

Tele-rehabilitation: present and future

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Summary. During the last decade we assisted to relevant progress in rehabilitation studies and in technological development. From the combination of these issues rises the tele-rehabilitation – a subfield of telemedicine consisting of a system to control rehabilitation “at distance” – as an actual possibility of application and a promising development in the future. The present paper offers a short review of the state of the art in the field of tele-rehabilitation, with a special focus on upper limb tele-rehabilitation. The experience is also briefly reported of the preliminary application of the H-CAD (home care activity desk) system and the HELLODOC (Healthcare service linking tele-rehabilitation to disabled people and clinicians) tele-rehabilitation service, conducted by the authors within two European projects in the period 2003-2005 and 2005-2007 respectively.

Key words: stroke, multiple sclerosis, traumatic brain injury, tele-rehabilitation, upper limb, home rehabilitation.

Riassunto (*Teleriabilitazione: situazione presente e prospettive future*). Nel corso dell'ultima decade si è assistito a un rilevante avanzamento in ambito riabilitativo, e a un concomitante progresso tecnologico. Dalla combinazione di questi due fattori emerge il successo della teleriabilitazione – un campo della telemedicina costituito da sistemi per il controllo dei percorsi riabilitativi a distanza – che va intesa come una potenziale risorsa applicativa attuale, e un promettente sviluppo per il futuro. Il lavoro qui di seguito esposto offre una breve revisione critica dello stato dell'arte nel campo della teleriabilitazione, con specifico riferimento alla teleriabilitazione dell'arto superiore. Si riportano anche, brevemente, le esperienze degli autori in relazione al sistema per teleriabilitazione H-CAD (*home care activity desk*) ed alla sua successiva implementazione come servizio di teleriabilitazione HELLODOC (*healthcare service linking tele-rehabilitation to disabled people and clinicians*). Le esperienze sono state condotte nell'ambito di due progetti europei, il primo nel periodo 2003-2005, il secondo nel periodo 2005-2007.

Parole chiave: ictus, sclerosi multipla, trauma cerebrale, teleriabilitazione, arto superiore, riabilitazione domiciliare.

INTRODUCTION

During the last decade we assisted to relevant progress in rehabilitation studies and in technological development. From the combination of these issues rises the tele-rehabilitation – a subfield of telemedicine consisting of a system to control rehabilitation “at distance” – as an actual possibility of application and a promising development in the future.

The rehabilitation studies demonstrate that in order to increase the efficacy, the rehabilitation program should: start as soon as possible; be intensive as much as possible; be prolonged during the recovery phase at home.

On the other hand the technological field offers now robotic or automated machines, electronically

controlled, that are suitable to be used locally to increase the intensity of rehabilitation and to introduce new exercise paradigms. These systems might be used also at distance and controlled via telecommunication systems.

Many initiatives have been taken to develop telemedicine applications in rehabilitation. Published studies and current experiences show that tele-rehabilitation mainly addresses:

- patient's functional assessment;
- patient's clinical management at distance;
- management of rehabilitation programs by remote;
- selection of the needs of the patient or the caregiver;
- tele-consulting;
- education of professionals and caregivers.

Patient assessment has been one of the first application [1-3] as well as patient clinical management [4, 5]. The telehealth systems have been also used to manage rehabilitation programs remotely. In the area of physiotherapy, examples of application are the Rutgers Arm [6], virtual reality systems [7], web-based libraries of status tests, therapy games, and progress charts, including a low-cost force-feedback joystick capable of assisting or resisting movement [8].

The above applications, together with other telemedicine applications in rehabilitation, are considered promising but the evaluation of currently existing telemedicine applications studies is still in its early stages. No large-scale clinical trials are available. DeChant *et al.* (1996) propose a four-staged approach for telemedicine evaluation addressing both narrow focused and comprehensive evaluations [9].

In this review the authors discuss the perspectives of rehabilitation in relation with present and future applications of tele-rehabilitation systems. Main points of discussion are:

- new perspectives in rehabilitation;
- robotics and new opportunities in rehabilitation;
- tele-rehabilitation;
- the effectiveness of tele-rehabilitation;
- future of tele-rehabilitation.

An example of a tele-rehabilitation application is also reported and briefly discussed which deals with H-CAD (home care activity desk), an activity instrumented desk for upper limb rehabilitation. The desk was part of a tele-rehabilitation service the authors implemented and validated within the European project frame HELLODOC (Healthcare service linking tele-rehabilitation to disabled people and clinicians).

NEW PERSPECTIVES IN REHABILITATION

Recent findings in neurophysiology of nervous system showed new perspectives in motor control and, consequently, in rehabilitation programs. In particular, the motor plan of frontal cortex is influenced by the environment and the context where the action takes effect [10]. In fact, in prefrontal cortex, there are areas that facilitate or inhibit the motor plan depending on the significance of the object the upper limb is going to reach [11]. Furthermore, there are areas which are sensitive to replicate the same action performed from another person. These neurons are named "mirror neurons" [12]. They are activated from both human and robotic action [13].

Based also on these observations, new rehabilitation paradigms have been developed as *task oriented therapy* [14]. Such a therapy is based on exercises inserted on meaning context through repetitive actions [15, 16]. The training can be carried out also without active movement, by thinking to the movement without activating muscles. This technique is named "mental practice" and it has been shown to be effective [17].

Another emerging issue is the importance of the intensity of treatment. Adding more treatment can

induce a better recovery especially in the lower limb but also in the upper limb [18, 19].

In the past years the chronic phase of recovery has been considered as a static period, according with the old conception of a "static brain". In recent years, several studies showed that the brain is continuously remapped according with the activation of brain areas [20]. The inactivity leads to a "learned non-use" with consequent impaired function of specific areas [21]. During the chronic phase any applied exercise increases function, thus indicating that in presence of an impairment there is indeed the need to maintain an adequate activity [22].

In rehabilitation one of the main constraint related to the effectiveness of the intervention is the setting where the program is applied. In acute phase of stroke patients the stroke units, characterized by an adequate level of rehabilitation, do decrease the mortality and the disability of the patients [23]. During the post-acute phase, the emerging role is at present that of the community occupational therapy, mainly performed at home [24]. Home rehabilitation has a critical role to finalize the potential recovery and to maintain the reached function. Special relevance have the exercises done with the physiotherapist and the occupational therapist [25, 26], supervised or self-done [27].

Summarizing, the main new issues in rehabilitation which form the basis for the tele-rehabilitation approach are:

- intensity of exercises;
- type of exercise;
- a new view of chronic condition;
- movement facilitation task;
- constraint induced movement;
- home rehabilitation.

ROBOTICS AND NEW OPPORTUNITIES IN REHABILITATION

Robotics is potentially related to tele-rehabilitation because each electronically controlled system might be remotely controlled and send data at distance. A series of studies in rehabilitation showed that robotics could be useful for the recovery as both alternative or integrative system to the classical physiotherapy [28], main limit being that most of robotic systems are not easily transportable, due to their size and weight. Most of robotics applications are focused on upper limb rehabilitation through different systems [29-32]. This type of intervention improves, at short- and long-term, the motor impairment of the paretic shoulder and elbow in sub-acute and chronic patients with no consistent influence on functional abilities. Furthermore, it seems to improve motor control more than conventional therapy [33].

Robotics is becoming promising for lower limb, too, with similar perspectives as for upper limb [34-36].

Another interesting application in rehabilitation and tele-rehabilitation is the interaction of hu-

mans with machines (HMI). Brain-machine interfaces (BMI) form a special subclass of HMI and, so far, have been used as a communication means for people who have little or no voluntary control of muscle activity. The BMI is an augmenting interface for domotics, rehabilitation and assistive robotics. Simple rehabilitation devices can be easily controlled by means of BMI technology. Prosthetic hands and wheelchairs as well as the head and the trunk can be controlled by means of BMI. In general, the BMI system could usefully be thought as a base for tele-rehabilitation applications.

Virtual reality (VR) is becoming a new approach in several rehabilitation fields [37, 38]. So far it has been utilized in upper limb rehabilitation [39], physical and learning disability [40], cognitive impairment [41], vestibular rehabilitation [42].

In a recent review about VR used in motor rehabilitation, several areas of application have been identified such as stroke rehabilitation – upper and lower extremity training, spatial and perceptual-motor training – acquired brain injury, Parkinson's disease, orthopaedic rehabilitation, balance training, wheelchair mobility and functional activities of daily living training. From the analyzed studies four major findings emerged: 1) people with disabilities seem to be capable of motor learning within virtual environments; 2) in most cases people with disabilities transfer those movements learned in VR to real world equivalent motor tasks; in some cases they even generalize to other untrained tasks; 3) few studies compared motor learning in real versus virtual environments, but in all cases some advantage for VR training has been found; and 4) no occurrences of "cybersickness" in impaired populations have been reported during those experiments in which VR has been used to train motor abilities [38].

Virtual reality shows significant advantages when applied to rehabilitation. These advantages include patient motivation, adaptability and variability based on patient baseline, transparent data storage, online remote data access, economy of scale, reduced medical costs. Challenges in VR use for rehabilitation relate to therapists' lack of computer skills, lack of support infrastructures, initially expensive equipment, inadequate communication infrastructure for tele-rehabilitation in rural areas, and patient safety concerns [43].

Applications of robotics and virtual reality were found to be very good candidates to be moved on tele-rehabilitation, because the instruments are usually portable [44] and might address most relevant issues of tele-rehabilitation – intensity and type of exercise, management of chronic condition, movement facilitation tasks, constraint induced movement, home rehabilitation.

TELE-REHABILITATION

The development of telecommunication technologies now allows to think to tele-rehabilitation as a reliable system to provide a series of rehabilitation-related services.

Several new issues contribute to render the tele-rehabilitation an appealing application. Among them the need of intensive rehabilitation, rehabilitation in chronic phases, and the effectiveness of home setting could lead the tele-rehabilitation towards a rapid development.

So far the tele-technologies have been used in related fields of rehabilitation – patient's functional assessment; patient clinical management at distance; management of rehabilitation programs; selection of the needs of the patient or the caregiver; tele-counseling; education of professionals and caregivers. First uses have been the tele-assessment in psychiatric field [45], the evaluation of the outcome of rehabilitation programs [3], the assessment of patient's needs [46-49].

Tele-rehabilitation may offer major benefits, particularly in terms of improved communication and access to health care over distance [50]. Increased communication allows information and medical data sharing with consequent advantage for patients, family, caregivers, clinicians, and researchers [51]. Access to health care over distance offers people living in remote areas the possibility to access to health care services supporting the families caring low responsive patients [52]. It also offers the possibility of early diagnosis, start of therapy under acute conditions, shortening of in-hospital period, continuous monitoring of people at risk, overall time and cost reduction.

For the specific application of tele-rehabilitation, the first experiences consisted of case studies in physiotherapy. They are briefly described here below:

- a connection to convey information about a stroke patient's movement capacity was used. During 8 weeks of physical tele-rehabilitation, the patient improved in several aspects of impairment and functional ability [53, 54];
- tele-rehabilitation of upper limb after stroke was applied, through a system including a web-based library of status tests, therapy games, and progress charts, which can be used with a variety of input devices, including a low-cost force-feedback joystick capable of assisting or resisting movement [8];
- the application of physiotherapy over distance in a single case of a person with a severe traumatic brain injury living 100 miles from the rehabilitation centre was studied [55]. The patient showed improvements in physical functioning and neuropsychological status.

Virtual reality techniques and high speed networks create an environment which allows clinicians and technical staff – located at a distance from the patient – to interact with 3D visualisation of patient's specific data [56].

Virtual reality with haptic interfaces and networked PCs was applied in orthopaedic rehabilitation. Burdea *et al.* reported on the application of the Rutgers & Stanford system for rehabilitation of hand, elbow, knee and ankle impairments, which al-

lows to provide exercises to the patient while being monitored remotely by therapists [57]. Preliminary results with the Rutgers Ankle system indicated that the system works well as a diagnostic/monitoring tool and that the subjective evaluation by patients was very positive [58].

A Cyber-Glove and Rutgers Master U-ND force feedback glove, which allows user-interaction with a virtual environment was also used in stroke rehabilitation. The program consisted of 4 rehabilitation routines, each designed to exercise one specific aspect of hand movement: range, speed, fractionation or strength. A pilot clinical trial using the system with three chronic stroke patients showed improvement on most of the hand parameters over the course of the training [59].

An internet-based virtual rehabilitation centre that provides rehabilitation, education and support services for traumatic brain injury patients was implemented and used. The modules of the virtual reality system consisted of tools for the assessment of reaction time and communication capabilities, and functional modules. The patients with greater cognitive impairment required more trials to acquire the requested skills. Also language processing appeared to be related to how effectively participants learned about the use of the virtual rehabilitation system [60].

Cognitive rehabilitation is a potential field of application for developing tele-rehabilitation systems, especially those using virtual reality [61]. This approach was mainly used for the recovery of traumatic brain injury (TBI) [55]. A series of single cases in TBI tele-rehabilitation shows a certain improvement, but its efficacy still remains to be proved with studies including an adequate number of patients [62].

Speech therapy was provided in few tele-rehabilitation experiences. The main findings of a relevant pilot study were that the approach is feasible, even though the protocols deserve a certain improvement [1].

The upper limb motor rehabilitation is one of the main fields of application in stroke patients; it basically exploits instrumented gloves [63], facilitating systems or virtual reality.

The constraint-induced movement therapy (CIMT) consists of a forced use of upper limb to improve the recovery and contrast the “learned non-use” [64]. Recently, this paradigm was implemented in the tele-rehabilitation system automated constraint-induced therapy extension (AutoCITE). In a pilot study, improvements were comparable in size with those previously reported for participants who received equal intensities of directly supervised AutoCITE training or standard one-on-one constraint induced (CI) therapy without the device [65].

A simplified tele-rehabilitation method is to use the web to effectively apply the CIMT [66].

A virtual reality system was recently developed which is based on a 3D motion tracking system (Polhemus 3Space Fastrack, Vermont, USA) to capture the patient’s arm movements by means of a magnetic receiver and to transmit it to the PC inter-

face. The receiver is attached to a real object (end effector) grasped by the patient, or to a glove directly worn by the patient himself [67].

A specific software package was developed and used in tele-rehabilitation (Massachusetts Institute of Technology, USA) for remotely managing the patient’s PC console and for processing motion data derived from the patient’s arm movement.

With the remote workstation, the operator creates the sequence of virtual exercises and supervises the patient’s execution. Virtual tasks mainly consist of simple movements which simulate activities of daily living, i.e., pouring water from a glass, using the hammer, posting an envelope into a mailbox slot, circumnavigating a donut, etc. The complexity of the task is determined by the physiotherapist, depending on patient’s motor deficit and the degree of motor recovery. The tele-rehabilitation system used in the pilot study consisted of two PC workstations settled at patient’s home and at the rehabilitation hospital respectively. The patient moved the real object – envelope, carafe, hammer – on virtual environment and followed the trajectory of the corresponding virtual object on the computer screen. During performance, the patient could visualize in real time not only his movement but also the correct trajectory that he had to execute with the end effectors, to meet the constraints of the exercise as it was designed by the physical therapist. The pilot study was carried out on 5 stroke patients. They underwent the tele-rehabilitation program for 4 weeks. The therapy significantly improved the Fugl-Meyer mean score, the mean duration and the velocity of the movements, but not the functional independence measure scale score [7].

The H-CAD system: an activity desk for rehabilitation of the upper limb

The H-CAD project was sponsored by the EC in the period 2003-2005. It dealt with the development of a tele-rehabilitation system to enable patients affected by multiple sclerosis (MS), stroke (S) or traumatic brain injury (TBI) to perform upper limb rehabilitation treatment at home. An activity desk was purposely designed to allow the patient to perform exercises at home, to monitor patient’s performance, and to transmit the monitored data to a hospital environment. There was also the possibility for the patients to interact with the therapist through a tele-conference system.

Feedback, and parameter measurement had two main purposes. The first one was to immediately inform the user about the performance of a specific task. The second one was to allow the therapist to remotely check how many attempts have been made to perform a certain task and how many of these attempts have resulted in successful task completion.

The H-CAD system and the implemented exercises were based on the concept of task oriented therapy. In order to apply this paradigms the instrumented

desk was designed to allow upper limb movements similar to those requested during normal daily activities (Table 1).

A pilot study was performed in two clinical centres, namely in the Guttmann Institute (Barcelona, Spain) and UORIN (Trevi, Italy).

The experimental phases were performed in 2 different settings:

- tests in a hospital environment, where healthy volunteers and a series of MS, S and TBI patients were recruited to test the system;
- tests at home, with a single study design for a series of patients.

In hospital, main purposes were:

- to check the reliability and feasibility of use of the H-CAD system including the desk and com-

munication system in patients affected by MS, S and TBI;

- to obtain reference data from pathological subjects;
- to measure the effect of the exercise in a hospital setting.

At home, main purposes were:

- to check the reliability and feasibility of use of the H-CAD system at home, in patients affected by MS, S and TBI;
- to measure the effect of the exercise in a home setting;
- to determine the acceptance of the system by both patients and caregivers.

The in-hospital experiment showed that H-CAD system had really good acceptance and good general

Table 1 | List of H-CAD 8 home care activity desk exercises

Task name	Action	Parameter	Movement components
Key	Pick up a key Insert in key-hole on shelf Turn 360° left & right	Number of attempts for key insertion Rotation amplitude Task duration	Reaching Precision Pro/supination
Cube	Pick up pieces Assemble cube (6 pieces) Fit in form on shelf	Cube assembled Task duration	Reaching Grasping Mobility Co-ordination Bimanual task
Light bulb	Switch light on & off Unscrew low socket Screw in upper socket Switch light on & off Unscrew upper socket Screw low socket Switch light on & off	Light bulb in socket Task duration	Reaching Dexterity Grasping
Book	Pick up from desk Hold against sensor on shelf Put book back on desk	Book position Task duration	Lumbrical grip Strength
Jar	Pick up from desk Hold against sensor on shelf Put jar back on desk	Position of jar Task duration	Hook grip Strength
Pencil	Pick up Write text Put pencil back	Number of characters written Task duration	3 point pinch grip Dexterity
Checkers	Pick up Place on board Put checkers back	Number of correct placements Task duration	Pinch grip Precision Mobility
Drawers	Open Close	Maximal amplitude Task duration	3 point pinch grip Hook grip Mobility Strength
Key-board	Type number sequence	Correct code Task duration	Push 1 finger Precision
Box	Pick up from shelf Put down on desk Put back on shelf	Box position Task duration	Reaching Grasping Bimanual task Strength

opinion. The worst scored characteristic of the H-CAD system was its aesthetic aspect.

As for the home-based tele-rehabilitation phase, the pilot study nine hole peg test values showed an improving trend from baseline to the end of home test. The analysis of data revealed a certain improvement in all tested participants. Trial limited length did not allow to know whether part of the improvement is sustained along time or motor function returns to baseline.

A further development of the H-CAD system was used in the HELLODOC project. HELLODOC is the acronym for “healthcare service linking tele-rehabilitation to disabled people and clinicians”. The project started on March 2005 as a 18-months European project co-financed by the European Community programme eTEN. It was successfully closed on February 2007 after a 6-months extension. The primary objective of the project was to validate the EU market – more specifically in Italy, Spain, The Netherlands and Belgium – for a home-care service. Main aim of the service was to extend the rehabilitation treatment at patient’s home under close supervision of the hospital. The tele-rehabilitation service was mainly addressed to neurological patients affected by MS, S and TBI. Basically, it consisted of two main apparatuses: an in-hospital based server and a portable unit – an improved version of H-CAD – to be installed at patients’ home.

The clinical effectiveness was investigated through a wide pilot study. 81 patients with chronic MS, S and TBI were recruited in all: 50 out of 81 received 1 month of H-CAD intervention, with one training session a day lasting 30 minutes for 5 days a week.

The overall satisfaction of both patients and therapists was high. The action research arm and the nine hole peg test, which were used as main outcome measures, proved the H-CAD system to be at least as effective as usual care. Maybe due to limited length and intensity of treatment, during the training month subjects improved on the individual H-CAD exercises but, as in the usual care group, the arm/hand function remained at the same level. An extensive description of the pilot study is accurately reported elsewhere.

THE EFFECTIVENESS OF TELE-REHABILITATION

Tele-rehabilitation is a quite recent field of basic research and clinical application. The first experimental studies only started few years ago. This short review focuses on 9 relevant studies to analyze the evidences of the effectiveness of tele-rehabilitation. Unfortunately, the studies included a small number of patients and the design is limited, since only 2 studies were randomized. One study was case-control and the other was observational, with or without intervention.

The first analyzed study was based on a tele-monitoring service to support frail elders. Patients were compared with a control group with same health problems and same age. The effect seemed relevant in terms of function, which improved in the intervention group [68]. Another observational study without specific intervention, emphasized the reliability of tele-monitoring approach [69].

The upper limb rehabilitation of stroke patients through virtual reality (VR) tools can be locally used to introduce new exercises; when applied remotely, it seems to be effective on improving the impairment without affect the function. The examined study was observational, non-randomized, and without a group of control; thus, the promising data should be confirmed with a larger trial [7]. Similar results with a similar VR paradigm were obtained in a further study [70].

The rehabilitation intervention from remote was proved at least as effective as the specific intervention of the therapist in a home setting [71]. Similar observation was reported in another study with different intervention. Chronic stroke patients trained with AutoCITE obtained similar results than the patients treated with a directly supervised program [65]. Similar results were found with different protocols of exercise in other studies [66, 72].

Most of the studies were carried out in neurorehabilitation field, but some research groups studied the effects of tele-rehabilitation in orthopaedics. Using an haptic glove, the recovery after hand surgery seemed to be facilitated [73].

From an overall analysis of the above studies we can conclude that there are not strong evidences about the efficacy of tele-rehabilitation due to the small size of the sample studied and the poor study design (*Table 2*). However, the tele-rehabilitation approach is promising, and the collected data show at least a trend towards a positive effect of such methodology.

FUTURE OF TELE-REHABILITATION: PEARLS, PERILS AND PITFALLS

Pearls

The tele-rehabilitation is a *work-in-progress* field where there is the opportunity to develop a lot of interesting rehabilitation paradigms according with the cost/benefit ratio.

One of the main opportunity is the possibility to increase the intensity and the duration of rehabilitation programs. Monitoring the patient at home via teleconferencing or/and applying robotic or electronic apparatuses to enhance training may allow to extend the time of the rehabilitation program and utilize the new opportunities provided from the new technologies. This opportunity induces the need to modify the organization of rehabilitation centers in order to provide this new service as a standard. To do that, a series of problems should be sorted out such as the accept-

Table 2 | Summary of research studies dealing with tele-rehabilitation

Study	Design	Intervention	Outcome measure	Results
Chumbler NR, Mann WC <i>et al.</i> (2004) [68]	Case-control	Frail elders-one that received care coordination via distance monitoring (home-telehealth) and one that received no intervention (pt = 111; c = 115)	IADL and FIM	Intervention group improved 2.2 points in IADL, 14.4 points in FIM motor scores, and 2.7 points in FIM cognitive scores compared to control group ($p < 0.0001$)
Piron L, Tonin P, <i>et al.</i> (2004) [7]	Experimental observational study	5 pt with stroke, virtual reality session at home guided from the therapist	Fugl-Meyer and functional independence measure scale	Improved the Fugl-Meyer mean score, the mean duration and the velocity of the movements, but not the FIM scale
Rintala DH, Krouskop TA, <i>et al.</i> (2004) [69]	Observational	57 wounds (39 ulcers, 19 amputation incisions) were evaluated by means of still photographs and skin temperature data sent via ordinary telephone lines	Intrarater agreements and McNemar chi(2) tests assessed; decisions after tele-rehabilitation and decisions made by the same rater after in-person sessions	Interrater agreement on 18 wounds was 78% ($kappa = 0.55$, $p < 0.02$) for the tele-rehabilitation sessions and 89% ($kappa = 0.77$, $p < 0.001$) for the in-person sessions
Sanford JA, Griffiths PC, <i>et al.</i> (2006) [71]	Randomized, clinical trial	33 adults were randomized to the control or UCG, 32 to the IG. Therapist intervention in home setting (trad. group $n = 16$) or remotely via tele-technology (tele-group $n = 16$)	Ten-item Likert-scale measure of mobility self-efficacy	No statistical sig between IG (SES: tele = 0.35, 95% CI = -2.5-0.95; trad = 0.54, 95% CI = 0.06-1.14)
Lum PS, Uswatte G, <i>et al.</i> (2006) [65]	Experimental observational study	Seven participants with chronic stroke trained with AutoCITE for 3 h/d for 10 consecutive weekdays	MAL	Gain MAL ($p. 0.9$) similar to the directly supervised program
Holden MK, Dyar TA, <i>et al.</i> (2007) [70]	Experimental observational study	Therapist to conduct interactive VE treatment sessions remotely with 11 patient at home	Fugl-Meyer; WMT; shoulder strength	All the outcome measure shown an significant improvement maintained over the 4 months of follow-up
Carey JR, Durfee WK, <i>et al.</i> (2007) [72]	Subjects with chronic stroke and 10 degrees of voluntary finger extension were randomly assigned to receive 1800 tele-rehabilitation trials over 2 weeks	Compare 2 tele-rehabilitation training strategies, repetitive tracking movements versus repetitive simple movements, to promote brain reorganization and recovery of hand function	Box and Block test, Jebsen Taylor test, and finger range of motion; finger-tracking activation fMRI	The track group showed significant improvement in all 4 behavioral tests; the move group improved in the Box and Block and Jebsen Taylor tests. The improvement for the track group in the Box and Block and Jebsen Taylor tests did not surpass that for the move group
Page SJ, Levine P, (2007) [66]	Pre-post, single-blinded case series	mCITE protocol, in which 4 persons with stroke participated in therapy sessions via the Internet	MAL and WMFT. Interview patients about their satisfaction with the protocol	Improvements in more affected arm use, quality of movement, as measured by the MAL
Heuser A, Kourtev H, <i>et al.</i> (2007) [73]	Experimental observational study	Rutgers Masters II haptic glove tested on five subjects, two weeks post-hand surgery. 13 sessions, 30 min per session, three sessions per week, and had no conventional outpatient therapy	Hand mechanical energy; virtual pegboard errors; virtual hand ball errors	Increases in grip (by up to 150%) and key pinch (up to 46%) strength in three of the subjects, while two subjects had decreased strength following the study; improved in their tip pinch strength

UCG: usual care group;
 IG: intervention group IG;
 mCITE:modified constraint-induced therapy extension;
 MAL: motor activity log;
 WMT: Wolf motor test;
 fMRI: functional MRI
 WMFT: Wolf motor function test;
 IADL: independent activity of daily living;
 FIM: functional independence measure;
 SES: standardized effective size;
 CI: confidence interval.

ance of the health professionals that work in rehabilitation centers, adequate technical support, daily organization that include time to spend for tele-assistance.

The home tele-rehabilitation could have a good cost/effectiveness ratio if the intervention of the therapist is not continuous but mainly used to address and monitoring the activities done by the patient or caregiver.

The possibility to stay in touch with the rehabilitation centers via tele-systems is relevant also for the severe disabilities such as severe traumatic brain injury, chronic condition after stroke, late stage of multiple sclerosis, etc. In these cases the contact from remote with the medical doctor, the nurses, the therapist could play an important role to address and solve the problems and decrease the access to the hospital. The contact could be useful also to monitor exercises provided by the patient himself or the caregiver in order to maintain the recovered function after the end of the intensive rehabilitation programs.

Perils

Tele-rehabilitation is a great opportunity but we ought to be aware of the perils and adverse effects. One problem could be the loss of real contact between the therapist and the patient. In fact, the sensory input passively induced by the physiotherapist is an important component in every rehabilitation techniques [74]. The traditional exercises should be considered as a standard during the intensive rehabilitation program. In this phase, robotic rehabilitation could play a complementary role if used locally in the rehabilitation hospital in order to extend the exercise time. In some cases, when the robotic or electronic apparatus is the same of that used at home, the time spent in hospital could be considered as a training for the home exercises, when the patient will be at home.

Tele-rehabilitation could also lead to a relegation of the patient at home. Sometimes the possibility to reach the rehabilitation center for an outpatient program is also a motivation to go outdoor and a strong stimulus to increase the participation to the community.

The exercises executed without direct control of the therapist or, at least, his supervision could be done with bad compensation strategies that lead to a low quality of recovery. An example could be the reaching movement of the upper limb, that should be done with the trunk fixed and a full movement of the arm. The usual compensation strategy used by the patient is to facilitate the reaching moving the trunk towards the target, which is a poor functional compensation.

Another issue to be sorted out is the high cost/benefit ratio particularly due to the cost of the various systems now available on the market. One of the challenges is to develop low cost apparatuses [75].

Pitfalls

The patients to be included in a tele-rehabilitation program should be selected according to the possibility of recovery according with the type of disease and the phase of recovery. The correct definition of such criteria should be carried out through specific studies. To date, the available studies do not show strong evidence, but the results do encourage to go on with both application and research.

Besides that, the effect on upper limb recovery seems to be small and only focused on improvement without changes in functioning in daily life activities [7].

Another potential problem is the transient effect of improvement. Especially in chronic phase of the disease, in fact, any type of exercise seems to work well and induce a temporary improvement that could last for weeks, rarely for months.

The new technologies are better accepted by the young patients, while diseases of high incidence and prevalence like stroke mainly involve elderly patients. The acceptance is also conditioned by the cultural level of the patient. To overcome this problems, an effort should be done to simplify the devices in order to be used by a large number of patients [76].

Tele-rehabilitation acceptance is not only a patient's but also a therapist's problem; the latter might in fact be worried about a loss of pivotal role in the rehabilitation management of the patients and about a lower quality of exercises. In an interesting paper dealing with occupational therapy, the concept is emphasized that for tele-rehabilitation "...issues remain of efficacy, cost, reimbursement, legal and ethical ramifications, and practitioner competence. There is a significant need for occupational therapy practitioners to document, research, and publish on the efficacy of consultation, intervention, and follow-up services provided using tele-rehabilitation technologies. Further investigation of the use of telehealth technologies in professional development and supervision is needed to clarify effectiveness and efficiency, as demand for services, particularly in rural areas, threatens to exceed services available..." [77].

A relevant improvement has been done on the development of technologies but there are still problems of reliability and validation of technologies, and problems with the need for high speed connections. The growing development and diffusion of wireless technologies will partly solve the problem.

Last but not least is the problem of reimbursement system. In fact, without a system for covering the cost of the service, which might be provided by government or private insurances, the application will be limited to experimental studies, or only used by those patients who have enough money to buy the apparatuses or pay the rental.

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