Trunk and Lower Extremity Muscle Endurance: Normative Data for Adults

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Abstract

Purpose. The purpose of this study was to establish a gender and age referenced table of normative values for seven standardized tests of trunk and lower extremity muscular endurance.

Subjects. 548 volunteers (276 women and 272 men) who had not missed work in the preceding six months due to back or neck pain.

Methods. Experienced therapists followed a standardized protocol to measure subjects' endurance on five isometric and two dynamic endurance tests.

Analysis and Results. For each test, 25th, 50th and 75th percentile scores were determined for 10 age/gender categories.

Conclusion and Discussion. In clinical practice, these tests can be used at intake or as an outcome measure by comparing a patient's scores with the normative percentile data to assess which muscles exhibit dysfunction and to what degree.

Key Words: normative database, muscle endurance, trunk muscles, back pain, percentile, outcome measure, standardized tests

Introduction

Despite trunk and lower extremity endurance being one of several measures routinely used in many clinical evaluations of disability or rehabilitation outcome, the back pain literature contains little data concerning normal endurance capacity of the back and lower extremity muscles. This lack of normative data is a limitation in the quantification of physical function of the spine and is the impetus for this study.

When evaluating muscle performance in the extremities, an examiner can compare the normal and abnormal sides to quantify diminished function.[15] This type of intrinsic control is not available for evaluation of the trunk. To identify alterations of the trunk musculature from "normal", it is necessary to reference a normative database.

With the use of normal endurance values as a baseline, clinicians who treat low back pain are able to determine departures from the norm for particular muscle groups. Whether reduced values are the cause or the result of the problem, identification of insufficient endurance permits the clinician to formulate an active, conservative strategy to restore function and hopefully reduce or eliminate symptoms. Objective quantitative data provide benchmarks for setting specific goals to increase muscle performance capacity and provide outcome measures for evaluating the success of an intervention. Testing at intake to a rehabilitation program provides a baseline measure for which subsequent testing at discharge and/or follow up can be compared, providing an indication of change in physical function over time. Comparing test results to normative percentile data allows for assessment of which muscles exhibit dysfunction and to what degree.

Collection of this objective data can help identify the presence of an impairment. Combining these results with the demands of the work environment and primary activities of daily living can help improve efficiency of the rehabilitation process and evaluate its effectiveness in reducing disability.

Background

Several studies cite inadequate trunk muscle endurance as a possible factor in the etiology of low back pain.[1-4] Some researchers[2,5,6] have postulated that endurance may be more important than "instantaneous muscle strength" in the prevention of back pain.[3] In a study by Jorgensen and Nicolaisen[7], persons with low isometric endurance of the trunk extensors had more serious attacks of low back pain than other individuals with similar trunk extensor strength. The frequency of low-back trouble has been shown to be greater in groups with high fatigability of the trunk extensors and flexors.[1,6] Biering-Sorensen[3] observed that a large isometric endurance capacity in the trunk extensors seemed to prevent first-time occurrence of low back pain. Although these studies have established a clear difference in trunk muscle function between patients with and without low back pain, it is unclear whether low endurance values are the cause or the result of low back pain.

Static endurance of the trunk muscles is important for mechanical support. These muscles must have the ability to sustain an isometric contraction to support the trunk in any given position. Biomechanical studies by Morris et al.[8] showed the importance of the trunk muscles in providing extrinsic spinal stability. The back extensors are particularly important postural muscles.[7] They function to help stabilize the whole vertebral column.[5,9] Because of their anti-gravitational function, the extensors are involved in the majority of human postures and movements. Tension in the abdominal muscles may provide additional stability to the vertebral column by generating tension in the thoracolumbar fascia as well as by increasing intra-abdominal pressure.[10]

Evaluations of muscle performance encompass both strength and endurance. Muscular strength is the amount of tension or force that a muscle or muscle group can voluntarily exert in one maximal effort under prescribed conditions.[11] The definition of muscular endurance is more obscure. It is insufficient to formally define endurance as the capacity to resist fatigue because muscle fatigue as a process is poorly understood. However, capacity to resist fatigue is an important performance dimension for the trunk and lower extremity muscles.Some might argue that it is more biochemical (metabolic) than physiological. The use of terms like "endurance strength"[12] heightens misunderstanding of this complex phenomenon. The relationship between strength and endurance is unclear. At least two studies[9,13] have concluded that there is no significant correlation between the maximum strength and maximum endurance of the trunk muscles. For the purpose of this study, muscular endurance is defined as the ability of a muscle to perform repeated contractions at a certain output (dynamic endurance) or to sustain a contraction over time at a certain level (static endurance).[11]

Specialized dynamometric and surface electromyography devices provide more accurate measures of dynamic trunk muscle performance than less technically driven non-dynamometric methods, but cost-effectiveness of this technology in common clinical application is a concern. In 1994, Rissanen et al.[14] demonstrated that arch-up and sit-up tests had a stronger association to perceived disability than isokinetic tests. The authors concluded that isokinetic testing cannot currently add clinical value to the non-dynamometric methods. The numerical output and fatigue curves generated by the sophisticated back machines presently add little to the determination of an appropriate treatment approach.

This study examines seven standardized trunk muscle endurance tests commonly applied in clinical practice. Each of the non-dynamometric techniques for measurement is simple to perform, safe for non-acute conditions, noninvasive, and inexpensive. Five static tests evaluate the ability of the muscle groups to sustain a contraction, while two dynamic tests determine their capacity to sustain force output during repetitive work at a uniform rate. The primary purpose of this study was to establish a gender and age referenced table of normative values for these endurance tests.

Methods

Subjects

Volunteers for this study were recruited by clinicians over a 12-month period from 20 cities across Canada. All participants signed a standard consent and release form prior to the initiation of testing. As a preliminary screening procedure, subjects were required to complete a physical activity readiness questionnaire (PAR-Q). Individuals who answered affirmatively to three or more questions were excluded.[16] Because the purpose of the study was to create a normative database, no subjects had missed work due to back or neck pain in the preceding six months. Subjects who reported that they regularly exercised at high intensity three or more times per week for a duration of more than 30 minutes per session were considered exceptional athletes and excluded from the study.

The study included 548 people, 272 males and 276 females. The mean age for men was 37.1 years, standard deviation 13.5, and range 19 to 77 years; for women, the mean age was 38.3 years, standard deviation 14.5, and range 19 to 80 years. For the purpose of constructing normative tables, males and females were classified into age groups of approximately 10-year intervals; 19-29, 30-39, 40-49, 50-59 and 60+.

Subjects represented a broad range of approximately 60 different occupations ranging from sedentary to physically demanding. Smokers comprised 12.4% of the sample, 11.4% of males and 13.4% of females. Activity levels varied within each age group, but overall, 64.2% of subjects, 66.2% of males and 62.3% of females, stated that they exercised regularly.

Procedure

Subjects performed seven different endurance tests in random order. Each test was measured once. Participants were individually instructed and supervised by experienced therapists specifically trained in the testing methodology. All tests were demonstrated and preceded by a practice trial.

Using the protocol developed by the Canadian Standard Test of Fitness (CSTF),[17] the upper abdominals were tested for isometric endurance (time in seconds) with the 1/4 sit-up (partial curl-up) test (Figure 1). The isometric chest raise, adapted from Biering-Sorensen,[3] tested the upper back extensor muscles (Figure 2). In each of these tests, the mass of the upper body represented the load. A supine bilateral straight leg raise to an elevation of 30 degrees measured lower abdominal isometric muscle endurance (Figure 3). At an angle of 30 degrees, the lower abdominals are primarily responsible for maintaining the lumbar spine in flexion and the pelvis in a posterior tilt.[18] Lower back extensor endurance was measured using a prone double straight leg raise (Figure 4). The previous two tests use the weight of the legs as the resistive load. A half-squat test measured leg muscle endurance with the individual's body mass as the load (Figure 5). Two isotonic movements repetitions of 1/4 sit-ups and chest raises, measured the dynamic endurance (number of repetitions) of the upper abdominals and the upper back extensors respectively.

The entire battery of tests took approximately twenty minutes per subject to complete. Any subject who was unable to assume the correct starting position or who was subsequently unable to perform a test correctly was given a time score of zero. Appendices 1 through 7 detail starting positions, instructions to examiners and termination criteria for each of the seven tests.

Testing was conducted at multiple locations including clinics, public gymnasiums, work sites and homes. All sites provided a warm room and minimized variables such as excessive noise or visual distractions. Because individuals respond to competition in various ways and these results may not accurately represent normative data, instructors endeavoured to establish a non-competitive atmosphere. Subjects were initially encouraged to give their maximum effort, but the instructors provided no further motivation.

Results were analyzed by gender for all five age groups. Histogram plots were generated to display the data graphically. Based on the shape of the distribution revealed by these graphs, percentiles were deemed a more appropriate format for the normative data than means and SD. For each age-sex category, quartile (25^{th} and 75^{th} percentiles) and median (50th percentile) scores were determined. To examine statistically the magnitude of inter-individual variability, coefficients of variation were calculated.

Results

The analysis of variance revealed no significant interaction between age and gender for any test ($p < 0.01$). There was a significant difference between age groups for both tests of dynamic endurance, i.e. repetitive 1/4 sit-up and repetitive chest raise, as well as for the prone double straight-leg raise ($p < 0.01$), static chest raise ($p < 0.05$) and half-squat ($p < 0.01$). Significant gender differences were present for the bilateral straight-leg raise, repetitive 1/4 sit-up and half-squat tests ($p < 0.01$) and for the repetitive chest raise ($p < 0.05$).

Histogram plots revealed that the distribution of data for both males and females for all seven tests was right-skewed, with the long tail of observations at the upper end yielding large standard deviations (SD). This lack of normality, as well as large variation in individual scores within each of the age/sex categories for the tests in this and previous endurance studies,[5,19,20] provided strong evidence for the use of percentiles rather than means in the normative database. The normative percentile data are presented in Tables 1a through 1g.

Table 1a: Normative Percentile Data in Number of Repetitions for Dynamic 1/4 Sit Up

	Age Groups									
percentile	19-29		30-39		40-49		50-59		60+	
	M	F	M	F	M	F	M	F	M	F
75	57	67	57	50	60	35	50	50	35	25
50	40	41	36	30	33	25	39	31	18	12
25	30	26	20	18	17	14	22	18	9	0

Table 1b: Normative Percentile Data in Number of Repetitions for Dynamic Chest Raise

	Age Groups									
Percentile	19-29		30-39		40-49		50-59		60+	
	M	F	M	F	M	F	M	F	M	F
75	70	70	70	70	70	50	54	50	50	30
50	54	50	50	45	45	33	41	31	26	17
25	35	31	30	30	26	20	22	18	15	4

Table 1c: Normative Percentile Data in Seconds for Static 1/4 Sit Up

Percentile	19-29		30-39		40-49		50-59		60+	
	M	F	M	F	M	F	M	F	M	F
75	81	78	84	84	85	73	120	85	60	62
50	59	56	62	55	59	35	60	38	28	15
25	30	36	28	25	30	18	27	15	16	0

Table 1d: Normative Percentile Data in Seconds for Bilateral Straight-Leg Raise

Percentile	Age Groups: 19-29		30-39		40-49		50-59		60+	
	M	F	M	F	M	F	M	F	M	F
75	51	40	61	36	74	32	58	43	53	22
50	35	20	37	16	44	18	38	19	26	10
25	18	10	20	4	21	5	23	7	2	0

Table 1e: Normative Percentile Data in Seconds for Static Chest Raise

Percentile	Age Groups: 19-29		30-39		40-49		50-59		60+	
	M	F	M	F	M	F	M	F	M	F
75	187	173	190	150	180	116	135	160	199	76
50	124	99	119	106	120	63	98	88	79	23
25	67	56	59	65	49	40	44	31	34	10

Table 1f: Normative Percentile Data in Seconds for Prone Double Straight-Leg Raise

Percentile	19-29		30-39		40-49		50-59		60+	
	M	F	M	F	M	F	M	F	M	F
75	130	126	123	111	95	87	80	83	60	40
50	88	74	73	73	55	45	48	37	22	23
25	55	49	45	45	35	29	22	18	11	7

Table 1g: Normative Percentile Data in Seconds for Half-Squat

Percentile	19-29		30-39		40-49		50-59		60+	
	M	F	M	F	M	F	M	F	M	F
75	130	114	133	120	121	63	130	60	65	51
50	92	85	86	72	82	45	71	39	45	25
25	67	50	62	47	55	27	40	15	22	12

(Age Groups)

Median values for males were generally higher than for females for all seven tests. The difference in median values between males and females was largest between the ages of 40 and 59 for all tests. The age variation in median scores for each of the seven endurance tests is evident in Figures 6 through 12. Results show that endurance generally decreased with increasing age.

For the dynamic chest raise, the prone double straight leg raise and the half-squat, median values for both males and females peaked at age 19-29. A steady decrease in values to age 60+ ensued. Medians for the static chest raise followed a similar steady decrease among the male subjects. The trend for females was more erratic, with the maximum median value at the 30-39 age bracket and another peak at 50-59.

Median values for the dynamic 1/4 sit up peaked at the 19-29 age bracket for both males and females. For both sexes, there was a steady decrease to the 40-49 bracket, then a rise at 50-59 followed by a considerable decline for the 60+ group. For females, the static 1/4 sit up followed the same trend as for the dynamic test. For males, median values for the first four age groups (19-29 to 50-59) were nearly equal, with a large decrease at age 60+.

The bilateral straight-leg raise showed a similar trend for the male and female subjects. The median peaked at 19-29 for females, then rose gradually again to the 50-59 age group before declining at 60+. For males, there was an increase to the peak value at age 40-49, then a steady decrease for the two upper age groups.

Discussion

A normative age and gender-referenced database is presented for seven easily administered mechanical tests of trunk and lower extremity muscle endurance. In clinical practice, these tests can be used at intake and throughout the course of treatment to quantify change over time. Identifying high or low endurance muscle groups can alert the patient and clinician to a need for possible modifications to the usual treatment regime. For example, if a patient tests at the 25th percentile for the static chest raise and above the 75th percentile for the wall squat, the clinician has helped quantify that much of the time and energy in physical conditioning should be directed towards upper back extensor exercises with less emphasis placed on the quadriceps muscles.

As an outcome measure, this test battery can be used by comparing a patient's scores with the normative percentile data to assess which muscles exhibit dysfunction and to what degree. This measurement of outcome can be completed on the patient's day of discharge and/or some predetermined follow up date.

Well-standardized tests minimize variability and enhance reproducibility. The examiners for this study strictly followed prescribed procedures. All investigators were therapists with extensive training and experience in the testing protocol. This congruency reduced inter-examiner variation. Because good control and specificity of body positions during testing are essential to produce reliable results, the investigator was instructed to be watchful for any alterations in posture, particularly during the dynamic tests. Reliability is compromised when dynamic tests are not performed smoothly, at a slow, even pace throughout the whole test movement.

Although clinicians customarily use many of the endurance tests examined in this study, scant consideration has been given to the fundamental issue of reliability. In an unpublished study,[21] the reliability coefficient[22] was determined for each of these seven tests. Results indicated fair to good test-retest reliability for the static 1/4 sit-up (r=0.77), static chest raise (r=0.633) and bilateral straight-leg raise (r=0.67) tests. Excellent reliability was obtained for the prone double straight-leg raise (r=0.81), repetitive 1/4 sit-up (r=0.84), repetitive chest raise (r=0.87) and half-squat (r=0.85) methods. Other research confirms good reliability for dynamic endurance of the upper abdominals[23], static and dynamic 1/4 sit-up[12] and isometric endurance of the upper back extensors[21,23].

Malchaire and Masset concluded that a number of factors including weight, height, muscularity, and sports and leisure activities were significantly associated with trunk performance.[26] The trunk performance measures investigated in that study were range of motion, maximum isometric strength and maximum trunk velocity. Endurance was not specifically examined. In the absence of research demonstrating an effect of anthropometric or occupational variables on trunk and lower extremity endurance, we confined the stratification of our normative data to age and gender. Further stratification would require a much larger sample.

Human strength measurements are subject to motivational influences.[27] Reliability in endurance testing is compromised if the subject does not cooperate to give a maximum effort to the point of fatigue. To limit the psychogenic effects on testing and gain the compliance and motivation required for maximum performance, study subjects were voluntary participants fully informed about the nature of the tests.

A potential consequence of voluntary participation is sample bias. The smoking and exercise habits of this group suggest that the individuals who took part in this study might have been more fit than the general population. However, the large range of test results indicate varying degrees of strength and endurance. If this sample had consistently higher levels of fitness, the results would have been more skewed.

Conclusion

Normative values have been established according to age and sex for five static and two dynamic trunk endurance tests that require minimal instrumentation and cost. Referral to a normative data table allows comparison of an individual's score on any of the seven standardized tests to the scores obtained by a population of normal adults. Percentile scores estimate the extent to which a patient's endurance deviates from the norm for his or her sex and age group. When the goal of treatment is to return to an able-bodied lifestyle, i.e. to recover from the injury, discontinue benefits and resume an active role in society, then comparison to able-bodied values is the most appropriate choice; hence, the need for normative data.

Clinicians who treat low back pain can use this normative data as a preliminary means to recognize muscle dysfunction or as an outcome measure to help evaluate residual disability. Further research to develop a normative database that includes physical demands as a separate variable might help to establish more precise objectives. Until such data is available, the age and gender-specific database generated from this investigation of 548 normal subjects provides an objective instrument against which an endurance score can be compared with broad percentile categories. This objective data combined with information about the physical demands of the work environment and primary activities of daily living can help guide or evaluate the effectiveness of the rehabilitation.

Appendix 1. Examiner Instructions for Repetitive 1/4 Sit Up

Starting Position

a) supine lying on an exercise mat, knees flexed at approximately 90 degrees and heels in contact with the floor
b) arms straight and parallel to the trunk
c) palms of hands in contact with the mat
d) fingertips touching strips of masking tape, positioned according to age (see 1. below)
e) head in contact with the mat

Instructions

1. To properly position masking tape strips, measure a 12 cm distance (8 cm if the subject is over 40 years old) from the end of the mat. At the tips of the fingers, attach two strips of tape to the mat, at right angles to the trunk.
2. Instruct the subject to raise the head and shoulders by sliding the palms of the hands forward from the tape until the fingertips touch the end of the mat.
3. Ensure that the heels maintain contact with the floor and the buttocks do not slide.
4. Instruct the subject to lower back down to the starting position so that the fingertips are once again in contact with the tape.
5. If necessary, re-position the subject and continue the test.
6. Ensure that the movement is slow, continuous and well-controlled at a rate of one repetition per 2-3 seconds.
7. Instruct the subject to breathe normally during the test movements.
8. Record the maximal number of successfully completed partial sit-ups.

Termination Criteria

1. Subject is unable to reach the end of the mat.

2. Subject is unable to maintain a regular cadence.
3. Subject can no longer produce another repetition
4. Subject refuses to attempt the test.

Appendix 2. Examiner Instructions for Repetitive Chest Raises

Starting Position

a) prone lying, legs extended

b) hands positioned at the temples, forearms perpendicular to the body

Instructions

1. Instruct the subject to raise his/her head, arms and chest from the exercise mat, and then return to the starting position.
2. Ensure that hips, knees and feet stay in contact with the mat.
3. Instruct the subject to perform repetitive chest raises at a controlled and regular pace until unable to continue.
4. Record the maximal number of successfully completed chest raises.

Termination Criteria

1. The subject is no longer able to complete a chest raise.

Appendix 3. Examiner Instructions for Static 1/4 Sit Up

Starting Position

a) supine lying on an exercise mat, with knees flexed at approximately 90 degrees and heels in contact with the floor

b) arms straight and parallel to spine, palms of hands in contact with the mat

c) head in contact with the mat

Instructions

1. Measure a distance of 12 cm (8 cm if the subject is over 40 years old) from the end of the mat. At the fingertips of the subject, attach two strips of tape to the mat at right angles to the trunk.
2. Instruct the subject to raise the head and shoulders by sliding the palms forward from the tape until the fingertips touch the end of the mat.
3. Instruct the subject to maintain the partial sit-up position for as long as possible.
4. Instruct the subject to breathe normally during the test.
5. Record the duration in seconds that the subject is able to sustain the partial sit-up position.

Termination Criteria

1. Subject is unable to reach the end of the mat.
2. Subject is unable to sustain the partial sit-up position.
3. Subject's feet do not maintain contact with the floor.
4. Subject terminates the test.

Appendix 4. Examiner Instructions for Supine Bilateral Straight-Leg Raise

Starting Position

a) supine lying, legs extended

b) arms crossed over chest

Instructions

1. Instruct the subject to perform a pelvic tilt and sustain this position throughout the entire movement.
2. To monitor the pelvic tilt, place one hand under the lumbar spine.
3. Instruct the subject to raise both legs to 30 degrees, as determined with an inclinometer or goniometer.
4. Instruct the subject to maintain the pelvic tilt and leg raise for as long as possible.
5. Instruct the subject to breathe normally during the test.
6. Record the duration in seconds that the subject is able to sustain the pelvic tilt and supine straight leg raise.

Termination Criteria

1. Subject is unable to maintain the lumbar spine flexed against the instructor's hand, indicating no pelvic tilt.
2. Subject is unable to lift both legs from the floor while maintaining the pelvic tilt.
3. Subject is no longer able to sustain a 30 degree straight leg raise (legs elevate or drop).
4. Subject terminates the test.

Appendix 5. Examiner Instructions for Static Chest Raise

Starting Position

a) prone lying, legs extended

b) hands positioned at the temples, forearms perpendicular to the body

Instructions

1. Instruct the subject to raise his/her head, arms and chest from the floor and hold the position for as long as possible.
2. Ensure that hips, knees and feet stay in contact with the mat.
3. Instruct the subject to breathe normally during the test.
4. Record the duration in seconds that the subject is able to sustain the chest raise.

Termination Criteria

1. Subject is unable to raise upper chest from the floor.
2. Subject is no longer able to keep the upper chest off the floor.
3. Subject terminates the test.
4. Subject refuses to attempt the test.

Appendix 6. Examiner Instructions for Prone Double Straight-Leg Raise

Starting Position

a) prone lying

b) legs extended

c) hands underneath forehead, forearms perpendicular to body

Instructions

1. Instruct the subject to raise both legs until knee clearance is achieved.
2. Monitor knee clearance by sliding one hand under the thighs.
3. Instruct the subject to breathe normally during the test.
4. Record the duration in seconds that subject is able to sustain this position.

Termination Criteria

1. Subject is unable to clear both legs from the floor.
2. Subject is no longer able to maintain knee clearance.
3. Subject terminates the test.
4. Subject refuses to attempt the test.

Appendix 7. Examiner Instructions for Half-Squat Test

Starting Position

a) head, shoulders and buttocks against a 90 degree wall

b) feet far enough away from the wall to allow hips, knees and ankles to flex to 90 degrees

Instructions

1. Instruct the subject to slide down the wall until the hips, knees and ankles are flexed at 90 degrees.
2. Instruct the subject to sustain the position for as long as possible.
3. Instruct the subject to breathe normally during the test.
4. Record the duration in seconds that the subject is able to sustain the wall squat position.

Termination Criteria

1. Subject is unable to assume the starting position.
2. Subject is no longer able to maintain the wall squat position.
3. Subject terminates the test.
4. Subject refuses to attempt the test.

Appendix 8. Physical Activity Readiness Questionnaire

Yes No

____ ____ 1. Have you missed work because of back or neck pain in the past 6 months?

____ ____ 2. Has your doctor ever said you have heart trouble?

____ ____ 3. Do you frequently have pains in your heart and chest?

____ ____ 4. Do you often feel faint or have spells of severe dizziness?
____ ____ 5. Have you ever had a seizure?
____ ____ 6. Has your doctor ever said your blood pressure was too high?
____ ____ 7. Do you experience difficulty breathing at rest?
____ ____ 8. Do you have a history of asthma or emphysema?
___ ____ 9. Do you have a persistent cough?
_____ _____ 10. Have you had a recent viral infection?
____ ____ 11. Have you had surgery in the past 12 months?
____ ____ 12. Do you have any problems with swelling in the lower extremities?
____ ____ 13. Are you currently on any medication?
____ ____ 14. If you are female, are you pregnant?
____ ____ 15. Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?

Note: If there are any changes in your status during the test, please bring this information to the attention of your therapist.

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