

PREDICTING FEMALE ARM STRENGTH FROM HAND LOCATION

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INTRODUCTION

Upper limb strength limits plays an important role in determining acceptable loads for many workplace tasks. To date, most efforts to estimate limits for these tasks have relied on biomechanical models to estimate the static strength at the shoulder (about three axes) and about the elbow flexion/extension axis. However, errors in these strength calculations at each joint can summate to affect the validity of the final estimates. The purpose of the current study was to directly measure maximum arm efforts at the hand, for a wide variety of hand locations relative to the ribcage. In addition, predictive regression equations were developed to predict the average population strength for a variety of hand positions.

METHODS AND PROCEDURES

A total of 29 female subjects were studied and they were divided into three groups: 1) 10 between 20-29 years, 2) 10 between 30-39 yrs and, 3) 9 between 40-55 yrs. Subjects stood upright and an extending padded rod was used to control the location of their manubrium (ie. ribcage). Data were collected with the hand in 18 locations, which were at a combination of three heights (shoulder, head/stature and waist height), three rotations over the transverse plane (hand directly in front of the shoulder, hand rotated 45 degrees, and hand directly lateral to the shoulder) and two reaches (approximately 40% and 80% of the maximum reach). The head/stature and waist

heights were an average of 18 cm above and 33.5 cm below the shoulder, respectively. The 40 and 80% reaches were an average horizontal distance of 22 and 44 cm from the shoulder, respectively. In each of the 18 hand positions, subjects performed two trials of maximum voluntary efforts (MVEs) in each of the following six directions: anterior push, posterior pull, up, down, medial (left) and lateral (right). All subjects were right-hand dominant and performed the efforts with the right hand, which grasped a vertically oriented, 2 cm diameter padded bar that was attached to a triaxial force plate and rigidly affixed to the testing apparatus. Subjects could stabilize themselves by grasping the apparatus with their left hand. Each effort was 3-5 seconds in duration and maximum forces were determined from a 2 second sliding average window. The higher of the two trials was recorded for each of the six directions in each hand position.

Stepwise regression analyses were performed to predict the average maximum force for a given hand location and effort direction combination. Separate equations were developed for each direction and it was determined that separate equations were needed for efforts at, or above, shoulder height and those at, or below, shoulder height. This resulted in a total of 12 equations and each had some combination of the horizontal (H), vertical (V) and lateral (L) displacement of the hand, relative to the shoulder location. Specifically, H, V, L, H², V², L², HxL, HxV and LxV were used as input variables.

RESULTS

There were substantial interactions between height, reach and angle for the MVEs in most directions, but there were some general trends observed. **Height:** the Down average MVE was highest at head height; Push, Pull, Medial and Lateral were highest at shoulder height; and Up was highest at waist height. **Reach:** while differences existed within reach/angle combinations, the pooled averages were similar between reaches for all six directions. **Angle:** average MVEs were highest when the hand was positioned in front of the shoulder for Push, Pull and Down directions and when rotated 90° (hand lateral) for the Medial and Lateral efforts. The highest average force was 160.7 N (36 lbs) for one of the eighteen Down efforts. Generally, the regression equations were very effective in estimating the group means for each of the 18 hand positions for each of the 6 directions (Table 1, Figure 1).

DISCUSSION

Overall, more than 97% of the variance was explained and the RMS errors were only 4 N (>1 lb) and 5%. Across all 108 combinations, the largest error was only 14.3 N (~3lbs) and even this was less than 10% of the criterion value. All directions maintained errors < 6% and r^2 values >94% (Table 1). Within each combination, the CVs were observed to range from 18%-43%, but were generally close to 30% for each direction, such that 25th percentile values can be approximated by multiplying the predicted equation values (50th %ile) by 0.80.

Future studies will determine if MVEs from 2 or 3 axes can be combined to predict strengths in any direction. This will allow for maximum forces to be estimated for efforts that are directed outside the 6 main axes tested. In addition, data will be collected for efforts performed with the hands above head height.

	Min (N)	Mean (N)	Max (N)	RMS Error (N)	RMS Error (%)	r^2
Push	51.6	85.5	130.2	3.9	4.5%	96.7%
Pull	50.4	87.2	142.4	4.5	5.2%	96.6%
Up	55.9	86.0	114.3	2.7	3.1%	97.6%
Down	76.3	111.2	160.7	6.1	5.5%	94.5%
Medial	63.8	89.2	135.0	2.2	2.4%	98.6%
Lateral	53.2	67.3	96.4	3.5	5.2%	92.0%
Overall	50.4	87.7	160.7	4.0	4.6%	97.2%

Table 1. Scatter plot of empirically measured, average maximum forces versus predicted, regression model outputs.

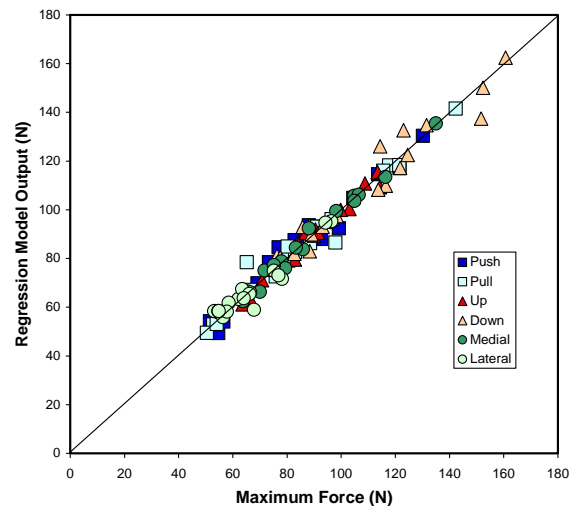


Figure 1: MVE statistics for each of the six directions. Regression statistics are provided for RMS error and correlation between the equation outputs and empirical data. Each number is calculated across the 18 positions.

SUMMARY

This study has successfully produced predictive equations to estimate arm strength in the six primary directions and determine acceptable loads in the workplace.

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