Physiological Assessment of Human Fitness

SECOND EDITION

Peter J. Maud / Carl Foster EDITORS

Physiological Assessment of Human Fitness

Second Edition

Peter J. Maud, PhD

New Mexico State University

Carl Foster, PhD

University of Wisconsin at La Crosse

Editors

HUMAN KINETICS

Library of Congress Cataloging-in-Publication Data

Physiological assessment of human fitness / Peter J. Maud, Carl Foster, editors.-- 2nd ed.
p. ; cm.
Includes bibliographical references and index.
ISBN 0-7360-4633-X (hard cover)
1. Exercise--Physiological aspects. 2. Physical fitness--Testing. 3. Exercise tests.
[DNLM: 1. Exercise--physiology. 2. Exercise Test. 3. Physical Fitness--physiology. QT 255 P5812 2006] I.
Maud, Peter J., 1938- II. Foster, Carl.
QP301.P57 2006
613.7'028'7--dc22

2005014253

ISBN: 0-7360-4633-X

The Web addresses cited in this text were current as of August 29. 2005, unless otherwise noted.

Acquisitions Editor: Michael S. Bahrke, PhD; **Developmental Editor:** Renee Thomas Pyrtel; **Assistant Editors:** Ann M. Augspurger, Bethany J. Bentley, and Kevin Matz; **Copyeditor:** Robert Replinger; **Proofreader:** Erin Cler; **Indexer:** Dan Connolly; **Permission Manager:** Dalene Reeder; **Graphic Designer:** Nancy Rasmus; **Graphic Artist:** Denise Lowry; **Photo Manager:** Sarah Ritz; **Cover Designer:** Jack W. Davis; **Photographer (cover):** © Getty Images; **Photographs (interior):** © Philippe Lopes (chapter 4), Everett Harman (chapter 7), Kenneth Rundell (chapter 10), Jill Kanaley (chapter 11), and Peter Maud (chapter 12); **Art Manager:** Kelly Hendren; **Illustrator:** Craig Newsom; **Printer:** Sheridan Books

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

Human Kinetics
Web site: www.HumanKinetics.com

United States: Human Kinetics, P.O. Box 5076, Champaign, IL 61825-5076
800-747-4457
e-mail: humank@hkusa.com

Canada: Human Kinetics, 475 Devonshire Road Unit 100, Windsor, ON N8Y 2L5
800-465-7301 (in Canada only)
e-mail: orders@hkcanada.com

Europe: Human Kinetics, 107 Bradford Road, Stanningley, Leeds LS28 6AT, United Kingdom
+44 (0) 113 255 5665
e-mail: hk@hkeurope.com

Australia: Human Kinetics, 57A Price Avenue, Lower Mitcham, South Australia 5062
08 8277 1555
e-mail: liaw@hkaustralia.com

New Zealand: Human Kinetics, Division of Sports Distributors NZ Ltd., P.O. Box 300 226 Albany, North Shore City, Auckland
0064 9 448 1207
e-mail: info@humankinetics.co.nz

preface

Many changes have been made in this second edition of the text. Some chapters have been eliminated, new ones have been added, and in some cases material from two chapters has been combined into one. Author coverage of some chapters has also changed. Significant changes have been made in all chapters to provide up-to-date coverage of the topic being discussed.

One of the most often evaluated fitness parameters is maximum oxygen uptake, which has long been considered the gold standard for the evaluation of cardiorespiratory fitness. Direct assessment of this variable is preferred. Many tests, however, have been devised to estimate maximum oxygen uptake, or general cardiovascular condition, using indirect measures purported to correlate well with direct assessment.

Direct methods for determination of aerobic power are detailed in chapter 2 by Davis, who gives a historical overview of the open-circuit method of determination of maximum oxygen uptake and the added value of using one of the many automated breath-by-breath systems. He discusses test modalities, exercise-testing protocols, and criteria for the achievement of maximum values.

In chapter 3, Billat and Lopes describe indirect methods for the estimation of maximum oxygen uptake and provide detailed examples of specific protocols.

Lopes and White discuss heart rate variability in chapter 4. They provide the background information about heart rate sympathetic and parasympathetic control mechanisms and different methods of variability measurement. The effect of heart rate variability in response to exercise programs is discussed, as is the possible use of this measure to identify overtraining.

The so-called anaerobic and aerobic thresholds, identified primarily by changes in lactate accumulation and ventilatory and respiratory values, provide information about the capacity to perform exercise of an endurance nature. Foster and Cotter review these phenomena in chapter 5, discuss various terminologies used, and provide a rationale concerning appropriate methods of measurement.

Testing for anaerobic abilities, covered in chapter 6, is a somewhat controversial issue in that no laboratory methods are universally accepted as appropriate. The two prime methods used are to measure either mechanical power output or oxygen deficit. Methods of measurement of these two variables are discussed, as are the limitations and problems of trying to quantify anaerobic energy contributions to exercise.

Muscular power is an important requisite for most athletic events. Methods of assessment range from field tests to laboratory techniques. In chapter 7 Harman describes the high-speed measurement of human mechanical power and gives a readily understandable review of the methodologies for recording mechanical power output. His discussion of specific technical requirements and techniques is of particular interest, especially to those with somewhat limited backgrounds in computer application.

Kraemer, Ratamess, Fry, and French provide a comprehensive review and an extensive bibliography of the strength-testing domain in chapter 8. Detailed methodologies for different modalities are provided with consideration given also to individual differences and specifics of performance method.

Evaluation of muscle tissue from muscle biopsy has been undertaken on numerous occasions (Gollnick & Matoba, 1984). Inclusion of a detailed chapter covering this area, however, may be controversial in that, as expounded by Gollnick and Matoba, routine evaluation of muscle tissue for prediction of athletic success should probably not occur. But this text is also designed for research purposes. Information obtained from muscle biopsy may contribute significantly to the study of chronic exercise effects. In chapter 9, McGuigan and Sharman provide an excellent introduction to, and comprehensive coverage of, muscle biopsy technique, histochemical preparation, fiber typing, and analysis of chemical composition of muscle tissue. These techniques allow complete analysis of muscle structure and function.

The use of near-infrared spectroscopy as a tool to measure tissue oxygen kinetics and blood flow dynamics noninvasively in the assessment of the athlete's response to exercise is described by Rundell and Im in chapter 10. This relatively new noninvasive technique is believed to hold great potential for evaluation of response to exercise training regimens.

Body composition is important when considering suitability for specific athletic events. Moreover, with national and world attention now being directed to the medical problems and associated potential astronomical costs of increased human obesity, body composition is important from a health fitness perspective. In chapter 11, Pollock, Kanaley, Garzarella, and Graves provide in-depth coverage of current body composition assessment techniques and complete bibliographical references.

Flexibility is also important for many athletes, whether they view performance in terms of time, distance, speed, or aesthetics. Many also suggest that flexibility is an important contributor to normal daily function from a health perspective. In chapter 12, Maud and Kerr discuss the limitations of certain measurement methods and provide details of preferred methods for assessment of joint range of motion and muscle length.

Chapter 13 is devoted to the collection of physiological data in the field, a topic that certainly warrants attention because it is too often neglected. As noted by authors Foster, Daniels, deKoning, and Cotter, athletic performance does not take place in the laboratory but rather in the field under a myriad of physical, environmental, sociological, and psychological conditions. Testing under these conditions results in more realistic exposure when considering athletic performance. The practical considerations for testing outside the laboratory are adequately covered.

Exclusions

Although a rationalization could be given for the inclusion of more comprehensive evaluations of cardiovascular function by use of such means as ECG exercise tolerance testing, particularly when health is the prime concern, and assessment of visual abilities when considering either health or athletic performance, tests such as these are not included because of their specialized nature and probable necessity for some form of medical supervision. Similarly, the perceptual motor domain is not included because, as already discussed, the commonly held view is that general motor ability does not exist. Instead, most believe that several broad and independent perceptual motor abilities and physical proficiencies usually apply to specific athletic events.

contents

one

Fitness Assessment Defined

Peter J. Maud, PhD
New Mexico State University

No definition of fitness appears to be widely accepted, nor is there agreement about what specific components should make up a fitness evaluation. Over 60 years ago Steinhaus (1936), evidently viewing fitness from the perspective of the physiologist, defined it as distance from death, a description somewhat like that of many in the medical profession, who tend to regard physical fitness as absence of disease. Willgoose (1961) has defined it as "a capacity for sustained physical activity" (p. 105). A more appropriate and universal definition of physical fitness, at least from a health perspective, may be the one found in *Mosby's Medical and Nursing Dictionary* (1986), which defines physical fitness as "the ability to carry out daily tasks with alertness and vigor, without undue fatigue, and with enough reserve to meet emergencies or to enjoy leisure time pursuits" (p. 880).

Differences in interpretation of the term probably depend on whether fitness is applied to health or relative to athletic competition. Higher levels of fitness are obviously necessary for success in athletics. Test items that are more specific are required for measurement of fitness attributes when successful, rewarding, and enjoyable participation in sport is desired. Here, where the primary intention is to discuss fitness from a physiological or physiologically related perspective, it is necessary to define fitness parameters and select those items appropriate for inclusion. Consideration must also be given to techniques that allow determination of changes that result from different types of training programs, whether information so gained is useful for planning health enhancement programs or for improving fitness for sport participation.

Fitness assessment may be viewed from several different perspectives, including determination of energy system utilization (which may be particularly important for sport participation), evaluation of fitness specifically for health enhancement purposes, or use of traditional component tests for determination of sport fitness and profiling. Evaluation of the perceptual motor domain and vision requirements for improved sport performance could also be included in fitness assessment. Additionally, study of the historical development of fitness testing is interesting and applicable to an understanding of current practices.

The inclusion of the term *physiological* in the title of the text may be somewhat debatable because several of the test areas assessed are not necessarily purely physiological. Some, for example, are more anatomical or morphological in nature. All of the testing areas included in the text, however, relate to attributes necessary for profiling human response to exercise.

Historical Perspectives

This chapter includes a few examples of the types of tests that were used to assess fitness in earlier times. The tests described here are not necessarily those that were the most accepted, but they serve as examples of what was thought to be current and appropriate at that time. Three general areas of fitness—anthropometry; muscular strength, endurance, and power; and cardiovascular fitness—received prime consideration. An extensive review of the development of fitness tests and an excellent source for references is the text titled *Physical Fitness Appraisal and Guidance*, published in 1947 by a renowned pioneer of fitness testing, Thomas Kirk Cureton.

Anthropometric Measurement

Some of the earliest tests used to evaluate or describe fitness were restricted to anthropometric measurement. An early pioneer of anthropometric assessment was Hitchcock of Amherst College, who measured such attributes as age, height, weight, chest girth, arm girth, forearm girth, and lung capacity, as described in the text that he coauthored with Seelye in 1893, and in which he described data collected approximately between the years 1861 and 1880. (Seaver, however, had published *Anthropometry in Physical Education* in 1890 and thus is perhaps the first modern author in this area.) Description of body type can be traced back to Hippocrates, who recognized two basic body types, and later to Rostan, who in the late 19th century proposed a classification system of three body types. Sheldon, in association with Stevens and Tucker (1940), made the first serious attempt to classify body types as having proportions that were a mixture of the three general classifications of ectomorph, mesomorph, and endomorph. The study of somatotype and anthropometry, and the study of their relationship to human motion are still important today, as illustrated by the formation of a new association, the International Society for the Advancement of Kinanthropometry in 1986, during the VIII Commonwealth and International Conference on Sport, Physical Education, Dance, Recreation, and Health held in Glasgow, Scotland. Beunen and Borms described the purpose and function of the new organization in 1990.

Assessment of Muscular Strength, Endurance, and Power

In about 1880, Sargent probably initiated the move to include strength tests as a major component of fitness evaluation. In 1896, however, Kellogg described a "universal dynamometer" that made possible muscle strength testing that was more accurate. Sargent, in a 1921 journal article titled "The Physical Test of Man," described the vertical jump test—or Sargent jump, as it is now popularly known—one of the first tests of muscular power. Rogers (1927) developed the strength index, considered a general test of athletic ability, and a physical fitness index, derived by comparing the strength index with norms based on gender, weight, and age. He probably contributed more to the popularity of strength testing than any other individual did during the earlier part of the century. The test used seven measurements, consisting of left and right handgrip strength, back strength, leg strength, strength of the arms and shoulder girdle as measured in men by dips on the parallel bars and by pull-ups with overhand grip, and forced vital capacity. Others modified the original test. For example, MacCurdy (1933) eliminated the endurance factors associated with the pull-up and dip tests by replacing them with static tests of arm strength using the back/leg dynamometer. McCloy (1939) later eliminated the lung capacity test, arguing that it was not a test of muscle strength.

Isometric tests evaluated by the cable tensiometer using methodology described by, for example, Clarke (1966), and the typical spring dynamometer are still in use, as are such field tests as dips, pull-ups, and push-ups. Still one of the more popular and applicable methods used to assess muscular strength is 1RM testing. Today, however, measurement of isometric and isokinetic strength by means of force transducers or load cells, and strain gauges, allows computer interface for data collection, thus facilitating test recording and evaluation.

Evaluation of Cardiovascular Fitness

Many well-known tests of cardiovascular fitness date back to the early 20th century. One of the first compared heart rate and systolic blood pressure responses between the horizontal and standing positions (Crampton, 1913). The belief was that a fitter person would exhibit a maximal rise in blood pressure with no change in heart rate, "evidencing such a complete working of the splanchnic mechanism that the heart would not be called to help raise blood-pressure" (McCurdy & Larson, 1939, p. 267). The Barach cardiovascular test, described in 1919, was another test that used blood pressure and heart rate to evaluate cardiovascular function. This test, which was claimed to indicate the energy demands of the circulatory system, produced an index by adding systolic and diastolic pressures and then multiplying by heart rate.

One of the earlier tests used to investigate the response of heart rate to exercise and recovery was the Foster cardiovascular test published in 1914. Preexercise, immediate postexercise, and 45 s postexercise heart rates were obtained. These three heart rates comprised separate tests with norms established for all three conditions. The exercise component consisted of stepping up and down on the floor for 30 s at a rate of 180 steps per min, with heart rate measured manually for a 5 s period. Lack of standardization of the stepping exercise and the potential for error in measurement of heart rate tended to invalidate the test.

Schneider (1920) used a combination of pulse rate and blood pressure obtained in the horizontal and standing positions, and pulse rates taken immediately following 15 s of bench-stepping exercise and during recovery, to evaluate aviators during World War I. Tuttle described his well-known pulse ratio test, using a bench 13.5 in. (34.3 cm) high, in 1931. A 2 min pulse count obtained following standardized exercise was divided by a 1 min pretest resting rate.

McCurdy and Larson (1939, p. 274) described a test of "organic efficiency" and provided comprehensive normative tables for males aged 18 to 80 years. Test items included sitting diastolic pressure, breath-holding ability taken 20 s following 90 s of standardized bench-stepping exercise, the difference between preexercise standing pulse rate and pulse rate obtained 2 min following standardized exercise, standing pulse pressure, and vital capacity.

More recent tests have included the renowned Harvard step test developed by Brouha (1943) and other step tests that are still in use. Other exercise modalities, such as the treadmill and the bicycle ergometer, have replaced bench stepping in popularity, but heart rates taken during either exercise or recovery are still widely used to assess cardiovascular fitness.

Contribution of Technology to Fitness Assessment

Some of the most significant advancements in fitness assessment have been made possible by the development of sophisticated equipment and techniques. For example, in the assessment of metabolic response, although the Douglas bag and associated chemical evaluation for gas composition using Scholander equipment may still be found in some laboratory settings, it is far more common to find elaborate, online computer equipment capable of providing instantaneous feedback using breath-by-breath analysis. Similarly, muscular strength, endurance, and power are commonly evaluated in the laboratory by isokinetic methods, with detailed computer analysis, rather than by spring dynamometer or cable tensiometer. Even heart rate measurement has been greatly facilitated and made more accurate by use of the ECG or small and simple, yet accurate, heart rate telemetry systems. In fact, the development of such systems, which now include the ability to make accurate measurement of beat-by-beat heart rate variability, is proving to be useful in the analysis of cardiovascular response to exercise and exercise training. Hydrostatic weighing, anthropometric measurement, and skinfold measurements are still used to assess body composition, but newer methods made possible by enhanced technologies now allow measurement by such means as air displacement plethysmography, bioelectric impedance, ultrasound, dual-energy projection, magnetic resonance imaging, and computed tomography. Advanced techniques in body tissue analysis and instruments like the electron microscope have greatly enhanced our ability to evaluate fitness changes at the cellular and ultracellular levels. From a historical perspective these advances have certainly changed the ways that fitness is assessed in the laboratory. Nevertheless, many techniques and methods used in earlier times are still appropriate, particularly the field tests used in many cases to evaluate sport fitness.

Energy Systems Approach

One approach to fitness evaluation is to base all tests on the energy systems used during physical activity. The contribution to energy requirements by initial stores of adenosine triphosphate (ATP) present within the muscle and the subsequent restoration of these stores by creatine phosphate (CP), by the anaerobic breakdown of glycogen, or by aerobic utilization of glycogen, fat, and protein, would require assessment. Fox, Robinson, and Wiegman (1969) classified activity by the prime source of energy being used and proposed four time periods. Period 1 comprised activities that lasted less than 30 s. They suggested that these activities depended primarily on the contribution of ATP and CP. Period 2, from 30 to 90 s, used mainly the phosphagens and anaerobic glycolysis. Period 3, lasting from 90 to 180 s, depended mainly upon anaerobic glycolysis and aerobic metabolism, and period 4, consisting of exercise past 180 s, was reported to be primarily aerobic in nature. Shephard (1978) described another classification system using a similar approach but with five phases. Phase 1 was a single maximum contraction; phase 2 comprised very brief events that lasted less than 10 s; phase 3 was for events that lasted 10 to 60 s; phase 4 was for activity that lasted from 1 min to 1 h; and phase 5 was for prolonged events that lasted in excess of 1 h. Skinner and Morgan (1984) have proposed another four-period classification system based on more recent research, particularly in the areas of power output and lactate tolerance. They suggested that it consists of a peak anaerobic power phase lasting 1 to 10 s, in which initial stores of ATP and CP would be the main energy sources; a mean anaerobic power phase of 20 to 45 s, in which anaerobic glycolysis, in addition to ATP and CP stores, would be the prime energy contributor; a lactic acid tolerance phase lasting 1 to 8 min; and an aerobic phase of 10 or more min, in which aerobic metabolism would be the prime energy source.

Use of gas analysis during maximal work tests to derive maximum oxygen uptake is well documented as indicating the contribution of the aerobic system to fitness. Methods for assessing other systems' contributions are far more controversial. Numerous tests have been devised to measure mechanical power output during time periods thought to represent the energy contribution phase. A short, single contraction, as in the vertical jump test described by Sargent (1921), would, if considered only from the perspective of the energy requirements for the activity, indicate the contribution of ATP stores. The 2 to 4 s required to complete the Margaria stair-run test (Margaria, Aghemo, & Rovelli, 1966) or the 5 s Wingate test (Bar-Or, 1987; Bar-Or et al., 1980) would represent peak anaerobic power in which ATP and CP stores should be the main energy contributors. The 30 s Wingate test (Bar-Or et al., 1980) measures mechanical mean anaerobic power output during the anaerobic glycolytic phase. But there are many problems in assuming that the power output during specified time periods does in fact represent specific energy contributions. Muscle biopsy techniques may allow quantification of ATP and CP stores, but the size, strength, and speed of contraction of the muscle, the predominant fiber type, the structural arrangement of the individual muscle, and coordination all affect power output. Because it is easy to measure, blood lactate is commonly used to predict anaerobic glycolytic ability, but diffusion of lactate into the blood does not provide an accurate assessment of individual muscle contribution. Furthermore, motivation plays an important role in tests requiring maximal effort. In the measurement of maximum oxygen uptake, parameters that denote achievement of a true maximal effort have been identified, but measurable characteristics to identify maximal effort are less clearly defined for anaerobic testing.

Health Fitness

Probably the most commonly accepted components of health fitness include cardiovascular endurance, body composition, flexibility, and muscular strength and endurance. These four components, however, are not necessarily accepted as the only ones that need to be assessed. Medically oriented health fitness evaluation centers offer far more comprehensive programs that may include, for example, extensive cardiovascular evaluations with an ECG exercise tolerance test, blood chemistry analysis and blood count, maximum oxygen uptake measurement, pulmonary function tests, and orthopedic assessments (Maud & Longmuir, 1983).

The American College of Sports Medicine (ACSM) (2000), for safety reasons, has recommended that subjects be screened before they undergo moderate to vigorous tests. These recommendations include using the PAR-Q questionnaire developed by the Canadian Society for Exercise Physiology (1994) as an initial screening procedure. The type of subsequent testing, submaximal or maximal, and whether medical supervision is required depends on the age of the subject and whether risk factors for cardiopulmonary or metabolic diseases are present. The ACSM guidelines should be reviewed and followed before conducting any fitness tests.

Although there may be debate as to whether or not extensive medical testing in the evaluation of fitness for the general population is beneficial, and the American College of Cardiology and the American Heart Association (1986) generally do not believe that diagnostic exercise testing is of value to apparently healthy people, such testing is readily available. Certainly such tests as blood chemistry, blood pressure screening, and ECG evaluations are invaluable when assessing health status and predisposition toward cardiovascular disease and diabetes (Smith, 1988).

Fitness Evaluation for Athletic Participation

A plethora of tests has been developed to evaluate the fitness of athletes representing a variety of sports and activities. Reviewing all athletic group fitness profiles or individual tests administered would be a monumental task. Methods used to evaluate athletic fitness depend on the requirements of the individual sport or event, the reason for administering the tests, the availability of equipment and facilities, the practicality of assessment, and the personal perspectives of the researcher.[1]

To give the reader some idea about the variety of tests that have been employed to assess athletes, fol-

[1] A detailed description of test methods and protocols used by a variety of Australian sporting organizations may be found in the authoritative text published for the Australian Sports Commission (2000), edited by Christopher Gore and titled, *Physiological Tests for Elite Athletes.*

lowing is a brief outline obtained from 14 studies covering the period from 1976 to 2004, a total of 28 years. Athletes from the following team sports were studied: basketball (Parr, Hoover, Wilmore, Bachman, & Kerlan, 1978), football (Wilmore et al., 1976), soccer (Raven, Gettman, Pollock, & Cooper, 1976), rugby union (Maud & Schultz, 1984), rugby league (Gabbett, 2002), Australian football (Parkin, 1982), field hockey (Rate & Pyke, 1978), team handball (Rannou, Prioux, Zouhal, Gratas-Delamarche, & Delamarche, 2001), and lacrosse (Withers, 1978). Individual and dual sports included are racquetball (Salmoni, Guay, & Sidney, 1988), tennis (Carlson & Cera, 1984), downhill skiing (National Alpine Staff, 1990), middleweight boxing (Guidetti, Musulin, & Baldari, 2002), and cheerleading (Thomas, Seegmiller, Cook, & Young, 2004). (Although not universally recognized as a sport, cheerleading is included because it has become a complex physical activity requiring many of the same physical attributes as other sports do.) These studies indicate the commonalities and diversities of test items used. Note that little has changed relative to the test items used during the 28-year period. Probably the most significant changes have been in the development of new equipment, such as heart rate monitors and small portable oxygen uptake systems that allow collection of data during athletic endeavors. Also occurring during this time has been a great increase in the amount of research being conducted to study the acute and chronic responses to exercise in normal, athletic, and special populations, which may or may not be applicable to fitness assessment.

- Many investigators have evaluated cardiovascular fitness by direct determination of maximum oxygen uptake, in studies of rugby (Maud & Schultz, 1984), football (Wilmore et al., 1976), soccer (Raven et al., 1976), lacrosse (Withers, 1978), field hockey (Rate & Pyke, 1978), basketball (Parr et al., 1978), handball (Rannou et al., 2001), boxing (Guidetti et al., 2002), tennis (Carlson & Cera, 1984), and cheerleading (Thomas et al., 2004). Others have assessed this parameter by indirect means, using a timed 15 min run for Australian football players (Parkin, 1982), a 2 mi (3.2 km) (McCurdy & Larson, 1939) or 1 mi (1.6 km) (National Alpine Staff, 1990) run for downhill skiers, a 15 min run for racquetball players (Salmoni et al., 1988), and by a multistage shuttle run in one of the rugby studies (Gabbett, 2002).

- Anaerobic capacities have been evaluated by a 440 yd (402 m) (National Alpine Staff, 1990) run for downhill skiers; by the Wingate test for rugby (Maud & Schultz, 1984), handball (Rannou et al., 2001), and racquetball (Salmoni et al., 1988) athletes; by the Margaria stair-run test for lacrosse (Withers, 1978), field hockey (Rate & Pyke, 1978), and tennis (Carlson & Cera, 1984) players; and by postexercise blood lactate levels in lacrosse players (Withers, 1978) and team handball players (Rannou et al., 2001).

- Grip strength has traditionally been used as a general measure of muscular strength, as in the studies of rugby (Maud & Schultz, 1984), soccer (Raven et al., 1976), Australian football (Parkin, 1982), tennis (Carlson & Cera, 1984), boxing (Guidetti et al., 2002), and racquetball (Salmoni et al., 1988). Leg strength has also been evaluated (Parkin, 1982; Salmoni et al., 1988), as has arm and shoulder strength by the bench press in soccer (Raven et al., 1976), football (Wilmore et al., 1976), and cheerleading (Thomas et al., 2004). Several studies (Carlson & Cera; Parr et al., 1978; Thomas et al., 2004) used isokinetic evaluation to assess strength.

- Testing for muscular endurance has commonly been accomplished by use of field tests. Five such tests were used in the Australian football study (Parkin, 1982). Two studies (Carlson & Cera, 1984; Parr et al., 1978) used isokinetic endurance evaluation.

- Testing for muscular power, one of the most important attributes for successful performance in many games and sports, has frequently used the vertical jump (Maud & Schultz, 1984; National Alpine Staff, 1990; Parkin, 1982; Raven et al., 1976; Salmoni et al., 1988; Gabbett, 2002). Besides being used to assess muscular strength and endurance, isokinetic evaluation was used for power evaluation of tennis (Carlson & Cera, 1984) and basketball players (Parr et al., 1978).

- The sit-and-reach test has been the most widely used measure of flexibility, despite its controversial nature. The only other flexibility assessments used in the studies being examined were wrist and shoulder flexibility in racquetball players (Salmoni et al., 1988) and back hyperextension in basketball players (Parr et al., 1978).

- Skinfold measurement was the most prevalent method for estimating body composition (Carlson & Cera, 1984; Maud & Schultz, 1984; Parkin, 1982; Rate & Pyke, 1978; Raven et al., 1976; Wilmore et al., 1976; Withers, 1978; Parr et al., 1978; Thomas et al., 2004). Four of the studies (Carlson & Cera, 1984; Wilmore et al., 1976; Parr et al., 1978; Thomas et al., 2004) also used the underwater weighing technique. One study (Carlson & Cera, 1984) also described skeletal widths and circumferences, and another described somatotype (Wilmore et al., 1976). In the boxing study (Guidetti et al., 2002) cross-sectional area of the arm and forearm was also described.

• Other data collected to describe athletic attributes have included measurement of speed by timing a 40 yd (36.6 m) dash (National Alpine Staff, 1990; Rate & Pyke, 1978; Salmoni et al., 1988; Gabbett, 2002) or, in the case of the Australian football study (Parkin, 1982), by using 15, 40, and 55 m run times and a 40 m run following a 15 m running start. Investigators measured agility by timing shuttle runs (National Alpine Staff, 1990) or agility runs (National Alpine Staff, 1990; Rate & Pyke, 1978; Raven et al., 1976; Salmoni et al., 1988; Gabbett, 2002).

These examples illustrate the diversity of sports evaluated and assessment methods used. They also illustrate the intermixing of two different types of tests, the so-called field tests and those that require special equipment or are conducted in the laboratory setting.

Field Tests

For the purpose of this chapter, field tests are defined as those tests that may be completed outside the laboratory environment and do not require specialized equipment for data collection or recording. This definition excludes tests that may be conducted in the field using specialized equipment varying from the relatively simple, such as skinfold calipers, to the sophisticated, such as the equipment used to determine oxygen uptake of athletic activities in the simulated competitive environment. Most tests described in this text are not field tests, although some are included in the chapters dealing with the indirect determination of aerobic power and measurement of muscular strength. Both of these types of tests have a place in the evaluation of health fitness and for the evaluation of athletes. Table 1.1 gives examples of both types of commonly used tests.

Table 1.1 **Classification of Test Types: Field Tests and Tests That Require a Laboratory or Specialized Equipment**

Fitness parameter	Examples of field tests	Examples of tests either conducted in a laboratory or requiring specialized equipment
Aerobic power		
(a) Maximal tests	1. Time to cover a specific distance 2. Distance covered in a specific period 3. Time taken, or distance covered, in a shuttle run to exhaustion, with incremental speed increases at specified time intervals	1. Continuous tests Maximum oxygen uptake obtained during a continuous progressively increased workload test using a specific exercise modality† a. Ramp test with workload continuously increasing b. Test with specific workload increase at specified time intervals 2. Discontinuous tests Like 1b except that specific recovery periods are interspersed between exercise stages
(b) Submaximal tests	1. Recovery heart rate following specific-height bench stepping at a specified rate for a specific period	1. Steady state heart rate response to a specified workload during a specific period†
Anaerobic power		
(a) Peak anaerobic power	1. Vertical jump height 2. Standing broad jump distance 3. Timed, short, specific-distance sprints in which time to completion is usually in the 5 s to 10 s range‡	1. Peak power output, usually recorded in W or W/kg, either per 1 s or 5 s, obtained during all-out exercise lasting 5 s to 10 s††
(b) Mean anaerobic power	1. Specific-distance sprints in which time to completion is usually within the 30 s to 60 s range	1. Mean power output, usually recorded in W or W/kg, obtained during all-out exercise over a 20 s to 60 s period†† 2. Oxygen deficit achieved during all-out exercise over a 20 s to 30 s period

Fitness parameter	Examples of field tests	Examples of tests either conducted in a laboratory or requiring specialized equipment
Body composition	1. Estimates of percent body fat from circumference measurements 2. Body height, weight, and frame size	1. Skinfold measurement 2. Underwater weighing 3. Air displacement plethysmography 4. Bioelectrical impedance 5. Ultrasound 6. Magnetic resonance imaging and computed tomography
Flexibility	1. Linear measurement from one body segment or specific identifiable site to another or to an external object	1. Use of goniometer and inclinometer to measure range of motion in degrees
Muscular strength	1. 1RM measurement 2. Use of muscular strength to overcome gravitational resistance of body or body part[‡‡]	1. Isometric strength measurement using a cable tensiometer or dynamometer 2. Isometric, isotonic, and isokinetic measurement of strength using force transducers or load cells, and strain gauges
Muscular endurance	1. Number of repetitions completed using a specific weight resistance or a percentage (e.g., 70%) of 1RM 2. Time to maintain a specific weight or percentage of 1RM in a set position 3. Number of repetitions that can be completed against gravitational pull on body or body part	1. Measurement of isokinetic endurance by measurement of number of maximum effort contractions that can be made before the maximum force drops below a specified percentage (e.g., 70%) of maximum 2. Time that a specific muscle group can maintain a joint at a specific angle using a percentage of maximum (e.g., 70%) force as the load

[†]Examples of types of equipment that may be used for exercise modality include the treadmill, cycle ergometer, arm ergometer, kayak ergometer, rowing ergometer, cross-country ski ergometer, and swimming flume.

[‡]Although running is usually the mode of activity tested, other activities such as bicycling, swimming, or rowing could be used.

[††]The two most commonly used modes of activity are all-out pedaling on the cycle ergometer or continuous, maximum effort vertical jumping.

[‡‡]Use of typical tests such as the pull-up are complicated by the fact that the greater the number of repetitions achieved, the greater the reliance on muscular endurance rather than muscular strength.

Overtraining

One area of research that certainly has important implications relative to elite performance is that of overreaching, which results in a short-term loss of performance capacity, or overtraining, which results in a relatively long-term negative effect on performance (Kreider, Fry, & O'Toole, 1998). Although numerous physiological, biochemical, psychological, and immunological signs and symptoms have been described as being present with overreaching or overtraining, finding tests that can identify markers that precede the ultimate drop in performance associated with these phenomena has been difficult. Obviously, tests that could predict the onset of overreaching or overtraining, probably specific to the individual, would be invaluable to the coach and sport physiologist when training athletes. Such tests have yet to be identified. See the comprehensive text by Kreider et al. (1998) for in-depth coverage of this area.

Perceptual Motor Domain

The performance of complex skills depends on neuromuscular coordination produced in response to sensory feedback and its subsequent processing. Testing within this domain is fraught with problems, mainly stemming from lack of agreement about the specific parameters that define the area.

Motor Ability

During the 1920s it was hypothesized that ability to perform motor tasks was an inherent characteristic much like intelligence. Researchers therefore believed that they could develop tests similar to those used to measure IQ to predict ability to perform the motor tasks involved in sport and other complex movement patterns. Brace, in 1927, was one of the earliest researchers to develop such a test battery, comprising

20 different stunts designed to evaluate "inherent motor skill" ability. In 1929 Cozens published a test that purported to identify "general athletic ability." This was followed by Johnson's test in 1932 used to evaluate "native neuromuscular skill capacity." McCloy then published a modification of the Brace test in 1937 in an attempt to evaluate "motor educability." Subsequently came the realization that general motor ability does not exist but that there may be a number of rather broad, yet relatively independent, motor abilities, as described by Fleishman (1964). He used a two-classification system to describe motor abilities, one consisting of perceptual motor abilities and the other of physical proficiencies. His tests of perceptual motor ability consisted of 11 items: "control precision, multi-limb coordination, response orientation, reaction time, speed of arm movement, rate control (timing), manual dexterity, finger dexterity, arm-hand steadiness, wrist-finger speed, [and] aiming." The physical proficiency battery included "extent flexibility, dynamic flexibility, static strength, dynamic strength, explosive strength, trunk strength, gross body coordination, equilibrium, [and] stamina" (Fleishman, 1975, p. 1132). This brief discussion of motor abilities indicates that many traits may contribute to fitness for athletic performance, particularly reaction time, balance, movement speed, agility, and coordination. Applicable to specific sports, these abilities need to be evaluated, and they form a significant part of many fitness-testing batteries.

Vision Testing

Whether vision testing should be separate from other sensory tests or from the psychomotor domain is debatable. Vision can certainly affect athletic performance, and vision testing has been part of the assessment of athletes in the sports medicine program at the United States Olympic Committee training center in Colorado Springs. In sports in which aiming is a crucial skill component, such as archery and shooting, visual abilities are paramount, but vision testing in other sports also has been undertaken. Tests have been designed to evaluate such traits as visual acuity (the sharpness and clarity of vision), dynamic visual acuity (the ability to see moving objects clearly), vision pursuit (the ability to follow the pathway of moving objects), depth perception (the ability to judge distance and speed), and eye–hand–body coordination. If tests such as these differentiate performance ability, then one can argue that they should be part of the process used in the evaluation of the athlete, particularly if training can remedy any deficiencies. Further discussion of this issue, however, is beyond the scope of this text.

Rationale for Text Test Items

Several authorities have suggested items that should be included in a typical fitness evaluation. The typical test items usually covered include aerobic fitness, peak and mean anaerobic power, anthropometry and body composition, flexibility, and muscular strength and endurance, all of which are used for both health fitness evaluation and assessment of athletic potential and ability. This text includes all of these items despite the argument put forward by Åstrand and Rodahl (1986) that many such test items, "including evaluation of flexibility, skill, strength, etc., are related to special gymnastic or athletic performance" and "are not really suitable for an analysis of basic physiological functions" (p. 355). Many of these items, however, may have a profound effect on physiological performance and, therefore, these tests should be included. Inclusion of such items in tests of health status or athletic ability should provoke little argument because they are crucial to both areas. Several new methods for assessment of physiological response to exercise such as measurement and applicability of heart rate variability, near-infrared spectrophotometry and its use in athletic assessment, and measurement of muscle structure and function are also included.

Summary

Undoubtedly, athletic competition requires fitness beyond that necessary for optimal health. But the value of specific fitness test items to athletes and coaches, and the use that can be made of data collected, have been much debated (Gollnick & Matoba, 1984; Noakes, 1988). Ultimately, physiological fitness professionals are responsible for assessing the value of the different areas that they might evaluate and the specific methods that they might use for those evaluations. Obviously, they will take different approaches depending on whether the goal is to evaluate health fitness, to assess fitness for successful athletic participation, or to research the response of the human body to varied exercise intensities and regimes.