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GUIDELINES

INDUSTRIAL ELECTROMYOGRAPHY (EMG)

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1. EMG Use

Electromyography (EMG) can be a very useful analysis tool if applied under proper conditions and interpreted in light of basic physiological, biomechanical and recording principles. Through proper design of ergonomic studies and by recognizing the limitations of the interpretive process, EMG can serve as a tool in work evaluation.

EMG is one of several methods which are used for analyzing the performance associated with the workplace. If the work is heavy, it is often best analyzed via physiological measures, such as oxygen consumption, which provide a general measure of whole body work. EMG can be used for the same purpose provided that many muscles of the body are evaluated during the performance of a task, however, EMG is more often used to evaluate lighter, repetitive work where the activity of specific muscles is of interest. Ergonomic analyses often use this technique when comparing the specific musculoskeletal stress (in given muscles) associated with various work positions, postures or activities and for validation of ergonomic principles. It is also used as input to biomechanical models that describe the synergistic effects of muscle activities upon joint loadings. Thus, the use of EMG is appropriate when it is suspected that a specified muscle or group of muscles is adversely affected due to the design of the workplace. The ergonomist should have an idea about which muscles will be affected by the work before EMG is used.

1.1 Information Derived From EMG

In general, four types of information can be derived from an EMG recording and depend upon the sampling conditions. First, the most basic information obtainable from an EMG consists of knowledge about whether the muscle was in use (on/off) during an exertions. In this cases the ergonomist need only observe if the muscle activity increases from a resting level to determine if the muscle is in use. Either the raw or "integrated" (processed) EMG signal may be used for this purpose. This determination is easy to make, but of limited use.

Second, a relative activity level, indicating muscle effort, can be determined by simply comparing the level of the processed signal under various conditions. This measure can be an indication of exertion level. The EMG signal can be affected by factors such as the length–tension relationship of the muscle and muscle motion. Therefore, this measure is not necessarily related to muscle force.

Third, quantitative information regarding force generation of the muscle is obtainable only if the exertion was performed under very restricted conditions. If force is of interest, the exertion must be static or must occur during constant velocity of the muscle. These obstacles may be overcome by designing the study so that EMG activity is only recorded during these phases of the task. In these cases the processed EMG signal must be calibrated and normalized.

EMG-muscle force calibration models must be used to assess muscle tension by scaling the influence of the EMG signal upon the prediction of muscle force. One method to facilitate the assessment of muscle force is to perform a calibration test by soliciting a maximum exertion of a muscle and noting the EMG level. An estimate of the cross-sectional area of the muscle of interest can be obtained via CT scans of the muscle, MRI procedures, cross-sectional anatomy literature, or by correlations with anthropometric dimensions. Once this area is determined, it must be multiplied by a force per unit area factor. Some have estimated this factor to be between 28 and 100 N per square centimeter of muscle tissue. This procedure will define an upper limit or "anchor" for EMG calibration. If a submaximal level of muscle force is observed during the task the muscle force estimate is scaled accordingly.

Fourth, if muscle fatigue is of interest, a standard submaximal isometric contraction must be maintained and the spectral components of the raw EMG signal must be evaluated. This is usually assessed via a fast Fourier Transform (FFT) of the signal. As the muscle fatigues the central portion of the frequency spectrum shifts to a lower level during the standard contraction. This standard contraction is usually solicited immediately before and after the work activity of interest.

1.2 Normalization Procedures

Most ergonomic studies are interested in evaluating the effects of several workplace variables (i.e., tool design, methods, work practices, etc.) upon some aspect of muscle activity. The ergonomist is usually interested in evaluating the contribution of several workplace variables upon the muscle activity for a general population of subjects. Therefore, repeatable, quantitative comparisons between subjects, conditions, and muscle groups are necessary and require normalization of the EMG signal. This is usually accomplished by comparing the EMG activity of a specified uptake area under an experimental condition to a reference. This will provide a relative measure of muscle activity that will justify between subject and between muscle comparisons.

The normalization procedure is typically performed in several ways depending upon the EMG measure of interest. If the EMG amplitude is of interest, a standard contraction for each muscle is performed with each muscle in a position that matches the position of the muscle assumed during the experimental task. The standard contraction is usually a maximal voluntary contraction, but can also consist of one or more submaximal contractions. The task EMG is divided by the maximum EMG and represents total effort (in percent of max) required for a task. The resting EMG level may also be subtracted from both the task and maximum EMG. This provides an estimate of the added muscle activity necessary to perform a task independent of posture.

Normalization procedures can also be applied to EMG frequency analyses. Most frequency based analyses are intended to evaluate the fatigue state of the muscle and are performed by observing a shift in EMG frequency to a lower level. The frequency spectrum can be normalized by expressing the amount of signal that is within a certain frequency range. In this situation, the percentage of signal power in a given (usually low) frequency range is the dependent variable.

2. EMG Recordinq Fundamentals

Critical features of EMG recording and analysis important for the application of EMG to ergonomic studies are summarized below.

2.1 Control of the pick up area

If the level of information desired from an EMG signal is any more sophisticated than just knowledge of whether the muscle is on or off, then great care must be taken to assure that the muscle recording conditions between exertions are comparable. Ergonomic investigations assume that one can compare the muscle activity over a given area of muscle when the task that is performed or the conditions of the workplace change. In order to interpret the muscle activities correctly, the muscle fiber depolarization must be observed over a constant portion of the muscle. Thus, it is of utmost importance to ensure that the volume of muscle that is recorded (pick up area) does not change between conditions. This may be controlled through proper experimental design. Whenever possible, the experiment should study static postures. If this is not possible, the experiment should be designed so that the muscle length and body position are in similar positions when EMG comparisons are made. Finally, when across muscle comparisons are of interest it is inevitable that different pick up areas must be compared and the basic pick up volume comparison assumption is violated. This problem may be controlled by comparing EMG activity in a relative sense via normalization.

2.2 Electrode Selection

Electrode selection is crucial to the successful recording and interpretation of an EMG signal. Bipolar electrodes are typically used in ergonomic studies. The bipolar electrode uses two detection electrodes which detect the potential of a muscle at two locations each with respect to the reference electrode. These two signals are then fed into an amplifier which eliminates the common noise (common mode) components of the two signals and accentuates the differences between the signals. In most ergonomic studies the surface bipolar electrode is preferred because it is easy to use, is non-invasive, and is easily tolerated by the subject. This type of electrode is found in many shapes and sizes but essentially consists of a silver–silver chloride disk connected to a wire (lead). The larger the electrode size, the greater the pick up area. If large muscles are of interest, the global state of the muscle is of interest, or high signal amplitude is needed then large electrodes should be used. However, small electrodes are superior in situations where cross-talk from adjacent muscles may be present or where the heart muscle signal (ECG) may be present. In other words, the smaller the electrode, the more selective the EMG information becomes.

2.3 Muscle Site Preparation

Once the muscle site has been identified, the site of the electrode–muscle–interface must be prepared in order to ensure a high quality signal. Several steps are necessary to prepare the muscle site for surface electrodes. These steps include (1) shaving the electrode site (if necessary), (2) cleaning the skin with alcohol, and (3) abrading the electrode attachment point with electrolyte gel.

If an estimate of muscle force is of interest, then several additional points are recommended since EMG–force relationship conditions must be maintained. First, the electrodes should be allowed to stabilize. The impedance of the electrode–skin interface will change as gel is dissolved into the skin and this will have a direct effect on the EMG–force relationship. Therefore, a twenty minute stabilization period is recommended. Second, postural changes should be minimized since muscle length and velocity have a dramatic effect upon muscle force and EMG relationship. Therefore, one should try to maintain static posture during the exertion if muscle force is of interest. Third, fatigue should be minimized. Fatigue will affect the EMG–force relationship. Experiments should be designed to minimize fatigue by incorporating rest periods in between exertions.

3. Equipment

The typical equipment configuration needed to perform an ergonomic study is depicted schematically in Fig. 1. As shown in this figure, the EMG signals are picked up by electrodes that are connected to preamplifiers. It is advantageous to locate these preamplifiers in close proximity to the electrodes, however they may be an integral part of the main amplifiers. Once the signal has been amplified by the preamplifiers, it is further amplified by the main amplifiers. The amplifier circuit should permit one to adjust the gain on each channel so that the signal does not clip and does not pick up adjacent EMG signals (cross-talk). After that, the signal is filtered, and may be conditioned or processed if that function is performed in the hardware. Low pass filtering is usually performed at 1 kHz. High pass or notch filtering is usually employed to control for 60 Hz signal contamination. Processing or integrating may consist of rectifying, averaging, defining a linear envelope, or performing an RMS processing of the signal. Sometimes, only the raw signal is recorded and the processing is performed in the software. A means of monitoring the signal on-line is usually connected to the main amplifiers. This may consist of a multi-channel oscilloscope, switchbox with an oscilloscope, stripchart recorder, or light pen recorder. Next, a recording device is used to maintain a permanent record of the signals. This recording device may consist of an FM tape or paper recorder, or it may be monitored with a computer through an analog-to-digital (A/D) converter. If one wishes to digitize a signal, it must be digitized at a rate of at least twice the maximum signal frequency (Nyquist Criteria). Signal conditioning may also take place in the software.

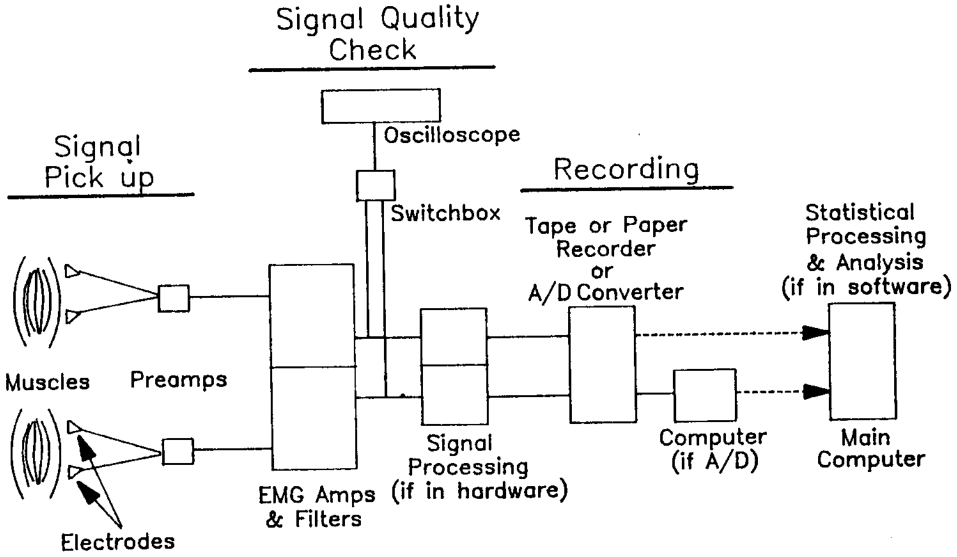

Fig. 1. Schematic representation of equipment configuration.

Once the data are quantified it is often analyzed statistically which is most efficiently performed on a computer (usually a mainframe).

4. Signal Quality

Once the electrodes have been prepared, the signal quality should be checked. This is done by hooking up the electrode leads (and a ground electrode) to an EMG amplification system and observing the signal. If the EMG amplifier does not have a display screen, an oscilloscope can be attached to the amplifier to view the raw EMG signal (see previous section). If multiple signals are to be observed, then a switchbox can be attached between the amplifier and the oscilloscope so that any one of the signals can be selected for viewing or a multi-channel oscilloscope can be used so that all channels can be viewed simultaneously. Signal quality is usually assessed qualitatively. When the muscle is at rest, the signal amplitude should be low and no or very little activity should be present. When the muscle is exerted at near maximal activity, the signal should react immediately by increasing its amplitude. It may be necessary to adjust the gain of the system at this point. The gain should be adjusted so that the EMG signal produces striking changes in activity level between exertion and resting levels but does not include "clipping" of the signal.

If multiple muscles are being observed it is a good idea to have the subject perform a task which isolates, as much as possible, the activity to the muscle of interest. Under these conditions only the target muscle should be active. and the other muscles should not exhibit EMG activity. If they do, then there may be cross-talk occurring. Cross-talk may be due to too large an electrode, excessive gain, improper skin preparation, an ECG artifact, or muscle sites which are too close to one another.

When the electrodes have been properly attached and the signal quality has been checked the electrode leads can be attached to the EMG preamplifiers (if they are contained in a separate unit). It is important to make sure that all electrodes including a ground electrode are attached to the EMG preamplifier before the amplifier system is turned on. The electrode lead (prior to the preamplifier) is often a source of EMG signal noise. The electrode lead often acts as an antennae and picks up various non-EMG signals such as those from electrical outlets. This problem can be minimized by keeping the electrode leads short. Short electrode leads can be accommodated by placing the preamplifier in close proximity to the electrode location. Several miniature, lightweight preamplifiers are available which allow the preamplifier to be placed very close to the electrode site. Another source of noise or artifact is due to the electrode lead motion during an exertion. The leads can be secured on the subject by taping the leads in place.

Other common sources of EMG artifact include poor electrode site preparation, placement of electrodes over large arteries, an intermittent break in a lead wire causing saturation, a DC offset due to dried out electrodes, or poor electrode site preparation. The danger associated with the existence of these types of artifacts in the EMG signal is risk of misinterpreting the results of the study. Once these artifacts are present in the signal it is extremely difficult to separate the true EMG signal from the artifact.

5. Experimental Control Procedures

In order to preserve the relative nature of the EMG signal, once the experiment has begun it is important not to change any of the amplifier gains or filter settings. If these settings are changed during the experiment, the relative nature of the data would be lost. The relative relationship of the EMG signal can also be affected by EMG electrode removal. As discussed earlier, an EMG signal compares a given portion of the muscle (pick up area) under different exertion conditions. The pick up area geometry is very unique to the exact location of the electrode. Thus, varying the electrode location, even by a small amount would create a different pick up area which would sample different motor units. Practically, this means that if an electrode comes off during the experiment, the entire experiment (including maximum exertions and resting levels) should be rerun.

6. Analysis and Interpretation

In any EMG study the results of one subjects data can not be interpreted as a trend. One must use statistical comparisons of several subjects' EMG data to accurately state that one particular workplace effect causes a change in muscle usage, muscular activity, muscle force, or fatigue compared to other work positions. Statistical comparisons in conjunction with a proper experimental design that considers all possible factors that may affect the EMG signal are needed to determine whether the trends observed in the data are real trends or due to chance. Such an analysis will also determine the relative contribution of the various main workplace factors and their interactions.

The techniques that are usually used to make statistical comparisons between EMG signals in response to any single workplace factor include the *t*-test or the one-way analysis of variance (ANOVA). If the effects of several workplace factors are of interest then it is necessary to evaluate the contribution of each of these factors as well as their interactions upon the behavior of the muscle. These statistical comparisons are usually best performed by evaluating the variance between the cells of the experiment using a multifactor AN0VA. In many EMG studies the influence of workplace factors upon the collective behavior or several muscles is of interest. Multivariate techniques such as multivariate analysis of variance (MANOVA) are used to determine whether several muscles, as a group, respond in a significantly different manner to experimental conditions. These statistical techniques enable the experimenter to make definitive statements about the influence of the workplace factors upon the usage of the muscles. Using these techniques the experimenter can assess the degree of influence that one or more factors has upon the activity of the muscle(s) of interest. Thus, the statistical analyses become the basis for accurate interpretation of EMG data and facilitate the use of EMG for workplace investigations.

7. Conclusions

This paper has briefly reviewed the logic involved in EMG use and has also shown the practical implications that must be considered for the application of EMG technology to the workplace. This guide is intended to be an overview. The reader is encourage to find more detailed information before using EMG for industrial studies.

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