# Prediction Model of One-handed Pull Strength in the Sagittal Plane

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**Abstract.** Understanding individuals' capability of one-handed pull strength is crucial in manual handling task design as one-handed pulling is frequently conducted in daily life. The present study was designed to develop prediction models of one-handed pull strength from anthropometrics and body-joint angles. One hundred Chinese adults were recruited and instructed to provide their maximum one-handed pull strength in the sagittal plane. Sagittal-plane photographs were taken for measuring three joint angles (i.e., trunk angle, knee angle, and ankle angle). T-tests, ANOVAs, and stepwise multiple regression analysis were conducted for data analysis. Five prediction models were developed with the adjusted $R^2$ values ranging from 0.621 to 0.818 (all *p*s <0.001). Significant predictors were reported and discussed. The findings contribute to physical ergonomics and human factors by providing prediction models for reference values of one-handed pull strength of a population, further facilitating safety designs of tasks involved one-handed pulling. (144 words)

**Keywords:** Physical Ergonomics · One-handed Pull Strength · Prediction · Sagittal Plane

## 1 Introduction

Mismatching between individuals' strength capability and task strength requirement can lead to musculoskeletal disorders for workers in manual material handlings. It is of importance to have and use reference strength data when designing the tasks. One-handed pulling is a frequently performed motion in many jobs and daily activities (e.g., pulling luggage out of a car's trunk or objects from a running conveyor in manufacturing facilities). To facilitate the design of tasks involved one-handed pulling, some researchers have conducted attempts to build reference data on one-handed pull strength [1-4]. For example, Lin and colleagues [2] collected static one-handed pulling strength from 84 Americans and built a normative dataset on the populational strength capability of one-handed pulling from four heights (24 inches, 30 inches, waist height, and above-shoulder height). Or and colleagues [1] utilized the same apparatus and experimental protocol that Lin et al. used [2] to test a Chinese population and established a normative dataset of one-handed pulling strength. However, creating a normative strength dataset is time consuming and costly, especially for population-level data [5]. A prediction model can be beneficial to the industry community by providing reference strength data for task design. Previous studies have reported some influencing factors on pull strength, for example, gender [4], age [6], body mass [7], hand-handle interface [8], friction between floor [9], and pulling heights and directions [1, 2]. These findings make it possible to develop prediction models for one-handed pull strength. However, only few prediction models were published in the literature. For example, Garg and Chaffin [10] established a biomechanical computerized model of hand forces, but the model was only for seating posture. Voorbij and Steenbekkers [6] created a prediction model of one-handed pull strength, but they only had one predictor – 'age'. To the best of our knowledge, no prediction model of one-handed pull strength was developed for Chinese population.

Therefore, the present study was designed to develop and validate prediction models of one-handed pull strength using a Chinese population. In order to well control the experimental environment, the hand-handle interface, floor friction, and pulling direction (i.e., the sagittal plane) were all remained unchanged during the experiment. Based on the literature [4, 6, 7], age, gender, body weight, and stature were selected as the potential predictors. Moreover, considering potential body twists in the pulling process, three main body-joint angles (trunk angle, knee angle, and ankle angle) were examined in the development of prediction models of one-handed pull strength.

## 2 Methodology

### 2.1 Participants

One hundred Chinese adults participated in the study, including 10 males and 10 females from each of five age groups (18-24, 25-34, 35-44, 45-54, and 55-64 years old). All participants self-reported heathy and free of musculoskeletal injuries at the time of conducting this study. Written consent forms were obtained from each participant.

### 2.2 Apparatus

Rulers and an electric weight scale were used to measure the participants' stature and body weight, respectively. One-handed pull strength was evaluated using the test frame in Figure 1. Four load cells (Model AG100, Scaime S.A.S., France) were mounted to the aluminum cross bar whose height was adjustable. When the participants pulled the cylindrical aluminum handle (diameter=4cm) mounted to the center of the cross bar, a computer-based application developed using MATLAB recorded the values of the four load cells and calculate the pull strength as a vector sum of the orthogonal components [1, 2]. The test frame was placed on a plywood slip-resistant platform (friction coefficient $\mu$=0.83). A camera was located on the right side of the participants to capture their sagittal-plane photographs. An angle measuring software (Image Tool v3.0) was used to measure the participants' trunk angle, knee angle, and ankle angle according to the published measurement protocol [10].

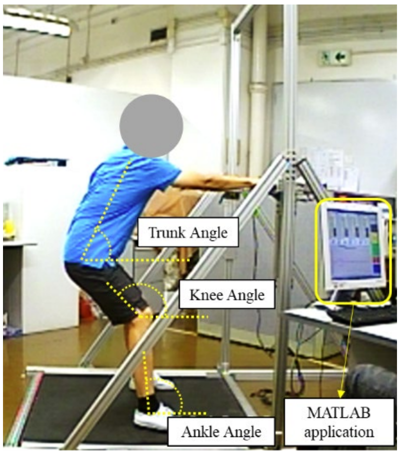


**Fig. 1.** Illustration of the test platform and three joint-angles.

### 2.3 Procedure

Two trained research assistants first explained the study protocol to the participants and collected their written consent form, following by a questionnaire for demographic information (e.g., gender and age) and the measurements of body weight and stature using weight scale and ruler, respectively. In the measurement of one-handed pull strength, the participants were asked to: 1) stand on the platform facing to the handle in front of the body (see Figure 1); 2) pull the handle towards the chest using their domain hand; 3) build up their strengths, without any jerk, in the first two seconds and hold the maximum for the following three seconds. Pulling process for each trial was accompanied with a slogan "ramp up, ramp up, hold, hold, hold, relax". The greater strength value of the two replications was used for data analysis. A sagittal-plane photograph was taken at the time of the second "hold". A 2-minutes rest (longer if needed) was given between trials.

### 2.4 Data analysis

Descriptive analysis was conducted to analyze the means and standard deviations (SDs) of anthropometrics. T-tests were used to evaluate the difference between two genders in anthropometrics and one-handed pull strength. One-way ANOVAs were performed to examine the effects of age-group and pulling height. The 100 participants were divided into two subsets: subset-1 comprising 80 participants (8 males and 8 females randomly selected from each of the 5 age groups) and subset-2 comprising the remaining 20 participants (10 males and 10 females). Stepwise multiple regression analysis was conducted for each pulling height, with age, gender, body weight, stature, trunk angle, knee angle, and ankle angle as potential predictor variables. The standard error of the estimate (SEE) and the mean absolute percentage error (MAPE) were calculated for validating the prediction models through the two equations below [11]. The smaller the SEE and/or MAPE values, the higher prediction accuracy and better validity [12].

$$\mathrm{SEE} = \sqrt{\frac{\sum(Y - \bar{Y})^2}{(n-2)}} \quad (1)$$

$$\mathrm{MAPE}=\frac{100\%}{n}\sum_1^n \left|\frac{Y-\bar{Y}}{Y}\right| \quad (2)$$

where Y is the observed value, $\bar{Y}$ is the predicted value, and n is the measurements.

## 3 Results and Discussion

Table 1 lists the means and SDs of age, body weight, and stature of the 100 participants. The results of t-tests showed significant differences between the two genders in body mass, $t(98)=6.235$, $p<0.001$, and stature, $t(98)=9.696$, $p<0.001$, but not age, $t(98)=0.035$, $p=0.972$.

**Table 1.** Anthropometric information (means and SDs) of the 100 participants.

| Characteristics | 18-24 | | 25-34 | | 35-44 | | 45-54 | | 55-64 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F | M | F |
| Age (years) | 21.5 (2.1) | 20.9 (2.1) | 27.6 (2.3) | 28.0 (2.5) | 39.2 (3.0) | 39 (2.4) | 50.3 (2.9) | 50.1 (2.0) | 58.5 (3.4) | 58.6 (2.9) |
| Body weight (kg) | 63.7 (7.9) | 53.6 (7.4) | 69.5 (8.8) | 52.6 (6.3) | 74.7 (15.9) | 58.9 (8.1) | 71.8 (7.9) | 55.6 (7.1) | 62.8 (7.5) | 60.3 (13.1) |
| Stature (cm) | 175.1 (3.7) | 163.0 (7.0) | 174.6 (5.4) | 161.3 (4.7) | 172.5 (5.8) | 162.0 (6.3) | 169.8 (6.6) | 158.7 (6.2) | 167.7 (5.5) | 156.1 (4.4) |

Table 2 shows the means and SDs of maximum one-handed pull strength when the participants pull in the sagittal plane. The difference in one-handed pull strength between females (172.6 N) and males (241.4 N) was significant, $t=-6.704$, $p<0.001$, consistent with previous studies [2, 5]. The ANOVA results showed no significant difference in one-handed pull strength among the five age groups for females ($F=0.421$, $p=0.793$) but significant difference was found for males ($F=3.870$, $p=0.009$). The results also presented that pulling height significantly affected the one-handed pull strength for females ($F=46.833$, $p<0.001$) and males ($F=103.185$, $p<0.001$), in line with previous studies [2, 5].

**Table 2.** Means (SDs) of maximum one-handed pull strength (in N) of the 100 participants.

| Pulling height | Age group | Female | Male |
|---|---|---|---|
| 20 inches | 18-24 | 210.8 (36.6) | 337.0 (122.1) |
| | 25-34 | 221.3 (50.7) | 378.1 (99.6) |
| | 35-44 | 223.5 (67.0) | 367.2 (63.9) |
| | 45-54 | 197.3 (59.6) | 285.1 (61.3) |
| | 55-64 | 235.82 (95.4) | 269.6 (96.5) |
| | Total | 217.7 (63.6) | 327.4 (98.1) |
| 32 inches | 18-24 | 183.0 (39.7) | 302.5 (91.9) |
| | 25-34 | 209.4 (45.1) | 312.6 (90.7) |
| | 35-44 | 196.5 (59.9) | 327.0 (57.2) |
| | 45-54 | 196.7 (68.2) | 258.6 (67.0) |
| | 55-64 | 182.87 (58.4) | 229.4 (64.0) |
| | Total | 193.7 (53.9) | 286.0 (81.2) |
| 44 inches | 18-24 | 151.3 (25.6) | 239.0 (37.8) |
| | 25-34 | 168.5 (28.9) | 249.4 (51.5) |
| | 35-44 | 175.4 (46.3) | 267.2 (51.8) |
| | 45-54 | 157.7 (43.8) | 219.4 (57.8) |
| | 55-64 | 162.48 (63.9) | 190.0 (54.8) |
| | Total | 163.1 (42.9) | 233.0 (55.9) |
| 56 inches | 18-24 | 134.8 (29.4) | 196.5 (33.6) |
| | 25-34 | 149.0 (44.3) | 233.5 (92.3) |
| | 35-44 | 159.2 (35.2) | 215.1 (47.5) |
| | 45-54 | 132.9 (24.1) | 175.0 (42.0) |
| | 55-64 | 162.06 (63.7) | 155.3 (37.6) |
| | Total | 147.6 (41.8) | 195.1 (59.7) |
| 68 inches | 18-24 | 126.8 (41.4) | 162.0 (37.0) |
| | 25-34 | 132.2 (65.3) | 200.8 (88.6) |
| | 35-44 | 143.4 (31.5) | 173.0 (43.1) |
| | 45-54 | 142.9 (39.4) | 152.3 (64.1) |
| | 55-64 | 158.9 (63.9) | 140.5 (31.2) |
| | Total | 140.8 (49.4) | 165.7 (58.3) |
| Total | 18-24 | 161.3 (46.2) | 247.4 (96.4) |
| | 25-34 | 176.1 (57.8) | 274.9 (104.4) |
| | 35-44 | 179.6 (55.6) | 269.9 (87.9) |
| | 45-54 | 165.5 (54.7) | 218.1 (75.6) |
| | 55-64 | 180.4 (73.5) | 197.0 (75.9) |
| | Total | 172.6 (58.3) | 241.4 (93.0) |

The results of stepwise multiple regression analysis showed that the predictors varied for different pulling heights (see Table 3). Age is a negative predictor for one-handed pull strength when pulling at the two lower heights, i.e., 20 inches and 32 inches. Stature is only a negative predictor when pulling at the highest height (68 inches). One possible reason could be that the higher-stature participants may attempt to pull the handle in a horizontal direction but cannot make use of their body weight, as compare to those with lower stature. Trunk angle plays as a positive predictor for the lowest height but a negative predictor for the two highest heights. For the pulling from a high height, a smaller trunk angle may denote that the participants bend their body and tried to make full use of their body weight for the pulling. Weight, ankle angle, and knee angle are all positive predictors for the one-handed pull strength from the five pulling height. The adjusted $R^2$ of the five models varied from 0.621 (for 20 inches) to 0.88 (for 44 inches) with all p values $<0.001$.

**Table 3.** Results of the stepwise multiple regression analysis for maximum one-handed pull strength (n=80) for each pulling height (in inches).

| Height | (Constant) | Age | Gender | Weight | Stature | KA | AA | TA | Adjusted $R^2$ | F, *p-value* |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | -913.3 | -1.8 | 0 | 4.6 | 0 | 2.4 | 5.8 | 2.4 | 0.621 | 26.9, *<0.001* |
| 32 | -752.7 | -0.8 | 0 | 3.2 | 0 | 3.0 | 4.2 | 0 | 0.772 | 67.9, *<0.001* |
| 44 | -643.2 | 0 | 0 | 2.6 | 0 | 2.6 | 3.6 | 0 | 0.818 | 119.2, *<0.001* |
| 56 | -549.1 | 0 | 0 | 2.0 | 0 | 3.1 | 3.4 | -1.2 | 0.809 | 84.9, *<0.001* |
| 68 | 77.2 | 0 | 0 | 2.0 | -3.4 | 4.0 | 3.9 | -3.2 | 0.716 | 40.8, *<0.001* |

The subset-2 data (n=20) were used for the model validation by calculating the SEE and MAPE values (see Table 4). The results showed that when predicting one-handed pull strength for 20 inches, both SEE value and MAPE value were the largest, i.e., 65.2 and 23.5%, respectively; when predicting for 44 inches, both SEE and MAPE were the smallest, i.e., 29.0 and 10.8%, respectively. One possible reason could be that pulling strength from 20 inches is more dependent to body weight and pulling posture (e.g., body twisting), which may make the prediction more sensitive.

**Table 4.** Means (SDs) of the actual strength and predicted strength for the subset-2 (n=20) and the validation results (i.e., SEE and MAPE values) for each pulling height (in inches).

| Height | Actual strength | Predicted strength | SEE | MAPE |
|---|---|---|---|---|
| 20 | 280.8 (118.4) | 291.5 (76.9) | 65.2 | 23.5% |
| 32 | 237.8 (90.0) | 224.3 (69.2) | 50.3 | 17.3% |
| 44 | 195.9 (59.3) | 191.4 (46.4) | 29.0 | 10.8% |
| 56 | 161.7 (41.3) | 150.9 (44.2) | 35.7 | 14.5% |
| 68 | 132.6 (32.0) | 141.8 (42.8) | 39.4 | 22.0% |

## 4 Conclusion

A normative dataset of one-handed pull strength was established for designing manual handling tasks that involve one-handed pulling. Based on the dataset, five prediction models were developed with the adjusted $R^2$ values ranging from 0.621 to 0.818 (all *p*s <0.001), among which body weight, knee angle, and ankle angle are three positive predictors regardless of pulling heights. Low SEE values and low MAPE values denote a good validity of the models. The findings contribute to physical ergonomics and human factors by providing prediction models for reference values of one-handed pull strength of a population, further facilitating safety designs of tasks involved one-handed pulling.

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