Biofeedback
Volume 41, Issue 2, pp. 50–55
DOI: 10.5298/1081-5937-41.2.03

SPECIAL ISSUE

Motor Control Recovery After a Severe Brain Injury: Applications of Quantitative Surface Electromyography

Jeffrey E. Bolek, PhD, BCB, and Jennifer Yost, PT, DPT

Cleveland Clinic Children's Hospital for Rehabilitation, Cleveland, OH

Keywords: surface electromyography, QSEMG, biofeedback, rehabilitation

In this case study, surface electromyography (SEMG) was used to help a severely brain-damaged adolescent regain head control. In addition to relearning a lost motor skill, the patient, because of the extensiveness of the injury, had to overcome deficits in memory, visual processing, and cognitive tone. The process of quantitative SEMG was used to teach the patient to use a targeted series of muscles, which, in 14 weeks, brought her to the point that for many activities a headrest was no longer needed.

Introduction

Gunshot wounds to the head have become the leading or second leading cause of traumatic brain injury (TBI) in urban areas in the United States. In people aged 25 to 34 years, 12% of all TBIs are attributed to firearms. About 50% of surviving patients will suffer from seizures requiring antiepilepsy medication (Kazim, Shamim, Tahir, Enam, & Waheed, 2011). Over the past 30 years, because of advances in emergency room care, neurological operating procedures, and knowledge as to how the brain functions, there has been a marked reduction in mortality and morbidity from patients who have sustained a gunshot to the head (Lin, Lam, Siracuse, Thomas, & Kasper, 2012). Once the patient is out of danger from the initial injury, there remains an often long and convoluted rehabilitation process. This article is an extreme example of how biofeedback can be used to improve the quality of life of a severely brain-injured patient.

History

"Jane" was a previously healthy 13-year-old who was sitting in her living room doing her homework when a bullet from a drive-by shooting penetrated the house and lodged in the right occipital area of her brain. By Day 2, the injury worsened, with near complete right cerebral infarction, cerebellar infarction, and herniation of the brain. She experienced several medical crises and finally became stable enough to begin rehabilitation 4 months postinjury at the Cleveland Clinic Children's Hospital for Rehabilitation. After 2 months of inpatient therapy, she was discharged to home and began home health therapies twice per week, later transitioning to outpatient work.

Patient Presentation

Jane's formal diagnosis was "severe traumatic brain injury with spastic quadriparesis (paralysis affecting all four limbs) secondary to a gunshot wound to the head." She had remained medically stable and did not require additional hospitalizations. She was not able to hold her head upright, thus her inability to use a power wheelchair. She was able to tolerate oral intake with a gastric tube used for medications and fluids. She received home-bound schooling.

The loss of head control had implications far beyond social appearance. The efficient chewing of food, swallowing, maintaining a patent (unobstructed) airway, and speech production are all dependent on the correct head position. A typical adult head weighs 8 to 12 lb, and the loss of upright balance requires other nearby muscles to support the weight. Typically, the muscles of the back (trapezius, both upper and lower) are overworked, causing chronic pain. Jane was unable to bring her neck forward to retrieve food without falling into full cervical neck flexion. The hope was

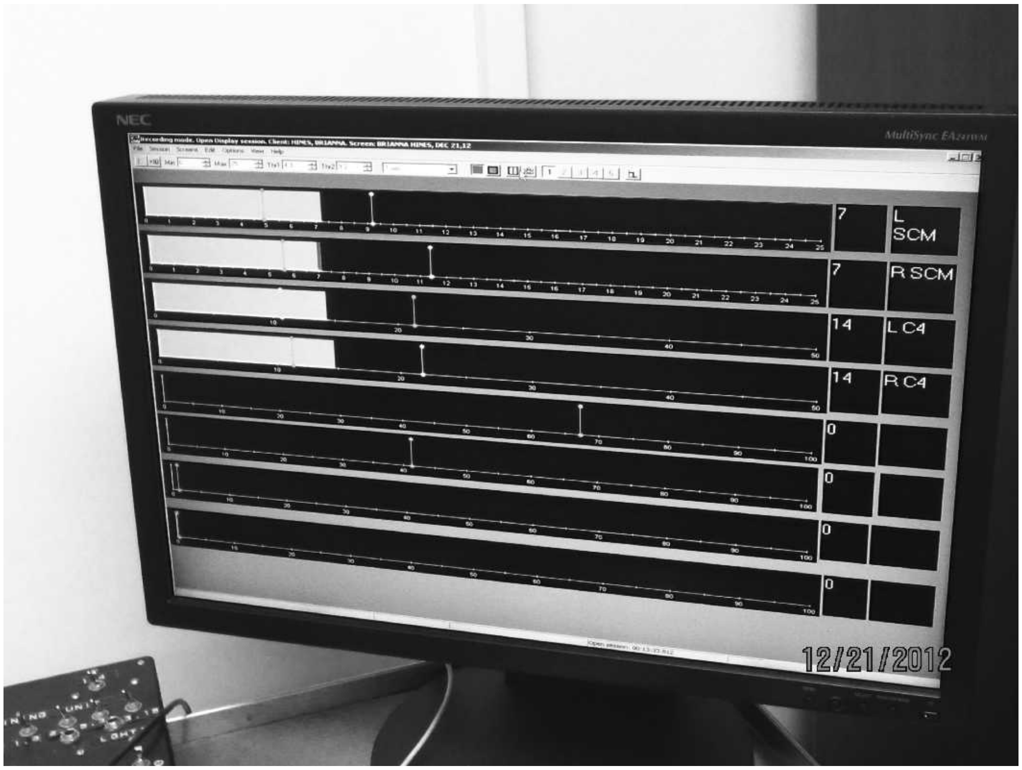

Figure 1. Biofeedback showing four surface electromyography signals, at the left and right sternocleidomastoid and left and right cerebral paraspinals at the fourth cervical (C4) level.

that improved head control along with gains in short-term memory and critical thinking would improve the chances of using a power wheelchair in the future.

Jane was seen for a series of 14 weekly visits in the motor control program. Treatment is ongoing. For all visits, she was confined to a wheelchair with the rear head support removed. Without the support, she displayed minimal antigravity head control. She was able to self-correct head position only by using her headrest with verbal and physical cueing. Aside from very brief attempts (5 seconds), her ability to hold her head in neutral was nonexistent and at first required moderate assistance to reposition.

Jane was able to converse in short sentences when she wanted to. Her voice tended to be soft with clipped speech. There were times when she showed lethargy for no apparent reason. Other times the lethargy appeared to be connected to poor sleep the night prior to the session. By her mother's report (and that of Jane's aide), Jane would use this to her advantage if she did not want to work. She would sit in her chair with her eyes closed, head leaning to one side seemingly asleep. This behavior appeared similar to avoidance techniques used by many adolescents when they do not wish to follow a request. Alternately learned helplessness or the belief that a situation is unchangeable may have been at work (Schwartz, 1978). There were instances in which she was unable to answer some simple questions during the session (when the clinician asked, "What's my name?" or "What day is it?") only to reply quickly with the correct answer at the end of the session. It appeared that anticipating going home (or possibly getting a snack on the way home) was her motivation to answer correctly. Therefore, a type of behavior plan was initiated in which active participation was required during the session to earn a favorite food snack. Also, her mother was asked to attend the sessions whenever possible because Jane tended to show minimal resistive behaviors with the mother.

Evaluation

Given Jane's severe impairments, teaching trunk control was not a viable option. Even when given support to ensure optimal alignment and positioning when sitting out of her wheelchair, she was unable to place her head in midline. This was due to a combination of poor neck muscular strength and limited awareness of her head position on her trunk. With her head placed in midline, she was able to maintain the position for up to 5 seconds. Any deviation in an anterior, posterior, or lateral direction of more than 5° was impossible for her to self-correct. Basically, she lacked the motor planning, control, and neck muscle strength to correct her head position once gravity had taken over. With her existing wheelchair headrest at the left temporal side of her head, she tended to fall into left lateral flexion more often than other positions.

Treatment

Quantitative surface electromyography (QSEMG) is an approach created by the first author in which the patient does not seek to control discrete muscles but rather a patterned response based on the constellation of muscles involved in the movement otherwise known as the myotatic unit (Bolek, 2012). In this case, the myotatic (functional muscle) unit consisted of bilateral sternocleidomastoid and cerebral paraspinals around the area of C4. These are the muscles involved in head flexion, extension, rotation, and lateral bending. The neck muscles that support the head include those in the back of the head (trapezius, levator scapula, splenius, suboccipitals, and posterior cervical muscles) and the front (sternocleidomastoid, infrahyoid). All of these muscles are deep except the trapezius, sternocleidomastoid, and posterior cervical muscles (Tank, 2009). Disposable pregelled electrodes (GS27, Bio-Medical Instruments, Inc., Warren, MI) were applied after the skin was abraded by rubbing with alcohol. The bandwidth of the encoder (Thought Technology Infiniti™) was set at 20 to 500 as recommended by Van Boxtel (2001) for these muscles.

Figure 1 shows the SEMG display (muscle activity is displayed as the root mean square [RMS]) for the four targeted muscles. If one looks closely, there are orange hash marks indicating the threshold parameters. If all the muscles remained in the area between the hash marks, then positive feedback in the form of a video reward was activated. This distribution of muscle activity corresponded with the head held in a neutral plane, upright such that the ears were equal distance from the shoulders with the head level when viewed from the front or side (see Figure 2A–2C). In practice, the session consisted of repeated attempts by Jane to hold her head upright, which early on in training was for a few seconds at best. This pattern was repeated over and over during the 60-minute session: a few seconds of success followed by losing head control followed by recovery.

A.
B.
C.

Figure 2. (A–C) Jane during biofeedback training, with video activated by achieving a patterned response measured at four muscle sites.

Outcome

Figure 3 is a summary of the percentage success achieved for each session over 8 weeks of treatment. The percentage success for any given session is the QSEMG score, which is the percentage of time all thresholds were met for the targeted muscle sites (in this case, four sites, bilateral sternocleidomastoid and cerebral paraspinals at C4). Perfor-

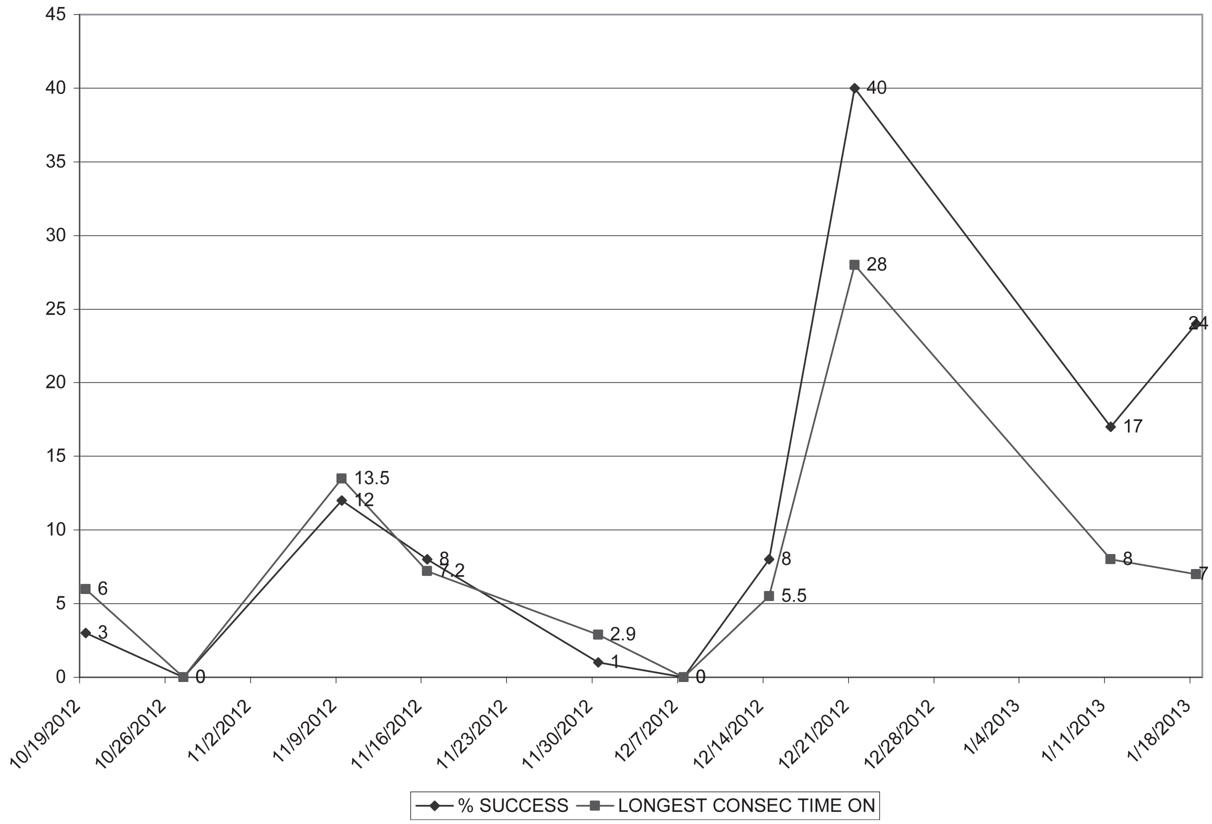

Figure 3. The diamond points show the percentage of session time, in a single session, during which all four muscles were in the criterion range. The square points show the longest consecutive time, during a single session, that all four muscles were in the criterion range.

mance is erratic for the first six sessions followed by a strong recovery on 12/14 and 12/21 and a leveling off on 1/11 and 1/18. Because the treatment occurred over the holidays, family members visited from out of town. Jane's mother stated that without any mention of this treatment, the relatives were surprised at Jane's ability to hold her head erect. Her occupational therapist observed that teaching self-feeding skills was much easier now with her newly established head control. Another observation is particularly telling. It was observed that Jane would increasingly arrive for the session with her head held upright in good form. This was also observed at the completion of a session, even when performance during the session was poor. Her mother's belief was that Jane did much better outside of the treatment sessions than in it. Perhaps Jane viewed this as a newly acquired skill and had become a bit bored with the treatment. In any case, it was decided to set a schedule to remove the supportive headrest on the back of her wheelchair for increasing periods when she was at home. It was felt by all that she no longer needed the headrest.

Discussion

There were a number of issues that arose during treatment. Jane had sustained a massive loss of brain tissue including subcortical structures. The limbic system (traditionally thought of as the hypothalamus, hippocampus, and the amygdala) are concerned especially with emotion and motivation (Mogenson, Jones, & Yim, 1980). As previously reported, Jane had problems with memory. The hippocampus is known to play an important role in the consolidation of new memories. There were many instances in which one had to take a guess as to what was going on, if Jane was not an active participant during the session. Was she truly not recalling what was done during the previous session or was it an attempt to escape working? Was she really falling asleep due to fatigue (a known true occurrence post–head injury) or was she feigning tiredness? A typical session played out all of the above scenarios. Our strategy was to encourage, guide, offer support, provide direction, and exercise firmness when needed, with much praise for success. Often a successful session was followed by a poor one the following week.

Figure 3 warrants further analysis. In the past, treatment using SEMG to teach motor control has focused on up-training the agonist and/or down-training the antagonist. Although such an approach may work in some simple cases, the vast majority of human movements are accomplished by the use of a constellation of muscle activity that involves effort (SEMG amplitude), inhibiting muscle activity (as when antagonist muscle groups relax), the timing of muscle contractions, and the frequency at which the muscle activation is occurring. As previously reported (Bolek, 2012), the profile of individual muscle activity plotted using RMS values does not capture the whole picture as to what is happening during a movement sequence.

Targeting a constellation of muscles may seem like a straightforward task; however, it involves more than just selecting the correct muscle group and setting appropriate thresholds. In what sequence do the muscles fire? Is there a pattern of one muscle group firing to make up for the inactivity of another more appropriate muscle group given the movement in question? If the appropriate muscle group fires for the movement desired, is there also a properly timed eccentric (muscle lengthening) after the work is done? Is there a predominance of Type I or Type II muscle activity? What level of muscle-firing velocity is seen during recruitment? Is there a smooth concentric/eccentric muscle contraction or is it irregular with pronounced peaks and valleys? Is the amount of time of muscle activity in the concentric/eccentric phase vastly different? Does the patient report different affective states during the movement? Is it described as pain, fatigue, or tightness? Can the patient generate the concentric/eccentric contraction on command? Is one muscle group serving as a brace for other muscle groups to function? Is there referred pain, reported during the movement, to other parts of the body? Is the movement performed at a cost of other physiological states such as breath holding or increases in overall tension? Any of the above can serve as a feed-forward/-backward system that can have a direct effect as to whether a treatment plan is successful.

Given the above, it is easier to understand why the only thorough review of this topic (Woodford, 2009) concluded that "EMG biofeedback does not appear to have any positive benefit for recovery" (p. 5). Not one of the studies analyzed in the review targeted a constellation of muscles involved in the movement. In fact, all of the studies limited the target muscles to two (e.g., Amagan, Tascioglu, & Oner, 2003; Bradley et al., 1998; Cozean, Pease, & Hubbell, 1988; Mulder, Hulstijn, & van der Meer, 1986). For example, if wrist extension/flexion is desired in a poststroke hemiplegic patient and only the wrist extensors/flexors (agonist/antagonist) are targeted, there is often weakness in the base of support (pelvis), which if not included in the targeted muscles will doom the treatment to failure. It is not possible to effectively treat a motor control problem without attending to the biomechanics of movement. Attending to the biomechanics of movement requires including the myotatic unit during treatment.

Some Closing Observations

The patient-clinician interaction during the sessions is an all-too-important element toward a successful outcome. The mechanics of the treatment have already been well described; however, consider for a moment what it means to spend a 60-minute session working on head control for a total of 14 hours over as many weeks. There were moments of laughter, quiet pauses, sternness, frustration, success, boredom, failure, enormous effort, small talk, rest, and encouragement, all of which needed to be carefully choreographed by the clinicians. During every session, there is learning going on, both for the patient and clinician.

References

Amagan, O., Tascioglu, F., & Oner, C. (2003). Electromyographic biofeedback in the treatment of the hemiplegic hand: A placebo-controlled study. *American Journal of Physical and Medical Rehabilitation, 82*, 856–861.

Bolek, J. E. (2012). Quantitative surface electromyography: Applications in neuromotor rehabilitation. *Biofeedback, 40*(2), 47–56.

Bradley, L., Hart, B. B., Mandana, S., Flowers, K., Riches, M., & Sanderson, P. (1998). Electromyographic biofeedback for gait training after stroke. *Clinical Rehabilitation, 12*, 11–22.

Cozean, C. D., Pease, W. S., & Hubbell, S. L. (1988). Biofeedback and functional electrical stimulation in stroke rehabilitation. *Archives of Physical Medicine and Rehabilitation, 69*, 401–405.

Kazim, S. F., Shamim, M. S., Tahir, M. Z., Enam, S. A., & Waheed, S. (2011). Management of penetrating brain injury. *Journal of Emergency Trauma & Shock, 4*, 395–402.

Lin, D. J., Lam, F. C., Siracuse, J. J., Thomas, A., & Kasper, E. M. (2012). Time is brain, the Gifford factor. *Surgical Neurology International, 3*, 98–102.

Mogenson, G. J., Jones, D. L., & Yim, C. Y. (1980). From motivation to action: Functional interface between the limbic system and the motor system. *Progress in Neurobiology, 14*, 69–97.

Mulder, T., Hulstijn, W., & van der Meer, J. (1986). EMG feedback and the restoration of motor control: A controlled group study of 12 hemiparetic patients. *American Journal of Physical Medicine, 65*, 173–188.

Pollock, A., Baer, G., Pomeroy, V., & Langhorne, P. (2007). Physiotherapy treatment approaches for the recovery of postural control and lower limb function following stroke. *Cochrane Database of Systematic Reviews*, 1, CD001920.

Schwartz, B. (1978). *Psychology of learning and behavior*. New York: W.W. Norton & Co., Inc.

Tank, P. W. (2009). *Grant's dissector*. Baltimore, MD: Lippincott, Williams and Wilkins.

Van Boxtel, A. (2001). Optimal signal bandwidth for the recording of surface EMG activity of facial, jaw, oral and neck muscles. *Psychophysiology*, *38*, 22–34.

Woodford, H. J. (2009). EMG biofeedback for recovery of motor function after stroke (review). *The Cochrane Collaboration, 1*. http://www.thecochranelibrary.com.

Jeffrey E. Bolek

Jennifer Yost

Correspondence: Jeffrey E. Bolek, PhD, BCB, Cleveland Clinic Children's Hospital for Rehabilitation, 2801 Martin Luther King Jr. Drive, Cleveland, OH 44104, email: bolekj@ccf.org.