

Progressive Isoinertial Lifting Evaluation

II. A Comparison with Isokinetic Lifting in a Disabled Chronic Low-Back Pain Industrial Population

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The Progressive Isoinertial Lifting Evaluation (PILE), as described in Part I of this series of articles, is a simplified test combining psychophysical and isoinertial protocols to provide an unconstrained lifting assessment. In the second part of this study, 100 chronically disabled low-back pain patients (57 men and 43 women) were studied at two points: 1) at initial evaluation, when referred for possible entry into a comprehensive Functional Restoration treatment program; and 2) at the conclusion of the treatment (an average 7 weeks later). Results of simultaneous lumbar PILE and Cybex Liftask (Lumex, Ronkonkoma, NY) tests are presented, showing that patients may frequently double or triple initial lifting capacity after undergoing the functional restoration training program, achieving lifting levels at or above normal for incumbent industrial workers. Overall, results demonstrate that the PILE test can be an effective baseline screening test for lifting capacity under certain circumstances. Although several drawbacks affecting the PILE as an isolated test are discussed, its usefulness as part of a battery of physical capacity tests making up a quantitative functional evaluation is clearly demonstrated. Finally, the potential use of PILE as a safe, inexpensive, simple, and relevant screening test for frequent lifting capacity in worker selection is discussed. [Key words: physical capacity assessment, Quantitative Functional Evaluation, isoinertial, isokinetic, psychophysical lifting tests, function restoration, low-back pain (LBP), spinal disorders, chronic low-back pain (CLBP), neck pain, cervical dysfunction]

TESTS OF LIFTING CAPACITY represent an important aspect of functional evaluation. Much interest has been devoted to "strength testing" involving isometric lifting in industry.^{3-6,10,11,14,19-23} The isometric strength testing protocols have been incorporated into the NIOSH (National Institute of Occupational Safety and Health) Work Practices Guide for manual lifting in techniques designed to identify and select workers at risk for overexertion injury. Such work has suggested potential usefulness of isometric lifting tests for impairment/disability evaluation, and lifting techniques are currently incorporated into proposed disability evaluation methodology of the State of California.

However, because of the perceived risks of injury with lifting incidents,^{1,2,4,5,7-9,11,24} incorporation of lifting tests into rehabili-

tation protocols has been slow to materialize. The correlation of lifting episodes with "injury" reported in up to 65% of industrial injuries has produced concern regarding usefulness of lifting tests in functional restoration or work-hardening programs. Yet, lifting is clearly a crucial "whole body" activity necessary to the performance of job demands in most industrial settings. The potential for lift quantification is greater than for other total body activities, in which specific loads cannot be identified (such as bending, twisting, or climbing). As such, lifting is an attractive test modality for use in rehabilitation and work capacity evaluation.

There are a number of ways of measuring lifting, but one must be aware of certain associated problems. Static (isometric) tests provide poor discrimination ability for effort, and may be more likely to produce overexertion incidents. Isokinetic tests "accommodate" to patient effort, making overexertion less likely. Such tests stabilize the velocity/acceleration variables, permitting only the torque to vary independently. The control of these variables produces a tighter distribution in the normative database, potentially improving test sensitivity and specificity. However, the disadvantage of restriction of the velocity/acceleration variable is interference with components of agility and coordination used in normal lifting, leaving a limited measurement of "lifting strength" that may fail to correlate with the patient's true potential in "real world" lifting.^{3-5,11,12,18-20}

By contrast, psychophysical and isoinertial lifting tests have no such limitations. Since they represent unconstrained lifting techniques, they potentially measure the patient's lifting strength as well as agility, leading to higher true lifting capacity.^{12,13,17,26,27} The progressive component of the lifting methodology, along with the psychophysical, aerobic, and safety end-points are felt to insure adequate patient feedback to provide reasonable safety. In the present investigation of this Progressive Isoinertial Lifting Evaluation (PILE) test, a discussion of the usefulness of it in a patient population undergoing rehabilitation will be presented. Comparison of the methodology with an isokinetic methodology also will be examined.

MATERIALS AND METHODS

A test of lifting capacity termed Progressive Isoinertial Lifting Evaluation (PILE) was developed and described previously.¹⁷ Test methodology, normalizing factors, and a normative database have been described. The procedures developed previously were used in evaluating a patient population of chronic low-back pain (CLBP) disabled workers.

Subjects. The patient sample consisted of 100 consecutive patients, 57 men and 43 women, all undergoing a comprehensive

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Table 1. PILE Study Patient Data

	Males (n = 57)				
	Age (yrs)	Weight (lbs)	Height (in)	Mos since injury	Prior spinal surgeries
Means	35.4	202.7	70.6	12.2	22%
Standard deviations	8.4	33.6	2.8	6.9	
	Females (n = 43)				
	Age (yrs)	Weight (lbs)	Height (in)	Mos since injury	Prior spinal surgeries
Means	36.5	160.6	63.6	12.6	27%
Standard deviations	8.3	44.3	2.1	9.5	

functional restoration program for chronic low-back and/or cervicothoracic disorders. Patient characteristics are shown in Table 1.

Procedure. The patients underwent assessment at two distinct times. An initial assessment was performed within 1 week of initial office evaluation by the senior author after referral for possible treatment, generally following the perception of previous treating physicians that the persistently disabled patient had failed prior therapeutic efforts. The second assessment was performed from 6 to 8 weeks later (average, 7 weeks), at the time of completion of a 2- or 3-week comprehensive functional restoration program at PRIDE. In this program, patients undergo physical training and work simulation, based on a battery of tests to quantify physical functional capacity, and a multimodal disability management approach using cognitive-behavioral techniques. Patients undergo total therapy team contact time of 53 hrs/wk, consisting of about 50% physical training and 50% education/counseling. Periodic reassessment documents progress, evaluates work capacity, and provides quantitative feedback to patients and medical professionals. Temporarily totally disabled patients generally participate in a 3-week comprehensive program with a variable preprogram period of preparation for the rigorous and demanding comprehen-

sive training program. The difference in time between assessments (the length of preprogram treatment) is determined by the degree of physical and psychosocial deconditioning detected on the initial assessment.

The entire assessment battery is known as the Quantitative Functional Evaluation (QFE). PILE tests and Cybex Liftask isokinetic tests (Lumex, Ronkonkoma, NY) are both performed as part of the QFE. The fact that both tests are performed simultaneously on each evaluation by each patient allows correlation of results of the simple PILE test vs. a more expensive and sophisticated isokinetic test. Isokinetic testing is generally performed at 18 in/sec, 30 in/sec, and 36 in/sec speeds based on prior work with a prototype device.^{12,15,16} Peak force/body weight values are measured on the isokinetic device. A computerized, commercially available device was used to test all patients, employing software releases available since 1986. Isokinetic lifting heights were also divided into lumbar (0-36 inches) and cervical (36-66 inches) tests. The tests were comparable, since the height of the Liftask handles (pulling a cable attached to a dynamometer) is the actual height described, whereas the hand grip height for the PILE test is actually about 6 inches higher than the shelf height. Thus, while shelf height of the PILE lumbar test is 30 inches, hand height positioned on the lifting boxes is 36 inches at conclusion of the test, and 6 inches at outset.

Based on normative values previously published,^{12,16} and the normative sample tested in Part I, patient PILE values were expressed as absolute values and percent normal for final weight lifted, work/power consumption, endurance time, and heart rate. These values were correlated, at two times, with Cybex Liftask measures. They also were used in assessing the degree of improvement shown by the patients between initial evaluation and comprehensive program discharge.

RESULTS

Patient PILE data were accumulated at two points: initial QFE, and comprehensive program discharge for men and women under both lumbar and cervical protocols. These data are presented in Table 2. As can be seen, dramatic improvement in lifting capability occurred during the average 7-week period between

Table 2. Patient PILE Results at Initiation and Conclusion of Functional Restoration Treatment

	Females						
	QFE		D/C		t Value	Significance Level	
	Mean	STD	Mean	STD			
PILE LF/AW (lb/lb)	0.17	0.08	0.37	0.08	-15.01	P < 0.001	
PILE CF/AW (lb/lb)	0.15	0.07	0.32	0.07	-13.76	P < 0.001	
PILE LTW/AW (lb-ft/lb)	4.99	4.84	19.29	8.10	-12.31	P < 0.001	
PILE CTW/AW (lb-ft/lb)	2.97	2.62	12.02	5.11	-11.57	P < 0.001	
	Males						
	PILE LF/AW (lb/lb)	0.22	0.1	0.47	0.1	-16.07	P < 0.001
	PILE CF/AW (lb/lb)	0.22	0.09	0.39	0.07	-14.57	P < 0.001
	PILE LTW/AW (lb-ft/lb)	5.94	4.19	22.8	8.26	-14.64	P < 0.001
	PILE CTW/AW (lb-ft/lb)	4.66	2.99	12.64	4.08	-14.38	P < 0.001

STD = standard deviation; QFE = Quantitative Functional Evaluation; D/C = Discharge; LF = lumbar force; AW = adjusted weight; CF = cervical force; LTW = lumbar total work; CTW = cervical total work.

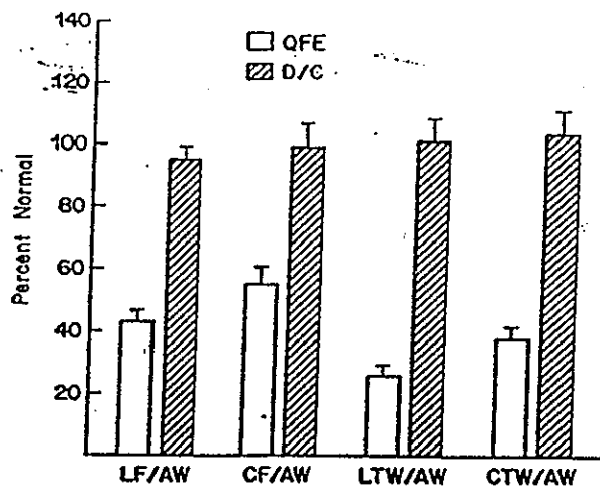


Fig 1. Results of male PILE testing in patients undergoing functional restoration with results of initial QFE and discharge (D/C) testing expressed as % normal. [LF = lumbar force; CF = cervical force; LTW = lumbar total work; CTW = cervical total work; AW = adjusted weight]

assessments, approximately doubling and occasionally tripling the dynamic lifting capacity value. In the patient population, testing was halted both by psychophysical and aerobic end-points, but not by the safety limit in any case. Differences between pre- and post-tests were always significant at the $P < 0.001$ level. Final forces/adjusted weight (AW) is unitless and expressed as a percent (and thus is identical for US and metric units), while the total work/adjusted weight ratio is in pound-foot/pound.

Figures 1 and 2 illustrate the changes for the patients on PILE testing from initial QFE to discharge testing. These figures are expressed as "% normal," to reflect comparison between the chronically disabled patient group and the incumbent industrial workers. Figure 1 represents male testing, while Figure 2 presents female testing. The changes in work are reflected on the right half of each

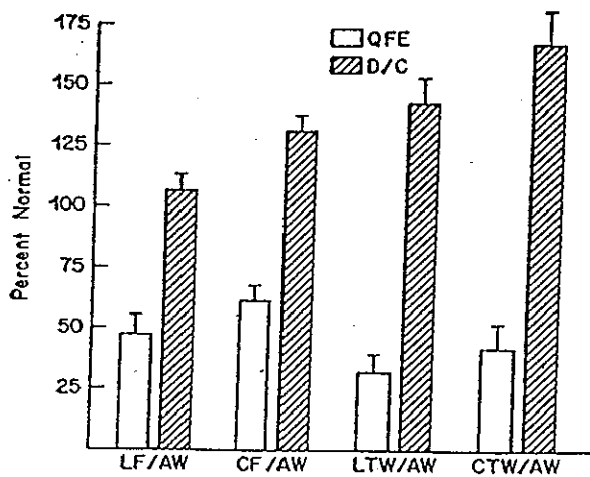


Fig 2. Results of female PILE testing in patients undergoing functional restoration with results of initial QFE and discharge (D/C) testing expressed as a % normal.

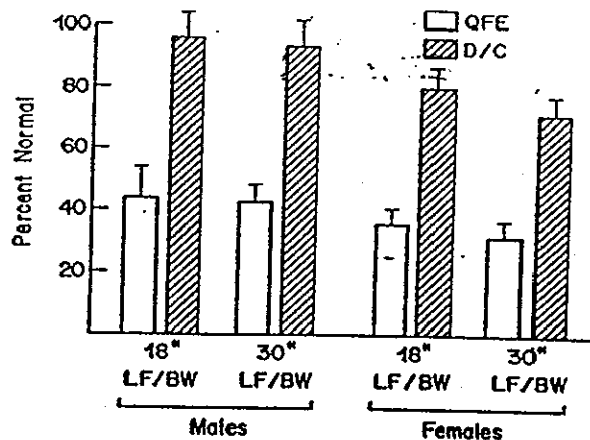


Fig 3. Results of Cybex isokinetic lift task testing at two speeds in male and female chronically disabled back pain patients undergoing functional restoration at initial QFE and discharge (D/C) from program [LF = lumbar force; BW = body weight; Speeds: 18 inches, 30 inches/sec.]

bar graph. As noted previously, all changes are significant at the $P < 0.001$ level.

Figure 3 documents patient change from initial QFE to discharge testing on the Cybex Liftask at 18 inches/second and 30 inches/second isokinetic speeds. The patient values have been individually normalized to a previously described and updated normative database.¹² Unlike the PILE protocol, in which both the lumbar and cervical tests are performed on all patients, Cybex testing is performed only according to the area of major patient complaints. While all patients underwent lumbar testing, only a small percentage underwent cervical Cybex testing, so results are only available for the lumbar Cybex Liftask protocol. Comparable increases were noted for both men and women at both speeds from one test to the next on peak force/body weight values expressed as a "% normal." Differences between tests at two times were all significant at the $P < 0.001$ level.

Table 3 provides correlation coefficients comparing normalized lumbar PILE values with normalized Cybex values at two speeds in order to assess the compatibility of one test with the other. Interestingly, test results for the women comparing isokinetic with isoinertial lifting are negatively correlated at each test session for each variable. For the men, the highest correlations occur on initial QFE testing, when test scores are considerably lower for both tests and greater variability based on fear of injury, pain, and muscular inhibition may be anticipated. At discharge, when normal to supernormal lifting capacity has been achieved, correlations are generally in a range in which less than 20% of the variance is accounted for by the comparison test.

DISCUSSION

Chronic low-back pain patients or inadequately conditioned workers will usually discontinue testing because of perceived fatigue (psychophysical end-point). Larger or older men and women are more likely to reach their target heart rates (aerobic end-point) than others, but neither aerobic nor safety limits was noted with much frequency in the present study. It is felt that such standardization and safeguards are adequate for an easily administered and reliable method of truly physiologic lift testing. With the endurance factor incorporated in the test, it gives a repeatable and objec-

Table 3. Correlations: PILE Data with Cybex Lifttask

	Females			
	QFE		D/C	
	Cybex 18 ^o LF/BW % normal	Cybex 30 ^o LF/BW % normal	Cybex 18 ^o LF/BW % normal	Cybex 30 ^o LF/BW % normal
QFE PILE LF/AW % normal	-0.09	-0.13		
QFE PILE LTW/AW % normal	-0.28	-0.32*		
D/C PILE LF/AW % normal			-0.11	-0.11
D/C PILE LTW/AW % normal			-0.09	-0.08
	Males			
QFE PILE LF/AW % normal	0.62†	0.62†		
QFE PILE LTW/AW % normal	0.61†	0.63†		
D/C PILE LF/AW % normal			0.42†	0.45†
D/C PILE LTW/AW % normal			0.38†	0.41†

QFE = Quantitative Functional Evaluation; D/C = Discharge; LF = lumbar force; BW = body weight; AW = adjusted weight; LTW = lumbar total work.

*P < 0.01.

†P < 0.05.

tive measure of the subject's frequent lifting capacity, that can be translated to training protocols or possibly job requirements in the workplace. With a normative database derived from testing incumbents in strenuous jobs requiring frequent lifting, the test offers the possibility of screening for limitations in endurance, cardiovascular functioning, or lift capacity that may impair the applicant's ability to perform as well as the incumbents. Such limitations may not be of significance, as larger, stronger, younger males may be below normal for their AW and yet easily fulfill job demands. Combining the mean normalized test scores (based on age, gender, and AW) with minimum standards based on a careful job analysis offers the potential for optimizing worker selection procedures.

Employers recognize a financial law of diminishing returns between the complexity of diagnostic testing and the information to be obtained from test performance. Clinical pressures imposed by the adversarial disability system may cause expensive tests to be used even when not medically justified, as exemplified by current overuse of lumbar radiographic procedures. The PILE test has the advantage of simplicity both with respect to equipment and test performance, allowing it to be performed in any physician or therapist office. The normative database (possible because test standardization and clear end-points with an effort factor create an objective psychophysical test) allows comparison with an ever-growing sample of industrial workers. As such, it offers the first truly standardizable whole body strength test not requiring special equip-

ment beyond the scope of the average clinician. When used in concert with simple office mobility and bicycle ergometry tests, it allows a simple, objective, basic screening functional capacity assessment to be performed by most ergonomists and clinicians. We cannot overemphasize the importance of the early recognition of physical capacity and effort deficits that then permits appropriate early intervention. Such intervention offers the possibility of decreasing iatrogenic and nomogenic factors in low-back pain. This may help alleviate some of the current clinical stagnation that leads to chronically disabled workers and unnecessary multiple surgeries.

The increases in PILE test results in the functional restoration patients in the present study were quite impressive. This two to three times increase in trunk strength over an average 7-week period is certainly more than would be expected in normal individuals attempting to train themselves as weight lifters. In the context of chronically disabled, injured workers with low-back pain who have a combination of muscle atrophy and neuromuscular inhibition, the dramatic changes become more believable. However, the achievement of normal to supernormal physical capacity, particularly among the women, is hard to understand. Certainly, initial test results were quite low and reflected a variety of factors: 1) weakness of trunk and extremity musculature; 2) a submaximal effort produced by pain, fear of injury, and low biomechanical efficiency leading to neuromuscular inhibition; or 3) lowered aerobic capacity, making the aerobic end-point easier to reach. Factors of effort can be overcome most easily through appropriate education, counseling, and initial training effects. Aerobic capacity responds at about the same rate as muscular capacity through the rigorous training program of the 7-week interassessment period.

The very high levels of physical capacity attained by the female patients, particularly in the cervical area, probably attest to the vigorous training pursued by our patients and the lower level of conditioning noted in our female normals. Unlike the primarily "blue collar" male normative database, the female norms were more slanted to white collar occupations, and their fitness was generally more a reflection of recreational pursuits than of regular industrial training. We will have to await development of a more industrially oriented job-specific female database to achieve better normalization, since female strength values are more highly variable than among men. The much higher "% normal" achieved by patients on discharge testing for cervical rather than lumbar protocols (with almost identical % normals on initial QFE) is reflective of the extensive upper extremity muscular training provided to female functional restoration program patients. It reflects major gains that can be made by female subjects in a relatively short training period who are not customarily exposed to extensive upper extremity conditioning.

Cybex % normal isokinetic values were found to more than double from initial QFE to discharge testing in parallel with the PILE test. Correlations were surprisingly low, however, in general accounting for less than 20% of the variance between the two tests (except on initial male QFE). The decrease in correlation coefficients (Table 3) in the men from initial QFE to discharge suggests that one or both tests is measuring a different factor in the lifting capacity improvement from QFE to discharge. Initial testing at low levels on both PILE and Cybex may simply impair sensitivity and discriminating ability for both tests. Women demonstrate negative correlations at both QFE and discharge. This would suggest that the tests are not measuring identical parameters, and cannot simply be substituted for each other. In other words, the data do not support the hypothesis that a simple PILE test can be used in place of isokinetic Lifttask testing under most circumstances. This

is not surprising since the PILE test, while it is standardized, is an unconstrained lifting test, allowing use of any combination of trunk strength, extremity strength, agility, body position, aerobic capacity, and muscular endurance. By contrast, the isokinetic test limits velocity and the "acceleration variable," producing a more constrained lift that decreases some of the distribution variability of normals inherent in psychophysical testing. Though both are dynamic tests, the Liftask provides an accommodating isokinetic resistance and a continuous computerized read-out of force and power production that permits better assessment of maximum voluntary capability and effort without necessitating use of an aerobic or safety end-point.

Both PILE and Cybex testing have been remarkably free of injuries. The accommodating resistance of isokinetic devices has often been cited as a reason for low injury rates, but this factor is obviously not operative in the PILE. The PILE (or its predecessor) now has been performed many thousands of times unaccompanied by verifiable injury, although temporary muscle soreness may follow testing. PILE testing is cited no more frequently than isokinetic dynamic testing as a source of such soreness, and less frequently than isometric testing (particularly the NIOSH "torso lift"). We may speculate that the "warm-up effect" produced by repetitive lifting at low initial levels may provide some protection from injury. In this way, the PILE test is distinguished from other forms of psychophysical lifting.^{25,26}

CONCLUSIONS

A new objective psychophysical lifting test (the PILE) is described which is safe, simple, inexpensive and quick to perform. The test is valid and reproducible, and is very relevant to the actual frequent lifting tasks it seeks to measure.

Adjusted weight (AW) is found to be the best normalizing factor for PILE capacity, leading to development of mean scores for a group of male and female industrial subjects tested on both lumbar and cervical protocols. Effort measurement depends on identification of heart rate at test termination, and is not applicable in patients on cardiac restrictions or rate-limiting medications. Dramatic improvement in PILE and isokinetic lift capacity is noted in a group of 100 consecutive patients undergoing functional restoration treatment for chronic disabling LBP. However, correlations between PILE and isokinetic methods are relatively low, suggesting some variation in the parameters inherent in lifting capacity that each test measures.

The simplicity, relevance, and lack of expense of the PILE potentially makes it an excellent screening tool for the medical clinic and workplace, though more sophisticated assessment using isolated strength measures and isokinetic tests may be required under some circumstances. The usefulness of the test in a rehabilitation setting is documented, but its usefulness in worker selection or disability evaluation awaits further investigation.

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Progressive Isoinertial Lifting Evaluation Erratum Notice

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IT HAS COME TO OUR attention that there is an error in the Methods section of our article entitled, "Progressive Isoinertial Lifting Evaluation I: A Standardized Protocol and Normative Database," (SPINE 13:993-997, 1988).¹ This error appears on page 994 of the article. The sentences appearing in paragraph 2 of this page: "Weight is incremented upwards at a rate equal to the initial free weight . . . every 20 seconds, with a rate of four lifting movements in each 20-second interval . . . The test is terminated when the first of the following end-points is achieved. . . ." should be replaced with the following:

"Weight is incremented upwards at a rate equal to the initial free weight (ie, 5 pounds for women, 10 pounds for men) every 20 seconds, with a rate of eight lifting movements (4 lifting cycles) in each 20-second interval (Figure 1.) A lifting movement involves a single transfer from one level to the next, ie, from floor to waist (0-30 inches) or waist to shoulder (30-54 inches). A lifting cycle involves two lifting movements to return to the starting point; ie, from floor to waist to floor, or waist to shoulder to waist. Lifting progresses in sequence, floor to waist to floor, until the patient reaches the first of the following end-points:

Both normative and patient data were collected using this protocol, and are accurately portrayed in Parts I and II of the PILE papers. Unfortunately, this error also carried over into some of the calculations presented later in the Methods section. Data for maximum weight lifted (Final Force), Endurance Time, and final heart rate are unchanged. However, calculations for Total Work (TW) and Total Power (TP) are in error because the distance-travelled parameter (distance travelled in 20 seconds based on 4 "lifting cycles" rather than 4 "lifting movements"), was stated incorrectly in the article. For a Lumbar test, the distance travelled every 20 seconds is 2.5 feet \times 8 = 20 feet, not 10 feet as originally presented. Similarly, the distance travelled in 20 seconds for the Cervical tests is 2 feet \times 8 = 16 feet, not 8 feet as originally presented. Therefore, both Work and Power values are double those shown in the original calculation. In the example shown in the text, if a female subject reaches an end-point after completing 100 seconds of lumbar testing, she will have a Final Force of 28 pounds (the weight lifted in the final 20 seconds). She will have performed Total Work on Lumbar PILE, which is calculated as follows:

$$TW = [8 + 13 + 18 + 23 + 28] \times 20 = 1,800 \text{ lb-ft} \quad (1)$$

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Total Power consumption (TP) is the work performed divided by the unit of time and is represented:

$$TP = TW/t = 1,800 \text{ lb-ft}/100 \text{ sec} = 18 \text{ lb-ft/sec or } 24.8 \text{ Watts} \quad (2)$$

In addition, if the same subject performs the Cervical tests in identical fashion (but with distance travelled per 20 seconds being 16 rather than 20 feet) then:

$$TW = [8 + 13 + 18 + 23 + 28] \times 16 = 1,440 \text{ lb-ft} \quad (3)$$

$$TP = 1,440 \text{ lb-ft}/100 \text{ sec} = 14.4 \text{ lb-ft/sec or } 19.8 \text{ Watts} \quad (4)$$

Based on the calculation error, the Normative Data presented in Table 3 for Total Work to Adjusted Weight (TW/AW) will be doubled in each instance. The corrected mean scores are as follows:

Corrections to Table 3: Normative Data

Males:	Lumbar TW/AW	45.6 lb-ft/lb
	Cervical TW/AW	24.6
Females:	Lumbar TW/AW	34.1
	Cervical TW/AW	14.6

In the PILE II study (*Progressive Isoinertial Lifting Evaluation II. A Comparison with Isokinetic Lifting in a Disabled Chronic Low-Back Pain Industrial Population*),² Table 2 presents patient data, which includes male/female TW/AW ratios for lumbar and cervical tests on admission and discharge from a functional restoration program. In each instance, the TW/AW mean value must be doubled. However, ratios and percent normal (as presented in Figures 1-3) are unchanged. These values are unlikely to be used by other research groups interested in replicating the tests and utilizing the norms, and therefore will not be recalculated.

The authors wish to stress that the test itself was implemented in a consistent fashion with accurate data collection and analysis. Other data and conclusions presented in the studies represent actual observations and are unaffected by the calculation errors introduced by the erroneously drafted protocol. The authors wish to apologize for any inconvenience produced to readers using this protocol. We hope that the published Errata will result in appropriate test implementation.

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