Special Issue

Future Directions in Surface Electromyography

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The use of surface electromyography (SEMG) has increased exponentially in the past four decades. SEMG is one of the most widespread measures employed today in psychophysiological assessment and one of three primary biofeedback modalities. This article briefly outlines three areas that the author believes are important for SEMG to address if it is to continue to flourish in the future: applications in telehealth, the use of telemetry and ambulatory monitoring, and studies on the stability or reliability of surface electromyography.

Surface electromyography (SEMG) has become one of the most widely used tools in psychophysiological assessment and in clinical biofeedback treatment. The present article examines three areas critical to the expanded clinical and research role of SEMG: the use of SEMG in telehealth, the use of telemetry and ambulatory SEMG monitoring, and evidence for the temporal stability or reliability of SEMG measures.

Applications in Telehealth

Telehealth, a relatively new medium for treatment delivery, has become more widely available and utilized in the past decade. Telehealth involves the use of high-resolution television cameras and monitors and high-speed communications lines to deliver treatment over a distance. This delivery system allows the clinician to remain in his or her office or medical facility while the patient is seen at a remote site nearer to the patient’s home or work. This technology potentially has the advantage of saving both the patient and the provider considerable time, effort, and monetary cost (i.e., travel time and associated expenses). In relatively large states, provinces, or countries with sizable and broadly dispersed rural populations, such direct and indirect cost savings could be considerable. These savings are, of course, predicated on the assumption that the telemedicine-delivered treatment is as efficacious as the office-based intervention. Arena and Stoddard (in press) have delineated some pitfalls in the use of telehealth psychophysiological applications, including (a) privacy and meeting HIPAA requirements, (b) state licensing board requirements and malpractice insurance, (c) providers’ comfort levels, (d) insurance reimbursement, (e) informed consent, and (f) use of support personnel.

Although this is likely the key direction that SEMG biofeedback and, indeed, biofeedback in general will be going in the future, there have been few applications of biofeedback in telehealth. Earles, Folen, and James (2001) described a videophone procedure for psychotherapy and psychophysiological treatment used in the military. They also presented three uncontrolled case reports: two patients suffering from vascular headache and another from irritable bowel syndrome. The two headache patients decreased their headache activity by 50% each and reported improved mood. All patients had both office and telemedicine sessions and reported no difference between the office and telemedicine settings. Folen, James, Earles, and Andrasik (2001) presented some data on two headache patients: one migraineur without aura and another with chronic daily headache. Both of these subjects had a single session of telemedicine biofeedback (over a videophone using standard telephone lines) interspersed with numerous sessions of office-based treatment.

Arena, Dennis, Devineni, Maclean, and Meador (2004) presented a case series that evaluated the preliminary effectiveness and feasibility of an analogue telemecine system for delivery of psychophysiological treatment (relaxation therapy and thermal biofeedback) for vascular headache. Results indicated that three of four subjects improved on measures of headache activity. Arena, Hannah, and Meador (2010) then evaluated the results of a standard office-based (n = 20) treatment compared with a telehealth (n = 23) system (subjects were brought to the clinic but received all treatment through a videoconferencing system, having no face-to-face contact with the therapist) for delivery of psychophysical treatment (12 sessions of relaxation therapy and thermal biofeedback). Results indicated no difference between the telehealth and standard groups posttreatment, with the averaged percentage improvement from baseline in terms of the headache index (defined as the mean daily headache activity score averaged per week and is considered to be the most
sensitive and frequently used measure in outcome research because it combines both headache intensity and duration) in both groups being greater than 50%. More importantly, in terms of clinical improvement (i.e., the percentage of individual subjects who at posttreatment achieved at least a 50% reduction in headache index scores from baseline), there was no difference between the groups. One-year follow-up on a subset of the subjects demonstrated that treatment results were maintained.

Morelli, Maccioni, Lanzetta, Macellari, and Giansanti (2008) recently designed and constructed force measurement equipment to assess hand-finger function in pressing tasks, which they evaluated in five subjects who had their hands transplanted. To monitor functionality of the hand and fingers, they created integrative software, which included SEMG biofeedback to provide real-time telemedicine feedback on hand function to both the patient and the therapist. Results indicated that both patients and therapists accepted the system, and it was found to be user-friendly and effective. This study is a very exciting application of telehealth applications of SEMG for physical therapy.

Although there are barriers to the implementation of telehealth applications, which Arena and Stoddard (in press) have previously described, it is likely that the future of biofeedback and applied SEMG lies in this area. Given that, the relative paucity of research regarding this topic is quite perplexing.

**Telemetry and Ambulatory Monitoring**

One area that would seem to be of great interest for applied psychophysiologists in general, and SEMG clinicians and researchers in particular, is ambulatory monitoring of patients in their everyday environment. For example, many clinicians and researchers postulate that muscle abnormalities may not be present when individuals are at rest but manifest only when people are in motion and going about their lives. More importantly, it could be the case that an individual can easily learn the biofeedback response when sitting in a recliner in a darkened office, in a temperature- and humidity-controlled room, but, when at their workplace, home, and so forth, they may not be able to utilize their biofeedback training (i.e., generalization of the biofeedback response). Ambulatory monitoring of psychophysiological responses such as SEMG may be able to assist researchers and clinicians in determining, and better understanding, the relationship between the physiological response and another variable, perhaps even leading to better understanding of the etiology of the disorder in that particular patient.

For example, through ambulatory monitoring of SEMG, along with daily diary monitoring of levels of stress and pain, one might examine four possible relationships in the etiology and/or maintenance of SEMG activity and (a) pain and (b) stress, using cross-lagged correlational techniques: an isomorphic relationship (same time changes in EMG activity lead to same time changes in pain or stress and vice versa), a consequence relationship (changes in pain or stress precede changes in SEMG activity), a precursor relationship (changes in EMG activity precede changes in pain or stress), and no relationship. A number of individuals (Arena et al., 1997; Geisser, Robinson, & Richardson, 1995; Hatch et al., 1991) have attempted to do just that, with little success (i.e., no relationship was found).

The use of SEMG ambulatory monitoring, although especially exciting for its possible treatment implications, must jump one important hurdle: the assumption that conducting ambulatory monitoring of SEMG will give clinicians important information in helping to determine how to proceed in treatment. This assumption must be empirically tested to demonstrate the clinical utility of SEMG ambulatory monitoring. That is, research must demonstrate that tailoring a treatment based on ambulatory monitoring data leads to better treatment outcomes than simply giving patients a standard treatment. If clinician-researchers cannot demonstrate this, then the procedure has little clinical application and is simply an expensive plaything.

There have been a limited number studies that have utilized ambulatory monitoring of psychophysiological responses, although there are considerably more than in telehealth. The vast majority of these studies have involved ambulatory heart rate and blood pressure monitoring (indeed, this is so commonly used in medicine that the term Holter monitor is now commonly known among laymen). Other non-SEMG examples of ambulatory recording are those of Freeman and Woodard (1992), who objectively measured hot flashes in 33 women by use of a 24-hour ambulatory monitoring of the sterna skin conductance level and randomly assigned them to eight sessions of paced respiration, relaxation therapy, or alpha biofeedback (paced respiration was superior to the other two treatments). Meuret, Wilhelm, and Roth (2001) successfully monitored end-tidal partial pressure of carbon dioxide (PCO2) using 24-hour ambulatory monitoring in four patients with panic disorder who were given PCO2 biofeedback therapy, which was successful in reducing panic symptoms. Jovanov, Raskovic, and Hormigo (2001) described an ambulatory thermister-based breathing sensor for circadian rhythm evaluation.
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In addition to the work by Arena and Hatch described above, a number of studies have been done on ambulatory monitoring of SEMG, including assessment and treatment of bruxism (Mizumori et al., 2009), measurements of quadriceps activity in both osteoarthritis individuals and healthy controls (Howe & Rafferty 2009), and upper trapezius SEMG activity in individuals with pain and without pain (Carlson et al., 1996). After 3 days of monitoring, Carlson and colleagues found no differences in the SEMG activity levels of the two groups.

Pettersen and colleagues (e.g., Pettersen, 2005; Pettersen & Westgaard, 2001) have successfully used ambulatory monitoring of SEMG in classical singers. In one study (Pettersen & Westgaard, 2001), trapezius and sternocleidomastoid muscle activity was recorded bilaterally using an ambulatory monitoring system in two groups of eight conservatory singing students. The students were then given EMG biofeedback on these muscles, which successfully lowered the muscle activity levels during the biofeedback training. In another article, Pettersen (2005) outlined similar work with professional opera singers. The work of Pettersen and his colleagues is an outstanding example of combining ambulatory SEMG monitoring and applied psychophysiology treatment. Ambulatory recording of SEMG has also been used in sports medicine, with groups such as golfers both with and without low back pain (Cole & Grimshaw, 2008) and runners (Mikkola, Rusko, Nummela, Pollari, & Häkkinen, 2007).

In an exciting and novel study, Sporrong, Sandsjo, Kadefors, and Herbergs (1999) used ambulatory SEMG with construction workers, while they were working, to assess shoulder pain. The authors discovered that "EMG data showed that nearly 50% of the work was spent with trapezius activity that exceeded that of the reference contraction used (about 15% of maximal voluntary contraction) and that the time spent in muscular relaxation was 10%" (p. 495). They concluded that “this method of workplace investigation can be used for improving work organization and workplace design, in order to reduce the risk of developing work related shoulder disorders” (p. 503).

Recently, a very interesting study has been published that incorporated both telehealth and ambulatory recording of SEMG. Kishimoto et al. (2009) developed a wearable system for monitoring SEMG and gait acceleration in elderly individuals and patients with gait problems that can be used over the Internet. The system successfully detected lack of exercise in healthy volunteers as well as hemiplegic walking in individuals with hemiplegic gait. This is an exciting marriage of the two technologies.

However, even though there has been a fair amount of research in SEMG ambulatory recording, much more needs to be done, especially in subjects with headache or lower back pain.

Reliability of SEMG

Temporal stability, or reliability, of SEMG and other measures used in psychophysiological assessment and treatment has been a topic of increasing importance in the past four decades. If an assessment measure is not stable over time, it is a poor indicator of what is purportedly tested. Given the wide range of factors that can affect the magnitude of the various psychophysiological responses, not surprisingly, there can be difficulties in obtaining stable recordings across time. Moreover, if the reliability of a measure is low, there is generally an inability to obtain a high estimate of validity (whether the measure actually records a true representation of the concept supposedly assessed).

Since the early 1980s, Arena and others have examined the reliability of SEMG responses, and there is now a significant body of literature supporting the assertion that SEMG measures, when employed as absolute values, have moderate to high reliability (correlations of .65 or greater) in healthy subjects in standard laboratory assessments (e.g., conditions such as baseline and relax body, as well as stressors such as mental arithmetic, negative imagery, and cold pressor). When SEMG is looked at in relative terms, such as raw change scores from baseline or percentage change from baseline, it is frequently less reliable. When examined in terms of stimulus response specificity (that is, individuals as an aggregate exhibit a response pattern specific to a stimulus) or individual response stereotypy (that is, a single individual always responds to various stressor conditions with one psychophysiological response), the measures are also reliable (e.g., Arena, Blanchard, Andrasik, Cotch, & Myers, 1983; Arena, Goldberg, Saul, & Hobbs, 1989; Arena & Hobbs, 1995; Foerster, Schneider, & Walschberger, 1983; Hinz, Hueber, Schreinicke, & Seibt, 2002; Robinson, Whitsett, & Kaplan, 1987).

The challenge for SEMG researchers and clinicians and applied psychophysiologists in general is to now explore the reliability of their psychophysiological measures in clinical populations as well as in new methodologies such as ambulatory monitoring. Researchers have begun to do just that. I will summarize one negative report and a series of encouraging reports in this area.

Callaghan, McCarthy, and Oldham (2009) examined the between-days reliability of SEMG recordings from the superficial quadriceps during a multijoint submaximal fatiguing protocol. They had three groups of subjects—
healthy controls, individuals with patellofemoral pain syndrome, and individuals with knee osteoarthritis—go through the protocol on 3 separate days. They concluded that “the poor between-days reliability and high measurement error suggests that surface EMG should not be adopted to assess fatigue during multi-joint sub-maximal isometric quadriceps testing” (p. 172).

Both Airaksinen and Airaksinen (1998) and Arena et al. (1994) have found SEMG ambulatory monitoring to have good reliability. In the Arena and colleagues (1994) study, 26 healthy controls wore a lightweight (24-ounce) device that measured bilateral upper trapezius SEMG, as well as peak and integral motion, for 5 consecutive days for up to 18 hours each day. Analyses of variance on the four measures revealed no difference between any of the four measures over the 5 days. Intraclass correlational coefficients for the two SEMG variables across 5 days were significant, with alpha levels set at .01. The two SEMG measures were highly correlated ($r = .77$); the two motion measures were also highly correlated ($r = .60$), but at a lower magnitude than SEMG values. Thus, at least when examined using healthy controls, the reliability of SEMG ambulatory recording appears to be reliable.

Arena, Sherman, Bruno, and Young (1990) measured bilateral SEMG recordings of paraspinal muscle tension in 29 lower back pain and 20 normal subjects in six different positions (standing, bending from the waist, rising, sitting with back supported, sitting unsupported, prone) on two occasions. Measures were highly reliable when examined using analysis of variance procedures. As with other research, statistically significant reliability coefficients were obtained when the absolute values of the measures were examined, and when examined as relative (percentage change from baseline [prone] condition) values, differences between the two groups were observed: The normal controls were statistically more reliable than lower back pain subjects during every condition. This study demonstrates how important it is to examine the reliability of SEMG measures in both healthy controls and clinical populations.

Cram, Lloyd, and Chan (1990) looked at the reliability of SEMG in three groups of 102 subjects (those with back, head, and neck pain) and found reliability coefficients on 10 muscle groups ranging from .41 to .94. Lariviere, Arsenault, Gravel, Gagnon, and Loisel (2002) looked at ways to increase the reliability of different SEMG indices developed for the assessment of back muscle impairment on 20 healthy controls and 20 individuals with low back pain. They found overall reliability coefficients for the individual muscles to be good to excellent (p. 95) for both low back pain subjects and controls. Pauliina, Jorma, Paula, and Olavi (2002) evaluated four different intravaginal SEMG probes for biofeedback exercises and measurements on nine urinary incontinent patients. Correlations ranged from .84 to .97, and there were no statistically significant differences between the probes. These strong correlations in several studies to date are encouraging for the reliability and validity of SEMG in both research and clinical work.

**Conclusion**

The future of SEMG is decidedly bright. By continuing to expand into relatively novel technologies such as telehealth and ambulatory recording, and by further examining the reliability of these measures in clinical populations and these new technologies, SEMG can be assured a future as triumphant as its past.

**References**


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