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Age and gender normative data for lift capacity

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Abstract.
BACKGROUND: Functional Capacity Evaluations (FCEs) are routinely used in physical medicine to ascertain an individual's work ability; with lift capacity being an important aspect of many evaluations. Despite the widespread use of lift capacity tests, there are few studies that provide age and gender normative data.
OBJECTIVE: To evaluate the safety, reliability, and validity of the EPIC Lift Capacity test, and to examine the effects of age and gender on lift capacity.
METHODS: This study used a test-retest design with 4,443 adult participants in good general health. Test-retest of participants' lift capacity was undertaken to examine safety and reliability. Age and gender and the self-reported physical demands of each employed participant's usual and customary job were collected to examine validity.
RESULTS: Safety and reliability were demonstrated for both measures of lift capacity for each of the six sub-tests in the EPIC Lift Capacity test battery. Inter-subtest differences and expected age and gender differences were found across all subtests.
CONCLUSIONS: The EPIC Lift Capacity test is a safe and reliable test of lift capacity. Normative data are presented that allow comparison within age and gender categories.

Keywords: Functional Capacity Evaluation, test safety, test reliability, norms, normal values

1. Introduction

Functional Capacity Evaluations (FCEs) are routinely used to measure the ability of an individual to perform work-related tasks, with lift capacity being an important aspect of many evaluations. Despite the widespread use of lift capacity tests, there are few studies that provide age and gender normative data.

Research on the psychometric properties of FCEs has resulted in more than 70 studies, which have been summarized by Innes [1–3]. In an extensive review of the literature, Innes [4] updated these studies and a clinician's guide [5], including interval studies that appeared in peer-reviewed publications between January 1998 and March 2006 on the reliability and validity of individual tests used in functional capacity evaluation and standardized FCE test batteries. Studies of reliability are more frequent than in prior years, generally demonstrating "moderate to excellent levels of reliability, particularly manual/material handling components." Validation studies continue to be rare, with weak relationships between test performance and return to work in some studies [6,7] and an absence of relationship to maintenance at work in other studies [8, 9]. None of these studies presented normative data.

Normative data are used throughout healthcare and

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rehabilitation with measures of grip strength [10–12] and fitness [13–16]. Normative data for these instruments are analyzed with reference to appropriate covariates that are likely to affect response to the test, which are used to stratify the data in a meaningful way. For example, an evaluee's grip strength is compared with age-referenced and gender-referenced normative data to provide an estimate of the evaluee's likely functional loss as a result of injury.

Age is a variable that is implicated in strength testing [17,18] and must be considered whenever lifespan normative data are presented. As a category of human performance that depends on many body systems that change with age, it is reasonable to expect that substantial age changes will be found with lift capacity, demonstrated as differences in cross-sectional studies. In order to perform valid normative comparisons, the extent of age differences in lift capacity must be known. Matheson [19] provided normative data for the West Standard Evaluation and the EPIC Lift Capacity Test (ELC) [20]. Mayer et al. [21] provided normative data for the Progressive Isoinertial Lifting Evaluation. However, only the more recent Matheson study stratified performance in terms of both age and gender. The current paper extends that study with a larger sample. The purpose of this study is to evaluate the safety, reliability, and validity of the ELC, and to examine the effects of age and gender on lift capacity in order to provide appropriately stratified normative lift capacity data.

2. Background

Lifting, "the act of manually grasping and raising an object of definable size" [22], is a component of many functional capacity evaluations because judgment about safety in jobs that require lifting requires a comparison of the worker's abilities and the job's demands [23]. Likewise, lift capacity testing is a component of many different types of occupational rehabilitation treatment programs [24–28]. To provide utility, such tests must meet widely agreed-upon criteria for safety, reliability, validity, and practicality [22, 29]. In order of importance, these tests must have been demonstrated to be safe with people who have already experienced an injury [30–32], reliable in these applications [33–35], and must provide valid answers for the issues the test is intended to measure, including the availability of normative data [36]. Practicality is based on the resources that must be expended to meet these criteria. The utility of a measure of lift capacity in rehabilitation is based on the degree to which it meets these criteria and the data can be used to:

1. Gauge treatment effect by comparing the baseline level of performance with performance as treatment progresses and at the conclusion of the treatment;
2. Set treatment goals that are reasonable within the context of normal values for patients of the same age and gender;
3. Estimate post-injury loss of function and work disability by comparing the patient's performance to expected values;
4. Make recommendations for work assignment by comparing the person's lift capacity to the job's demands.

While the first and last of these purposes can be achieved without reference to normative values, the second and third purposes are only possible with age-based and gender-based normative data.

2.1. Equipment design

The Epic Lift Capacity (ELC) equipment are standardized and described in an examiner's manual [37–39], where the formal test procedures are also presented. The test requires a standardized steel-reinforced lifting crate with offset handles and a set of masked weights, a heart rate monitor, and sturdy shelves. Color-coded masked weight containers weighing 2.3 kg (5 lbs) to 6.8 kg (15 lbs) of exactly the same exterior dimensions are used. The empty weight of the ELC crate is 4.5 kg (10 lbs).

2.2. Evaluation process

The ELC is conducted on a blind basis beginning with an empty crate at 4.5 kg (10 lbs) and increasing in 4.5 kg increments (loaded by the evaluator) for all evaluees. The evaluee is not told the beginning weight or the weight increments. The combinations of starting height and range (achieved by adjusting the shelves) are standardized into three categories, based on the participant's height over three vertical ranges; waist to shoulder, floor to waist, and floor to shoulder. The frequency of the ELC is one lift per cycle or four lifts per cycle, depending on the subtest. To minimize the effect of accumulated work, the starting loads for the later tests in the battery are proportionally based on the maximum acceptable weight attained in the earlier tests. Body mechanics are affected by both the physical parameters of the lifting task and the behavior of the evaluee, which is evaluated through the use of "high-risk work style" (HRWS) measurement guidelines applied during the lift. Instructions must be read verbatim or minimally paraphrased. A psychophysical performance target is provided in the instructions. The evaluee is asked to rate the perceived load before being asked whether or not he/she would be able to perform the lifting task on a "safe and dependable basis eight to twelve times per day" immediately after each task cycle. Heart rate is monitored continuously. Performance on a sub-test cannot begin if the evaluee is at or above 70% of age-based predicted maximum heart rate (PMHR). In addition, performance is immediately stopped if the evaluee achieves 85% of PMHR. A scheme to restrict loads to a proportion of ideal body weight based on gender and height is used, with a separate limit for each sub-test for each gender. Thus, there are twelve such guidelines. These guidelines are used to identify the point at which the load exceeds a generally acceptable maximum based on ergonomics research. If there is a good reason to exceed this load and if the evaluee's performance indicates that it would be safe, the test can proceed. If either of these conditions is not met, the test must be terminated. As previously described, the ELC test protocol can be terminated for many reasons including surpassing safe physiological, psychological and biomechanical limits [35]. The Maximum Acceptable Weight (MAW) is determined by the evaluator based on these guidelines and procedures. For the present study, a target load was not used; each participant was tested to his or her safe and dependable maximum acceptable weight.

3. Materials and methods

The EPIC Lift Capacity (ELC) test has demonstrated safety and reliability [20,35,40] that led to its use in a functional capacity evaluation test battery in a multi-site study in California [41]. Subsequent studies by this research team examined the construct validity and utility of the ELC in treatment settings [25], finding that aerobic capacity and back strength made significant independent contributions to lift capacity [42]. Mooney and colleagues [43] found that the combination of self-reported physical function as assessed by the Multidimensional Task Ability Profile test, gender, and age accounted for 67% of the variance in lift capacity. The purpose of the current large scale study ($n =$ 4,443) is to confirm safety, reliability, and validity as well as the development of normative age and gender data.

3.1. Test design

A test-retest design with a one-week interval was used with healthy normal participants to study the cross-sectional effects of age and gender on lift capacity. Participants were unpaid adult volunteers recruited by word of mouth during the ELC health provider certification program, after the provider completed a seven-hour formal training experience. Subjects self-reported as healthy and subsequently were screened with a structured health history questionnaire, the Cornell Medical Index [44] and provided a physical screening to rule out cardiovascular or orthopedic contraindications to exercise. Volunteers who were found to have cardiovascular signs and symptoms, hypertension (resting heart rate $>$ 90 bpm or resting BP $>$ 159/100 mm Hg), or musculoskeletal impairment were excluded from further study.

3.2. Variables

Lift capacity was measured by the ELC on a progressive-demand basis, with the maximum acceptable weight (MAW) operationally defined as the load that the evaluee is able to lift "on a safe and dependable basis, eight to twelve times per day", along with the standard decision criteria followed to determine MAW that have been published previously, as depicted in the flow chart in Fig. 1.

An important aspect of the ELC training process is the development of skills used to implement this series of decision criteria to safely determine Maximum Acceptable Weight. The formal training program and formal knowledge evaluation with a 50-item test preceded the "hands-on" testing conducted by the provider with 5 volunteers on a test-retest basis that provide the data for the present study.

3.3. Participants

This study employed a convenience sample of 4,443 adult volunteers (41% male), with an age range of 15 years to 65 years and mean (SD) 30.6 (8.8) years. The participants were unpaid volunteers who were recruited by applicants for certification in the ELC certification program. All participants were unfamiliar with the ELC protocol, without history of a musculoskeletal injury or cardiovascular contraindications. National distribution data are presented in Table 1.

Canada and the United States, Great Britain, China, Australia, and New Zealand contributed participants.

Table 1
National distribution of subjects

	Nation							
	AUS	CAN	CHN	GB	NZ	US	Unknown	Total
Male	48	1212	9	1	10	527	13	1820
Female	92	1752	16	4	17	723	19	2623
Count	140	2964	25	5	27	1250	32	4443
Percent	3.2%	66.7%	0.6%	0.1%	0.6%	28.1%	0.7%	100.0%

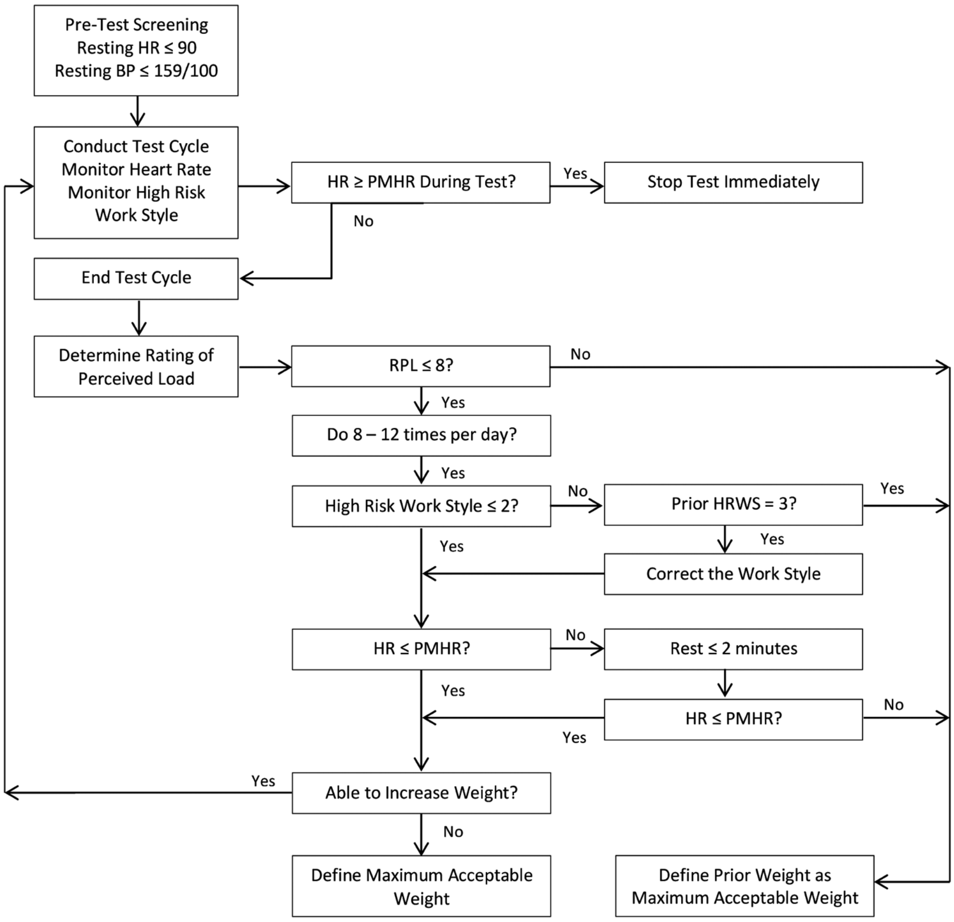

Fig. 1. Determination of maximum acceptable weight.

Participants for whom a country designation could not be made were grouped into the "unknown" category. Participants' descriptive data are presented in Table 2, with distribution of the participants by age and gender presented in Table 3.

Separate one-way analyses of variance demonstrated significant differences between males and females in terms of age ($F_{1,4440} = 13.24$, $p < 0.001$), and height ($F_{1,3319} = 2693.52$, $p < 0.001$) and weight ($F_{1,3262} = 2405.98$, $p < 0.001$) with males being older, taller, and heavier, respectively. In this sample females and young adults predominate, with young females being especially prevalent.

3.4. Procedures

3.4.1. Informed consent

This research project was reviewed and approved by the first author's institutional review board. Prior to participation in the study, each candidate provided written informed consent using a consent process that was approved by the institutional review board.

Table 2
Descriptive data

		N	Mean	SD	Minimum	Maximum
Age years	Male	1820	31.2	8.94	15	65
	Female	2622	30.2	8.74	15	64
	Total	4442	30.6	8.84	15	65
Height (cm)	Male	1428	178.7	7.6	144.8	210.8
	Female	1893	165.1	7.2	132.1	200.7
	Total	3321	170.9	10.0	132.1	210.8
Weight (cm)	Male	1409	82.2	12.5	50.0	159.1
	Female	1855	62.7	10.2	39.5	111.4
	Total	3264	71.1	14.8	39.5	159.1

Table 3
Distribution by age and gender

	Age group (years)					
	$15 < 30$	$30 < 40$	$40 < 50$	$50 \leqslant 60$	60+ yrs	Total
Male	987	526	208	83	16	1820
Female	1617	606	269	119	11	2622
Count	2604	1132	477	202	27	4442
Percent	58.6%	25.5%	10.7%	4.5%	0.6%	100.0%

Table 4
ELC subtest order

Subtest	Vertical range	Frequency
1	Waist to shoulder	1 rep/cycle
2	Floor to waist	1 rep/cycle
3	Floor to shoulder	1 rep/cycle
4	Waist to shoulder	4 reps/cycle
5	Floor to waist	4 reps/cycle
6	Floor to shoulder	4 reps/cycle

3.4.2. Health questionnaire

After the informed consent process was completed, each participant completed a 45-item medical history questionnaire that was subsequently reviewed by the evaluator. This is composed of sections from the Cornell Medical Index health questionnaire [44] that pertain to cardiovascular and musculoskeletal health and cardiac signs and symptoms. Each completed health questionnaire was reviewed by the evaluator and submitted for review by the authors with the evaluation records and informed consent documents. Affirmative responses to questions in the participant's medical history that indicated cardiovascular signs and symptoms precluded participation in the study. Completion of the requirements for inclusion in the study was confirmed by the evaluator. Self-reported height and weight were recorded, based on participants' response to questions by the evaluator.

3.4.3. Resting heart rate and blood pressure

After the health questionnaire was reviewed, while the participant was seated at rest, resting heart rate and blood pressure were measured. Participants were excluded if they were found to have elevated resting heart rate (> 90 bpm) or hypertension (> 159/100 mm Hg).

3.4.4. Normal job demands

Self-report data from incumbent workers to measure the physical demands of work have formed the backbone of functional job analysis since the 1950's [45–48], and are the basis of the Dictionary of Occupational Titles [49–51]. While questionnaires have sometimes been found to be unreliable [52], other studies have found them to be reliable and valid [53] and are generally recognized as both useful and necessary [54]. In the current study a 12-item job demands questionnaire [55] was used to identify the physical demand characteristics level of the participant's usual and customary job based on the definitions of the strength demands of work used in the Dictionary of Occupational Titles [56], as operationally defined in the Revised Handbook for Analyzing Jobs [57]. The questions are presented in Fig. 2.

The questionnaire has been used in functional capacity evaluation [41,58] and has found to be a useful tool in participatory ergonomics programs [59–61]. The questionnaire was administered to each participant immediately prior to the initial ELC test session. The physical demand characteristics rating based on the 5-level Dictionary of Occupational Titles system for each participant's usual and customary job was derived after the ELC test performance data had been submitted by blind review of the completed questionnaire. This review was conducted by a data analyst using a simple protocol that confirmed consistency among responses to the 12 items in the questionnaire. When consistency was demonstrated, the response to item 12 was taken as the participant's physical demand characteristics level. When consistency was not demonstrated, the questionnaire was determined to be "inconsistent" and this datum was not entered in the participant's database.

3.4.5. Lift capacity evaluation

The ELC was administered in the standard manner by a wide variety of healthcare professionals who were participating in the ELC certification program. In this program, each applicant is trained to use the ELC protocol in either a one-day in-person workshop or in a 7-hour self-study program with the same printed and audiovisual materials including an examiner's manual [37–39]. After training, each applicant for certification is required to pass a written exam on the test procedures and safeguards before testing 5 healthy normal volunteers on a test-retest basis. These test records

1. How many hours per week do you usually work on this job? .... __________
2. Work postures: Fill in the hours per day that you usually work in these postures.

	Max at 1 Time	Total Hours
Sitting down (office, car, truck, etc.)...	___________	___________
Standing (at a counter, at a machine, etc.)....................................	___________	___________
Walking while carrying less than 20 pounds..................................	___________	___________
Walking while carrying more than 20 pounds	___________	___________

Use this rating scale to answer questions 3 – 11:

(A)	(B)	(C)	(D)	(E)
not at all (never)	rarely (less than 1/10 of the time)	occasionally (less than 1/3 of the time)	frequently (1/3 to 2/3 of the time)	constantly (more than 2/3 of the time)

3. How often do you have to kneel or crawl in your work?.. __________
4. How often do you have to lie down (for example, as an auto mechanic) in your work?. __________
5. How often do you have to squat or bend or twist at the hips in your work?.................. __________
6. How often do you do work which caused vibrations to your whole body? .... __________
7. How often do you have to operate a foot pedal?.. _________
8. On this job, how often do you lift:
   10 to 20 pounds: .... __________
   20 to 50 pounds: .... __________
   50 to 100 pounds: .... __________
   More than 100 pounds:.. __________
9. On this job, how often do you carry:
   10 to 20 pounds:.. __________
   20 to 50 pounds:.. __________
   50 to 100 pounds:.. __________
   More than 100 pounds: .... __________
10. How often do you jump from one level to another?.. __________
11. About how often per day do you climb steps on this job? .... __________
12 Five ratings of physical demands are below. Please mark the one that best describes your job.

( )	Sedentary	Sometimes I stand or walk, but I sit down most of the time. Occasionally, I lift up to a 10-pound load.
( )	Light	Any of the following: - I walk or stand more than one third of the time - I often lift up to 10 pounds - I sit down, but often work foot pedal
( )	Medium	I often lift up to 20 pounds, or sometimes up to 50 pounds.
( )	Heavy	I often lift up to 50 pounds, or sometimes up to 100 pounds.
( )	Very Heavy	I often lift over 50 pounds, or sometimes over 100 pounds.

Fig. 2. Job demands questionnaire.

were submitted for review to assure adherence to standardized test procedures and understanding of the decision criteria to determine maximum acceptable weight (MAW). The data from the certification program were used in the current study. In the standard ELC administration, each participant's heart rate is continuously monitored and documented. Maximum acceptable weight is measured in six separate subtests for each participant, as depicted in Table 4. Following the standard ELC protocol, standing rest breaks of two minutes were provided between subtests. The measure of lift capacity was the Maximum Acceptable Weight (MAW) for each of the six subtests. Follow-up testing was conducted mean (SD) 5.8 (5.9) days after the initial testing (range 1 to 70 days), using the same testing protocol. The MAW for each subtest in the initial test

Table 5
Subjects' maximum acceptable weight (kilograms) across all subtests

	Male				Female			
	Test		Retest		Test		Retest	
Subtest	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	33.74	7.74	33.88	7.82	19.54	5.79	19.89	6.13
2	38.50	8.26	38.33	8.29	24.70	7.18	24.56	7.36
3	34.24	7.80	34.34	7.77	19.29	5.82	19.67	5.80
4	27.74	6.83	28.20	6.97	15.82	5.07	16.34	5.05
5	31.26	7.93	31.77	7.69	19.44	6.43	20.03	6.94
6	26.39	7.28	27.07	6.91	14.86	5.20	15.51	5.09

Table 6
Subjects' response to retest

	Subtest #1		Subtest #2		Subtest #3		Subtest #4		Subtest #5		Subtest #6	
Source	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Retest	5.28	0.022	0.68	0.408	11.79	0.001	10.51	0.001	3.46	0.063	0.94	0.331
Retest × Age	1.30	0.254	2.55	0.110	4.95	0.026	0.50	0.481	0.07	0.785	5.07	0.024
Retest × Sex	3.04	0.082	0.02	0.895	6.59	0.010	0.27	0.605	0.34	0.560	0.00	0.962

Table 7
Test-retest $ICC_{(2,1)}$ maximum acceptable weight; 95% confidence intervals

Subtest	ICC	Lower bound	Upper bound
1	0.925	0.920	0.929
2	0.926	0.921	0.930
3	0.938	0.934	0.941
4	0.910	0.991	0.915
5	0.865	0.857	0.872
6	0.890	0.884	0.896

administration was used as the datum for the normative data analyses in this study.

3.4.6. Symptom follow-up

Immediately prior to follow-up testing, each participant completed a questionnaire that screened for any symptoms or injuries that were encountered during the initial occasion of testing. If symptoms were reported, the questionnaire was reviewed by the evaluator before proceeding to the retest.

4. Data analysis

Analysis of variance and repeated measures analysis of variance were used to examine group-wise differences among participants. The Intraclass Correlation $ICC_{(2,1)}$ procedure was used to examine reliability and stability of the data. Frequency analyses for each subtest within each gender and age group were used to determine normative data. Significance level was set at $p = 0.01$. Data were maintained in Excel^{TM} spreadsheets and analyzed with SPSS Statistics^{TM} version 19. Guidelines regarding interpretation of correlation coefficients follow Portney and Watkins [62], in which coefficients below 0.50 represent poor reliability, coefficients from 0.50 to 0.75 indicate moderate reliability, and values above 0.75 indicate good reliability.

5. Results

In this phase of the ELC Certification program, 912 evaluators contributed 4,443 complete test-retest data sets. While most of the evaluators were occupational therapists, physical therapists, and kinesiotherapists, other healthcare professionals such as medical physicians, chiropractors, athletic trainers, registered nurses, vocational evaluators, and rehabilitation psychologists were also involved in the training and certification program.

5.1. Safety

Overall, the ELC test was administered to 4,443 participants. No serious adverse events were reported. Side effects were rare, typically minor, and temporary. Of the 4,443 participants who began the initial testing, 4,440 (99.9%) were able to complete the first three subtests in the battery and 4,375 (98.5%) were able to complete all six subtests. Of the 68 participants who did not complete the full battery, 39 completed all but Subtest #6. Typical reasons for not completing all six subtests were that the participant's heart rate did not recover sufficiently within the time allowed to permit continuing or that maximum acceptable weight on either of the frequent subtests was too low to al-

Table 8
Lift capacity (kilograms) by gender and age group

	Age (years)	Sub-test 1 Mean	SD	Sub-test 2 Mean	SD	Sub-test 3 Mean	SD	Sub-test 4 Mean	SD	Sub-test 5 Mean	SD	Sub-test 6 Mean	SD
Male	15 < 30	34.4	7.4	39.1	7.9	35.0	7.6	28.3	6.6	32.0	7.5	27.0	7.3
	30 < 40	33.7	7.7	38.5	8.2	34.1	7.6	27.6	6.8	31.1	8.0	26.3	7.3
	40 < 50	33.4	7.9	38.1	8.5	33.5	7.8	27.6	7.2	30.8	8.5	25.3	7.4
	50 < 60	28.9	8.5	33.5	9.2	29.5	8.8	23.7	7.4	25.7	8.8	20.5	8.8
	60+ yrs	25.1	6.9	31.5	10.3	26.6	8.3	20.2	7.2	21.4	9.7	17.9	7.0
Female	15 < 30	19.8	5.7	25.3	7.0	19.6	5.7	15.9	5.0	19.9	6.3	15.0	5.1
	30 < 40	19.9	5.7	25.1	7.1	19.6	5.7	16.3	5.2	19.8	6.4	15.1	5.6
	40 < 50	18.3	5.7	22.3	7.3	17.6	5.9	14.7	5.2	17.4	6.5	13.3	5.5
	50 < 60	16.9	6.0	20.6	7.1	16.5	6.3	13.2	5.7	15.6	6.7	12.3	6.4
	60+ yrs	17.4	5.2	20.0	7.5	16.5	5.5	13.2	4.6	15.3	5.6	12.2	4.5

Table 9
Lift capacity adequacy: Comparing lift capacity with job demands

	PDC	Job demand Sedentary	Light	Medium	Heavy	Very heavy	Total	% Inadequate
Lift capacity	Sedentary	11	22	6	1	0	40	72.50%
	Light	39	22	11	0	0	72	15.28%
	Medium	255	239	75	4	2	575	1.04%
	Heavy	595	820	294	26	8	1743	0.46%
	Very heavy	242	387	206	66	19	920	0.00%
	Total	1133	1471	586	96	29	3350	1.40%

Table 10
Lift capacity across job demand categories

	PDC	N	Mean	SD	Minimum	Maximum
Job demand	Sedentary	1142	17.6	8.0	0	45.5
	Light	1490	19.0	8.0	0	50.0
	Medium	592	21.2	8.8	0	52.3
	Heavy	97	26.5	7.8	0	45.5
	Very heavy	29	27.9	8.8	9.1	40.9
	Total	3350	19.2	8.4	0	52.3

low Subtest #6 to be undertaken. Another 14 participants reported symptoms of pain that caused the evaluator to stop the test before its conclusion. All of these participants returned for retest. On return, each completed the symptom follow-up questionnaire and none reported that the pain had indicated an injury; all pain had resolved without medical intervention other than over-the-counter non-steroidal anti-inflammatory medication or acetaminophen.

5.2. *ELC Test performance*

A series of one-way analysis of variance based on gender demonstrated a significant difference in terms of maximum acceptable weight for all six subtests in the ELC battery on both the test and retest. Men consistently demonstrated greater capacity than women on all tests on both testing occasions (all $p < 0.0001$) (Table 5).

Repeated measures analysis of variance of each subtest based on gender with age as a covariate confirmed significant effects for age and gender (all $p < 0.001$). There is also a significant effect for retest on Subtest #3 and Subtest #4, with a significant interaction between retest and gender on Subtest #3 (Table 6).

5.3. *Reliability*

The results of separate analyses using the $ICC_{(2,1)}$ Shrout and Fleiss [64] convention are presented in Table 7.

5.4. *Validity*

Performance in the ELC subtests was studied in terms of both age and gender, the results of which are presented in Table 8.

Main effects for both age group and gender are found for each of the subtests, (all $p < 0.001$). Across all subtests, men were stronger than women, and younger subjects were stronger than older subjects.

An important use of the ELC data is to determine the adequacy of a person's lift capacity for his or her job's demands. In the current research, this was addressed by comparing the participant's responses to the job demands questionnaire administered prior to the initial ELC test with his or her lift capacity as measured by

Table 11
Lift capacity normative data (kilograms)

		Male				Female			
	Percentile	15 < 30 yrs	30 < 40 yrs	40 < 50 yrs	50 < 60 yrs	15 < 30 yrs	30 < 40 yrs	40 < 50 yrs	50 < 60 yrs
Subtest 1	90th	45	45	45	41	27	27	27	23
	75th	41	41	41	36	23	23	23	18
	50th	36	36	36	27	18	18	18	18
	25th	27	27	27	23	14	16	14	14
	10th	23	23	23	18	14	14	9	9
Subtest 2	90th	45	45	45	45	36	32	32	32
	75th	45	45	45	41	32	32	27	27
	50th	41	41	41	36	27	27	23	18
	25th	36	32	32	27	18	18	18	14
	10th	27	27	27	23	18	14	14	9
Subtest 3	90th	43	43	43	41	27	27	25	25
	75th	41	39	39	36	23	23	20	20
	50th	36	34	34	30	18	20	18	16
	25th	32	30	27	23	16	14	14	14
	10th	25	25	23	18	14	14	9	9
Subtest 4	90th	36	34	34	32	23	23	23	20
	75th	32	32	32	27	18	20	18	16
	50th	30	27	27	25	16	16	14	14
	25th	23	23	23	18	14	14	11	9
	10th	20	18	18	14	9	9	9	7
Subtest 5	90th	41	41	41	36	27	27	27	25
	75th	36	36	36	32	25	25	23	18
	50th	34	32	32	25	20	20	18	16
	25th	27	27	25	18	16	16	14	9
	10th	23	20	18	16	11	11	9	7
Subtest 6	90th	34	34	34	32	23	23	20	20
	75th	32	32	32	27	18	18	16	16
	50th	27	27	27	20	16	16	14	11
	25th	23	23	20	16	11	11	9	9
	10th	18	16	16	9	9	9	7	5

the initial ELC Subtest #6. The five-level Physical Demand Characteristics of work system [57] was used to classify both (Table 9).

In Table 9, the shaded cells indicate mismatches in which the participant's lift capacity was inadequate for the job's demands. In this set of 3,350 participants, 1.4% of the participants were found to have inadequate lift capacity. Another way to look at these data is on a group-wise basis with analysis of variance, considering participants' lift capacity grouped by the PDC level of their jobs (Table 10).

A one-way analysis of variance demonstrated significant differences among the job categories in terms of lift capacity as demonstrated in Subtest #6 ($F_{4,3310} = 50.43$, $p < 0.001$). As job demands increase, the average lift capacity of the participant in the job increases, reflecting the combined effects of job participation in developing and maintaining lift capacity and the selection of stronger persons into the more demanding jobs.

Normative data were based on frequency analyses and are presented as percentile rankings of MAW for each subtest across each gender and each age group in Table 11.

6. Discussion

The ELC is used within the context of professional guidelines as well as numerous state and federal laws. Guidelines for testing have been published by the American Psychological Association [36], the American Physical Therapy Association [64], and the American Academy of Physical Medicine and Rehabilitation [65]. There is agreement among these professional entities that use of a test must be undertaken within the context of these standards:

Safety – Given the known characteristics of the evaluee, when used properly the test should not be expected to lead to injury. This study demonstrated that the ELCcan be administered safely by trained professionals in several health care disciplines.

Reliability – Reliability is the dependability of the test over time and between evaluators. This research demonstrates good reliability of the ELC on a test-retest basis for all ELC subtests.

Validity – Validity is the extent to which the measure of performance is dependably related to a criterion [36,64,65]. The use of the ELC to determine adequacy for the evaluee's self-reported physical demands of work, to reflect age and gender differences, and to be consistent with ergonomic demands posed by vertical lifting range and lift frequency has been demonstrated in this study.

Normative data for hand strength and physical fitness are useful in health care and medical science. In exercise science, there has been an interest in using standardized reliable measures to collect age-relevant normative performance data [66]. Without standard measures, it was not possible to communicate energy costs of aerobic exercise in common language. Normative data were developed through standardized testing protocols, which when repeated verified their reliability and validity [66,67]. The American College of Sports Medicine used these data to recommend different levels of exercise to achieve and maintain health [68]. The current study's measure of lift capacity provides a useful addition to the constellation of normative data available to assess healthy adults.

The age-based differences in lift capacity in the ELC normative data are consistent with those reported in the classic paper by Fisher and Birren [69] and many others, indicating that strength appears to peak in the late 20's and decreases slowly with maturity. This also compares well with several studies from the field of ergonomics [70–74], and helps to emphasize the importance of attending to age-wise and gender-based differences in lift capacity.

Comparison of the current findings to the work of other researchers who have studied the maximum acceptable weight of lift to develop safe work standards is difficult because these studies [75–80] have not included the effects of age and body mass and are usually based on small sample sizes, with subjects who are young or in early middle age and of average weight. Such studies do not allow an opportunity to take a look at age effects, the combination of age and gender effects, or the effect of body mass, all of which have been demonstrated to be important predictors of lift capacity [20].

As the workforce ages, becomes gender-balanced, and experiences increased body mass per worker, these factors must be included in models that are used to design safe jobs [81,82]. Normative data of all types are useful in industrial settings to design jobs that are likely to be safely performed by people of all ages and both genders. Data provided in this study may be useful in that regard.

7. Summary

This study of lift capacity as assessed by the ELC of healthy normal volunteers demonstrated safety in use of the test across a wide range of health care and rehabilitation professionals who have participated in formal training. Analysis of the data with regard to reliability on a test-retest basis across each of the six subtests in the battery demonstrated good reliability for both lift capacity measures. Validity for the adequacy of lift capacity in terms of the self-reported physical demands of the participant's usual and customary job was established. The effects of age and gender that are reported in the scientific literature also were found in this study. Given these effects, normative data from the test session are presented separately across gender for each age category and each sub-test. Retest normative data were not presented because most applications of ELC test data will be with persons who are naïve to the test.

This is the first large-scale study of lift capacity to include simultaneous examination of the test-retest reliability and validity of test performance, which is an obvious strength; the normative data can be confirmed as stable over time and related to self-reported physical demands of the usual and customary job.

In terms of limitations, this study used a convenience sample, which leads to restriction in use of the data to the age and gender categories that were well-represented. Additionally, most of the participants in the study were from North America, which presents another restriction on the use of this study's normative data.

Disclosure

Dr. Matheson has a proprietary interest in the company that developed and licenses the EPIC Lift Capacity test, and receives financial benefits from its use. Neither Dr. Verna nor Dr. Dreisinger, nor Dr. Mayer nor Mr. Leggett have a proprietary interest in the EPIC Lift Capacity test, or receive financial benefits from its use.

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