the movements to virtual games and tasks with degrees of difficulty. ArmeoSpring working principle relies on reshaping cortical and transcallosal plasticity which improves UL functions. The system enables movement in 3D space while magnifying any active motion performed by the patient. The distal handle measures the pressure applied on the handle grip, to adjust the sensitivity, and level of complexity of the virtual tasks. The measured outputs are the resistance, range of motion, speed of movement, followed path to reach certain virtual objects, and strength.

REAPlan [4], [49] is an end-effector robot that allows the movement in the horizontal plane while sending virtual feedback on the hand position and movement coordinates. The device is used mainly with children with the aid of desktop games that simulate certain games and tasks. The handle is provided with force sensors that measure the force applied from the patient's hand while performing the tasks.

InMotion 2, 3 [39], [40], [50] are two different versions from Interactive Motion Technologies Inc. for upper limb rehabilitation. InMotion2 system is used for shoulder and elbow (proximal limb) and InMotion3 is for wrist rehabilitation. InMotion2 is actuated through a direct-drive mechanism that allows 2 DOF for the proximal limb, yet InMotion3 provides 3 DOF for wrist movement. Regarding the power generation, InMotion2 is powered by the impedance control that guides the patient's movement. InMotion3 includes two actuators mounted on two sides of the system and another DC motor for the pronation movement.

CyberGrasp [42] is an exoskeleton developed by cyber glove system LLC, USA. The system is used for wrist and finger rehabilitation. The system is actuated by electrical actuators fixed on the dorsal side of the glove and the force is then transmitted to the fingers through low friction tendons. This system is heavy which can cause fatigue if it was used for long periods.

Novint Falcon [43], [51] is a haptic device designed originally for gaming purposes. The device consists of a spherical handle that allows movement in 3D. The device is connected to a computer via different sensors to visualize the performed motions and send the needed feedback. The virtual game on the computer requires the patient to move certain objects to certain positions that would be stored for later motor learning evaluation process.

ChARMin [45] is an exoskeleton designed for children with impaired motor functions. The device aims to enlarge the range of motion of the patient’s arm due to the wide workspace. The device allows movement in 3D space and the training is applied on single or multiple joints. ChARMin was originally designed as a 4 DOF exoskeleton and then it was developed to be 6 DOF suitable for children aged between 5-13 years old.

YouGrabber [46], [52] is a training system developed to perform uni-or bi-manual tasks and to send visual, acoustic, and sensory feedback. The device has three training modes for rehabilitation: normal mode in which real hands control their virtual version, visual mirror therapy in which both virtual arms are controlled using only one hand, and the third one is virtual following which is like the previous one without the mirroring option.

MyPam [48] is a desktop-based rehabilitation device. MyPam is developed for children with CP to provide appropriate therapeutic exercises for arm, shoulders, and elbows. The device consists of two joysticks which can be used independently, a GUI, and computer games system. The joysticks are actuated through motors and the feedback signals are sent by the encoders connected to these motors.

4.2. ROM-based designs

HAL-SJ [37] is short for single-joint hybrid assistive limb which is a wearable robot for the elbow joint. The exoskeleton enables real-time elbow flexion caused by muscle bioelectric signals measured by surface electrodes attached to the anterior and posterior of the arm skin. The main purpose of HAL-SJ is to use biofeedback to assist the elbow flexion of patients with limited upper limb abilities.

Gloreha-hand [53] is a device in the shape of a glove concerned with hand rehabilitation. The glove is powered mechanically through a beam physically separated from the glove itself. This design makes the device lighter which does not affect the rehabilitation process. Gloreha glove enables the finger to move freely with a variety of motion ranges and different velocities. The glove is connected with virtual simulation to represent the movements of the patient’s hand.

NJIT-RAVR [44] is a 6 DOF system that is designed for children with CP. The system includes Haptic Master and a rehabilitation suite for simulations. The system offers inter-active virtual environments along with levels of difficulties for each game determined based on the patient’s condition improvement.

Dexo-hand [47] is an exoskeleton developed for the right middle finger and thumb. The device consists of a control box and two wearable robotic fingers. The device targets the joints in both fingers such as metacarpophalangeal (MCP), proximal interphalangeal (PIP), distal interphalangeal (DIP). All three joints are similar in index, ring, middle, and pinky fingers, and the thumb only has MCP and interphalangeal (IP) joints. The exoskeleton is driven through motors that transmit the motion to the cables connected to the fingers.

5. RAT EVALUATION PROTOCOLS

This section presents the clinical protocols for robotic rehabilitation used in the selected studies. These protocols are performed by the patients in order to evaluate the clinical trials and treatment results. A quick overview will be presented for some of the selected devices. Table 2 summarizes the fundamental features and the followed clinical assessment for each of the selected robotic devices. The studied clinical trials varied in the determined treatment duration for each device as shown in bar chart Figure 4.

ArmAssist (AA) [34] depends on using active gravity-supported 2D plan which provides only support to the arm without actively moving it. In the selected clinical trial, AA was providing virtual games with different levels of difficulties that requires the shoulder to perform abduction and adduction movements and for the elbow to perform flexion and extension. The outcomes were then evaluated using foundational model of anatomy (FMA) motor score, WolfMotor function test (WMFT), and barthel index (BI). FMA scale measures the degree of synergistic movements for the targeted upper limb. WFMT scale uses functional and timed activities to evaluate upper extremity performance.

ArmeoSpring has a working principle based on weight counterbalancing. The device supports the weight of the upper limb via the attached springs. ArmeoSpring records the kinematics of upper limb movements, as well as other parameters as resistance and strength [54]. The device is designed for stroke recovering patients and CP children as it is proved through clinical application to improve upper limb movement quality. The results of using the device are measured using BBT and MAUULF. The first scale measures the gross in manual dexterity, and the second scale specialized for children with neurologic disorder to evaluate the performance of upper limb movement. Another clinical study done on stroke patients used multiple other clinical evaluation scales such as MAS which include nine subjects and scale from zero to six to evaluate performance of hand movements, upper limb functions, and advanced hand activities.

REAPlan operates based on the received from force sensors and position feedback. The device then provides the required assistance to the child's hand. The assisting force has two main types: a lateral interaction force Flat, and longitudinal interaction force Flong. The lateral force helps the patient follow the reference trajectory by increasing the stiffness coefficient Klat which corresponds to the amount of the provided lateral assistant. Flong helps the patients to move at reference velocity by changing the equivalent damping coefficient Clong. Clong has direct relation with Flong and that corresponds with the smoothness of the movement.

Table 2. Fundamental features of the selected clinical studies

Robot Device	Mean Age	Clinical Assessment	Results
ArmAssist	65.5	FMA, WMFT, BI	Significant improvement in FMA and WMFT. No considerable improvement in BI.
ArmeoSpring	59.2	WMFT	Significant improvement in WMFT for proximal arm functions.
ArmeoSpring	54.6	MI, FM, MAS, MFT, WMFT	Significant improvement in Fm and MI for all functions. No changes in muscle tone in FMT, WFMT, and MAS scales.
ArmeoSpring [41]	13.3	BBT, MAAULF	Significant improvement in BBT for exergame performance. No considerable improvement in MAAULF.
REAPlan [36]	8.0	QUEST, MAS, BBT	Significant improvement in manual upper dexterity in all the scales.
Gloreha-hand	68.9	NIHSS, BI, MI, VAS, QuickDASH	Significant outcomes in QuickDASH, and VAS scales. Moderate improvements in BI, MI, and NIHSS
InMotion 2 [53]	31.0	FMS, MAS	Significant outcomes in FMS. No considerable changes in MAS.
InMotion 2 [39]	61.0	FMS, SIS	Increase in motor function in FMS, yet it decreased at the end. Significant scores increase in SIS.
InMotion 3 [42]	64.4	FMS	Movement speed improved in FMS.
NJIT-RAVR	8.5	MA	Overall percentage score increases in MA.
Novint Falcon [40]	8.5		Enhancement in movement quality. No complaining about pain during the process.
CHARMin	12.1		The subjects stated the device was comfortable. No pain complaints were stated.
YouGrabber	58.5	MAL, BBT, Fatigue severity score	Significant improvement in MAL.
YouGrabber	65.0		Improvement in arm functions.
Dexo-hand	55.5	MAS, ROM	Significant improvement in joint movements.

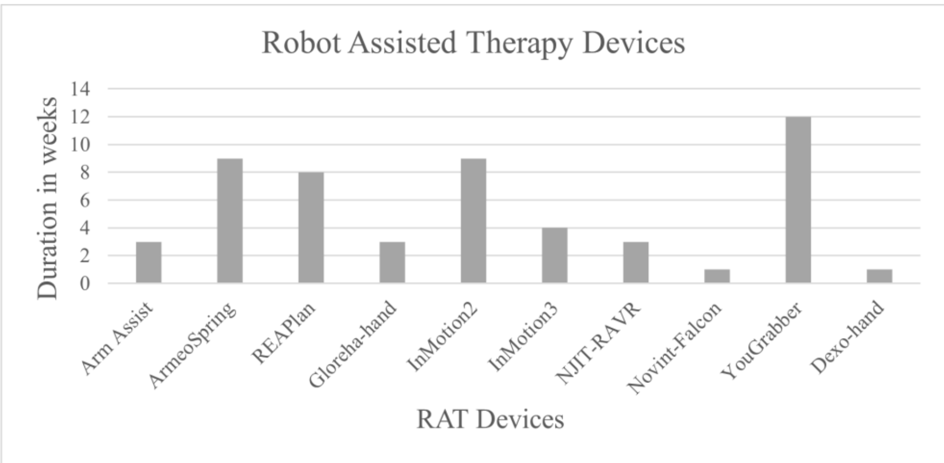

Figure 4. Treatment duration for the selected robotic devices

6. CHALLENGES AND FUTURE STUDIES

The first consideration drawn from this review is that using smart robotic devices in the rehabilitation process is an emerging field that requires more effort and focus. The fact that Cochrane Library has multiple recent systematic reviews that include clinical trials of RAT for stroke patients, proves the importance of the field [55]–[57]. Despite of the great attention drawn to RAT for sensorimotor defects, the majority of robotic devices were designed for adult patients recovering from chronic stroke [58]. The option for adjusting the devices for children with neuroplasticity is quite limited, despite the proof that RAT will achieve better results with younger patients [59]. The main target for robotic devices in rehabilitation was to enhance motor learning and to develop control algorithms to promote neuroplasticity caused by neurologic injury [60]. The non-motor aspect during the rehabilitation process is limited to the user's motivation and involvement in the therapy session [61]. Those factors can affect the result and the quality of the rehabilitation process directly, hence VR environments and tasks are needed. A variety of video games and playful tasks motivates both the physical and sensorimotor involvement that results in faster neurodevelopment [62], [63].

Regarding neuroplasticity, the other interesting aspect is diagnosis of sensorimotor defects in children [64], [65]. For adults, the diagnosis can be concluded with a minimum value of uncertainty, however; in children, it requires appropriate assessment methods to detect the problem [66], [67]. For example, CP in children can be observed during the early stages of life based on the spontaneous movements of the infant yet detecting the stage and the level of motor damage cannot be known for sure until later [68]. Another result that emerged from the selected studies, is the consequences of early intervention of RAT in different cases of neuroplasticity. The intervention using active tasks, social and environmental engagement influence the neurodevelopment process positively [69], [70].

According to selected feasibility studies, applying RAT in clinical rehabilitation processes results in more physical resources which is costly to provide intensive sessions to promote motor functions [71], [72]. Considering the RAT as an optimal solution, that will decrease the overall cost as well as providing high quality therapy for shorter periods. In [73], selecting devices that require shorter set-up time and provide more efficient treatment was the sustainable solution to use RAT in specific rehabilitation centers. According to [74], the feasibility in using RAT was the ability of the device to be adaptive and patient specific. The adaptivity can be achieved using different training modes that suit each patient as well as encourages more engagement in the training.

Regarding the feasibility of RAT, two before and after feasibility trials besides the studied clinical trials were selected to study motor learning. In [50] thirty-five ABI survivors were divided into three groups; group A received only RAT, group B received RAT besides conventional therapy, and group C received only conventional therapy. The therapy included training for hand gestures and range of motions of elbow and shoulder. The results showed the occurrence of motor learning in the three stages: skill acquisition, generalization, and retention. In the first study, the evaluation showed an increase in the grey matter in five brain areas which enhanced the motor skills [75]. In [76] the trial focused on reaching abilities in the shoulder and elbow using RAT. The results showed major improvement in skill acquisition for the elbow and shoulder after two weeks of sessions.

7. CONCLUSION

The present review was reached through studying the number of nine systematic reviews, fourteen articles developing RAT devices, and seventeen articles for clinical trials. The conducted review emphasizes the different control strategies of fourteen robotic devices used for upper limb rehabilitation. Training assessments and protocols associated with the tested devices showed faster and better improvements for children and adults with neuromotor disorders. However, the discussion about the optimum control approach or device type remains open for more clinical trials to determine the most efficient control strategy and assessment protocols. The results concluded from this review is that adaptive and adjustable robotic device is still open for research and trials. In addition, the design of virtual tasks is an emerging aspect in RAT that can improve the whole process of recovering motor functionality.

InMotion 2 uses repetitive massed reaching for the rehabilitation process. The device is based on impedance control strategies. The device provides different levels of assistance based on the signals from EMG on the muscles, speed of end-effector movement, and the time taken to finish tasks. The measured parameters are used to adapt and adjust the rehabilitation based on the capabilities of each patient. In the selected clinical trials, InMotion 2 and 3 were used for CP, stroke, and ABI patients. the results of the robotic therapy were evaluated through MAS, functional mobility screen (FMS), stroke impact scale (SIS).

NJIT-RAVR's working principle is based on weight counterbalancing assistance and the performance of the patient. The controller can be adjusted to a certain threshold and the assistance is provided through haptic effects. The assistance provides the needed support to push the hand to the desired target if the speed is lower than the threshold. The studied clinical trial tested the device with children with CP along with providing an interactive virtual environment to decrease motor impairments. This addition was proved to decrease the patients' stress level and increase motivation during the rehabilitation process. Novint Falcon has impedance-based control strategy that allows the child's arm to move freely to reach the target as well as providing the needed resistance to push the arm to follow the path. The clinical trial trains the abduction/adduction and flexion/extension of CP patients.

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