FACTORS EFFECTING DYNAMIC STRENGTH

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ABSTRACT

Dynamic strength testing is another dimension in the field of pre-employment screening. Most manual work requires the use of dynamic strength. That is to say, most industrial work is not static, but requires dynamic qualities for such activities as lifting, pushing, and carrying. Because velocity and acceleration are involved in these activities, these factors must be measured and their effects on human strength determined. The accuracy of dynamic strength testing depends on dynamic factors such as speed of movement and starting position. This paper examines the effect of starting position and speed of movement on the maximum dynamic strength.

1. INTRODUCTION

1.1 Background

Work injuries are a major source of incapacitation, suffering and cost to workers as well as expense to employers. The National Safety Council (1996) in Accident Facts estimated that in 1995 the workforce of the United States experienced 3.6 million work-related injuries. For government, industry, insurance companies, labor, and researchers, the reduction of work injuries remains a significant concern.

Previously, injuries have been prevented through such practices as careful worker selection, good training procedures, and designing the job to fit the worker (Snook and Ciriello, 1972). The obvious means to reduce work injuries is to design a job without excessive lifting, lowering, pushing, pulling, carrying, holding, etc. Ergonomic job design is the primary way of preventing work injuries. Good job design is especially important because it offers a more permanent engineering solution by reducing workers' exposure to hazards, which consequently reduces medical and legal worker-selection problems and makes it easier to select appropriate replacement for absent workers. Designing the job to fit the worker can reduce injuries by as much as one-third according to Snook, 1978. Thus, although job design is not a complete solution, it is significantly more effective than merely selecting the worker for the job or training the worker to fit the job. However, good job design requires a knowledge of worker capabilities and limitations, and, according to Snook, Campanelli and Hart, 1979, careful selection and training of workers should also be used.

Automation and the mechanization of jobs have decreased human strength demands somewhat, but manual power is still the primary energy source in many occupations. For example, jobs requiring muscular strength. such as materials handling or maintenance work, often are not practical to automate totally. Workers whose strengths are not well matched to the muscular requirements of their jobs are at greater risk of sustaining injuries than their co-workers who are better matched (Chaffin, 1975; Chaffin et al,, 1977; Snook et al., 1979). When manual handling tasks require more strength or endurance than a worker can exert without excessive stress, injuries occur. Chaffin et al. (1978) concluded that a systematic strength assessment and job placement program can significantly reduce injuries. Matching the requirements of the job and the muscular attributes of worker would benefit not only the worker, but also industry.

1.2 PRE-EMPLOYMENT STRENGTH TESTING

The assessment of human strength has been of considerable interest to ergonomists and researchers. Many questions have been raised regarding what type strength tests are effective and how many tests should be performed.

Chaffin et al. (1978) investigated the potential effectiveness of pre-employment strength testing in reducing the incidence and severity of musculoskeletal and back problems in materials handling jobs. In the study, strength tests were given to 551 employees before assignment to new jobs, where they were monitored for 18 months. Chaffin found that a worker's likelihood of sustaining a back injury or musculoskeletal illness increases when job lifting requirements approach or exceed the isometric strength capability demonstrated by the individual in a simulation of the job. The study suggests that industry should implement pre-employment programs based on the strength performance criterion.

Traditionally, pre-employment strength-testing programs designed to reduce work injuries have consisted of isometric (static) testing. Static strength is defined as "the maximal force muscles can exert isometrically in a single voluntary effort" (Roebuck, Kroemer, and Thompson, 1987). A strength-testing standard recommending the use of static tests for measurement of human strength was developed in 1972 (Caldwell, et al., 1974) and adopted several years later as an "Ergonomics Guide for the Assessment of Human Static Strength" by the American Industrial Hygiene Association (Chaffin, 1975). However, since people work dynamically, isometric tests may not provide accurate information on industrial work because a static test can not truly simulate a dynamic task. For example, the lifting of a 25 pound box from the floor to waist level is not static because moving the box requires acceleration. For this manual task, static testing is not a precise form of evaluation because acceleration changes the true load, and the body movement changes the worker's posture and the contribution of the different muscle groups.

The alternative for providing a more accurate measure of strength is dynamic testing. By simulating the dynamic tasks required in industrial work, dynamic strength testing may provide a better measure of the strength needed to perform the tasks. Dynamic testing can provide sensitive detection of muscle weakness specific to some part of the range of motion or some functional contraction speed. By creating a better simulation, such as that provided by dynamic strength testing, allows more accurate matching between the force requirements of the job and the worker's strength. This match would result in fewer injuries and in the end, fewer expenses for industry in jobs requiring human strength.

The accuracy of dynamic strength testing depends on dynamic factors such as speed of movement and starting position, and control of subject posture (which is fixed during isometric strength testing). This paper examines the effect of starting position and speed of movement on the maximum dynamic strength through and extensive isokinetic study of dynamic knee movement. The knee was chosen because its uniaxial planer simplifies measurements. Also, measurements of knee strength are more repeatable than measurements of back strength, and the knee is less susceptible to injury than the back.

2. METHOD

2.1 Subjects

Ten healthy adult male subjects volunteered to participate in this study. Their ages ranged from 20 to 36 years, with a mean of 26.6 years. Their heights ranged from 66 to 74 inches, with a mean of 69.40 inches. Their weights ranged from 120 to 185 pounds, with a mean of 158.60 pounds. Subjects with similar physical backgrounds (without athletic training) were chosen to eliminate possible muscle-training effects on the measured strength.

Eliminating large variations in the subjects' anthropometric characteristics increases the homogeneity of the data. Therefore, when possible, subjects with similar anthropometric characteristics were selected. This allowed a consistent distance from the center of knee rotation to the point at which the KIN-COM arm contacted the subject's knee (moment arm). Keeping the moment arm reasonably constant minimized the effect of mechanical advantage on the results of this study.

2.2 Testing Device (KIN-COM)

The Kinetic Communicator Exercise System is a hydraulically-driven, microcomputer-controlled dynamometer for the test, measurement, and rehabilitation of human joint function. The KIN-COM user performs a movement, or a series of movements, against a resistance that the machine provides via a rotating lever-arm system. The machine-controlled movement modes include isokinetic, semi-isotonic (lever-arm speed is continually adjusted to maintain constant resistance), and passive joint movement. The unit can induce concentric, eccentric, or isometric contractions of the muscles involved. The KIN-COM is controlled through feedback loops that monitor the position and speed of the lever arm and the force being exerted y the user. A strain gauge bridge is used to measure force. A bar-encoded shift measures position and speed. This machine compares favorably with other dynamometers such as the CYBEX II. For most clinical and muscle-strength research applications, the KIN-COM appears to provide acceptable and valid measurements, and it is at least as accurate as other available dynamometers (Asoudegi, 1987).

2.3 Testing procedure

After completion of a health questionnaire, each subject was examined for left knee muscular disorder by a physical therapist. Subjects with past knee injuries or cardiovascular problems were excluded from the study. A consent form was signed by these subjects who were qualified by the physical therapist to participate in this knee study.

Before starting the experiment, each of the subjects, was acquainted with the equipment and experimental procedure. To start the exercise, the subjects were positioned supine with the pelvis strapped to the table of the exercise unit. Each subject was required to perform a minimum of nine tests representing all possible combinations of speed (0 degree/second, 60 degrees/second, 120 degrees/second) and starting position (40 degrees, 60 degrees, 80 degrees of knee flexion). The sequence of these combinations was randomized for each subject. Each test consisted of four consecutive maximal concentric and eccentric knee movements resisted by KIN-COM dynamometer.

To eliminate the effect of fatigue, each subject was given a three minute rest period between each test. During each test, subjects were instructed verbally to exert as much force as they could. No feedback was given regarding their performance.

2.4 Experimental Design

The objective of this study was to investigate the effect of starting angle and speed of motion (independent variables) on maximum observed torque. To accomplish this, an orthogonal polynomial model was used with the speed of movement and the starting angle as the two independent variables and the maximum torque as the dependent variable.

3. DATA ANALYSIS AND RESULTS

To test for the effect of the starting position and speed of movement on the maximum torque, the following polynomial model was proposed:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{1i} x_{2i} + \beta_4 x^2_{1i} + \beta_5 x^2_{2i} + \varepsilon_i \qquad (1)$$

Where:

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are parameters

Dependent variable Y represents the maximum observed torque (newton x meter)

Independent variable X_1 represents the speed of movement (degree/second)

Independent variable X_2 represents the starting angle (degree)

ε_i is the random error term $N(0, \sigma^2)$

The two independent variabls X_1 and X_2 were deliberately selected at equispaced levels so that the proposed model could be transformed to an orthogonal polynomial model.

The maximum torque for each subject during strength testing is recorded for each combination of starting angle (40 degrees, 60 degrees, 80 degrees) and speed of movement (0 degrees/second, 60 degrees/second, 120 degrees/second).

Since X_1 and X_2 are at equispaced levels, the polynomial model (1) can be transformed to an orthogonal polynomial model such as:

$$y_i = \alpha_0 + \alpha_1 z_1(x_{1i}) + \alpha_2 z_1(x_{2i}) + \alpha_3 z_1(x_{1i}) z_1(x_{2i}) + \alpha_4 z_2(x_{1i}) + \alpha_5 z_2(x_{2i}) + \varepsilon_i$$

Where $Z_1(X_1)$ and $Z_1(X_2)$ are polynomials of degree one in X_1 and X_2. Also $Z_2(X_2)$ are polynomials of degree two in X_1 and X_2. The results of statistical analysis, shown in table 1, were used to evaluate a series of null hypotheses.

These hypotheses were evaluated in two phases. In the first phase, only the following null hypotheses were tested:

H_o: j = 0 for j = 3,4,5

Against alternative hypotheses:

H_A: j ≠ 0 for j = 3,4,5

From the results in Table 1, we conclude that the parameters α_3, α_4, α_5 are statistically insignificant.

The additive property of an orthogonal polynomial makes it possible to pool the sum of squares for these parameters with the error sum of squares for these parameters with the error sum of squares without recomputing the coefficient of significant terms. Also, the degree of freedom for each parameter can be added to the degree of freedom for the error term.

Table 1
Results of orthogonal polynomial analysis for the effect of starting position and speed of movement on the maximum strength

Source of Variation	SS	df	F Ratio (Phase I)	F Ratio (Phase II)	Regression Coefficients	Estimated Regression Coefficients
(Intercept)	5201775	1	2015.30	2037.18	a_0	240.41
(Speed of movement)	10073	1	3.92	3.95	a_1	-11.60
(Starting Angle)	120064	1	46.51	47.02	a_2	44.73
(Speed of Movement) (Starting Angle)	1882	1	.70	-	a_3	-8.40
(Speed of Movement)^2	2960	1	1.15	-	a_4	3.78
(Starting Angle)^2	576	1	.22	-	a_5	-11.70
Error	214235	83	-	-		
Total	5551505	89	-	-		

In the second phase, the following null hypotheses were tested:

H_o: j = 0 for j = 0,1,2

Against alternative hypotheses:

H_A: j ≠ 0 for j = 0,1,2

Results from the second phase indicate that parameters α_0,α_1, and α_2 are statistically significant ($P<.05$).

From the tested hypotheses, it can be concluded that speed of movement and starting angle have a significant effect on the maximum observed torque.

4. SUMMARY

Determining the effect of the starting angle and speed of movement on maximum measured strength was a major objective of this study. The starting position determines which part of the range of motion needs to be measured to determine a subject's maximum strength.

An orthogonal polynomial model with maximum strength as its dependent variable and starting angle and speed of movement as its independent variables was used to test for the effect of starting position and speed of movement on maximum strength. This study showed that the speed of movement and starting angle significantly affect the maximum measured strength.

The resulting polynomial model indicated that the maximum measured strength increases as the starting angle increases. Also, the results show that the maximum measured strength increases as the speed of 0 degrees/second (isometric). If isometric strength testing is used to assess human strength during dynamic activities, it will tend to over-estimate the subject's strength. This over-estimation may be a serious problem for a person assigned to a dynamic job based on isometric strength tests. The worker is at an increased risk of injury while performing the job because his true strength capability (dynamic strength) is lower than the measured isometric strength.

5. REFERENCES

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