Submaximal Exercise Testing: Clinical Application and Interpretation

Compared with maximal exercise testing, submaximal exercise testing appears to have greater applicability to physical therapists in their role as clinical exercise specialists. This review contrasts maximal and submaximal exercise testing. Two major categories of submaximal tests (ie, predictive and performance tests) and their relative merits are described. Predictive tests are submaximal tests that are used to predict maximal aerobic capacity. Performance tests involve measuring the responses to standardized physical activities that are typically encountered in everyday life. To maximize the validity and reliability of data obtained from submaximal tests, physical therapists are cautioned to apply the tests selectively based on their indications; to adhere to methods, including the requisite number of practice sessions; and to use measurements such as heart rate, blood pressure, exertion, and pain to evaluate test performance and to safely monitor patients. [Noonan V, Dean E. Submaximal exercise testing: clinical application and interpretation. *Phys Ther.* 2000;80:782–807.]

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Although maximal exercise testing is considered the gold standard for assessing maximal aerobic capacity, the role of such testing is limited in people whose performance may be limited because of pain or fatigue rather than exertion and in cases where maximal exercise testing is contraindicated. Submaximal exercise testing overcomes many of the limitations of maximal exercise testing, and it is the method of choice for the majority of individuals seen by physical therapists in that these individuals are likely to be limited physically by pain and fatigue or have abnormal gait or impaired balance. This article contrasts maximal and submaximal exercise testing and describes the clinical application of submaximal testing. The strengths and limitations of both predictive and performance submaximal tests and the means of maximizing validity and reliability of data are presented. Predictive tests are submaximal tests that are used to predict maximal aerobic capacity. Typically, heart rate (HR) or oxygen consumption ($\dot{V}o_2$) at 2 or more workloads is measured.[1,2] A predicted $\dot{V}o_2$ value is obtained by extrapolating the relationship between HR and $\dot{V}o_2$ to age-predicted maximal heart rate (HRmax). Performance tests involve measuring the responses to standardized physical activities that are typically encountered in everyday life. Finally, we discuss the use of submaximal exercise testing in clinical decision making and the implications for professional education and research.

Maximal Versus Submaximal Exercise Tests

Maximal exercise tests either measure or predict maximum oxygen consumption ($\dot{V}o_2$max) and have been accepted as the basis for determining fitness.[3–7] They

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have served as a standard against which to compare other measures.[8] Maximum oxygen consumption is dependent on the ability of the oxygen transport system to deliver blood and the ability of cells to take up and utilize oxygen in energy production.[9] Theoretically, a maximal test is defined by the plateau of $\dot{V}o_2$ with further increases in workload.[10,11] Other indexes used to assess maximal effort include obtaining HRmax within 15 beats per minute (bpm) of age-predicted HRmax (ie, 220−age) and a respiratory exchange ratio >1.10 (ratio of metabolic gas exchange calculated by carbon dioxide production divided by $\dot{V}o_2$).[12] Maximum oxygen consumption is typically expressed relative to body weight (ie, $mL \cdot kg^{-1} \cdot min^{-1}$),[13] which enables individuals of different body masses to be compared. When a maximal test is performed but the criteria for $\dot{V}o_2$max are not met, the maximal $\dot{V}o_2$ achieved is termed a "$\dot{V}o_2$peak."[14] Few individuals reach a true $\dot{V}o_2$max, and $\dot{V}o_2$peak values are often incorrectly reported as maximal values.[14] The intraindividual day-to-day variation in measuring $\dot{V}o_2$max is between 4% to 6% in individuals with no known cardiopulmonary pathology or impairment.[15,16] In people with various diagnoses, such as those with chronic obstructive pulmonary disease (COPD), this variation is between 6% and 10%.[17]

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There are several limitations to assessing maximal performance with a $\dot{V}o_2$max test. Unless an individual is able to attain a $\dot{V}o_2$max without fatiguing first or being limited by musculoskeletal impairments or other problems, the results of the test are invalid. In addition, higher levels of motivation are required by the individual, and maximal tests require additional monitoring equipment (eg, electrocardiograph machine) and trained staff and are labor intensive.[1,13,18]

In comparison with maximal tests, submaximal exercise tests and their applications have been less well developed, which we find surprising given the large number of patient types and individuals who should be able to benefit from nonmaximal exercise tests. For the purpose of this review, submaximal tests are classified as either predictive tests or performance tests.

Clinical Application of Submaximal Exercise Testing

Safety
Exercise constitutes a physiologic stress that may pose a greater risk to people with various diagnoses than to people without pathology or impairment. The space for testing must be sufficient to minimize injury should the patient fall or have an arrest. All physical therapists should have current certification in cardiopulmonary resuscitation. Emergency procedures and basic equipment need to be in place to ensure that the individual has immediate care until paramedical or medical assistance arrives. There are other critical needs for exercise testing. Basic emergency supplies, including a sugar source for people with diabetes, should be on hand. A portable oxygen source and suction device should be accessible. People who are stable and who have a history of angina should have their antianginal medication, and the physical therapist should have access to this medication. Monitoring equipment should be maintained and regularly calibrated.

Indications for testing and any contraindications for testing should be determined before testing.[19] In the presence of relative contraindications, the person may require additional monitoring (eg, 12-lead electrocardiography) or be cleared for such testing by an appropriate medical practitioner. A high proportion of people over the age of 65 years without known cardiac disease have a high incidence of cardiac dysrhythmias,[20,21] which may necessitate greater attention to monitoring cardiac status during exercise. Individuals requiring additional monitoring or considered to be at hemodynamic risk should be tested in a setting with medical personnel present.

Indications
Maximal exercise testing has a role in the assessment of maximal aerobic capacity or functional work capacity. Because people are frequently limited by cardiopulmonary, musculoskeletal, and neuromuscular impairments and complaints such as exertion, dyspnea, fatigue, weakness, and pain during their activities of daily living, maximal testing is often contraindicated or of limited value. In people without cardiopulmonary or musculoskeletal impairments, the reserve capacity of the cardiopulmonary and musculoskeletal systems is thought to be barely tapped during daily activities.[22] In people with pathology, this reserve can be greatly reduced, and a greater than usual proportion of a person's maximal capacity may be needed to perform routine activities.[23]

Exercise constitutes a major physiological stress that can lead to untoward responses in patients as well as in individuals without known pathology. In addition, such testing is resource intensive and thus should be applied and performed judiciously. The purposes of maximal tests include determination of $\dot{V}o_2$max and use as diagnostic or treatment outcome tools. Submaximal exercise tests can be used to predict $\dot{V}o_2$max, to make diagnoses and assess functional limitations, to assess the outcome of interventions such as exercise programs, to measure the effects of pharmacological agents, and to examine the effect of recovery strategies on exercise performance.[13,19,23–25]

Guidelines for Test Selection
There are numerous submaximal tests from which to choose. These tests have been developed to meet the needs of people with various functional limitations and disabilities and the needs of older adults. In our opinion, however, inappropriate selection may lead to either understressing or overstressing the individual. Such understressing or overstressing of the person, in our view, can lead to invalid conclusions because of ceiling or floor effects, and the testing may be hazardous. The goal of testing should be to produce a sufficient level of exercise stress without physiologic or biomechanical strain. Factors that we believe should be considered in selecting the appropriate test include the person's primary and secondary pathologies and how these pathologies physically affect the person's daily life. Other factors include cognitive status, age, weight, nutritional status, mobility, use of walking aids or orthotic or prosthetic devices, independence, work situation, home situation, and the person's needs and wants. People who may be medically unstable and at risk for an arrest may need to be tested in the presence of a cardiologist or pulmonary specialist or by a physical therapist in a specialized setting where emergency services are on hand. The population for which a given test was developed, the degree of validity and reliability of measure-

ments obtained with each test, and test sensitivity also should be considered (Appendix). Reports in the literature on the common submaximal tests described in this article vary with respect to the adequacy of establishing validity, reliability, and sensitivity; thus, test interpretation may be limited. These limitations should be considered in the selection of each test. Physical therapists should determine what information will be added by performing an exercise test and how that information will alter clinical decision making.

Pretest Workup

A detailed medical and surgical history is needed to identify the indications for an exercise test and to alert the physical therapist about any underlying conditions (eg, cardiovascular, pulmonary, musculoskeletal, or neurological dysfunction or the presence of diabetes, hypertension or heart block requiring a pacemaker, anemia, thyroid dysfunction, obesity, deformity, vertigo, or impaired cognitive function). The therapist should be aware of medications (indications, response, and side effects) that can influence the test procedures and the response to the exercise. Laboratory tests and investigations that may be relevant include electrocardiograms, echocardiograms, pulmonary function tests, investigations of peripheral vascular function, blood chemistry tests, bone density measures, radiographs, scans, thyroid function tests, glucose tolerance tests, autonomic nervous system function tests, sleep studies, nutritional assessment, and tests for level of hydration.

The effect of each medication on exercise response and the medication's side effects should be known to the person administering the test. Beta blockers, for example, attenuate normal HR and blood pressure (BP) responses to exercise and contribute to fatigue in some people. The purpose of the test must be clear so that the person can be appropriately premedicated (eg, with antidysrhythmic drugs, inotropic drugs, anticoagulants, antithrombolytics, bronchodilators, vasodilators, diuretics, and analgesics). For example, medications such as bronchodilators and analgesics have peak effect times; thus, it is important to ensure that these medications are at peak effect during the test and that this effect is replicated on subsequent tests.

People with a history of angina should be screened carefully. The objective of submaximal testing is to test the individual below the work rate that induces angina. The person's anginal history will divulge the range of activities and the activities that are not associated with symptoms. Labile angina, angina at rest, and frequent premature ventricular contractions (PVCs) at rest are, in our opinion, absolute contraindications to exercise testing in the absence of a cardiologist unless in a specialized setting where physical therapists are qualified to

perform such testing. Premature ventricular contractions can be detected reliably only with electrocardiograms and not by palpation or verbal report. A detailed anginal history, including what triggers episodes of angina and the frequency of self-medication with antianginal medication and its effect, should be recorded. Any history of chest discomfort or pain from any cause should be noted by the tester. We also believe that any medication should be checked for its expiration date and should be available in the event it is needed during or after the test. A person with a history of angina and for whom antianginal medication is prescribed, in our opinion, should be considered at risk even if the medication has not been required for a prolonged period. We advise that a risk assessment should be conducted for every individual, regardless of whether a maximal exercise test or a submaximal exercise test is being performed. This assessment will help to determine which test is appropriate, predict an adverse response to testing, identify the level of monitoring needed, and whether there are any contraindications to submaximal exercise testing.

Standardization of Procedures

A primary concern about submaximal exercise testing is the lack of standardization of the procedures. We believe that general procedures should include informing the person about the type and purpose of the test and instructing the person to avoid any strenuous activity for 24 hours prior to testing and to avoid a heavy meal, caffeine, or nicotine within 2 to 3 hours of testing.[19] Medications taken prior to testing should be noted by the examiner, and, if appropriate, their use should be consistent from one test to the next. The individual should become familiar with the equipment and test procedures to minimize anxiety. Many tests require one or more practice sessions. If time and resources do not permit these practice sessions, we argue that the test should not be performed because the results, in our view, will not be valid. Appropriate rest periods, in our opinion, need to be scheduled between practices and between the last practice and the actual test. We have previously shown that performance of a submaximal treadmill walking test requires at least one practice session, even in young subjects without functional impairments, in order for the measurements to be valid.[26] For some individuals, more practice sessions are justified. The number of practice sessions required to make the results valid, in our opinion, is dependent on the test and on the experience and functional capacity of the person being tested. Verbal encouragement in submaximal testing should be standardized to ensure that this does not affect the person's performance.[27] Failure to calibrate both exercise devices and monitoring equipment can lead to erroneous results.

Measurements

Basic measures of exercise responses include HR, BP, respiratory rate (RR), rating of perceived exertion (RPE), and breathlessness. Depending on the person's history and other variables, the examiner may find other measures to be useful (eg, a 3-lead electrocardiogram, arterial saturation assessed using a pulse oximeter, cadence, ratings of fatigue and discomfort or pain). Because tests are performed over a wide area or circuit, monitoring equipment should be portable. Repeated measurements of each variable of interest, in our opinion, should be taken prior to the exercise test to ensure a stable baseline, at various points during the test (depending on the type of test), and during the cool-down period, if applicable, and these measurements should be repeated during recovery to ensure that the measures have returned to baseline levels. As a precaution, we recommend that the person should not leave the testing area until all measures have returned to within 10% of resting values.[19] Based on the history of the person being tested, additional monitoring may be indicated to maximize the safety of the test.

Because the measurement of BP is an important part of exercise testing, the validity of these measurements should be maximized with an appropriately sized cuff, its position on the midshaft of the humerus, its tightness, the cuff deflation rate, and the position of the stethoscope over the brachial artery as it courses over the antecubital fossa.[28] Skill in recording BP is essential, given that many people have undiagnosed or poorly controlled hypertension.

Measures of exertion, breathlessness, fatigue, discomfort or pain, and well being in response to physical activity or exercise are important exercise responses reported by the person being examined. Many people, particularly older people, more readily and reliably monitor and act on their complaints, rather than using measures such as HR to guide their activities or exercise intensity.

Interpretation

The interpretation of the submaximal exercise test results is based primarily on the type of test conducted, its indications (eg, assessment, diagnostic, exercise prescription), specified outcomes, and, in some instances, norms (Appendix). Submaximal exercise tests can be used to predict aerobic capacity or to assess the ability to perform a standardized exercise or task. In addition, measurements taken before, during (where applicable), and after the test can yield valuable information regarding the person's exercise response. These values can be compared across subsequent tests. They can alert the physical therapist to undue pretest arousal (a measure of the adequacy of the pretest standardization), exaggerated exercise responses, and delayed recovery, which are

Table 1.
Modified Bruce Treadmill Test: Protocol[a]

Stage	Speed (mph)	Grade (%)	Duration (min)
0	1.7	0	3
0.5	1.7	5	3
1	1.7	10	3
2	2.5	12	3
3	3.4	14	3
4	4.2	16	3
5	5.0	18	3
6	5.5	20	3
7	6.0	22	3

[a] Adapted from Bruce RA. Exercise testing of patients with coronary artery disease: principles and normal standards for evaluation. *Ann Clin Res.* 1971;3:323–332 and Bruce RA, Kusumi F, Hosmer D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. *Am Heart J.* 1973;85:564–562. The standard Bruce protocol begins at stage 1; stages 0 and 0.5 are used for individuals with reduced exercise capacity.

consistent with deconditioning or pathology, or both. Comparison of the responses with pretest and posttest measurements is particularly useful for assessing the effect of an intervention such as an exercise program. In this case, a reduction in submaximal exercise responses such as HR, RR, and BP can be consistent with improved aerobic conditioning or movement economy, or both. *Movement economy* refers to the efficient use of energy during movement (ie, not excessive $\dot{V}o_2$ for a given activity or work rate).

Predictive Submaximal Exercise Tests

Modified Bruce Treadmill Test

Description. The Bruce Treadmill Test[5] is a maximal test that was designed to diagnose coronary heart disease. Some preliminary stages have been added to the original test, which has given rise to the use of the Modified Bruce Treadmill Test in people with other conditions.[29,30] Compared with the original test, which starts at 1.7 mph at a grade of 10%, the modified test has a zero stage (1.7 mph at 0% grade) and a one-half-stage (1.7 mph at 5% grade) (Tab. 1). Predictive equations for estimating $\dot{V}o_2$max have been developed and can be used with the original and modified tests. Bruce et al[5] developed the first predictive equations, which are population-specific for active and sedentary adults with and without cardiac conditions. Individuals must be correctly classified to determine which equation is appropriate. Foster et al[30] later developed a regression equation applicable to all men based on a sample of 230 men of various ages with a variety of clinical conditions (symptomatic angina, n=14; postmyocardial revascularization surgery, n=36; outpatient cardiac rehabilitation surgery, n=63; preventative medicine program, n=90, and athletes, n=27) and activity levels. The details of the

Modified Bruce Treadmill Test are provided in the Appendix.

Reliability and validity. Bruce et al[5] reported Pearson product moment correlation coefficients (r) between predicted $\dot{V}o_2max$ and measured $\dot{V}o_2max$ of .94 for without cardiac conditions (n=292), .93 for women without cardiac conditions (n=509), and .87 for men with cardiac disease (n=153). Foster et al[30] compared predicted $\dot{V}o_2max$ and measured $\dot{V}o_2max$ for the general equation and the population-specific equations introduced by Bruce et al.[5] The average predicted error was -0.6 mL·kg^{-1}·min^{-1} for the general equation versus -2.0 mL·kg^{-1}·min^{-1} for the population-specific equations. The correlation between measured $\dot{V}o_2max$ and predicted $\dot{V}o_2max$ for the general equation was high ($r=.96$), with a multiple correlation coefficient (R) of .98 and a standard error of the estimate (SEE) of 3.5 mL·kg^{-1}·min^{-1}.[30]

Strengths and weaknesses. The Bruce Treadmill Test and the Modified Bruce Treadmill Test are widely used, especially for the diagnosis of coronary heart disease, and, as a result, normative data are available. Compared with the original protocol, which starts with a large workload, the modified protocol has a more gradual initial workload. Thus, we contend that the modified protocol is more applicable for individuals with low functional capacity. The large increases in workload in the original protocol, however, allowed the test to be completed within 6 to 9 minutes.[23]

Single-Stage Submaximal Treadmill Walking Test

Description. Ebbeling et al[12] developed the Single-Stage Submaximal Treadmill Walking Test (SSTWT), which can be used by individuals of various ages and fitness levels. The test was developed on a sample of 139 volunteers with no health problems (67 men and 72 women) aged 20 to 59 years. The subjects were randomly assigned to either an estimation group (n=117) or a cross-validation group (n=22). Subjects walked on a treadmill at a constant speed, ranging from 2.0 to 4.5 mph at grades of 0%, 5%, and 10%, with each stage lasting 4 minutes. A maximal test was then performed. The regression equation used to estimate $\dot{V}o_2max$ was based on data obtained from the estimation group from the 4-minute stage at a grade of 5%. The details of the SSTWT are given in the Appendix.

Reliability and validity. The SSTWT was validated by correlating the estimated $\dot{V}o_2max$ and the measured $\dot{V}o_2max$ in the cross-validation group. A correlation (r) of .96 was obtained, with a multiple correlation (R) of .86 (SEE=4.85 mL·kg^{-1}·min^{-1}).

Strengths and weaknesses. This test is suitable for testing people with various diagnoses in clinical and research settings. It consists of only a warm-up session and a single stage on the treadmill. This test, in our view, is useful for assessing people who are prone to fatigue.

Further research is needed to validate this test in people with various diagnoses, in individuals over 60 years of age, and in both unfit and highly trained individuals. Further studies are needed to establish its sensitivity to detect change. Finally, because this test is based on HR, factors that affect HR must be controlled; otherwise, the test results will be invalidated.

Astrand and Ryhming Cycle Ergometer Test

Description. The Astrand and Ryhming (A-R) Cycle Ergometer Test, which is used to predict $\dot{V}o_2max$ by use of a cycle ergometer, is based on the linear relationship between $\dot{V}o_2$ and HR.[31] Astrand and Ryhming[31] noted that, in subjects aged 18 to 30 years, the men had an average HR of 128 bpm at 50% of $\dot{V}o_2max$ and an average HR of 154 bpm at 70% of $\dot{V}o_2max$, and the women had an average HR of 138 bpm at 50% of $\dot{V}o_2max$ and an average HR of 164 bpm at 70% of $\dot{V}o_2max$. A nomogram was developed by Astrand and Ryhming[31] to estimate $\dot{V}o_2max$ (Fig. 1), and later an age-correction factor was incorporated to account for the decrease in HRmax with age (Tab. 2).[32] Modification of the A-R nomogram were proposed by Legge and Banister[33] and by Hartung and colleagues[9,34] to improve the accuracy of the equation. A revision to the A-R nomogram was also proposed by Siconolfi et al.[35] The details of the A-R Cycle Ergometer Test are presented in the Appendix.

Reliability and validity. Astrand[32] reported a correlation (r) of .71 between the measured $\dot{V}o_2max$ and the estimated $\dot{V}o_2max$ in the original A-R Cycle Ergometer Test and a correlation (r) of .78 between the measured $\dot{V}o_2max$ and the A-R Cycle Ergometer Test using the age-correction factor. Teraslinna et al[36] reported a correlation (r) of .69 between the original A-R Cycle Ergometer Test and the measured $\dot{V}o_2max$ and a correlation (r) of .92 using the age-correction factor in a sample of 31 sedentary men. Kasch[37] reported that the A-R Cycle Ergometer Test predicted a $\dot{V}o_2max$ that was too low (by 21%) in 83 men aged 30 to 66 years. Other researchers[38,39] have reported similar findings. Hartung et al,[34] in a study of women aged 19 to 70 years, found that the A-R method overestimated $\dot{V}o_2max$ by 3% to 21%. In addition, an overestimation of $\dot{V}o_2max$ by the A-R method has been documented in women who were pregnant.[40]

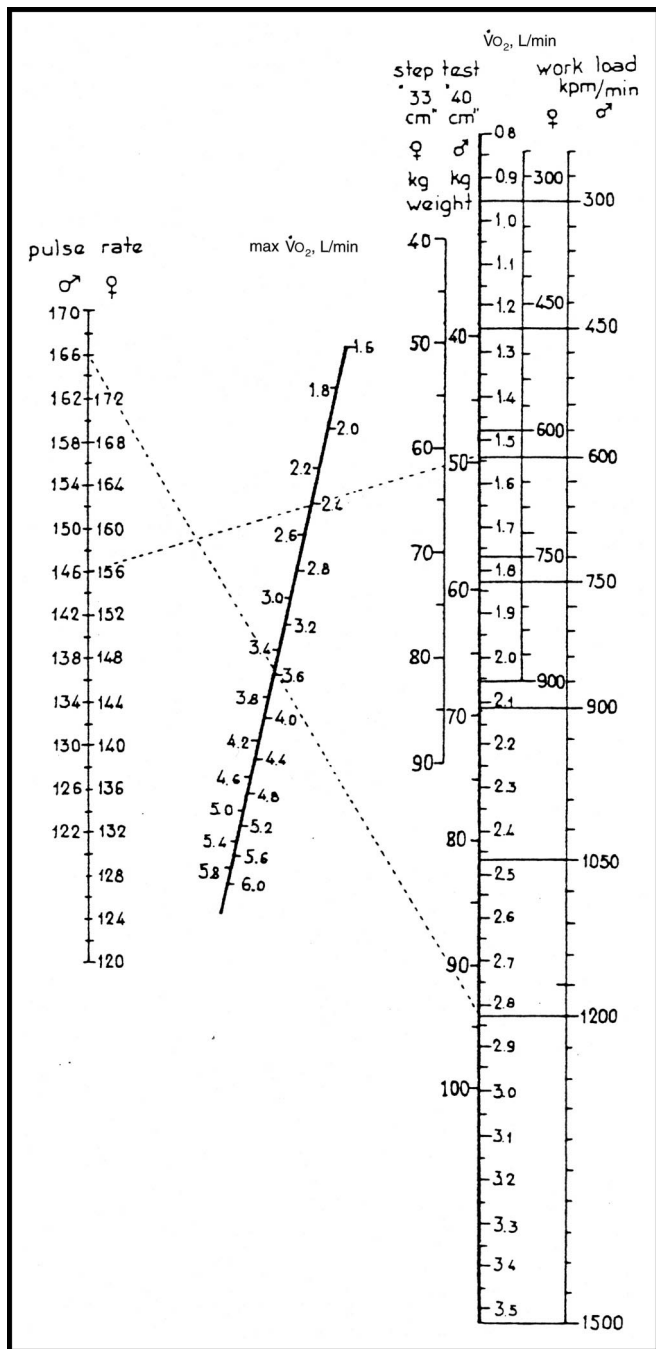Legge and Banister[33] reported a correlation (r) between their revised nomogram and the measured $\dot{V}o_2max$ of

Figure 1.
The Astrand and Ryhming nomogram. Estimated maximum oxygen consumption ($\dot{V}O_2$max) can be determined by reading horizontally from the body weight scale (step test) or workload scale (cycle test) to the oxygen uptake ($\dot{V}O_2$) scale. The predicted $\dot{V}O_2$max value is obtained by connecting the point on the $\dot{V}O_2$ scale ($\dot{V}O_2$, liters per minute) with the corresponding point on the pulse rate scale (in beats per minute). The horizontal line extends from the workload and $\dot{V}O_2$ scales to the pulse rate scale. Where the line intersects the max $\dot{V}O_2$ scale (liters per minute) is the estimate of the individual's $\dot{V}O_2$max. Reprinted with permission from Astrand I. Aerobic capacity in men and women with special reference to age. *Acta Physiol Scand.* 1960;49(suppl 169):2–92.

.98. Hartung and colleagues[9,34] reported a correlation (r) of .95 between the measured $\dot{V}O_2$max and the estimated $\dot{V}O_2$max using their revised nomogram. However, the revised nomogram still predicted a $\dot{V}O_2$max that was too low (by 8.1 mL·kg^{-1}·min^{-1}) in a sample of sedentary and trained men.[9] In a sample of women (n=38) aged 19 to 47 years, the revised nomogram overestimated $\dot{V}O_2$max by 18.5%.[34]

Strength and weaknesses. The A-R Cycle Ergometer Test is one of the most frequently used submaximal cycle ergometer tests.[41,42] This test has been a standard used by fitness facilities as part of fitness evaluations and to develop a training plan and evaluate the results.[43] The protocol uses HR, which is easy to measure. Limitations of the test include the margin of error in the predicted $\dot{V}O_2$max values. The protocol can elicit lower-extremity discomfort in some people, which may invalidate the results.

Canadian Aerobic Fitness Test

Description. The Canadian Aerobic Fitness Test (CAFT), formerly known as the Canadian Home Fitness Test, is unique in that it was designed to promote fitness testing at home. The CAFT was developed on a sample of 1,544 individuals (699 men and 845 women) aged 15 to 69 years.[44] The CAFT is a measure of fitness and is based on the duration of the step test and a 10-second recovery of HR (Tabs. 3 and 4). Norms for the recovery HR in men and women have been reported,[44] and a "Physical Fitness Evaluation Chart" for various age groups is available (Tab. 5). In addition, Jette et al[45] developed a regression equation for the CAFT to predict $\dot{V}O_2$max. A sample of 59 individuals, aged 15 to 74 years, completed the CAFT and then underwent a progressive treadmill test to evaluate $\dot{V}O_2$max.

The CAFT was modified (mCAFT)[46,47] following reports that it predicted a $\dot{V}O_2$max that was too low in women aged 20 to 30 years and in heavy, older, and well-trained individuals.[48–50] Use of too few stages can produce a ceiling effect, and, if the target HR is not attained, the $\dot{V}O_2$max prediction may be too low.[46] The modification allows an individual to complete the number of stages necessary to reach a target HR within 85% of the age-predicted maximum. Weller et al[46] developed 2 additional stages for the original CAFT for individuals who exceed stage 6. A new regression equation was also developed.[51] The details of the CAFT[52] are shown in the Appendix.

Reliability and validity. The reliability of measurements of recovery time for HR for the CAFT was determined using a sample of 102 individuals (r=.79).[44] In terms of validity, the regression equation developed by Jette

Table 2.
Astrand and Ryhming Cycle Ergometer Test: Correction Factor for Age-Predicted Maximal Heart Rate[a]

Age (y)	Factor	Maximal Heart Rate (bpm)	Factor
15	1.10	210	1.12
25	1.00	200	1.00
35	0.87	190	0.93
40	0.83	180	0.83
45	0.78	170	0.75
50	0.75	160	0.69
55	0.71	150	0.64
60	0.68		
65	0.65		

[a] Use the correction factor if the individual is over 30 to 35 years of age or if the maximal heart rate is known. The actual factor should be multiplied by the value in Table 2. Note: one correction factor is multiplied by age, and the other correction factor is multiplied by maximal heart rate. Reprinted with permission from Astrand PO, Rodahl K. *Textbook of Work Physiology.* 2nd ed. New York, NY: McGraw-Hill Book Co; 1977:279.

Table 3.
Canadian Aerobic Fitness Test: Starting Tempo of the Stepping Exercise Based on Age and Sex[a]

Age (y)	Starting Exercise[b]	
	Males	Females
60 and over	1 (66)	1 (66)
50–59	2 (84)	1 (66)
40–49	3 (102)	2 (84)
30–39	4 (114)	3 (102)
20–29	5 (132)	3 (102)
15–19	5 (132)	4 (114)

[a] Reprinted with permission from *Operations Manual: Canadian Home Fitness Test*, 2nd ed, Health Canada. © Minister of Public Works and Government Services Canada, 2000.
[b] Stepping tempo (in parentheses) in steps per minute.

et al[45] had a multiple correlation (R) of .905 ($SE_{meas}=4.08$ mL·kg^{-1}·min^{-1}). The regression equation for the mCAFT demonstrated the same strength between the predicted $\dot{V}o_2max$ and the measured $\dot{V}o_2max$ as the original equation for the CAFT (mCAFT, $r=.88$; CAFT, $r=.99$), but there was a lower mean square error (mCAFT=37.0 and CAFT=63.3).

Strengths and weaknesses. The CAFT is a step test and, therefore, is inexpensive to administer and requires no electricity or calibration. A person's power output can be calculated within 6% to 7% if the individual steps in time with the beat, stands erect on the top step, and places both feet flat on the ground at the end of each stepping cycle.[11]

This test may not be suitable for people whose ability to balance is diminished because no handrail is used. It is also difficult to monitor individuals while they are stepping. Because we believe there is a ceiling effect, we contend that the original protocol appears to be more suited for assessing individuals who are unfit. Further research is needed to validate both the CAFT and the mCAFT with people with various diagnoses.

12-Minute Run Test

Description. The 12-Minute Run Test (12-MRT) was developed by Cooper[53] in 1968. This test is based on the work of Balke,[54] which indicated that various run-walk tests could relate $\dot{V}o_2$ to either the distance covered in a given period of time or the time taken to cover a given distance. A sample of 115 men with no health problems aged 17 to 52 years completed two 12-MRTs and a $\dot{V}o_2max$ test on a treadmill, and a regression equation

Table 4.
Canadian Aerobic Fitness Test: Ceiling Postexercise Heart Rates[a]

Age (y)	Heart Rate	
	10 s After 1st Stage	10 s After 2nd Stage
60 and over	24	23
50–59	25	23
40–49	26	24
30–39	28	25
20–29	29	26
15–19	30	27

[a] Reprinted with permission from *Operations Manual: Canadian Home Fitness Test*, 2nd ed, Health Canada. © Minister of Public Works and Government Services Canada, 2000.

was developed. The details of the 12-MRT are shown in the Appendix.

Reliability and validity. Test-retest reliability (r) of measurements obtained with the 12-MRT was reported by Cooper[53] to be .90. In terms of validity, Cooper[53] reported a correlation (r) of .90 between the 12-MRT distance and $\dot{V}o_2max$. Jessup et al[55] reported a lower correlation (r) of only .13 between the 12-MRT and $\dot{V}o_2max$ in a sample of male subjects with no health problems aged 18 to 23 years. Safrit et al[56] reported findings similar to those of Jessup et al.[55]

Strengths and weaknesses. The 12-MRT requires no specialized equipment and allows more than one individual to be tested at a time. We suggest that this test is appropriate for assessing the cardiopulmonary fitness of individuals with high levels of function. The 12-MRT has been modified as a 12-Minute Walk Test (12-MWT), which we believe is more appropriate for the rehabilitation setting.

This test was developed using a male population. No cross-validation group was used to validate the equation. The 12-MRT requires a constant level of motivation, and

Table 5.
Canadian Aerobic Fitness Test: Physical Fitness Evaluation Chart[a]

Age Group	Start at Stepping Exercise No. Males	Females		Your pulse rate after first exercise			
60s	1	1	Stop if 24 or more	If 24 or more, you have an undesirable (below average) personal fitness level		Go only if 23 or less	Everybody stop
50s	2	1	Stop if 25 or more	If 25 or more, you have an undesirable personal fitness level		Go only if 24 or less	Stop if 23 or more
40s	3	2	Stop if 26 or more	If 26 or more, you have an undesirable personal fitness level		Go only if 25 or less	Stop if 24 or more
30s	4	3	Stop if 28 or more	If 28 or more, you have an undesirable personal fitness level		Go only if 27 or less	Stop if 25 or more
20s	5	3	Stop if 29 or more	If 29 or more, you have an undesirable personal fitness level		Go only if 28 or less	Stop if 26 or more
15–19	5	4	Stop if 30 or more	If 30 or more, you have an undesirable personal fitness level		Go only if 29 or less	Stop if 27 or more

Your pulse rate after second exercise			Your pulse rate after third exercise		
			* Caution: The advanced version of the Canadian Home Fitness Test is intended for use only by those individuals who have attained the recommended fitness level.		
If 23 or more, you have the minimum personal fitness level	If 22 or less, you have the recommended personal fitness level		**Advanced ONLY**		
If 23 or more, you have the minimum personal fitness level	Go only if 22 or less	Everybody stop	If 23 or more, you have the recommended personal fitness level GOOD	If 21–22, you have the recommended personal fitness level VERY GOOD	If 20 or less, you have the recommended personal fitness level EXCELLENT
If 24 or more, you have the minimum personal fitness level	Go only if 23 or less	Everybody stop	If 24 or more, you have the recommended personal fitness level GOOD	If 22–23, you have the recommended personal fitness level VERY GOOD	If 21 or less, you have the recommended personal fitness level EXCELLENT
If 25 or more, you have the minimum personal fitness level	Go only if 24 or less	Everybody stop	If 25 or more, you have the recommended personal fitness level GOOD	If 23–24, you have to recommended personal fitness level VERY GOOD	If 22 or less, you have the recommended personal fitness level EXCELLENT
If 26 or more, you have the minimum personal fitness level	Go only if 25 or less	Everybody stop	If 26 or more, you have the recommended personal fitness level GOOD	If 24–25, you have the recommended personal fitness level VERY GOOD	If 23 or less, you have the recommended personal fitness level EXCELLENT
If 27 or more, you have the minimum personal fitness level	Go only if 26 or less	Everybody stop	If 27 or more, you have the recommended personal fitness level GOOD	If 25–26, you have the recommended personal fitness level VERY GOOD	If 24 or less, you have the recommended personal fitness level EXCELLENT

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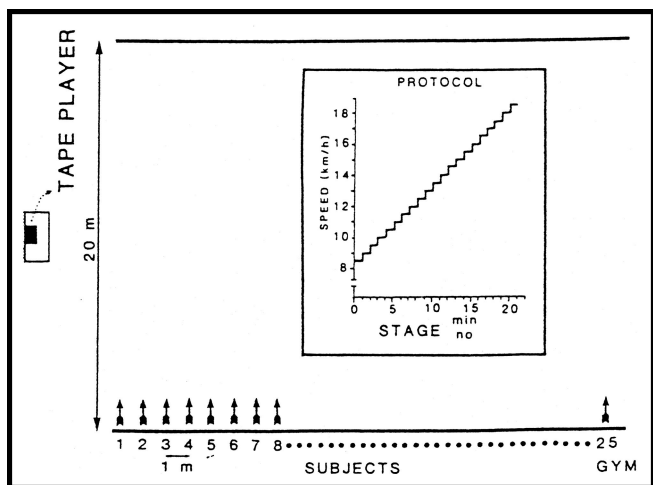
Figure 2.
The setup and protocol for the 20-Meter Shuttle Test. Reprinted with permission from Leger LA, Mercier D, Gadoury C, Lambert J. The multistage 20-meter shuttle run test for aerobic fitness. *J Sports Sci.* 1988;6:93–101.

the individual must pace herself or himself. The wording of the instructions makes this a potentially maximal exercise test, so well-defined testing criteria are needed to ensure that it is a submaximal exercise test. Finally, this test fails to account for age or body weight, which can influence exercise responses.[18]

20-Meter Shuttle Test

Description. The 20-Meter Shuttle Test (20-MST)[57,58] assesses maximal aerobic power. This test was designed for children, adults attending fitness classes, and athletes participating in sports requiring constant stopping and starting. The test requires subjects to run between 2 lines spaced 20 m apart at a pace set by signals on a pre-recorded cassette tape (Fig. 2). Starting speed is 8.5 km·h^{-1}, and the frequency of the signals is increased 0.5 km·h^{-1} each minute. When the subject can no longer maintain the set pace, the last completed speed (ie, stage) is used to predict $\dot{V}o_2$max. Leger and Lambert[59] found that maximal speed, subsequently termed "maximal aerobic speed" (MAS), for 2-minute stages in the 20-MST, could predict $\dot{V}o_2$max, with a correlation (r) of .84 (SEE=10.5%). A regression equation was developed on a sample of 188 boys and girls aged 8 to 19 years.[58] Another regression equation was developed for adults based on a sample of 77 adults (53 men and 24 women) aged 18 to 50 years, in which age is held constant at 18 years.[58] Norms have been established for children aged 6 to 17 years.[57] Berthoin et al[60] modified the 20-MST by incorporating 1-minute stages rather than 2-minute stages because they reported that faster speeds could be achieved when the work stages were shorter. The details of the 20-MST are presented in the Appendix.

Reliability and validity. In terms of reliability, the test-retest correlation (r) for the 20-MST was reported to be .89 for children (n=139) aged 8 to 19 years and .95 for adults (n=81) aged 20 to 45 years.[58] Leger et al[58] reported a correlation (r) of .71 (SEE=5.9 mL·kg^{-1}·min^{-1}) between the 20-MST and measured $\dot{V}o_2$max in children and a correlation of .90 in adults. Paliczka et al[61] confirmed the validity of measurements obtained with the 20-MST by demonstrating a high correlation between 20-MST and $\dot{V}o_2$max (r=.93), as well as with a 10-km race time (r=−.93). The test has been further validated on active women.[62] The 20-MST was reported to yield valid and sufficiently sensitive measurements such that the intensity of exercise could be modified for children with asthma.[63]

Strength and weaknesses. The 20-MST is based on an individual's MAS. This test has multiple stages, enabling a wide range of fitness levels to be tested. It requires little equipment, and more than one individual can be tested at a time. The 20-MST is unique because it paces the individual with the use of sound signals on a pre-recorded cassette tape.

Due to the frequent stopping and starting of this test, we believe that it is important to screen the individual prior to testing to ensure that she or he is suitable. The test may not be suitable for some individuals due to the progressive increments of speed each minute and the requirement to pivot when they run between 2 lines. For example, this test may not be suitable for elderly people or those with musculoskeletal impairments. Some individuals may find it difficult to pace themselves with the signals. Finally, testing criteria are needed to ensure that the test is submaximal.

1-Mile Track Walk Test (Rockport Fitness Test)

Description. The 1-Mile Track Walk Test (1-MTW), also known as the Rockport Fitness Test, estimates $\dot{V}o_2$max across a range of age groups and fitness levels. The prediction equations were developed based on a sample of 390 volunteers with no health problems (183 men and 207 women, aged 30 to 69 years).[64] Each individual performed a minimum of two 1-MWTs on separate days. The walk times in the 2 tests had to be within 30 seconds. All individuals also performed a $\dot{V}o_2$max test on a treadmill. This test has also been validated on individuals with mental retardation.[65,66] Variations in the distance used with this test have been reported (eg, 1-mile run/walk,[67,68] 1.5-mile run,[68] 2-mile run[69]). The details of the 1-MWT are given in the Appendix.

Reliability and validity. Kline et al[64] reported the reliability (r) of measurements obtained for the last quarter-mile HRs to be .93 (SEE=7.6 bpm) and the reliability (r)

of measurements obtained for the total time for the 2 trials of the track walk to be .93 (SEE=0.26 minute). The validity of the regression equation was established by having a validation group (n=174) and a cross-validation group (n=169). The sample of 390 volunteers were assigned to the validation and cross-validation groups based on alternate case assignment (ie, odd-even case selection). Descriptive statistics revealed no difference between the 2 groups. The correlation (r) between the predicted $\dot{V}o_2max$ and the actual $\dot{V}o_2max$ was .93 (SEE=0.325 L·min^{-1}) for the validation group and .92 (SEE=0.355 L·min^{-1}) for the cross-validation group.

Strengths and weaknesses. This test, in our view, is applicable to a wide range of individuals. It requires little specialized equipment and uses the familiar activity of fast walking. Thus, we contend that it is suitable for use in the rehabilitation setting. The test was cross-validated, which confirms the accuracy of prediction.

The test and regression equations need to be validated in patient groups. Finally, research is needed to determine whether a practice test improves the prediction.

Performance Submaximal Tests

Self-Paced Walking Test

Description. The Self-Paced Walking Test (SPWT)[70] is an exercise test developed for elderly and frail individuals. It consists of free walking at 3 speeds down an indoor corridor (ie, 250 m). Various exercise responses can be assessed such as speed, time, stride frequency, stride length, HR, and predicted $\dot{V}o_2max$. The test was developed on 24 individuals aged 64 to 66 years. Ten active students aged 19 to 21 years served as a comparison group. Each subject performed the SPWT and a progressive cycle ergometer test. Only 17 elderly individuals could complete the cycle ergometery test, whereas all of them completed the SPWT.

Performance of the SPWT is correlated with $\dot{V}o_2max$ and is independent of age.[71] Following an exercise program, the speed of walking was reported to increase, whereas HR remained unchanged.[72] A predicted $\dot{V}o_2max$ can be obtained from estimating $\dot{V}o_2$ from an aerobic demand curve and then extrapolating a predicted $\dot{V}o_2max$ from $\dot{V}o_2$ and HR. To date, this test has been used primarily with older individuals.[71–73] The details of the SPWT are presented in the Appendix.

Reliability and validity. The test-retest reliability for measurements obtained with the SPWT when it was repeated a few days later for the older group was ±5.2%, ±4.7%, and ±11% for the fast, normal, and slow paces, respectively.[70] The younger group varied by ±7%, but

Table 6.
Modified Shuttle Walking Test: Protocol^a

Level	Speed (m/s)	Speed (mph)	No. of Shuttles
1	0.50	1.12	3
2	0.67	1.50	4
3	0.84	1.88	5
4	1.01	2.26	6
5	1.18	2.64	7
6	1.35	3.02	8
7	1.52	3.40	9
8	1.69	3.78	10
9	1.86	4.16	11
10	2.03	4.54	12
11	2.20	4.92	13
12	2.37	5.30	14

^{a} Reprinted with permission of the BMJ Publishing Group from Payne GE, Skehan JD. Shuttle walking test: a new approach for evaluating patients with pacemakers. *Heart.* 1996;75:414–418.

no difference was found between the 2 tests on separate days. In terms of validity, the assessments (ie, standardized HR from the SPWT and a progressive cycle test) were correlated (r=.79).[70]

Strengths and weaknesses. The SPWT assesses cardiopulmonary fitness as well as walking efficiency, both of which are beneficial in daily activities.[70] This test is suitable for individuals requiring mobility devices or when a treadmill or cycle ergometer is not indicated. This test may also be suitable for monitoring an older person's mobility status over time, including the effects of aging and the effect of using mobility aids and devices.[70] The information obtained from this test can provide safety guidelines (eg, for crossing an intersection safely requires a speed of 3.5 ft/s).[24] Individuals who are at risk for injury while crossing an intersection may be identified. Individuals who are not able to walk at this speed should be identified as being not safe, and alternative means of mobility or mobility aids need to be recommended.

This test is limited because it does not provide a measure of endurance and may not be sufficiently sensitive to test individuals with higher levels of function. For some individuals with diminished function, it may be too difficult to complete the 3 selected walks with only 5 minutes of rest.

Modified Shuttle Walking Test

Description. The Modified Shuttle Walking Test (MSWT) was modified from the 20-MST to provide a standardized progressive test for obtaining a symptom-limited maximum performance in individuals with chronic airway obstruction (CAO).[74,75] The individual walks up and down a 10-m course at incremental speeds

of 0.17 m/s each minute dictated by a prerecorded audio signal on a cassette deck[74] (Tab. 6), whereas the original 20-MST required the individual to run a 20-m distance at a starting speed of 8.5 km/h with increments of 0.5 km/h each minute.[58]

A sample of 35 individuals with CAO aged 45 to 74 years was used to develop the test.[74] This test has been further validated on individuals with pacemakers.[76] Singh and colleagues[74,75] have recommended the MSWT for use as an assessment tool for individuals with a wide range of cardiac and respiratory disabilities. The details of the MSWT are shown in the Appendix.

Reliability and validity. The measurements obtained with this test were replicable in a sample of 10 individuals after one practice trial.[74] The mean difference between trials 2 and 3 was −2.0 m (95% confidence interval of −21.9 to 17.9 m). The validity of measurements obtained with the test, which was established by comparing the distance completed during the MSWT with the distance completed during the 6-Minute Walk Test (6-MWT), was moderate (rho=.68).[74] The HRs, however, were higher on the MSWT, indicating a greater cardiovascular response. A strong relationship (r=.81 and r=.88) was observed on comparing the $\dot{V}o_2$max recorded in 2 tests using treadmill walking with the $\dot{V}o_2$max recorded during the MSWT.[75]

Strengths and weaknesses. The MSWT requires little equipment and is easy to administer. The audio signal standardizes the increments in walking speed and motivates the individual. We believe that the initial speed is sufficiently slow to be used with most types of patients. No individual in the studies attained the highest level (ie, level 12).[74,75] This test can be used to prescribe an appropriate walking speed for an exercise program by evaluating the individual's HR and RPE responses at the various stages.[74]

This test, however, requires a near-maximal effort by having the speeds continue to increase. We believe, therefore, that it is essential to monitor the individual during the test to ensure that she or he is responding appropriately. Familiarizing the individual with the pacing required for the test may require some time.

Bag and Carry Test

Description. The Bag and Carry Test (BCT)[77] is used to assess a task that evaluates both endurance and muscle force. The BCT involves walking a circuit carrying a 0.9-kg package for 7.5 m, up and down a 4-step flight of stairs, and back 7.5 m. On the completion of each circuit, 0.9 kg is added to the package until the individual can no longer complete the circuit. It requires 10

minutes to complete. A sample of 61 women aged 48 to 93 years was recruited from the community and a residential home. Fifty-six subjects completed the test. The maximal weight they could carry up and down the stairs ranged between 3 and 26 kg. The test developers concluded that this test was easy to administer and suitable for testing individuals with higher levels of function. The details of the BCT are presented in the Appendix.

Reliability and validity. The test-retest reliability of measurements obtained with the BCT was established by administering the BCT 3 days later (r=.89). Maximal HR was 90%±10% of the HR achieved during the $\dot{V}o_2$peak test on a cycle ergometer. The BCT correlated with force of the quadriceps femoris muscle (r=.43), hamstring muscle (r=.54), gastrocnemius muscle (r=.52), and soleus muscle (r=.62).[77]

Strength and weaknesses. The BCT is designed to integrate endurance, muscle force, and balance capability and is based on an everyday activity. This test, in our view, is easy to administer and can be used in research and clinical settings. However, it may be difficult to replicate the test with 4 steps. A platform or landing should be at the top of the stairs to allow the individual to turn around safely.

The guidelines for administering this test are not well described in the literature. There are no specifications regarding the height of the steps, whether the individual is allowed to use a handrail for support, or whether a practice trial is required. In the absence of criteria for administering the test, this test could become a maximal test if the individual is not properly monitored during the test. We argue that this test has the potential to be a very useful submaximal exercise test if the individual is timed as opposed to being scored by only the weight he or she carried. The number of circuits completed in a specified time could be measured, or the time to complete the circuit while carrying a specified weight and walking at a safe and comfortable pace could be scored.

Timed Up & Go Test

Description. The Timed Up & Go Test (TUGT)[78] was modified from the Get-up & Go Test.[79] Both tests are based on a functional task of rising from a standard armchair, walking 3 m, turning, and returning to the chair. Podsiadlo and Richardson,[78] however, changed the scoring system from an observer rating of 1 to 5 to a timed version. The test was modified using a sample of 60 frail, community-dwelling, elderly individuals (23 men and 37 women, aged 60 to 90 years) and 10 volunteers with no health problems (6 men and 4 women, aged 70 to 84 years). Medical diagnoses of the study population included cerebrovascular accident

(n=23), Parkinson disease (n=10), rheumatoid arthritis or osteoarthritis (n=9), and miscellaneous conditions (eg, postsurgical hip fractures, general deconditioning) (n=8).[78] The TUGT has been used as a test of mobility to assess change following an exercise program for elderly individuals aged 79 to 86 years[80] and aged 75 to 96 years.[81] No improvement in mobility based on this test following an exercise programs was reported.[80,81] The details of the TUGT are given in the Appendix.

Reliability and validity. The interrater reliability for times obtained on the same day and the intrarater reliability tested 3 days to 5 weeks apart were good (intraclass correlation coefficient=.99 for both).[78] Validity was assessed by correlating the time (in seconds) on the TUGT with the log-transformed scores on the Berg Balance Scale ($r=-.72$), gait speed ($r=-.55$), and Barthel Index of Activities of Daily Living ($r=-.51$). The correlations were negative, indicating that those individuals who took longer with the TUGT had lower scores on the Berg Balance Scale, with gait speed, and on the Barthel Index.

Strengths and weaknesses. The TUGT is easy to administer, and no training is required. This test is easy to perform in research and clinical settings. The results from this test provide information related to mobility. Based on the time taken to complete the test, the level of assistance required in mobility tasks can be determined.[78]

A limitation of this test is that it may not detect a change following an exercise program because of the lack of sensitivity of the measure.[81] Further studies are warranted to examine its sensitivity, using a larger sample, and to investigate its predictive capacity. Sensitivity could possibly be improved by increasing the distance walked or having subjects sit down and get up again at each end of the 3-m walkway, but research is needed to determine whether this is true.

12- and 6-Minute Walk Tests

Description. The 12-MWT was introduced by McGavin and colleagues[82,83] to assess the distance covered in 12 minutes in individuals with chronic bronchitis. The total distance covered in 12 minutes is recorded, and the individual is allowed to stop and rest. This test was modified from the 12-MRT described by Cooper[53] for individuals without health problems. The 12-MWT has been used primarily for people with COPD,[82–91] but it has also been used with college-aged students.[92]

Butland et al[93] reported that similar results could be obtained in 6 minutes. Guyatt et al[94] applied the 6-MWT in individuals with heart failure. The 6-MWT has been used with individuals with end-stage lung disease,[95] people with chronic heart failure,[96,97] people with COPD,[98–100] children who are severely ill,[101] people with chronic renal failure,[102] and older adults between the ages of 65 and 89 years.[103] Two practice tests appear to be required to obtain reproducible results,[93,94] the walking circuit needs to be identical,[92] and encouragement needs to be standardized.[27] Walk tests with durations of 4 minutes[104] and 2 minutes[93] have also been reported. The details of the 6-MWT and the 12-MWT are presented in the Appendix.

Reliability and validity. Reliability has been assessed for measurements obtained with the 12-MWT. Mungall and Hainsworth[89] reported a coefficient of variation of ±8.2% over 6 tests. This statistic, however, is not a probabilistic measure, which is normally used to assess reliability. If the results of the first 2 tests were eliminated, however, the coefficient of variation was reduced to ±4.2%. Guyatt et al[94] also reported that 2 practice tests are required. Other researchers[95,96] have reported intraclass correlation coefficients of .96 to .99 between the second and third administrations of the 6-MWT, suggesting that only one practice test is required.

The concurrent validity of measurements obtained with the 6-MWT and the 12-MWT based on measurements of $\dot{V}o_2max$ or $\dot{V}o_2peak$ is not clear. Some investigators have reported a correlation between the distance covered in the 6-MWT and $\dot{V}o_2peak$ ($r=.64$[96] and $r=.70$[101]) as well as between the distance covered in the 12-MWT and $\dot{V}o_2max$ ($r=.49$[85] and $r=.52$[82]). Other researchers have reported no correlation between $\dot{V}o_2max$ and either the distance covered in the 6-MWT[94] or the distance covered in the 12-MWT.[82] The physiologic demand of the walk test appears to be distinct from that of cycle ergometer tests and, therefore, may be a better indicator of function in normal daily activities.[102,105] The correlation between lung function and the distance covered in the 6-MWT and the 12-MWT has also shown conflicting results.[85,99,100]

Strengths and weaknesses. The 6-MWT and the 12-MWT are simple tests that are inexpensive to administer. Walking for a given time seems, in our opinion, to correspond to functional activities used in daily activities. These tests, therefore, can be administered to individuals without health problems and to patients with a variety of diagnoses. The use of a standard time rather than a predetermined distance provides a better test of endurance.[82] The tests allow the individual to set her or his own pace and stop if necessary. The 12-MWT can be used to detect a change following an exercise program.[86]

In the literature in which these tests are described, the number of practice trials varies. Often only one practice

test was given,[99–102] and there was considerable variation in the rest periods between tests. Some investigators[95,96,100,102] reported having the subjects perform the test on the same day as the practice, whereas other investigators[94,99,105] reported having the test and practice on separate days. In addition, different versions of the instructions have been used for both the 6-MWT and the 12-MWT. Some investigators[101] stated in their instructions that the individual was allowed to stop if necessary, whereas other investigators[85] instructed the individual to pace herself or himself so that she or he would not have to stop. The scoring of the test has also varied. Most investigators[83,94,105] used the final distance (ie, that of the last test trial), whereas some investigators[99] reported the longest distance of all test trials. We believe that other limitations of the timed walk tests include lack of monitoring of physiological variables while the individual is completing the test and the lack of specific performance criteria to ensure that a maximal effort is not performed.

Other Performance Tests

Performance tests are frequently incorporated as a measure of mobility in global physical assessments used for elderly people. The most common performance test is a measure of walking speed, which is similar to the 3 walking speeds (ie, slow, normal, and fast) used with the SPWT. Typically, a 10-ft walk[106–108] is used for assessing individuals who are confined indoors and a 50-ft walk[107,109–111] is used for all others. A 30-m walk has also been used, as this is the usual distance for pedestrian crossings.[112] The instructions are for the individual to walk from a standing start at his or her regular pace and to use any mobility devices that he or she normally uses.[106] The individual is timed, and the walking speed (in meters per second or feet per second) is calculated. Reports of average walking speed range from 0.74 ± 0.29 m·s^{-1} for individuals aged 60 to 99 years[113] to 1.1 and 1.2 m·s^{-1} for 70-year-old women and men with no health problems, respectively.[112]

The assessment of walking speed is very important for assessing independent mobility in the community. Pedestrian intersection crossing times are calculated based on a walking speed of 1.22 m·s^{-1}.[114] A walking speed of 11.5 m·min^{-1} is a threshold value for predicting nursing home status,[107] with a normal walking speed being 70 m·min^{-1}.[107] Two factors, quadriceps femoris muscle weakness and joint impairment, are thought to be critical variables in determining walking speed, which, in turn, determines some aspect of dependency in elderly people. Variations in walking speed are due to a change in stride length rather than an alteration in frequency or cadence.[113] The onset of pathology shortens the stride length and influences speed of walking.[113]

Chronologic age is not thought to be a primary factor in determining gait speed.[113]

Researchers have assessed a maximum walking speed for a given distance (eg, 30 m). In a sample of 70-year-old subjects (n=602), the maximum walking speed was the most reliable predictor of dependence in activities of daily living.[112] The critical levels for the threshold of being dependent in activities of daily living was found to be a maximum walking speed of 1.7 m·s^{-1} in men and 1.5 m·s^{-1} in women. It is not entirely clear whether a decline in cardiopulmonary fitness affects walking speeds for short distances; it is more likely to be a contributing rather than a primary factor.[112]

Other performance tests cited in the literature include a step test. This test requires 3 boxes combined to form steps of 10, 20, 30, 40, and 50 cm in height and a handrail on the wall.[112] The highest possible step height that the individual is able to climb up and down with either leg and without a rail is recorded. There are also variations of this step test.[115,116] Correlations have been reported between the maximum step height up and down with a comfortable walking speed in 70-year-old men ($r=.39$) and women ($r=.37$).[112]

An obstacle course described by Imms and Edholm[113] is used in a test that is similar to the BCT. In this test, the individual rises from a chair, walks across the room, climbs 3 stairs (rails on either side), turns around, descends the stairs, and returns to the chair. The individual is allowed to go at her or his own speed and to use a mobility aid. Two practice trials are given, and the time (in seconds) taken to complete the course is recorded. In a sample of 71 subjects (28 men and 43 women) aged 60 to 99 years, the time to complete the course was not correlated with age but was correlated with walking speed ($r=-.80$).[113]

Examples of Test Selection

1. The patient is a 65-year-old man with severe chronic airflow limitation and right atrial enlargement. He has no history of angina but does have hypertension, which is controlled with medication. He is 18.1 kg (40 lb) overweight and is unaccustomed to physical activity. His activity is normally terminated by shortness of breath.

Indications: to establish an exercise profile to ensure that he is safe to undertake an exercise program and to define the parameters for such a program.

Test: 6-MWT or SPWT.

Clinical Decision-Making Process: The 6-MWT and the SPWT are both suited for older patients with chronic lung disease. This patient is deconditioned, overweight, and hypertensive. These tests enable him to perform an

activity (ie, walking) that is useful to him on a daily basis. In addition, with portable equipment, including HR monitor, BP measurement apparatus, and pulse oximeter, he can be readily monitored. Furthermore, the scale of breathlessness can be used to assess his symptoms. The physical therapist can correlate the rating of breathlessness and physiologic parameters to prescribe the parameters of an exercise program, including type of exercise, intensity, frequency, duration, continuous versus discontinuous program, and its course. These tests can be repeated at various intervals to evaluate the outcome of the training program.

2. The patient is a 52-year-old man who had bypass surgery 10 years ago. He had one recurrence of angina. He has intermittent claudication in the left calf at a moderate walking speed.

Indications: to establish safe exercise intensity (no anginal symptoms) and a training program for his peripheral vascular disease as well as heart disease.

Test: Modified Bruce Treadmill Test, SPWT, or 6-MWT.

Clinical Decision-Making Process: This patient is showing signs and symptoms of reocclusion of his coronary arteries and stenosis of a lower-extremity artery, which results in claudication. He could be a candidate for maximal exercise testing; however, if he stops because of leg pain, the test results will be limited. Alternatively, he could undergo submaximal exercise testing (eg, Modified Bruce Treadmill Test, SPWT, 6-MWT). Because of his cardiac history, precautions must be taken. Having a cardiologist present is recommended, and the treadmill test is preferable for monitoring electrocardiographic activity. If the electrocardiogram is normal, the SPWT or the 6-MWT can be performed, and one of these tests can be used to assess training response, if preferred. The parameters of the training program are set to keep the patient below his anginal threshold and his leg pain tolerable.

Summary and Conclusions

Physical therapists are clinical exercise specialists who apply exercise as an assessment and diagnostic tool and in treatment. We believe that they should have a thorough knowledge of exercise testing, including submaximal exercise testing. Physical therapists, in our opinion, need to assume a role in refining existing exercise tests and measures and to assume a leadership role in developing new tests and measures. Refinement of submaximal exercise tests is needed to increase their sensitivity as assessment, diagnostic, and treatment outcome tools and to provide valid indexes of a person's capacity to assume a given type of employment, homemaking activities, and activities of daily living. They also need to serve as a basis for exercise prescription.

We believe that there is a need for standardized submaximal ergometer tests for people with musculoskeletal limitations, people who have impaired balance, people who are overweight, people who are unable to walk on a treadmill for other reasons, and for people who require close monitoring during exercise. There is also, in our opinion, a need for the development of upper-extremity submaximal exercise tests for people with lower-extremity paresis or severe deformity.

We contend that stringent monitoring of exercise responses is essential both for test validity and for safety. When testing people with a wide range of conditions, including cardiovascular and cardiopulmonary conditions that can be life threatening, even people without known health problems can exhibit unexpected responses. People without known health problems, for example, can have cardiac dysrhythmias; and this incidence increases with advancing age.[20] Safety and minimizing undue strain, in our view, are essential in planning and implementing submaximal exercise testing.

Research is also needed for the development and refinement of scales used to assess exercise response (eg, exertion, breathlessness, fatigue, discomfort or pain, and even well being associated with physical activity). Given that people are limited by their symptoms that correlate to physiologic measures, assessment of their symptoms can provide critical information about their exercise responses as well as a basis for setting the intensity of tolerable physical activity or an exercise program.

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Appendix.
Predictive and Performance Submaximal Exercise Tests[a]

Predictive Submaximal Exercise Tests

Test	Set-up and Supplies	Practice	Protocol	Outcome	Regression Equations	Population Studied
Modified Bruce Treadmill Test[5,29,30]	Clinic/laboratory • Motor-driven treadmill • HR monitor • Stopwatch • Electrocardiogram (optional)	Familiarize the individual with treadmill walking	• The individual uses 1 to 2 fingers for handrail support • Follow the Modified Bruce Treadmill Test protocol (Tab. 1) and the individual continues until he or she develops predetermined signs or symptoms[30] • Reduce the grade to 0%, reduce speed, and continue walking slowly to cool down	A predicted $\dot{V}O_2$max value $(mL \cdot kg^{-1} \cdot min^{-1})$ is obtained using the appropriate regression equation	1. Bruce and colleagues[5,30]; Ward et al[18] (a) Active men, estimated $\dot{V}O_2$max $(mL \cdot kg^{-1} \cdot min^{-1})$ = $3.778 \times$time (min)+0.19 (b) Sedentary men, estimated $\dot{V}O_2$max=$3.298 \times$time (min) +4.07 (c) Patients with cardiac disease, estimated $\dot{V}O_2$max=$2.327 \times$ time (min)+9.48 (d) Adults in good health, estimated $\dot{V}O_2$max= $6.70 - 2.82 \times$sex (1=men and 2=women)+$0.056 \times$ time (s) 2. Foster et al[30] $\dot{V}O_2$max $(mL \cdot kg^{-1} \cdot min^{-1})$= $14.76 - 1.38 \times$time (min) $+0.451 \times$time (min)^2 $-0.012 \times$time (min)^3	• Men and women in good health • Patients with cardiac disease • Endurance athletes • Sedentary individuals (see Bruce et al[5])
Single-Stage Submaximal Treadmill Walking Test (SSTWT)[12]	Clinic/laboratory • Motor-driven treadmill • HR monitor • Stopwatch • Rating of perceived exertion (RPE) scale	Familiarize the individual with treadmill walking	• Establish a safe, but comfortable, walking speed between 2.0 and 4.5 mph, at a 0% grade for 4 min; an HR between 50% and 70% of age-predicted HRmax should be obtained • Increase the grade to 5% and walk at the established speed for 4 min • Record the HR and RPE at the end of the warm-up session and the first stage • Reduce the grade to 0% and continue walking slowly to cool down	A predicted $\dot{V}O_2$max value $(mL \cdot kg^{-1} \cdot min^{-1})$ is obtained using the regression equation	Estimated $\dot{V}O_2$max $(mL \cdot kg^{-1} \cdot min^{-1})$= $15.1 + 21.8 \times$speed (mph) $-0.327 \times$HR (bpm) $-0.263 \times$speed$\times$age (y) $+0.00504 \times$HR$\times$age+5.98 $\times$sex (0=women, 1=men)	• Men and women in good health aged 20–59 y

Test	Setting	Equipment	Familiarization	Procedure	Calculation	Reference Populations
Astrand and Ryhming (A-R) Cycle Ergometer Test[31,32]	Clinic/laboratory	• Mechanically or electrically braked cycle ergometer • HR monitor • Stopwatch • Metronome	Familiarize the individual with pedaling on a cycle ergometer	• Adjust the seat height • Select a workload of 450 kg·m·min^{-1} (75 W), 600 kg·m·min^{-1} (100 W), or 900 kg·m·min^{-1} (150 W), depending on level of training and sex; a suitable workload is 450 or 600 kg·m·min^{-1} for women and 600 or 900 kg·m·min^{-1} for men; for an older individual or an untrained individual, a workload of 300 kg·m·min^{-1} may be appropriate • The pedal speed is set at 50 rpm, and the first workload is maintained for 6 min; measurements of HR are taken for the last 15 to 20 s of every minute • If the individual has an HR between 130 and 170 bpm and the difference between the HR values of minutes 5 and 6 is less than 5 bpm, the test is finished • If the difference between the HR values of minutes 5 and 6 is greater than 5 bpm, the individual continues pedaling for 1 min or longer; if the individual's HR is less than 130 bpm, the workload is increased by 300 to 600 kg·m·min^{-1} and is maintained for another 6 min; the test is continued until the HR values for minutes 5 and 6 are within 5 bpm • On completion of the test, the individual should continue to pedal with no resistance to cool down	The mean value for the HRs of the last 2 min and the final workload (kg·m·min^{-1}) are required for the nomogram (Fig. 1); multiply the derived $\dot{V}O_2$max value (L·min^{-1}) by the age-correction factor (Tab. 2)	• Men and women in good health aged 18–30 y[31] • Men in good health aged 19.9±2.39 y; modified protocol[41] • Men in good health aged 19.7±2.2 y[42] • Pregnant women aged 30.9±0.7 y (SE) at time of delivery[40] • Men in good health aged 18–24 y (conditioned and sedentary)[39] • Men in good health aged 17–33 y[38] • Men in good health aged 47.7±7.3 y[37] • Men and women in good health 20–70 y[35] • Men in good health 23–49 y[36] • Men in good health (trained and untrained) aged 20–29 y[33]

Predictive Submaximal Exercise tests

Test	Set-up and Supplies	Practice	Protocol	Outcome	Regression Equations	Population Studied
Canadian Aerobic Fitness Test (CAFT)[44,45,52] and modified CAFT (mCAFT)[46,47,51]	At home or clinic/laboratory • A double 8-in (20.3-cm) step • HR monitor • Prerecorded audiotape • Cassette recorder • Sphygmomanometer • Stethoscope • Stopwatch	Demonstrate the stepping cycle and allow the individual to practice	• CAFT[44,52] • Measures of resting BP and HR are optional • Following a warning signal on an audiotape, the individual is instructed to climb a double 8-in step for a 3-min "warm-up" at a stepping tempo based on his or her age (see Tab. 3)[52]; the Standardized Test of Fitness package[52] contains the cassettes with the various tempos; following the first stage, the instructions on the cassette indicate when to obtain a 10-s measurement of HR • Consult the table "Ceiling Postexercise Heart Rates" (see Tab. 4)[52] to determine whether the individual continues for a second stage or whether the test is terminated • If the individual has an HR below the ceiling HR indicated in the table, he or she proceeds to the second stage; HR is measured again following the second stage to determine whether he or she proceeds to the third and final stage; a measure of HR is taken for 10 s following the third stage • In the postexercise period, measurements of BP can be taken in the first 2 min and measurements of resting HR can be taken in the third minute • Following the test, the individual should continue stepping or walking slowly to cool down • For the protocol of the CAFT, see Weller and colleagues[46,47]	Consult the "Physical Fitness Evaluation Chart" (see Tab. 5) to determine level of fitness based on the final exercise HR reading[52]; a predicted $\dot{V}O_2$max value ($\text{mL·kg}^{-1}\cdot\text{min}^{-1}$) is obtained using the regression equation	1. CAFT (Jette et al[45]) estimated $\dot{V}O_2$max ($\text{mL·kg}^{-1}\cdot\text{min}^{-1}$)= $42.5+16.6\times\dot{V}O_2$ (L·min^{-1})*$-0.12\times$body weight (kg)$-0.12\times$HR following last stage (bpm)$-0.24\times$age (y) *$\dot{V}O_2$ is the average oxygen cost of the last completed stage (L·min^{-1}); obtain value from the table "Energy Requirements for the Various Stages of the CAFT"[45] 2. mCAFT (Weller et al[51]) estimated $\dot{V}O_2$max ($\text{mL·kg}^{-1}\cdot\text{min}^{-1}$)= $32.0+16.0\times\dot{V}O_2$ for final stage (L·min^{-1})$-0.17\times$body weight (kg)$-0.24\times$age (y)	• Men and women in good health aged 15–69 y[44,45] • Men and women in good health aged 15–74 y, modified protocol[47] • Men and women in good health aged 15–69 y[46,47] • Men and women in good health aged 15–69 y[51]

Test	Equipment	Procedure	Calculation	Population
12-Minute Run Test (12-MRT)[53]	Measured track • Stopwatch • Tape measure Familiarize the individual with the track and the concept of pacing	• The individual is instructed to "cover the longest possible distance in 12 min, running preferably but walking whenever necessary to prevent becoming excessively exhausted"[53] • Record the distance in miles completed in 12 min • On completion of the test, the individual should continue walking to cool down	A predicted $\dot{V}O_2$max value $(mL \cdot kg^{-1} \cdot min^{-1})$ is obtained using the regression equations 1. Cooper[53] walk/run distance=$0.3138+0.0278 \times \dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$ 2. Ward et al[18] estimated $\dot{V}O_2$max $(mL \cdot kg^{-1} \cdot min^{-1})=$ $35.97 \times$distance (mile) -11.29	• Men in good health aged 17–52 y[53] • Men in good health aged 18–23[55]
20-Meter Shuttle Test (20-MST)[57–59]	Measured corridor • HR monitor • Prerecorded audiotape • Cassette recorder • Pylons • Tape measure Familiarize the individual with the course	• The individual runs between 2 lines 20 m apart; when the individual hears a short sound, he or she has to be on 1 of these 2 lines, and when a long sound is heard, it indicates a change in stage • The first stage is 8.5 km·h⁻¹ for women and 10 km·h⁻¹ for men; the speed is increased by 0.5 km·h⁻¹ per 1-min stages (see Fig. 2) • The individual continues until she or he is unable to maintain the rhythm of running • The speed at the last completed running stage is termed the "maximal aerobic speed" (MAS) • On completion of the test, the individual should continue walking to cool down	A predicted $\dot{V}O_2$max value $(mL \cdot kg^{-1} \cdot min^{-1})$ is obtained using the regression equations 1. General equation (Leger et al[58] estimated $\dot{V}O_2$max $(mL \cdot kg^{-1} \cdot min^{-1})=31.025$ $+3.238 \times$speed $(km \cdot h^{-1})$ $-3.248 \times$age (y) $+0.1536 \times$(age$\times$speed) 2. Adults (Leger et al[58] estimated $\dot{V}O_2$max $(mL \cdot kg^{-1} \cdot min^{-1})=$ $-24.4+6.0 \times$speed $(km \cdot h^{-1})$	• Men and women in good health aged 20–45 y[58] • Boys and girls in good health aged 6–19 y[58,62] • Boys and girls in good health aged 8–19 y[58] • Active men in good health aged 18–42 y (modified protocol)[60] • Men and women with asthma aged 12–17 y[63]

Predictive Submaximal Exercise tests

Test	Set-up and Supplies	Practice	Protocol	Outcome	Regression Equations	Population Studied
1-Mile Track Walk Test (Rockport Fitness Test) (1-MTW)[64]	Measured track • Stopwatch • HR monitor • Tape measure	• A minimum of 2 tests are required; the times of both tests should be within 30 s of each other; otherwise, subsequent tests are performed until this is achieved	• The individual is instructed "to walk as fast as possible around the course"[64] • Record HR at the end of every quarter mile • Record the time to complete the test (in minutes) • On completion of the test, the individual should continue walking to cool down	The HR at the end of the fourth quarter of the test is used for the regression equation; a predicted $\dot{V}O_2max$ value ($L\cdot min^{-1}$) is obtained using the regression equation	Kline et al[64] estimated $\dot{V}O_2max$ ($L\cdot min^{-1}$)=6.9652+0.0091 ×body weight (lb) −0.0257×age (y) +0.5955×sex (men=1, women=0)−0.2240×T_1 (track walk time) −0.0115×HR_{1-4} (fourth quarter HR for track walk)	• Men and women in good health aged 30–69 y[64] • Men and women with mental retardation aged 26–40 y[65]

Performance Submaximal Exercise Tests

Test	Set-up and Supplies	Practice	Protocol	Outcome	Population Studied
Self-Paced Walking Test (SPWT)[70]	Measured corridor • HR monitor • Stopwatch • Tape measure • Pylons	Familiarize the individual with the course	• The individual is instructed to walk a measured distance (ie, 250 m) at 3 different speeds, with a 5-min rest between trials: (a) rather slowly (ie, slow pace), (b) at a normal pace, neither fast nor slow, and (c) rather fast, but without overexerting yourself (ie, fast pace) • Record the time in seconds for each of the 3 trials • Following the 3 trials, the individual should continue walking slowly to cool down	For each walking trial, the speed, time to complete the distance, and stride frequency are calculated; in addition, average HR, stride length, and a predicted $\dot{V}O_2max$ value can be determined	• Men in good health aged 64–66 y • Active men in good health aged 19–21 y[70] • Men in good health aged 19–66 y[71,72]

Test	Setup/Equipment	Practice	Procedure	Measurement	Population
Modified Shuttle Walking Test (MSWT)[74,75]	Measured corridor 10 m in length with 2 pylons placed 0.5 m from each end • HR monitor • Prerecorded audiotape • Cassette recorder • Pylons • Tape measure • RPE scale	One practice trial is required	• The test starts with a triple beep; after that, a single beep indicates when the individual should be walking around the cone; a triple beep also signifies a change in stage • The individual is instructed: "Walk at a steady pace, aiming to turn around when you hear the signal, you should continue to walk until you feel that you are unable to maintain the required speed without becoming unduly breathless"[74] • The MSWT starts at 0.50 m·s^{-1} (1.12 mph) for level 1; each level lasts 1 min, and the speed is increased by 0.17 m·s^{-1} for 12 min; the final speed is 2.37 m·s^{-1} (see Tab. 6) • The individual continues until: (a) he or she is too breathless to maintain the required speed, (b) he or she is more than 0.5 m away from the cone when the beep is sounded, or (c) attainment of 85% of age-predicted HRmax • The total number of completed shuttles (10-m lengths) at each level is recorded (in meters) • On completion of the test, the individual should continue walking slowly to cool down	Total number of shuttles at each level; report total distance (in meters)	• Men and women with chronic airway obstruction aged 45–74 y[74,75] • Men and women with pacemakers aged 27–74 y[76]
Bag and Carry Test (BCT)[77]	Measured course 7.5 m in length, in addition to a 4-step flight of stairs • HR monitor • Package to carry weights • Weights of 0.9 kg each • Stopwatch • Tape measure		• The individual is instructed to walk the circuit carrying a package weighing 0.9 kg, with both arms, 7.5 m, up and down a 4-step flight of stairs, and back 7.5 m • On completion of each circuit, 0.9 kg of weight is added to the package, the individual continues until he or she is no longer able to complete the circuit carrying the package; record the heaviest weight the individual carried	The heaviest weight (in kilograms) carried by the individual	• Women aged 48–93 y

Performance Submaximal Exercise Tests

Test	Set-up and Supplies	Practice	Protocol	Outcome	Population Studied
Time Up & Go Test (TUGT)[78]	Clinic/corridor that has at least a 3-m floor space • Armchair (seat height of 46 cm) • Stopwatch • Tape • Tape measure	One practice trial is required	• The individual starts with his or her back against the chair, arms resting on the armrests, and mobility aid in hand, if needed; no physical assistance is given • Instructions are "On the word 'Go,' you are to get up and walk at a comfortable and safe pace to a line on the floor 3 meters away, turn, return to the chair, and sit down again"[74]; record the time (in seconds)	Report the time (in seconds)	• Older inpatients and outpatients; male and female geriatric patients aged 52–74 y[79] • Elderly men and women in good health aged 70–84 y • Men and women, aged 60–90 y, with Parkinson syndrome, stroke, rheumatoid arthritis and osteoarthritis, postsurgical hip fractures, general deconditioning[78] • Elderly men and women with limited mobility aged 75–96 y[81]
12-Minute Walk Test (12-MWT)[82,83] 6-Minute Walk Test (6-MWT)[27,94]	Measured corridor, approximately 33 m in length • HR monitor • Stopwatch • Tape measure	Two practice trials are required	• The individual walks a measured distance (eg, 33 m) • For the 12-MWT, the individual is instructed "to cover as much ground as possible on foot in 12 minutes and to keep going continuously if possible but not to be concerned if you have to slow down or rest"[82,83]; at the end of the test, subjects should feel they could not have covered more ground in the time • For the 6-MWT, the individual is instructed "to walk from end to end, covering as much ground as possible in 6 minutes"[94]; at the end of the 6 or 12 min, the individual is instructed to stop; the total distance is recorded • If encouragement is given, predetermined phrases should be delivered every 30 s while facing the individual • On completion of the test, the individual should continue walking to cool down	Report the total distance covered (in meters)	• 12-MWT; men with chronic bronchitis aged 40–70 y[82] • 12-MWT; men and women with chronic bronchitis aged 22–75 y[83] • 6-MWT; patients with chronic heart failure (respiratory and cardiac conditions) aged 64.7±8.3 y[27,94] • 6-MWT; men and women with COPD aged 40–84 y[92] • 12-MWT, modified protocol; men with COPD aged 67±4 y[85] • 12-MWT; men and women with COPD aged 31–75 y[87] • 12-MWT; men and women with COPD aged 68.4±9.6 y[88] • 6-MWT; men and women with COPD aged 48–85 y[98] • 4-MWT; men and women with low back pain (no age range reported)[104] • 12-MWT; men with chronic respiratory disability aged 61.2±5.0 y[86] • 6-MWT; men and women with advanced heart failure aged 49±8 y[96]

- 6-MWT; men and women with chronic renal failure aged 22–67 y[102]
- 6-MWT; men and women with end-stage lung disease aged 43.5±11 y[95]
- 6-MWT; men and women with chronic lung disease and asthma aged 57.4±12.9 y and 62.3±9.1 y[100]
- 6-MWT; boys and girls with cystic fibrosis, pulmonary hypertension, and obstructive lung disease aged 9–19 y[101]
- 12-MWT; men and women with chronic airway obstruction aged 38–75 y[84]
- 12-MWT; men and women with chronic obstructive lung disease aged 49–73 y[90]
- 6-MWT; men and women with COPD aged 58±10 y[99]
- 6-MWT; elderly people and men and women with chronic heart failure aged 70–90 y[97]
- 12-MWT; men with chronic obstructive airway disease aged 47–64 y[89]

[a]HR=heart rate, V̇o₂max=maximum oxygen consumption, HRmax=maximal heart rate, COPD=chronic obstructive pulmonary disease, BP=blood pressure, V̇o₂=oxygen consumption.