The Role of Biofeedback in Stroke Rehabilitation: Past and Future Directions

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Biofeedback has been applied to many aspects of stroke rehabilitation, with mixed results. This is largely due to the varying modalities, differences between study designs, and methods of measuring success and progress. How well biofeedback works appears to be inversely related to the direct observability of the function about which information is being provided. The more covert the function (e.g., swallowing muscle activity, attention, cortical functioning, etc.), the more helpful biofeedback is likely to be. However, biofeedback in general can have a very positive impact, even through indirect means. Improvements in self confidence, shifting of locus of control, and instantly being provided information regarding changes in one’s physical functioning as a result of mental activity can be helpful in setting the tone for success in rehabilitation more generally. Key words: acquired brain injury, attentional control, balance, biofeedback, cognitive rehabilitation, cortical reorganization, gait, neurofeedback, neurotherapy, recovery of function, rehabilitation, stroke

Stroke incidence is approximately 158 per 100,000 and is a leading cause of disability in the United States.1,2 There are close to 4.4 million stroke survivors in the United States, and nearly 40% of these individuals have at least moderate functional impairments, with 15%–30% having severe disabilities.3 Because of the heterogeneous manifestations of stroke, functional impairments resulting from ischemic or hemorrhagic events can vary widely. Common physical sequelae include hemiparesis or hemiplegia, incontinence, as well as dysphagia and dysarthria.4 Common cognitive sequelae of stroke include aphasia, abulia, impairments of attention and memory, spatial neglect, personality changes, and anosagnosia.2,5,6 However, there is good support for the notion that rehabilitation efforts can significantly impact the degree of disability that individuals experience in the weeks and months following stroke.7 Specifically, meta-analytic studies and systematic literature reviews have revealed specific significant benefits in functional outcomes (e.g., FIM™ scores) for physical therapy,8 occupational therapy,9 and cognitive rehabilitation.10

Recent Ottawa Panel evidence-based clinical practice guidelines for poststroke rehabilitation include biofeedback as a positive recommendation for management of several conditions poststroke.11

One benefit of using biofeedback in stroke rehabilitation is that it can give the patient and practitioner access to information about physiological functioning in various domains that might otherwise be too subtle to detect or too subjective to accurately assess and consciously manipulate. The current article is meant to serve as a brief overview of the efficacy literature regarding the application of biofeedback to various aspects of functioning in poststroke recovery.

Biofeedback Applications to Physical Recovery

Hemiparesis

An early application of biofeedback technology to stroke rehabilitation was in the domain of electromyographic (EMG) biofeedback for neuromuscular reeducation in individuals with hemiparesis. In this application of biofeedback, electrodes are placed on specific muscles that are important in particular limb movements, and information...
about the electrical activity that accompanies muscle contraction is provided to the patient through visual or auditory feedback. This might be particularly helpful when the degree of muscle contraction is small and less easily observable kinesthetically or visually, as in the earlier stages of stroke recovery or when paresis is more severe. Schleenbaker and Mainous reported a meta-analysis of eight studies \((N = 152)\) in which there was an effect size of 0.81 (95% confidence interval [CI] 0.5 to 1.12) and determined that biofeedback was an effective tool for assisting in the rehabilitation of hemiparesis. However, there were methodological problems with this analysis; the authors included two studies in which the comparison group was provided with no treatment, potentially skewing the findings in a positive direction for biofeedback.

A later meta-analysis with more appropriate inclusion criteria examined the role of EMG biofeedback in improving lower extremity function after stroke and found that the application of biofeedback was superior to conventional treatment alone in rehabilitating ankle dorsiflexion muscle strength (effect size \([ES] = 1.17; 95\% CI .50 to 1.85; p = .0006) and found a statistical trend for its efficacy in improving gait quality (\(ES = .48; 95\% CI –.06 to 1.01; p = .08).^{13}\)

In a meta-analysis of EMG biofeedback for the rehabilitation of upper extremity mobility and functioning in hemiparetic stroke survivors, Moreland and Thomson found small effect size increases with the addition of biofeedback compared to conventional physical therapy. Given the small number of studies included in the analysis (five), there was a chance of simply failing to detect a statistical difference in this analysis due to lack of power. The authors concluded that factors such as patient preference, cost, and ease of application should be determining factors in whether the use of biofeedback for the rehabilitation of upper extremity mobility is appropriate in individual cases.

A more recent synthesis of the literature suggests that an integrated program of therapy including biofeedback is likely to yield the best results. The report indicated that sensorimotor training with the use of imagery and electrical stimulation with biofeedback in combination with activities that engage the client in repetitive, novel tasks can be effective in reducing upper extremity motor impairment after stroke.

Thus, the literature is generally supportive of the application of EMG biofeedback in the rehabilitation of hemiparesis following stroke, with some specific advantages in lower extremity functional recovery. This straightforward application of biofeedback is perhaps one of the most obvious, but potentially least informative, applications of biofeedback technology, as muscle activity in the limbs is fairly directly observable without the use of electrophysiological amplifiers.

### Swallowing and dysphagia

The act of pharyngeal swallowing is a complicated coordination of several small muscles in the mouth, neck, and throat. In cases of dysphagia, where control of the muscles of the mouth and throat are affected, the ability to swallow can be lost entirely. Given the difficulty that one might have in directly observing the complex of muscles involved in producing a swallow, a system providing information about the functioning of specific muscles involved in the process could be extremely valuable in retraining this ability. Logemann and Kahrilas reported a single case study in which surface EMG (sEMG) biofeedback was utilized to retrain specific elements of the pharyngeal swallow of an individual with dysphagia secondary to a medullary infarct at 45 months poststroke. This intervention allowed the individual to practice and relearn specific maneuvers that would likely have been too subtle to address directly without the assistance of biofeedback. This approach was integrated into a swallow rehabilitation program, and its effectiveness was evaluated on a sample of 25 individuals with dysphagia poststroke and 20 patients with dysphagia from head and neck cancer resection. Ninety-two percent of patients recovering from stroke improved their functional intake of food and liquid, compared to 80% of patients recovering from head and neck cancer. Persons with stroke required more therapy sessions, but because of their greater functional improvement, they had lower cost per unit of functional change. It should also be noted
that treatment of dysphagia in individuals with stroke improves nutritional status and may impact long-term survival rates.\textsuperscript{18}

**Urinary incontinence**

According to a recent Cochrane review,\textsuperscript{19} urinary incontinence affects 40%–60% of individuals admitted to hospitals with stroke. At hospital discharge, 25% still show some problems and 15% still have incontinence problems at 1 year poststroke. This same review indicated that there were insufficient data to evaluate the effectiveness of biofeedback for urinary incontinence specifically in stroke patients. However, Capelini et al.\textsuperscript{20} reported findings indicating the successful application of biofeedback with pelvic floor strengthening exercises to treat stress urinary incontinence in a sample of 14 women. Biofeedback and pelvic floor exercises significantly reduced number of urinary leakage episodes and daytime frequency. Urodynamic evaluation revealed a significant increase in Valsalva leak-point pressure, cistometric capacity, and bladder volume at first desire to void. Thus, biofeedback appears to be a potentially promising intervention for treatment of urinary incontinence following stroke, but more research is needed in this area to demonstrate its efficacy with this specialized population.

**Balance and gait**

Many stroke survivors have difficulties with balance and gait, generally secondary to hemiparesis. Force platform biofeedback is a method of providing patients with information about the location of their center of gravity with reference to the location of their feet. In cases where proprioception may be impaired, an additional source of information about one’s balance may be helpful in regaining standing stability and improving mobility. Nichols\textsuperscript{21} reviewed literature examining the impact of force platform biofeedback on various dimensions of balance. Although this was a qualitative review of the literature, she indicated that there appeared to be no significant advantage to the use of biofeedback in terms of outcomes related to sway, dynamic stability, or symmetry, but she pointed out that there may be advantages if limb load measures were included in the analyses, which at the time of her review, had not been specifically examined in hemiparetic patients.

In a more recent Cochrane review, force platform biofeedback was also found to have no impact on clinical measures of balance (the Berg Balance Scale, and Timed Up and Go tests) or sway measures. However, force platform biofeedback was found to significantly impact stance symmetry when using visual feedback (standardized mean difference [SMD] –0.68; 95% CI –1.31 to –0.04; \( p = .04 \)) and concurrent visual and auditory feedback (weighted mean difference [WMD] –4.02; 95% CI –5.99 to –2.04; \( p = .00007 \)), reflecting the finding predicted by Nichols regarding limb load measures, with stance symmetry serving as a quantitative measure of the active use of the paretic limb.\textsuperscript{22}

In a counterintuitive use of feedback manipulation, Bonan et al.\textsuperscript{23} demonstrated that during poststroke recovery, reliance of visual feedback may impede recovery of balance. These investigators compared conventional balance therapy delivery and therapy delivery under visual deprivation. The results indicated that individuals deprived of visual information regarding spatial orientation actually improved significantly more on six measures of balance than a control group that was allowed to rely on vision during balance therapy. It is possible that by depriving the patients of visual cues, the intervention improved proprioception by way of necessity.

Generally, biofeedback appears to be a valuable adjunct to conventional therapies for some aspects of mobility recovery, balance retraining, and swallow recovery. Biofeedback also shows promise in the area of treating incontinence, but more research is needed in this domain with stroke survivors, specifically.

**Biofeedback for Cognitive Rehabilitation**

Traditional therapy for cognitive changes following stroke has largely centered on speech therapy for aphasia. However, other interventions have been developed to address difficulties in specific cognitive functions within the last decade.\textsuperscript{10}
Until very recently, in the field of stroke rehabilitation, cognition has been the tool of biofeedback rather than its object. Biofeedback has relied on cognition to alter the functioning of some other physiological process, largely EMG activity, as in the studies summarized previously. However, there are emerging approaches that utilize the principles of biofeedback to affect the brain’s activity directly and, therefore, the cortical substrates of the cognitive functions themselves. This section will focus on two of these emerging therapeutic approaches: electroencephalographic (EEG) biofeedback, or neurofeedback, and Interactive Metronome® technology.

**EEG biofeedback or neurofeedback**

The field of neurofeedback is an exciting new area of application of the principles of biofeedback to stroke rehabilitation. In this approach, electrodes record the EEG activity at one or more given scalp locations, and a computer displays information about the brain’s activity to the patient. Most current neurofeedback systems can display a wide range of information to the practitioner and the patient such as frequency composition, amplitude of activity in a particular frequency band (e.g., delta 1–4 Hz, theta 4–8 Hz, alpha 8–12 Hz, beta 13–21 Hz, high beta 21–32 Hz, and gamma 32–60 Hz), coherence between two sites in one or more frequency bands, phase lag, or any of a number of other derived measures. Then, operant conditioning combined with various cognitive strategies or functional tasks are used to alter the EEG activity in the desired direction. Given the relationship between EEG activity in particular frequency bands over specific cortical locations and metabolic rates of various cortical structures, this approach allows the therapist and patient to alter cortical metabolism and thereby influence neural activity and neuroplasticity in various regions of the brain.

Although there are little actual data on the application of this new approach specifically to stroke rehabilitation, two case studies appear in the literature. The earliest report by Rozelle and Budzynski describes neurofeedback treatment of a 55-year-old male who was 1 year post a left-sided ischemic stroke with posterior temporal/parietal infarctions secondary to occlusion of the left internal carotid artery at the outset of therapy. Prior to treatment, the patient reported difficulties with word finding and halted speech, paraphasia, and difficulty focusing his right eye.

Quantitative EEG analysis revealed increased left-side 4–7 Hz activity and alpha persistence on eye opening. The patient received a 6-month course of neurofeedback; training began with a few sessions of EEG entrainment feedback, followed by neurofeedback to inhibit 4–7 Hz activity and increase 15–21 Hz activity over sensorimotor and speech areas on the left side of the cortex. Following treatment, the patient’s quantitative EEG showed significantly decreased slow wave activity. The authors reported that the patient also demonstrated significantly improved speech fluency, attention and concentration, coordination and balance, as well as improved mood.

Because the most rapid spontaneous recovery occurs within the first year following a stroke, it is important to note that this patient began neurofeedback approximately 1 year poststroke. However, since no formal statistics were used in this early case report, the improvements reported cannot be quantified objectively. Nonetheless, this early attempt suggests that neurofeedback may be applied to stroke recovery with possible benefit to the patient’s functioning beyond the period of expected recovery.

A later report by Bearden et al. describes the treatment of a 52-year-old male, 1 year post cerebrovascular event. This man’s stroke resulted in infarcts in the left thalamus and temporoparietal areas of the cortex. Following a 14-week course of neurofeedback to reduce slow wave activity over the affected areas two to three times per week, he demonstrated significant decreases in 4–7 Hz activity in the left hemisphere and restored alpha attenuation upon eye opening. He also demonstrated statistically significant improvements on...
neuropsychological tests of attention, working memory, divided attention, processing speed, and sequencing.

Again, these case studies are encouraging, but much more research is needed to evaluate the effectiveness of this approach in comparison to other treatments for postacute rehabilitation of cognitive impairments related to stroke.

In a review of the literature regarding attention rehabilitation, Michel and Mateer report that there may be specific benefits to attention following stroke from neurofeedback. Citing studies that report significant improvements in attention following neurofeedback training in children and adults with attention deficit disorder, the authors point out that attention difficulties are often associated with excessive slow wave activity in the EEG of the frontal cortex in both attention deficit disorder and after acquired brain injury and stroke.

Laibow et al. reported that operant conditioning to decrease the ratio of theta (4–8 Hz) to beta (15–30 Hz) activity has been demonstrated to improve overall symptom severity in a number of domains in individuals with severe to moderate acquired brain injury (i.e., traumatic brain injury, stroke, and hemispherectomy). Symptom severity ratings were determined by agreement of caregiver, patient, and physician reports. Even though this study included patients with brain injury of other etiologies as well as those resulting from stroke, it points out the potential utility of neurofeedback in this patient population.

In summary, neurofeedback appears to be a promising new treatment for cognitive and emotional problems following stroke that can provide measurable benefits to patients beyond the time range of expected spontaneous improvement. Further research is needed to determine the relative clinical efficacy of this approach in comparison to and in combination with other treatment approaches to cognitive rehabilitation following stroke. An important question for future research, from this author’s point of view, is whether neurofeedback can impact specific cognitive functions (e.g., attention, memory, verbal fluency) that result from the focal lesions produced by stroke, or whether the effects of this intervention appear to be more general (e.g., global cognitive functioning).

**Interactive metronome technology**

Another emerging brain-based technology with promise for the field of cognitive rehabilitation following stroke is Interactive Metronome® therapy. This technology uses operant conditioning of an individual’s motor planning, sequencing, timing, and attention through having them engage in simple, repetitive motor tasks such as clapping the hands or tapping the feet in time with a set beat. The system provides both visual and auditory feedback to indicate how far off-beat each repetition of the task is (in milliseconds) and whether the repetition was early (before the beat) or late (after the beat) to allow the individual to alter the rate of movement on a beat-by-beat basis. The default tempo of the beat is 54 ms but is adjustable for individuals with limited mobility. Thus, in the course of just over a second, the individual receives audio and visual feedback about their last response, tracks the next beat, adjusts their behavior accordingly, and makes the next response. The deceptively simple task is cognitively demanding, and many patients find it frustrating and confusing in the beginning of their treatment. To do well at the task, multiple cognitive functions must be synchronized and sustained, producing activation and coordination of several cortical regions and encouraging neuroplasticity throughout the brain.

The current research literature on clinical outcomes following treatment with Interactive Metronome® technology has focused largely on the remediation of attention deficit disorder in children. However, these initial efforts have revealed a wide range of benefits that may translate well into stroke rehabilitation. Specifically, statistically significant improvements were demonstrated in attention, motor planning and coordination, language processing, reading, and the regulation of aggression. Currently, there are several ongoing studies investigating the applicability of Interactive Metronome® technology to rehabilitation of traumatic brain injury, Parkinson’s disease, and developmental disorders.

Because it addresses the underlying cognitive functions of processing speed, attention, timing, coordination, planning, and sequencing, Interactive Metronome® therapy has great potential to be
helpful in many cognitive domains that may be affected by stroke, but more research is clearly needed on this promising new approach.

Summary and Discussion

Biofeedback appears to be an effective adjunct to conventional therapies for a number of the problems that patients encounter following stroke. It appears to assist with some aspects of the rehabilitation of hemiparesis and mobility recovery and is valuable in the rehabilitation of swallowing in patients with dysphagia. Biofeedback also shows promise in the domain of controlling urinary incontinence.

In regard to cognitive rehabilitation, the emerging field of EEG biofeedback, or neurofeedback, appears to hold great promise for the rehabilitation of attention, language processing, working memory, and even motor coordination. The preliminary reports of case studies and a single reported application of this treatment approach have been encouraging. However, more detailed research should be carried out to explore the mechanisms of action and direct application of neurofeedback to specific focal difficulties that stroke survivors often encounter.

Similarly, Interactive Metronome® technology appears to be very promising for the rehabilitation of the processes underlying multiple higher level cognitive functions and has shown some positive initial results in other populations with cognitive difficulties, but more research will be required to assess its effectiveness with stroke survivors in particular.

In the areas that are otherwise difficult to access, biofeedback supplies information that is most valuable and has the largest physiological and functional impact. Given that the process of healing is a conscious one, and that consciousness naturally assists the regulation and direction of the healing process, we can only directly change those things of which we can be consciously aware. If a process is hidden from our view, we are less able to correct any problems with its functioning. This is the value of biofeedback in general. It reveals hidden processes and enables conscious regulation of them. In the case of motor recovery, this role may be somewhat less valuable, because the information provided by biofeedback in this application is largely available to us directly through other avenues (visual, kinesthetic, etc.). However, in cases where the information is not easily accessible through other means, as in the intricate maneuvers of swallowing, or the regulation of cortical potentials and metabolic rates, or the fine-grained awareness of timing and cognitive coordination, biofeedback becomes most valuable. I predict that areas of research building on this observation will have the greatest benefits to our patients and our understanding of the healing and recovery process.

Recommendations for the Application of Biofeedback in Stroke Rehabilitation

Recommendations regarding the application of biofeedback interventions in conjunction with conventional approaches to rehabilitation must be made from both an evidence-based position and from the vantage of clinical utility. An account of the evidence to support the use of biofeedback in stroke rehabilitation has been the focus of this article. However, a quality that is more difficult to quantify is that of clinical utility. Biofeedback has unique clinical utility in that it can powerfully demonstrate to patients that they can exert control over aspects of their functioning of which they do not otherwise have awareness. The impact of this demonstration alone could be an argument that the technology should be applied early in the course of rehabilitation. Shifting the locus of control to an internal orientation is empowering; an individual recovering from stroke is certainly likely to benefit from increased feelings of control over the functioning of the body.

Also, there will likely be some added benefit to the natural course of expected spontaneous recovery to include these interventions as early as possible. More active forms of biofeedback (e.g., force platform biofeedback for balance) should be applied as soon as the patient is medically stable enough to begin active rehabilitation. However, less strenuous interventions such as heart rate variability biofeedback, which has been shown to reduce stress and depression in samples with coronary heart disease, may be applied even earlier with good result.

In sum, biofeedback is a useful tool in the recov-
dency of function following stroke and should be
provided as a part of the conventional program of
rehabilitation. It has great potential to improve
self-efficacy, to emphasize an internal locus of con-
trol, and to contribute substantially to the recovery
of function in a number of domains.

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