Work 37 (2010) 387–394
DOI 10.3233/WOR-2010-1092
IOS Press

Isometric strength assessment, Part II: Static testing does not accurately classify validity of effort

Robert Townsend[a], Darrell W. Schapmire[b,*], James St. James[c] and Larry Feeler[d]
[a] *WCS Occupational Rehabilitation Sports Medicine, Naperville, IL, USA*
[b] *X-RTS Software Products, Inc., Hopedale, IL, USA*
[c] *Millikin University, Decatur, IL, USA*
[d] *WorkSTEPS, Austin, TX, USA*

Received 14 April 2009
Accepted 21 June 2009

Abstract. *Objective:* The purpose of this study was to determine if these two commonly-administered isometric tests are accurate indices of effort.
Participants: 34 healthy subjects were tested once giving a maximum voluntary effort and once attempting to feign weakness of 50% of maximum.
Results: During feigned weakness sessions, 20 of 34 subjects (58.5%), produced CVs of 15% or less during the Leg Lift. At the 95% CI, the expected frequency of false negatives for feigned weakness is 42.3 to 75.3% for the Leg Lift. At the 95% CI, the expected frequency of false negatives for feigned weakness is 51.9% to 83.3% for the Arm Lift.
Conclusions: Neither isometric lift is appropriate for classifying validity of effort. Use of these isometric lifts should be discontinued for the assessment of effort.

Keywords: Sincerity of effort, isometric testing

1. Background

The use of the CV(SD/Mean, expressed as a percentage) to classify sincerity of effort during the measurement of isometric strengths has been investigated many times in the past. Such assessments are typically related to the testing of insurance claimants in medical/legal cases. Early investigations into the use of isometric strength focused on the concept of assessing workers for fitness to perform physically demanding jobs [1, 7–9,12,15,19,23]. These studies proposed methods of testing workers' isometric strengths on the assumption that isometric strength was predictive of the ability to safely perform specific jobs. They involved measurement of physical performance parameters for individuals who were presumed to be "healthy," and therefore, the impact of secondary gain issues were assumed to be absent. As a result, the assessment of sincerity of effort was only a tangential issue.

Ideally, tests that are used to assess workers prior to being hired could also be used to assess the physical condition subsequent to a reported injury. Also ideally, the same type of testing could be used to assess sincerity of effort. As a result, numerous isometric devices were developed and are now promoted on web sites of various manufacturers and providers of employment testing services. These entities are listed in Table 1. These companies promote isometric equipment as be-

*Address for correspondence: Darrell Schapmire, MS, X-RTS Software Products, Inc., P.O. Box 171, Hopedale, IL 61747, USA. Tel.: +1 309 449 5483; E-mail: ds@xrts.com.

Table 1
Entities of companies promoting isometric testing

Company	Web site (Links Verified October 26, 2010)
Baltimore Therapeutics Equipment	http://www.btetech.com/evaltech.htm
ARCON/ISTU	http://www.fcesoftware.com
Occupational Performance Corporation	http://www.physicalcapacityprofile.com
Metron Products	http://www.metronproducts.com
QMA System	http://www.qmasystem.com
Chatillon	http://www.chatillon.com
Myogauge	http://www.myogauge.com
Ability Works, Inc.	http://abilityworksinc.com
JTech Medical	http://www.jtechmedical.com
Jackson Strength Evaluation System	http://www.rehaboutlet.com
Lake Erie Medical of Ohio	http://www.lakeeriemed.com/assess/er.html
Physical Capacity Profile Testing System	http://www.physicalcapacityprofile.com
Simwork Systems	http://www.simwork.com
Global Functional Testing	http://www.globalfce.net/technology.htm

ing useful for assessing physical strength and/or validity of effort testing.

The quest for an isometric testing system that classifies effort during various isometric strength tests has centered around two basic methods: analysis of force curves and an assessment of consistency using the coefficient of variation (CV). The results have been mixed.

Yang and Winter [35] investigated the use of surface electromyography (EMG) to determine if the CV for a physiological measurement would distinguish between maximal and sub-maximal isometric contractions. It was concluded, in part, that substantial measurement error occurs when using EMG to assess effort. These findings were similar to Hoffmaster, Lech and Niebuhr [16] who found that the pattern of force production for EMG readings differed between sincere and feigned weakness sessions, but the physical output was consistent when the subjects were giving a good effort and when they were feigning weakness during grip testing. However, in a controlled study, Gilbert and Knowlton [13] reported 87.5% and 80.0% accuracy in classifying effort for the 16 female and 20 male subjects, respectively, with the classification being made according to an analysis of the force-time curve in testing the hands.

In a controlled study involving grip strength, Smith, Nelson, Sadoff and Sadoff [33] used a combination of force curve analysis and CV to classify effort of 43 asymptomatic volunteers. Sensitivity was 95% and specificity was 90% for males, but the same parameters were 93.5% and 58.7%, respectively, for the female subjects when considering just the CV. Used in conjunction with various force-time curve characteristics, perfect specificity was never attained and the highest sensitivity for females was 93.5%. Chengular, Smith, Nelson and Sadoff [10] reported similar results investigating the same physical parameters (force curves in conjunction with CV's) and applying the validity criteria proposed by Smith to a population of patients.

Harber and SooHoo [15] assessed the degree of intra-data set variation during six tests of isometric strength. Although CV's averaged 13% to 18% during isometric testing in which the subjects exerted "force until discomfort," it was speculated that CV's greater than 35% might be considered as evidence of non-cooperation. However, no specific CV cutoffs were suggested. No breakdown regarding the sensitivity or specificity of the methodology was provided.

Agre et al. [2] used a portable dynamometer to measure strength for lateral pinch between thumb and index finger, elbow flexion, elbow extension, shoulder flexion, hip flexion, hip extension, hip abduction, knee flexion, and ankle dorsiflexion. A total of four subjects participated in the study. CV's ranged from 5.1% to 8.3% during maximal effort trials for upper extremity testing and from 11.3% to 17.8% for lower extremity testing. The CV for feigned weakness was not assessed by Agre et al.

A study of six asymptomatic persons, assessed for knee extension strength on different occasions over a six month period of time produced CV's ranging from 4.5 to 14.0% in sessions assumed to be maximal efforts. [36] However, in testing 20 clients with peripheral neuromuscular disorders, the CV ranged from 3.6% to 27.3% during maximum voluntary effort testing for isometric grip and knee extension strengths. Bohannon [6] conducted a controlled study of 31 healthy females to determine if a CV cutoff could accurately classify effort during testing for elbow flexion strength, measured with a handheld dynamometer. The mean CV during maximal effort trials was "3.6 $\pm$ 1.6 per cent" and the mean CV during submaximal contraction was "15.1 ± 14.6 percent." A substantial overlapping is noted in these distributions of scores. Although Bohannon reported that the majority of the subjects had CV's greater than 7.5% during submaximal effort testing, such was not universally the case. Although 67.7% of the submaximal effort sessions had CV's greater than 8.0%, no specific information regarding the frequency of scores above the mean of 15.1% during submaximal sessions was reported.

Niemeyer, Matheson and Carlton [24] reported the CV to be useful in classifying sincerity of effort on the BTE Work Simulator when using the equipment with five of the attachments commonly used to assess the upper extremity in the Employment and Rehabilitation Institutes of California (ERIC) protocol. The CV cutoffs suggested ranged from 8.6% to 16.3% and were dependent upon the subject's sex, dominant versus nondominant extremity, and the tool used to perform the isometric measurement. The CV cutoffs were reported to have been in use for more than two years and "appear to differentiate well between individuals who put forth maximum effort and those who do not." However, no reference is made to sensitivity or specificity of these cutoffs, nor is any reference made to a controlled study. This appears to be anecdotal evidence. Furthermore, the authors offered the CV cutoffs with the caveat that they could only be used to assess sincerity of effort if the part of the body being evaluated *was not alleged to be injured*. However, Barren et al. [4] investigated the ERIC protocol in a controlled study of 15 female subjects and found the ERIC protocol to be incapable of distinguishing between submaximal and maximal effort.

Robinson et al. [25] examined the reproducibility of isometric lumbar extension in each of seven positions. The manufacturer of the equipment represented the machine to be able to classify consistency of effort by the degree of reproducibility of extension torque at each of these positions. The analysis was performed by a visual examination of the spline depicting force production at each of the measurement points for repeated measures. Although the CV was not specifically included in the attempt to classify effort, the attempt to assess sincerity of effort in this study was based upon the theory that maximum isometric contractions were reproducible and would be distinguishable from submaximal contractions, which were presumed to have low reproducibility. It was reported, however, that a visual assessment of the spline which depicts forces produced in seven positions of lumbar extension could not distinguish between maximal and submaximal efforts.

Robinson et al. [26] concluded that performance on the lumbar extension device was reliable and, therefore, could be a useful measure of lumbar function in a clinical setting. Inexplicably, although Robinson [25] found the testing apparatus to be inappropriate for use in classifying validity of effort, validity of effort in Robinson [26] was subrogated by the issue of "reliability." As a result, the isometric testing device is properly described as a machine that may actually record isometric exertion that is reliable, but not necessarily valid.

Lin [22] investigated torque variability to classify validity of effort during isometric and isokinetic testing. Although sensitivity to feigned weakness during *isokinetic* knee extension was 84%, submaximal *isometric* knee extension was not detectable.

Birmingham and Kramer [5] aplied the CV to the assessment of effort during isometric and isokinetic knee extension. Effort was classified according the differences between peak torques in these two testing methods. Although there were differences between group scores (submaximal and maximal effort), the method lacked accuracy in the classification of individual test scores.

Hutten, Muller and Hermens [17] measured isometric lumbar torques on the Isostation B-200 in a controlled study. Statistically smaller CV's were noted in torque production during maximum effort testing, but the standard deviations for the distributions of scores for maximum effort and feigned weakness were large and overlapping. As a result, the CV was rejected as an accurate method of classifying effort.

Jackson and Dishman [18] studied 110 subjects who were instructed to exert force against a chest pad, generating what each believed was 25%, then 50%, then 75% of a maximal contraction. Next, the subjects were asked to exert maximum force. No audio or visual feedback was provided to the subjects. Despite this, subjects were able to consistently reproduce submaximal forces.

Symons et al. [34] found CV's of 8% to 10% for average isometric and isokinetic torques and 8% to 17% for peak torques in geriatric males when measuring isometric knee extension. The subjects were presumed to be giving full effort. No assessment was made of variability for subjects feigning weakness.

Numerous studies and literature reviews have addressed the use of the CV in the assessment of hand strength and found the CV to be inaccurate for the purpose of assessing effort during hand strength assessment [11,20,29–32]. However, one study [28] reported new methodology involving simultaneous testing of both hands that produced a system of classification of effort that was found to be 99.5% accurate (100% specific, 99% sensitive) in a controlled study involving 200 sets of data. The analysis of performance consisted of seven validity criteria, four of which involved the use of the CV as a measure of consistency of effort. The methodology used a unique distraction-based testing protocol – simultaneous bilateral testing of the hands – a method that is impractical to implement in many other kinds of isometric tests.

Isometric devices have been used for over 30 years for the stated purpose of classifying validity of effort. Despite the common use of isometric measurements to classify validity of effort, a review of the literature reveals there is no consensus and no definitive study that indicates that either peak or sustained isometric forces are an accurate index of effort. Furthermore, the authors of this study have found no controlled studies that specifically address the use of the Static Leg Lift and Static Arm Lift in the classification of effort.

2. Methods

2.1. Subjects

This study was conducted according to guidelines and oversight provided by the Institutional Review Board (IRB) of Millikin University, Decatur, IL. As a condition for participation in this study, subjects were required to read and sign an informed consent approved by the IRB. One subject below the age of 18 received parental permission to participate in the study. A total of 34 subjects were tested. Seventeen subjects were males. The mean age for males in this study was 26.5 years. The mean age for females was 31.2 years. None of the subjects had previously been tested for isometric strength.

2.2. Apparatus and procedures

Data were collected in three locations. Ten sets of data were collected by the first author. Seventeen sets were collected by the fourth author. Seven sets were collected at a third facility. Strain gauges were used to measure isometric strength during the isometric Leg Lift and Arm Lift. Twenty-four sets of data were collected on an electronic Chatillon Dynamometer. Data on these devices was displayed on a LED screen, electronically rounded to the nearest half pound. Ten sets were collected on a mechanical strain gauge. These data were visually estimated to the nearest pound. No information regarding the results of this study was shared until after the data collection process had ended.

Subjects were tested twice, with a minimum of five minutes between testing sessions. Both testing sessions occurred on the same day for all subjects. Prior to test sessions, each subject was read a standardized script, which provided precise instructions for the test. Subjects were told they were free to discontinue participation at any time, and that they were to discontinue exertion if they felt undue discomfort or pain, or if they believed they might be injured during their participation.

In one testing session, subjects were instructed to exert a sincere effort for each of three 5-second trials. Approximately 30 seconds of rest was allowed between each trial. In the other testing session, subjects were instructed to attempt to consistently exert 50% of the amount of force they believed they could actually produce. The order of testing (sincere effort or feigned weakness) was counterbalanced. Peak forces for each trial were manually entered onto a data collection sheet.

The Leg Lift was performed with the handles of the gauge parallel to and 15” above the floor. Subjects were instructed to stand with the feet approximately shoulder width apart, to bend at the knees and grasp the handles with the hands in a pronated position. They were told to maintain lumbar lordosis throughout the trials and to exert an upward lifting force for the duration of each trial. The Arm Lift was performed with the handles of the gauge parallel to the floor, held by each subject with the hands supinated and at a height that would allow the elbows to be at approximately 90 degrees of flexion. The feet were approximately shoulder width apart. For both lifts during the maximum voluntary effort sessions, subjects were instructed to generate force gradually for the first two seconds of each trial and, during the sincere effort sessions, to exert maximum lifting force during the last three seconds of each trial. This is the method described by Caldwell [7]. For all trials, test administrators counted the number of seconds for each trial aloud to cue each subject as to when to begin and end each trial. No other audio feedback was provided.

3. Results

Table 2 reports the average amount of force produced by the subjects for all tested activities. CV’s for sincere

Table 2
Mean metric static lifting forces for all subjects

	Mean force, SD, high and low force for leg lift, sincere effort	Mean force, SD, high and low force for leg lift, feigned weakness	Mean force, SD, high and low force for arm lift, sincere effort	Mean force, SD, high and low force for arm lift, feigned weakness
All Subjects	Mean = 102.33 (kg) SD = 42.72 Low = 48.98 (kg) High = 195.27 (kg)	Mean = 35.78 (kg) SD = 20.23 Low = 9.75 (kg) High = 83.28 (kg)	Mean = 29.57 (kg) SD = 11.20 Low = 14.96 (kg) High = 51.07 (kg)	Mean = 12.51 (kg) SD = 6.94 Low = 3.62 (kg) High = 27.80 (kg)
All Males	Mean = 138.03 (kg) SD = 30.66 Low = 76.43 (kg) High = 195.27 (kg)	Mean = 48.39 (kg). SD = 20.59 Low = 38.55 (kg). High = 83.28 (kg).	Mean = 39.32 (kg) SD = 7.03 Low = 28.57 (kg) High = 51.07 (kg)	Mean = 16.87 (kg). SD = 6.75 Low = 7.25 (kg). High = 27.80 (kg).
All Females	Mean = 66.67 (kg) SD = 12.88 Low = 48.98 (kg) High = 93.98 (kg)	Mean = 24.08 (kg) SD = 10.02 Low = 9.75 (kg) High = 46.08 (kg)	Mean = 19.82 (kg) SD = 3.53 Low = 14.96 (kg) High = 29.39	Mean = 8.48 (kg) SD = 3.99 Low = 3.62 (kg) High = 17.28 (kg

Table 3
Mean CV's for isometric leg lift and arm lift for all subjects, per sex of subjects for sincere effort and feigned weakness sessions

	Leg lift sincere effort	Leg lift feigned	Arm lift sincere effort	Arm lift feigned
All Subjects	7.0 (SD = 4.2) Range = 1.2–22.4	15.9 (SD = 10.7) Range = 2.2–48.6	6.5 (SD = 5.4) Range = 0.0–20.8	13.6 (SD = 9.9) Range = 0.0–38.0
All Males	7.3 (SD = 5.0) Range = 1.2–22.4	13.5 (SD = 9.0) Range = 2.2–36.3	5.6 (SD = 4.9) Range = 0.5–20.8	10.0 (SD = 5.4) Range = 3.1–38.0
All Females	6.7 (SD = 3.0) Range = 4.1–14.1	18.4 (SD = 11.2) Range = 2.7–48.6	7.5 (SD = 5.5) Range = 0.0–16.0	12.4 (SD = 9.2) Range = 0.0–32.3

Table 4
Lower and upper bounds for expected frequency of CV's < 15% in the general population

Activity	%< 15	Lower bound	Upper bound
Sincere Leg	97.1	91.5	100.0
Feigned Leg	58.8	42.3	75.3
Sincere Arm	91.2	81.7	100.0
Feigned Arm	67.6	51.9	83.3

effort and feigned weakness sessions are reported in Table 3. The mean CV's were compared using a 2 (arm vs. leg) x 2 (sincere vs. feigned) repeated-measures ANOVA. There was a significantly higher mean CV for sincere effort ($M = 6.76$, $SD = 4.82$) than for feigned weakness ($M = 14.79$, $SD = 10.30$), $F(1, 33) = 35.11$, $p = 0.000$. The means for the arm and leg did not differ significantly, $F(1, 33) = 1.39$, $p = 0.247$. The interaction of limb and feigned versus sincere was not significant, $F < 1$.

Referring to the third and fourth columns of Table 4, we can state with a 95% confidence interval (CI) that the true proportion of people who could successfully feign weakness for the isometric Leg Lift by producing a CV less than 15% is between 42.3% and 75.3%. Also, with a 95% CI, the true proportion of people who could successfully feign weakness for the isometric Arm Lift is between 51.9% and 83.3%. Note that the lower bound for CV's < 15%, when giving a *sincere* effort during these isometric lifts, are 91.5% for the Leg Lift and 81.7% for the Arm Lift, indicating a relatively high frequency of false positives for feigned weakness.

To further illustrate the dilemma which occurs when using the CV to assess sincerity of effort during these isometric activities, an analysis was performed to determine if it would be possible to improve the accuracy of classification by raising or lowering the cutoff point and/or by classifying sincerity of effort based on the number of CV's which exceed any given cutoff point. Cutoff CV's of 12.5%, 15.0% and 17.5% were used as examples. The results for sensitivity (proper identification of subjects feigning weakness) and specificity (proper identification of subjects giving a sincere effort) are shown in Table 5 for each of these three proposed cutoffs. In Table 5, "accuracy" is the average of sensitivity and specificity.

To demonstrate that sensitivity does not improve by devising an arbitrary standard for the "frequency" by which a CV would exceed the thresholds of 12.5%, 15.0% and 17.5%, the data are reported in Table 6. Decreasing the CV cutoff increases sensitivity to feigned weakness at the expense of a lower specificity. At-

Table 5
Sensitivity, specificity and accuracy* for three CV cutoffs

	12.5% CV sensitivity/ specificity/ accuracy	15.0% CV sensitivity/ specificity/ accuracy	17.5% CV sensitivity/ specificity/ accuracy
Leg Lift	55.8% (19/34)/ 88.2% (30/34)/ 72.0% (49/68)	44.1% (15/34)/ 97.0% (33/34)/ 72.0% (49/68)	38.2% (13/34)/ 97.0% (33/34)/ 64.7% (44/68)
Arm Lift	38.2% (13/34)/ 85.2% (29/34)/ 64.7% (44/68)	32.3% (11/34)/ 91.1% (31/34)/ 61.7% (44/68)	26.4% (9/34)/ 94.1% (32/34)/ 60.2% (31/68)

*Accuracy has been calculated by averaging sensitivity and specificity.

Table 6
Sensitivity per CV cutoff and frequency of failure

	12.5% CV cutoff	15.0% CV cutoff	17.5% CV cutoff
Just One CV Exceeding Cutoff	23/34 (67.6%)	19/34 (55.8%)	15/34 (44.1%)
Both CV's Exceeding Cutoff	11/34 (32.3%)	7/34 (20.5%)	6/34 (17.6%)

tempting to avoid false positives for feigned weakness by raising the CV threshold to 17.5%, results in a substantial reduction in sensitivity.

In this population, 12 (35.2%) subjects feigning weakness produced CV's less than 12.5% in during both static lifts. Sixteen (47.0%) also produced false negatives for feigned weakness with CV's less than 15.0% in both static lifts. When the CV threshold was raised to 17.5%, 18 subjects (52.9%) had false negatives for feigned weakness.

Arbitrarily deciding to classify validity according to the frequency with which various CV thresholds are exceeded does not improve the classification model. In Table 6, a standard of "just one Arm or Leg CV $>$ 15.0% $=$ feigned weakness," results in sensitivity of only 55.8%. Sensitivity decreases to 20.5% with a criterion of "both CV's $>$15% $=$ feigned weakness." To completely remediate the problem of false positives in this study, the cutoff CV for the Leg Lift and the Arm Lift would have to be raised to 22.5 and 20.9 respectively. Increasing the CV's to these levels improves specificity, but has a corresponding adverse affect on an already deficient sensitivity.

Comparisons of the lowest CV's produced during feigned weakness sessions to the average CV's produced during sincere effort sessions illustrates the degree to which uninitiated subjects can successfully reproduce submaximal isometric contractions with variability that would not be remotely suspect of being less than a maximal effort. The mean CV during sincere effort sessions for all subjects for the Leg Lift was 7.0%. During feigned weakness sessions, 7/34 (20.5%) of all subjects produced CV's $\leqslant$ 7.0%. The mean CV during sincere effort for all subjects during the Arm Lift was 6.5%. During feigned weakness sessions, 10/34 (29.4%) produced CV's $\leqslant$ 6.5%.

4. Discussion

The CV's produced by both male and female subjects during this study are significantly higher during feigned weakness sessions than they are during sincere effort sessions. However, "statistical significance" does not tell the whole story. There is a large overlap in the distributions of scores for both testing modes. As a result, it is not possible to assign group membership according to a CV unless it is, by most standards, "high" (greater than 22.4% for this study, as shown in Table 3). Although we can be reasonably sure that a "high" CV is likely to indicate feigned weakness, we cannot be sure at all that a low CV indicates a sincere effort. Note in Table 4 that the lower end of the ranges for CV's for both lifts during feigned weakness sessions ranged from 0.0%–2.2%, well within "acceptable" ranges for being classified as "valid efforts." Although the CV's less than 15% in these subjects, during feigned weakness sessions, indicate high intra-test reliability, the data are not valid expressions of true isometric strengths. Rather, they merely represent sub-maximal efforts, in other words, invalid data that are reproducible.

It is reasonable to believe that tissue trauma – including relatively inconsequential orthopedic injuries – may enhance a subject's ability to modulate force output during isometric testing. Even minimal proprioceptive feedback as the result of an old injury would provide the subject with an enhanced ability to perform at a sub-maximal level during isometric testing and go undetected. Therefore, *the sensitivity to feigned weakness reported in this study may actually underestimate the number of persons able to consistently reproduce sub-maximal isometric forces*.

Although there were relatively few "high" CV's during sincere effort testing, it should not be acceptable to use testing methods and analyses which are shown to result in the misclassification of persons who are actually cooperating during an evaluation. A practice such as this unfairly penalizes persons who are completely innocent. Table 5 very clearly illustrates how increasing the threshold to 17.5% results in a significant reduction in the sensitivity of the test – but still fails to meet a gold standard of "no false positive designations for feigned weakness."

The findings of this study apply to the use of the CV for peak forces in a three-trial protocol, which a common method of test administration and analysis. Although such testing has been performed for approximately 40 years, it appears to have been conducted in the absence of any compelling proof that it is an accurate method of assessing effort. Regardless as to the CV threshold used to distinguish between good effort and feigned weakness, and regardless as to the number of "positive" tests chosen to classify effort, the method does not appear to be accurate.

5. Conclusions

Intra-test variation, as mathematically described by the CV for peak isometric strengths, does not accurately classify validity of effort for the Static Arm Lift or Leg Lift. The peak CV lacks the sensitivity and specificity required to assess effort with any reasonable degree of clinical certainty when applied to these isometric lifts. No previous studies have unequivocally validated the use of isometric force curves as an index of effort during the measurement of the two lifts in this study. Therefore, the Static Leg Lift and Static Arm Lift are not scientifically reliable for the purpose of classifying validity of effort. The use of the Static Arm Lift and Leg Lift for the purpose of classifying validity of effort should be discontinued.

References

[1] F. Aghazadeh and M.M. Ayoub, A comparison of dynamic- and static-strength models for prediction of lifting capacity, *Ergonomics* **28** (1985), 1409–1417.

[2] J. Agre, J. Magness, S. Hull et al., Strength testing with a portable dynamometer: reliability for upper and lower extremities, *Arch Phys Med Rehabil* **68** (1987), 454–458.

[3] S.M. Al-Obaidi, R.M. Nelson, S. Al-Awadhi and N. Al-Shuwaie, The role of anticipation and fear of pain in the persistence of avoidance behavior in patients with chronic low back pain, *Spine* **25** (2002), 1126–1131.

[4] N. Barren, A. Gant, F. Ng et al., The validity of the ERIC maximal voluntary effort protocol in distinguishing submaximal effort on the BaltimoreTherapeutic Equipment Work Simulator, *National Association of Rehabilitation Professional in the Private Sector Journal & News* **7** (1992), 223–228.

[5] T.B. Birmingham and J.F. Kramer, Identifying submaximal muscular effort: reliability of difference scores calculated from isometric and isokinetic measurements, *Percept Mot Skills* **87** (1998), 1183–1191.

[6] R.W. Bohannon, Differentiation of maximal from submaximal static elbow flexor efforts by measurement variability, *Am J Phys Med* **66** (1987), 213–218.

[7] L.S. Caldwell, D.B. Chaffin, F.N. Dukes-Dobos et al., A proposed standard procedure for static muscle strength testing,*Am Ind Hyg Assoc J* **35** (1974), 201–206.

[8] D.B. Chaffin, Ergonomics guide for the assessment of human static strength, *Am Ind Hyg Assoc J* **36** (1975), 505–511.

[9] D.B. Chaffin, G.D. Herrin and W.M. Keyserling, Preemployment strength testing: an updated position, *J Occup Med* **20** (1978), 403–408.

[10] S.N. Chengalur, G.A. Smith, R.C. Nelson and A.M. Sadoff, Assessing sincerity of effort in maximal grip strength tests, *Am J Phys Med Rehab* **69** (1990), 148–153.

[11] A.H. Fairfax, R. Balnave and R.D. Adams, Variability of grip strength during isometric contraction, *Ergonomics* **38** (1995), 1819–1830.

[12] A. Garg, A. Mital and S.S. Asfour, A comparison of isometric strength and dynamic lifting capacity, *Ergonomics* **23** (1980), 13–27.

[13] J.C. Gilbert and R.G. Knowlton, Simple method to determine sincerity of effort during a maximal isometric test of grip strength, *Am J Phys Med* **62** (1983), 135–144.

[14] T.H. Hansson, J. Stanley, S.J. Bigos et al., The load on the lumbar spine during isometric strength testing, *Spine* **9** (1984), 720–724.

[15] P. Harber and K. SooHoo, Static ergonomic strength testing in evaluating, *J Occup Med* **26** (1984), 877–884.

[16] E. Hoffmaster, R. Lech and B.R. Niebuhr, Consistency of sincere and feigned grip exertions with repeated testing, *J Occup Med* **35** (1984), 788–794.

[17] M.M. Hutten, M.T. Muller and H.J. Hermens, Discrimination between maximal and submaximal effort in lumbar dynamometry, *Clinical Biomechanics* **13** (1998), 27–35.

[18] A.W. Jackson and R.K. Dishman, Perceived submaximal force production in young adult males and females, *Med Sci Sports Exerc* **32** (2000), 448–451.

[19] W.M. Keyserling, G.D. Herrin, D.B. Chaffin et al., Establishing an industrial strength testing program, *Am Ind Hyg Assoc J* **41** (1980), 730–736.

[20] D.E. Lechner and S. Bradbury, Detecting sincerity of effort: a summary of methods and approaches, *Physical Therapy* **78** (1998), 867–898.

[21] Y. Lee and Y. Chen, An isometric predictor for maximum acceptable weight of lift for Chinese men, *Human Factors* **38** (1996), 646–653.

[22] P.C. Lin, M.E. Robinson, J. Carlos, Jr. and P. O'Connor, Detection of submaximal effort in isometric and isokinetic knee extension tests, *J Orthop Sports Phys Ther* **24** (1996), 19–24.

[23] A. Mital and S.S. Asfour, Modeling of isometric strength and lifting capacity, *Human Factors* **22** (1980), 285–290.

[24] L.O. Niemeyer, L.N. Matheson and R.S. Carlton, Testing consistency of effort: BTE Work Simulator, *Industrial Rehabililitation Quarterly* **2** (1989).

[25] M.E. Robinson, M. MacMillan, P. O'Connor et al., Reproducibility of maximal versus submaximal efforts in an isometric lumbar extension task, *J Spinal Disorders* **4** (1991), 444–448.
[26] M.E. Robinson, A.F. Greene, P. O'Connor et al., Reliability of lumbar isometric torque in patients with chronic low back pain, *Phys Ther* **72** (1982), 186–190.
[27] J.C. Rosecrance, T.M. Cook and N.S. Golden, A comparison of isometric strength and dynamic lifting capacity in men with work-related low back injuries, *J Occup Rehab* **4** (1991), 197–205.
[28] D. Schapmire, J.D. St. James, R. Townsend et al., Simultaneous Bilateral Testing: Validation of a New Protocol to Detect Insincere Effort During Grip and Pinch Strength Testing, *J Hand Ther* **15** (2002), 242–250.
[29] O. Shechtman, Using the coefficient of variation to detect sincerity of effort of grip strength: a literature review, *Journal of Hand Therapy* **13** (2001), 25–32.
[30] O. Shechtman, The coefficient of variation as a measure of sincerity of effort of grip strength, Part I: the statistical principle, *J Hand Ther* **14** (2001), 180–187.
[31] O. Shechtman, The coefficient of variation as a measure of sincerity of effort of grip strength, Part II: sensitivity and specificity, *J Hand Ther* **14** (2001), 188–194.
[32] O. Shechtman, S.D. Anton, W.F. Kanasky and M.E. Robinson, The use of the coefficient of variation in detecting sincerity of effort: a meta-analysis, *Work* **26** (2006), 335–341.
[33] G.A. Smith, R.C. Nelson, S.J. Sadoff and A.M. Sadoff, Assessing sincerity of effort in maximal grip strength tests, *Am J Phys Med Rehabil* **68** (1989), 73–80.
[34] T.B. Symons, A.A. Vadervoort, C.L. Rice et al., Reliability of a single-session isokinetic and isometric strength measurement protocol in older men, *J Gerontol A Biol Sci Med Sci* **60** (2005), 114–119.
[35] J.F. Yang and D.A. Winter, Electromyography reliability in maximal and submaximal isometric contractions, *Arch Phys Med Rehab* **64** (1983), 417–420.
[36] C.M. Wiles and Y. Karni, The measurement of muscle strength in patients with peripheral neuromuscular disorders, *J Neurol Neurosurg Psychiatry* **46** (1983), 1006–1013.