Science of Strength and Conditioning Series

NSCA's Guide to TESTS AND ASSESSMENTS

NSCA™
National Strength and Conditioning Association

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EDITOR

NSCA's Guide to Tests and Assessments

National Strength and Conditioning Association

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Human Kinetics

Library of Congress Cataloging-in-Publication Data

National Strength & Conditioning Association (U.S.)
NSCA's guide to tests and assessments / National Strength and Conditioning Association ; Todd Miller, editor.
p. ; cm. -- (Science of strength and conditioning series)
Includes bibliographical references and index.
ISBN-13: 978-0-7360-8368-3 (hard cover)
ISBN-10: 0-7360-8368-5 (hard cover)
I. Miller, Todd, 1967- II. Title. III. Series: Science of strength and conditioning series.
[DNLM: 1. Athletic Performance--physiology--Guideline. 2. Physical Fitness--physiology--Guideline. 3. Exercise--physiology--Guideline. 4. Exercise Test--methods--Guideline. 5. Physical Examination--Guideline. 6. Sports--physiology--Guideline. QT 260]

613.7--dc23

2011038488

ISBN-10: 0-7360-8368-5
ISBN-13: 978-0-7360-8368-3

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The web addresses cited in this text were current as of August 2011, unless otherwise noted.

Developmental Editor: Kevin Matz; **Assistant Editors:** Steven Calderwood and Bethany J. Bentley; **Copyeditor:** Patsy Fortney; **Indexer:** Betty Frizzell; **Permissions Manager:** Dalene Reeder; **Graphic Designer:** Nancy Rasmus; **Graphic Artist:** Joe Buck; **Cover Designer:** Keith Blomberg; **Photographs (interior):** Neil Bernstein, all photos © Human Kinetics unless otherwise noted; **Photo Asset Manager:** Laura Fitch; **Visual Production Assistant:** Joyce Brumfield; **Photo Production Manager:** Jason Allen; **Art Manager:** Kelly Hendren; **Associate Art Manager:** Alan L. Wilborn; **Art Style Development:** Jennifer Gibas; **Illustrations:** © Human Kinetics; **Printer:** Sheridan Books

We thank the National Strength and Conditioning Association in Colorado Springs, Colorado, for assistance in providing the location for the photo shoot for this book.

Printed in the United States of America 10 9 8 7 6 5 4 3 2 1

The paper in this book is certified under a sustainable forestry program.

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E4846

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Aerobic Power

Jonathan H. Anning, PhD, CSCS*D

Aerobic power refers to the ability of the muscles to use oxygen received from the heart and lungs to produce energy. As this process becomes more efficient, aerobic power improves. Therefore, improvements in aerobic power are usually monitored by determining $\dot{V}O_2max$, or the maximal volume of oxygen a person consumes and uses with the active muscles during exercise.

Developing aerobic power is a lower training priority for athletes participating primarily in anaerobic activities (i.e., for which oxygen is not necessary for energy production) than it is for athletes participating in aerobic activities such as long-distance events. Obviously, long-distance walking, running, cycling, swimming, and even cross-country skiing are highly aerobic activities and thus require oxygen to produce energy. Yet, long-distance athletic potential is not entirely related to maximal aerobic power because improvements in anaerobic threshold result in competitive differences among athletes (see chapter 6) (Bosquet, Léger, and Legros 2002).

Consider the fact that sedentary people can improve aerobic power by training near the anaerobic threshold, whereas trained athletes must train above the anaerobic threshold (Londeree 1997). Nonetheless, tests specifically designed to measure maximal aerobic power during walking, running, cycling, or swimming competitions appear to be best suited for comparing endurance capabilities with performance outcomes. Conversely, aerobic power tests are not appropriate for sports performed at high intensities because these activities are predominantly anaerobic.

Because anaerobic activities are associated with greater fatigue, the value of aerobic power is limited to facilitating energy recovery during repeated efforts of such activities. Although there is no set formula for determining aerobic power needs within a sport, the repetitive high-intensity demands combined with game duration highlights a need for anaerobic system recovery. Sports that may require aerobic power to facilitate continuous recovery include field hockey, ice hockey, lacrosse, mixed martial arts, downhill skiing, soccer, wrestling, and to a lesser extent, basketball and American football (Baechle and Earle 2008). Athletes in these sports must switch instantaneously from high- to low-intensity activities, and vice versa, over the course of a game.

The additional challenge placed on athletes in anaerobic sports is recovery from dependence on the anaerobic glycolytic system, which breaks down carbohydrate to produce energy while decreasing pH levels in the body. The decrease in pH is referred to as metabolic acidosis, and this interferes with the athlete's ability to continue performing at a high level. For the athlete to overcome the fatigue associated with metabolic acidosis, the recovery process must include removing the prohibitive by-products while replacing the energy stores. Therefore, athletes involved in interval training, or the manipulation of exercise and rest ratios to maximize these metabolic pathways, are improving the aerobic and anaerobic systems simultaneously.

Another aspect of anaerobic activities experienced in sport is the foundational fitness, or progression, aspect. Even though the aerobic demand of sports such as baseball, field events, golf, and weightlifting are minimal (Baechle and Earle 2008), the proper progression of muscle adaptations begins with establishing a strong fitness foundation that includes cardiorespiratory and musculoskeletal health components during the off-season. Consequently, aerobic power need only be measured at the beginning and end of the off-season to confirm an athlete's training commitment and fitness foundation prior to preseason conditioning.

The advantage of selecting aerobic power tests for predominantly anaerobic sports is that they offer more choices, whereas individuals competing in long-distance events are limited by the specificity principle. Choosing aerobic power tests and protocols for endurance athletes should begin with knowing the person's training preferences. The next step is to ensure that the administration of the test will meet general maximal or submaximal assessment criteria. The primary criterion for ensuring the accuracy of the results of a maximal aerobic power test is that the person reaches volitional fatigue within 8 to 12 minutes. Submaximal aerobic power tests, on the other hand, should be based on research literature recommendations for protocol intensities that achieve a heart rate steady state (American College of Sports Medicine 2010). The heart rate steady state is the plateau at which the heart rate and rate of oxygen consumption tend to remain relatively stable at a given workload. An examiner can verify steady state by measuring the heart rate during the final two minutes of a protocol stage to determine whether those two measurements are within six beats per minute (bpm) of each other. Nonetheless, unless the examiner is trying to determine an athlete's ability to perform longer than 12 minutes, the recommendation is to select the maximal or submaximal aerobic power test that best matches the demands of the sport.

Tables 5.1 and 5.2 summarize the maximal and submaximal exercise tests, respectively, described in this chapter. To facilitate the selection of an appropriate cardiorespiratory test, population-specific correlations and standard errors reported in the referenced literature are included in the tables. Correlation coefficients between predicted and observed $\dot{V}O_2max$ values have been proposed at a minimum of .60 by Mayhew and Gifford (1975), but it should be noted that correlations above .80 are much more preferable (Baumgartner and Jackson 1991). In addition, a value of ±4.5 $mL \cdot kg^{-1} \cdot km^{-1}$ as a standard error of estimate is considered an acceptable range for predicting aerobic power (Dolgener et al. 1994; Greenhalgh, George, and Hager 2001). After identifying the cardiorespiratory test that appears to address the athlete's goals accurately, the fitness professional should refer to the textbook page identified in the table for more details about the specific protocols.

Regression Equation Variables

Tables 5.1 and 5.2 consist of regression equations that require the data variables in table 5.3 to perform the calculations. Some data require little skill to collect, such as age, height and weight, elapsed time (measured with a stopwatch), the distance traveled on a track, the speed and grade of the belt on the treadmill, and the cycle ergometer workload (e.g., revolutions each minute along with resistance). Conversely, collecting other forms of data requires technical proficiency. For instance, using the regression equation to determine the maximal mile run for healthy youth (Buono et al. 1991) requires a sum of skinfolds in addition to the elapsed time. Another technical proficiency is determining heart rate because it is essential for almost all of the testing protocols, especially the submaximal testing protocols used to measure improvements in aerobic power. Chapter 2 describes the techniques used to measure tricep and subscapular skinfold sites. Chapter 3 describes the palpation, heart rate monitor, and electrocardiograph methods for determining heart rate.

Maximal Exercise Testing Methods

The maximal laboratory exercise tests in table 5.1 are optimal for assessing aerobic power because they offer the best opportunity for gas measurements. Oxygen and carbon dioxide analyzers permit the collection of gases while facilitating the performance goal prescription and monitoring process. Although these gas analyzers have a high degree of sophistication in measuring cardiorespiratory fitness, the technical expertise necessary for administering and interpreting the data exceeds the scope of this chapter. Hence, only the heart rate methods for performing a maximal exercise test

TABLE 5.1 Maximal Exercise Tests Used to Predict Aerobic Power ($\dot{V}O_2max$)

MODE: TREADMILL

Test protocol	Population (age)	Regression equations ($\dot{V}O_2max$ = mL · kg^{-1} · min^{-1}; *r* value; SEE)	Textbook page	Resource
Bruce	Healthy adults (18-29)	Males: 3.88 + 3.36 (time in minutes) Females: 1.06 + 3.36 (time in minutes) *r* = .91; SEE = 3.72	104	Spackman et al. 2001
	Healthy females (20-42)	4.38 (time in minutes) – 3.9; *r* = .91; SEE = 2.7	104	Pollock et al. 1982
	Healthy adults (29-73)	Males: 3.88 + 3.36 (time in minutes) Females: 1.06 + 3.36 (time in minutes) *r* = .92; SEE = 3.22	104	Bruce, Kusumi, and Hosmer 1973
	Healthy males (35-55)	4.326 (time in minutes) – 4.66	104	Pollock et al. 1976
	Healthy males (48.1 ± 16.3)	14.76 – 1.38 (time) + 0.451 (time^2) – 0.012 (time^3); *r* = .977; SEE = 3.35 *Note:* Time is expressed in minutes.	104	Foster et al. 1984
	Healthy sedentary and active males (48.6 ± 11.1)	Sedentary: 3.288 (time in minutes) + 4.07 Active: 3.778 (time in minutes) + 0.19 *r* = .906; SEE = 1.9	104	Bruce, Kusumi, and Hosmer 1973
Balke	Healthy females (20-42)	1.38 (time in minutes) + 5.2; *r* = .94; SEE = 2.2	105	Pollock et al. 1982
	Healthy males (35-55)	1.444 (time in minutes) + 14.99	104	Pollock et al. 1976

MODE: CYCLE ERGOMETER

Test protocol	Population (age)	Regression equations ($\dot{V}O_2max$ = L · min^{-1} except 5K cycle ride; *r* value; SEE)	Textbook page	Resource
Storer-Davis	Sedentary adults (20-70)	9.39 (workload in watts) + 7.7 (weight in kg) – 5.88 (age in years) + 136.7 *r* = .932; SEE = 1.47 L · min^{-1} *Note:* Watts = resistance in kp × 300 / 6.12	106	Storer, Davis, and Caiozzo 1990
Andersen	Healthy adults (15-28)	0.0117 (workload in watts) + 0.16 *r* = .88; SEE = 10% *Note:* Watts = resistance in kp × 300 / 6.12	106–107	Andersen 1995
5K cycle ride	Healthy adults (27 ± 5)	316 – 97.8 (log of cycle time in seconds) *r* = -.83; SEE = 14%	107	Buono et al. 1996

MODE: TIMED FIELD TESTS				
Test protocol	**Population (age)**	**Regression equations ($\dot{V}O_2max$ = mL · kg^{-1} · min^{-1}; *r* value; SEE)**	**Textbook page**	**Resource**
5-minute run	Healthy youth (12-15)	12 years: 0.024 (distance in meters) + 22.473; *r* = .672 13 years: 0.034 (distance in meters) + 15.257; *r* = .751 14 years: 0.022 (distance in meters) + 26.165; *r* = .534 15 years: 0.035 (distance in meters) + 16.197; *r* = .685	107–109	MacNaughton et al. 1990
	Sedentary and active males (18-46)	3.23 (run velocity in km · hr^{-1}) + 0.123 *r* = .90; SEE = 5% *Note:* Run velocity = 12 (distance in km).	107–109	Berthon et al. 1997b
	Trained athletes (19-38) and runners (20-46)	Athletes: 1.43 (run velocity in km · hr^{-1}) + 29.2; *r* = .56; SEE = 4.6% Runners: 1.95 (run velocity in km · hr^{-1}) + 26.6; *r* = .69; SEE = 6.6% *Note:* Run velocity = 12 (distance in km).	107–109	Berthon et al. 1997a
Cooper's 12-minute run	Military males (17-52)	35.97 (distance in miles) – 11.28; Outdoor ¼-lap = 0.0625 miles 35.97 (distance in meters / 1,609) – 11.28; Outdoor ¼-lap = 100 meters *r* = .897 *Note:* Best accuracy ≥ 1.4 miles.	107–109	Cooper 1968
Cooper's 12-minute swim	High school swimmers (13-17)	Run $\dot{V}O_2max$ = 10.69 + 0.059 (distance in yards) *r* = .47; SEE = 6.82	107–109	Huse, Patterson, and Nichols 2000
	Healthy males (18-32)	Swim $\dot{V}O_2max$ = 0.028 (distance in meters) + 34.1 *r* = .40; SEE = 5.7 Run $\dot{V}O_2max$ = 0.023 (distance in meters) + 43.7 *r* = .38; SEE = 5.14	107–109	Conley et al. 1991
	Healthy females (18-34)	Swim $\dot{V}O_2max$ = 0.026 (distance in meters) + 24 *r* = .42; SEE = 4.5 Run $\dot{V}O_2max$ = 0.026 (distance in meters) + 29.8 *r* = .34; SEE = 6.0	107–109	Conley et al. 1992

(continued)

TABLE 5.1 *(Continued)*

Test protocol	Population (age)	Regression equations ($\dot{V}O_2max$ = mL · kg⁻¹ · min⁻¹ unless noted; *r* value; SEE)	Textbook page	Resource
MODE: TIMED FIELD TESTS (CONTINUED)				
15-minute run	Healthy youth (12-15)	12 years: 0.01 (distance in meters) + 19.331; r = .881 13 years: 0.012 (distance in meters) + 18.809; r = .851 14 years: 0.013 (distance in meters) + 18.756; r = .671 15 years: 0.015 (distance in meters) + 16.429; r = .881	107–109	MacNaughton et al. 1990
20-minute run	High school students (14-17)	Males: 22.85 + 8.44 (distance in miles) + 3.98 Females: 22.85 + 8.44 (distance in miles) r = .80; SEE = 4.36	107–109	Murray et al. 1993
MODE: DISTANCE FIELD TESTS				
Mile (1,600 m) run	Endurance-trained children (8-17)	Combined: 96.81 – 8.62 (time) + 0.34 (time²) Male: 98.49 – 9.06 (time) + 0.38 (time²) Female: 82.2 – 6.04 (time) + 0.22 (time²) r = .70; SEE = 3 *Note:* Time in minutes.	109	Castro-Pinero et al. 2009
	Healthy males and females (8-25)	Combined: 96.81 – 8.62 (time) + 0.34 (time²) Male: 98.49 – 9.06 (time) + 0.38 (time²) Female: 82.2 – 6.04 (time) + 0.22 (time²) r = .72; SEE = 4.8 *Note:* Time in minutes.	109	Cureton et al. 1995
	Healthy youth (10-12)	22.5903 + 12.2944 (speed in m · sec⁻¹) – 0.1755 (weight in kg) r = .804; SEE = 5.54	109	Massicotte, Gauthier, and Markon 1985
	Healthy youth (10-18)	Males: 86.1 – 0.04 (time) – 0.08 (sum of skinfolds) – 4.7 – 0.15 (kg wgt) Females: 86.1 – 0.04 (time) – 0.08 (sum of skinfolds) – 9.4 – 0.15 (kg wgt) r = .84; SEE = 9% *Note:* Time in seconds; refer to chapter 2 for skinfold procedures.	109	Buono et al. 1991
	College students (18-30)	Males: 108.94 – 8.41 (time) + 0.34 (time)² + 0.21 (age) – 0.84 (BMI) Females: 108.94 – 8.41 (time) + 0.34 (time)² – 0.84 (BMI) r = .7-0.84; SEE = 4.8-5.28 *Note:* Time in minutes; refer to chapter 2 for BMI calculation procedures.	109	Plowman and Liu 1999
	Trained male runners (27.5 ± 10.3)	2.5043 × (0.84 (run velocity in km · hr⁻¹) r = .95; SEE = 2.3% *Note:* Run velocity = 96.558 / time in minutes.	109	Tokmakidis et al. 1987

MODE: DISTANCE FIELD TESTS (CONTINUED)				
1.5-mile (2,400 m) run	Healthy youth (13-17)	22.5903 + 12.2944 (speed in m · sec^{-1}) – 0.1755 (weight in kg) r = .804; SEE = 5.54	109	Massicotte, Gauthier, and Markon 1985
	College students (18-26)	Males: 65.404 + 7.707 – 0.159 (weight in kg) – 0.843 (time in minutes) Females: 65.404 – 0.159 (weight in kg) – 0.843 (time in minutes) r = .86; SEE = 3.37	109	Larsen et al. 2002
	Healthy adults (18-29)	Males: 88.02 + 3.716 – 0.1656 (weight in kg) – 2.767 (time in minutes) Females: 88.02 – 0.1656 (weight in kg) – 2.767 (time in minutes) r = .90; SEE = 2.8	109	George et al. 1993a
2-mile (3,200 m) run	Healthy females (20-37)	72.9 – 1.77 (time in minutes); r = .89	109	Mello, Murphy, and Vogel 1988
	Healthy males (20-51)	99.7 – 3.35 (time in minutes); r = .91; SEE = 3.31	109	Mello, Murphy, and Vogel 1988
	Female runners (31.1 ± 5.7)	90.7 – 3.24 (time in minutes) + 0.04 (time in minutes^2) r = .94-.96; SEE = 2.78-3.58	109	Weltman et al. 1990
	Male runners (31.1 ± 8.3)	118.4 – 4.770 (time in minutes) r = .73; SEE = 4.51	109	Weltman et al. 1987
3-mile (5K) competition	Trained male runners (27.5 ± 10.3)	3.1747 × (0.9139 (run velocity in km · hr^{-1}) r = .98; SEE = 2.3% *Note:* Run velocity = 300 / time in minutes.	109	Tokmakidis et al. 1987
6-mile (10K) competition	Trained male runners (27.5 ± 10.3)	4.7226 × (0.8698 (run velocity in km · hr^{-1}) r = .88; SEE = 4.8% *Note:* Run velocity = 600 / time in minutes.	109	Tokmakidis et al. 1987
Marathon (42K) competition	Trained male runners (27.5 ± 10.3)	6.9021 × (0.8246 (run velocity in km · hr^{-1}) r = .85; SEE = 5.6% *Note:* Run velocity = 2531.7 / time in minutes.	109	Tokmakidis et al. 1987

Note: A kp is equivalent to a kg of force.

TABLE 5.2 Submaximal Exercise Tests Used to Predict Aerobic Power ($\dot{V}O_2max$)

MODE: TREADMILL

Test protocol	Population (age)	Regression equations ($\dot{V}O_2max$ = mL · kg^{-1} · min^{-1}: *r* value; SEE)	Textbook page	Resource
Walking	Healthy adults (20-59)	Males: 15.1 + 21.8 (mph) – 0.327 (HR) – 0.263 (mph × age) + 0.00504 (HR × age) + 5.98 Females: 15.1 + 21.8 (mph) – 0.327 (HR) – 0.263 (mph × age) + 0.00504 (HR × age) *r* = .91; SEE = 3.72 *Note:* Speed in mph, HR immediately postexercise.	112	Ebbeling et al. 1991
Jogging	Healthy adults (18-29)	Males: 54.07 + 7.062 – 0.193 (weight) + 4.47 (mph) – 0.1453 (HR) Females: 54.07 – 0.193 (weight) + 4.47 (mph) – 0.1453 (HR) *r* = .88; SEE = 3.1 *Note:* Weight in kg, speed in mph, HR immediately postexercise.	113	George et al. 1993b
	Healthy adults (18-40)	Males: 58.687 + 7.520 + 4.334 (mph) – 0.211 (weight) – 0.148 (HR) – 0.107 (age) Females: 58.687 + 4.334 (mph) – 0.211 (weight) – 0.148 (HR) – 0.107 (age) *r* = .91; SEE = 2.52 *Note:* Speed in mph, weight in kg, speed in mph, HR immediately postexercise.	113	Vehrs et al. 2007
Walk/jog/run	Healthy adults (18-65)	Males: 30.04 + 6.37 – 0.243 (age) – 0.122 (weight) + 3.2 (mph) + 0.391 (PFA) + 0.669 (PA) Females: 30.04 – 0.243 (age) – 0.122 (weight) + 3.2 (mph) + 0.391 (PFA) + 0.669 (PA) *r* = .94; SEE = 3.09 *Note:* Weight in kg, speed in mph, table 5.4 question responses for PFA and PA[1].	114	George et al. 2009

MODE: CYCLE ERGOMETER

Test protocol	Population (age)	Regression equations ($\dot{V}O_2max$ = L · min^{-1} except YMCA; *r* value; SEE)	Textbook page	Resource
YMCA	Male and female triathletes (19-41)	Equation offers maximal workload (WL) without traditional graphing process: WL2 + [(WL2 – WL1) / (HR2 – HR1)] × (age-predicted HR_{max} – HR2) *Note:* Two stages with HR between 110 and 150 bpm and match WL in kg · min^{-1}. [(Maximal WL in kg · min^{-1} × 1.8) + (weight × 7)] / weight *Note:* Body weight in kg, kg · min^{-1} is bike resistance in kp × 300. *r* = .546; SEE = 14% *Note:* General population error about 10-15% due to age-predicted HR_{max}.	117	Golding, Myers, and Sinning 1989; Dabney and Butler 2006

Test protocol	Population (age)	Regression equations ($\dot{V}O_2max$ = mL · kg⁻¹ · min⁻¹ unless noted; *r* value; SEE)	Textbook page	Resource
		MODE: CYCLE ERGOMETER (CONTINUED)		
Åstrand	Trained adults (20-30) and healthy males (18-33)	Determine aerobic power using nomogram and age correction factor in figure 5.1. *r* = .83-0.90; SEE = 5.6-5.7 *Note:* kg · min⁻¹ is bike resistance in kp × 300, HR immediately postexercise.	117	Åstrand and Rhyming 1954; Cink and Thomas 1981
Modified Åstrand	Trained adults (20-70)	Determine aerobic power using nomogram in figure 5.1; then use equation: Males: 0.348 (nomogram L · min⁻¹) – 0.035 (age) + 3.011 *r* = .86; SEE = 0.359 L · min⁻¹ Females: 0.302 (nomogram L · min⁻¹) – 0.019 (age) + 1.593 *r* = .97; SEE = 0.199 L · min⁻¹ *Note:* kg · min⁻¹ is bike resistance in kp × 300, HR immediately postexercise.	118	Siconolfi et al. 1982
		MODE: DISTANCE FIELD TESTS		
Test protocol	**Population (age)**	**Regression equations ($\dot{V}O_2max$ = mL · kg⁻¹ · min⁻¹ unless noted; *r* value; SEE)**	**Textbook page**	**Resource**
Quarter-mile walk	College students (18-29)	Males: 88.768 + 8.892 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) Females: 88.768 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) *r* = .84; SEE = 4.03 *Note:* Weight in pounds, 4 × minute time, HR immediately postexercise.	118–119	Greenhalgh, George, and Hager 2001
	College students (18-29)	Males: 132.853 + 6.315 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) Females: 132.853 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) *r* = .81; SEE = 4.33 *Note:* Weight in pounds, 4 × minute time, HR immediately postexercise.	118–119	Greenhalgh, George, and Hager 2001
Half-mile walk	Obese females	53.23 – 1.98 (time in minutes) – 0.32 (BMI) – 0.08 (age); *r* = 0.76; SEE = 2.89 *Note:* Refer to chapter 2 for BMI calculation procedures (best accuracy ≤ 28 kg · m²)	118–119	Donnelly et al. 1992

(continued)

TABLE 5.2 *(Continued)*

MODE: DISTANCE FIELD TESTS (CONTINUED)				
Mile walk	High school students (14-18)	Males: 88.768 + 8.892 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) Females: 88.768 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) $r = .84$; SEE = 4.5 *Note:* Weight in pounds, time in minutes, HR immediately postexercise.	118–119	McSwegin et al. 1998
	College students (18-29)	Males: 88.768 + 8.892 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) Females: 88.768 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) $r = .85$; SEE = 7.93 *Note:* Weight in pounds, time in minutes, HR immediately postexercise.	118–119	Dolgener et al. 1994
	College students (18-29)	Males: 88.768 + 8.892 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) Females: 88.768 – 0.0957 (weight) – 1.4537 (time) – 0.1194 (HR) $r = .85$; SEE = 3.93 *Note:* Weight in pounds, time in minutes, HR immediately postexercise.	118–119	Greenhalgh, George, and Hager 2001
Rockport mile walk	High school students (14-18)	Males: 132.853 + 6.315 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) Females: 132.853 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) $r = .80$; SEE = 4.99 *Note:* Weight in pounds, time in minutes, HR immediately postexercise.	118–119	McSwegin et al. 1998
	College students (18-29)	Males: 132.853 + 6.315 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) Females: 132.853 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) $r = .84$; SEE = 4.03 *Note:* Weight in pounds, time in minutes, HR immediately postexercise.	118–119	Greenhalgh, George, and Hager 2001
	Healthy adults (30-69)	Males: 132.853 + 6.315 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) Females: 132.853 – 0.3877 (age) – 0.1692 (weight) – 3.2649 (time) – 0.1565 (HR) $r = .88$; SEE = 5 *Note:* Weight in pounds, time in minutes, HR immediately postexercise.	118–119	Kline et al. 1987

MODE: DISTANCE FIELD TESTS (CONTINUED)				
1.25-mile (2K) walk	Healthy obese and inactive adults (25-65)	Males: 189.6 – 5.32 (time) – 0.22 (HR) – 0.32 (age) – 0.24 (weight) *r* = .81; SEE = 6.2 *Note:* Time in minutes, HR immediately postexercise, weight in kg.	118–119	Oja et al. 1991
		Females: 121.4 – 2.81 (time) – 0.12 (HR) – 0.16 (age) – 0.24 (weight) *r* = .87; SEE = 4.5 *Note:* Time in minutes, HR immediately postexercise, weight in kg.	118–119	Oja et al. 1991
Mile jog	Healthy adults (18-29)	Males: 100.5 + 8.344 – 0.1636 (weight) – 1.438 (time) – 0.1928 (HR) Females: 100.5 – 0.1636 (weight) – 1.438 (time) – 0.1928 (HR) *r* = .87; SEE = 3.1 *Note:* Weight in kg, time in minutes, HR immediately postexercise.	118–119	George et al. 1993a

Note: PFA is perceived functional ability; PA is physical activity.

TABLE 5.3 Regression Equation Data Collection Variables

Collected data variables	Units	Conversions
Age	year	
Height	in., cm, m	in. × 2.54 = cm / 100 = m
Weight	lb, kg	lbs / 2.2 = kg
Time	sec, min	sec / 60 = min
Distance	yard, m, km, mile	yard × 0.9144 = m / 1,000 = km km × 0.62137119224 = mile
Speed (velocity)	mph, $m \cdot sec^{-1}$, $km \cdot hr^{-1}$	mph × 0.44704 = $m \cdot sec^{-1}$ × 3.6 = $km \cdot hr^{-1}$
Workload	$kg \cdot min^{-1}$, watts	$kg \cdot min^{-1}$ / 6 = watts
Survey	PFA and PA survey answers (table 5.4)	
Body dimensions	Sum of skinfolds, BMI	
Heart rate	bpm	
Aerobic power	$mL \cdot km^{-1}$, $L \cdot km^{-1}$, $mL \cdot kg^{-1} \cdot km^{-1}$, MET	$mL \cdot km^{-1}$ × 1,000 = $L \cdot km^{-1}$ $L \cdot km^{-1}$ × 1,000 / weight in kg = $mL \cdot kg^{-1} \cdot km^{-1}$ $mL \cdot kg^{-1} \cdot km^{-1}$ / 3.5 = MET

will be discussed with the assumption that the fitness professional has the time to perform the test and the athlete is willing to provide a maximal effort.

Confirming a maximal effort is essential for improving estimates of aerobic power. Without sophisticated analyzers to identify gas and lactate levels at the completion of a maximal exercise test, heart rate measurements are expected to be above 70% of heart rate reserve or above 85% of age-predicted (220 – age) heart rate maximum (American College of Sports Medicine 2010). Although these maximal heart rate criteria provide objectivity with relative ease, large errors of 10 to 12 bpm at all ages are cause for concern when using the age-predicted value as a reason for test termination or as a basis for maximal effort (American College of Sports Medicine 2000).

The age-predicted maximal heart rate concerns arise from overestimated younger adult and underestimated older adult values (Gellish et al. 2007). To reduce the concern of estimating maximal heart rate, the equation $HR_{max} = 207 - (0.7 \times age)$ is recommended for everyone between the ages of 30 and 75 to reduce estimation errors by 5 to 8 bpm (American College of Sports Medicine 2010; Gellish et al. 2007). Furthermore, examiners should attempt to verify age-predicted maximal heart rate calculations by observing signs of fatigue and performance technique deficiencies when athletes request to stop a maximal effort test (Pettersen, Fredrikson, and Ingjer 2001). Heart rate tests are discussed in more detail in chapter 3.

When interpreting the results of a maximal effort test, critical assumptions must be addressed. Without calibrated equipment, examiners must rely on the previously mentioned relationship between oxygen consumption and heart rate, meaning that they are assuming that the heart rate increases linearly with the workload up to maximal effort. Based on this assumption, the accuracy of the prediction equation will be limited to specific populations as long as the correlations are strong with low standard errors. Nevertheless, the best alternatives to using gas measurements (i.e., oxygen and carbon dioxide) to measure aerobic power are the maximal exercise testing methods identified in table 5.1 (Balke and Ware 1959; Bruce, Kusumi, and Hosmer 1973; George 1996; Spackman et al. 2001; Storer, Davis, and Caiozzo 1990).

Laboratory Maximal Treadmill Tests

The treadmill and the bicycle ergometer are the most popular modes for exercise testing in the United States and Europe (Maeder et al. 2005). The treadmill appears to elicit higher maximal oxygen consumption values than the bicycle ergometer (Hambrecht et al. 1992; Maeder et al. 2005; Myers et al. 1991; Wicks et al. 1978). Higher maximal heart rates have also been observed on the treadmill compared to the bicycle ergometer (Buchfuhrer et al. 1983; Hambrecht et al. 1992; Wicks et al. 1978), but other studies have found that both modes elicit comparable heart rates (Maeder et al. 2005; Myers et al. 1991). Nonetheless, the treadmill is expected to generate the highest aerobic power relative to other exercise modes regardless of the protocol.

The Bruce and Balke–Ware treadmill protocols are most commonly used in clinical and laboratory settings because of their high levels of predictive accuracy and low rates of estimation errors (American College of Sports Medicine 2010; refer to table 5.1 for comparisons). Furthermore, exercise time to exhaustion during the Bruce and Balke protocols was determined to be a simple indication of cardiorespiratory functions and physical fitness capabilities (Balke and Ware 1959; Bruce, Kusumi, and Hosmer 1973). Bruce, Kusumi, and Hosmer (1973) even differentiated between sedentary and physically active lifestyles based on regular participation in jogging, running games, or activities with equivalent exertion levels.

Today, the common practice when testing young and physically active people is to use large increases in speed and grade (i.e., 2 to 3 METs), such as during the Bruce protocol. With older, chronically diseased, or deconditioned people, smaller increments (≤1 MET per stage) are used, such as during the Balke protocol (American College of Sports Medicine 2010). Although the workload increments are smaller for the Balke protocol, for some subjects (e.g., chronically diseased people), the speed may still be too fast (i.e., 3.1 miles per hour at 0% grade) and challenging (i.e., 20 $mL \cdot kg^{-1} \cdot min^{-1}$) within the first five minutes of testing.

Modified versions of the Bruce protocol do exist. For instance, one or two preliminary stages (i.e., 1.7 miles per hour at 0% grade and 5% grade) have been added when working with very deconditioned people or cardiac patients. Conversely, the initial stage can be eliminated when testing well-conditioned athletes. However, these modifications are appropriate only when using gas analyzers because the developed regression equations are based on time to completion.

General Guidelines for Laboratory Maximal Treadmill Tests

Once the most appropriate and accurate population-specific equation is chosen (see table 5.1), examiners can use the following steps for data collection:

1. Collect age, height, weight, and resting heart rate measurements.
2. Collect exercise heart rate. The heart rate is taken every minute.
3. Collect recovery heart rate for three to five minutes, and longer if necessary to ensure the safe recovery of the subject.
4. Estimate the subject's $\dot{V}O_2max$ using the appropriate population-specific equation identified in table 5.1.
5. Convert absolute ($mL \cdot min^{-1}$) to relative ($mL \cdot kg^{-1} \cdot min^{-1}$) $\dot{V}O_2max$ by dividing $mL \cdot min^{-1}$ by the subject's body weight in kilograms.

6. Determine the subject's aerobic power by classifying the estimated $\dot{V}O_2max$ based on table 5.7 (p. 119).

Note: Throughout the test, the subject should be monitored and questioned for signs (e.g., wheezing, blue or pale skin color) and symptoms (e.g., leg cramps, dizziness, chest pain) indicating the need to terminate the test. In addition, the examiner should make sure to collect the heart rate upon completion of the test along with the reason for termination.

BRUCE PROTOCOL

The examiner collects heart rate every minute of the test, but uses the total number of minutes of the test for calculation.

1. Minutes 0-3: The subject walks at 1.7 miles per hour (2.7 km $\cdot$ hr^{-1}) at a grade of 10%.
2. Minutes 3-6: The subject walks at 2.5 miles per hour (4 km $\cdot$ hr^{-1}) at a grade of 12%.
3. Minutes 6-9: The subject jogs at 3.4 miles per hour (5.5 km $\cdot$ hr^{-1}) at a grade of 14%.
4. Minutes 9-12: The subject jogs at 4.2 miles per hour (6.8 km $\cdot$ hr^{-1}) at a grade of 16%.
5. Minutes 12-15: The subject jogs at 5.0 miles per hour (8 km $\cdot$ hr^{-1}) at a grade of 18%.
6. Minutes 15-18: The subject jogs at 5.5 miles per hour (8.9 km $\cdot$ hr^{-1}) at a grade of 20%.
7. Minutes 18-21: The subject jogs at 6.0 miles per hour (9.7 km $\cdot$ hr^{-1}) at a grade of 22%.

BALKE PROTOCOL (MALES)

The examiner collects heart rate every minute of the test, but uses the total number of minutes of the test for calculation.

1. Minutes 0-1: The subject walks at 3.3 miles per hour (5.3 km $\cdot$ hr^{-1}) at 0% grade.
2. After one minute: Increase 1% grade each minute until volitional fatigue or maximal effort (exertion).

2. Collect exercise heart rate, blood pressure (optional), and rating of perceived exertion (RPE) measurements. The heart rate is taken every minute, whereas the blood pressure and RPE are taken during the last minute of every three-minute stage.
3. Collect recovery heart rate and blood pressure (optional) for three to five minutes, and longer if necessary to ensure the safe recovery of the subject.
4. Estimate the subject's $\dot{V}O_2max$ using the appropriate population-specific equation identified in table 5.1.
5. Determine the subject's aerobic power by classifying the estimated $\dot{V}O_2max$ based on table 5.7 (p. 119).

Note: The subject should be closely monitored and questioned for signs (e.g., wheezing, blue or pale skin color) and symptoms (e.g., leg cramps, dizziness, chest pain) requiring test termination throughout the test, particularly during running, when excessive arm movements can produce interfering noises that result in unreliable blood pressure measurements (Maeder et al. 2005). All measurements should be collected immediately at the conclusion of the test along with the reason for terminating the test.

STORER-DAVIS PROTOCOL

The examiner should collect heart rate every minute of the test, but use the maximal workload of the test for calculation.

1. Minutes 0-4: The subject pedals at 60 rpm against 0 kp.
2. After four minutes: The subject pedals at 60 rpm and increase 0.25 kp (15 watts) each minute until volitional fatigue.

ANDERSEN PROTOCOL (MALES)

The examiner should collect heart rate every minute of the test, but use the maximal workload of the test for calculation.

1. Minutes 0-7: The subject pedals at 70 rpm against 1.5 kp.
2. After seven minutes: The subject pedals at 70 rpm and increase 0.5 kp (35 watts) every two minutes until volitional fatigue.

ANDERSEN PROTOCOL (FEMALES)

The examiner collects heart rate every minute of the test, but uses the maximal workload of the test for calculation.

1. Minutes 0-7: The subject pedals at 70 rpm against 1.0 kp.
2. After seven minutes: The subject pedals at 70 rpm and increase 0.5 kp (35 watts) every two minutes until volitional fatigue.

5K CYCLE RIDE

Beyond the adolescent and general populations, adult trained cyclists might consider the 5K cycle ergometer ride, which requires timing how long it takes to pedal that distance (Buono et al. 1996). Although the cyclist performs at a self-regulated pace, the objective is to pedal 5K as fast as possible against a resistance calculated by dividing body weight in kilograms by 20 and multiplying the value by 0.5 kp.

1. Determine how long it takes the subject to ride 5K.
2. Minutes 0-2: The subject pedals at a self-selected pace against 1.0 kp.
3. Minutes 2-3: The subject pedals at a self-selected pace against resistance based on body weight (0.5 kp per 20 kg of body weight).
4. Minutes 3-5: The subject rests.
5. After five minutes: The subject pedals at a self-selected pace and resume resistance based on body mass until completion of the 5K ride.

Maximal Field Tests

Maximal field tests offer practical exercise settings outside the laboratory. Field tests are usually much easier to administer than laboratory tests, which require more sophisticated equipment and technical expertise. Instead of relying on laboratory measurements, maximal field tests provide aerobic power estimates based on performance distance or time. As a result of training specificity, athletes improve their distances and times in environments that are practical for field testing.

Timed Maximal Field Tests

There are many maximal running field tests ranging from 5 to 20 minutes. These timed field tests require that the subject be highly motivated to run, bike, or swim as far as possible within a designated time. Because the time limit is the basis of these tests, the main requirement is to monitor how far the subject travels. The examiner must be sure to observe the subject during the entire time limit so that the distance can be determined accurately. For instance, if the selected test requires the subject to travel as far as possible in 12 minutes, a track or pool would permit continuous observation while the subject was running, cycling, or swimming.

Cooper (1968) introduced the 12-minute run to assess aerobic power among male U.S. Air Force officers. Even though the prediction equation was based on the performance of officers between 17 and 52 years of age, most of them were younger than 25; the greatest accuracy was seen in those exceeding 1.4 miles (2.3 km) in distance (Cooper 1968). In another study, Cooper's run test slightly overestimated aerobic power among trained subjects between 17 and 54 years of age, but Wyndham and others (1971) recommended against the use of this protocol with sedentary people in their 40s and 50s. The 5-minute run may be a viable alternative for 18- to 46-year-olds of various fitness levels because it appears to provide an accurate assessment of cardiorespiratory endurance (Berthon et al. 1997b; Dabonneville et al. 2003).

MacNaughton and others (1990) tested competitively active high school students' aerobic power to compare 5- and 15-minute run tests to the Bruce protocol. Obviously, the Bruce protocol provided the most accurate aerobic power measurement, but the next best predictor of aerobic power was the 15-minute run, whereas the 5-minute run provided only satisfactory estimates (MacNaughton et al. 1990). Coincidentally, aerobic power estimates made from the 15-minute run demonstrated similar correlation values to those of the 20-minute run, which included a relatively low reported standard error. This suggests that longer durations may be more beneficial for high school students (Murray et al. 1993). However, motivation and local muscular fatigue and discomfort have prompted the recommendation of limiting maximal aerobic power tests to 8 to 10 minutes for youth and untrained people (Massicotte, Gauthier, and Markon 1985).

All the time trial field tests discussed previously estimate aerobic power based on performance distance, but running economy may also need to be taken into consideration to address training efficiency. For instance, most fitness professionals would expect performance to improve with training specificity. However, Cooper (1968) found that repeated 12-minute run testing resulted in minimal training effects. Therefore, Berthon and others (1997a) suggest determining running speed at $\dot{V}O_2max$ to evaluate running economy. The significance of this suggestion is evidenced by the inability to estimate aerobic power as accurately as running speed for runners and athletes (Berthon et al. 1997a), whereas both components of running economy are estimated accurately among the general population (Berthon et al. 1997b). Overall, a 5-minute run appears to be too short for the accurate estimation of running speed (Berthon et al. 1997a; 1997b).

Other maximal field test options that address training specificity are timed swimming and road cycling. Cooper (1982) developed a 12-minute swim and a 12-minute road cycling test. Road cycling distances are best measured using an odometer and pedaling on a flat terrain with winds less than 10 miles per hour (16 km/h). Swimming distances (with any stroke) are best determined by knowing the pool dimensions. Although there are a few equations that estimate aerobic power for swimming, the relatively low correlations and standard errors associated with the estimates indicate a greater value in recording the traveled distance without calculating aerobic power. The same recommendation of recording distance measurements applies to road cycling as well. Although nothing has been published in the literature, these testing strategies could also be used with other endurance activities such as cross-country skiing. Regardless of the endurance event, changes in distances over a training period would be the basis for identifying training effectiveness on swimming, road cycling, and skiing performance.

Distance Maximal Field Tests

Rather than base aerobic power estimates on the duration of a field test, some fitness professionals select a maximal protocol reliant on distance. Regardless of the mode (e.g., walking or running), the objective is to complete a specified distance within the shortest time period.

Several equations that predict aerobic power have been developed for maximal running tests ranging from one mile to marathon distances (see table 5.1). These distances reflect the suggestion that runners must run farther than a mile to estimate cardiorespiratory fitness with the greatest accuracy (Fernhall et al. 1996). During the development of running prediction equations for aerobic capacity, data suggested that at least 600 yards are ideal for healthy populations, but a mile or farther is preferable (Cureton et al. 1995; Disch, Frankiewicz, and Jackson 1975). Based on the specificity principle, common sense suggests that using specific road race distances in tests of competitive runners will result in greater accuracy. Furthermore, Tokmakidis and others (1987) suggested that aerobic power estimation accuracy may be improved by using two running performances under the same conditions (i.e., health status, environment, course). Because of the high-intensity nature of running field tests, sedentary people and those with cardiovascular or musculoskeletal risks should not be assessed using this all-out run approach (American College of Sports Medicine 2010).

General Guidelines for Maximal Distance and Timed Field Tests

Once the most appropriate and accurate population-specific equation is chosen (table 5.1), examiners can use the following steps for data collection:

1. Collect age, height, weight, and resting heart rate measurements. Tricep and subscapular skinfold measurements are required when using the regression equation for the mile run to assess youth

between 10 and 18 years of age (Buono et al 1991). Chapter 2 describes the procedures for determining these skinfold measurements.

2. Have the subject perform a general warm-up using the mode of exercise being tested.
3. Have the subject perform the activity within the specified time limit or distance.
4. Record the distance for a timed protocol or the duration for a distance protocol. Because aerobic power estimation accuracy is questionable with cycling and swimming field tests, performance distances also provides a satisfactory basis for monitoring training progress. Although the swimming and road cycling performance distances are sufficient for assessment purposes, unconfirmed interpretation tables are available (Cooper 1982).
5. Estimate the subject's $\dot{V}O_2max$ using the appropriate population-specific equation identified in table 5.1.
6. Convert metabolic equivalent (MET) to relative ($mL \cdot kg^{-1} \cdot min^{-1}$) $\dot{V}O_2max$ by multiplying MET by 3.5.
7. Determine the subject's aerobic power by classifying the estimated $\dot{V}O_2max$ based on table 5.7 (p. 119).

Submaximal Exercise Testing Methods

Estimating aerobic power with submaximal exercise testing methods is time efficient. Because most submaximal tests are completed within 6 to 12 minutes with minimal exertion, the risk of medical complications is low. Unfortunately, extrapolating exercise prescriptions is difficult because the testing is performed at submaximal workloads. Only the heart rate responses observed during the submaximal testing session can be incorporated into the exercise prescriptions confidently. Given that the observed heart rates are only within the assessed intensities, any higher heart rates must be assumed based on an estimated maximal heart rate (220 – age). Despite the disadvantages of submaximal exercise testing, the multitude of protocols available provides strong evidence that this form of testing is advantageous to fitness professionals. This section addresses the numerous testing options, including the treadmill, cycle ergometer, and field tests identified in table 5.2 (pp. 98–101).

Laboratory Submaximal Treadmill Tests

Once the most appropriate and accurate population-specific submaximal treadmill equation is chosen, examiners should refer to the following protocol steps for data collection.

TABLE 5.4 Perceived Functional Ability (PFA) and Physical Activity (PA) Questions

Question	Scale
Perceived Functional Ability (26-point scale based on total of both questions)	
1. How fast could you cover a distance of 1 mile and NOT become breathless or overly fatigued. Be realistic.	1 – I could walk the entire distance at a slow pace (18 minutes per mile or more) 2 – I could walk the entire distance at a slow pace (17 minutes per mile) 3 – I could walk the entire distance at a medium pace (16 minutes per mile) 4 – I could walk the entire distance at a medium pace (15 minutes per mile) 5 – I could walk the entire distance at a fast pace (14 minutes per mile) 6 – I could walk the entire distance at a fast pace (13 minutes per mile) 7 – I could jog the entire distance at a slow pace (12 minutes per mile) 8 – I could jog the entire distance at a slow pace (11 minutes per mile) 9 – I could jog the entire distance at a medium pace (10 minutes per mile) 10 – I could jog the entire distance at a medium pace (9 minutes per mile) 11 – I could jog the entire distance at a fast pace (8 minutes per mile) 12 – I could jog the entire distance at a fast pace (7.5 minutes per mile) 13 – I could run the entire distance at a fast pace (7 minutes per mile or less)
2. How fast could you cover a distance of 3 miles and NOT become breathless or overly fatigued. Be realistic.	1 – I could walk the entire distance at a slow pace (18 minutes per mile or more) 2 – I could walk the entire distance at a slow pace (17 minutes per mile) 3 – I could walk the entire distance at a medium pace (16 minutes per mile) 4 – I could walk the entire distance at a medium pace (15 minutes per mile) 5 – I could walk the entire distance at a fast pace (14 minutes per mile) 6 – I could walk the entire distance at a fast pace (13 minutes per mile) 7 – I could jog the entire distance at a slow pace (12 minutes per mile) 8 – I could jog the entire distance at a slow pace (11 minutes per mile) 9 – I could jog the entire distance at a medium pace (10 minutes per mile) 10 – I could jog the entire distance at a medium pace (9 minutes per mile) 11 – I could jog the entire distance at a fast pace (8 minutes per mile) 12 – I could jog the entire distance at a fast pace (7.5 minutes per mile) 13 – I could run the entire distance at a fast pace (7 minutes per mile or less)
Physical Activity (10-point scale)	
Select the number that best describes your overall level of physical activity for the previous 6 months.	0 – Avoid walking exertion (e.g., always use elevator, drive when possible instead of walking) 1 – Light activity: walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration 2 – Moderate activity: 10-60 minutes per week of moderate activity (e.g., golf, horseback riding, calisthenics, table tennis, bowling, weightlifting, yard work, cleaning house, walking for exercise) 3 – Moderate activity: over 1 hour per week of moderate activity as described above 4 – Vigorous activity: run less than 1 mile per week or spend less than 30 minutes per week in comparable activity (e.g., running or jogging, lap swimming, cycling, rowing, aerobics, skipping rope, running in place, soccer, basketball, tennis, racquetball, or handball) 5 – Vigorous activity: run 1-5 miles per week or spend 30-60 minutes per week in comparable physical activity as described above 6 – Vigorous activity: run 5-10 miles or spend 1-3 hours per week in comparable physical activity as described above 7 – Vigorous activity: run 10-15 miles or spend 3-6 hours per week in comparable physical activity as described above 8 – Vigorous activity: run 15-20 miles or spend 6-7 hours per week in comparable physical activity as described above 9 – Vigorous activity: run 20-25 miles or spend 7-8 hours per week in comparable physical activity as described above 10 – Vigorous activity: run over 25 miles or spend over 8 hours per week in comparable physical activity as described above

Reprinted, by permission, from J.D. George, W.J. Stone, and L.N. Burkett, 1997, "Non-exercise $\dot{V}O_2$max estimation for physically active college students," *Medicine and Science in Sports and Exercise* 29:415-423.

General Guidelines for Submaximal Treadmill Tests

Once the most appropriate and accurate population-specific equation is chosen (see table 5.2), examiners should use the following steps for data collection:

1. Collect age, height, weight, and resting heart rate. If administering the walk/jog/run protocol, have the subject complete the perceived functional ability and physical activity questions in table 5.4.
2. Collect exercise heart rate. The heart rate is taken every minute, but the steady state heart rate collected immediately at the conclusion of the test is used for calculation purposes.
3. Collect recovery heart rate and blood pressure (optional) for three to five minutes, and longer if necessary to ensure the safe recovery of the subject.
4. Estimate the subject's $\dot{V}O_2$max using the appropriate population-specific equation identified in table 5.2.
5. Determine the subject's aerobic power by classifying the estimated $\dot{V}O_2$max based on table 5.7 (p. 119).

Single-Stage Submaximal Treadmill Protocols

Walking and jogging single-stage submaximal treadmill protocols are convenient and practical. Unfit or older people appear to get the best aerobic power estimates using the walking submaximal treadmill protocol (Ebbeling et al. 1991; Vehrs et al. 2007). Conversely, the jogging submaximal treadmill test is more appropriate for the relatively fit ($\geq$35.9 mL · kg^{-1} · min^{-1}) between 18 and 29 years of age (George et al. 1993b). In 2007, Vehrs and others added age to the aerobic power prediction equation because they found that accuracy was improved among relatively fit ($\geq$33.4 mL · kg^{-1} · min^{-1}) people older than 29. Following are guidelines for performing submaximal treadmill tests; specific protocols appear immediately afterward.

SUBMAXIMAL TREADMILL WALKING TEST PROTOCOL

1. Minutes 0–4: The subject walks at 0% grade and determines a comfortable speed between 2 and 4.5 miles per hour (3.2 and 7.2 km · hr^{-1}) that elicits 50 to 70% of the age-predicted (220 – age) maximal heart rate.
2. Minutes 4–8: Increase to 5% grade and maintain speed during the first four minutes. The four- to eight-minute pace should elicit 50 to 70% of the age-predicted maximal heart rate (use post-HR in equation).

SUBMAXIMAL TREADMILL JOGGING TEST PROTOCOL (MALES)

1. Minutes 0–2: The subject jogs at 0% grade and determines a comfortable speed between 4.3 and 7.5 miles per hour (7 and 12 km $\cdot$ hr^{-1}).
2. Minutes 2–5: The subject maintains the jogging speed established during the first two minutes. The two- to five-minute pace should not exceed 85% of the age-predicted maximal heart rate (use post-HR in equation).

SUBMAXIMAL TREADMILL JOGGING TEST PROTOCOL (FEMALES)

1. Minutes 0–2: The subject jogs at 0% grade and determines a comfortable speed between 4.3 and 6.5 miles per hour (7 and 10.5 km $\cdot$ hr^{-1}).
2. Minutes 2–5: The subject maintains the jogging speed established during the first two minutes. The two- to five-minute pace should not exceed 85% of the age-predicted maximal heart rate (use post-HR in equation).

Multistage Submaximal Treadmill Protocols

Although a multistage submaximal treadmill protocol may last longer than the single-stage walking and jogging treadmill protocols, George and others (2009) developed a walk/jog/run protocol that offers an opportunity to educate athletes. In addition to performing the exercise test, subjects answer the perceived functional ability and physical activity questions in table 5.4.

The multistage submaximal treadmill exercise protocol ends at the completion of the stage in which 70 to 90% of the age-predicted (220 – age) maximal heart rate is achieved during walking for the lower fitness level, jogging for the average fitness level, and running for the higher fitness level. Furthermore, subjects classify themselves as walkers, joggers, or runners with the perceived functional ability questions, which helps with the selection of training exercises. The subject's previous six-month physical activity rating then permits the fitness professional to discuss realistic training habits.

Athletes' responses on the perceived functional ability and physical activity questionnaire (table 5.4) are incorporated into the multistage treadmill equation in table 5.2 to estimate aerobic power. When subjects' performances on the treadmill are different from their perceptions of their capabilities, the fitness professional has an opportunity to discuss the relationships between training and physiological responses. This empowers the subject while helping the fitness professional design a cardiorespiratory training program based on realistic goals. Overall, the walk/jog/run submaximal treadmill protocol relates the subject's perceptions to personal exercise performance, enabling the fitness professional to teach about choosing safe exercise modes and training at effective intensities to achieve realistic goals (George et al. 2009).

SUBMAXIMAL WALK/JOG/RUN PROTOCOL

1. Minutes 0–4: The subject walks at 0% grade and determines a comfortable speed between 3 and 4 miles per hour (4.8 and 6.4 km · hr^{-1}) within the initial 20 seconds. (End the test at this stage if the subject is within 70 to 90% of the age-predicted [220 – age] maximal heart rate and use the treadmill speed in the equation.)
2. Minutes 4–8: The subject jogs at 0% grade and determines a comfortable speed between 4.1 and 6 miles per hour (6.6 and 9.7 km · hr^{-1}) within the initial 20 seconds. (End the test at this stage if the subject is within 70 to 90% of the age-predicted [220 – age] maximal heart rate and use the treadmill speed in the equation.)
3. Minutes 8–12: The subject runs at 0% grade and determines a comfortable speed above 6 miles per hour (9.7km · hr^{-1}) within the initial 20 seconds. (The final stage should elicit 70 to 90% of the age-predicted [220–age] maximal heart rate and use the treadmill speed in the equation.)

Laboratory Submaximal Cycle Ergometer Tests

Although both maximal and submaximal laboratory cycle ergometer tests raise concerns about training specificity, submaximal tests may have a greater standard error in predicting aerobic power than maximal tests do. Therefore, special attention needs to be paid to the protocol's pedal cadence and the position of the legs during the downstroke. When the lower extremity is straightened at the bottom of the pedaling revolution, the knee angle should be at 5° of flexion for the greatest muscle efficiency (American College of Sports Medicine 2010). Achieving this knee angle requires an adjustment to the proper seat height beforehand.

A review of the research on Åstrand and YMCA submaximal bike tests highlights the aerobic power estimation concerns with these protocols. In 1954, Åstrand and Ryhming developed a nomogram to estimate aerobic power from a six-minute single-stage protocol for well-trained males and females. After exploring various workloads, they discovered that the greatest accuracy occurred at 900 kg · min^{-1} (150 watts) for females and 1,200 kg · min^{-1} (200 watts) for males. Figure 5.1 provides the current Åstrand nomogram that has been modified with an age correction factor (Åstrand 1960). To differentiate fitness levels among males, Cink and Thomas (1981) found that the Åstrand age correction factor must be used to improve the accuracy of the test.

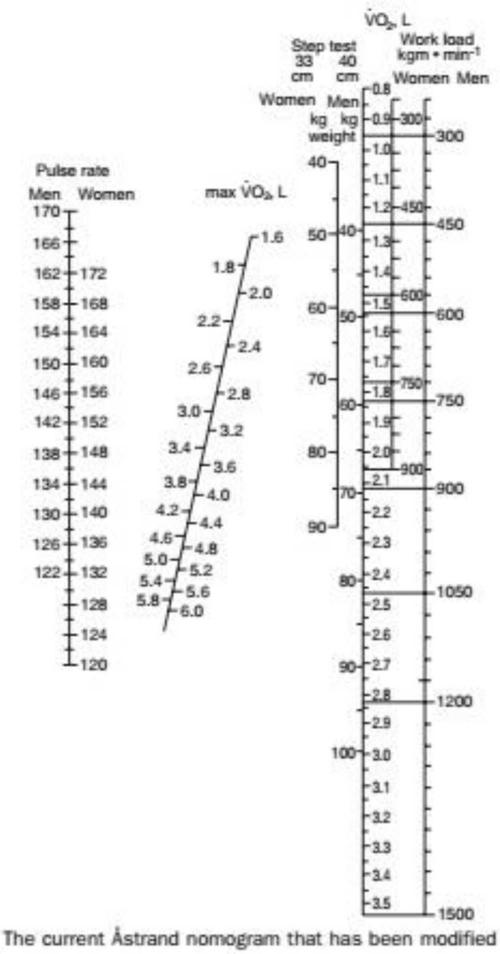

FIGURE 5.1 The current Åstrand nomogram that has been modified with an age correction factor.

Reprinted, by permission, from I. Åstrand, 1960, "Aerobic capacity in men and women with special reference to age," *Acta Physiologica Scandinavica* 49 (Suppl. 169): 51.

Golding, Myers, and Sinning (1989) introduced the multistage YMCA submaximal bike test, which also provides an opportunity to adjust workloads to accommodate various fitness levels. When both submaximal protocols were compared, the YMCA protocol ($r = .73$) was more accurate in estimating aerobic power than the Åstrand protocol was ($r = .56$) among physically active people (Kovaleski et al. 2005). A comparison of the YMCA submaximal bike test and the Bruce protocol revealed that the YMCA test

TABLE 5.5 YMCA Submaximal Bike Test Resistances

Stage 1 HR	Stage 2 load
>100 bpm	1 kp (50 watts)
90-100 bpm	1.5 kp (75 watts)
80-89 bpm	2.0 kp (100 watts)
<80 bpm	2.5 kp (125 watts)

TABLE 5.6 Åstrand Submaximal Bike Test Resistances

Training status	Test load
Untrained	1.5 kp (75 watts)
Moderately trained	2 kp (100 watts)
Well trained	3 kp (150 watts)

underestimated aerobic power values by 14% (Dabney and Butler 2006). These findings indicate that these submaximal bike tests should be limited to trained females and physically active males.

Alternatives are available to fitness professionals working with untrained people. Siconolfi and others (1982) modified the Åstrand submaximal bike test and developed a regression equation based on the nomogram and age for inactive men and women. Another accommodation was to adjust the traditional pedal rate of 50 rpm even though it was well within the recommended pedaling frequency range of 40 to 70 rpm for optimal economy (Åstrand and Rodahl 1986). Sharkey (1988) suggested that pedaling against high resistance at 50 rpm is not easy for untrained people; they perform better at 60 to 70 rpm.

General Guidelines for Submaximal Cycle Ergometer Tests

Once the most appropriate and accurate population-specific submaximal cycle ergometer equation is chosen (see table 5.2), examiners should use the following protocol steps for data collection:

1. Collect age, height, weight, and resting heart rate measurements.
2. Collect exercise heart rate. The heart rate is taken every minute, but the steady state heart rate collected immediately at the conclusion of each stage (YMCA protocol) or at the end of the test is used for calculation purposes.
3. Collect recovery heart rate for three to five minutes, and longer if necessary to ensure the safe recovery of the subject.

4. Estimate the subject's $\dot{V}O_2max$ using the appropriate population-specific equation identified in table 5.2.
5. Convert absolute ($L \cdot min^{-1}$) to relative ($mL \cdot kg^{-1} \cdot min^{-1}$) $\dot{V}O_2max$ by dividing $L \cdot min^{-1}$ by the subject's body weight in kilograms and multiplying the value by 1,000.
6. Determine the subject's aerobic power by classifying the estimated $\dot{V}O_2max$ based on table 5.7 (p. 119).

YMCA SUBMAXIMAL BIKE TEST

1. Warm-up: The subject pedals at 50 rpm against 0 kp.
2. Stage 1: The subject pedals at 50 rpm against 0.5 kp (25 watts) and continues the stage for three minutes or longer to achieve steady state HR.
3. Stage 2: The subject pedals at 50 rpm for three minutes at modified resistance based on table 5.5.
4. Additional stages (if necessary): If the steady state HR is not between 110 and 150 bpm for stage 1 and stage 2, the subject continues pedaling at 50 rpm and increases 0.5 kp (25 watts) every three minutes or longer to achieve steady state HR. While the speed is maintained at 50 rpm, the resistance will continue to be increased 0.5 kp (25 watts) for as many stages as necessary to achieve a steady state HR within 110 to 150 bpm for two stages. When within 110 to 150 bpm, the two stages' corresponding heart rates and workloads are then used to determine aerobic power based on the YMCA bike test equation found in table 5.2.

ÅSTRAND SUBMAXIMAL BIKE TEST (MALES)

1. Minutes 0–3: The subject pedals at 50 rpm against 0 kp.
2. Test: Apply resistance according to table 5.6, and have the subject pedal at 50 rpm for six minutes or longer to achieve steady state HR within the 130 to 170 bpm range.
3. Additional stage (if necessary): If the test HR is less than 130 bpm, the subject pedals at 50 rpm and increases 1 to 2 kp (50–100 watts) for an additional six minutes or longer to achieve steady state HR between 130 and 170 bpm. When the subject is within the 130 to 170 bpm range, the immediate postexercise HR and final workload are used in the nomogram.

ÅSTRAND SUBMAXIMAL BIKE TEST (TRAINED FEMALES)

1. Minutes 0–3: The subject pedals at 50 rpm against 0 kp.
2. Test: The subject pedals at 50 rpm against 2 to 3 kp (100–150 watts) for six minutes or longer to achieve steady state within a range of 125 to 170 bpm. When the subject is within the 125 to 170 bpm range, the immediate postexercise HR and final workload are used in the nomogram.

Submaximal Field Tests

Once the most appropriate and accurate population-specific submaximal field test equation is chosen, fitness professionals use the following protocol steps for data collection:

General Guidelines for Submaximal Field Tests

Once the most appropriate and accurate population-specific submaximal field test equation is chosen (see table 5.2), examiners should use the following protocol steps for data collection:

1. Collect age, height, weight, and resting heart rate measurements.
2. Have the subject perform a general warm-up using the specific mode of exercise being tested.
3. Have the subject perform the activity within the protocol-specified distance.
4. Record the duration for a distance protocol and collect postexercise heart rate immediately upon completion of the test if necessary.
5. Estimate the subject's $\dot{V}O_2$max using the appropriate population-specific equation identified in table 5.2.
6. Determine the subject's aerobic power by classifying the estimated $\dot{V}O_2$max based on table 5.7 (p. 119).

Quarter-mile to 2-kilometer (1.25 miles) submaximal walking distances are possible protocol selections for people of all ages, but low-fit people and those whose training regimen consists of walking appear to be the best suited for this mode of field testing. For instance, elderly people and those with physical limitations (e.g., overweight, obese, mentally impaired, cardiopulmonary patients) tend to be assessed using walking tests (Larsen et al. 2002; McSwegin et al. 1998). Conversely, underestimations in aerobic power are common with highly trained people performing these submaximal walking protocols because the cardiorespiratory system is inadequately

TABLE 5.7 Aerobic Power Classifications

Age group	Low	Fair	Average	Good	High	Athletic	Olympic
Women							
20–29	<28	29–34	35–43	44–48	49–53	54–59	60+
30–39	<27	28–33	34–41	42–47	48–52	53–58	59+
40–49	<25	26–31	32–40	41–45	46–50	51–56	57+
50–65	<21	22–28	29–36	37–41	42–45	46–49	50+
Men							
20–29	<38	39–43	44–51	52–56	57–62	63–69	70+
30–39	<34	35–39	40–47	48–51	52–57	58–64	65+
40–49	<30	31–35	36–43	44–47	48–53	54–60	61+
50–59	<25	26–31	32–39	40–43	44–48	49–55	56+
60–69	<21	22–26	27–35	36–39	40–44	45–49	50+

Note: $\dot{V}O_2$max is expressed in tables as milliliters of oxygen per kilogram of body weight per minute.

Adapted, by permission, from I. Åstrand, 1960, "Aerobic capacity in men and women with special reference to age," *Acta Physiologica Scandinavica* 49 (Suppl. 169): 1–92.

challenged (Kline et al. 1987). Anyone who cannot achieve a heart rate above 110 bpm when walking briskly would be considered highly trained (George, Fellingham, and Fisher 1998).

Another approach that goes beyond determining the duration of a submaximal field test is measuring the final heart rate after walking or jogging a mile (1.6 km) (Dolgener et al. 1994; George et al. 1993a; Kline et al. 1987). Note that the mile jog must take longer than eight minutes for males and nine minutes for females, and subjects must maintain a heart rate below 180 bpm for the test to qualify as submaximal (George et al. 1993a).

Regression Equation Calculations

In addition to being skilled at collecting data, fitness professionals also must understand the order of operations to perform regression equation calculations. A common technique for remembering the order of operations is the abbreviation PEMDAS, which stands for Parentheses, Exponents, Multiplication and Division, and Addition and Subtraction. The phrase *Please Excuse My Dear Aunt Sally* is helpful for remembering the order of the letters. When performing calculations, the order of operations refers to a ranking order: (1) parentheses, (2) exponents, (3) multiplication and division working from left to right, and (4) addition and subtraction working from left to right. As an example, we explore the process of determining aerobic power after selecting the submaximal treadmill walk/jog/run protocol and regression equation. Consider the following four-step process:

1. Heart rate is taken during the submaximal treadmill walk/jog/run protocol. A heart rate monitor or electrocardiograph would facilitate the process because of the difficulty of palpating a moving arm during exercise. The purpose of monitoring the heart rate is to determine when a steady state is achieved. The heart rate steady state is the plateau at which the heart rate and rate of oxygen consumption tend to remain relatively stable at a given workload. The examiner can verify steady state, which is optimal for any submaximal test, by determining that the heart rate on the monitor or electrocardiogram is within 6 bpm of each other (American College of Sports Medicine 2010) during the final two minutes of the walking, jogging, and running protocol stages. Even if a steady state is not achieved at the end of the protocol stage, the subject progresses from walking to jogging to running every four minutes until the heart rate falls between 70 and 90% of the age-predicted (220 – age) maximum, which establishes the treadmill speed that will be used in the regression equation. In addition to performing the exercise test, the subject answers perceived functional ability and physical activity questions (table 5.4). The age and weight of the subject must also be known. Here are some results from the submaximal treadmill walk/jog/run protocol to perform the regression equation calculations:

Age = 40 years

Weight (wgt) = 70 kg

Running treadmill speed (miles per hour) = 7 miles per hour

Perceived functional ability (PFA) = 24

Physical activity (PA) = 8

2. Aerobic power calculations require using the preceding information in the following regression equation for males:

Aerobic power = 30.04 + 6.37 – 0.243 (age) – 0.122 (wt) + 3.2 (mph) + 0.391 (PFA) + 0.669 (PA)

Aerobic power = 30.04 + 6.37 – 0.243 (40) – 0.122 (70) + 3.2 (7) + 0.391 (24) + 0.669 (8)

Aerobic power = 30.04 + 6.37 – 9.72 – 8.54 + 22.4 + 9.384 + 5.352

Aerobic power = 55.3 $mL \cdot kg^{-1} \cdot min^{-1}$

3. Aerobic power interpretations are based on the cardiorespiratory fitness levels presented in table 5.7. Within the table, the aerobic power is expressed relative to body weight ($mL \cdot kg^{-1} \cdot min^{-1}$), which means that 55 $mL \cdot kg^{-1} \cdot min^{-1}$ is classified as athletic. Be aware that absolute ($L \cdot km^{-1}$ or $mL \cdot min^{-1}$) and metabolic (MET) values need to be converted to relative body weight to use the table. In addition, although classifying the subject may be a goal, the ultimate goal should be to use the aerobic power estimations to improve cardiorespiratory fitness with appropriate exercise prescription strategies.

4. Exercise prescription for developing aerobic power is based on assessments. Whether fitness professionals are determining a baseline or training cardiorespiratory fitness level, interpretation of the aerobic power value will enable them to monitor training specificity. Specificity refers to the principle that the body adapts according to the stimuli it is exposed to during exercise. For example, swimmers train in the water and become very efficient at swimming, but this does not mean they will be good at running or cycling. Nonetheless, as a result of endurance training specificity, aerobic power is expected to improve 5 to 30% regardless of the mode (American College of Sports Medicine 2006). Therefore, a well-selected aerobic power protocol should permit the fitness professionals to monitor and adjust an athlete's training program to accomplish realistic goals based on ongoing assessment results.

Professional Applications

Owing to the large variety of cardiorespiratory endurance tests available, fitness professionals must be knowledgeable about them and capable of selecting the best test for assessing an athlete's aerobic power. Proper test selection depends on understanding the physiological and biomechanical principles of a sport or activity while applying the evidence-based research to the athlete's capabilities. Therefore, the maximal (table 5.1) and submaximal (table 5.2) tests presented in this chapter have been organized into SMARTS charts to explore the science and art of exercise selection.

SMARTS stands for Specificity, Mode, Application, Research, and Training Status (see tables 5.8 and 5.9). First, the fitness professional must know the specific metabolic demands of the sport or activity—that is, whether it is predominantly aerobic or anaerobic physiologically. Maximal tests might be more appropriate for sports or activities emphasizing aerobic metabolism, whereas submaximal tests might be best suited for athletes primarily dealing with anaerobic training. Obviously, sports or activities that alternate between aerobic and anaerobic metabolic demands may use either maximal or submaximal tests.

Second, the fitness professional must select an exercise mode that best matches the athlete's training or competitive activity. For instance, a cycle ergometer test might be appropriate for an American football lineman because the athlete must be able to sustain or overcome forces against resistance during an entire game.

Third, the fitness professional must determine whether an aerobic power test would provide applicable information. Referring to the previous example, by determining the aerobic power of the athlete, the coach would have a basis for deciding future training strategies along with duration recommendations for keeping the football lineman in the game without a break.

(continued)

(continued)

TABLE 5.8 SMARTS Chart for Maximal Exercise Test Selection

SPECIFICITY ↔ MODE				ARTS OF EXERCISE PRESCRIPTION		
Treadmill	**Cycle ergometer**	**Timed field test**	**Distance field test**			
Arizona State University protocol Bruce protocol Balke protocol Modified Bruce protocol	Storer protocol Andersen protocol 5 km cycle ride	Cooper's 12-minute run 15-minute run 20-minute run 5-minute run Cooper's 12-minute swim	Marathon competition 6-mile competition 3-mile competition 2-mile run 1.5-mile run Mile run	Application	Strong ↑ Research ↓ Weak	Advanced ↑ Training Status ↓ Beginner

TABLE 5.9 SMARTS Chart for Submaximal Exercise Test Selection

SPECIFICITY ↔ MODE			ARTS OF EXERCISE PRESCRIPTION		
Treadmill	**Cycle ergometer**	**Distance field test**			
Jogging protocol Walk/jog/run protocol Walking protocol	YMCA protocol Modified Åstrand protocol Åstrand protocol	Mile jog Rockport mile walk Mile walk 1.25-mile walk Quarter-mile walk Half-mile walk	Application	Strong ↑ Research ↓ Weak	Advanced ↑ Training Status ↓ Beginner

Fourth, the fitness professional should refer to the research for population-specific correlations and standard errors to ensure that the selection is evidence based. Because the anaerobic football lineman would be performing a submaximal cycle ergometer test, research appears to favor the YMCA protocol over the Åstrand protocol.

Fifth, the fitness professional must take into account the athlete's training status. Even though the YMCA protocol may be more accurate in estimating aerobic power, the traditional or modified Åstrand protocol might be more appropriate if the football lineman is untrained after a long off-season.

Fitness professionals should keep in mind that these are only examples of how to use the SMARTS charts; no one method is best for assessing all football linemen or any other types of athletes. Nonetheless, specificity, mode, application, research, and training status all play valuable roles in the selection of an appropriate aerobic power test.

Once they have chosen the aerobic power test, fitness professionals must determine the data variables they need to collect. Based on the variables, any skills that need to be developed should be addressed prior to the testing session. Otherwise, undeveloped skills may require the selection of an alternative testing option. Fitness professionals should practice the skills prior to the testing session regardless of their proficiency, especially if time has elapsed since they last performed the test on an athlete.

After collecting the data and calculating the aerobic power estimate, fitness professionals have a foundational cardiorespiratory fitness level for prescribing an individualized training program. This will result in realistic training goals that may maintain or improve the athlete's aerobic power. In addition, fitness professionals should remember that improvements in aerobic power require sustained activities near or above anaerobic threshold; these assessments are presented in the next chapter.

SUMMARY

- The proper selection and administration of a protocol are essential because they affect the accuracy of the results of the cardiorespiratory fitness test. Tests are chosen based on equipment availability, technical expertise, and available time, and they should be population specific while providing the least amount of error in estimating aerobic power. If multiple cardiorespiratory fitness tests are applicable to an athlete, the fitness professional may be able to reduce the standard error by comparing two or more options.
- Knowledge of the athlete's training program exercises prior to testing will allow the fitness professional to make adaptations to address the specificity of the exercise, which will facilitate the selection of an appropriate cardiorespiratory assessment protocol. Regardless, interpreting aerobic power for cardiorespiratory fitness will be based on careful considerations that ensure the test protocol accurately identifies training adaptations and exercise program effectiveness.