Muscular Performance Modeling of the Upper Limb in Static Postures

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Abstract The purpose of the present paper is to describe and evaluate the polynomial models for predicting the muscular work capacity of the upper limb during sustained holding tasks. This research was concerned with the relationship between indicators of performance, i.e., specific posture or specific level of maximum voluntary contraction (MVC), and then modeling the functional data based on experimental results to estimate factors that may have an effect on task performance. To this end, we designed an experiment using 10 subjects in which each subject performed sustained isometric shoulder and elbow flexion endurance exercise under 27 conditions [3 shoulder angles (SA) × 3 elbow angles (EA) × 3 levels of %MVC]. Throughout all experiments, subjective perception of effort was assessed using the Borg scale, every 60, 30, and 10 s during the 20%, 40%, and 60% MVC tests, respectively. Proposal models were represented by three approaches: model A: estimation of endurance time (ET), with input variables such as SA, EA, and %MVC; model B: estimation of recommendation time (RT, the time during which the operator was able to maintain a position under the desired condition), with input variables such as SA, EA, %MVC, and required rate on the Borg scale; and model C: estimation of limit strength or %MVC, with input variables such as SA, EA, request limit time for work (LT), and required rate on the Borg scale. Statistical analysis indicated that the three proposal estimation models based on polynomial regression functions showed high significance (p<0.0001). The proposal models suggested and recommended the possibility of finding the best positions entailing the reduction and minimization of total muscular strain from manual material handling tasks in different work situations, with the consequent increase in work efficiency. J Physiol Anthropol 22 (3): 149–157, 2003 http://www.jstage.jst.go.jp/en/

Keywords: muscular performance modeling, endurance time, Borg scale, shoulder and elbow flexion, manual material handling

Introduction

As an essential part of most jobs today, operators must often perform work tasks and assume postures that require sustained exertion over extended periods of time. For instance, mechanization and the use of electrically powered machines and tools require the operator to exert and maintain forces by using specific muscle groups to perform a specific activity in a specific posture (Deeb et al., 1992; Mathiassen and Åhsberg, 1999). These types of tasks are characterized by static contractions of the shoulder and arm muscles. Also, static contractions are used to maintain body postures such as supporting the arms when operating tools or holding, carrying, or pushing objects. It has been suggested that static contraction during task performance (especially at a low level of exertion for a long period of time) places a larger load on the muscles than does dynamic contraction. Although new technologies in modern industrial society have generally reduced the amount of exertion and sustained forces needed by muscles to perform activities in specific postures, it remains the case that muscles are used to manipulate large loads in the workplace. In addition, prolonged holding of an object can cause decreased work efficiency, if poor postures are adopted. All these situations have been identified as the source of musculo-skeletal strain and fatigue leading to decreased performance capacity of the muscle, physical stress, pain, and even injury (Chaffin, 1973; Grandjean, 1986).

Isometric endurance time, i.e., the time until exhaustion during an isometric effort starting from rest, is a commonly used metric for the fatiguing effects of local muscle exertions (Mathiassen and Åhsberg, 1999). The muscular load influence on the endurance time of isometric effort has been reported to be a function of the percent of the maximum voluntary contraction (MVC) (Björksten and Jonsson, 1997; Caldwell, 1963; Rohmert, 1960). Current physiological applications based on isometric endurance (Dul et al., 1994; Grandjean, 1988; Jonsson, 1982; Rohmert, 1973) have been inferred from
studies of, preferentially, extremity muscles. In this regard, generalized mathematical models have been developed to describe the relationship between endurance time and muscle load relative to maximal capacity. Endurance in isometric shoulder and elbow activity has been specifically assessed in several studies (Bäckman et al., 1995; Corlett and Manenica, 1980; Gerdle et al., 1993; Hagberg, 1981; Hagberg and Kvarnström, 1984; Hagberg et al., 1987; Hägg and Ojok, 1997; Hansson et al., 1992; Hermans and Spaepen, 1997; Larsson et al., 1995; Mathiassen, 1993; Sato et al., 1984; Takala and Viikari-Juntura, 1991; Takala et al., 1993). None of these authors has, however, interpreted his or her results in terms of ergonomic guidelines, and the relationship between endurance time and different levels of loads with varying shoulder and elbow postures has been examined only with respect to relative contraction intensity (Sato et al., 1984), gender and age (Bäckman et al., 1995), muscle groups (Deeb et al., 1992), and disorders in the shoulder and neck (Hagberg et al., 1987; Hansson et al., 1992). Thus, in spite of the large amount of literature on muscular performance, a specific and reliable reference regarding changes in postures and in load production is still lacking.

With this in mind, the primary purpose of the present study was to develop a mathematical model that would evaluate and explain functional data of isometric shoulder and elbow endurance tasks, with special emphasis on the predictive ability of muscular work capacity while holding of an object in hand. To this aim, we designed sustained holding tasks (isometric contraction) as part of our experiment.

**Materials and Methods**

**Experimental protocol**

We investigated sustained isometric shoulder and elbow flexion endurance in 10 healthy male subjects (age: 24±1.2 years, height: 1.71±0.05 m, body mass: 61.3±5.8 kg) who gave free, informed consent to participate in this study. The shoulder angle (SA) was defined as the angle between the midline of the upper arm and the vertical line from the shoulder to the hip joint, and the elbow angle (EA) was defined as the angle between the midline of the upper arm and the forearm (Deeb et al., 1985). Both the SA and EA were in the sagittal plane. Experiments were performed under 27 conditions provided by a combination of 9 postures [3 shoulder angles (SA: 0°, 30°, 60°)×3 elbow angles (EA: 120°, 90°, 60°)] and 3 different percentage values of MVC (20%, 40%, 60%). Each subject was tested under each of the 27 conditions. After the subject was properly seated in a specially built chair with a comfortable, flat, horizontal seat pan and a vertical straight back, he performed three standard procedures of MVC (Caldwell et al., 1974) at each pre-determined joint angle to assess maximal strength. The best trial was adopted as the MVC and used to calculate the value for the submaximal contraction. Each subject was then asked to hold a weight that corresponded to %MVC at the designated posture, and he was instructed to maintain that condition for as long as possible until exhaustion. The electrogoniometer was placed on the lateral side of the shoulder and elbow in order to electrically record the joint angles. Both the signals of SA and EA as well as horizontal lines indicating the accepted deviation (±10°) were displayed on a computer screen to provide visual feedback to the subject. In this study, the time during which the subject was able to maintain the target angles was considered to constitute the endurance time.

**Borg scale data collection**

The perception of effort and exertion has been studied both with ratio scaling methods and with category methods (Borg, 1973), and the relationship between these methods is well known for work on the bicycle ergometer (Borg, 1977). This makes it possible to convert category scale values to ratio values. The most commonly used category scale for ratings of perceived exertion, the RPE-scale (Borg, 1970), which goes from 6 to 20 to cover the heart rate variation from 60 to 200 beats/min, is constructed to grow linearly with workload and heart rate. Using the linear relation between the RPE-scale and the physical workload, Borg has constructed a specific category scale with ratio properties. Borg’s 10-point scale (Borg, 1982) is a simple category scale that has been developed for differential use with the advantages of a general-ratio scale, and it has been found to correlate positively with workload and heart rate for various types of activities (Borg and Johansson, 1986; Capodaglio et al. 1995).

In this study, we assessed subjective perceptions of exertion based on Borg’s scale every 60, 30, and 10 s during the 20%, 40%, and 60% MVC tests, respectively. The numbers as a rating scale (modified from a 10-point scale to a 100-point scale) correspond to no exertion at all (0); very, very weak exertion (5); very weak exertion (10); weak exertion (20); somewhat strong exertion (40); strong exertion (50); very strong exertion (70); very, very strong (almost maximal exertion, 100) and last “maximal exertion” placed outside the scale that was stronger, they were allowed to exceed 100. The scores were further analyzed with statistical methods.

**Data analysis**

Because the endurance time varied among the subjects in each experimental condition, the endurance time and Borg scale data were normalized in order to make possible the comparison of subjects’ own assessment of exertion and to use that assessment as an input variable in estimations models. We normalized the time in contraction by setting the endurance time as 100%. For Borg scale results, we used a Lagrange polynomial function to interpolate data. The corresponding
point of endurance time at this interpolation curve was considered as the maximum on the Borg scale (100%). Normalized Borg scale data were calculated at every 10th percent of endurance time, so that a sample of 11 points (from 0 to 100%) was obtained. The best curve fitting was obtained using the nonlinear power function regression. We computed the linear and power coefficient of regression in the curve’s equation \((a \text{ and } b, \text{ respectively})\) for each individual experimental condition to establish proposal models. This method was repeated for each subject, in all experimental conditions.

**Model Description**

Several literatures (Brown et al., 1983; Marquardt and Mai, 1994; Schober et al., 1997) indicate that regression functions have been used to establish mathematical modeling. In these studies, each special kind of regression was employed depend on the model characteristics. Since in our study there are many variables, we used a polynomial regression function to calculate and establish proposal estimation models. Moreover, this type of regression function has also been used in previous studies for musculo-skeletal modeling in human upper limb muscles (Pigeon et al., 1996; Shimomura et al., 2000; Wang et al., 1998). The polynomial regression (which was developed by calculating the coefficients of all terms) can be determined using the following expression:

\[
E = \sum_{i=0}^{p} \left( \sum_{j=1}^{m} \text{Coeff}_{ij} \cdot \text{Ind V}_{j} \right)^{p-j}
\]

where \(E=\) estimate of dependent variable (such as endurance time: ET), \(p=\) power, \(m=\) number of independent variables, \(\text{Coeff}_{ij}=\) coefficient numbered by \(i\) and \(j\), and \(\text{Ind V}_{j}=\) independent variable numbered by \(j\) (such as variable \(j=\) shoulder angle: SA). In order to calculate coefficients of all terms in the polynomial regression function and also as a statistical method for finding the best curve to fit the data, we used a mathematical CAD software program (Mathcad Professional 2001, MathSoft, Inc.). Proposal models of muscular work capacity estimation were established using three approaches:

**Model A:** Estimation of endurance time (ET), with input variables SA, EA, and %MVC.

**Model B:** Estimation of recommendation time (RT, the time for which the operator was able to maintain that condition), with input variables SA, EA, %MVC, and Borg scale rating.

**Model C:** Estimation of limit strength (or %MVC, which indicates the weight of the objects that an operator could sustain during a holding task under the desired conditions), with input variables SA, EA, LT (request limit time for work), and Borg scale rating.

**Definition of variables**

- \(SA=\) Constant shoulder angle (degree)
- \(EA=\) Constant elbow angle (degree)
- \(\%MVC=\) Isometric relative load on the hand
- \(\text{Borg}=\) Specific value of subjective evaluation, using Borg scale rating
- \(\text{ET}=\) Endurance time (s), maximum time of performance of the task
- \(\text{RT}=\) Recommendation time (s), time until subject shows designated Borg (as a dependent variable)
- \(\text{LT}=\) Limit time (s), request limit time for work at designated Borg (as an independent variable)
- \(a=\) Linear coefficient of regression in normalized Borg scale vs. normalized ET
- \(b=\) Power coefficient of regression in normalized Borg scale vs. normalized ET

**Process and steps in the development of proposal models**

We calculated the mathematical presentation of the three estimation models (to the power of 3) using a “linear combination” of all terms, which was determined by the expression described in the above section. The process and steps in the development of proposal estimation models are explained and evaluated as follows using Mathcad program instructions.

**Step 0.** Format the matrix data Mathcad, including all variables (Table 1).

**Step 1.** Define the independent variables (\(\text{Ind V}\)) and dependent variables (\(\text{Dep V}\)) in each model for the regression function.

- For model A:
  \[
  \text{Ind V}=SA, \text{ EA, } \%\text{MVC} \\
  \text{Dep V}=\text{ET}
  \]

For models B and C we had to set the Borg scale rating and calculate the Borg limit time and then convert that to the actual time.

- For model B:
  \[
  \text{RT}_i = \left( \frac{\text{Borg}}{a_i} \right)^{1/3} \frac{\text{ET}_i}{100} \\
  \text{Ind V}=SA, \text{ EA, } \%\text{MVC} \\
  \text{Dep V}=\text{RT}
  \]

- For model C:
  \[
  \text{LT}_i = \frac{\text{RT}_i}{100} \\
  \text{Ind V}=SA, \text{ EA, } \%\text{MVC} \\
  \text{Dep V}=\text{LT}
  \]

The Borg scale was set at 75 (very strong) as a sample.

**Step 2.** Calculate the coefficients (\(\text{Coeff}\)) of all terms in
Table 1  Format of matrix data in the Mathcad program including all variables

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Subjects</th>
<th>SA (0°, 30°, 60°)</th>
<th>EA (120°, 90°, 60°)</th>
<th>%MVC (20%, 40%, 60%)</th>
<th>Individual ET (sec)</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>1</td>
<td>120</td>
<td>20</td>
<td>544.2</td>
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<td>1</td>
<td>1</td>
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<td>20</td>
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<td>13.9</td>
<td>0.4</td>
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<td>2</td>
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<td>3</td>
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<td>670.3</td>
<td>24.5</td>
<td>0.3</td>
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<td>20</td>
<td>973.6</td>
<td>1.8</td>
<td>0.9</td>
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<td>8</td>
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<td>20</td>
<td>405.5</td>
<td>5.5</td>
<td>0.6</td>
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<td>9</td>
<td>120</td>
<td>20</td>
<td>354.9</td>
<td>6.1</td>
<td>0.7</td>
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<td>40</td>
<td>403</td>
<td>29.6</td>
<td>0.3</td>
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<td>120</td>
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<td>139.2</td>
<td>17.3</td>
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<td>120</td>
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<td>17.3</td>
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<td>60</td>
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<td>39.4</td>
<td>0.2</td>
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<td>60</td>
<td>60</td>
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<td>0.2</td>
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<tr>
<td>269</td>
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<td>10</td>
<td>60</td>
<td>60</td>
<td>41</td>
<td>28.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

SA: shoulder angle; EA: elbow angle; MVC: maximum voluntary contraction; ET: endurance time, i.e., the time until exhaustion in an isometric effort; a: linear coefficient of regression in normalized Borg scale vs. normalized ET; b: power coefficient of regression in normalized Borg scale vs. normalized ET.

Table 2  Coefficients of all terms in polynomial functions (to the power of 3) for three proposal estimation models calculated using a “linear combination” of all terms

<table>
<thead>
<tr>
<th>Model A</th>
<th>Model B</th>
<th>Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimation of ET (x=SA, y=EA, z=%MVC)</td>
<td>Estimation of RT (x=SA, y=EA, z=%MVC)</td>
<td>Estimation of LT (x=SA, y=EA, z=LIM)</td>
</tr>
<tr>
<td>Terms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>where the rate of Borg scale was set at 75 (very strong)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model A</th>
<th>Model B</th>
<th>Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4.129×10⁻³</td>
<td>-1.763×10⁻³</td>
<td>-8.089×10⁻⁻²</td>
</tr>
<tr>
<td>-1.602×10⁻³</td>
<td>-1.3×10⁻⁴</td>
<td>-1.094×10⁻⁶</td>
</tr>
<tr>
<td>0.018</td>
<td>7.492×10⁻¹³</td>
<td>-1.227×10⁻⁹</td>
</tr>
<tr>
<td>-1.473</td>
<td>-0.66</td>
<td>1.517×10⁻¹³</td>
</tr>
<tr>
<td>-3.364×10⁻⁵</td>
<td>1.054×10⁻⁴</td>
<td>3.481×10⁻⁶</td>
</tr>
<tr>
<td>3.159×10⁻⁴</td>
<td>-3.262×10⁻⁴</td>
<td>3.771×10⁻⁶</td>
</tr>
<tr>
<td>0.107</td>
<td>0.067</td>
<td>4.873×10⁻⁴</td>
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<td>11.535</td>
<td>5.063</td>
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<td>0.487</td>
<td>0.191</td>
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<td>-2.847×10⁻⁴</td>
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<tr>
<td>6.788×10⁻⁵</td>
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<td>2.208×10⁻⁵</td>
</tr>
<tr>
<td>1.307×10⁻³</td>
<td>6.922×10⁻⁴</td>
<td>8.517×10⁻⁵</td>
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<td>-0.168</td>
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<tr>
<td>-0.062</td>
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<td>7.145×10⁻⁴</td>
<td>4.461×10⁻⁴</td>
<td>8.253×10⁻⁶</td>
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<td>-0.025</td>
<td>-8.082×10⁻³</td>
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<td>0.012</td>
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<tr>
<td>5.448×10⁻³</td>
<td>1.54×10⁻³</td>
<td>-1.477×10⁻⁴</td>
</tr>
<tr>
<td>1.061</td>
<td>0.466</td>
<td>0.077</td>
</tr>
</tbody>
</table>

SA: shoulder angle; EA: elbow angle; MVC: maximum voluntary contraction; ET: endurance time, i.e., the time until exhaustion in an isometric effort; RT: recommendation time, i.e., the time during which the operator was able to maintain the required specific condition; LT: limit time, i.e., the request limit time for work at a designated rate of Borg scale.
polynomial functions (to the power of 3) to estimate $\text{Dep V}$ using the “regression function (regress)”:

$$\text{Coeff} = \text{regress} [\text{Ind V}, \text{Dep V}, 3]$$

Step 3. Estimate the dependent variable using “interpolation functions (interp)”:

$$E_i = \text{interp} [\text{Coeff}, \text{Ind V}, \text{Dep V}, (\text{Ind V})^3]$$

Step 4. Evaluate the polynomial functions using correlation coefficient $2$.
- Calculate the sum of squares of deviation ($S_{\text{dev}}$) and residual errors ($S_{\text{res}}$).
- Determine the results with correlation coefficient $2$:

$$R^2 = \frac{S_{\text{dev}} - S_{\text{res}}}{S_{\text{dev}}}$$

For the models A, B, and C, correlation coefficient ($R^2$), was 0.70, 0.59, and 0.85, respectively.

Step 5. Evaluate the significance of the polynomial function using analysis of variance (ANOVA).
- Calculate the degree of freedom (DOF) of regression (DOF $\text{regress}$) and residual errors (DOF $\text{res}$).
- Calculate the mean squares (Msq) of regression:

$$\text{Msq} \text{regress} = \frac{S_{\text{dev}} - S_{\text{res}}}{\text{DOF} \text{regress}}$$

For models A, B, and C, the value of Msq $\text{regress}$ was $5.32 \times 10^2$, $1.253 \times 10^3$, and $3.237 \times 10^3$, respectively.
- Calculate the mean squares of residual errors:

$$\text{Msq} \text{res} = \frac{S_{\text{res}}}{\text{DOF} \text{regress}}$$

For models A, B, and C, the value of Msq $\text{res}$ was $1.71 \times 10^4$, $6.53 \times 10^3$, and $42.19$, respectively.
- The $F$ ratio calculation and significance is determined as follows:

$$F = \frac{\text{Msq} \text{regress}}{\text{Msq} \text{res}}$$

For models A, B, and C the value of $F$ was 31.11, 19.19, and 76.71, respectively.
- The $P$ value was calculated using the probability distribution function ($pF$):

$$P = 1 - pF(F, \text{DOF} \text{regress}, \text{DOF} \text{res})$$

For our three proposal models $P=0$.

**Results and Discussion**

Figure 1(A) shows the results of the estimation model A, which indicate the relationship between specific postures and ET for a required specific level of effort (%MVC). As a sample of exerted and sustained force produced by an operator, 20%, 30%, and 40% MVC were selected to show the results and predict ET in Figure 1(A). In contrast to model A, which exists irrespective of subjective evaluation, estimation models B and C are directly dependent on the specific rate of Borg scales. In other words, first we had to set the rate of the Borg scale at a required specific level of effort, and then we could find the results of RT (model B) or %MVC (model C). Figure 1(B, C) shows the results of estimation models B and C, where the rate of the Borg scale was set at 75 (very strong). As shown in Fig. 1(B), at a low level of contraction (20% MVC), the value of RT was found to be greater than 200 s, whereas for 40% and 60% MVC it was found to be less than 50 s. This rapid decrease of RT found in our proposal model for contraction levels above 20% MVC was in good agreement with previous studies with regard to the relationship between isometric endurance and force expressed as %MVC (Petrofsky and Phillips, 1980; Sato et al., 1984). Figure 1(C) illustrates the results of %MVC (or limit strength) estimation, during three specific task durations (30, 360, and 720 s) at a specific level of subjective evaluation (75: very strong) of fatigue. This proposal model demonstrated that upper limb strength could be mathematically modeled by a polynomial regression function.

The high level of the correlation coefficient ($R^2$=0.70) for model A implies that this model might be a reliable reference in determining endurance times for isometric activities of upper limbs of the human body. The values of $R^2$ for the estimation models B and C were not constant, and, depending on the required rate of the Borg scale, different values of $R^2$ could be found. The values of $R^2$ when the Borg scale was set at 10 (very weak), 50 (strong), and 100 (very, very strong or maximal exertion) were 0.19, 0.43, and 0.70 for model B, and 0.35, 0.74, and 0.82 for model C, respectively. This clearly indicated that the level of correlation coefficient increased as the Borg scale level increased. Therefore, our proposal estimation models B and C show a higher precision at a high level of effort and sustained contraction than at a low level of force.

Statistical analysis using ANOVA in the Mathcad program indicated that our three proposal estimation models based on polynomial regression functions showed a high level of significance ($p<0.0001$). It was more obvious in Fig. 1 (in particular at A and B) that the regression surfaces in estimation models clearly changed for each specific SA, while no significant differences were observed for EA at each different level of %MVC. It can be clearly seen in Fig. 1 (A, B) and should be noted that the maximum and minimum estimate values of ET and RT occurred when the SA was set at approximately 10° and 50°, respectively, which indicated that in isometric endurance, the posture of the shoulder should be...
considered as an important factor in muscular performance, and it has a significant effect on the development of muscular work capacity. Interestingly, these relationships between factors and results of proposal models also confirm and were in good agreement with our previous studies (Koleini et al., 2001, 2002).

It is important to note here that, as expected, there are some estimation errors in the regression models. Specially, in our proposal models based on polynomial regression function, at a low level of force (contraction levels below 20% MVC), estimation errors were found in three models. Since our research was performed under limited experimental conditions (3 levels of force: 20%, 40% and 60% MVC), additional experiments at contraction levels of 5%, 10%, and 15% MVC were suggested to develop the models from this viewpoint of errors. Using another type of regression function, i.e., logarithm regression (Sato et al., 1984), a decrease in estimation errors would be found, but as explained before, since our study has many variables, polynomial regression might be best for proposal modeling. On the other hand, the current proposal models were established based on calculation coefficients of a polynomial function powered by 3. The rate of estimation errors also could be decreased if we selected power 2 for estimation models, but this would result in low R² values.

It should, however, be noted that many researchers have investigated the force-time relationship of isometric muscle contractions to determine the ET of a given relative force (Deeb and Drury, 1990; Mathiassen and Åhsberg, 1999; Sato et al., 1984) and presented models, while direct studies of muscular performance during sustained static holding tasks toward the development of estimation models have not yet been reported. Hence, our study might contribute to the knowledge about muscular performance.

Applications

The implementation of models to represent muscular performance in the human body is a relatively recent development in applied ergonomics (Kayis and Hoang, 1999). The proposal models in the present study may find applications in daily life and industrial activity, in the design of industrial jobs such as assembly lines, in the modeling of exercise physiology to prescribe a particular exercise program, and in the design of computer manikins. A computer manikin was defined as a human model that simulates various human characteristics in a computer. Although almost all the essential human characteristics were considered in the design of existing computer manikins (Das and Sengupta, 1995; Mattila and Karwowski, 1992), one of the most important physiological characteristics, muscular work capacity, has not yet been...
simulated. Therefore, the proposal models in the present study might complement the existing computer manikins. Here we would like to present two examples of the practical application of proposal models B and C as described above.

**Example 1 – Holding an object**

Using the model B estimation of recommendation time (RT), it is possible to estimate the maximum time for holding an object at a designated posture with a specific rate of Borg scale. If SA=45°, EA=90°, Borg scale rating=80, and the weight of the object was considered to equal 6.5 kg (correspond to about 28.8%MVC), then the maximum time for holding the object under these conditions is predicted to be approximately 123 s, with $R^2=0.62$ (Fig. 2).

**Example 2 – In industry, working during holding a specific tool**

Using the model C estimation of limit strength (%MVC), it is possible to estimate the maximum weight of an object that will be hand-held for a requested duration to perform a specific task with a specific rate of Borg scale. If SA=60°, EA=120°, Borg scale rating=50, and the request limit time for working equals 350 s, then the maximum weight of the tool should be less than or equal to approximately 3.97 kg (corresponding to about 23%MVC), with $R^2=0.74$ (Fig. 2).

**Conclusion**

In the present study, we established mathematical models to estimate the relationship between factors that may have an effect on muscular work capacity, based on experimental data. The proposal models may help to predict what would be expected in occupational tasks in which the major musculoskeletal strain originates from manual material handling tasks. The models may help those who use them to find the positions which minimize and reduce total muscular strain in different work situations, with consequent increased muscular performance and decreased feelings of fatigue in the upper limb area. Also, these proposal models may guide the practitioner considering pre-employment selection of operators, and they may help to improve future ergonomic guidelines. This study presents extensive data on shoulder and elbow flexion endurance time and discusses whether it is predictable based on the personal evaluation of fatigue, postures, loads, and maximal strength. Since the relationship between the subjective perception of effort and indicators of task performance were investigated, further research is needed to confirm the validity of subjective perception as a predictor of muscular work capacity.

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