Handgrip strength and hand segment dimension relationships

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Abstract: Twenty five hand dimensions in 126 Jordanian males and females were analyzed to determine the relationship between power grip strength of the hand and various hand dimensions. The results showed that the breadth and depth of the middle finger at the second joint, the breadths of the hand, age, and sex together accounted for 80% of the variation in grip strength. A predictive model for grip strength has been derived from regression analysis. The model fit, with these variables as predictors, was as good as the fit from other published hand grip strength models that used predictors not relating to the hand or hand segments. A model without age, but with four other dimensions accounted for 76% of the variation, and a model with just finger segment dimensions, omitting age, hand length and hand breadth, accounted for 65%.

1. INTRODUCTION

Handgrip strength has been one of the most commonly used physical attributes of people for describing a variety of characteristics. Among its applications are assessment in neuromuscular diseases (Wiles et al., 1990), assessment of nutritional status (Jeejeeboy, 1998), an indicator of manual handling capabilities in work situations, assessment of people's ability to perform manual tasks requiring gripping and squeezing (Kroemer et al., 2001), and determining force design parameters in hand tools (Fransson and Winkel, 1991).

The availability of hand strength data for a particular population is, therefore, of paramount importance. However, in some situations, this strength data may not available, and it may be practical to estimate from a statistical equation that uses easy to measure predictors. A few published studies have produced fairly good regression equations for predicting handgrip strength from anthropometric and demographic data (Vaz et al., 2002; Imrhan et al., 2005). Variables such as age, stature, body weight, and various pinch strengths have been presented as predictor variables in these studies. These other strength and whole body variables have been investigated as predictors because of their common association with various body strengths and the size of the arm. However, no study has so far investigated the relationship between handgrip strength and anthropometric dimensions of the hand and fingers. This paper presents the results of a study to develop a predictive regression equation for handgrip strength from hand and finger dimensions. It is expected that such an equation would be not only predictive but would extend our understanding of handgrip strength and its relation to the anthropometric characteristics of the hand.

2. METHODS AND MATERIALS

A sample of 31 female adults and 54 male adult volunteers in Jordan, were measured for various dimensions of the hand. All subjects were of good health, as self-reported. Permission was granted from the Hashemite University research council to collect hand anthropometric and strength data. This research has also been supported and funded by the Hashemite University. This sample represents the early stage of an on-going study in anthropometry and strength in the Jordanian population.

Handgrip strength was measured as the peak MVC force from a 3-5 second contraction, in the standard way, using a Stoelting handgrip dynamometer (0-100 kg, in increment of 1 kg). For each measurement two repetitions were taken, at random, and the larger was taken as representing the particular MVC strength and used for analysis. Twenty five measurements of the hand and hand segments were taken in the standard way as described in Mandahawi et al. (2005). The measurement is shown below in Table 1. The definitions may be found in Mandahawi et al., 2005).

Table 1. Hand and finger segment measurements

Finger segment lengths
1 Fingertip to root digit 5
2 Fingertip to root digit 3.
3 1st joint to root digit 5
4 1st joint to root digit 3
5 2nd to root digit 5
6 2nd to root digit 3
Finger segment breadth
7 Breadth at tip digit 5
8 Breadth at tip digit 3
9 Breadth at 1st digit 5
10 Breadth at 1st digit 3
11 Breadth at 2nd joint digit 5
12 Breadth at 2nd joint digit 3
Finger segment depths (thicknesses)
13 Depth at tip digit 5
14 Depth at tip digit 3
15 Depth at 1st joint digit 5
16 Depth at 1st joint digit 3
17 Depth at 2nd joint digit 5
18 Depth at 2nd joint digit 3
Palm Measurements
19 Maximum breadth of the hand
20 3rd to base of the thumb
21 Depth of knuckles
22 Maximum depth of the hand
23 Breadth of Knuckles
24 Length of hand
25. Grip circumference.
26. Data analysis methods

First, scatterplots of handgrip strength against each predictor were examined to identify statistical relationships and to recognize potential outliers. The latter were later analyzed in more detail from the residuals produced from an initial model. The scatterplots were also used to search for curvature in strength-dimension relationships. An 'initial' model based on all potential predictor variables (listed above) was first fitted, and the residuals tested for violation of the assumptions of a linear regression model (Kutner et al., 2004). The stepwise and backward regression method was then applied to the data, to find a reduced number of variables (designated as 'k') that was suitable for a final regression equation. This variable reduction stage was then followed by 'all possible regression' method with k-, k, and k+1 variables using model selection criteria such as R^2, Mallow's Cp, and mean square error (MSE) to determine the final predictive models.

3. RESULTS AND DISCUSSION

The data from 85 subjects were used for modeling. The data from the other 41 were used for statistical validation of the final model. Subject's age ranged from 20.0 to 58.1 years, with a mean of 35.1 years. Most were students of a local university. Exploratory correlation analysis, with visual evaluation of scatterplots, indicated that all the hand anthropometric variables were significantly correlated with handgrip strength ($p<0.02$). Three of the hand variables (hand breadth at the knuckles, maximum hand breadth, and hand length) had linear correlation coefficients over 0.7; and 15 others, over 0.55. The breadths and depths of the finger segments seem to be more strongly correlated than lengths, indicating that leverage may be less important for statistical prediction than other size parameters. There were numerous significant pairwise correlations ($p<0.05$) among the list of potential predictor variables, indicating some possibility of multicollinearity in the final model. The scatterplots between handgrip strength and each predictor showed two potential outliers. Later examination of their residuals (Rstudent = 3.79 and 3.82, respectively) from the initial model warranted their elimination from the data set. A scatterplot also showed a slight curvature in the relationship between handgrip strength and age but not in any of the other predictors. A new variable, age-squared was therefore created and entered into the list of potential predictors to be used in the variable search methods. The initial regression equation with all possible predictors yielded residuals which showed no violation of the assumptions for least squares regression modeling. The stepwise selection and backward elimination regression methods yielded 6 and 7 variables, respectively. All possible regression method was therefore carried out to examine all possible 5, 6, 7, and 8 variable models, using all starting predictors. This method looks at all sets of 5, 6, 7, and 8 variable models, apart from the final models produced by the stepwise regression. The results yielded the final 6 predictor model below.

Handgrip strength = -56.252
- 0.255*Age
+12.12*Sex
+2.082*(Breadth of the 2nd joint of digit 3)
-2.806*(Depth of the second joint of digit 3)
+ 0.449*(Maximum hand breadth of hand)
+ 0.758*(Hand breadth at the knuckles).

Model statistics were: R^2= 0.80; MSE= 46.38. Mean handgrip strength was 37.0 kg in the sample of subjects (males and females combined). Three of the four variables selected by the regression procedure were breadths (two palmar and one for digit).

***Validation of model*:** Data from a sample of 41 subjects were available to validate the model, by using the model equation to predict their handgrip strengths. This validation sample was measured at the same time as the model development sample, before data analysis. The percentage error of prediction and absolute percentage error of prediction were calculated. The results indicated that the model over-predicted by 10.0 % (signed percentage) and was in error by 20.2 % (absolute percentage). Though this latter percentage may not be considered very small for some ergonomic designs, other models of handgrip strength that did not use hand segment variables are hardly more accurate. The mean square prediction error (MSPR) from the validation data set was about the same as the mean square error (MSE) for the model from the data from which they were developed. This indicates that MSE may be taken as indicative of the models' future predictive abilities (Kutner et al., 2005). It was 46.2 kg^2. The root of this quantity was 18% of the mean handgrip strength.

The model presented in this paper is not a biomechanical one and, therefore, the predictors should not be interpreted as the ones that generate forces. The predictors are those that are most highly (statistically) associated with the variation of handgrip force across people. There was moderate multicollinearity among the 6 predictors in the predictive model (VIF = 1.2 to 5.6).

4. CONCLUSIONS

The kind of model developed in this study may be used for predicting hand grip strength of a person, given his or her age and five hand or finger measurements. No claim is being made that this is the best model available in the literature, only that it is the first one that requires no other anthropometric measurements except those of the hand and fingers. While the data from this model is based on the Jordanian people, there is no reason to believe that it is not relevant to other populations. Further testing is required to support or negate this belief. The subject sample was not a random one, and there was a fairly large percentage of young adults in it. An improved model is being sought, with an age distribution that is more representative of the society. Validation of such a model, on other populations, would lead to a better appreciation of its relevance and applicability. This study adds to the global body of knowledge about anthropometry and strength.

5. REFERENCES

Fransson, C. and Winkel, J., 1991, Hand strength: the influence of grip span and grip type, *Ergonomics*, 34, 881-892.

Imrhan, S.N., Mandhawi, N. and Sarder, M.B. (2005). "Regression Models for predicting handgrip strength across a wide age range." *The 10th Annual International Conference on Industrial*

Engineering Theory, Applications & Practice, Clearwater, FL, December
Jeejeeboy, K.N., 1998. Nutritional assessment. Gastroenterology Clinics of North America. 27, 347-369.
Kroemer, K.H.E., Kroemer, H.B. and Kroemer-Elbert, K.E. (2001). *Ergonomics: How to Design for Ease and Efficiency*. Prentice Hall, NJ.
Kutner, M.H., Nachtsheim, C.J and Neter, J. (2004). Applied linear regression model. McGraw-Hill/Irwin , Dubque, IL.
Mandahawi, N., **Imrhan, S.N**., Al-Shobaki, S. and Sarder, B. (2008). Hand anthropometry survey for the Jordanian population, *International Journal of Industrial Ergonomics*, 38 (11-12), 966-976.
Vaz, M., Hunsberger, S. and Diffey, B. (2002). Predictive equations for handgrip strength in healthy Indian male and female subjects encompassing a wide age range. Annals of Human Biology, 2002, 29(2), 131-141.
Wiles, C.M., Karni, Y., and Nicklin, J., 1990. Laboratory testing of muscle function in the management of neuromuscular disease. Journal of Neurology, Neurosurgery, and Psychiatry, 53, 384-387.