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THE USE OF MULTIVARIATE JOHNSON DISTRIBUTIONS TO MODEL TRUNK MUSCLE COACTIVATION

Gary A. Mirka
Naomi F. Glasscock
Paul M. Stanfield
Jennie P. Psihogios

Department of Industrial Engineering
North Carolina State University

ABSTRACT

A model for predicting trunk muscle coactivation patterns is developed in this research. Electromyographic (EMG) data from ten trunk muscles were collected from 28 subjects as they performed simulated lifting tasks. Nine repetitions of each combination of independent variables were performed by each subject. Included in these exertions were asymmetric postures and dynamic (isokinetic and constant acceleration) exertions. The muscle activity data collected during these trials were used to develop marginal distributions of trunk muscle activity as well as a 10 x 10 correlation matrix that describes how these muscles cooperate in the development of these trunk extension torques. These elements were then combined to generate multivariate distributions describing the coactivation of the trunk musculature.

INTRODUCTION

When developing a biomechanical model of the torso, researchers are faced with two questions regarding trunk muscle coactivation: 1) How to allow for antagonistic muscle activity and 2) Should the biomechanical system be modeled deterministically or stochastically? One approach to answering these questions is to develop an empirically-based model of trunk muscle activity.

One such model is found in Mirka and Marras (1993), but this empirical model was limited because the distributions describing muscle activations were simple univariate distributions. A much more robust approach would be to generate a 10 dimensional multivariate system that will allow each muscle to influence every other muscle. This multivariate approach is developed in this study.

METHOD

Subjects

Twenty eight people from the university community served as subjects in this study. There were twenty one men and seven women. None of the subjects had a history of low back disorders. Experience in manual material handling tasks varied.

Apparatus

A Kin/Com dynamometer was used in conjunction with a trunk motion reference frame to control the forces, postures and movements of the subjects. (See Figure 1.) The EMG hardware system employed in this study filtered, rectified and averaged the raw EMG signals over a 20 msec window to arrive at the "integrated" EMG values. These time-dependent processed EMG data along with torque, angle, and velocity were sampled at 100 Hz by the A/D data collection system.

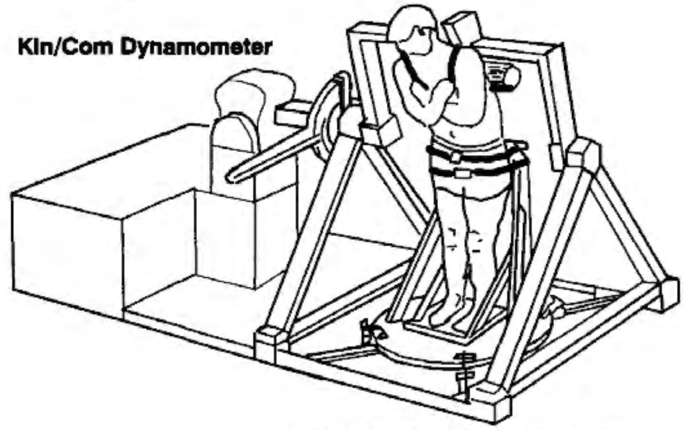

Figure 1. Experimental Apparatus (Trunk Motion Reference Frame and Kin/Com dynamometer)

Experimental Design

Independent Variables. In order to quantify the variability of the muscle activity during lifting, the subjects in this experiment were asked to perform controlled trunk extension exertions repeatedly. These trials included isometric, isokinetic (10 or 45 deg/sec) and constant acceleration (50 deg/sec/sec) exertions. Torque exerted by the subjects were either 30 Nm or 80 Nm for all experimental trials. Two trunk positions were used in the isometric trials: 5 and 40 degrees of forward sagittal bend. Two levels of trunk asymmetry were used in this study: 0 degrees (sagittally symmetric posture) and 30 degrees twisted to the right. Each of these combinations was repeated 9 times per subject.

Dependent Variables. The dependent variables in this study were the normalized processed EMG values of ten trunk muscles: right and left pairs of the erector spinae, the latissimus dorsi, the rectus abdominis, the external obliques and the internal obliques muscles.

Procedure

Posture-specific maximum static trunk extensions and flexions were collected first. These were used to normalize the task EMG values. Each subject then performed a sequence of randomized trunk extension exertions. If the subject failed to maintain the designated amount of torque (+/- 10%) the trial was repeated.

Data Analysis

The EMG data were normalized with respect to the maximum and resting EMG values that occurred at a particular trunk posture. The data was then standardized across subjects so that the variability between subjects would not influence the results. This was accomplished by calculating a mean and a standard deviation for each subject in each experimental condition. The overall mean and pooled standard deviation were then also calculated for each condition. Using these values the individual EMG values were then standardized to avoid an artificial inflation of the variance.

Model Development

At this point the data was in the form of 32 - {10 X ROW} matrices, where ROW refers to the number of trials that met the strict criteria laid out for the acceptability of the data. The 32 different matrices refer to the 32 unique combinations of the independent variables. Each of these 32 data sets were then used to generate a 10-dimensional multivariate distribution. The procedure used is described in greater detail in Stanfield (1993) and is briefly outlined below.

1) Determine the first four moments of the data in each column (mean, standard deviation, skewness and kurtosis) and the correlation coefficients between columns.
2) Develop a lower triangular matrix V such that $V V^T = C$, where C is the {10 X 10} correlation matrix.
3) Develop two new standardized {1 X 10} skewness and kurtosis vectors using the following equations:

   $s^* = (V^3)^{-1} * s$ where s is the original {1 X 10} skewness vector

   $k^* = (v^4)^{-1} * (k - 6 * \sum \sum V^2_{ij} * V^2_{il})$ where k is the original {1 X 10} kurtosis vector
4) Using the above standardized skewness and kurtosis vectors fit a marginal Johnson distribution to each of the muscle distributions.
5) Finally, to generate samples that reflect the multivariate nature of the data use the following relationship:

   $X = S (V * Y) * \mu$

   where: X is a {1 X 10} vector of actual multivariate values

   S is a {10 X 10} diagonal matrix containing the original standard deviations

   V is the {10 X 10} lower triangular matrix see (2)

   Y is a {1 X 10} vector of the marginal distributions generated using the Johnson distributions developed in 4) above.

   μ is a {1 X 10} vector of the original means

RESULTS

The results of this simulation are distributions for each of the trunk muscles in each of the experimental conditions. Displayed in Figures 2 and 3 are a sample of these fitted distributions.

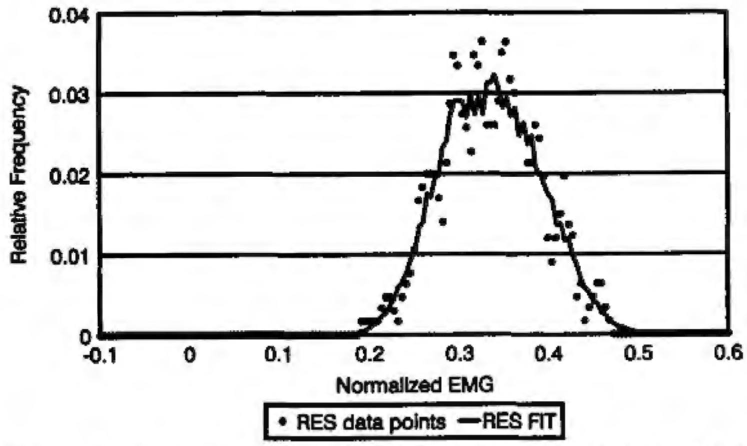

Figure 2. Empirical Data and Best Fit Distribution for the Right Erector Spinae

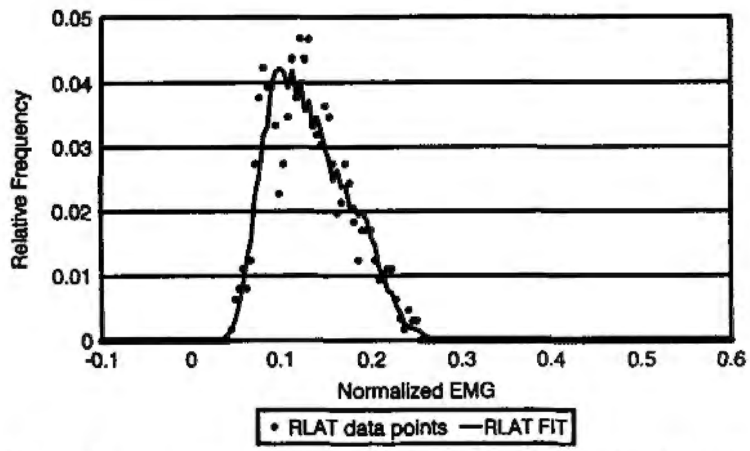

Figure 3. Empirical Data and Best Fit Distribution for the Left Latissimus Dorsi

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