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A VERSATILE PROGRAM FOR THE ANALYSIS OF ELECTROMYOGRAPHIC DATA

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Ergonomists and researchers often utilize electromyographic (EMG) recordings to produce estimates of muscular work load in occupational exposure assessment. Prolonged measurements, possible with recent technological advances in portable data acquisition and compact memory storage technologies, require efficient data reduction methods not always available in commercial software packages. The Iowa EMG Analysis Program (IEAP) was created to provide researchers the means to incorporate multiple processing techniques suited for the analysis of prolonged EMG measurements. IEAP currently includes subroutines to calculate the amplitude probability distribution function, exposure variation analysis, clustered exposure variation analysis, and gaps analysis profiles for up to four channels of root-mean-square processed EMG data. Data management functions include the creation of customized hypertext markup language (HTML) documentation and text files able to seamlessly incorporate analysis results into existing statistical software packages. IEAP is a powerful EMG analysis tool ideally suited for ergonomists and researchers involved in occupational ergonomics studies.

INTRODUCTION

Surface electromyography (EMG) is an established tool in the assessment of muscular work load. However, the data processing techniques utilized in EMG analysis vary greatly according to the application of interest. Studies of work-related musculoskeletal disorders often use root-mean-square (RMS) processed EMG signals as the basis for quantitative estimates of force demands during work (Hägg, Öster, & Byström, 1997; Cook, Rosecrance, Zimmermann, Gerleman, & Ludewig, 1998). Novel methods of reducing and analyzing RMS-processed EMG recordings have been reported in the literature (Jonsson, 1982; Veiersted, Westgaard, & Andersen, 1990; Mathiassen & Winkel, 1991; Anton, Cook, Rosecrance, & Merlino, 2003), though software manufacturers have not yet universally adopted these methods in their product offerings. The Iowa EMG Analysis Program (IEAP) was created to provide researchers with a suite of EMG analysis subroutines relevant to contemporary exposure assessment in a variety of occupational settings. Specifically, IEAP offers functionality consistent with current research innovations that are ideally suited to the analysis of prolonged RMS-processed EMG recordings.

THE IOWA EMG ANALYSIS PROGRAM

Software Platform

IEAP was created with LabVIEW 7.0 (National Instruments, Austin, TX), a graphical data collection and signal processing programming environment. For users without LabVIEW 7.0, a stand-alone executable is available that can run on most versions of Microsoft Windows.

Input Data File Formats

IEAP is configured to accept up to four channels of RMS-processed EMG data in tab-delimited ASCII text format, with each channel represented in one column of data. Currently, IEAP is designed to analyze data that has previously been normalized to a maximum voluntary exertion (%MVE). Modifications are underway to expand the number of channels from four to eight, and to allow data normalized to sub-maximal reference voluntary exertion (%RVE). Also under consideration is a subroutine that would execute the normalization process on previously non-normalized data.

User Interface

Upon execution, IEAP prompts the user through a four-step process that defines the parameters of the data set and desired analyses. A combination of pop-up dialog boxes, on-screen text input, menu functions, and checkboxes are used to direct the user and record entered information. Required inputs include a subject identifier, the sampling rate, and the number of data channels within the data file. The user also has the option to enter names for each channel of data and can select whether or not to include a particular channel in the analysis.

Once the input parameters are entered and accepted by the user, IEAP automatically displays the data. Mouse-driven zooming and scrolling functions are available to assist in visualization. The range of the data to be analyzed is defined by two cursors that the user can move to any desired location within the data record. A screen shot of the data display, showing three active channels of data, is given in Figure 1.

When the data is ready to be analyzed, IEAP prompts the user to enter a task to associate with the region between the cursors. IEAP then uses a combination of the subject ID and task when generating names for the analysis output files.

EMG Processing Routines

Basic Analyses. The Basic Analyses portion of IEAP provides the user with the arithmetic mean and peak values of the RMS-processed EMG signals. Separate plots are created for each of the active data channels, and the mean and peak values are indicated on the graphs.

Amplitude Probability Distribution Function. The Amplitude Probability Distribution Function (APDF) returns the cumulative probability distribution of each EMG signal within the specified analysis period. Also displayed are the %MVE values at 90%, 50%, and 10% probabilities, referring to the peak, median, and resting EMG levels, respectively, within the analysis period(Jonsson, 1982). Since the APDF results from a mathematical integration of the amplitude histogram, the probability percentages reflect the percentage of the sampling time the EMG signal is at or below a given amplitude level. APDF has been used in a number of occupational ergonomics studies as a method of comparing the physical demands of different work tasks (Winkel & Bendix, 1986; Mathiassen, Burdorf, & van der Beek, 2002; Simoneau, Marklin, & Berman, 2003).

Exposure Variation Analysis. While the APDF provides information about the percentage of the sampling time spent at different EMG amplitude levels, it does not present information related to the length of individual muscular contractions. A processing technique called exposure variation analysis (EVA) builds on the APDF by further characterizing the percentage of time spent at given EMG amplitude levels into discrete contraction duration categories(Mathiassen & Winkel, 1991). IEAP uses an algorithm in which amplitude and duration are categorized into eight and seven levels, respectively, resulting in a total of 56 cells. The value in a particular cell reflects the percentage of the sampling time that the EMG signal within a specific combination of amplitude and duration. Table 1 lists the default amplitude and duration categories. Typically, the EVA tabular output is plotted as a three-dimensional bar graph, as shown in Figure 2. IEAP does not produce the bar graph within LabVIEW, but instead outputs tabular data directly into Microsoft Excel (Microsoft, Redmond, WA) upon user request for immediate visualization. The default amplitude and duration category boundary definitions may be customized.

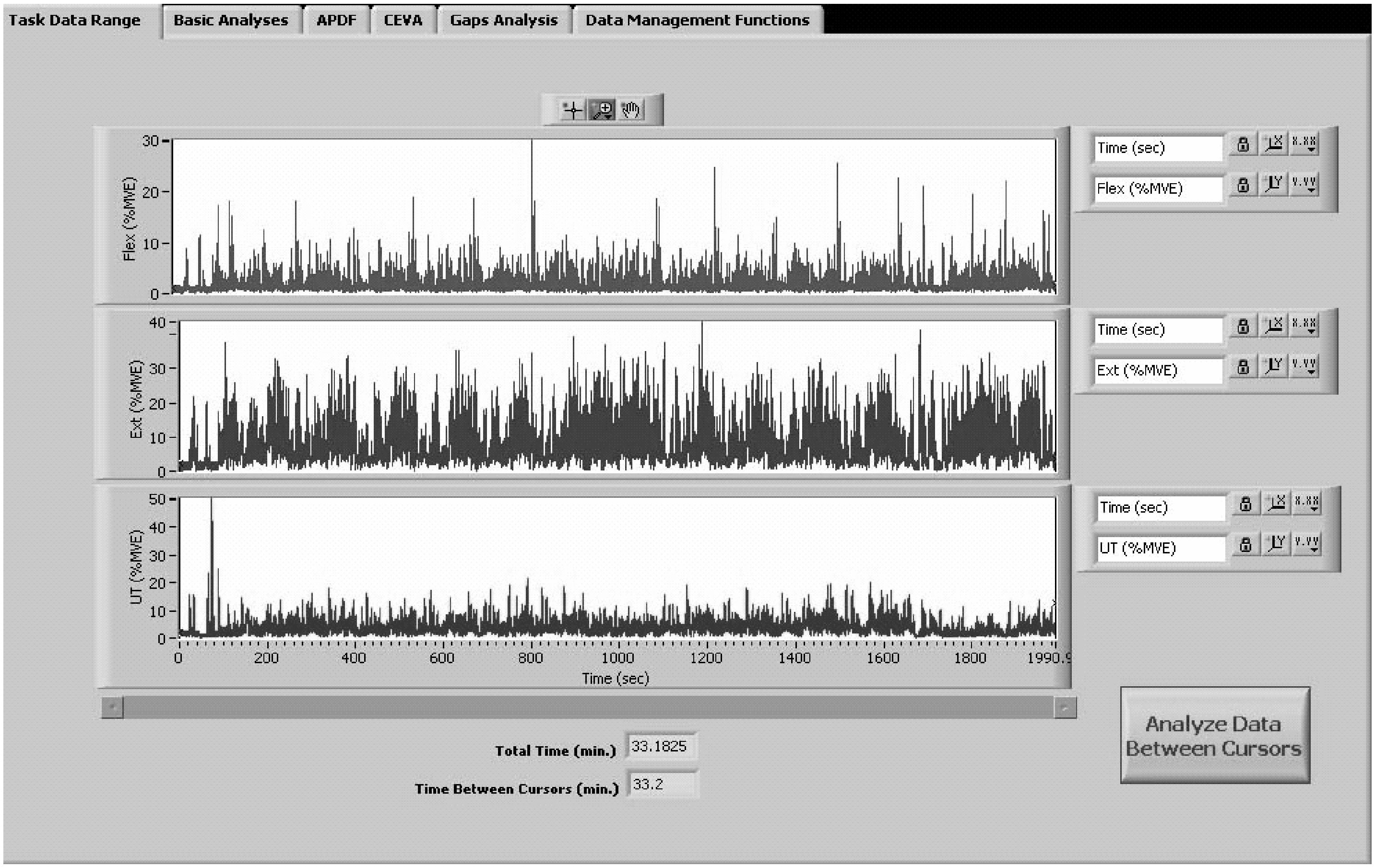

Figure 1: IEAP screen shot, with three active data channels.

Clustered Exposure Variation Analysis. Anton and colleagues (2003) developed a modification of EVA called clustered exposure variation analysis (CEVA), in order to simplify the interpretation of the results. In the CEVA subroutine, the eight amplitude and seven duration categories

Table 1: Default EVA amplitude and duration categories

Amplitude (%MVE)	Duration (s)
> 0 – 0.3	> 0 – 1
> 0.3 – 1	> 1 – 3
> 1 – 3	> 3 – 7
> 3 – 7	> 7 – 15
> 7 – 15	> 15 – 31
> 15 – 31	> 31 – 63
> 31 – 63	> 63
> 63	

from EVA are combined into three amplitude (Low, Moderate, High) and two duration clusters (Short, Prolonged). The six resulting CEVA categories are listed in Table 2, and Figure 3 depicts the CEVA output generated from the same data set shown in Figure 2. The CEVA amplitude and duration category boundary definitions are linked to the EVA subroutine, so changing the default EVA settings also changes the CEVA definitions.

Table 2: Default CEVA categories

Category	Amplitude (%MVE)	Duration (s)
Low amplitude / short duration	> 0 – 1	> 0 – 3
Low amplitude / prolonged duration	> 0 – 1	> 3
Moderate amplitude / short duration	> 3 – 15	> 0 – 3
Moderate amplitude / prolonged duration	> 3 – 15	> 3
High amplitude / short duration	> 31	> 0 – 3
High amplitude / prolonged duration	> 31	> 3

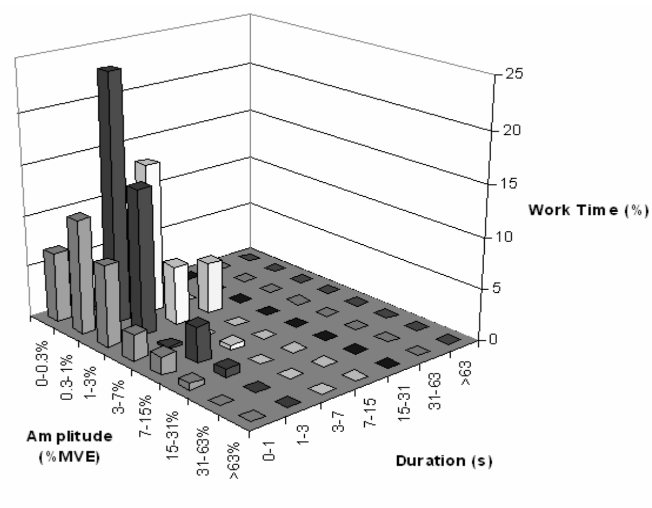

Figure 2: EVA output example

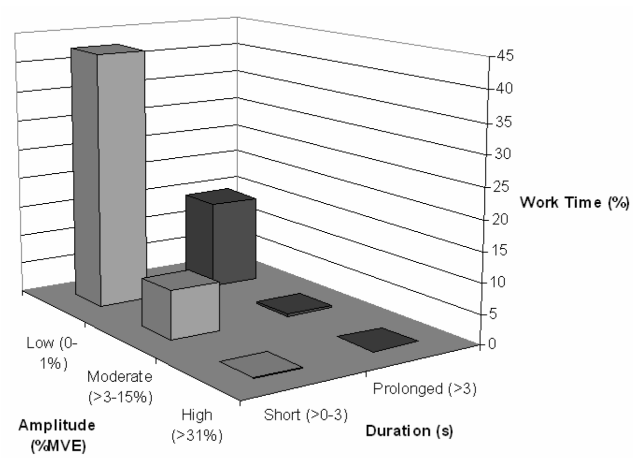

Figure 3: CEVA output example

Gaps Analysis. Gaps analysis is a processing technique that quantifies the frequency and duration of low-amplitude "gaps" within the RMS-processed EMG data record (Veiersted et al., 1990; Hansson et al., 2000). A gap is defined as a portion of the EMG signal below a threshold amplitude for a specified minimum duration, and represents a period of muscular rest. IEAP uses an amplitude threshold of 0.3% MVE and minimum gap duration of 0.10 seconds. The output of the gaps analysis subroutine includes the gap frequency (gaps per minute), and the percent of the total EMG signal that is considered muscular rest, which is the sum of the duration of all identified gaps.

Data Management Functions

IEAP outputs several different documentation forms. Since the user applies a cursor window to specify the region of interest for analysis, the data contained within the window may be output to a separate tab-delimited ASCII text file. This file can easily be imported into other data visualization software, such as Microsoft Excel or Sigma Plot (SPSS Inc., Chicago, IL). The EVA and CEVA tables can be automatically output to an Excel spreadsheet to facilitate graphing. Graphs created within IEAP by the basic analyses and APDF subroutines can be saved to separate jpeg files for easy incorporation into reports and presentations. In addition, a screen shot function is available that, when clicked, sends a screen image to a HyperText Markup Language (HTML) document. A space is also provided for the user to add any comments about the data to the HTML file.

An important function of IEAP is the ability to generate exposure assessment variables for the purposes of making statistical comparisons involving multiple subjects. To eliminate manual data entry, the exposure values created in each EMG processing subroutine can be sent to a separate, customizable, ASCII text file. For example, if the APDF subroutine is active, then the %MVE values at the 90%, 50%, and 10% probabilities for each data channel are available for direct export. The exposure variable text file is tab-delimited by default and can be read directly into SAS (SAS Institute, Cary, NC), SPSS (SPSS Inc., Chicago, IL), or other statistical software. In addition, users have the option to include as many additional variables as desired to the exposure variable text file. Additional variables may include subject characteristics such as height, weight, and age, or other variables associated with the experimental conditions.

IEAP APPLICATIONS

Currently, IEAP is being used as the primary EMG analysis package in a longitudinal study of upper extremity musculoskeletal disorders among manufacturing workers. RMS-processed EMG data from three muscle groups is sampled continuously for up to 2 hours per study participant. Data recordings from over 600 expected participants include a sample of each task performed during a normal work day and are synchronized with digital video. Each EMG data file needs to be analyzed multiple times, depending on the number of tasks represented. IEAP has proven to be a valuable tool, able to efficiently reduce large amounts of data and automatically produce output files that are ready for immediate import into a variety of graphing and statistical software packages.

CONCLUSIONS

Newer EMG processing techniques, such as EVA and gaps analysis, assist in the interpretation of prolonged data recordings, but commercial software packages have not universally incorporated these methods into their product offerings. The Iowa EMG Analysis Program presents the researcher with a series of contemporary EMG analysis subroutines and the ability to automatically export results into fully customizable formats suitable for statistical analysis.

The reduction and analysis of large amounts of EMG data in occupational ergonomics studies has traditionally required a significant time investment. Though not explicitly tested for the purposes of this paper, IEAP has the potential to greatly reduce EMG processing time requirements.

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