An Apparatus and Protocol to Measure Shoulder Girdle Strength

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Abstract

Background: Muscles actuating the shoulder girdle are important for stabilizing the scapula and coordinating phased kinematics of the shoulder complex. If these muscles become weak or imbalanced, joint instability and injury may result. Reliable measurement of shoulder strength is thus important for prevention, diagnosis, and rehabilitation of shoulder problems. To date, studies quantifying the strength of the shoulder girdle are limited. The purpose of this work was to design and evaluate a custom apparatus and corresponding protocol for measuring maximal, voluntary, isometric strength of the shoulder girdle muscles during various forms of shrugging exercise.

Methods: A custom apparatus was constructed as a rigid frame with a vertical post supporting a seat, seat back, and horizontal beam. The beam extends laterally on either side beyond and around the shoulders of a seated subject. A pair of arm extension members pivots on the beam about an axis aligned with the shoulder flexion-extension axis. These members can be locked in place at any angle. Between them is mounted a force-sensing grip assembly which can be adjusted proximally or distally to accommodate varying shoulder girdle positions. Subjects grasp the grip assembly handles with extended elbows and push or pull as forcefully as possible. Nine female and ten male subjects participated in a protocol using the apparatus to measure maximum isometric force generated at three positions each for elevation, depression, protraction, and retraction of the shoulder girdle (3 positions x 4 modes = 12 tests). A video motion capture system was used to measure shoulder girdle angles. The reliability of the approach was evaluated based on the repeatability of measured shoulder elevation angle, protraction angle, and total force over three days of testing.

Results: The apparatus performed well during the tests, providing a stable, rigid, yet adjustable platform for measuring shoulder girdle strength. Repeatability of force measurements was interpreted as
very good to excellent, with ICC (2,1) values ranging from 0.83 to 0.95 for all tests except one (ICC=0.79). Repeatability of angle measurements was interpreted as good to excellent. For tests measuring elevation and depression strength, the ICC of elevation angle ranged from 0.85 to 0.89. For tests measuring protraction and retraction strength, the ICC of protraction angle ranged from 0.68 to 0.88.

Conclusions: This type of apparatus could be an effective clinical tool for measuring strength in the shoulder girdle muscles. Use of the video motion capture system is optional.

Keywords: scapula, isometric, reliability, repeatability, elevation, protraction

Introduction

The reliable measurement and characterization of human joint strength is valuable for a wide range of applications. For example, in clinical settings joint strength measurements can be used to assess injury, track progress of recovery, and evaluate rehabilitative programs [1]. In sports, measurement of joint strength can be used to identify muscles important for performance, monitor agonist-antagonist strength balance, and evaluate training programs [2, 3]. In engineering applications, joint strength measurements are valuable for the safe and effective design of products and devices [4, 5]. Finally, in research applications joint strength measurements can reveal the variability of joint forces in motor control tasks [6], and facilitate the development and validation of musculoskeletal computer models capable of simulating human biomechanics [7-9].

Many studies have investigated the reliability of devices and techniques to measure joint strength, and these have involved a wide range of joints and exercises. For example, studies have looked at the reliability of devices ranging from the larger, fixed commercial dynamometers such as Biodex (Biodex Medical Systems, Shirley, New York) and Cybex (Cybex, Division of Lumex, Ronkonkoma, New York) [10-13], to hand-held devices [14-16], and to custom-built apparatuses [16-18]. Techniques using these devices have measured strength in lower-extremity joints including the hip [12, 16, 18, 19], knee [10, 20, 21], and ankle [13, 22, 23], in upper-extremity joints including the shoulder [11, 15, 24], elbow [15], and hand [14], and even in the back joint [17, 25].
Studies measuring strength in the region of the shoulder girdle have been more limited, perhaps because this joint is embedded within the trunk segment and therefore less accessible to testing apparatus. However, the shoulder girdle is actuated by a number of large muscles including the trapezius, rhomboids, and serratus anterior, which are important for stabilizing the shoulder girdle, positioning the glenoid for overall upper extremity motion, and transmitting forces and energy from the trunk to the arms. In addition, the action of these shoulder girdle muscles plays a key role in the alignment of forces around the glenohumeral joint which affect shoulder function and its susceptibility to overload rotator cuff injury [1, 3, 26].

Historically, shoulder girdle strength has been measured indirectly through basic exercises whose gross movements involve the shoulder muscles, such as pull-ups, push-ups, wall push-ups, scapular pinches, seated lat pull, seated chest press, and flexed arm hang [26, 27]. More recently, a limited number of studies have considered the shoulder girdle more directly in strength measurements. Smith [28] investigated how isometric glenohumeral flexion strength in the sagittal plane was affected by shoulder girdle protraction-retraction position. Cools [29] evaluated the Biodex closed-chain attachment for measuring isokinetic strength of shoulder girdle protraction and retraction in the scapular plane. To our knowledge, no study has looked at measuring isometric strength over varying positions of the shoulder girdle in elevation, depression, protraction and retraction.

This paper presents a novel apparatus and corresponding protocol for measuring the force generated by the shoulder girdle muscles and transmitted through the glenohumeral joint during maximum, isometric “shrugging” exercises (Fig. 1). The term “shrugging” is here generalized to include elevation, depression, protraction, and retraction of the shoulder girdle (clavicle and scapula). The reliability of the measurement protocol was evaluated based on the repeatability of shoulder girdle position and force generation over three days of testing. Results of the reliability analyses are presented in this paper. The strength measurements are published separately [30].
Methods

A series of experiments were performed to 1) measure the position of the shoulder girdle and the magnitude of force generated through the glenohumeral joint during 12 maximal-effort, isometric shrugging trials, and 2) evaluate the repeatability of the results over three days of testing. The experiments were approved by the Institutional Review Board (IRB) of Baylor University.

Subjects

Nine female and ten male volunteers were recruited to participate in the study. Subject ages ranged from 19 to 24 years. All subjects were healthy, involved in physical activity at least three times weekly, and without a recent history of joint disorder or injury to the arms, shoulders, neck, or back. All participants signed informed consent.

Apparatus

A custom apparatus was designed and constructed to facilitate the experiments (Fig. 2). The base of the apparatus consists of a sturdy, four-footed frame supporting a rigid, vertical post. Bolted along the height of the vertical post are a padded seat back and a seat support assembly with a padded seat. A pattern of bolt holes (not shown) permits the mounting of the seat support assembly to be adjusted up or down on the vertical post, although this feature was not used in the current experiments. Bolted symmetrically to the top of the vertical post is a horizontal beam that spans laterally beyond shoulder width on either side. On each end of this beam is a projection which reaches anteriorly to the axis of shoulder flexion and extension.

A rotating arm assembly is hinged on both sides of the anterior projections of the horizontal beam so that the axis of rotation coincides approximately with the shoulder flexion/extension axis of a seated subject. The arm assembly consists of two mirror-symmetric sets of a semicircular plate and an arm extension member. The arm extension member on each side of the arm assembly extends beyond the maximum arm length of human subjects. Rotation of the arm assembly is arrested by pins on both sides passing through the semicircular plates and anterior projections of the horizontal beam. The plates are
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each constructed with an array of pin holes that permit the arm assembly to be pinned in place at a range of angles from vertically downward, to horizontally forward, to vertically upward.

A grip assembly spans across the width between the two arm extension members. The main structural components of the grip assembly are two, parallel, rectangular plates which slide along the arm extension members on either side. An array of numbered holes (12.7 mm (1/2 inch) center to center) in the arm extension members permit the grip assembly to be pinned at a range of positions from proximal to distal, and prevent the grip assembly from slipping during isometric trials. Two rectangular blocks, clamped between the rectangular plates medial to the arm extensions on either side, serve as mounting points for force-sensing grip handles which extend proximally back toward the seated subject. The block mounts are bolted in slots in the rectangular plates to permit adjustment in the medio-lateral direction and alignment of the grip handles with the width of the subject’s shoulders.

Testing

To conduct the isometric strength trials the subjects were seated with back and hips pressed comfortably against the seat back. As the subjects were entering the apparatus, the arm assembly was raised or lowered into one of the vertical positions to ease access to the seat. The arm assembly was then pinned at an angle corresponding to the shoulder flexion-extension angle prescribed for the particular test. For elevation (pulling) and depression (pushing) tests this angle was vertically downward. For protraction (pushing) and retraction (pulling) tests this angle was horizontally forward. For each trial the grip assembly was adjusted along the arm extension members and pinned so that the subject, with fully extended elbows, was able to maintain a firm grip on the handles at the prescribed shoulder girdle position (e.g., a depressed position for an elevation trial, as in Fig. 1). For shoulder depression tests a padded board was placed in the subject’s lap, and a padded ratcheting strap was wrapped snugly around the seat assembly and board to hold the subject against the seat as they pressed downward on the handles. For shoulder retraction tests the board was positioned on the subject’s chest, and the strap was wrapped around the vertical post and board to hold the subject against the seat back as they pulled on the handles.
Most female subjects preferred not using the padded board for retraction trials, and so only the padded strap (tucked under the armpits) was used for these subjects. For protraction and depression tests (both pushing) the subjects pressed with their palms against either the grip handles or the flat mounting surface just behind the handles (Fig. 2, inset), according to their preference. Individual subject preferences regarding straps and hand positioning were repeated consistently across all days of testing.

**Data Collection**

Five seconds of force and position data were collected during each shrugging trial. Force-sensing load cells, mounted between each grip handle and the corresponding mounting block, were used to record forces applied to the grips as generated through the glenohumeral joint. The SSM series load cells (Transducer Techniques, Temecula, CA) were rated to measure up to 2.2 kN (500 lb, nonlinearity and hysteresis < 4N) each in both tension and compression. A three-camera, video motion capture system (zFlo Motion, Inc., Quincy, MA) was used to record motion of adhesive reflective markers attached to the subject at the jugular notch (JN), the superior surface of the left acromion at the acromioclavicular joint (AC), and the spinous process of the seventh cervical vertebra (C7). Video data was recorded at 60 Hz and force data was recorded at 300 Hz.

**Experimental Protocol**

The testing protocol involved one familiarity session and three data collection sessions. Each session occurred on separate, non-consecutive days. During the familiarity session subjects were asked to practice a number of trials in each of the four testing modes: elevation, depression, protraction, and retraction. To begin, subjects were asked to practice sub-maximally and then build to maximal contractions. The subject’s range of motion (ROM) in each testing direction was recorded on video by unpinning the grip assembly and asking the subject to move as far as possible in either direction without moving the trunk or bending the elbow.

For each testing mode three grip assembly locations within the ROM were identified as appropriate for strength measurements, and the corresponding pin-hole numbers were recorded. Elevated,
neutral, and depressed positions were selected for elevation and depression trials. Protracted, neutral, and retracted positions were selected for protraction and retraction trials. Neutral positions were selected between the two other positions in each direction, and near the natural, anatomical position. Positions chosen for elevation and protraction trials were not necessarily the same as those for depression and retraction trials, respectively. Generally, the subjects could generate a reasonable level of force at locations ranging from one extreme of the ROM to somewhat less than the other extreme. For example, subjects were able to generate substantial retraction (pulling) force from the most anterior location of the ROM, but not from the most posterior. Therefore, the selected locations for retraction tests included the most anterior over the ROM (fully protracted), a location slightly anterior (usually one or two pin holes) from the most posterior over the ROM (nearly retracted), and a third, midway location. Grip assembly locations for protraction, elevation, and depression tests were selected in a similar manner.

For each of the three data collection sessions the subjects were asked to complete three maximum-effort shrugging trials at the respective grip assembly locations selected for each of the four modes of testing. Thus, each subject performed a total of 36 trials (3 collection sessions x 4 testing modes x 3 grip locations). Subjects were instructed to maintain a stable posture with straight arms throughout the 5-second duration of each trial, and to smoothly press against the apparatus handles as forcibly as possible. In advance of the trials the subjects were asked to warm up for several minutes on a hand-powered cycle ergometer with light resistance. Between trials subjects were given one to two minutes of rest while the apparatus was adjusted in preparation for the next trial. The order of the trials was varied from one testing session to the next to minimize the chance of bias.

Data Analysis

The data from each trial were analyzed visually to identify the time instant where shoulder position was stable and maximum total force across both hands was generated. For this time instant the corresponding shoulder elevation angle, protraction angle, and peak total force were recorded. In most
cases these three variables were fairly constant during the trial. There was little difficulty selecting the appropriate time instant. Figure 3 shows a set of sample data.

Elevation angle and protraction angle were computed from the Cartesian coordinates of the three reflective markers (JN, C7, and AC). For the purposes of this study these angles were defined as follows. Considering the three-dimensional midpoint, MP, between JN and C7, the elevation angle was taken to be the angle of the line from MP to AC above the axial (horizontal) plane (Fig. 4A). In turn, the protraction angle was taken to be the angle of the line from MP to AC anterior to the frontal plane (Fig. 4B).

Several statistical measures were computed to judge the reliability of the measurement techniques. First, one-way analysis of variance (ANOVA) with repeated measures on the three data collection sessions was performed for elevation angle (E), protraction angle (P), and peak shrugging force (F) for each of the 12 tests (4 testing modes x 3 grip locations). On all significant main effects follow-up comparisons (Bonferroni) were conducted. Next, for each subject the standard deviations (SD) of E, P, and F over the three data collection sessions, and the averages of these SD’s (AvgSD) over all subjects were computed. These calculations were performed on both actual and normalized E, P, and F values. The angular values (E and P) were normalized for each subject by the respective ranges of motion, and the force values (F) were normalized for each subject and each test by the average of peak forces over the three sessions. Finally, intraclass correlation coefficients (ICC) and corresponding root mean-squared-error (RootMSE) and 95% limits of agreement (95% LOA) were computed for each test over the three sessions using the Shrout and Fleiss [31] two-factor formula for random effects (2,1). The ANOVA, ICC, and RootMSE calculations were performed using SAS (Release 8.02, SAS Institute, Inc., Cary, NC). The 95% LOA were computed as: 95% LOA = 1.96 x 2^{0.5} x RootMSE [32, 33].

**Results**

Of the ideal total of 684 testing trials (19 subjects x 12 trials x 3 days), 660 were completed (two male subjects completed only two days of testing each). Of the 660 completed trials, only three exhibited data anomalies (e.g., video marker obscured from view) for which they were discarded. One male
volunteer had exceptionally broad shoulders and was excluded from the study because he could not
perform some elevation and depression trials without interference with the arm extension members. A
few other subjects had difficulty performing some depression trials because the grip assembly cross bar
could not be adjusted high enough to accommodate the hand position without interference with the seat
assembly. For these subjects a custom handle extension was made to raise the grip several inches for
these trials, eliminating the problem. Results of statistical computations are reported in Tables 1, 2, and 3
for elevation angle, protraction angle, and peak shrugging force, respectively.

Table 1. Results of statistical calculations on measurement of elevation angle over three days of testing
for each of 12 tests: elevation at an inferior, neutral, and superior position; depression at an inferior,
neutral, and superior position; protraction at an anterior, neutral, and posterior position; and retraction at
an anterior, neutral, and posterior position. AvgSD = average of subjects’ standard deviations over three
sessions; ICC = intraclass correlation coefficient; RootMSE = root mean-squared-error; LOA = limits of
agreement.

<table>
<thead>
<tr>
<th>TEST</th>
<th>AvgSD (deg)</th>
<th>% ROM</th>
<th>ICC(2,1)</th>
<th>Root MSE (deg)</th>
<th>95% LOA F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elev-Inf</td>
<td>2.139</td>
<td>7.0%</td>
<td>0.862</td>
<td>2.082</td>
<td>5.771</td>
<td>5.220</td>
</tr>
<tr>
<td>Elev-Neut</td>
<td>2.156</td>
<td>6.9%</td>
<td>0.853</td>
<td>2.497</td>
<td>6.920</td>
<td>1.990</td>
</tr>
<tr>
<td>Elev-Sup</td>
<td>2.176</td>
<td>7.0%</td>
<td>0.902</td>
<td>2.244</td>
<td>6.219</td>
<td>3.030</td>
</tr>
<tr>
<td>Dep-Inf</td>
<td>1.521</td>
<td>5.0%</td>
<td>0.855</td>
<td>1.808</td>
<td>5.013</td>
<td>1.640</td>
</tr>
<tr>
<td>Dep-Neut</td>
<td>1.772</td>
<td>5.6%</td>
<td>0.864</td>
<td>2.208</td>
<td>6.119</td>
<td>0.810</td>
</tr>
<tr>
<td>Dep-Sup</td>
<td>2.025</td>
<td>6.5%</td>
<td>0.893</td>
<td>2.390</td>
<td>6.624</td>
<td>2.310</td>
</tr>
<tr>
<td>Prot-Ant</td>
<td>2.244</td>
<td>7.5%</td>
<td>0.809</td>
<td>2.350</td>
<td>6.514</td>
<td>5.710</td>
</tr>
<tr>
<td>Prot-Neut</td>
<td>2.424</td>
<td>8.1%</td>
<td>0.788</td>
<td>2.564</td>
<td>7.106</td>
<td>5.380</td>
</tr>
<tr>
<td>Prot-Post</td>
<td>2.360</td>
<td>8.0%</td>
<td>0.820</td>
<td>2.671</td>
<td>7.403</td>
<td>3.230</td>
</tr>
<tr>
<td>Ret-Ant</td>
<td>3.313</td>
<td>11.1%</td>
<td>0.728</td>
<td>3.656</td>
<td>10.135</td>
<td>3.560</td>
</tr>
<tr>
<td>Ret-Neut</td>
<td>3.924</td>
<td>12.8%</td>
<td>0.731</td>
<td>4.036</td>
<td>11.187</td>
<td>3.930</td>
</tr>
<tr>
<td>Ret-Post</td>
<td>3.801</td>
<td>13.0%</td>
<td>0.709</td>
<td>4.246</td>
<td>11.771</td>
<td>2.800</td>
</tr>
</tbody>
</table>

The one-way ANOVA showed significant effects (p < 0.05) on elevation angle for several tests
(tests 1, 7, 8, 10, and 11 in Table 1) and on protraction angle for one test (test 5 in Table 2). However, the
post-hoc (Bonferroni) analysis showed no differences among the sessions for all main effects. There was
no significant effect (p < 0.05) found on peak force for any of the twelve tests (Table 3).
Table 2. Results of statistical calculations on measurement of protraction angle (see caption of Table 1 for descriptions).

<table>
<thead>
<tr>
<th>TEST</th>
<th>Avg of SD (deg)</th>
<th>% ROM</th>
<th>ICC(2,1)</th>
<th>Root MSE (deg)</th>
<th>95% LOA (deg)</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Elev-Inf</td>
<td>3.508</td>
<td>9.9%</td>
<td>0.713</td>
<td>3.767</td>
<td>10.441</td>
<td>1.360</td>
<td>0.271</td>
</tr>
<tr>
<td>2 Elev-Neut</td>
<td>4.286</td>
<td>11.9%</td>
<td>0.695</td>
<td>4.433</td>
<td>12.287</td>
<td>0.570</td>
<td>0.570</td>
</tr>
<tr>
<td>3 Elev-Sup</td>
<td>3.175</td>
<td>8.8%</td>
<td>0.789</td>
<td>3.562</td>
<td>9.873</td>
<td>0.250</td>
<td>0.778</td>
</tr>
<tr>
<td>4 Dep-Inf</td>
<td>2.612</td>
<td>7.2%</td>
<td>0.838</td>
<td>2.873</td>
<td>7.963</td>
<td>2.220</td>
<td>0.124</td>
</tr>
<tr>
<td>5 Dep-Neut</td>
<td>3.691</td>
<td>10.6%</td>
<td>0.731</td>
<td>3.810</td>
<td>10.560</td>
<td>4.220</td>
<td>0.023</td>
</tr>
<tr>
<td>6 Dep-Sup</td>
<td>4.495</td>
<td>12.8%</td>
<td>0.621</td>
<td>4.831</td>
<td>13.392</td>
<td>2.400</td>
<td>0.106</td>
</tr>
<tr>
<td>7 Prot-Ant</td>
<td>2.365</td>
<td>6.2%</td>
<td>0.858</td>
<td>2.751</td>
<td>7.626</td>
<td>2.290</td>
<td>0.117</td>
</tr>
<tr>
<td>8 Prot-Neut</td>
<td>2.678</td>
<td>7.2%</td>
<td>0.684</td>
<td>2.804</td>
<td>7.771</td>
<td>2.440</td>
<td>0.103</td>
</tr>
<tr>
<td>9 Prot-Post</td>
<td>2.708</td>
<td>7.2%</td>
<td>0.878</td>
<td>2.945</td>
<td>8.164</td>
<td>1.180</td>
<td>0.319</td>
</tr>
<tr>
<td>10 Ret-Ant</td>
<td>3.234</td>
<td>8.4%</td>
<td>0.749</td>
<td>3.643</td>
<td>10.099</td>
<td>1.380</td>
<td>0.266</td>
</tr>
<tr>
<td>11 Ret-Neut</td>
<td>3.449</td>
<td>9.4%</td>
<td>0.742</td>
<td>3.762</td>
<td>10.426</td>
<td>2.700</td>
<td>0.082</td>
</tr>
<tr>
<td>12 Ret-Post</td>
<td>3.934</td>
<td>10.6%</td>
<td>0.737</td>
<td>4.081</td>
<td>11.313</td>
<td>1.030</td>
<td>0.369</td>
</tr>
</tbody>
</table>

Table 3. Results of statistical calculations on measurement of peak force generated through both glenohumeral joints (see caption of Table 1 for descriptions).

<table>
<thead>
<tr>
<th>TEST</th>
<th>Avg of SD</th>
<th>N (lb)</th>
<th>% Avg</th>
<th>ICC(2,1)</th>
<th>Root MSE</th>
<th>95% LOA</th>
<th>N (lb)</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Elev-Inf</td>
<td>N (lb)</td>
<td>94 (21.2)</td>
<td>9.8%</td>
<td>0.883</td>
<td>27.513</td>
<td>339 (76.3)</td>
<td>1.110</td>
<td>0.342</td>
<td></td>
</tr>
<tr>
<td>2 Elev-Neut</td>
<td>N (lb)</td>
<td>81 (18.3)</td>
<td>9.3%</td>
<td>0.928</td>
<td>22.954</td>
<td>283 (63.6)</td>
<td>0.540</td>
<td>0.588</td>
<td></td>
</tr>
<tr>
<td>3 Elev-Sup</td>
<td>N (lb)</td>
<td>89 (19.9)</td>
<td>11.0%</td>
<td>0.883</td>
<td>28.386</td>
<td>350 (78.7)</td>
<td>0.680</td>
<td>0.513</td>
<td></td>
</tr>
<tr>
<td>4 Dep-Inf</td>
<td>N (lb)</td>
<td>73 (16.4)</td>
<td>11.8%</td>
<td>0.842</td>
<td>20.919</td>
<td>258 (58.0)</td>
<td>0.250</td>
<td>0.782</td>
<td></td>
</tr>
<tr>
<td>5 Dep-Neut</td>
<td>N (lb)</td>
<td>88 (19.9)</td>
<td>12.1%</td>
<td>0.840</td>
<td>21.836</td>
<td>269 (60.5)</td>
<td>1.110</td>
<td>0.342</td>
<td></td>
</tr>
<tr>
<td>6 Dep-Sup</td>
<td>N (lb)</td>
<td>75 (16.9)</td>
<td>10.2%</td>
<td>0.916</td>
<td>18.286</td>
<td>225 (50.7)</td>
<td>0.390</td>
<td>0.679</td>
<td></td>
</tr>
<tr>
<td>7 Prot-Ant</td>
<td>N (lb)</td>
<td>89 (19.9)</td>
<td>10.6%</td>
<td>0.944</td>
<td>24.245</td>
<td>299 (67.2)</td>
<td>0.470</td>
<td>0.631</td>
<td></td>
</tr>
<tr>
<td>8 Prot-Neut</td>
<td>N (lb)</td>
<td>91 (20.4)</td>
<td>8.8%</td>
<td>0.949</td>
<td>23.424</td>
<td>289 (64.9)</td>
<td>1.770</td>
<td>0.186</td>
<td></td>
</tr>
<tr>
<td>9 Prot-Post</td>
<td>N (lb)</td>
<td>111 (24.9)</td>
<td>11.3%</td>
<td>0.921</td>
<td>28.592</td>
<td>353 (79.3)</td>
<td>0.680</td>
<td>0.515</td>
<td></td>
</tr>
<tr>
<td>10 Ret-Ant</td>
<td>N (lb)</td>
<td>109 (24.4)</td>
<td>12.4%</td>
<td>0.872</td>
<td>29.220</td>
<td>360 (81.0)</td>
<td>1.550</td>
<td>0.228</td>
<td></td>
</tr>
<tr>
<td>11 Ret-Neut</td>
<td>N (lb)</td>
<td>92 (20.8)</td>
<td>13.4%</td>
<td>0.893</td>
<td>23.227</td>
<td>286 (64.4)</td>
<td>0.190</td>
<td>0.829</td>
<td></td>
</tr>
<tr>
<td>12 Ret-Post</td>
<td>N (lb)</td>
<td>93 (20.9)</td>
<td>17.1%</td>
<td>0.794</td>
<td>26.383</td>
<td>325 (73.1)</td>
<td>0.680</td>
<td>0.512</td>
<td></td>
</tr>
</tbody>
</table>

For tests measuring elevation and depression force (tests 1-6), results indicate that the elevation angle was more repeatable than the protraction angle (first six rows in Tables 1 and 2). The AvgSD of elevation angle (Table 1) ranged from 1.5º to 2.2º, or 5.0% to 7.0% of subject ROM, while the AvgSD of protraction angle (Table 2) ranged from 2.6º (7.2%) to 4.5º (12.8%). The lowest ICC was 0.85 for elevation angle, and 0.62 for protraction angle. The 95% LOA ranged from 5.0º to 6.9º for elevation angle, and from 8.0º to 13.4º for protraction angle. To help clarify the trends noted in this and the
following paragraph, the averages of tests involving each testing mode (elevation, depression, protraction, and retraction) are graphed in Fig. 5 for ICC and 95% LOA. The graphs show that for both elevation tests and depression tests, correlations are higher and limits are lower, for elevation angle than for protraction angle.

For tests measuring protraction and retraction force (tests 7-12), the repeatability of protraction angle proved to be very similar to that of elevation angle (last six rows in Tables 1 and 2). The AvgSD of protraction angle (Table 2) ranged from 2.4º (6.2%) to 3.9º (10.6%), while that of elevation angle (Table 1) ranged from 2.2º (7.5%) to 3.9º (13.0%). Note that because the percentage AvgSD values represent angles normalized by the respective subject’s ROM, the ranking of actual and normalized values are not always identical (e.g., compare actual and normalized AvgSD values for last two rows in Table 1). The lowest ICC values were 0.71 and 0.68 for elevation angle and protraction angle, respectively, although on a test-by-test basis the protraction angle ICC was higher for all but one of the protraction-retraction tests. In this one case (test 8, protraction test at a neutral angle), the 95% LOA value is quite consistent over all three protraction tests, suggesting that the lower ICC value for this test may be misleading (see Discussion). The 95% LOA were nearly identical between protraction and elevation angles on a test-by-test basis, ranging from 6.5º to 11.8º. Again, these trends are illustrated in Fig. 5 which shows that ICC for elevation angle is essentially the same as that for protraction angle, for both protraction tests and retraction tests, respectively. The same is also true of 95% LOA.

The reliability of force measurements proved to be higher than those of angle measurements, and fairly similar between elevation-depression tests and protraction-retraction tests (Table 3). Protraction-retraction tests exhibited both the lowest and highest ICC values (0.79 and 0.95, respectively), while ICC for elevation-depression trials ranged from 0.84 to 0.93. Similarly for AvgSD, the normalized values for protraction-retraction trials encompassed those for elevation-depression trials, with the former ranging from 8.8% to 17.1%, and the latter ranging from 9.3% to 12.1%. Aside from test 10 measuring retraction force at the most posterior position (Table 3), all trials exhibited ICC values exceeding 0.83, and
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normalized AvgSD values less than 13.5%. The 95% LOA on force measurements ranged from 225 N (50.7 lb) to 360 N (81.0 lb) over all trials.

Discussion

The shoulder is a complex joint involving multiple bone articulations and numerous multi-articulated muscles. It permits a wide range of motion resulting from phased coordination between rotations of the clavicle, scapula (which glides along the thorax), and humerus [34]. These motions are driven by active muscle contractions which must produce balanced moments to both execute proper kinematics and stabilize both the glenohumeral joint [1] and the scapula [26]. The strength ratios between agonist and antagonist muscles are believed to be important for preserving stability, mobility, and asymptomatic function in the shoulder [3]. Muscle weakness due to trauma, strain, inhibition, nerve injury, or other causes may result in moment imbalance which, at the scapula, is highly correlated to the occurrence of rotator cuff problems and glenohumeral instability problems [26]. In addition, most shoulder abnormalities from sports injuries can be traced to alterations in the function of the scapular muscles [26]. For these reasons it has been argued that consideration of the role of the scapula [26], and reliable recording of shoulder strength [1], are important factors in the diagnosis and rehabilitation of shoulder problems.

Despite its importance, strength of the shoulder girdle has generally been evaluated manually using basic upper-extremity exercises [26, 27]. Few previous studies have sought to quantify strength of the shoulder girdle directly, and none are known to have measured isometric force transmitted through the glenohumeral joint for various shrugging positions. Cools [29, 35] used a closed-chain attachment on the Biodex dynamometer to measure peak force and total work performed during isokinetic tests at various speeds. These experiments were performed unilaterally and focused on protraction and retraction in the scapular plane. Wilk [3, 36] used a hand-held dynamometer to measure the isometric scapular muscle strengths of professional baseball players for elevation, depression, protraction, and retraction of the
shoulder girdle. However, the study’s methods were not clearly described, the results were reported in units of torque rather than force, and no reliability analysis was performed.

In this paper we present a novel apparatus and method for measuring isometric elevation, depression, protraction, and retraction strength in the human shoulder girdle. The method was successfully applied to measure the bilateral strength of amateur, healthy male and female subjects at three different shrugging positions over the ranges of motion for each of the four modes of testing. Statistical analysis revealed the reliability of the testing protocol on the basis of repeated measures over three days of testing. We anticipate that this type of measurement approach may be helpful in the evaluation, rehabilitation, and prevention of shoulder injury by permitting robust measurement of the agonist and antagonist strength of shoulder girdle muscles in multiple modes of testing and in multiple, prescribed positions.

Our reliability analysis involved several statistical measures. Atkinson [32] reports that ICC is a popular measure for judging reliability over repeated tests. It has advantages over the Pearson correlation coefficient, $r$, in that it is univariate and can be used when more than one set of re-test data are available. In addition, it can be calculated in different ways so as to account for the presence of systematic bias in the data. In this study, we used the Shrout and Fleiss [31] random effects calculation (2,1) which is appropriate to determine whether the repeatability can be generalized to other individuals from a similar pool (i.e., young, healthy adults). Atkinson [32] noted, however, that ICC, like the Pearson coefficient, is affected by sample heterogeneity and should be accompanied by an additional, absolute measure of reliability such as the 95% LOA. In this study, we have included the 95% LOA value to indicate that with 95% certainty the expectation of the difference between any two additional tests on an individual from the studied population will lie within the range: bias ± the 95% LOA value. The bias reflects systematic trends over subsequent tests such as a learning effect. Among the measures of elevation angle, protraction angle, and peak force, one would least expect a learning effect in the position angles because there is no apparent reason for a subject to systematically vary elevation or protraction angle from one day to another due to testing familiarity. Indeed, the ANOVA and post-hoc analyses confirmed that
subjects did not show systematic bias in shoulder positioning over three days of testing. On the other hand, one might anticipate a learning effect in the peak force over subsequent testing sessions. However, the ANOVA analysis showed no significant effect in the peak force between any two testing sessions. Therefore, we assume the bias to be negligible (zero) for all three measures.

Interpretation of the ICC values seems to lack universal standards (other than values closer to “1” indicate greater reliability). Atkinson [32] reports finding no references in the sport and exercise science literature providing thresholds relating to analytical research goals. Atkinson does reference Vincent [37] to suggest that values from 0.7 to 0.8 might be “questionable”, while values above 0.9 would indicate “high” reliability. However, Fleiss [38] suggests that values above 0.75 indicate “excellent” reliability, while values between 0.40 and 0.75 indicate “fair to good” reliability. Previous studies of strength measurement have interpreted values above 0.85 as “almost perfect” [14], “fair” as low as 0.54 [23], “poor” below 0.68 [12], and “unacceptable” below 0.80 [20].

In light of the Fleiss [38] comments and our use of the Fleiss and Shrout [31] formula, the results of the ICC calculations in the present study are interpreted to indicate good to excellent reliability. In particular, the measurement of elevation angle for the six elevation and depression tests was quite reliable, all scoring ICC values above 0.85. Measurements of force for all trials were likewise quite reliable, with five of the twelve tests scoring above 0.90, eight scoring above 0.87, and all scoring above 0.79. ICC calculations for measurement of protraction angle for all tests, and elevation angle for the protraction and retraction tests, are interpreted to indicate good reliability. For protraction angle, three of the twelve tests scored above 0.83, nine scored above 0.73, and only one scored as low as 0.62. For elevation angle, three of the six protraction-retraction tests scored above 0.78, and all scored above 0.70.

Several factors may contribute to the imperfect repeatability of the various measures. Naturally, perfect repeatability in strength measurements depends on consistent subject effort over repeated tests, which cannot be guaranteed. However, the verbal instructions for maximum effort and the high correlation coefficients of force over all tests suggest that the force recordings are representative of the maximum effort of subjects. Repeatability of measured shoulder girdle angles also depends on subject
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consistency over repeated tests. In each test, only one of the measured angles was prescribed using the testing apparatus, while the other angle was freely adopted by the subject. This liberty may explain, for example, why protraction angle (freely adopted) exhibited less repeatability for the elevation and depression trials than elevation angle (prescribed). To examine this hypothesis further, the values of AvgSD, ICC, and 95% LOA were averaged across the 12 tests (Table 4), and pairwise t-tests were performed on each parameter to compare between elevation angle and protraction angle and to compare between prescribed angle and freely adopted angle. The average and t-test calculations on ICC were performed on values converted by Fisher Z transformation to reduce distribution skewness. When comparing between elevation angle and protraction angle, significant effects were seen on both AvgSD ($t(1,11)=-3.1, p<0.05$) and 95% LOA ($t(1,11)=-3.3, p<0.05$), but not on ICC ($t(1,11)=2.2, p=0.58$). These results indicate that measured elevation angle was more consistent across the testing days than measured protraction angle (Table 4, first two rows). And, when comparing the prescribed angles against the freely adopted angles, the pairwise t-test was significant on all three measures: AvgSD ($t(1,11)=-2.8, p<0.05$), 95% LOA ($t(1,11)=-2.8, p<0.05$), and ICC ($t(1,11)=3.0, p<0.05$). This result indicates that prescribed angles were, indeed, more consistent across the testing days than the freely adopted angles (Table 4, last two rows).

Table 4. Averages (standard deviations) of the average of standard deviations (AvgSD), intraclass correlation coefficients (ICC), and 95% limits of agreement (LOA), computed across the 12 tests for each of four variables: elevation angle, protraction angle, prescribed angle, and unprescribed angle. The prescribed angles included the elevation angles for elevation and depression tests (tests 1-6) and the protraction angles for protraction and retraction tests (tests 7-12). The unprescribed angles included the protraction angles for tests 1-6 and the elevation angles for tests 7-12.

<table>
<thead>
<tr>
<th>Variable</th>
<th>AvgSD</th>
<th>ICC (2,1)</th>
<th>95% LOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elev Ang</td>
<td>2.5 (.77)</td>
<td>0.83 (.07)</td>
<td>7.6 (2.2)</td>
</tr>
<tr>
<td>Prot Ang</td>
<td>3.3 (.70)</td>
<td>0.76 (.08)</td>
<td>10.0 (1.8)</td>
</tr>
<tr>
<td>Prescribed</td>
<td>2.5 (.72)</td>
<td>0.83 (.07)</td>
<td>7.7 (2.0)</td>
</tr>
<tr>
<td>UnPrescribed</td>
<td>3.3 (.77)</td>
<td>0.75 (.06)</td>
<td>9.9 (2.2)</td>
</tr>
</tbody>
</table>
Inconsistencies in angle measurements may also have stemmed from other sources, such as deviations in subject positioning against the seat and seat back, gripping of handles, strapping, marker placement, and video tracking. Of the four modes of testing, the lowest repeatability of angle measurements seemed to occur for retraction trials, where the subject was strapped around the chest and asked to pull on the handles with maximum effort against the strap. Strap tightness would likely influence measured angles, but was controlled only subjectively to be as tight as the subject could tolerate comfortably and still execute the trial.

The strength-measurement protocol utilized a video motion capture system to record absolute positions of the JN, C7, and AC. These data permitted calculation of absolute elevation angle and protraction angle for each trial as defined in the Methods section. However, the shoulder girdle positions adopted by each subject were prescribed not through the video system but by positioning of the grip assembly through pin hole selection. That is, the subject assumed a shoulder girdle position for each trial based on where the grip assembly was pinned, and not on any feedback from the video measurements. Thus, the benefit of the video system was only in monitoring the absolute positions, and so it would only be needed if knowledge of these absolute angles were required. Because fairly wide differences between subjects were observed for minimum angle, maximum angle, and range of motion, respectively, it may be more appropriate to prescribe and report shrugging position as a percentage of the ROM, which can be based on the arm extension pin holes rather than the video system. The reliability results reported in this study for angles measured with the video system suggest that the use of the same pin holes over repeated measures provides good control for repeatability of position.

The testing apparatus we describe in this study has a number of appealing features, but also areas where improvements could be made. The apparatus generally performed well during the experimental trials, providing a stable, rigid frame for measurement of shrugging forces that in some cases exceeded 2.3 kN (517 lb). The use of two load cells in line with the grip handles provides independent, simultaneous measurement of bilateral forces generated in both shoulders. The hinged arm assembly accommodates strength measurements at shoulder flexion angles ranging from vertically downwards to
vertically upwards in 15-degree increments. This resolution could be increased if needed by drilling additional holes into the semicircular plates of the arm assembly. The apparatus can also be adjusted to accommodate subjects with different arm lengths, trunk heights, and shoulder widths. However, the 24 inch inside-to-inside width of the arm assembly proved a little narrow for the shoulders of one prospective male subject. Also, clearance under the seat should be improved to facilitate higher grip assembly positioning when the arm assembly is in the vertically-downward orientation. Finally, two activities proved to be mildly cumbersome, though unavoidable, during the experimental trials: 1) raising or lowering the arm assembly for seating of the subject, and 2) using the ratcheting straps and padded board for securing the subject.

Shrugging strength was defined in this study as the amount of force that could be transmitted through the glenohumeral joint in elevation, depression, protraction, and retraction of the shoulder girdle. This force was measured at the grip handle assuming that glenohumeral force would be effectively transmitted through the arm to the hand. We believe this assumption is reasonable because for all tests the elbows were fully extended so that the arm acted as a rigid link along the line of force action. However, additional limb bracing may be needed for some patients who may be unable to maintain this straight-arm position. For two testing modes, elevation and retraction, force transmission to the load cell depended on the hand grip strength. We do not believe that hand grip strength was a limiting factor for these tests as the grip handle was wrapped with tennis handle wrap, there was no instance of anyone losing grip, and no complaint or indication of anyone struggling to maintain grip. However, again, additional supporting straps may be required to test patients who may be unable to maintain a firm grip.

**Conclusion**

The apparatus and experimental protocol presented in this paper was effective for measuring isometric shrugging strength during exercises involving elevation, depression, protraction, and retraction of the shoulder girdle at multiple positions. Correlations over repeated measures were interpreted as very good to excellent for force transmitted through the glenohumeral joint, and good to excellent for
measured angles representing elevation and protraction positions of the shoulder girdle. Though minor improvements could be made to improve its ease of use and the range of subject sizes it could accommodate, we anticipate that this type of apparatus could be an effective tool for strength measurements that are important for evaluation, rehabilitation, and prevention of shoulder problems.

Acknowledgements

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References

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Figure 1. Subject demonstrating use of the custom apparatus in a test measuring shoulder elevation strength at a depressed position of the shoulder girdle. The subject performs the test with fully-extended elbows by pulling upward on the force-sensing handles with maximal, voluntary effort. The apparatus is adjustable to accommodate tests measuring strength (pulling or pushing) at a range of shoulder flexion-extension angles, and a range of shoulder girdle “shrugging” positions.
Figure 2. Custom apparatus for measuring the isometric strength of shoulder shrugging exercises. The apparatus base consists of a four-footed frame, vertical post, attached seat back, adjustably-attached seat support assembly, and laterally projecting horizontal beams with anterior projections. Hinged to the anterior projections are the arm extension members, which rotate about the hinge axis from vertically downward, to horizontally forward (as shown), to vertically upward. The hinge axis is aligned with the center of shoulder rotation to facilitate isometric tests at a range of shoulder flexion angles. Pins inserted through semicircular plates on the arm extensions arrest the rotation at a prescribed angle. Adjustably mounted between the arm extensions is a grip assembly containing force-sensing handles (inset) to measure pulling or pushing strength. Pins inserted through the grip assembly and arm extensions permit the grip handles to be locked in place at a range of positions from proximal to distal. The handles can also be adjusted medio-laterally to accommodate shoulders of different widths.
Figure 3. Graphs of sample data from three separate testing days showing total force (thick solid lines), elevation angle (thin solid lines), and protraction angle (thin dashed lines). These data were measured from one of the strongest male subjects during elevation trials in the neutral shoulder girdle position. The vertical dashed lines indicate the time instant, and corresponding data points, selected to represent the subject’s performance during each respective trial.
Figure 4. Illustration of Elevation Angle (A) and Protraction Angle (B) used to describe overall shoulder girdle position. The angles are defined with respect to three anatomical landmarks, the jugular notch (JN), the spinous process of the seventh cervical vertebra (C7), and the acromioclavicular joint (AC), and the midpoint (MP) between C7 and JN. Elevation Angle is the angle of the line from MP to AC superior to the horizontal plane. Protraction Angle is the angle of the line from MP to AC anterior to the frontal plane. These definitions align angular displacements with the direction of force measured for elevation and protraction trials, respectively, and provide for neutral positions with angular values near zero.
Figure 5. Bar graphs of intraclass correlation coefficients (ICC) and 95% limits of agreement (LOA) on elevation angle (from Table 1) and protraction angle (from Table 2), averaged over all tests (all three shoulder girdle positions) for each of the four modes of testing: elevation (Elev), depression (Dep), protraction (Prot), and retraction (Ret). The bar graphs highlight results indicating that elevation angle measurements were more repeatable than protraction angle measurements for elevation and depression tests, but that for protraction and retraction tests the relative repeatability of the two angle measurements was fairly similar.