Surface electromyography holds great potential in helping patients recover from injuries that result in motor impairments. To be able to assist the patient, the clinician must consider research obtained from the study of implicit/explicit learning, contextual interference, and basic learning theory. Quantitative surface electromyography (QSEMG) is a technique that is constructed around this basic research in order to present the optimal learning environment for the patient.

Why Research Does Not Support the Use of SEMG as a Means to Facilitate Motor Re-education

In a review published in the Cochran Review in 2009, Price found that “When all the available data are combined, electromyographic biofeedback does not appear to have any positive benefit for recovery after stroke” (p. 5). Unfortunately, the available research is a combination of biofeedback therapy during functionally goal-directed dynamic movements, mixed in with programs that target a simple movement involving one or two muscle sites unrelated to function (Glanz, Klawansky, & Chalmers, 1997; Moreland, Thompson, & Fuoco, 1998; Schleenbaker, 1993). The former, such as training how to reach for and hold a cup, produces much more transfer to the real world than the latter, such as training simple wrist extension/flexion, which is not linked to a functional movement (Huang, Wolf, & Jiping, 2006). Another reason for the perceived lack of efficacy in using SEMG to restore motor function is that the typical benchmark used to measure effectiveness is the difference from baseline in the mean microvolt level or average integral value (Finley, Etherton, Dickman, Kari- mian, & Simpson, 1981; Mulder, Hulstijn, & van der Meer, 1986). As will be seen, changes (or the lack of) in SEMG microvolt level are not necessarily related to changes in function. Lee, Hill, Johnston, and Smiehorowski (1976) and Mroczak, Halpern, and McHugh (1978) found SEMG ineffective in restoring motor function, but they used only changes in SEMG amplitude rather than voluntary function as an outcome (dependent) measure. A number of research studies (e.g., Mulder, Hulstijn, & van der Meer, 1986) show that changes in SEMG amplitude do not correlate with changes in functional performance. In addition, increases in SEMG amplitude are only interpretable when muscles are used at a constant speed or muscle length, which is not the case in daily living.
case during functional movement (Keefe & Surwit, 1978). During functional movement the kinematics of the joints change, causing an alteration in the amount of effort a muscle needs to expend to accomplish a task. For example, the activity level of the bicep under a load while flexing the arm will be different depending on how far extended the arm is from the body. While this is an obvious example, other changes in joint position are not as obvious. Another reason for failure is that SEMG feedback is used as a “crutch” during training without attending to basic learning principles, leaving no long-term carryover effect outside of the treatment session (Moreland & Thomson, 1994).

**Two Major Learning Systems**

There are two major learning systems: implicit and explicit. Implicit (or procedural) learning is the ability to acquire motor skills through practice and is not directly accessible through conscious recollection of facts. It occurs incrementally, with practice, over a period of time, and there is no conscious recollection of what elements of performance improved (Vidoni & Boyd, 2007). Procedural learning is mostly dependent on the basal ganglia, which also happens to mediate the effects of reward and punishment (Willingham, Salidis, & Gabrieli, 2002). Reward but not punishment enhances the implicit learning of sequences (Wachter, Lungu, Willingham, & Ashe, 2009). Performance of implicitly learned motor skills are less affected by anxiety than explicitly learned motor skills (Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010). Procedural learning is knowing “how.” Explicit (or declarative) motor learning is the conscious memory of facts, events, and episodes. Explicit learning is knowing “that.” Explicit learning is associated with the medial temporal lobe and diencephalic brain structures (Squire, 1992). Implicit learning can be disrupted by first giving the patient suggested (explicit) instructions on how to perform the task (Boyd & Weinstein, 2003; Schmidtke & Heuer, 1997). In other words, first telling the patient “This is how you do it” actually interferes with the formation of a motor plan (Green & Flowers, 1991). This may be because the access to flexible knowledge for implicit learning to occur conflicts with the need for automatic responses supported by the basal ganglia, motor cortical regions, and the cerebellum (Vidoni & Boyd, 2007).

**Why QSEMG?**

Quantitative analysis is a means by which a signal is partitioned into its component parts based on a predetermined algorithm. For example, quantitative electroencephalography (QEEG) is a method of electrically processing the EEG signal to numerically represent the contributions of each brain wave frequency (Wallace, Wagner, Wagner, & McDeavitt, 2001). A common application is to monitor 19 sites over the scalp. By using spectral analysis, a segment of the EEG signal is separated into its component frequencies along with the amplitude of same. I have coined the term “QSEMG,” or quantitative surface electromyography, to describe a similar quantitative interpretation of the SEMG signal. In QSEMG, the SEMG signal from multiple sites is statistically processed so that the root mean square (RMS) data are transformed into a functional time domain score (FTDS), where “function” is defined as the ability to use muscle recruitment to accomplish a task. The task may be anywhere on the continuum from the ability to hold a cup to throwing a 90-mile-per-hour fastball. In QSEMG, the focus is to internalize the correct muscle pattern recruitment rather than relying only on individual muscle line tracings on a display screen. Each target muscle is selected relative to a unique and specific therapeutic threshold, which is selected by the clinician for its relevance to the functional goal. When this constellation of muscle groups is on target, positive feedback, such as a video reward, is activated. In a typical motor activity, some muscles need to be used and some relaxed. Failure to maintain any muscle at the therapeutic threshold (either above or below, depending on the outcome desired) terminates the reward. In this way, a form of bandwidth corrective feedback (Weinstein, 1991) is employed to provide information when the patient performs outside a preset band of accuracy. Activation of a video is a preferred reward due to the ease of controlling the on/off set. Over the course of a 60-minute session, the patient may start and stop the reward many times, as the correct movement pattern is found, lost, and regained.

**QSEMG Promotes Learning by Increasing the Contextual Interference Effect**

There is a body of research on the contextual interference effect (Magill, & Hall, 1990) that supports the use of QSEMG. The contextual interference effect occurs when several tasks must be learned and are practiced together (Batig, 1979). Under these conditions, the immediate performance of the task is depressed but the later learning is enhanced. By having the patient practice several different but related motor skills during the same practice session, multiple SEMG sites increase the contextual interference effect, leading to greater retention and transfer of learning. A greater transfer of learning is critically important to challenge previous criticisms that improvements achieved during SEMG treatment of motor dysfunction do not transfer to the “real world.”
Operant Conditioning Principles

In operant conditioning, a positive reinforcer increases a behavior by presenting a reward following the behavior, while a negative reinforcer increases a behavior by terminating an unpleasant event after the behavior. Similarly, a positive punisher decreases a behavior by presenting an unpleasant event following the behavior, while a negative punisher decreases a behavior by terminating a pleasant event following the behavior (Schwartz, 1978). Iwata and Bailey (1974) and Schwartz (1978) presented data that positive reinforcement and negative punishment are equally effective in modifying behavior. As described above, QSEMG utilizes both these forms of operant conditioning. In QSEMG, meeting the criterion thresholds results in a movie appearing on a TV screen or monitor (positive reinforcement). Failure to maintain the correct recruitment pattern, once achieved, results in termination of the movie (negative punishment).

The Application of QSEMG in a Clinical Setting: Two Patient Examples

Case One
KL was a four-year-old female with cerebral palsy and spastic diplegia. Spastic deplegia is a neuromuscular condition of hypertonia and spasticity, affecting the lower extremities. The goal was to teach her independent standing, with weight evenly distributed, pelvis level, back straight, and her arms at her sides.

Figures 1, 2, and 3 show the usual line graphs of the root mean square (RMS) of two SEMG signals, one from the left and one from the right side of three different muscle groups, for a one-hour treatment session. The muscle groups were: (a) the L/R Quadriceps, programmed to be above threshold, (b) the L/R Upper Thoracic muscles, set to be within a threshold range, and (c) the L/R Thorocolumbar muscles, also set to be within a threshold range. Thus, each of the three muscle groups had its own separate goal. Figure 4 shows the QSEMG, representing, at successive moments during the training, the length of time that the muscles at all targeted sites were at the training criteria (at or above threshold, below threshold, or within the designated range). The QSEMG provides information that is not readily visible on the RMS muscle charts. Looking only at the RMS profiles it does not appear that either the left or right quadriceps were changing in their energy output. The upper thoracic and thorocolumbar RMS profiles are especially difficult to interpret because the thresholds are within a range of SEMG values (i.e., both greater than and less than). One would be hard pressed to use just this...
Figure 2. RMS SEMG of L/R upper thoracic, set to be within a threshold range.

Figure 3. RMS SEMG of L/R thorocolumbar, set to be within a threshold range.
information as an indicator of progress. However, the QSEMG on Figure 4 shows the patient progress very clearly. There is a steady increase in the time all thresholds are met, with a peak at or around 16 seconds midway through, and a gradual fatigue-induced tapering off. This indicates that by midsession, KL was keeping all three muscles at their training goal for about 16 seconds at a time. With the QSEMG data shown on Figure 4, one could feel confident that the treatment appeared to be on the right track. Additional plotting of the QSEMG in future sessions will either support or challenge this conclusion.

Case Two
AM was a six-year-old female, poststroke. Figures 5 through 9 show line graphs of the RMS SEMG values for specific muscles, the left gluteus maximus, programmed to be at or above a threshold; the left hip adductor, set to be at or above a threshold; the left hamstring, set to be below threshold; the left medial quadriceps, set to be above threshold; and the left lateral quadriceps, set to be below threshold. Figure 10 shows the QSEMG, representing the times when all five muscles are meeting the thresholds set for them.

It is difficult to see any pattern on the RMS profiles of the left gluteus maximus, left lateral quadriceps, and left medial quadriceps. The left adductor appears to be on a downward trend, as does the left hamstring. Overall the five charts are difficult to interpret. Because the QSEMG is a composite of all the targeted sites, the data therein is much richer than if one were to just look at individual profiles. AM’s QSEMG shows a steady increase in the time that all the thresholds were met, reaching a span of meeting thresholds for nearly 80 seconds at the end of the session.

Discussion and Summary
QSEMG addresses many of the criticisms that have been repeatedly mentioned in past outcome studies on the use of SEMG in the treatment of motor dysfunction. Past studies have criticized the following: attempts to change a functional movement by targeting only the muscle agonist/antagonist, an oversimplified reliance on isolated changes in SEMG amplitude as an indicator of functional change, and the failure to plan in the treatment program for transfer of the skill to the real world.

1. Explicit directions are deliberately avoided, allowing the patient to discover and internalize via SEMG the correct motor plan in order to learn a functional movement.
2. Past outcome studies on the effectiveness of SEMG in the treatment of motor dysfunction often found that the learning dissipated in followup studies (Gentile, 1998).
Figure 5. RMS SEMG of left gluteus maximus, set to be at or above threshold.

Figure 6. RMS SEMG of left adductor, set to be at or above threshold.
Figure 7. RMS SEMG of left hamstring, set to be below threshold.

Figure 8. RMS SEMG of left medial quadriceps set to be above threshold.
Figure 9. RMS SEMG of left lateral quadriceps set to be below threshold.

Figure 10. QSEMG, showing times that all targeted sites met the threshold goals.
By using multiple muscle sites, QSEMG increases contextual interference leading to improved transfer and retention of the newly learned motor plan.

3. Because changes in SEMG amplitude do not correlate with changes in functional performance, a new metric, the functional time domain score (FTDS), is used to evaluate performance. Because the FTDS is composed of all muscles that are part of the treatment, it represents a more accurate overall picture of the patient’s progress, both within and between treatment sessions. Changes needed in the treatment plan stand out in bold relief in the QSEMG chart.

4. Each 1-hour treatment session produces a FTDS. As treatment progresses over several weeks, each FTDS (percent success in a given session) can be plotted on a graph to determine if the treatment program is working (Bolek, 2006). Midcourse corrections can improve the likelihood of a successful treatment program.

5. The transfer of skills learned during treatment to “real life” is facilitated by using basic learning theory principles such as successive approximation, chaining individually mastered motor plans, and fading the feedback whenever possible.

Further research is needed to validate the usefulness of the QSEMG approach with external indicators of success, such as physical and occupational therapy-based tests of improved function (WeeFIM, 2011). Both patients in this report began to make progress toward functional goals (standard physical therapy goals), which had not occurred prior to the use of QSEMG.

References


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