Rehabilitation—Emerging Technologies, Innovative Therapies, and Future Objectives

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Abstract Stroke is the leading cause of long-term disability. The goal of stroke rehabilitation is to improve recovery in the years after a stroke and to decrease long-term disability. This article, titled “Rehabilitation—Emerging Technologies, Innovative Therapies, and Future Objectives” gives evidence-based information on the type of rehabilitation approaches that are effective to improve functional mobility and to address cognitive impairments. We review the importance of taking a translational approach to neuro-rehabilitation, considering the interaction of motor and cognitive systems, skilled learned purposeful limb movement, and spatial navigation ability. Known biologic mechanisms of neurorecovery are targeted in relation to technology implemented by members of the multidisciplinary team. Results from proof-of-concept, within subjects, and randomized controlled trials are presented, and the implications for optimal stroke rehabilitation strategies are

discussed. Developing clinical practices are highlighted and future research directions are proposed with goals to provide insight on what the next steps are for this burgeoning discipline.

Keywords Outcomes · Behavioral neurology · Rehabilitation · Stroke recovery · Neuroprosthetics · Cognitive impairment · Constraint induced movement therapy

Introduction

Cerebrovascular disease is the leading cause of long-term disability in the United States (U.S.), increasing costs of post-acute care and caregiver burden [1, 2]. Rehabilitation Medicine is a relatively young and diverse field that extends from the first days of inpatient care to ensuing care by rehabilitative specialists to years of chronic care in a range of settings [3]. The goal of stroke rehabilitation is to improve recovery years after a stroke and to decrease long-term disability.

Stroke rehabilitation centers on a multidisciplinary concept, including input from the physician, nursing, physical and occupational therapy, speech-language pathology, social work, and case management. The rehabilitation team uses a variety of techniques to improve performance after stroke, such as strengthening of both weak and intact extremities, use of assistive devices and bracing, environmental modification at home and at work, and prevention of further disability [4]. Stroke rehabilitation also offers the opportunity for powerful knowledge translation, because the differences we observe between stroke survivors in response to specific therapies may, in large part, be directly attributable to differences in the brain networks supporting the desired behavior. For the advancement of the field, a

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knowledge of translational science is at the best interest of the stroke rehabilitation practitioner [5–10].

Rather than taking a new molecular compound “from the bench to the bedside,” as in pharmaceutical drug development, a stroke rehabilitation translational process requires that we take a developed concept or therapy and apply it across disciplines. Studies by van Peppen et al. [11] demonstrated that these therapies should be functional, meaningful, and challenging for a patient to maximize purposeful retention [12]. In this chapter, we will focus on some of these new developments in rehabilitation approaches, as well as those that are in a fast track for clinical use, but for which ideal application is not yet fully defined.

Constraint Induced Movement Therapy

Originally studied by Knapp et al. [13] in 1958, constraint induced movement therapy (CIMT) is based on the laboratory observation of learned nonuse in primates [13]. The explanation of learned nonuse in monkeys with a deafferented upper extremity and the positive efficacy after applying forced use paradigm was published by Knapp et al. [14] in 1963, setting the stage for translational research.

CIMT forces the use of the hemiparetic side by restraining the unaffected side. The patient then uses his or her hemiparetic limb repetitively and intensively for a specific duration of time. The first translational CIMT studies in the 1980s examined the efficacy of applying the intervention on 1 hemiplegic patient or a small group of either stroke or traumatic brain injury patients [15, 16]. This was followed by CIMT studies that controlled factors, such as severity of hemiparesis and time after onset of symptoms [17, 18]. After the severity of hemiparesis was studied, the next trials focused on the location of improved function. Koyama et al. [19] determined that the hemiparetic hand most benefitted from CIMT in their pre-test/post-test analysis.

Pertinent randomized controlled trials (RCTs) of CIMT are by Taub et al. [20], who conducted a placebo-controlled trial of CIMT vs a fitness, cognition, and relaxation exercise program; Dromerick et al. [21] performed a conventional intervention-controlled trial of CIMT vs traditional occupational therapy, including strength, range of motion, and activity of daily living training.

Lin et al. [22] found that that increased motor function, basic and extended functional abilities, and improved quality of life were demonstrated after modified CIMT intervention (i.e., intensive training and wearing restraint out of clinic) compared with a control group that received conventional rehabilitation and had been wearing a restraint out of the clinic.

In the EXCITE trial, Wolf et al. [23] found that CIMT produced statistically significant improvement in arm motor function, which persisted for at least 1 year among patients who had a stroke within the previous 3 to 9 months in comparison with those who received customary care.

Systematic reviews and the development of clinical guidelines have facilitated the transition of CIMT from human clinical research to physician practice. Hakkennes and Keating [24] performed a systematic review of RCTs focused on CIMT in the stroke population. Lillie and Mateer [25] studied whether CIMT had cognitive applications for patients with speech disorders. Taub et al. [26] reviewed the general clinical applications of CIMT to physical rehabilitation.

An intervention protocol was developed by Morris et al. [27], elucidating the ease of CIMT use in patients with hemiparesis after neurologic injury.

Practice-based CIMT research focused on patient tolerance to CIMT using a 1 or 2 group pre-test/post-test design. Underwood et al. [28] compared pain, fatigue, and intensity of therapy between subacute and chronic hemiparetic patients. Sterr et al. [29] evaluated different training schedules, with variations in the duration and intensity of CIMT treatment. The clinical applications of CIMT have been studied by Blanton et al. [30], specifically patient screening, reimbursement, post-acute follow-up, and the combination of CIMT with other modalities, including robotics, cortical stimulation, and pharmacotherapies.

Body-Weight-Supported Gait Training

Body-weight-supported (BWS) gait training augments the ability to ambulate after stroke by allowing the patient to practice complex gait cycles unweighted [31]. A type of CIMT, BWS gait training allows the patient to practice nearly normal gait patterns and to avoid developing compensatory walking habits, such as hip hiking and circumduction [32]. The intervention involves the patient being suspended in a harness system hanging from an overhead frame (Fig. 1). Traditionally, the frame is situated over a treadmill or flat ground, with 1 to 2 physical therapists providing assistance for balance and advancement of the paretic limb [33]. This is a disadvantage of BWS gait training; the effort needed by the therapist to set the paretic limbs and to control weight shift likely limits the intensity of therapy.

The biologic mechanism of BWS gait training may be associated with cortical activation changes. Enzinger et al. [34] observed bi-hemispheric activation increases with greater recovery both in cortical and subcortical regions with movement of the paretic foot. Greater walking endurance was associated with increased brain activity in

Fig. 1 Body-Weight-Supported Gait Training (Robomedica, Mission Viejo, CA). In this example, the patient is suspended from above using a harness system, with two therapists providing facilitation of leg movement and one therapist assisting with core stabilization. [Courtesy of TIRR Memorial Hermann (The Institute for Rehabilitation and Research), photo by Stockyard Photos]

the primary sensorimotor cortex, the paracentral lobules, the cingulate motor area, the bilateral caudate nuclei, and in the lateral thalamus of the affected hemisphere.

Despite a burgeoning understanding of the underlying biologic mechanisms, the literature on BWS training reports mixed results [12, 35]. Walking velocity and endurance correlate positively with gait ability in stroke patients [36]. Previous randomized controlled trials of BWS treadmill training with the help of a treadmill and manual assistance failed to show superior gait function and walking velocity in nonambulatory stroke patients [33]. Franceschini et al. [37] performed a single blind RCT of 97 subjects within 6 weeks of stroke onset, who were randomly assigned to either conventional rehabilitative treatment plus BWS on a treadmill or conventional treatment with over ground gait training only. Assessments were made at baseline, after 20 sessions of treatment, 2 weeks after treatment, and 6 months after stroke. After 4 weeks of treatment

consisting of 60 minutes a day, 5 days a week for 4 weeks, all patients were able to walk. Both groups showed improvement in all outcome measures at the end of the treatment and at follow-up with no differences noted between the groups.

Other studies showed that patients who received BWS gait training returned to walking faster. In the MOBILISE trial (Randomized Trial of Treadmill Walking with Body Weight Support to Establish Walking in Subacute Stroke) [38], 126 stroke patients who were unable to walk were recruited and randomly allocated to an experimental or a control group within 4 weeks of stroke. The experimental group undertook as many as 30 minutes per day of treadmill walking with body weight support via an overhead harness, whereas the control group undertook as many as 30 minutes of over ground walking. The BWS group walked 2 weeks earlier, with a median time to independent walking of 5 weeks compared to 7 weeks for the control group. In addition, 14% more patients from the BWS group were discharged home vs rehabilitation centers or nursing homes.

Pohl et al. [39] in Germany studied BWS gait training using an elliptical machine, described as an “electromechanical gait trainer” in lieu of over ground ambulation or the use of a treadmill. In a single-blinded RCT of 155 nonambulatory patients less than 60 days post-infarct, group A received 20 minutes of BWS training and 25 minutes of traditional physical therapy, whereas group B received only physical therapy. The duration of treatment was 5 days a week for a period of 4 weeks. A significantly greater number of patients in group A were able to ambulate independently and had reached a Barthel Index of ≥ 75 , and the superior gait ability persisted at 6-month follow-ups. The finding of improved ambulation by this group could be attributed to pure patient effort; patients who received BWS gait training with the use of a treadmill may have made too few steps on the treadmill belt, with the physical therapists facilitating the actual movement.

Although these results are encouraging, a better understanding is needed concerning the type of advancement device (treadmill vs elliptical trainer), the intensity and the duration of intervention, and the time to initiation of BWS gait training.

Functional Electrical Stimulation

Functional electrical stimulation (FES) in the hemiparetic stroke patient provides a bypass of central nervous system input to the muscles of the affected limb. Using coordinated bursts of electricity applied to the peripheral nerve, FES generates action potentials in motoneurons, which propagate toward the muscle causing its contraction [40].

In the upper extremity, FES is used to activate the posterior interosseous nerve to initiate extension at the wrist; in the lower extremity, the deep peroneal nerve is stimulated to reproduce ankle dorsiflexion at the tibialis anterior. FES is not useful in the presence of lower motor neuron disease (i.e., peripheral neuropathy, radiculopathy) and it probably has greater functional usefulness for the lower extremities.

Foot drop, caused by total or partial paresis of the ankle dorsiflexor muscles, can increase the fall risk of patients due to ineffective clearance of the foot during the swing phase of gait [41, 42]. There are two surface peroneal nerve stimulators available in the U.S. and a third in Great Britain. A Cochrane review in 2006 [43] concluded lower extremity FES was beneficial compared to no treatment for gait and motor recovery, although the quality of research was generally poor. A small study by Ring et al. [44] compared the use of FES to an ankle foot orthosis (AFO) in 15 patients with chronic hemiparesis. During the 8-week study period, 4 weeks were spent adapting to the use of both FES and the AFO during the day to increase the use of the device. After 8 weeks, there was no significant difference in gait speed; however, stride time improved and swing time decreased with the use of FES compared to the AFO. In addition, gait asymmetry improved by 15% with the use of FES.

Embrey et al. [45] performed a randomized crossover trial of 28 patients with poststroke hemiplegia to determine whether FES timed to activate the dorsiflexors and plantar flexors during gait improves the walking of adults. Intervention “A” included 3 months of wearing the FES system, which activated automatically during walking for 6 to 8 h/day, 7 day/week, plus walking 1 h/day, 6 days/week. Intervention “B” included 3 months of walking 1 h/day, 6 days/week without FES. Crossover occurred at 3 months.

The three primary outcomes were the 6-minute walk test, the Emory Functional Ambulatory Profile, and the Stroke Impact Scale. In phase 1, patients who received treatment “A” first showed improvement compared with patients who received treatment “B” first on the 6-minute walk test ($p=0.02$), the Emory Functional Ambulatory Profile ($p=0.08$), and the Stroke Impact Scale ($p=0.03$). In phase 2, the treatment “A” first group maintained improvement in all 3 primary outcomes even without FES. Both groups improved significantly on all primary outcome measures, comparing 6-months to initial measures ($p=0.05$).

There are several upper extremity FES units available in the U.S., and despite the mixed quality of the research, there seems to be a positive impact on motor recovery at the wrist. Powell et al. [46] randomized 60 subjects (mean time poststroke=22 days) to 30 minutes FES for 8 weeks vs standard rehabilitation treatment. At 32 weeks, better motor recovery was reported in the FES group.

Robotic-Assisted Therapies

Robotic-assisted therapies have been used in stroke rehabilitation for more than 15 years, with a focus primarily on upper extremity devices [47, 48]. Robotic-assisted therapy allows patients to train independently in an effort to improve their functional level. Advantages of this technology include a combination of visual and tactile stimuli, ability to track progress longitudinally with a duration of time, improved patient participation, and repetition of specific movements [49].

The most extensive upper extremity work has used the MIT-MANUS (Interactive Motion Technologies Inc., Cambridge, Massachusetts, USA) and the MIME (Staubli Unimation Inc., Duncan, South Carolina USA) units.

The MIT-MANUS is a robot that allows subjects to execute reaching movements in the horizontal plane. There are 2 degrees of freedom (DoF) that the robot enables unrestricted movements of the shoulder and elbow joints [50]. The MIME robot consists of a 6-DoF robot arm. The robot enables the bilateral practice of a 3-DoF shoulder–elbow movement, whereby the nonparetic arm guides the paretic arm [51]. A meta-analysis of 218 patients in 2007 [48] concluded that upper extremity robotic treatment results in improved upper extremity motor recovery compared to traditional rehabilitation therapy, but no differences were found for performance-based measures. This was challenged in 2010 by Lo et al [52], who conducted a randomized control trial comparing robot-assisted therapy, intensive comparison therapy, and usual care in 127 patients with moderate-to-severe upper-limb impairment 6 months or more after a stroke. Using the MIT-MANUS robotic system, they found that robot-assisted therapy did not significantly improve motor function at 12 weeks, however, there were some improvements in outcomes as measured on the Fugl-Meyer Score and the Wolf Motor Function Test.

The Lokomat (Hocoma Ag, Volketswil, SZ) is the best studied robotic-assisted lower extremity device. Similar to the tenants of BWS gait training, the Lokomat provides active control at the hip and knee and passive control at the ankle (Fig. 2). The study results for the Lokomat have been mixed. Schwartz et al. [53] performed a nonblinded prospective RCT of 67 patients in the first 3 months after stroke. They found that the Lokomat group showed greater gains with independent ambulation, expressed by improved functional ambulatory capacity and by a decrease in the National Institutes of Health Stroke Scale.

This was contradicted by Hidler et al. [54], who conducted a multicenter RCT of 63 participants >6 months poststroke comparing Lokomat to conventional gait training. Participants who received conventional gait training experienced significantly greater gains in walking speed and

Fig. 2 Lokomat robotic-assisted therapy (LokoMat, Hocoma Ag, Volketswil, SZ, CH-8604). In this example, a patient is engaged in the robotic lower extremity device and suspended over a treadmill using a harness system. The patient can be unweighted for a percent of their body mass based on parameters set by the therapists. [Courtesy of John Lynch, Memorial Hermann Healthcare System]

distance than those trained on the Lokomat. These differences were maintained at the 3-month follow-up evaluation. In a pilot study by Westlake and Patten [55] comparing the Lokomat and manual-assisted treadmill training, there were no significant differences in self-selected over ground walking speed and paretic step length ratio. However, within the Lokomat group, self-selected walk speed and paretic step length ratio improved. Additional studies are needed to determine which populations would benefit most from this technology.

Cognitive Disorders Interacting With Movement

Aphasia, Limb Apraxia, Spatial Neglect

The rehabilitation partnership involving the speech-language pathologist, allied health professional in occupa-

tional and physical therapy, physician, psychologist, and other members of the team, especially nurses, is arguably most relevant when we deal with acquired cognitive disorders after stroke. Speech and language, skilled purposive movements, as those used with tools, and spatial computations are all cognitive in the classic sense, having multiple levels of information processing that can be separated as in a computer model [56]. The rehabilitation practitioner might be surprised, however, to learn that all cognitive disorders have a powerful influence on the recovery of motor function. Although several mental conditions affect recovery of paralysis, and disorders of memory and attention impair arm, hand, and locomotor recovery [57–59], we will focus here on 3 extremely common cognitive sequelae of middle cerebral artery stroke: aphasia, limb apraxia, and spatial neglect. Specific rehabilitation of these 3 disorders facilitates recovery of physical functions, activities of daily living, and participation (see Eskes and Barrett [59] for a review), and thus we propose that specific, early intervention for these conditions is indicated, even when therapy goals are exclusively motoric or physical.

Definition of Aphasia, Limb Apraxia, and Spatial Neglect and Obstacles to Effective Traditional Treatment

Aphasia is an acquired communication disorder affecting speech and language centers in the left brain in most individuals. We avoid calling the disorder “dysphasia:” a “dys-” prefix is often reserved for developmental deficits (e.g. dyslexia), and this word is confusingly similar to “dysphagia.” Speech-language pathologists and occupational therapists are both trained in assisting in the rehabilitation of abnormal skilled learned purposive movements, not caused by weakness (limb apraxia), and in treating spatially asymmetric reporting, responding, orienting, or body movement, accompanied by functional disability (spatial neglect) [60, 61]. Physical therapists are also frequently trained in techniques for management and treatment of spatial neglect. Two problems interfere with systematic treatment of aphasia, limb apraxia, and spatial neglect; oftentimes psychologists who practice in rehabilitation settings have not received hands-on training in management and treatment of these disorders, and many allied health professionals managing and treating these disorders do so without using defined entry criteria, standardized treatment protocols, or uniform outcome assessment measuring impairment, function, or participation.

Thus, in many cases, this represents significant innovation when a rehabilitation medical director or stroke rehabilitation program leader organizes transdisciplinary clinical practice guidelines. These would consist of standard assessments, defined methods of treatment assignment, and a system for evaluating and documenting treatment outcome and adjusting ongoing care on an

individual and institutional basis. Guidelines for how to begin this organization, implementation, and self-auditing of organized team treatment was recently described for treatment of poststroke spatial neglect by Riestra and Barrett [62]. The clinical program that regularly trains, implements, and self-audits in this fashion is also well-positioned to respond to managed care and federal initiatives monitoring iatrogenic complications, such as falls, medication self-administration problems, and quality of life outcomes in rehabilitation patients, since aphasia, limb apraxia, and spatial neglect have a direct and powerful impact on these outcomes [63–65].

A Motor Rehabilitation Approach to Speech and Language?

It might seem odd that we should separate the way we think about “lower order” motor systems from the way we think about “higher order” systems like those supporting communication. However, because language is a cognitive function, there is dedicated linguistic information processing that prepares the movements of the lips, mouth, throat, and tongue for articulatory speech, just as motor control processes critically prepare movements of the arms and hands. Of course, limb movements can also be linguistically processed (e.g., when speaking the American sign language), but even nonsigners make communicative arm/hand gestures as part of linguistic cognitive processing. Thus, language is a motor activity, as well as a perceptual/representational activity [66], and approaches used to stimulate recovery in motor systems have been used in hopes that they may stimulate communication recovery.

Constraint-Induced Language Therapy

The constraint-induced language treatment approach has been evaluated in 16 studies, as recently reviewed by Berthier and Pulvermüller [67]. The therapeutic method differs from conventional therapy in 2 critical ways that define the approach: treatment is intensive (e.g., 3 h/day Monday-Friday for a 2-week period), and integrates techniques (e.g., visual blocking) preventing gestural communication or shared object regard between the therapist and survivor. This is the therapy’s “constraint,” in which it forces the survivor to engage solely in verbal communication to execute therapy tasks. This treatment approach has been reported to improve laboratory language testing in both acute and chronic aphasia, and in a randomized controlled trial, in which it also improved everyday communication [68]. The challenge for most healthcare providers is in freeing the resources for outpatient, daily, intensive sessions. In addition, if intensive outpatient speech therapy is feasible, the current constraint-therapy studies do not rule out the possibility that other treatments, delivered at similar

intensity, may result in similar communication and participation improvements [69].

Noninvasive Brain Stimulation

Although at present, using transcranial magnetic stimulation is clinically approved only for treatment of partially refractory depression, within-subject group studies using this intervention (slow repetitive transcranial magnetic stimulation) [70–72] demonstrated improved language test performance in poststroke aphasia. In these studies, stimulation was applied to the uninjured hemisphere, reducing the risk of treatment-related seizure [73]. In addition, studies reported that a mild electrical current to the scalp (transcranial direct current stimulation), with a device similar to that currently used for transcutaneous nerve stimulation, improved motor and language function in healthy people and potentially benefits depression [74, 75]. Since then, transcranial direct current stimulation proof-of-concept research suggests this may represent an adjunctive treatment improving communication recovery in acute stroke, inducing recovery in the chronic stroke recovery phase, or optimizing the effects of poststroke behavioral co-training [76, 77]. At the time of this writing, at least 2 “Phase IIb” large-scale studies to investigate optimal methods of stimulation administration, dose-response parameters, and appropriate methods to define criterion response are underway to determine feasibility in the clinical setting and explore different methods of delivering stimulation. It is unclear if beneficial results of noninvasive brain stimulation on aphasia occur, even partly, as a result stimulation-induced mood improvement, but even so, the high prevalence of depression after stroke in people with aphasia makes this a potentially promising treatment.

Social and Humanistic Care of Aphasia. Aphasia is extremely socially disabling, as well as shame-producing. It is a sad fact that many stroke survivors with aphasia leave the hospital without understanding that their problem with communication is a cognitive problem affecting language not their intelligence or character strengths. An innovative area of aphasia care is a focus on the impact of aphasia on the individual, and an attempt to improve the adverse impact of aphasia on life with therapeutic interventions [78]. Advocacy organizations, such as the National Aphasia Association (www.aphasia.org) and the Aphasia Institute (www.aphasia.ca) suggest that we provide a communication-accessible environment for people with aphasia (e.g., personnel answering phones who are trained to communicate with people with aphasia), and that people with aphasia receive any explanation of the nature of their symptoms and treatments that are available as they progress to chronic phases of recovery, and eventual successful community transition.

Aphasia and Limb Apraxia

Using Gestures to Treat Language

Classically, we would consider training oral/auditory language to be restorative or restitutive for aphasia, seeking to re-establish functional patterns of activation in damaged neural systems. In contrast, training stroke survivors using other communication modalities (gesture, reading/writing) would classically be regarded as compensatory [79]. As previously mentioned, emerging treatments such as constraint-induced therapy prohibit the survivor and therapist from using alternate communicative methods, based on the idea that using alternate communication modalities may reduce plastic change in cortical regions supporting the spoken and heard language. However, a third possibility is delivering “vicariative” intervention, activating a system independent of the impaired system, but neuropsychologically interacting with it. This activation results in indirect support of functional activation patterns in damaged neural systems, rather than inhibition of damaged neural systems by competitive activity. In a multiple-baselines group study of “vicariative” gestural training to improve speech, Raymer et al. [80] trained stroke survivors with aphasia to make communicative gestures with the left, nonparetic hand. They reported that not only communication, but oral language improved after gesture training of the broad improvement of naming for trained words, with group level benefits across word classes (nouns/verbs: 17.4%/17.0%), in 55% of individuals, across anomic impairments (semantic, phonological, and mixed). Most participants (88%) also showed large improvements in complex motor behaviors (spontaneous gestures increased 40%). Other investigations confirmed these effects and demonstrated that even training nonsymbolic intentional limb movements resulted in oral language improvement [81, 82].

It is important to understand that several aspects of how movement/gestural training may improve language are still unclear, and thus this approach is not yet completely or clinically ready. What kind of limb movements optimally stimulate oral language recovery has not yet been determined as to whether movements should be meaningful/meaningless; or whether, if meaningful, they should pantomime nouns or verbs; or whether, if pantomiming verbs, they should use a tool and take an object (e.g., hammering, a transitive gesture), or use no tool at all and take no object (e.g., waving goodbye, an intransitive gesture). Training gestures to improve communication, however, is an exciting and innovative idea for rehabilitation, because it is not only inexpensive and feasible for most settings, but it may clarify whether basal ganglia and right frontal brain structures support intentional or preparatory systems necessary for successful language, cognitive, and also motor recovery [83].

Innovative Means of Directly Improving Limb Apraxia

Limb apraxia interferes with eating, and this is associated with increased risk of falls and accidents (see a review by Barrett et al. [64]) [84]. A highly innovative idea on this disorder is that it may exert separate and further disabling effects on movement of paralyzed limbs, especially in left brain stroke survivors. In these people, assistive devices augmenting movement may actually worsen function, because trajectory, timing, and purpose of movements is dysfunctional. In stroke survivors with limb apraxia, managing the environment is a key part of improving safety, including removing access to weapons and power tools, and simplifying tools and visual cues to movement in the home.

Translationally treating limb apraxia is probably much simpler and less expensive than developing a new pharmacotherapeutic agent, or engineering an expensive device. In a

Table 1 Translational concepts from motor learning literature potentially affecting limb praxis recovery*

Treatment Principle	Influencing Factors
Practice schedule	Distributed may be preferred to massed practice, rest breaks may benefit
Intensity	Increased intensity may benefit
Training conditions	Training a variety of related, similar movements may benefit
Feedback	Appears to benefit learning, potentially more for simple skills
Opportunities for error	May disrupt learning; shaping performance and maintaining high accuracy by slow increase in difficulty and variety may benefit
Strategy for error correction	Augmented feedback
Stimuli used in training	Using objects with shape signaling associated actions may benefit
Training conditions	Minimizing distraction from task irrelevant objects and activities may benefit

*See Buxbaum et al. [84]

recent consensus conference funded by the McDonnell foundation, a group of researchers in this area concluded [84] that a major obstacle to retraining skilled learned movements such as tool use is lack of treatment generalization. Wisdom from motor learning studies in healthy people indicate that factors increasing motor learning generalization in other contexts might dramatically increase limb praxis treatment effectiveness (see Table 1).

It is absolutely critical to consider limb apraxia when planning other paralysis treatments, especially newer options for which interactions with other treatments and differential response of clinical subgroups are not yet known. For example, using robotic assistive technology might obscure the feedback on movement accuracy that a stroke survivor with limb apraxia needs to correct gestural trajectory during movement training. Thus, such a stroke survivor might actually worsen with respect to movement accuracy during robotic training. In addition, a stroke survivor with limb apraxia may not be able to implement mental motor imagery because of loss of movement concept representations [85]. Because the survivor cannot implement the treatment, prescribing mental motor imagery might actually result in a slowed rate of paralysis improvement, or might result in more problems with movement coordination in this patient. We recommend that practitioners carefully assess strength, skilled learned purposeful movement, and functional impact of motor disability (e.g., caregiver burden) when assessing the success or failure of a motor therapy.

Spatial Neglect

Spatial neglect treatments have not yet been demonstrated to broadly improve functional behavior; this is less because of treatment shortcomings than because the studies are only now beginning to use or assess functional-based outcomes [86–88]. Although this limits our ability to judge results of spatial neglect treatment on activity and participation, we favor 3 treatment approaches that received level 1a or “strong” support in 7 evidence-based published sources [89–95]. Using these approaches could assist in standardizing clinical patient care and evaluating the need to improve treatment outcomes. The approaches we believe are supported are the visual scanning treatment [96, 97], limb activation therapy [98] (see also Kalra et al. [99] and Eskes et al. [100]), and “general treatment” [89], which we regard as a form of “perceptual training” [94].

The difficulty with these approaches is that controlled studies supporting their use required intensive periods of treatment exposure that are much greater than the time available within the U.S. inpatient or outpatient therapy process (1 h daily for 4 weeks for visual scanning training).

An emerging treatment that is much more feasible with time is the prism adaptation training [101, 102], which is positively supported by case series evidence (see study reviews by Teasell et al. [94] and Menon et al. [95]) and was superior to control treatment in 1 of 3 randomized controlled studies currently available [103–105]. We are reluctant to recommend this as standard training yet because the critical determinants of treatment effect, the functional abilities likely to improve, and the characteristics of patients most likely to benefit are still not established yet. Research from 1 of our laboratories [104] supports beneficial effects of this treatment primarily on motor-intentional “aiming” spatial bias, with perceptual-attention of “where” spatial errors relatively are unaffected by the intervention.

Summary

In this article, we introduced several emerging therapies for paralysis and cognitive-motor disorders (i.e., aphasia, limb apraxia, and spatial neglect). Some of these treatments are not clinically standard yet, or they are just becoming available for inpatient and outpatient use. The “post-approval” process in rehabilitation, unlike pharmaceutical development, is a dynamic exciting period in which many clinicians can participate, generating information regarding the experience of their client subgroups and their institutions, which are considerably valuable. We encourage rehabilitation clinicians to prepare for wide availability of these therapies, and the need for community feedback regarding quality improvement assessment of these interventions as they come into clinical use.

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