

Technology for rehabilitating the upper limb after stroke: the hand

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ABSTRACT

Complete recovery of upper-limb function occurs in less than 20% of surviving stroke patients. Functional task-oriented training has been demonstrated to be the most effective therapeutic intervention. However, the number of repetitions of an action required within a session to stimulate cortical changes is significantly higher than is achieved in standard hands-on therapy sessions. New technology is enabling patients to engage in high-intensity, repetitive training and has augmented feedback to improve performance.

Key Words Stroke, upper-limb rehabilitation, task-oriented training, rehabilitation technology

The prognosis for the recovery of hand function following stroke is often considered poor when compared with the potential for regaining mobility. The ability to grasp, hold and manipulate objects remains deficient in 55–75% of patients 3–6 months following their stroke. Only 5–20% have been found to make a near-complete functional recovery (Nakayama et al, 1994). This contrasts with the finding that up to 83% of surviving stroke patients relearn the ability to walk (Friedman, 1990; Feys et al, 1998). The most important predictive factor for upper-limb recovery appears to be the initial severity of motor impairment or function (Coupar et al, 2012). Those patients with no shoulder or elbow control on admission have been found to recover the least amount of hand function (Houwink et al, 2013).

There are a number of reasons for the difference between regaining mobility and regaining hand function. Functional activity of the arm requires the recruitment and complex integration of muscle activity from the shoulder to the fingers. By contrast, functional walking can be

achieved following a minimal amount of recovery of muscle activity in the hemiplegic leg. Secondary complications such as developing a painful shoulder can hinder the rehabilitation of the hemiplegic arm. Furthermore, patients experience many spontaneous opportunities for lower-limb rehabilitation during functional activities, such as transfers or standing to wash or dress, that require bilateral activity in the legs. By contrast, patients often use their unaffected side exclusively when performing upper-limb activities (Feys et al, 1998).

Lindgren et al (2007) reported that shoulder pain restricted daily life often or constantly when dressing for 51% of patients at 4 months and for 31% at 16 months. They also found that shoulder pain restricted patients when walking, with 29% being affected at 4 months and 13% at 16 months. Some patients will only regain independent mobility with the use of a bilateral walking aid such as a walking frame or rollator (Friedman, 1990). The presence of moderate to severe pain or insufficient functional recovery will affect not only their ability to engage in bilateral upper limb activities,

but also crucially their potential for independent mobility.

The dominant physical rehabilitation approach in the UK involves hands-on therapy using the principles of the Bobath approach. However, there is little supporting evidence for hands-on therapy interventions, whether Bobath or otherwise (Luke et al, 2004; Winter et al, 2011). By contrast, there is a growing evidence base for the clinical effectiveness of interventions for upper-limb therapy following stroke using rehabilitation technology. This technology includes mechanical and electrical devices that assist with opening and closing the hand and may involve augmented biofeedback, enabling patients to incorporate their affected hand into an upper-limb exercise programme. The Intercollegiate Stroke Working Party (2012) concluded that the most effective treatment interventions following stroke are those that are characterised by high intensity, repetition and task specificity.

High-intensity, repetitive, task-specific training

It is now widely accepted that the brain has the potential for neural repair following stroke and other injuries through neural plasticity (Senelick, 2010). Goldstein and Davis (1990) detailed three mechanisms that have been found to underlie this repair process in adult animals after brain injury: pruning, which involves the injured neurons, and collateral sprouting and ingrowth, which involve the uninjured neurons (*Box 1*).

Nudo (1997, 2006) demonstrated that neuroplasticity and repair depend on the performance of functional tasks rather than limb movement alone. He compared

the response of monkeys performing only range-of-movement exercises with the response of monkeys that performed multiple repetitions of functional tasks. He found that the greatest functional gains were made by the monkeys that performed functional tasks. These functional gains correlated with cortical changes, with brain areas adjacent to the damaged area adopting its functions.

Effective rehabilitation through neuroplasticity depends not only on the performance of functional tasks but also on the number of repetitions (Senelick, 2010). Kleim and Jones (2008) provided evidence that critical levels of rehabilitation and repetition are needed for patients to experience improvements and maintain these functional gains outside a therapy setting. They found that 400–600 repetitions per session are required to stimulate the cortical changes that lead to functional gains. However, Lang et al (2009), who observed a sample of 312 physical and occupational therapy sessions for people with stroke, found that although task-specific, functional upper-extremity movements were practised in 51% of sessions, the average number of repetitions per session was only 32. These findings have implications both for therapy and for nursing team members. Therapists need to use interventions that facilitate multiple repetitions, and nurses need to encourage patients to continue to practise and use newly acquired skills outside therapy (Alon et al, 2007; Intercollegiate Stroke Working Party, 2012). The challenge for therapy is to incorporate an affected hand with minimal movement or even moderate spasticity into a therapy intervention that includes 400–600 repetitions of task-oriented activity per session. Recent technological advances have enabled the production of rehabilitation equipment that allows therapists to accommodate these principles into treatment interventions: the SaeboFlex and the Bioness H200 (Senelick, 2010; Hoffman and Blakey, 2011; Stuck et al, 2012).

SaeboFlex

The SaeboFlex (Figures 1 and 2) is a custom-fabricated hand–wrist orthosis

Box 1: Mechanisms underlying repair after brain injury*

Responses of injured neurons

- Pruning: When an axon is injured, nearby uninjured collateral axons from the same neuron expand to reinnervate the vacant target.

Responses of uninjured neurons

- Collateral sprouting: The uninjured neuron extends neurites to replace nearby degenerating axons. Collateral sprouting occurs widely in the brain and usually results in an increase in the density of sprouting neuronal terminals at the target. This mechanism can also be maladaptive and lead to an increased deficit.
- Ingrowth: In contrast to collateral sprouting, ingrowing neurons form new connections in response to the lost neuronal input at a target. This mechanism is invariably maladaptive and leads to an increased deficit.

*Goldstein and Davis (1990)



Figures 1 and 2. The SaeboFlex helps the patient to release a grasped object. Images courtesy of Saebo

that supports the patient's affected hand in a functional range of wrist extension. The patient grasps an object by voluntarily closing his or her fingers. A system of variable-strength springs assists in reopening the hand so that the patient can release the object. The SaeboFlex enables the patient to incorporate hand movements into an upper-limb therapy programme as soon as they have recovered sufficient flexion (closing) activity to grasp an object. The assistance of the springs facilitates repetitions in excess of the minimum of 400 recommended by Kleim and Jones (2008) within a 45-minute therapy session. If patients are able to comply with a second or third session in a single day, they can exceed 1000 repetitions per day. Once the SaeboFlex has been configured for the patient,

exercise sessions can be supervised by therapy assistants or nurses. A trained therapist is only required to modify the SaeboFlex fitting as the patient progresses.

Stuck et al (2012) explored the use of the SaeboFlex with acute stroke patients (<4 weeks following their stroke). The patients practised up to a maximum of three 45-minute sessions per day for 12 weeks in addition to conventional rehabilitation. Six out of the seven patients achieved clinically significant improvements in the Action Research Arm Test. There were statistically and clinically significant improvements in the other primary outcome (UL Motricity Index) and various secondary outcomes. Other studies have demonstrated encouraging results in the chronic stroke population (Barry et al, 2012; Jeon et al, 2012).



Figure 3. The Bioness H200 enables the patient to open and close their hand and to perform key or pincer grips with their thumb. Image courtesy of Bioness

The SaebFlex requires that the patient has some return of flexion activity in order to grasp the object. The Bioness H200 offers patients with no volitional grasp the opportunity to practise functional tasks.

Bioness H200

The Bioness H200 (Figure 3) is a micro-processor-based functional electrical stimulation (FES) system. It is composed of a forearm/hand-moulded orthosis containing an array of five surface electrodes ranging in size from 2×2 cm to 6×4 cm. The electrodes transmit small electrical currents to the motor nerves of the extensor digitorum, extensor pollicis brevis, flexor digitorum superficialis, flexor pollicis longus and thenar muscles. The position of the electrodes in the orthosis can be customised for each patient to enable them to open and close their hand and to perform key or pincer grips with their thumb. The H200 software has default minimum timing parameters for opening and releasing that preclude the number of repetitions exceeding 400 in a 45-minute session, but the device can be safely worn for longer and patients can engage in two or more sessions per day.

Alon et al (2007) explored the use of upper-limb FES in the rehabilitation of

acute stroke patients. They compared an experimental group of patients (FES group) engaging in task-oriented training using the H200 FES with a control group engaging in task-oriented training alone. The subjects in both groups had been admitted with a stroke no less than 2 weeks and no more than 4 weeks prior to commencement of the study. The task-oriented training included weight-bearing activities, reaching activities, grasp/hold/release activities and upper-limb activities of daily living such as dressing, grooming, bilateral carrying of objects and manipulation of small objects. The experimental group performed these activities with the assistance of the FES, whereas the control group performed them without. The specific exercises were tailored to each individual at the start of the 12-week study and modified by the research therapist to incorporate improved performance in both groups. The study continued on discharge with both groups practising at home with assistance from a family member when required. At the conclusion of the study all patients had regained some hand function. The FES group achieved significantly better improvements ($p<0.05$) than the control group in all of the clinical measures of hand function used in the study (box and blocks test,

Jebsen-Taylor lifting light object test, modified Fugl-Meyer test).

Ring and Rosenthal (2005) explored the use of the Ness HandMaster, a prototype version of the Bioness H200, in 22 patients with sub-acute stroke (3–6 months post-onset). The patients were attending a day hospital three times weekly and were receiving both physical and occupational therapy. They were clinically stratified into two groups: type I had no active finger movement ($n=10$) and type II had partial active finger movement ($n=12$). They were then randomised into either the experimental or the control group. Both groups received the same levels of therapy intervention at the day hospital, which involved a minimum of 3 hours of therapy intervention. The experimental group used the FES at home three times per day for up to 50 minutes per session for the 6-week duration of the study. The study found that patients using the FES at home with minimal active motion (type I) prior to the treatment programme demonstrated significantly greater improvements in spasticity reduction and tended toward greater active range of motion of the proximal limb than those in the control group. For those patients in the experimental group with partial active motion at the start of treatment (type II) there were significantly greater improvements in tests of hand function and spasticity reduction and increased voluntary movement than in the control group. Additionally, for the few patients with pain or oedema in the involved limb, all of those treated with the FES improved whereas only one of six (five with pain and one with oedema) improved in the control group.

One of the key differences between the mechanical SaebFlex and the FES-based H200 is the aperture of the hand opening. The spring extension system in the SaebFlex facilitates consistently larger apertures than those achieved using FES. Cameron et al (1999) demonstrated that although electrical stimulation of the long finger extensors can increase the opening of the hemiplegic hand, the degree of opening is

strongly dependent on wrist posture. The maximum grasp aperture was achieved when the wrist was in full flexion, but the aperture progressively declined as the wrist was extended. At 40° of wrist extension there was a zero hand aperture. However, patients using a SaeboFlex with moderate-to-severe tone in their finger flexors require strongly resistive springs to open their hand. Some of these patients find that they are unable to overcome the resistance of the extension spring system to achieve a functional grasp. To tackle this, the SaeboFlex has recently been coupled with an electrical stimulator that features reciprocal electromyography-triggered stimulation (RETS) in the Saebo Myotrac Infiniti. This device uses RETS to trigger the extensors to open the hand when the inbuilt electromyography sensors detect volitional relaxation of the long finger flexors. The electrical assistance for opening provided by the device reduces the need for the highly resistive springs that can hinder grasp for some patients.

Augmented feedback for upper-limb rehabilitation

Molier et al (2010) reported that augmented feedback can assist in upper-limb rehabilitation following stroke, and its use is supported in the recommendations of the Intercollegiate Stroke Working Party (2012). Biofeedback enables physiological events to be brought to conscious awareness through the use of instrumentation. This information can be used in the clinical context to improve learning and conscious control. The term augmented feedback is often used to describe concurrent feedback that provides information about specific parameters of a target movement (Schmidt and Wrisberg, 2004).

A significant technological development in upper-limb stroke rehabilitation that uses augmented feedback is the MediTouch HandTutor (*Figure 4*). This comprises a glove and forearm sleeve housing sensors that relay computer measurements of finger and wrist as well as finger and thumb movements to a laptop. The HandTutor software system

records the movements and concurrently provides the patient with augmented (exaggerated) visual and auditory feedback of even the slightest amount of displacement at the wrist or finger joints. The software provides the user with various therapeutic exercises in the form of computer games. The games demand different combinations of movements and encourage the user to flex and extend their fingers while maintaining appropriate alignment of their wrist.

Carmeli et al (2011) studied the use of the HandTutor in combination with

traditional rehabilitation with 31 stroke patients in a randomised controlled trial. The selection criteria were that the patients were between 10 days and 10 weeks post-stroke, had a minimum of 10° of extension and/or flexion of the wrist or fingers and had an ability to flex and extend the wrist joint five times continuously without losing active range of motion. The experimental group underwent hand rehabilitation using the HandTutor combined with traditional therapy. The control group received only traditional therapy. The traditional therapy



Figure 4. The HandTutor provides the patient with augmented feedback of finger and wrist as well as finger and thumb movements. Image courtesy of MediTouch

included passive and active therapeutic exercises focussing on range of motion plus strength and endurance training of the wrist and fingers. Following 15 consecutive treatments, significantly greater improvements were observed for the experimental group in Brunnstrom-Fugl-Meyer and box and blocks tests.

The SaebFlex is the most widely adopted of the rehabilitation technologies in the UK and is currently in use in over 70 acute, sub-acute and community rehabilitation services. However, there is increasing interest in the Bioness H200 and HandTutor.

Implications for nursing practice

There are implications for nursing practice in two areas: promoting recovery by giving patients opportunities for informal practice outside formal therapy, e.g. using their affected hand to assist with washing or supporting a beaker when drinking, and ensuring the avoidance of secondary complications affecting the upper limb following stroke, i.e. painful shoulder, soft-tissue and joint contractures. The author has often observed the custom of placing intravenous lines into the affected hand in acute stroke settings so as not to encumber the unaffected hand. However, should the line fail and fluid infiltrate the interstitial space, the subsequent oedema can severely affect the recovery of hand function.

Conclusion

Effective rehabilitation for the upper limb following stroke has been demonstrated with intensive, repetitive, task-oriented exercises. As new developments in rehabilitation technology that enable patients to engage in such exercises are more widely adopted into stroke rehabilitation services, the prognosis for upper-limb recovery will become more optimistic. **BJNN**

Declaration of interests

The author has received honoraria from the manufacturers of orthotic devices for presenting at conferences and symposia.

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