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Isometric strength assessment, Part I: Static testing does not accurately predict dynamic lifting capacity

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Abstract. *Objective*: To determine if isometric (static) strength accurately predicts dynamic lifting capacity.
Participants: 107,755 male and 23,078 female prospective workers taking part in a post-offer employment test.
Methods: Subjects were tested for strength three standard static lifts and attained physical maxima for four dynamic lifts.
Results: The data confirms modest correlations between isometric and dynamic measures. However, the standard errors of estimate for all isometric-to-dynamic predictions make such predictions meaningless for the practical purpose for which they are most commonly used.
Conclusions: The Static Leg Lift, Static Arm Lift and Static Back (Torso) Lift are not appropriate for making predictions relative to dynamic lifting capacity. Given the likely degree of error in such predictions, and in light of potential safety concerns as reported by previous investigators, employers, clinicians and risk managers now have substantial objective evidence to call such testing into question.

Keywords: Employment testing, post-offer testing, strength testing, static leg lift, static arm lift static back lift

1. Background

The psychophysical assessment for determining maximum dynamic lifting capacities has been described in many previous studies [10,11,13,22,26–29]. The term "psychophysical" refers to a method in which subjects perform lifts to determine maximum, safe levels of exertion. In practice, this method is dependent upon full cooperation from the subject, expertise from the evaluator, and good judgment on the part of both the subject and evaluator to ensure the safety of the test and the accuracy of the physical performance data. Standardizing variables such as cooperation, expertise and good judgment may be perceived by some as a significant challenge. The authors speculate that this perception fed the desire in the early 1970's to develop testing methods that would provide accurate tests to determine if prospective workers were capable of performing the essential functions of specific jobs. If a universally-applicable and standardized method of testing could accurately predict the ability to perform a broad range of job functions, the process of testing could be reduced to a "one size fits all" methodology. In the quest to identify such a protocol, isometric testing was proposed as the quick and easy answer to the complex question "Can the prospective employee do the job?"

Isometric strength, also called "static strength," is a measurement of the force exerted against an immov-

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Table 1
Manufacturers and promoters of isometric testing

Company	Web site (Links Verified September 13, 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/http://www.qmasystem.com
Chatillon	http://www.chatillon.com
Myogauge	http://www.myogauge.com
Ability Works, Inc.	http://abilityworksinc.com/technology.htm
JTech Medical	http://www.jtechmedical.com/http://www.jtechmedical.com
Jackson Strength Evaluation System	http://www.rehaboutlet.com/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

able object. This measure of raw strength has been the subject of many published studies. Some of these studies have sought to establish a link between isometric strength and subsequent back pain and/or injury on the job [2,4,5,7,19,24]. Two studies focused on predicting multiple isometric strengths, based upon the measurement of other isometric strengths [21,30]. One of these studies [21] also attempted to correlate demographic and anthropomorphic variables with dynamic lifting capacities, presumably in the hope that such measures would be a reasonable substitute for actual functional assessment. Other studies investigated the relationship between isometric strengths and dynamic lifting capacities in asymptomatic as well as patient populations for the purpose of developing models that would predict the ability to perform dynamic lifting capacities [1,4,6,7,14,18,20,23,25]. Graveling [15] conducted a lengthy review of the studies pertaining to isometric strengths and of studies pertaining to the psychophysical and metabolic approaches to assessing dynamic lifting capacities.

Typically, the isometric research has focused on the relationship between isometric strength and dynamic lifting capacity. These studies have reported relatively modest correlations (r values). One study of asymptomatic individuals reported isometric-to-dynamic correlations ranging from 0.29 to 0.39 [21]. Another study of patients reported correlations of 0.30 to 0.73 and strongly recommended that isometric testing be replaced by an assessment of dynamic function because of the potential errors in making predictions based on isometric strengths [25]. None of these studies have been instructive on the issue of using isometric data to accurately predict dynamic lifting capacity, either from peak isometric forces or from sustained isometric forces. The reason for this failure is quite basic: A correlation is a comparison of the linear relationship between two variables – and unless a correlation is *perfectly linear* ($r = 1.0$), such predictions must be expressed as a range of values. The only remaining issue is to determine the range for such predictions.

Despite the lack of any substantial evidence that isometric testing devices are capable of accurately predicting dynamic lifting capacity, numerous isometric devices have been developed over the past 40 years and are now promoted on web sites of various manufacturers and providers of employment testing services. These entities and their web sites are listed in Table 1. The purpose of this study was to use archival data from a large database to quantify the potential error in isometric-strength-to-dynamic-lifting-predictions through the calculation of the standard error of estimate.

2. Methods

2.1. Subjects and data collector preparation

Subjects participating in the testing procedures were successive job applicants tested according to a protocol developed by WorkSTEPS®, Austin, TX. The Millikin University IRB (Decatur, IL) waived review of the study since all data are reported as anonymous group data that were derived from the archives of the WorkSTEPS® database. As a condition for participation in the WorkSTEPS protocol, subjects were required to read and sign an informed consent. The total sample consisted of 107,755 males and 23,078 females. Data were collected in 129 facilities. All therapists and technicians collecting subject data had received training in the WorkSTEPS® methodology and were certified as proficient in the administration of the testing procedures.

Table 2
Static testing results – Males only

	N	Mean	SD
Arm Lift	93,611	36.88 kg	10.52 kg
Leg Lift	90,542	111.36 kg	33.47 kg
Back Lift	85,653	100.24 kg	32.25 kg

Table 3
Static testing results – Females only

	N	Mean	SD
Arm Lift	19,470	20.41 kg	6.99 kg
Leg Lift	18,726	58.79 kg	20.77 kg
Back Lift	18,111	56.35 kg	19.37 kg

Table 4
Male dynamic lifting capacities

	N	Mean	SD
Floor to Knuckle Lift	107,408	60.60 kg	12.61 kg
12” to Knuckle Lift	96,355	69.81 kg	15.15 kg
Knuckle to Shoulder Lift	99,850	35.79 kg	7.48 kg
Shoulder to Overhead Lift	105,165	37.56 kg	8.07 kg

Table 5
Female dynamic lifting capacities

	N	Mean	SD
Floor to Knuckle Lift	22,744	31.21 kg	8.75 kg
12” to Knuckle Lift	20,547	37.78 kg	10.07 kg
Knuckle to Shoulder Lift	21,096	19.82 kg	4.63 kg
Shoulder to Overhead Lift	21,747	20.32 kg	5.22 kg

2.2. Data collection procedures

The dynamic lifts assessed in this study were: Floor to Knuckle (FL-KN), 12” to Knuckle (12”-KN), Knuckle to Shoulder (KN-SH), and Shoulder to Overhead (SH-OH). For the dynamic lifts, weights were added for each successive lifting trial, following the protocols prescribed by the WorkSTEPS® methodology. Dynamic lifting activities were terminated when the subject indicated that a maximum safe level of lifting had been attained or when the evaluator determined that lifting heavier workloads would be unsafe.

The static lifts assessed were: Arm Lift, Leg Lift, and Back Lift (also known as the “Torso Lift”). Three trials were administered for each static posture performed during the testing session. Subjects were read standardized instructions for performing each of the lifts. They were instructed to build force gradually for the first half of the five second trials and to exert a maximum voluntary effort in the last half of each trial. This method of isometric testing was described by Caldwell [3]. Not all subjects performed all of the lifts. Sample sizes for specific comparisons are reported in Results. Data were recorded in pounds. For purposes of reporting, the metric conversion was based upon 2.2046 kg per lb.

During the Leg Lift, subjects stood with their feet shoulder width apart and the metatarsal joint aligned with the vertical line of the pulling force. The dynamometer handle was placed between the subjects’ knees at the supra-patellar level. Upper extremities were extended at the elbows with the subjects’ hands pronated. Lordosis was maintained in the lumbar spine while the subjects exerted an upward lifting force.

During the Back Lift, subjects were instructed to stand with the metatarsals in a straight line with the upward vertical force. The feet were in close proximity to one another. The handle of the dynamometer positioned at the appropriate height and placed in front of the knees at the supra-patellar level. Upper extremities were extended at the elbows with the subjects’ hands pronated. Lordosis or neutral lumbar posture was maintained while the subjects exerted an upward lifting force.

For the Arm Lift, subjects stood with their feet shoulder width apart, elbows at the side of the body in 90 degrees of flexion with the hands supinated. Subjects were instructed to exert an upward lifting force, keeping the axial skeleton in a vertical orientation. The isometric exertions were five seconds in duration. Peak force measurements for three trials in each of the three static tests were recorded and averaged for the purpose of data reporting in this study.

Since data were collected in 129 clinical sites, there was considerable variation in the instruments used to take the measurements. Some of the data collection sites used mechanical spring gauge dynamometers while others used electronic data collection systems.

Because of the technical limitations of all commercially available gauges, the true static maximum of a small number of subjects was not obtained because their force production exceeded the capacity of the data collection devices. Such limits did not affect the data due to the large number of subjects involved and the fact that such data was more than 3 SD above the mean for males.

3. Results

3.1. Static and dynamic strengths

Tables 2 through 5 report the mean static and dynamic strength measurements separately for male and female subjects. The database is, to the knowledge of

Table 6
Correlations among dynamic measures – Males only

Variables (Y, X)	Correlation	S_e(Y)	S_e(X)	N
FL-KN, 12”-KN	0.801	7.53 kg	9.07 kg	96,305
FL-KN, KN-SH	0.547	10.57 kg	6.26 kg	99,771
FL-KN, SH-OH	0.572	10.34 kg	6.67 kg	105,088
12”-KN, KN-SH	0.480	13.29 kg	6.54 kg	95,636
12”-KN, SH-OH	0.555	12.61 kg	6.72 kg	95,249
KN-SH, SH-OH	0.642	5.76 kg	6.21 kg	98,807

S_e(Y) is the standard error of estimate of Y from X.
S_e(X) is the standard error of estimate of X from Y.

Table 7
Correlations among dynamic measures – Females only

Variables (Y, X)	Correlation	S_e(Y)	S_e(X)	N
FL-KN, 12”-KN	0.806	5.13 kg	5.99 kg	20,466
FL-KN, KN-SH	0.576	7.21 kg	3.76 kg	20,952
FL-KN, SH-OH	0.591	7.12 kg	4.22 kg	21,609
12”-KN, KN-SH	0.533	8.62 kg	3.89 kg	20,050
12”-KN, SH-OH	0.613	8.03 kg	4.13 kg	19,742
KN-SH, SH-OH	0.683	3.36 kg	3.81 kg	20,551

S_e(Y) is the standard error of estimate of Y from X.
S_e(X) is the standard error of estimate of X from Y.

the authors, the largest normative data base of physical performance parameters of industrial employees in the United States. A follow-up study, which will present age- and sex-based norms for dynamic lifting, is in preparation. Tables 6 and 7 report the correlations among the dynamic activities for male and female subjects. Tables 8 and 9 provide the correlation coefficients between isometric strengths and dynamic lifting capacities for male and female subjects.

3.2. *“Statistical Significance” and the standard error of estimate*

Given the large sample size, (smallest female population = 16,562, smallest male population = 84,802) all correlations in Tables 6–9 are statistically significant at $p \leqslant 0.0005$. It is tempting to assume that a statistically significant correlation means that one variable is a good predictor of another. Statistical significance does imply that there is a high probability of a real relationship between the variables, but does not necessarily indicate that one variable is highly predictive of another.

The best way to determine how well one variable can be predicted from another is to examine the standard error of estimate (S_e) for the correlation. To that end, the reader's attention is directed to Tables 6–9. In each of these tables, two of the variables, e. g. “Arm, Leg,” are shown in the left hand column, labeled “Variables (Y, X).” The Y variable is the first of the activities in the column. The X variable is the second. The correlation

Table 8
Intercorrelations among dynamic and static lifts – Males only

Variables (Y, X)	Correlation	S_e(Y)	S_e(X)	N
FL-KN, Static Arm	0.330	11.79 kg	9.89 kg	93,450
FL-KN, Static Leg	0.346	11.66 kg	31.34 kg	90,392
FL-KN, Static Back	0.252	12.07 kg	31.16 kg	85,506
12”-KN, Static Arm	0.255	14.61 kg	10.16 kg	89,913
12”-KN, Static Leg	0.339	14.15 kg	31.48 kg	87,827
12”-KN, Static Back	0.237	14.61 kg	31.25 kg	84,802
KN-SH, Static Arm	0.380	6.85 kg	9.71 kg	91,370
KN-SH, Static Leg	0.352	6.99 kg	31.39 kg	88,286
KN-SH, Static Back	0.332	7.03 kg	30.48 kg	84,995
SH-OH, Static Arm	0.311	7.67 kg	9.93 kg	92,421
SH-OH, Static Leg	0.294	7.67 kg	31.93 kg	89,341
SH-OH, Static Back	0.220	7.89 kg	31.39 kg	84,478

S_e(Y) is the standard error of estimate of Y from X.
S_e(X) is the standard error of estimate of X from Y.

Table 9
Intercorrelations among dynamic and static lifts – Females only

Variables (Y, X)	Correlation	S_e(Y)	S_e(X)	N
FL-KN, Static Arm	0.363	8.12 kg	6.49 kg	19,293
FL-KN, Static Leg	0.376	8.12 kg	19.23 kg	16,562
FL-KN, Static Back	0.324	8.21 kg	18.19 kg	17,950
12”-KN, Static Arm	0.326	9.53 kg	6.62 kg	19,001
12”-KN, Static Leg	0.382	9.34 kg	19.19 kg	18,355
12”-KN, Static Back	0.334	9.53 kg	18.19 kg	17,819
KN-SH, Static Arm	0.388	4.22 kg	6.44 kg	18,814
KN-SH, Static Leg	0.368	4.31 kg	19.28 kg	18,069
KN-SH, Static Back	0.363	4.31 kg	17.96 kg	17,522
SH-OH, Static Arm	0.377	4.85 kg	6.49 kg	18,566
SH-OH, Static Leg	0.369	4.94 kg	19.32 kg	17,838
SH-OH, Static Back	0.328	4.94 kg	18.23 kg	17,233

S_e(Y) is the standard error of estimate of Y from X.
S_e(X) is the standard error of estimate of X from Y.

between the two variables is shown in the second column labeled “Correlation.” The third column, “S_e(Y),” is the Standard Error of Estimate (S_e) of the Y variable, predicted from X. The fourth column, “S_e(X),” is the Standard Error of Estimate ($S_{e)}$of the X variable, predicted from Y. The last column reports the number of subjects in the sample.

Assuming a bivariate normal distribution of the two variables, approximately 68% of cases will fall between a predicted score and one S_e above and below that score.Approximately 95% of cases will fall between a predicted score and two S_es above and below that score.

Consider as an example, the correlation between two similar test postures, the 12”-KN Lift and the static Leg Lift. For males, this correlation in our data was r = 0.339 (Table 9). The regression equation predicting 12”-KN from static leg strength was 12”-KN = 52.950 + 0.069 * Static Leg. For a person with the average Static Leg strength of 111.36 kg (245.5 lbs), the predicted 12”-KN lift capacity is 69.89 kg (154.1 lbs).

Table 10
Pearson correlations among dynamic lifting capacities and various demographic features and other physical performance parameters

	Age	Height	Weight	3-Minute Step Test	Sorenson Test	FLKN	12KNLordotic	KNSH	SHOH	R. Grip
Height	−0.049									
Weight	0.092	0.410								
3-Minute Step Test	0.150	−0.077	0.257							
Sorenson Test	−0.031	−0.034	−0.295	−0.188						
FLKN	−0.135	0.465	0.323	−0.112	0.034					
12KNLordotic	−0.136	0.462	0.293	−0.115	0.051	0.887				
KNSH	−0.153	0.485	0.364	−0.102	0.010	0.747	0.700			
SHOH	−0.203	0.459	0.311	−0.120	0.018	0.758	0.742	0.793		
R. Grip	−0.074	0.548	0.344	−0.084	0.000	0.601	0.570	0.609	0.611	
L. Grip	−0.051	0.539	0.342	−0.087	0.002	0.612	0.583	0.616	0.620	0.911

$P < 0.0005$ for all correlations except KN-SH and Sorenson ($p = 0.001$), Right Grip and Sorenson ($p = 0.860$), and Left Grip and Sorenson ($p = 0.486$).

That figure represents the best *point prediction* of 12”-KN lift capacity. However, an interval estimate based on the S_e of 14.15 kg (31.2 lbs), means that 95% of the time the person’s true capacity will be between 41.59 kg (91.7 lbs) and 98.20 kg (216.5 lbs). It will be within the narrower range of 60.41 kg (133.2 lbs) to 79.38 kg (175.0 lbs) 50% of the time. In other words, when predicting a male’s 12”-KN dynamic lifting capacity from the static Leg Lift, 50% of the time the true value will be within 9.48 kg (20.9 lbs) above or below the point prediction. Put another way, 50% of persons tested will have actual dynamic strength that differs from the prediction by 9.48 kg (20.9 lbs) or more. And 95% of the time, the best point prediction will be within 28.3 kg (62.4 lbs) above or below the true value. Therefore, 5% of the persons tested will have actual dynamic strength that differs from the predicted strength by 28.3 kg (62.4 lbs) or more. Another way to look at these numbers is to note that approximately 25% of persons tested will have a true maximum 12”-KN dynamic lifting capacity of at least 9.48 kg (20.9 lbs) greater than predicted, and approximately 25% will have a dynamic lifting capacity at least 9.48 (20.9) lbs lower than predicted. If we consider the lower correlations, such as the FL to KN related to the static BACK lift, where $r = 0.252$, predicting the floor lift from the static would result in a variance of plus or minus 68.69 lbs. We ask the reader to consider whether this is accurate enough for practical, legal, or clinical purposes.

3.3. Bivariate distribution of data

As a check on the assumption that our data approximate a bivariate normal distribution, we assessed the actual percentage between one S_e above and below the mean predicted 12”-KN measures in our male data. As noted above, for the mean Static Leg Lift of 111.36 kg (245.5 lbs), the predicted 12”-KN capacity was 69.89 kg (154.1 lbs). Of the 407 persons with that predicted capacity, 70% were within one S_e above or below that predicted capacity. For one standard deviation above the mean for the Static Leg lift, 148.92 kg (327.6 lbs), the predicted value was 75.59 kg (166.2 lbs) of dynamic capacity. Of the 190 persons with that value, 65.7% were within one S_e. For one standard deviation below the mean for the Static Leg lift, 81.96 kg (180.3 lbs), the predicted value was 65.42 kg (143.9 lbs) of dynamic capacity. Of the 523 persons with that value, 71.5% were within one S_e. Thus, our observed ranges of 12”-KN strength measures were reasonably consistent with the predicted 68% falling within one standard error of estimate.

3.4. Correlations among dynamic lifting capacities and other variables

To assess the possibility that various demographic characteristics and other physical performance test results are correlated to, and hence predictive of, dynamic lifting capacities, a correlation matrix was developed. Table 10 shows the relationship among these variables. The population sizes for the various comparisons in the table range from 113,123 to 129,858 – are large enough by any standard to draw definitive comparisons.

While nearly all of the correlations in Table 10 are “statistically significant,” the comparisons between hand grip strength and lifting capacity, $r = 0.570$ to 0.616. Standard errors of estimate were not calculated for these variables. The Dial case [12] alone should be instructive relative to the legalities pertaining to the selection process of prospective workers. In this landmark decision, the decision against the defendant was not based upon the fact that predictions of one kind or another violated federal law. The decision was rendered, in part, because the employment testing performed by a clinic employed by the defendant did not assess essential functions of the job in an accurate manner. Very simply, such testing must be job-specific. Other variables (i.e., age, height, weight, 3-Minute Step Test and Sorenson's Test) have r values even lower than the grip-to-dynamic-lifting comparisons and, thus, would also seem to have scant legal basis for making hiring decisions if lifting is an essential function of a job.

Lastly, with regard to Table 10, the comparisons among the various dynamic lifting capacities have the highest r values, ranging from 0.700 to 0.887. Although these are the highest correlations in the matrix, the standard errors of estimate for predicting one dynamic lifting capacity, based on another dynamic lifting measurement range from 5.67 kg (*12.50 lbs*) to 13.29 kg (*22.29 lbs*) for males and 3.36 kg (*7.40 lbs*) to 8.62 kg (*19.00 lbs*) for females. Therefore, the authors believe it is imperative to perform dynamic lifting that accurately reflects the specific postures required to perform job related and essential functions and/or individual specific vocational/ household functions as a part of any disability management/functional testing program. Abbreviated testing protocols which are not job-specific may also run the risk of being out of compliance with federal law if used during employment testing protocols to make a hiring recommendation or decision.

4. Discussion

4.1. Implications

The prospective workers in the present study were job applicants for occupations that required some degree of material handling. Thus, by definition, they were more likely to be individuals whose work was more physically demanding than that of an office worker. As a result, these data reflect physical capacities which exceed that of professional white collar workers or persons typically employed in sedentary jobs.

There are important implications for using static data to predict an individual's dynamic lifting capacity. First, it is very likely that when static data are used to make assessments regarding an individual's ability to perform dynamic lifting activities as well as the essential functions of a job, a substantial number of applicants – as well as injured workers who are returning to the job – will be assigned to jobs that pose a significant risk to their safety and health because the predictions will overestimate their actual working capacities. At the same time, substantial numbers of applicants may be denied jobs because the predictions underestimate their true dynamic strength.

The second implication is that if static data are used to determine a financial award for a disability claim or a work-related injury, some claimants will receive an unjustified windfall while others will receive an undeservedly-low settlement. Predicting dynamic lifting capacities on the basis of static data will, in fact, be relatively accurate for some individuals, but it is impossible to identify which ones. Accurate predictions related to "lost function" will, therefore, be a matter of chance.

The third implication is the problematic use of isometric measures to predict dynamic function in a disabled/patient population. Due to the musculoskeletal length-tension relationship of the human body, maximum force is typically produced in the mid-range of motion. Static measures typically taken near mid-range of motion do not account for the "weakest" portion of the range of motion and, therefore, may be even more misleading when extrapolated to predict dynamic function in a patient population.

The standard error of estimate (S_e) for all possible comparisons indicate that using one dynamic lifting posture's capacity to predict another dynamic lifting posture's capacity is also an exercise that is fraught with potentially significant error. These data highlight the importance of making dynamic lift recommendations specifically on the basis of actual measurements taken during a test, not on the basis of an extrapolation. Here again, there appears to be no shortcut to determining an individual's functional capacity. These data indicate the necessity of administering tests which answer specific questions related to functional requirements and abilities.

Finally, Hansson [16] raised the most fundamental issue – the *safety* of static strength testing. Using a straightforward biomechanical approach, the compressive and sheering forces on vertebral bodies and major joints were calculated. The calculations were based upon the amount of force produced during five isometric strength tests, the length of the anatomic levers used in each strength test and the angle of the torso. The calculations revealed that the isometric torso lift, squat lift, arm lift, trunk extension lift and trunk flexion lift were shown to be potentially injurious, "even during submaximal efforts of the subjects." Thus, based upon the safety of test subjects alone, static testing poses a significant element of risk that should be carefully weighed by clinicians before performing such tests.

A theoretical weakness of the study is that data collection was not obtained on one single piece of equipment. The methodology, however, was constant. Furthermore, by definition, isometric activity is the generation of force against an immovable object. Therefore, our conclusions would apply to all isometric testing devices, irrespective of the name brand, presuming that all equipment manufacturers have devices that provide valid measurements of force.

Another possible weakness of this study is that there is no practical way to ensure that all gauges were calibrated at all times. Given the strong bivariate distributions of the data, all indications would strongly support that "instrument error" did not affect the quality of data reported herein. The sheer volume of subjects in the WorkSTEPS® database itself provides statistical evidence that cannot be refuted by any means other than replicating the activities with a similar number of subjects – and producing different results. The fact that these isometric data were collected at multiple locations throughout the United States by multiple individuals on multiple devices, results in a global view of isometric strength measurement, unlike any other studied in the past. As such, it would be difficult to reasonably argue that the results do not apply to all isometric testing devices and the associated protocols that are purportedly used to predict dynamic lifting capacity.

It is conceivable that an employer, clinic, or equipment manufacturer could produce anecdotal evidence that the use of isometric strength measures have been used in a worker selection process, resulting in a reduced incidence of injuries in a given occupational setting. However, unless such evidence can be produced which indicates that the testing regimen, as opposed to other factors, have resulted in the reduction of injuries, anecdotal evidence will not likely withstand legal challenge. Another consideration with such anecdotal evidence is the likely disparate impact associated with such a testing regimen. Specific reference is made to female job applicants, definitively shown in this study to be weaker, as a group, than male subjects across all static and dynamic lifting measures. Equal Employment Opportunity Commission *vs*. Dial[17] is a cautionary tale in the use of testing methods that do not accurately measure job specific essential functions and thereby result in disparate impact and or treatment of protected classes.

5. Conclusions

There is a relatively strong correlation among all the dynamic lifting capacities examined in this study, but not strong enough to make accurate predictions of one dynamic lift based upon the measurement of another dynamic lifting capacity. Correlations among the static capacities are smaller than the correlations among the dynamic lifting capacities. Correlations among the static and dynamic lifting capacities are all lower than the static versus static or the dynamic versus dynamic lift comparisons for all males and females.

Given the standard errors of estimate (S_es) of the isometric-strength-to-dynamic-strength correlations, it is not possible to use any static lift in this study to predict with a reasonable degree of certainty, any dynamic lifting capacity discussed in this study. Coupled with the potential for injury from static testing, we conclude that static measures of strength should not be used as predictors of dynamic lifting capacity for prospective employees or for injured workers.

References

[1] F. Aghazadeh and M.M. Ayoub, A comparison of dynamic- and static-strength models for prediction of lifting capacity, *Ergonomics* **28** (1085), 1409–1417.

[2] M. Batti'e, S. Bigos, L. Fisher et al., Iosmetric lifting strength as a predictor of industrial back pain reports, *Spine* **14** (1989), 851–856.

[3] 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.

[4] D.B. Chaffin, Human strength capability and low-back pain, Presented at the 58th annual meeting of the American Industrial Health Conference, Denver, 16–19 April 1973.

[5] D.B. Chaffin, Human strength capability and low-back pain, *J Occup Med* **16** (1974), 248–254.

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

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

[8] V.M. Ciriello and S.H. Snook, A study of size, distance, height and frequency effects on manual handling tasks, *Human Factors* **25** (1983), 473–483.

[9] V.M. Ciriello, S.H. Snook and G.J. Hughes, Further studies of psychophysically determined maximum acceptable weights and forces, *Hum Factors* **35** (1993), 175–186.

[10] S.H. Ciriello, S. H. Snook, A.C. Blick and P.L. Wilkinson, The effects of task duration on psychophysically-determined maximum acceptable weights and forces, *Ergonomics* **2** (1990), 187–200.

[11] V.M. Ciriello, S.H. Snook and G.J. Hughes, Further studies of psychophysically determined maximum acceptable weights and forces, *Hum Factors* **35** (1993), 175–186.

[12] Equal Employment Opportunity Commission vs. Dial. Case No. 99-C-3356, Northern District, Illinois, 29 April 2003.

[13] A. Garg, D.B. Chaffin and G.D. Herrin, Effects of lifting frequency and technique on physical fatigue with special reference to psychophysical methodology and metabolic rate, *Am Ind Hyg Assoc J* **40** (1979), 894–903.

[14] A. Garg, A. Mital and S.S. Asfour, A comparison of isometric strength and dynamic lifting capacity, *Ergonomics* **23** (1980), 13–27.
[15] R. Graveling, Historical Research Report – Manual handling: limits to lifting, Prepared for the World Health Organization, 1985.
[16] 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.
[17] P. Harber and K. SooHoo, Static ergonomic strength testing in evaluating, *J Occup Med* **26** (1984), 877–884.
[18] W.M. Keyserling, Isometric strength testing in selecting workers for strenuous jobs, Developed for the National Institute of Occupational Safety and Health, 1979.
[19] W. M. Keyserling, G.D. Herrin and D.B. Chaffin, Isometric strength testing as a means of controlling medical incidents on strenuous jobs, *J Occup Med* **22** (1980), 332–336.
[20] Y. Lee and Y. Chen, An isometric predictor for maximum acceptable weight of lift for Chinese men, *Human Factors* **38** (1996), 646–653.
[21] A. Mital and S.S. Asfour, Modeling of isometric strength and lifting capacity, *Hum Factors* **22** (1980), 285–290.
[22] A. Mital, The psychophysical approach in manual lifting – a verification study, *Human Factors* **25** (1983), 485–491.
[23] A. Mital, K. Waldemar, A.K. Mazouz and E. Orsarh, Prediction of maximum acceptable weight of lift in the horizontal and vertical planes using simulated job dynamic strengths, *Am Ind Hyg Assoc J* **47** (1986), 288–291.
[24] V. Mooney, K. Kenney, S. Leggett S and B. Holmes, Relationship of lumbar strength in shipyard workers to workplace injury claims, *Spine* **21** (1996), 2001–2005.
[25] 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 Rehabil* **4** (1981), 197–205.
[26] S.H. Snook and C.H. Irvine, Maximum acceptable weight of lift, *Am Indus Hyg Assoc J* **28** (1967), 322–329.
[27] S.H. Snook, C.H. Irvine and S.F. Bass, Maximum weights and work loads acceptable to male industrial workers, *Am Ind Hyg Assoc J* **31** (1970), 579–586.
[28] S.H. Snook and V.M. Ciriello, Maximum weights and work loads acceptable to female workers, *J Occup Med* **8** (1974), 527–534.
[29] S.H. Snook, The design of manual handling tasks, *Ergonomics* **21** (1978), 963–985.
[30] J. Zen, T. Hasson, S. Bigos et al., Isometric strength testing: recommendations based on a statistical analysis of the procedure, *Spine* **11** (1986), 43–46.