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# A Preliminary Analysis of EMG Variance as an Index of Change in EMG Biofeedback Treatment of Tension-Type Headache

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*The effectiveness of EMG biofeedback training for tension headache has been well established. Previous studies evaluating changes in an average EMG activity score from pre- to posttreatment have not consistently found a relationship between a reduction in average EMG activity and headache improvement at posttreatment. The current study is a preliminary analysis of the utility of EMG variance as another possible mechanism of change. Frontalis EMG average activity and variances from 6 chronic tension-type headache sufferers who demonstrated significant improvement in headache activity at posttreatment (at least 70%) and 6 chronic tension-type headache sufferers who did not demonstrate improvement (less than 30%) were examined across 6 sessions of biofeedback treatment. The improved group demonstrated larger time-specific EMG variance in relation to mean EMG amplitudes during all treatment sessions. A dramatic decline in time-specific variance was observed during the later treatment sessions for improved participants; this pattern was not observed in the group who demonstrated little or no improvement. Results from the current study suggest that the inclusion of both average EMG activity and EMG variance may provide a more comprehensive measure to evaluate possible physiological changes responsible for improvement in headache activity following EMG biofeedback training.*

**KEY WORDS:** EMG; change mechanisms; biofeedback treatment; chronic tension-type headache.

## INTRODUCTION

Tunis and Wolff (1954) suggested that tension headaches resulted from sustained contraction of the scalp, face, and neck muscles. Budzynski, Stoyva, Adler, and Mullaney (1973) evaluated the efficacy of EMG biofeedback training as a nonpharmacological treatment for tension headaches on the basis of this etiological model. Namely, EMG biofeedback training could result in an improvement in the ability to control muscle activity. This enhanced skill could be practiced throughout the day to reduce muscle tension and decrease tension

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headache activity. Three decades of research have supported the efficacy of EMG biofeedback as a treatment for tension-type headaches (see Blanchard & Andrasik, 1985; Bogaards & ter Kuile, 1994).

Although the use of EMG biofeedback training was originally based on the assumption that tension headaches result from sustained muscle contraction, overall decreases in EMG activity following EMG biofeedback training have not consistently predicted improvement in tension headache activity (Andrasik & Holroyd, 1980; Arena, Bruno, Hannah, & Meador, 1995; Cox, Freundlich, & Meyer, 1975; Hart & Cichanski, 1981; Holroyd et al., 1984; Holroyd, Andrasik, & Noble, 1980; Kroener-Herwig & Weich, 1989; Lacroix, Clarke, Bock, & Doxey, 1986; Rokicki et al., 1997). A landmark study conducted by Holroyd et al. (1984) found that an increase in self-efficacy (i.e., the belief that one has the ability to control the onset and course of a headache) was the only significant predictor of tension headache improvement following EMG biofeedback training. Decreases in frontalis EMG activity from pre- to posttreatment were unrelated to improvement in headache activity, and these findings have been replicated (Rokicki et al., 1997).

Thus, EMG biofeedback training has been found to be an efficacious treatment for tension headache, but the mechanism thought to be responsible for improvement has not been supported. However, changes in EMG activity over the course of treatment have typically been represented as the difference between mean EMG activity at pretreatment baseline and the mean EMG activity score at posttreatment. It is possible that examining an EMG change score results in a "loss" of valuable information and that other statistical analyses or characteristics of the EMG signal may better identify possible mechanisms related to headache improvement.

The EMG signal has several qualities that can provide information about muscle activity occurring near the electrode site. When at rest, motor units (i.e., the motor neuron and muscle fibers it innervates) have a negative charge associated with them. Depolarization is observed during motor unit action potentials (MUAPs). The EMG signal represents the changes in the electrical charge of motor units near the recording electrodes. The raw EMG signal is biphasic, with a mean of zero. Most EMG biofeedback equipment rectifies the signal, which results in absolute positive voltage values. The amplitude of the signal is believed to represent either the summation of the MUAPs or the relative recruitment of an ensemble of motor units that underlay the electrodes (Basmajian, 1989). Thus, EMG values represent the average number of motor units active at the same time near the recording electrodes; the higher the EMG amplitude, the greater the overall muscle activity occurring near the recording electrodes.

On the basis of the above description, it is obvious that calculating an average EMG amplitude for an entire recording trial (durations typically range between 1 and 30 min) could result in a loss of valuable information. All of the motor unit voltage changes detected by the electrodes throughout the entire recording session are reduced to a single observation. An additional component of the EMG signal that is readily obtainable and is oftentimes already present in the type of feedback provided during the training session is the variability of the signal (i.e., spread of observations). The variability in the EMG signal may represent the variability in the number of motor units recruited combined with the rate at which they fire during the acquisition of an EMG sampling period. The variance of EMG may provide additional information that is "lost" when using only an average EMG amplitude as EMG variance may indicate *how* the average muscle activity is occurring. Specifically,

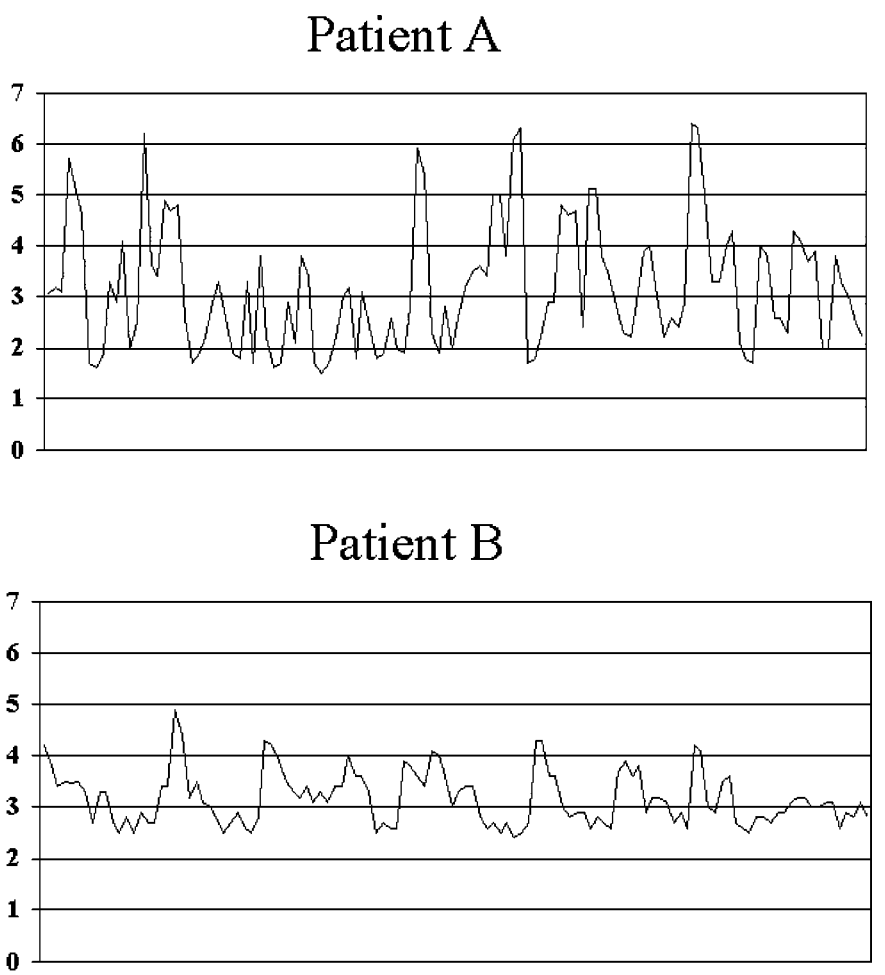


**Fig. 1.** Differences in frontalis EMG variance observed in two headache patients with similar frontalis EMG means.

a higher variance may indicate greater recruitment of motor units or more rapid firing rates of recruited motor units.

For example, Fig. 1 depicts frontalis EMG data of two headache sufferers. The mean scores of these two recordings are the same (3.711 mV). However, Patient A demonstrated much greater variability in EMG activity than did Patient B. The auditory feedback the two patients received were quite different. The "overall" pitch of the tone (representing average EMG amplitude) was similar for these two individuals, however, Patient A heard much more variability in each of the tones presented compared to Patient B. Thus, it is possible that the variablility in the EMG signal impacts an individual's biofeedback training experience and the resulting ability to control muscle activity. No treatment studies evaluating possible change mechanisms responsible for headache improvement following EMG biofeeedback treatment have examined variance of EMG activity as a possible predictor of improvement.

The current pilot study evaluated the possible relationship between time-specific variance in EMG activity, average EMG amplitudes, and improvement in headache activity following combined relaxation/EMG biofeedback treatment.

## METHODS

### Participants

Undergraduate students from a midwestern university who met the International Headache Society diagnostic criteria (Headache Classification Committee of the International Headache Society, 1988) for chronic tension-type headache were offered the opportunity to participate in a treatment study consisting of six sessions of combined relaxation and EMG biofeedback training (see Rokicki et al., 1997). The current study includes EMG data from six females who demonstrated clinically significant improvement (>70%) in headache activity at posttreatment and six females who reported little or no improvement (<30%) in headache activity at posttreatment. The headache improvement scores of the two male participants did not meet the criteria for inclusion into one of the two improvement groups. The two groups were demographically similar with the exception of headache improvement status (see Table I).

Participants had frontalis muscle activity monitored using the Biolab system, which was connected to an IBM PS/2 computer, and was run using Biotext software (Version 1.61). This system has a bandpass of 100–250 kHz. The muscle sites were cleaned with a 70% isopropyl alcohol solution and then gently abraded to ensure a resistance of less than 10 KΩ. Beckman electrode paste served as the electrolyte. A 10-mm Beckman silver/silver chloride electrode was placed approximately 2.5 cm above each eyebrow and centered over each eye (Andrasik, 1979). A common ground Sensor-Medics earclip was coated with electrolyte and clipped to the right earlobe. The electrodes were directed to an EMG

**Table I.** Pretreatment Demographics of the Two Improvement Groups

| Variable | Group | |
|---|---|---|
| | Improved | Unimproved |
| Age (years) | | |
| Mean | 19.33 | 18.83 |
| Standard deviation | 1.03 | 0.98 |
| Headache chronicity (months) | | |
| Mean | 42.00 | 60.00 |
| Standard deviation | 24.88 | 33.08 |
| OTC analgesic medication (# of pills weekly) | | |
| Mean | 5.92 | 7.78 |
| Standard deviation | 6.00 | 4.85 |
| Headache-free days (per week) | | |
| Mean | 1.98 | 2.59 |
| Standard deviation | 1.05 | 1.80 |
| Peak headache pain (0–10 scale) | | |
| Mean | 6.42 | 6.40 |
| Standard deviation | 0.85 | 1.71 |
| Previously sought treatment | 50% | 33.3% |

*Note*. OTC = Over-the-counter.

module (module M130) of the Biolab system. The EMG data were rectified and integrated. The resulting data file for each 5-min baseline consisted of 480 observations; each data point represented the average EMG activity that occurred every 0.625 s. A more detailed description of the treatment protocol can be found in a previously published paper (Rokicki et al., 1997).

## Data Preparation

Movement during a recording session can artificially inflate EMG values by as much as 1000%. As a result, the 480 data points of each baseline session for each participant were plotted, reviewed by five experimenters, and values believed to represent movement artifact by at least four experimenters were deleted. In most cases the agreement between experimenters was absolute, and relatively few observations were removed (2.27% of the data). Missing values were not replaced, and a mean EMG amplitude for each baseline session was calculated (see Table II).

Several complex statistical analyses are available to analyze the data. For example, frequency analysis (e.g., Fourier analysis) could have been used to evaluate changes in EMG activity. However, conceptualization and interpretation of results is difficult as the unit of analysis is the median power frequency. The procedure described below allows for evaluation of changes within a time domain. Thus, results can be interpreted as changes in variance during a particular time period.

The total variance of any baseline session was conceptualized as consisting of three components: variance due to trend, variance due to time-specific muscle activity, and variance due to error (i.e., Total Variance = Trend + Time-specific activity + Error). Trend

**Table II.** Mean EMG Amplitudes, Time-Specific Variances, and Coefficient of Variation Scores

| Session | Group | |
|---|---|---|
| | Improved | Unimproved |
| *Mean EMG amplitude* | | |
| 1 | 18.04 | 7.97 |
| 2 | 10.46 | 5.45 |
| 3 | 10.43 | 5.60 |
| 4 | 4.72 | 5.45 |
| 5 | 4.28 | 10.57 |
| 6 | 4.87 | 4.42 |
| *Mean EMG time-specific variance* | | |
| 1 | 966.63 | 65.56 |
| 2 | 490.58 | 62.35 |
| 3 | 1311.44 | 182.49 |
| 4 | 79.85 | 41.61 |
| 5 | 110.82 | 398.40 |
| 6 | 75.78 | 30.81 |
| *Mean coefficient of variation (CV) score* | | |
| 1 | .201 | .137 |
| 2 | .201 | .125 |
| 3 | .223 | .114 |
| 4 | .187 | .134 |
| 5 | .242 | .146 |
| 6 | .156 | .138 |

variance is observed when an individual's EMG levels generally increase or decrease over the course of an entire recording session. Interestingly, the goal of biofeedback training is to establish a trend such that the individual decreases EMG activity throughout the training session. However, at any given moment, fluctuations in EMG activity may occur in addition to the overall increases or decreases that are often observed; these fluctuations represent time-specific variance and are the discreet changes in the tone of the feedback an individual receives during a training session. The current study examined the role of time-specific variance after removing variance due to trend.

For the purpose of removing variance due to trend, each session was divided into four consecutive subsessions; each subsession consisted of 120 observations. The subsessions were created to improve the accuracy of the linear removal of trend. Specifically, smaller trends (drifts) that may not have been detected using the entire observation period were more likely to emerge during trend analysis of the subsessions. The 120 observations from each subsession were regressed onto time, the residuals from the regression were saved and used in all subsequent analyses. Thus, analysis of the residuals allows examination of the variance in EMG activity due to time-specific activity and error. Figure 2 depicts this process visually. Specifically, Fig. 2(a) displays an individual's baseline EMG activity with a large degree of trend. Figure 2(b) displays the residuals for that same session after the EMG levels were regressed onto time. The trend has been removed, yet time-specific variability remains.

The residuals from each of the four subsessions were rejoined into a single datafile of 480 data points. The variance of the residuals of each baseline session as well as a coefficient of variation (CV) were calculated (see Table II). The CV was also calculated because the variance could potentially be dependent on the amplitude of the observations. Thus, by dividing the standard deviation of the residuals by the mean EMG amplitude of that session, the CV provides a standardized unit of muscle activity. The CV takes into account average EMG amplitude as it relates to time-specific variance and represents the time-specific variation as a percentage of the mean.

Nonparametric analyses were conducted because of the small sample sizes and large degree of variability in EMG activity across the participants. Because of insufficient statistical power and the preliminary nature of the current study, statistical trends were interpreted in an attempt to identify areas that may warrant continued attention in future research.

## RESULTS

The average frontalis EMG time-specific variances and amplitudes for each session for the two groups are presented in Fig. 3. It is noteworthy that time-specific variance was not directly related to average EMG amplitudes. An increase or decrease in variance was not consistently reflected by a similar change in EMG amplitude. Visual inspection suggested that the improved group demonstrated more time-specific variance and higher average EMG amplitudes in the initial sessions, with dramatic reductions in later sessions. Conversely, minimal time-specific variance and lower mean amplitudes were observed during the initial sessions for the not-improved group, with increases occurring during certain subsequent sessions. A statistical trend was observed for changes in EMG amplitudes across sessions for both groups using Friedman tests, $\chi^2(5) = 8.95$, $p < .15$, for the improved group;

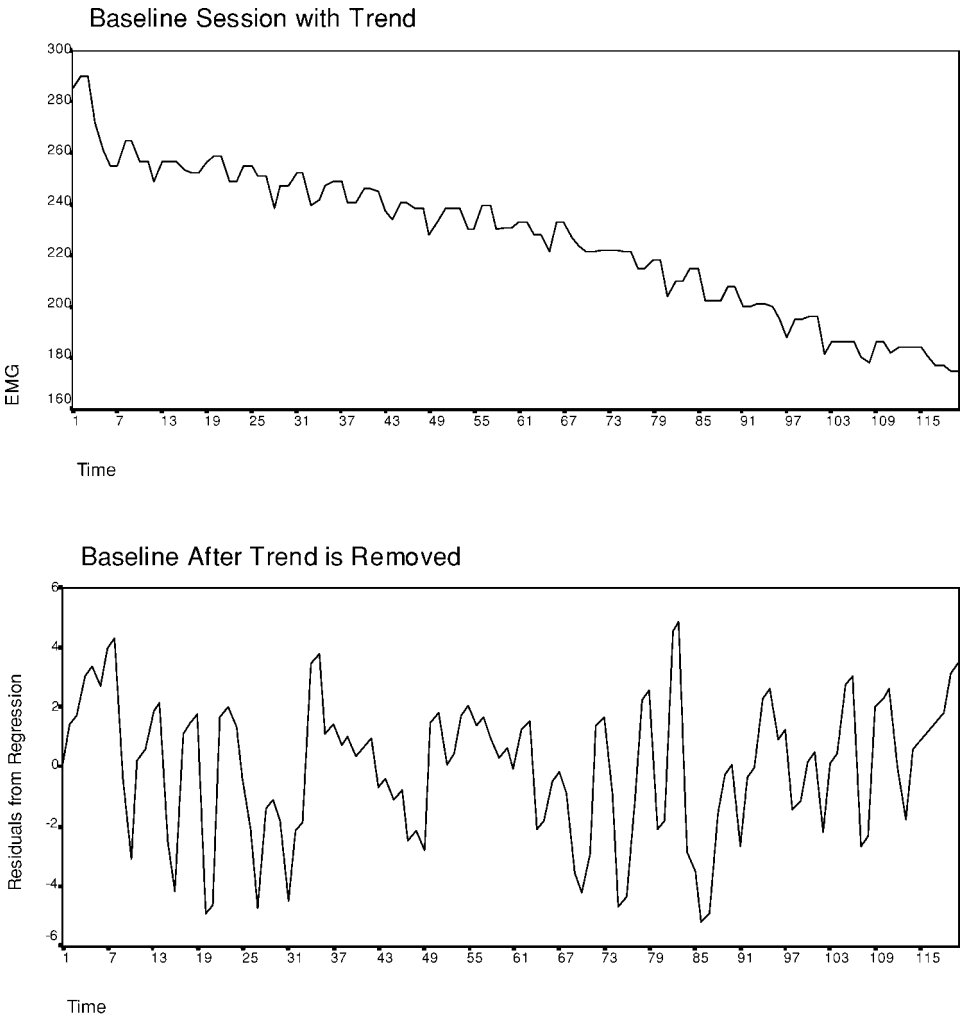


**Fig. 2.** A demonstration of the removal of trend variance using regression and keeping the residuals from the regression.

$\chi^2(5) = 8.43$, $p < .15$, for the not-improved group. Between-session changes in EMG time-specific variance were not statistically significant.

The CV scores for the two groups were examined to better conceptualize muscle activity changes throughout biofeedback training. Within-group changes across biofeedback sessions were not statistically significant, but an interesting pattern emerged when the CV scores were plotted for each group (see Table II). For the improved group, an increase in time-specific variance (i.e., higher CV score) seemed to result in a substantial decline in time-specific variance during the subsequent session. Such a pattern was not observed in the group of individuals who did not improve.

Mean-rank scores were computed for both average EMG amplitude and CV scores (Table III lists group mean ranks). The mean rank is the average rank of each subject in

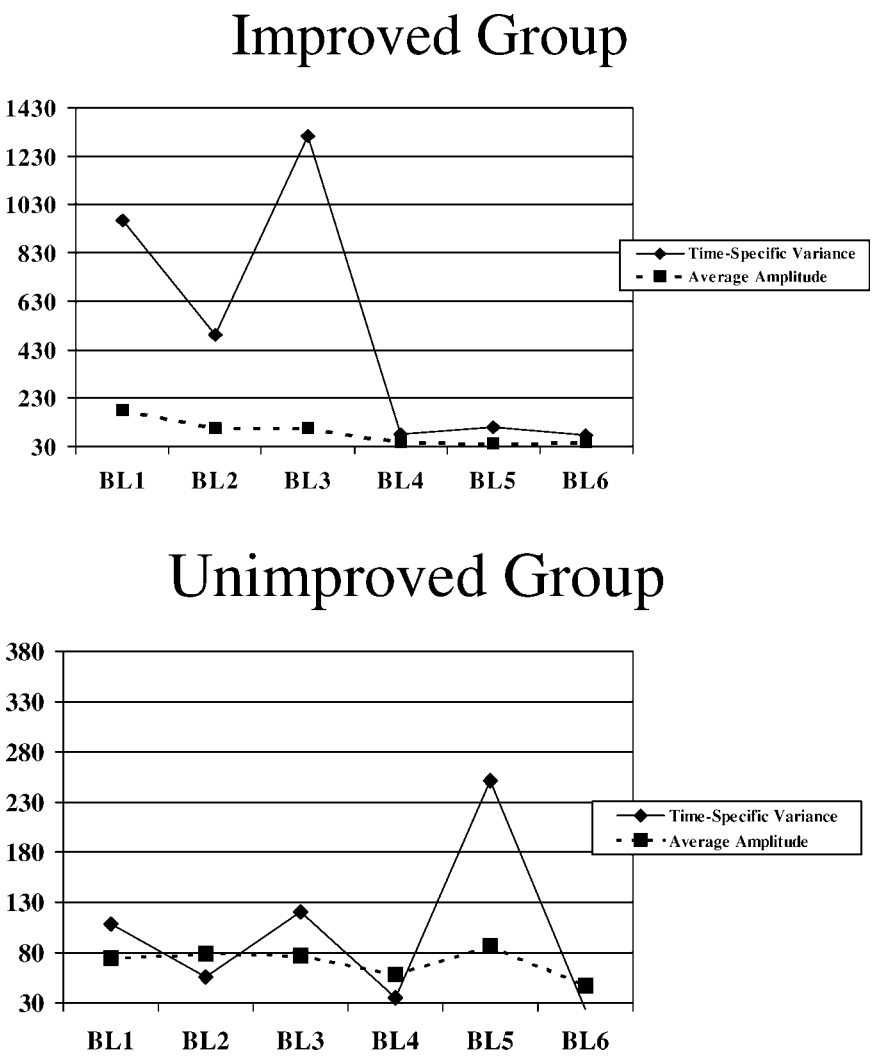


**Fig. 3.** Frontalis EMG means and variances for the improved and unimproved groups.

**Table III.** Mean Ranks for EMG Amplitude and Coefficients of Variation by Group

| | Mean EMG amplitude | | CV (*SD*/Mean) | |
|---|---|---|---|---|
| Session | Improved | Unimproved | Improved | Unimproved |
| 1 | 7.83 | 5.17 | 7.50 | 5.50 |
| 2 | 8.17 | 4.83 | 7.50 | 5.50 |
| 3 | 6.83 | 6.17 | 8.67 | 4.33* |
| 4 | 6.67 | 6.33 | 7.83 | 5.17 |
| 5 | 4.83 | 7.4 | 7.00 | 3.80* |
| 6 | 8.17 | 4.83 | 7.00 | 6.00 |

* $p < .052$.

relation to the rest of the sample. Arbitrarily, higher ranks indicate larger scores in comparison to the other subjects in both groups. Improved participants had higher mean ranks (indicating higher means) for average EMG amplitudes than the not-improved participants in 5/6 sessions. However, none of the rank comparisons were significant. Higher CV mean-rank scores were observed in the improved group for 6/6 sessions. Two of the pairwise comparisons on the magnitude of these differences were significant (sessions 3 and 5; see Table III). A binomial test indicated that the probability of obtaining this pattern of results was less than chance ($p = .031$). Thus, there was a greater than chance probability that improved participants would demonstrate more time-specific variance in relation to EMG amplitude during any treatment session than would individuals who had not improved. Neither group demonstrated changes in EMG amplitude or CV score mean ranks over time using a repeated-measure Friedman Test.

## DISCUSSION

This study piloted the utility of time-specific EMG variance as another summary variable for muscle activity. For this initial exploration, baseline frontalis EMG activity over the course of six biofeedback treatment sessions was examined using two extreme groups of tension-type headache sufferers: six women who demonstrated at least 70% improvement in headache activity, and six women who demonstrated little or no improvement in headache activity (<30% improvement). The inclusion of individuals falling at the extreme ends of the "treatment-response spectrum" was intentionally done in an attempt to enhance the probability that differences would be observed in this pilot study. Essentially, if no differences emerged between extreme groups, then one could argue that the utility of EMG variance as a summary variable for muscle activity is questionable, and further investigation is not warranted. Group differences did emerge in the current study, with improved participants demonstrating larger time-specific EMG variance in relation to mean EMG amplitudes during all sessions. In addition, a decline (although not statistically significant) in time-specific variance was observed during the later treatment sessions for improved participants, and this pattern was not observed in the group who reported little or no improvement.

One possible explanation for this finding is that time-specific EMG variance and EMG amplitudes are positively related and that a change in one variable is reflected by a similar change in the other. A coefficient of variation score helps address this issue because variablility is examined as a percentage of its mean and the impact of EMG amplitude on variance is minimized.

Theoretically, average EMG amplitudes and EMG time-specific variance represent different qualities of muscle activity. The amplitude of the EMG signal is believed to represent either the summation of motor unit action potentials or the relative recruitment of an ensemble of motor units that underlay the recording electrodes (Basmajian, 1989). The mean EMG amplitude represents the average number of motor units active at the same time near the recording electrodes over the course of the entire recording session. EMG time-specific variance represents the number of motor units recruited or active during the acquisition of a single EMG data point. The average EMG time-specific variance will then represent the overall degree of recruitment or number of motor units active on the basis of each acquisition of EMG data. Thus, the mean EMG amplitude provides information about overall muscle activity, and the average EMG time-specific variance provides information

about *how* the muscle activity is occurring. Specifically, larger time-specific variance suggests a greater recruitment of motor units combined with a more rapid rate of firing during the acquisition of an EMG sampling period. An average EMG amplitude score does not provide this information.

An explanation warranting further consideration is that the variability in the EMG signal may represent a preexisting difference in muscle functioning, which may render individuals more or less responsive to biofeedback treatment. Although not statistically significant, a pattern of results emerged in which the not-improved group demonstrated less variability during the initial baseline sessions compared to the improved group. If this pattern is consistently found in future research, then it is possible that greater variability in EMG activity may serve as a positive indicator for biofeedback treatment.

Clinically, individuals who receive auditory EMG biofeedback training may be more aware of changes in time-specific variance rather than overall changes in average EMG amplitude. For example, most biofeedback equipment provides a tone that represents the value of the EMG data point that was just obtained. An individual with less time-specific variance will hear a tone that is more consistent, whereas an individual with larger time-specific variance will hear a tone that is more variable. The greater variability in the tone may provide additional information to individuals and enhance their perceptions of or actual abilities to control muscle activity. Future research should investigate the relationship between changes in self-efficacy and EMG time-specific variances. It is possible that the greater variability in the auditory feedback enhances one's perception that he or she has the ability to control muscle activity; self-efficacy has been the only variable that is consistently related to improvement in headache activity following biofeedback training (Holroyd et al., 1984; Rokicki et al., 1997).

As mentioned previously, frequency analysis (Fourier analysis) could have been used to examine changes in EMG variance during biofeedback training sessions after using a difference procedure to control for trend. The current statistical analysis utilized the time domain to keep the level of analysis focused on a more meaningful concept (i.e., variance vs. median power frequency). However, if a suitable summary statistic describing the frequency domain were utilized, the results of frequency analysis and the current study would be comparable.

The utility of time-specific variance of the EMG signal warrants further investigation. Certainly, the criticism of reduction of average EMG amplitudes to a single observation can also be applied to the current study that reduced EMG variance to an average score. Furthermore, because of the preliminary nature of the study, small sample sizes, and the nature of the groups (i.e., college-aged female chronic tension headache sufferers), caution must be exercised when drawing any conclusions from results of the current study. However, examination of the two summary scores in combination did appear to provide useful information. An examination of individual EMG amplitudes and time-specific variance over the course of a single recording session may provide further understanding of changes in muscle activity as a result of biofeedback training.

## REFERENCES

Andrasik, F. (1979). *A test of the specific effects in the biofeedback treatment of tension headache*. Unpublished doctoral dissertation, Ohio University, Athens.

Andrasik, F., & Holroyd, K. A. (1980). Physiologic and self-report comparisons between tension headache sufferers and nonheadache controls. *Journal of Behavioral Assessment, 2,* 135–141.

Arena, J. G., Bruno, G. M., Hannah, S. L., & Meador, K. J. (1995). A comparison of frontal electromyographic biofeedback training, trapezius electromyographic biofeedback training, and progressive muscle relaxation therapy in the treatment of tension headache. *Headache, 35,* 411–419.

Basmajian, J. V. (1989). *Biofeedback: Principles and practice for clinicians* (3rd ed.). Baltimore: Williams & Wilkins.

Blanchard, E. B., & Andrasik, F. (1985). *Management of chronic headaches: A psychological approach*. New York: Pergamon.

Bogaards, M. C., & ter Kuile, M. M. (1994). Treatment of recurrent tension headache: A meta-analytic review. *The Clinical Journal of Pain, 10,* 174–190.

Budzynski, T. H., Stoyva, J. M., Adler, C. S., & Mullaney, D. J. (1973). EMG biofeedback and tension headache: A controlled outcome study. *Psychosomatic Medicine, 35,* 484–496.

Cox, D. J., Freundlich, A., & Meyer, R. G. (1975). Differential effectiveness of electromyographic feedback, verbal instructions, and medication placebo with tension headaches. *Journal of Consulting and Clinical Psychology, 43,* 892.

Hart, J. D., & Cichanski, K. A. (1981). A comparison of frontal EMG biofeedback and neck EMG biofeedback in the treatment of muscle-contraction headache. *Biofeedback and Self-Regulation, 6,* 63–74.

Headache Classification Committee of the International Headache Society. (1988). Classification and diagnostic criteria for headache disorders, cranial neuralgias, and facial pain. *Cephalalgia, 8*(Suppl. 7), 1–96.

Holroyd, K. A., Andrasik, F., & Noble, J. (1980). A comparison of EMG biofeedback and a credible pseudotherapy in treating tension headache. *Journal of Behavioral Medicine, 3,* 29–39.

Holroyd, K. A., Penzien, D. B., Hursey, K. G., Tobin, D. L., Rogers, L., Holm, J. E., et al. (1984). Change mechanisms in EMG biofeedback training: Cognitive changes underlying improvements in tension headache. *Journal of Consulting and Clinical Psychology, 52,* 1039–1053.

Kroener-Herwig, B., & Weich, K. (1989). Biofeedback in chronic headache: Is physiological learning necessary for positive outcome? *Cephalalgia, 9*(Suppl. 10), 383–384.

Lacroix, J. M., Clarke, M. A., Bock, J. C., & Doxey, N. C. (1986). Physiological changes after biofeedback and relaxation training for multiple-pain tension-headache patients. *Perceptual and Motor Skills, 63,* 139–153.

Rokicki, L. A., Holroyd, K. A., France, C. R., Lipchik, G. L., France, J. S., & Kvaal, S. A. (1997). Change mechanisms associated with combined relaxation/EMG biofeedback training for chronic tension headache. *Applied Psychophysiology and Biofeedback, 22,* 21–41.

Tunis, M. M., & Wolff, H. G. (1954). Studies on headache: Cranial artery vasoconstriction and muscle contraction headache. *Archives of Neurology and Psychiatry, 71,* 425–434.