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Self-Assisted Upper Limb Rehabilitation Devices, A Comprehensive Review

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Abstract: For the purpose of Upper Limb rehabilitation, the use of mechanical and robot assisted rehabilitation the rapiesarenota new concept. Such system sallow patients to perform the rapies with minimalorno assistance. The complexity of such systems vary from being as simple as a custom made bars to highly so phisticated roboticexo skeletons. The advancement of robotics and motor control mechanisms has fueled interest in this domain and we see a lot of development in the field of robot assisted rehabilitation with in a comparatively short span of time. This paper presents a review and tabulates the results of a few selected rehabilitation devices. The devices include mechanical as well as intelligent robotics based rehabilitation devices.

Keywords: Robotic devices, Self-Assisted Rehabilitation, Upper limb.

1. INTRODUCTION

Self-assisted rehabilitation devices target those patients who are capable of carrying out upper limb rehabilitation routines themselves by using less impaired limb to control the most impaired one. The main advantage of self-performed rehabilitation exercises is that they allow a patient to vary thetrainingintensityandfrequencyofaparticularroutineasp ertherequirement and capability and hence increasing the effectiveness of that exercise in rehabilitation. The more robust and ergonomic a system is, the more effective will be there habilitation routines which in turn improve the recovery time of the patient. A patient with limited upper arm mobility can easily and efficiently operate a particular rehabilitation system only if it is:

a. Lightweight.
b. Easy to integrate with the target limb(s).
c. Includes all necessary safety mechanisms.
d. Causes minimum to zero hindrance to patient's body movement (other than the target limb(s)).

With the advancement of fabrication techniques and materials, modern rehabilitation devices become increasingly user friendly in terms of installation/ integration, training and safety. For example, modern systems that are targeted for aiding flexion and extension of fingers of a human hand, are capable enough to do so for each finger individually as well as for all of them simultaneously.

2. REHABILITATION DEVICES SELECTED

Depending up on the type of recovery and the target muscle group, numerous rehabilitation systems have been developed each having their own method of operation. These systems include both mechanical devices and robotic devices. The systems focused for study and analysis are discussed briefly as follows:

A. Mechanical manual operated Devices

a. Bilateral arm training with rhythmic auditory cueing (BATRAC)

Bilateral arm training with rhythmic auditory cueing (BATRAC) consists of two T-bar handles mounted on a plane with minimum friction. The training procedures involves pushing or pulling of the bar perpendicular to the user using both arms simultaneously (in- phase) or alternatively (anti-phase).

b. Reha-Slide Duo

Reha-Slide Duo has the similar working mechanism to that of BATRAC except that the plane on which the handles are mounted can be inclined / titled to a maximum of 20°. More over the exercise (pushing or pulling) is made more effective by adding brake elements make of rubber which can offer a maximum brake force of 80N.

c. Active-passive bimanual movement therapy (APBT)

APBT is custom made to target the symmetricorneara symmetric (maximum60°) coordination of wrist movement (extension and flexion) in horizontal plane. The system consists of a unit that couples two manipul and a using a connection of crankshafts.

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B. Robot Automatic Devices

a. The Mirror Image Movement Enhancer (MIME)

The MIME is a6-DOFs robot supports the shoulder and elbow function with the help of actuators. The arm of the patient which is less affected is connected to apposition digitizer while the most affected arm is bound to a customized harness restricting movement and is connected to the movement controller. With the help of position digitizer, the patient can practice a wide (Burgar *et al.,* 2000). Buschfort, *et al.,* 2010). variety of complex movements because of 6-DOF srobot.

b. The bilateral force-induced isokinetic arm movement trainer (BFIAMT)

The BFIAMT is a device quite similar to Reha-Slide with load cells to detect the push or pull movement while the servo–motors are used to support or resist the movement for exercise purposes. The push and pull forces are detected by load cells, (Chang, *et al.,* 2007). (Cordoetal, 2009). (Duret, *et al.,* 2015). while the corresponding force is provided by the servomotors.

c. The In Motion 2.0 Arm robot

The In Motion robot is the result of a project which was aimed at creating commercial version of MIT–Manus robot. The MIT–Manus was designed and developed by Massachusetts Institute of Technology (MIT) for rehabilitation of the subjects which are in acute or sub–acute phase of stroke recovery. The system consists of a robot with 2– DOF translational movement capability. The robot focuses on the shoulder and wrist (flexion/extension).

d. Bright Arm™ upper extremity rehabilitation system

The Bright Arm rehabilitation system consists of a table motorized table with a mechanical setup for fore arm support, two over head digital cameras and a high definition LCD screen. With the help of LCD screen, customized games can be played by the patient which present tasks to be completed. The over head cameras monitor the movement of the patient and record them for study purposes.

e. Robot-assisted rehabilitation using myoelectric control on upper limb motor recovery

The system consists of a mechanical system with 1–DOF to aid the wrist flexion/extension. The actuation system consists of aluminum splint, torque sensor and movement is provided by Direct Drive AC servomotor. (Lum, *et al.,* 2002) (Rabin *et al,* 2012). (Song, *et al,* 2013). (Stinear, *et al,* 2004). The actuation signal is obtained by means of EMG signals generated by the user. The generated signals are read and the corresponding action is provided by the actuating mechanism.

f. The Hand Wrist Assistive Rehabilitation Device ('HWARD')

The HWARD system is a robotic device with 3–DOF which helps in grasping and releasing functionality of a human arm. (Takahashi, *et al.,* 2005) (Whitall, *et al.,* 2000).. The methodology includes the grasping/releasing exercises in which, after initial effort from the patient, the robot provides the required force to complete the exercise (if necessary).

g. Assisted Movement with Enhanced Sensation (AMES)

This system consists of a robotic device which can offer rehabilitation exercises for ankles as well as fingers and wrists of a human hand by vibrating the tendons of corresponding muscles. The system automatically applies the flexion/extension force and angle to the required joint while the user only has to assist the working of the device.

3. RESULTS ANDDISCUSSION

The analysis of all the systems studied are summarized as follows. The summary is based on type of device (mechanical/robotic) and the focus of different aspects (target muscle groups, commercial availability, ease of use etc.). The analysis of mechanical devices under consideration is tabulated in **(Table-1) (Fig-1):**

Table1: Mechanical devices

S. No	Device Name	Target Muscle group	No. of testing/ training phases	Total training/ testing phases	Percentage of Fugl-Meyer scores improved after final phase (overall)	Percentage improvement per week
1	*BATRAC*	Shoulder and Elbow	3 (Pre-test, post-test and retention)	14 weeks	26%	1.86%
2	Reha-Slide Duo	Shoulder and Elbow	1 (Training)	3 weeks	27.8%	9.27%
3	APBT	Wrist	3 (T1, T2 and post intervention)	4 weeks	18.67%	4.67%

The above mentioned analysis are summarized as follows:

b. Robotic devices

Robotic devices are much complex systems as compare to mechanical systems. The complexity of the robotic systems is because of the sophisticated method of operation. The complexity of these devices on the other hand ensures increased capabilities such a sufficient control mechanism, increased patient's safety, higher rate of recovery and much more increased durability and flexibility as compared to mechanical systems.

Table2: Robotic Devices

S. No	Device Name	Target Muscle group	No. of testing/ training phases	Total training/ testing period	Percentage of Fugl-Meyer scores improved after final phase (overall)	Percentage improvement per week
1	MIME	Wrist	1 (training)	24 weeks	6%	0.25%
2	BFIAMT	Wrist	3 (Pre-test, post-test and retention)	8 weeks	27.45%	3.43%
3	In Motion 2.0	Shoulder and Elbow	After equal duration of training	16 weeks	49%	3.06%
4	Bright Arm™	Shoulder and Elbow	3(Pre-training, post-training and follow up)	6 weeks	18.2%	3.03%
5	Robot assisted rehabilitation using myoelectric control	Wrist	1(Training)	5 - 7 weeks	17.12%	2.45%
6	HWARD	Wrist and fingers	1(Training, 4 Assessments)	3 weeks	23%	7.67%
7	AMES	Fingers	1 (Training)	24 weeks	46.4%	1.93%

The analysis of robotic devices under consideration are tabulated in **(Table-2) (Fig-2):**

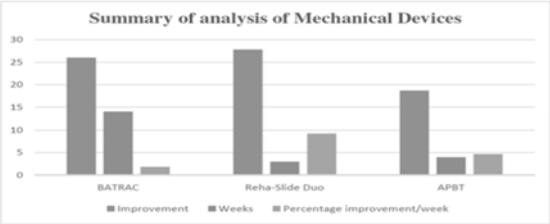


Fig The above mention analysis is summarized as follows:

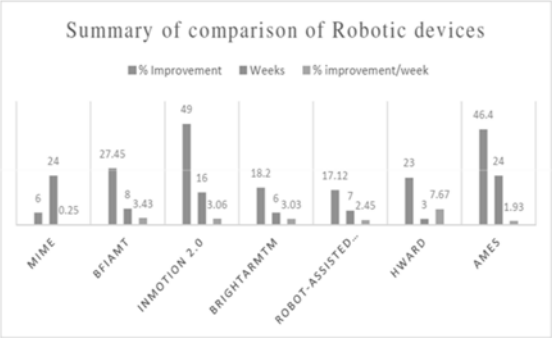


Fig-2: Summary of Analysis of Robotic devices

From the summary above, it is noted that none of the devices address every necessary criterion. In terms of improvement v/straining period, In Motion 2.0 and AMES can be considered best devices but it is also noted that in terms of percentage improvement per week, the Hand Wrist Assistive Rehabilitation D e v i c e (HWARD) is the most efficient system achieving highest percentage of improvement in the smallest amount of time.

The **(Fig-2)** shows that by using (HWARD) for extended periods, we can achieve the fastest upper limb recovery targeted for wrist and fingers. romthe summary above, it is noted that none of the devices address every necessary criterion. In terms of improvement /straining period, In Motion 2.0 and AMES can be considered best devices but it is also noted that in terms of percentage improvement per week, the Hand Wrist Assistive Rehabilitation D e v i c e (HWARD) is the most efficient system achieving highest percentage of improvement in the smallest amount of time. The **(Fig-2)** shows that by using (HWARD) for extended periods, we can achieve the fastest upper limb recovery targeted for wrist and fingers.

4. CONCLUSION

For the purpose of upper limb post stroke therapy, numerous studies, analysis and devices are carried out. The aim of such devices is to devise a system with highest recovery rate with in limited amount of time. Also, the device should also be flexible enough to accommodate all necessary muscle groups namely: finger, wrist, elbow and shoulder, to provide maximum upper limb rehabilitation using a single device. In the current paper, numerous devices have been studied and analyzed in terms of performance matrices mentioned above. After the study, it is concluded that though devices are improving more and more in terms of recovery rate and training time, the devices with comparatively large recovery rate are focused to a limited no. of muscle groups. So then of target muscle groups should be increased so as to cater wide range of post stroke patient categories. Amongst the mechanical devices Reha Slide duo is the most efficient device. But being a mechanical system, introducing more

capabilities to the device will increase the complexity and bulkiness of the system which may in turn prove difficult for old age subjects/patients to operate the device. The Robotic devices allow us to design systems with more and more flexibility with comparatively low complexity. From our study of Robotic devices, we come to know that the HWARD device is the most efficient device for upper limb rehabilitation having the highest percentage of recovery per week.

The pneumatic actuation combined with computerized control in HWARD allows the device to perform tasks with level of difficulty as per requirement. The placement of precision air regulators allows controlled entry of the air in to the system thus limiting the amount of maximum force being applied to the patient's limb. The man in feature of HWARD system is back drive ability, meaning that the patient can manually move the mechanism of the device when it is in passive state. So the device will not hinder the natural movement of the patient even when the device is providing assistive forces.

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