A Guide for Use and Interpretation of Kinesiologic Electromyographic Data

Physical therapists are among the most common users of electromyography as a method for understanding function and dysfunction of the neuromuscular system. However, there is no collection of references or a source that provides an overview or synthesis of information that serves to guide either the user or the consumer of electromyography and the data derived. Thus, the purpose of this article is to present a guide, accompanied by an inclusive reference list, for the use and interpretation of kinesiologic electromyographic data. The guide is divided into 4 major sections: collecting, managing, normalizing, and analyzing kinesiologic electromyographic data. In the first of these sections, the issues affecting data collection with both indwelling and surface electrodes are discussed. In the second section, data management through alternative forms of data processing is addressed. In the third section, various reasons and procedures for data normalization are discussed. The last section reviews qualitative descriptors once used as the only means of analyzing data, then focuses on more quantitative procedures that predominate today. The guide is intended as a tool for students, educators, clinicians, and beginning researchers who use and interpret kinesiologic electromyographic data. Modifications will likely be needed as alternative forms of collecting, managing, normalizing, and analyzing electromyographic data are proposed, used in various settings, and reported in the literature. [Soderberg GL, Knutson LM. A guide for use and interpretation of kinesiologic electromyographic data. *Phys Ther.* 2000;80:485–498.]

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Kinesiologic electromyography (KEMG) as a method of analyzing muscle function has evolved over the last 50 years. As primary users of KEMG techniques, physical therapists use and evaluate the methods of KEMG in many applications directed at the study of muscle function. As either a user or an interpreter of KEMG data, we believe enhanced knowledge is essential to the physical therapist to assist with the evaluation of data important to effective clinical practice. In the most general form, KEMG has been used to evaluate muscle activity for function, control, and learning. Examples of specific applications that have been made include: (1) assessing muscle function during or as a result of exercise and therapeutic procedures,[1–10] (2) providing "biofeedback" to patients,[11–14] (3) evaluating "control" by assessing muscle onset time and durations[15–17] or establishing motor unit discharge rates,[18,19] (4) assessing gait,[20–28] (5) critiquing the work site,[29–31] and (6) determining matters relative to fatigue.[32–34]

Although the techniques and instruments associated with KEMG data can be easy to use, steps in the process, from collection through analysis, in our view, are best suited to *a priori* selection. Some support for selections can be found in the literature, but in other cases only suggestions are available as to how to select the most appropriate recording technique.[30,35–39] There appears to be no guide available, such as the one provided in this article, that presents a comprehensive view of the alternatives available when using KEMG. Furthermore, the user of the guide can resort to the chart provided in the Figure to assist with a critical analysis of whether others have used KEMG appropriately. We have divided the text and the chart into 4 sections that are useful for planning and interpreting the results of clinical or basic research studies: collecting, managing, normalizing, and analyzing KEMG data.

General Considerations

Before using any section of the guide, we advise potential users of KEMG or those who want to interpret KEMG data to study the overall schema presented in the Figure to appreciate how all factors are associated. For example, the selection of the reference value to be used in the normalization process may be related to the form of analysis that is selected. Another example is that use of the maximal voluntary isometric contraction (MVIC) may preclude use of fine-wire electrodes because of the pain that may be elicited during the contraction.

Physical therapists are among the most common users of electromyography as a method of understanding function and dysfunction of the neuromuscular system.

We acknowledge, and the reader should be aware, that this guide may not cover all applications of KEMG. Additionally, there are many instances where data to support the selection do not exist.[40] Although we have attempted to be thorough in providing evidence when it exists, the reader is referred to appropriate sources or presented with options to be considered in the cases where little or no information is available. Furthermore, the reader should appreciate that KEMG is enigmatic in that it is easy to use and just as easy to be misunderstood and misused. Attention should be given to use the appropriate scientific basis when there is guiding information.

Although this article has been written to more broadly consider the use of electromyography (EMG) in the context of human movement, we believe applications to biofeedback can be made in the areas of electrode selection and application (avoidance of artifacts), in signal processing, and in the use of nonnormalized data from which comparisons are made. Applications to biofeedback are noted in the appropriate sections.

We further acknowledge that the guide could be divided into categories or headings different from those presented. The approach we have chosen has been useful in our teaching of how to use and understand KEMG.

Collecting

Primary considerations germane to collecting KEMG data are (1) the study purpose, (2) cabling versus

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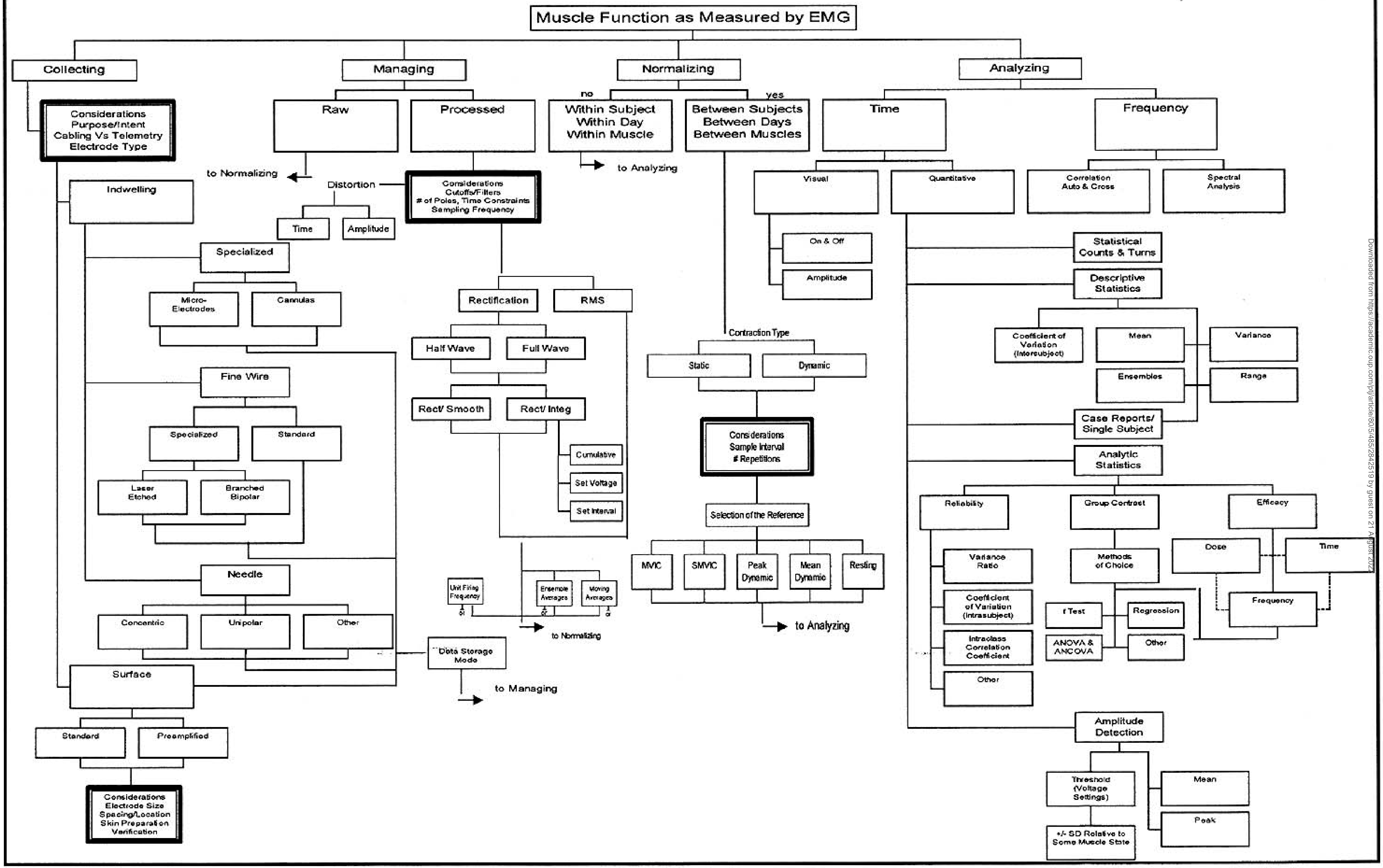
telemetry, and (3) the type of electrodes. The first of these considerations, the study purpose, directly or indirectly determines whether surface or indwelling electrodes are used. For example, surface electrodes are useful for deriving general information from superficial muscles, whereas indwelling electrodes are designed to discriminate motor units, study the control of motor units, or ensure sampling from muscles located deep in the body. The advantages and disadvantages of the different electrode types are discussed in detail elsewhere.[30,41] An important point, however, is that studies comparing EMG data collected simultaneously with fine-wire and surface electrodes demonstrate greater reliability with surface electrodes.[21,42,43] This finding is likely due to the more limited recording area of fine-wire electrodes and difficulties in inserting these electrodes into the same location (ie, geographical) of a muscle. The suggestion has also been made that inserting the wires via 2 needles decreases intersubject variability and improves signal amplitudes.[44] The more global view of muscle activity is certainly represented by surface electrodes, and for most work of physical therapists, including biofeedback, we believe this type of electrode is the correct choice. This position is supported by the reliability studies that indicate that measurements with less error can be derived across multiple trials or days when information is derived from surface electrodes. However, when motor unit activity is of interest, fine-wire electrodes are the preferred choice because of the small recording surfaces of the wire and the proximity to the motor units.[35,36,41]

The second consideration pertains to the decision to use telemetry or a system requiring cabling. The major advantage of telemetry, where EMG information is sent by FM signal through the air to a receiver from a small pack worn by the subject, is freeing the subject from the encumbrances of cabling or tethering to other instrumentation. Cables may affect subject performance. Freeing the subject from the encumbrances of cabling, however, may be gained at the expense of difficulties associated with good signal acquisition.[30] In particular, there are possible limitations in signal sampling rates with FM systems in that the multiplexed signal is used to transmit data from multiple channels. Thus, both the user and the interpreter of data should express and know, respectively, that the actual sampling rate (samples per second or hertz) of each channel exceeds the minimum recommendation (preferably higher than 700 Hz).[45] Many of the "hard-wired" or cable systems use electronics within the electrode, minimizing the likelihood of artifact.[30] Additionally, the mass or bulk of the pack worn by the subject may be more disruptive (eg, to a small child) than cables trailing behind the subject or carried by an assistant. Telemetered and cabled systems have been used in clinical and laboratory settings.[24,46–51] The decision on which system to use is often driven by individual preference, experience, equipment availability, level of technical support, and which system introduces the least encumbrance for the subject. For example, if engineering help from the manufacturer, hospital personnel, or private sources is available and patients are to be analyzed from the home to the athletic field, then telemetry is likely your method of choice. Settings primarily confined to laboratories, often with less technical support, are more likely to use the cabled systems. When purchasing any equipment for EMG studies, a thorough analysis of the available systems is in order, with particular attention to how the systems meet instrumentation requirements,[30,52,53] how signals are managed by system software, and how compatible the data will be with other data collected in the setting, such as kinetic and kinematic data.

The third consideration is electrode type: indwelling or surface. If the study purpose will best be met with the use of indwelling electrodes, one possible selection is one of a number of specialized electrodes. Many of these electrodes have been developed primarily based on methods of Stälberg[54] for the study of single-fiber EMG and of Gath and Stälberg[55] and van Veen et al[56] for the purpose of obtaining highly selective EMG recordings from multiple openings in a cannula. Generally, however, these electrodes have limited application in KEMG because they are primarily designed to study potentials from single muscle fibers.

The most common type of indwelling electrode used in KEMG is the fine-wire electrode. This electrode consists of 2 wires, each with a diameter of 50 μm or less, that are inserted into the muscle after the wires have been threaded through a hollow-core needle.[57] Practice acts in each state may govern the use of needles for EMG, so any potential user of this technique is advised to check with the appropriate governing agency. If this technique is used, note should be made that the number of potentials recorded will vary depending on the amount of bared wire.[36] These fine-wire electrodes are likely the choice if the interest is to study motor units or their control or to study muscles not accessible by surface EMG such as the brachialis or popliteus muscles. Electromyographic activity in more localized areas of muscles, such as from divisions of the erector spinae muscle, can also be successfully recorded with fine-wire electrodes. These electrodes do have potential complications, such as patient discomfort[58] and wire fracture.[59] The incidence of these problems is extremely low[59] and is not considered a threat to subjects by most experienced electromyographers. Muscle damage with implanted electrodes has been reported in two 1971 studies in rats,[60,61] but we know of no current work on this topic.

DECISION GUIDE



Several specialized versions of fine-wire electrodes have also been developed, but their use is normally limited to special applications associated with collecting and interpreting data from single motor units. Nelson and Soderberg[62] described an electrode with the insulation laser etched so that the recordings were more selective for the motor unit potentials of interest. Enoka and coworkers[63] have also reported on a special version of an indwelling electrode that apparently maximizes signal "stability" and "muscle potential selectivity." Their electrode differs from the others in that it is a branched, bipolar electrode positioned subcutaneously over the belly of the muscle. This electrode tends to produce less discomfort while being capable of discriminating potentials during efforts up to maximal voluntary contraction. Selection of any version of these fine-wire electrodes is primarily dependent on the user's familiarity with this type of electrode and the ease of production of the electrode.

Needle electrodes are another type of indwelling electrode. Concentric and unipolar designs are the most common, but at least some cannulas can be considered needle electrodes because they consist of a needle through which the electrode is inserted into the muscle. The most common use of needle electrodes is for diagnostic EMG[64] rather than KEMG. The application of these electrodes in KEMG is extremely limited[65] because needle displacement during muscle contraction causes either pain or muscle damage.[60,61]

Most extensively used in KEMG are the surface electrodes. Surface electrodes are readily available and easily applied and free of discomfort.[36,39] Designs include individual electrodes of various diameters, electrodes of fixed interelectrode distances, and electrodes that do or do not contain on-site preamplification.[36,39] None of these electrodes are necessarily selective to any given muscle and thus may pick up activity from underlying or adjacent muscles (labeled as "cross talk").[45,66–70] Probably the best rule of thumb is that the smaller the muscle from which the recording is to be made, the smaller should be the electrode,[30] and probably the interelectrode distance. Preamplified electrodes are typically mounted in a lightweight housing containing instrumentation that will amplify the signal close to the site of the electrode pickup (on-site amplification).[15,39,40,71–74] Electrodes with preamplication have the advantage of decreasing artifacts that tend to be included in the EMG signal.

In selecting surface electrodes, we believe consideration should be given to electrode diameter, spacing and location of the electrodes relative to the muscle mass, and the skin preparation required. Loeb and Gans[35] have made recommendations for electrode diameter and placement, but the reader should keep in mind that there is a wide range of acceptable standards for each variable, depending on what is being studied. Basmajian and DeLuca[36] suggested an "interdetection surface" spacing of 1 cm for surface electrodes. Small oblong bars or circular discs with the electrodes premounted are available, the latter varying in diameter from 1 to 5 mm and encircled by Teflon* or other similar material. In some cases, electrodes are mounted (often with "preamplification") so that the interelectrode distance is fixed; thus, the decision about electrode distance has already been made. The constraint in this case is that if different size muscles are to be examined, there is no adjustment available for the interelectrode distance. There is little to no evidence to determine a standard for interelectrode distance.

Some authors[35,75] advocate an electrode location parallel to the muscle fiber, and other authors[76–79] recommend specific locations, either with or without methods to adjust for differences among subjects. Placing electrodes on either side of a motor point has often been founded on faulty reasoning.[36] Because of considerations relative to signal-to-noise ratio and stability (reliability and cross talk across channels), Basmajian and DeLuca[36] stated that the preferred location of an electrode is in the region halfway between the center of the innervation zone and the distal tendon. Their book[36] provides a full discussion of the electrophysiological basis. The ground or reference electrode necessary for recording using surface or fine-wire electrodes is usually placed over a relatively electrically neutral location such as a bony prominence.

We recommend that users of KEMG determine whether journals to which they may submit articles based on their work have any standards to which they must conform. The amount of latitude available is obvious in the listing under the heading of electrodes in the standards published in the *Journal of Electromyography and Kinesiology*.[45] No precise rules are stated, but the standards suggest reporting: (1) electrode material and geometry, (2) electrode size, (3) preparation and application technique, (4) interelectrode distance, and (5) electrode location and orientation with respect to tendons, motor point, and muscle fiber direction.[45]

Regardless of the decision to use indwelling or surface electrodes, techniques can be used in an attempt to verify the electrode location. We strongly recommend this step. In the case of the fine-wire technique, some electromyographers have used stimulation through the implanted wires to determine whether the appropriate muscle contracts.[36] In most cases, the appropriateness and quality of contraction is determined on a subjective basis, such as by using a muscle test while observing the recording to ensure the muscle tested shows activity.

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Appropriate electrode location cannot be ensured by the muscle test method unless there is paralysis in surrounding muscle tissues. Surrounding local muscle or nerve blocks are not practical for the purpose of electrode location verification.

No matter whether indwelling or surface electrodes are used, the electromyographer has the choice to collect the data via many data storage modes, of which the most common today is the computer and the accompanying software. Although the purpose of this article is not to discuss all available options, reference can be made to literature that addresses the characteristics of specific devices.[37,45,80] Advances in personal computing technology with large hard-drive storage and drives for data back-up have resulted in many investigators eliminating signal storage systems such as FM tape recorders and videotape recorders.

Managing

Management of KEMG data can be done using either a raw, also called "unprocessed," signal or a processed version of the signal. The raw data are the most fundamental, and using data in this is, in our opinion, an underused technique. As a minimum, we contend that the user should monitor the raw EMG data, usually visually on an oscilloscope or a computer monitor set by software to simulate an oscilloscope, to ensure artifact-free signal recording during data collection. Storage of the raw data is also recommended[45] because storage allows the user the option to revisit the raw data should any questions or problems arise with the remainder of the analysis. "Scoring" of the raw data (ie, visually determining the contraction intensity) has been performed[48,81] primarily for patient populations and can be considered only if the purpose is to simply evaluate whether a muscle is active or not. As discussed in the "Analyzing" section, available technology allows for similar decisions. Software is readily available to assist the user of KEMG with this more acceptable method of determining onset and level of muscle activity.

Relative to processing of the EMG signal, this guide cannot present or discuss all of the requisite knowledge necessary for a skilled user or interpreter of KEMG data. Rather, we will focus on the most common aspects as they appear in the literature. One good reference to review is a brief listing of essential topics relative to KEMG,[37] reprinted in a book titled *Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives.*[30] An important point to remember is that, if raw data are processed, the resulting information has a strong dependency on the instrumentation characteristics, regardless whether the processing is done with hardware or software. In most instances, processed data are preferred because quantification results. In an effort to provide valid quantification, decisions need to be made as to the adequacy of the processing system. The most important factors relative to these decisions will be discussed for the most commonly used forms of data management. Additional guidelines can be located in a number of sources.[37,45,52]

Managing data requires decisions relative to factors such as data filtering, the number of poles to be used in a filter, the time constants used by the filter to smooth the data, and the data sampling frequency. For specifics, the reader is referred to other sources.[36,53] Each of these factors has an effect on the data, and incorrect choices can lead to distortion of data, which may alter interpretations applied to either temporal or amplitude features.[82,83] One example of appropriate filter choices is included in the *Journal of Electromyography and Kinesiology*, which states that low- and high-pass filters and filter types should be specified in articles describing KEMG.[45] Because most of the power in the EMG signal is in the frequency range of 5 to 500 Hz, submissions to that journal will not be considered unless the filter retains signals in the range of 10 to 350 Hz for surface electrodes and 10 to 450 Hz for intramuscular electrodes.[45] This frequency range (bandwidth) is not to be confused with the sampling frequency discussed earlier. An example of where the journal's guidelines are not followed occurs in biofeedback units, where the low end of the frequency range is set at 100 Hz. The advantage of this low frequency is that artifact is reduced. However, there is a very large amount of the EMG signal in this low end of the power spectrum that most authors believe should not be discarded. In reality, most filters are selected on the basis of availability, with second consideration given to specific characteristics of the instrumentation. The reader is referred to texts such as those by Soderberg,[30] Loeb and Gans,[35] and Basmajian and DeLuca[36] and to other sources[53,84] for helpful resources in elucidating the characteristics associated with each component of the selected instrumentation.

One commonly used technique is rectification, a method that allows data to be numerically managed. Although half-wave rectification has been done, literature citing the use of this procedure is uncommon, most likely because in this process all raw EMG voltages below the baseline (the line around which all voltages fluctuate) are discarded. The literature much more commonly includes descriptions of full-wave rectification (in millivolts),[15,49,69,73,74,85–90] the current method of choice for the user of KEMG. Whether processing beyond rectification is used to smooth the data depends on the purpose and intent of the study using KEMG. The most common form of processing chosen for use in KEMG studies is rectification followed by filtering.[15,25,41,86,87,91] It is important to understand the electrical characteristics of the EMG signal, because they affect how much and what type of filtering of the data can be done.

It is important to decide what kind, or even whether, smoothing of the data is desirable. In essence, smoothing of the data accomplishes a leveling of the sharp peaks of the rectified raw EMG signal.[30,38] Often, this process also reduces the number of voltage values forming what has been called a "linear envelope." Research reports describing the use of this method often include a statement such as "smoothing with a low-pass filter of (x) milliseconds was accomplished."[45] This procedure, which lets more high frequencies through, requires a selection of the "x," or time constant, value. The normal range is 50 to 250 milliseconds.[45] A time constant of 250 milliseconds would smooth the data extensively and is a value frequently not selected because such a high degree of smoothing may eliminate data that show what occurred as the result of changes in the speed of walking or the existence of pathology. In locomotion studies, a time constant of 50 milliseconds is more likely, resulting in a cutoff frequency of 3.2 Hz, which is less than the minimum of 5 Hz at the low end of the EMG spectrum. There are many versions of the low-pass filter, but any selection should be based on the question of interest to the user of the EMG. The chapter by Hillstrom and Triolo[53] will guide the reader to a more in-depth discussion of the relevant issues.

Occasionally, users select rectification followed by integration (millivolts × seconds), including cumulative integration or other techniques where the interval or voltage levels of EMG are set.[8,37,49,53] Any of these methods allow for signal quantification. However, descriptions of these methods are relatively uncommon in the KEMG literature,[50,51,92] and these methods do not appear to offer any particular advantage over other forms of data management. Selection apparently is due primarily to availability of this type of instrumentation.

A relatively popular and acceptable alternative method is calculation of the root mean square (RMS) (in millivolts), a technique believed by some researchers to have a more sound mathematical basis than the simple linear envelope (rectification followed by smoothing with a low-pass filter).[30] Essentially, this procedure squares each value in the signal, creates an average, and then calculates the square root. When using this method, we believe the user should select and report the time period over which the average is calculated, a value that should be consistent with the purpose of the study. For example, a slower movement, such as during gait, can use a greater time period in the calculation, whereas in a fast movement, such as reflexes or responses to perturbations, a shorter time course is necessary. The principles of cutoff frequencies should also be taken into account when making these selections.[53] These manipulations are easily completed either in hardware or software, and the output from the RMS and the linear envelope look virtually identical if the same data are processed with the 2 techniques. Because using this processed form is a sound decision and it is commonly available, the technique has been used in numerous works, only a few of which are cited.[9,14,72,93–95]

A moving average is another form of a smoothing function.[30,38] In this situation, an average is calculated for a specified window of data points. As such, these methods are typically applied to rectified data not yet smoothed with a time constant or treated by integration. Thus, this technique can also be used to form the linear envelope and, in turn, the ensemble average, which sums the linear envelopes obtained from trial or subject repetitions. Procedures such as this have been used in studies of normal and pathological gait and in studies entailing any repetitive or cyclic activity when variability exists and the user would like to ensure a true average.[9,15,20,49,72,85,88,93,96] Fine details, however, may be lost due to the "averaging." Ensemble averages of events that are repeatable (eg, reflex activity, single motor unit firings, spike-triggered averaging)[73,97,98] are appropriate, whereas an "average" for surface EMG may not look like any of the data contributing to the "average." Like moving averaging, ensemble averaging is, in effect, a smoothing technique. Ensemble averaging has also been the decision of choice when the study purpose pertains to reproducibility.[28,43,72,85,86,90,99–101]

Normalizing

Either raw or processed versions of data can be entered into the normalization module, which allows for the process of referencing the EMG data to some standard value, usually by dividing the derived EMG data by a reference value. The decision to normalize or not normalize is based on the type of descriptions or comparisons to be made. For example, if comparisons are made between subjects, days, muscles, or studies, the process is required.[30,38] Those researchers using biofeedback should make special note of this requirement. Conversely, if subjects serve as their own control and contrasts are made within a day and on the same muscle, with the electrode not being removed, normalization is not thought to be necessary. When normalization is not necessary, the user should collect the data and proceed to the analysis step in the decision process. We generally advise normalizing EMG data, however, because this step is necessary if results are to be compared with similar data from other studies.

When normalization is performed, the user should decide whether a static effort or a dynamic effort is to be used as the reference muscle contraction. The most frequently used value is the MVIC,[9,20,24,39,42,45,96,102,103] but the reader should note that the ability to maximally activate all motor units depends on many factors, such as the muscle activated, training level, and motivation. There have been trends over the last 15 years to use alternatives such as (1) a percentage of the MVIC,[20,96] (2) the peak EMG value obtained during a dynamic activity,[16,20,26] or (3) the mean EMG value obtained during a dynamic activity.[20,85] In general, we believe the isometric contraction is preferred; however, without proper training of the subject, the MVIC can be 20% to 40% less than the true maximum.[45] Use of a value taken from the dynamic event has been favored by many authors[16,20,21,28] for this group of subjects. However, use of the dynamic contraction is confounded by the EMG/force-velocity relationship[39] and other factors such as the change in muscle mass under the electrode site. Thus, the magnitude of the detected EMG signal is likely to be affected. Thus, the decision to use the dynamic contraction may be questioned. Despite any of these concerns, some researchers[16,20] have recommended using the mean or peak EMG value from the dynamic contraction because doing so reduces the intersubject coefficient of variation. Allison and coworkers[104] described general concern about how normalizing EMG data altered the statistical feature, the coefficient of variation, of data compared with the nonnormalized data.

Another alternative has been the use of EMG data obtained from subjects who are simply resting or passive. The disadvantage is that the data provide no information for considering data relative to maximal exertion. However, the application of testing is for patients with neurological dysfunction, such as cerebral palsy or stroke,[16,91] and also for testing elderly people and those with osteoporosis. Thus, resting level may be a normalizing choice out of necessity. A modification of this procedure has been used for patients subsequent to stroke.[91] In this case, to accurately represent the activity in an agonist muscle, the KEMG users elected to compare the values on the hemiplegic side with those of the same muscle on the uninvolved side, forming a ratio. This alternative normalization procedure appears to have been a method of choice in cases where there is known asymmetry that may preclude direct comparisons with the contralateral side or with a control subject. However, the danger is in the across-muscle comparison, which violates the standard for normalizing to the muscle of interest.[38,39]

Little is really known about the best standard to use for normalization. The rationale for selection has generally been based on logic or opinion. From a reliability viewpoint, Knutson and colleagues[90] found that EMG measurements obtained from the gastrocnemius muscle were most reliable when normalized to MVIC versus mean or peak dynamic EMG data. Yang and Winter[96] also addressed the choice of reference contraction from a reliability perspective and found in favor of submaximal contraction levels versus MVIC. Although any of the 4 contraction forms—maximal, submaximal, peak dynamic, or mean dynamic—may be reasonable alternatives, we advise use of the MVIC until the matter is further clarified in the literature. The KEMG user should be alert to standards that may emerge to enhance between-laboratory comparisons of data.

In addition to selecting which reference contraction is to be used for normalization, the electromyographer must also make decisions about what sampling interval or period is most appropriate and the number of repetitions that should be used. Probably the most common interval for MVIC is of 3 seconds' duration, often with 1 or 2 additional seconds at the beginning to allow for achieving peak EMG amplitude. Although no one appears to have studied the appropriateness of this 3- to 5-second data collection interval, the literature provides a general consensus for this amount of time. The primary concern is likely avoidance of fatigue during the contractions of interest by keeping the contraction time relatively short. Standards for the number of repetitions to be used in the normalization process have varied across studies, and investigators have used the contraction producing the greatest EMG activity, the mean of a number of trials, or other methods to arrive at the criterion for normalization. None of these techniques appear to have a singular or most convincing theoretical basis, although in one study that included up to 5 trials, reliability of maximal and submaximal contractions increased as the number of trials increased.[96] Intraclass correlation coefficients ranged from .59 to .81 for the maximal contraction across the 3 test days, from .81 to .93 for the 50% maximal contraction, and from .87 to .95 for the 30% maximal contraction. Thus, the KEMG user appears to be free to select the most justifiable alternative. Reliability testing for the procedures to be used in any particular KEMG study is recommended, particularly if the methods and equipment used in one's own clinic or laboratory establish the repeatability of the measurements.

Analyzing

Electromyographic data have been and will continue to be subjected to many different types of analyses, according to time or frequency domains. Many applications in the time domain call for a visual analysis of data, including evaluation direct from the computer, oscilloscope displays, or printed versions. This step is a convenient way to (1) ensure an artifact-free signal, (2) judge whether there is any muscle activity (on-off), (3) assess the duration of activity as a consequence of the on-off decision, or (4) estimate the level of activity. Visual displays are also convenient for instruction (eg, on various states of activity or the difference produced by a concentric contraction versus an eccentric contraction when performed under similar mechanical conditions). The difficulty with decisions made purely from a visual analysis is that the determination is amplifier gain dependent. That is, as the magnitude of amplification is increased on the EMG hardware controls, the selection of the on and off times may change because the signal is now increased in size on the display device. Often, there are no rules applied for visual determinations, and the amount of gain and the decisions are left to user discretion. As a result of these arbitrary decisions, increased objectivity has been advocated and made possible through computer programs, a need that is distinct for applications associated with biofeedback in the clinic. Despite visual decision-making processes becoming less common, examples can still be found in the literature for recognition of motor units[18,65,105] and for description of surface EMG potentials produced during functional activities.[17,21,23,27,106]

In order to determine onsets, offsets, means, and peaks, quantification has assisted in the use of EMG amplitude as the appropriate criterion. Waveform discriminators,[107] quantifiers of single motor unit features,[108] and computer processing,[99,109] the latter proving highly reliable, have all been used. These techniques allow the user to set specific criteria. Often, the data are smoothed using the RMS or linear envelope form prior to submitting the data to threshold detectors or voltage settings for determining muscle activity (on) or inactivity (off). The level selected to make this "on" or "off" designation remains somewhat arbitrary. Results can be substantially influenced by those decisions, and the user is encouraged to have a theoretical basis or use a level that holds a theoretical basis or general agreement among users.[22,32,53] To establish a more standardized and justifiable technique for these determinations, the use of a criterion such as the mean of a baseline (usually resting) plus 2 or 3 standard deviations, or a percentage of peak, has been suggested.[22,72,74,99] Certainly, these techniques can be applied to address issues such as coordination and agonist-antagonist interactions.[110] If these techniques are used, a review of one methodological study that compared 27 methods of determining onsets of muscle contraction is advised.[109]

Five options for analysis are listed in the Figure under the "Quantitative" heading. Limited information will be provided because these techniques are primarily statistical procedures that can be applied to any data set. When there are specific implications for the KEMG data, comments are included in the following paragraphs.

Amplitude detection has been addressed. The remaining modes of analysis are all statistical in nature, with the exception of case reports and single-subject designs. The special circumstances associated with a subject number as low as 1 preclude the use of group statistics but allow for descriptions, as outlined under the option labeled "Descriptive Statistics" in the Figure, when the subject has repeated performances. "Counts and turns," although adding completeness to the Figure, is a rather special case, and not a decision with which users are faced. Sometimes referred to as the "number of zero line crossings," this method is infrequently used because contemporary analysis techniques are preferred. Descriptive statistics are standardly used for EMG data. Only the intersubject coefficient of variation (CV), which describes dispersion of the group mean ($CV = \sqrt{SD/mean}$), cannot be used for case reports or single-subject design studies.

The last of the major options for analysis is analytic statistics, used for multiple specific purposes usually falling into the broad areas of reliability, group contrasts, and efficacy. The issue of reliability has been addressed for 4 decades, dating back to the original work of Lippold,[111] who demonstrated variability in the EMG-tension relationship across 10 experiments. Since that time, studies have addressed issues of reliability for (1) both surface and fine-wire electrodes, (2) within- and between-day conditions, (3) within-task conditions, and (4) level of muscular contraction.[26,43,85,96,111–115] Generally, these studies show higher reproducibility for within-day conditions than for between-day conditions and for surface electrodes as opposed to fine-wire electrodes. One study[96] showed reliability to be higher for submaximal voluntary isometric contractions than for MVICs. Caution should be exerted by the electromyographer when interpreting results from these studies to ensure limitations are noted in the study design and the use of only selected variables. Reliability reports often provide values of variance ratio (error), intrasubject CV, or intraclass correlation coefficient. Other statistical measures such as the Pearson or Spearman correlation coefficient might also be applicable. A comprehensive view of the reliability issue relative to the normalization of EMG data has been published.[90] As noted earlier, readers and KEMG users are advised to complete measures assessing reliability for their own specific circumstances to help ensure high quality of the data.

Studies, particularly as related to exercise, have appeared and will continue to appear in the literature when the derived EMG is the measure of interest.[1–3,6–9,50,100,116] The most frequently evaluated variables with regard to efficacy are dose, time, and frequency, all of which are usually associated with treatment protocols. For these types of studies, analytic statistics are usually applied. The user should select the statistical procedure for group contrasts or efficacy studies (*t* test, regression analysis, analysis of variance, or analysis of covariance) based on the experimental design and the questions proposed for the study. That selection should be based on sound principles of statistics, and there are no special considerations just because the variable of interest is derived via the electromyogram. Analyses by a variety of investigators are representative of the many reported studies using statistics for EMG data.[25,28,74,117]

For frequency analyses, there has been relatively little use of the methods of autocorrelation and cross-correlation.[66] The use of spectral analyses, however, has become more common. Both median frequency and mean power frequency, derived from the spectral analysis, have been used to evaluate questions related to fatigue,[29,32–34,118] the influence of exercise,[119,120] behaviors of motor units,[121] and the influence of sex.[117] This type of analysis may be useful in determining whether there is inhibition of muscle activity secondary to pain. A historical overview of EMG-based spectral measurement techniques for assessing and classifying paraspinal muscle impairments in patients with low back pain is provided in the work of Roy and Oddsson.[122] As the applications of the spectral analysis continue to expand, there will likely be additional uses of the spectral analysis suggested in the literature. Although not noted in the Figure, descriptive statistics (with the exception of ensembles), case reports and single-subject designs, and analytic statistics can be conventionally applied to studies using spectral analysis. The limitation, however, is that users of KEMG will ordinarily need advanced technology and knowledge to apply these methods to a clinical or theoretical problem.

Summary

This article has presented a guide for the process and decisions commonly made relative to collecting, managing, normalizing, and analyzing KEMG data. Text supporting each step of the guide complements the conceptual model presented in the Figure. Physical therapists should find the guide helpful as they strengthen their expertise in using KEMG to evaluate and treat patients with movement dysfunctions of all types. Awareness of both the components of the guide and the supporting literature included in this article will strengthen the physical therapist's use and interpretation of EMG data. As other techniques for recording, managing, normalizing, and analyzing KEMG data become available, additional iterations of the guide will likely be necessary.

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