

# **Contribution of Aerobic Fitness and Back Strength to Lift Capacity**

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**Structured Abstract**

**Study Design** – This study used a concurrent validation design with 45 healthy female participants.

**Objectives** – The objective of this study was to measure the relative contributions of aerobic capacity and back strength to lift capacity.

**Summary of Background Data** – This was the first concurrent study of the relationships among spinal strength, aerobic capacity, and lift capacity. Previous research has demonstrated moderate to strong relationships between spinal strength and lift capacity and between aerobic capacity and lift capacity.

**Methods** - Multiple regression techniques were used on reliable and valid measures of each construct to study the individual and joint contributions of spinal strength and aerobic capacity to lift capacity.

**Results** – Both spinal strength and aerobic capacity make significant independent contributions to lift capacity, accounting for 11% and 27% of the variance, respectively. Taken together, the predictive power of these variables on lift capacity accounts for 43% of the variance.

**Conclusions** – Lift capacity is dependent on both back strength and aerobic capacity. It may be inappropriate to use lift capacity as an indicator of the severity of spinal impairment in a disability determination system without taking into account the individual's aerobic capacity.

Treatment that is intended to improve the lift capacity of persons with spinal impairment should anticipate that both improvement in back strength and aerobic capacity will improve lift capacity.

**Key Words** – spinal impairment, functional limitation, lift capacity, back strength, aerobic capacity.

**Key Points** – 1. Both back strength and aerobic capacity make independent contributions to lift capacity. 2. Back strength and aerobic capacity make joint contributions to lift capacity that are greater than either factor's contribution alone. 3. Treatment and evaluation of persons who have impaired lift capacity should address both the person's back strength and his or her aerobic capacity.

**Mini Abstract**

This concurrent study of the contributions of back strength and aerobic capacity to lift capacity found that each factor makes an independent contribution. Jointly, the factors account for a substantial portion of the variance in lift capacity.

**Introduction**

Functional limitation of lift capacity is the central focus of bureaucratic disability determination in many jurisdictions, including the United States' Social Security Administration <sup>24</sup>, the United States Railroad Retirement Board <sup>18</sup>, and the California workers' compensation system <sup>9</sup>.

Information about the limitation of lift capacity experienced by the applicant as a result of medical impairment determines whether or not disability benefits are provided in the Social Security Administration system. For the Railroad Retirement Board and the California workers' compensation system, limitation of lift capacity also affects the extent of these benefits. The use of lift capacity as a central construct in disability determination indicates that, of all the functional consequences of spinal injury, decrements in lift capacity are among the most important. When lift capacity decrements are used in these systems as an indicator of spinal impairment, their use assumes that lifting decrements are primarily dependent on spinal impairment and proportionally reflect the degree of impairment. How correct is this assumption? Is it appropriate to not consider the effect on lift capacity of factors such as the aerobic fitness of the spinal-impaired worker? In a comprehensive review of the state of research in the United States, the Institute of Medicine <sup>12</sup> reports "to date no studies have systematically reported on the relationship of specific impairments to lifting functional limitations." (Ch. 5 Pg.16) Although intuitively we understand that musculoskeletal spinal impairment limits the patient's ability to lift, how much of this is attributable to actual decrements in spinal function, and how much is attributable to other factors, such as aerobic capacity?

The scientific literature provides information about some aspects of the relationships among aerobic capacity, lumbar strength, and lift capacity, but to this point in time there has not been a concurrent study of these relationships. One study<sup>25</sup> reported that there is a high correlation ( $r = 0.96$ ) between isometric lumbar extension strength and functional lifting capacity in healthy young males and females. Bevier and colleagues<sup>3</sup> found that isometric back extensor strength and aerobic capacity are significantly correlated in males ( $r = 0.47$ ), but not in females. Petrie and associates<sup>17</sup> concluded that in pre-menopausal females, isometric back strength is significantly correlated to measures of physical activity, but not to aerobic capacity. In several studies of the relationship between aerobic capacity and lift capacity, dependable relationships are generally found, although the method of measurement of aerobic capacity is quite important.<sup>20</sup> Measures of aerobic capacity that involve the upper extremities alone, such as with an arm-crank dynamometer are not as closely related to lift capacity as when aerobic capacity is measured on a treadmill. The optimum method is to measure aerobic capacity during the lift capacity test, with stable relationships found between the measures. With regard to the development of lift capacity, it is unclear whether the development of aerobic capacity alone or in concert with the development of back strength is optimum. Research has demonstrated that progressive resistance training improves the amount of work that a subject can perform in a lifting task, although aerobic capacity does not improve.<sup>19</sup>

The purpose of this basic research project is to determine the relative contributions to lift capacity made by back strength and aerobic capacity. In addition to providing guidance to bureaucratic disability determination systems, the results of this study may guide treatment for spinal impairment. In recommending treatment for spinal impairment, should the focus be on

improving back strength or on general fitness? Knowledge about the relative contributions of these variables will assist health care professionals to better understand how to improve lift capacity so that return to work can be facilitated, disability can be minimized, and recurrence of injury avoided. Additionally, such information may be useful in pre-placement employee screening. The pioneering work of Cady and colleagues<sup>7,8</sup> demonstrated the significance of fitness to subsequent safety on the job. Are the contributions of lumbar strength to lift capacity as important as the contributions made by aerobic capacity? If back strength or aerobic capacity determines lift capacity, pre-placement screening of the applicant's status on these variables may be useful.

## **Materials and Methods**

### ***Design***

This is a concurrent study of 45 healthy adult females in which separate measures of the two independent variables, aerobic capacity and lumbar strength are compared with a measure of lift capacity through the use of stepwise multiple regression techniques. Testing of each subject occurred at the University of California San Diego, Orthomed facility on two days, separated by approximately 72 hours to allow for any residual soreness or fatigue to subside. Using a coin toss for randomization, subjects were randomly assigned to the lumbar strength test and lift capacity test on one day and to the aerobic capacity test on the other day.

*Variables*

Lumbar Strength – Each subject’s voluntary maximum isometric lumbar extension strength was evaluated using a lumbar extension dynamometer (MedX, Ocala, FL), which has been shown to be ‘highly reliable and specific for the quantification of isometric lumbar extension strength through a 72 degree arc of lumbar extension’<sup>10</sup> (pg. 293). The variable for this construct is the mean value in Newton-meters of torque for all seven positions of lumbar flexion for each subject.

Aerobic Capacity – Direct determination of oxygen consumption is the standard measure to the person’s response to exercise<sup>1</sup>. It requires the use of breathing valve for collection and analysis of the subject’s air that is expired during exercise. Each subject’s maximal oxygen uptake was evaluated using a treadmill test that employed the Bruce protocol<sup>6</sup> to exercise the subject to volitional fatigue. The Bruce protocol is the most widely used treadmill protocol<sup>1</sup> in the United States. This protocol requires involving a change in speed and grade every three minutes. The variable for this construct is maximum oxygen consumption relative to the individual’s body mass, expressed as  $O_{2Max} \bullet ml^{-1} \bullet min^{-1}$ .

Lift Capacity - Lift capacity was measured by the EPIC Lift Capacity (ELC) test, operationally defined as the maximum acceptable weight that the evaluatee is able to lift “on a safe and dependable basis, eight to twelve times per day”<sup>13</sup>. The ELC is a battery of six related tests of dynamic lift capacity, representing three different vertical ranges with two frequencies of repetition. The ELC has been demonstrated to be a safe, valid, and reliable method for

determining lift capacity<sup>14-16</sup>. The variable for this construct is maximum acceptable weight of lift, expressed in kilograms.

### ***Subjects***

This study employed a convenience sample comprised of 45 healthy female volunteers, mean (SD) 31.2 (7.4) years of age. Most were students, health care professionals or office workers. Prior to participation in the study, each subject completed and signed an informed consent document that had been approved by the University of California San Diego institutional review board. Subsequently, each subject completed a medical history form. Affirmative responses to questions on the medical history form that indicated cardiovascular signs and symptoms precluded participation in the study. No subjects were excluded on that basis. Resting heart rate and blood pressure were measured with the subject seated at rest. No subjects were excluded due to elevated resting heart rate (> 90 bpm) or hypertension (> 159/100 Hg). Height and weight were based on subjects' response to the medical history form. Descriptive data are presented in Table 1.

Insert Table 1 Here

All descriptive variables were normally distributed in this sample. Based on reported weight and height data, none of the subjects was obese.

*Procedures*

**Relative Aerobic Capacity Evaluation** - A maximal treadmill test that employed the Bruce protocol <sup>6</sup> was used to exercise each subject to volitional fatigue. A Quinton Q4500 treadmill and monitor were used for this test. The subject was prepped according to the Mason-Likar 12 lead. The subject was fitted with the Hans Rudolph two-way non-rebreathing mask that allowed for the collection of expired gases. Throughout the test, the subject's EKG was monitored and oxygen consumption was measured. Every minute the subject's rating of perceived exertion was recorded, according to the Borg 0-10 rating of perceived exertion scale. <sup>4,5</sup> All subjects were encouraged to give a maximal effort. At the end of each stage, each subject was asked to indicate if she was not able to progress to the next stage. The test was terminated when the subject indicated that she was unable to proceed. The measure of aerobic capacity was the relative VO<sub>2</sub> maximum, expressed in milliliters of oxygen per kilogram of body mass per minute.

**Back Strength Evaluation** - Each subject's maximum voluntary isometric lumbar extension strength was evaluated using a lumbar extension dynamometer at seven angles of lumbar flexion (72, 60, 48, 36, 24, 12, and 0 degrees) using standard procedures <sup>10</sup>. Prior to the test, a dynamic warm-up exercise was performed. The dynamic exercise consisted of 10 full-range repetitions of lumbar extension with resistance of 40 foot-pounds. Subsequently, a three-angle sub-maximal isometric test was administered for instruction and practice. A brief rest period followed, after which formal testing was undertaken. During the test, after each maximal isometric contraction, a thirty-second rest period was provided before testing at the next angle. Each subject was reminded of the instructions prior to the test at each of the seven angles of lumbar flexion. After completing the lumbar strength evaluation, each subject rested in a self-selected seated or

standing posture for 15 minutes before the lift capacity evaluation was undertaken. The measure of back strength was the mean peak torque of all seven angles of lumbar flexion, expressed in Newton-meters.

**Lift Capacity Evaluation** - The EPIC lift capacity (ELC) test was administered in the standard manner<sup>13</sup>, except that each subject wore headgear that consisted of a Hans Rudolph two-way non-rebreathing mask<sup>1</sup>, allowing expired gases to be collected and analyzed. Each subject's heart rate was continuously monitored. Maximum acceptable weight was measured in six separate sub-tests for each subject, representing different combinations of vertical range and frequency of lift, as described in Table 2.

Insert Table 2 Here

Following the standard ELC protocol, standing rest breaks of a minimum of two minutes were provided between sub-tests. The measures of lift capacity were the maximum acceptable weights for each of the six sub-tests, as well as the mean of the sub-tests taken together, expressed in kilograms of mass.

## **Results**

All subjects completed all of the tests without injury. Relative aerobic capacity data are presented in Table 3, lumbar extension strength data in Table 4, and lift capacity data in Table 5.

Insert Table 3 Here

Most subjects continued in the treadmill test to predicted maximum heart rate levels. Relative aerobic capacity measured by  $VO_{2max}$  performance indicates that these subjects are above average based on age norms <sup>23</sup>.

Insert Table 4 Here

Based on the normative data for women in this age group, this sample has an average level of lumbar extension strength. Across the sub-tests, the mean value for lumbar extension strength varies in a manner that is consistent with published studies <sup>10,11</sup> and increases linearly as the angle of lumbar flexion increases.

Insert Table 5 Here

Across the sub-tests, the mean value for lift capacity varies in a manner that is consistent with published studies <sup>14,15</sup> and indicates that this sample has somewhat better lift capacity than other women do in this age group. Across the sub-tests, the mean values for aerobic demand vary with published studies <sup>14</sup>. The relative aerobic demand dependably increases as the amount of work in each subtest increases, from approximately one-quarter of the individual's aerobic capacity on average to approximate one-half of each subject's aerobic capacity.

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<sup>1</sup> Hans Rudolph, Inc. , 7200 Wyandotte, Kansas City, Missouri 64114 USA

The relationships among aerobic capacity, lumbar strength, and lift capacity were studied through the use of stepwise multiple regression analyses for each ELC sub-test and for overall ELC test performance.  $VO_2$  maximum from the maximal treadmill exercise test was the measure of aerobic capacity, while the mean of the trials at each position on the lumbar extension dynamometer was the measure of lumbar strength. Dependent variables were maximum acceptable weight for each ELC sub-test, and the average of all ELC sub-tests. The results of each analysis are presented in Table 5.

Insert Table 6 Here

The data presented in Table 6 indicate that aerobic capacity and back strength provide explanatory power for lift capacity. Both maximal oxygen consumption and back strength made independent contributions to predicting lift capacity, with the multiple regression coefficients ranging from  $R = .582$  to  $R = .644$  (all  $p < .01$ ) across the six ELC sub-tests.

## **Discussion**

This is the first study that has considered aerobic capacity, back strength and lift capacity concurrently. The results indicate that aerobic capacity and back strength make a substantial joint contribution to lift capacity, explaining 34% to 41% of the total variance. Additionally, both aerobic capacity and back strength make important independent contributions to lift capacity. Several research studies have demonstrated the relationship between improved aerobic capacity and increased lift capacity.<sup>2,22</sup> Separate studies have found that a relationship between fitness and work capacity and safety in physically demanding jobs.<sup>7,8</sup> Progressive resistance

training does not appear to produce an increase in aerobic capacity.<sup>19</sup> Of importance to treatment of persons with spinal impairment, these results support the complimentary use of fitness training and back strength training in treatment programs. This combination will be especially important when improvement of lift capacity is a goal, as it is often with patients whose benefits from some disability determination systems are related to degree of functional lifting limitation.<sup>9,18</sup> If return to work that involves lifting after a spinal injury is a pertinent goal, these results indicate that the use of either intervention alone is likely to be less effective than both interventions. To appropriately address the efficacy of such a treatment approach, a randomized clinical trial comparing the two approaches in a population of persons with spinal impairments is necessary.

With regard to functional capacity evaluation, the current results indicate that tests of aerobic capacity and back strength are both useful in work screening situations in which lifting is an important job demand. Measurement of either may not be substituted for measurement of lift capacity. This is consistent with earlier research<sup>20</sup> that found substantial inter-subject difference in the relationship between aerobic capacity and lift capacity, when the measure of aerobic capacity differed substantially from lifting tasks. This study hypothesized that skill, technique, and morphological differences contributed to differences between people and recommended measurement of aerobic capacity during the lift capacity test. When lifting is an important job demand, baseline measures of both variables collected immediately before and during a lift capacity test would be useful in the event that medical impairment due to injury or disease is subsequently experienced.

The availability of information about both aerobic capacity and back strength may be of value to occupational medicine physicians who are involved with medical oversight in the transfer of workers from one job to another. Previous research has shown that exercise heart rate can accurately predict energy cost of lifting tasks based on a previously defined heart rate to aerobic capacity relationship.<sup>21</sup> Given additional information about the back strength of the individual, perhaps the use of exercise heart rate to predict lift capacity would be improved. Research to address this relationship is needed.

The Institute of Medicine (IOM) report on “Enabling America”<sup>12</sup> presents the current state of rehabilitation science in order to develop a national agenda for research. This report describes spinal dysfunction and back pain as “the leading causes of disability” in the United States. (pg. 5:16) Among the recommendations, the IOM report includes “any test that could be used to relate strength, range of motion, and other impairments to lifting functional limitations would provide an important improvement to rehabilitation strategies.” (Ch. 5 Pg.16) Although the concurrent design of this study and the use of healthy normal subjects does not allow attribution of lift capacity limitations to impairment of aerobic capacity or impairment of back strength, these results suggest that such studies will be possible. The EPIC Lift Capacity test may be useful in a research project of persons with either spinal impairment or aerobic impairment that examines the attribution of lift capacity limitations to such impairments.

### **Summary**

This study of the contributions made by aerobic capacity and back strength to lift capacity in a sample of healthy normal females demonstrated that the three variables are closely related, and

that both aerobic capacity and back strength making significant independent and joint contributions to lift capacity. The results of the study set the stage for research concerning the effect of impairment of aerobic capacity and back strength on lift capacity. Given the prevalence of back injuries and the importance of lift capacity in many disability determination systems, such research will be valuable. These results also suggest a need for research concerning the effect on lift capacity of treatment programs that emphasize each variable separately in comparison with a treatment program that integrates the development of both aerobic capacity and back strength.

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**Table 1.** Subjects' descriptive data (n = 45).

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Variable	Mean	SD	Low	High
Age (years)	31.2	7.4	19	48
Height (cm)	164.4	6.9	150	175
Weight (kg)	61.4	7.6	45	79
Resting Heart Rate (bpm)	68.7	11.2	47	84
Resting Systolic BP (mm Hg)	114.8	9.5	100	136
Resting Diastolic BP (mm Hg)	75.3	8.0	58	86

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**Table 2.** Order of EPIC Lift Capacity sub-tests.

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Sub-Test	Vertical Range	Frequency
Sub-Test 1	Waist to Shoulder	1 rep / cycle
Sub-Test 2	Floor to Waist	1 rep / cycle
Sub-Test 3	Floor to Shoulder	1 rep / cycle
Sub-Test 4	Waist to Shoulder	4 reps / cycle
Sub-Test 5	Floor to Waist	4 reps / cycle
Sub-Test 6	Floor to Shoulder	4 reps / cycle

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**Table 3.** Aerobic capacity on maximum treadmill test (n = 45).

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Variable	Mean	SD	Low	High
Maximum Heart Rate (beats • min <sup>-1</sup> )	187.56	9.3	170.0	203.0
VO <sub>2max</sub> (ml • kg <sup>-1</sup> • min <sup>-1</sup> )	42.55	7.6	26.3	60.6
Volume Expired (l • min <sup>-1</sup> )	98.67	20.2	53.2	150.4
Maximum Rating of Perceived Exertion	8.02	1.4	5.0	10.0

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**Table 4.** Lumbar strength on isometric dynamometer (n = 45).

Sub-Test	Mean <sup>a</sup>	SD	Low	High
0° Lumbar Flexion	46.98	18.0	11.4	110.4
12° Lumbar Flexion	54.96	17.2	10.4	97.7
24° Lumbar Flexion	61.59	19.3	20.0	108.6
36° Lumbar Flexion	65.42	20.7	16.4	115.0
48° Lumbar Flexion	69.02	21.0	25.4	115.9
60° Lumbar Flexion	74.85	18.9	41.8	123.6
72° Lumbar Flexion	82.60	20.1	45.4	128.2
Mean of All Sub-Tests	65.06	18.3	27.3	111.4

<sup>a</sup> Measured in Newton-meters of torque.

**Table 5.** Lift capacity on progressive lift capacity test (n = 45).

Sub-Test	<u>Maximum Lift</u>				<u>Percent of VO<sub>2</sub> Max</u>			
	Mean <sup>a</sup>	SD	Low	High	Mean	SD	Low	High
Sub-Test 1	20.50	5.7	9.1	32.0	27%	8%	11%	44%
Sub-Test 2	25.96	6.3	13.6	36.4	29%	9%	12%	51%
Sub-Test 3	20.55	5.4	11.4	31.8	33%	9%	19%	59%
Sub-Test 4	17.93	4.6	9.1	27.3	36%	11%	20%	70%
Sub-Test 5	21.87	5.6	11.3	31.8	45%	9%	23%	67%
Sub-Test 6	17.07	4.4	9.1	25.0	49%	11%	32%	77%

<sup>a</sup> Measured in Kilograms.

**Table 6.** Relationship of aerobic capacity and back strength to lift capacity.

Epic Lift Sub-Test	Multiple R	Aerobic Capacity	Lumbar Strength
Sub-Test 1	.586	.457	.315
Sub-Test 2	.590	.494	.267
Sub-Test 3	.582	.401	.376
Sub-Test 4	.638	.491	.351
Sub-Test 5	.584	.471	.292
Sub-Test 6	.644	.564	.251
Sub-Test Average	.653	.520	.336