[Primary Care]

What Performance Characteristics Determine Elite Versus Nonelite Athletes in the Same Sport?

Daniel S. Lorenz, DPT, PT, LAT, CSCS, USAW,*†
Michael P. Reiman, PT, DPT, OCS, SCS, ATC, FAAOMPT, CSCS,‡ B.J. Lehecka, DPT,§
and Andrew Naylor, PT, DPT, SCS‖

Context: There are significant data comparing elite and nonelite athletes in anaerobic field and court sports as well as endurance sports. This review delineates specific performance characteristics in the elite athlete and may help guide rehabilitation.

Evidence Acquisition: A Medline search from April 1982 to April 2012 was undertaken for articles written in English. Additional references were accrued from reference lists of research articles.

Results: In the anaerobic athlete, maximal power production was consistently correlated to elite performance. Elite performance in the endurance athlete is more ambiguous, however, and appears to be related to the dependent variable investigated in each individual study.

Conclusion: In anaerobic field and court sport athletes, maximal power output is most predictive of elite performance. In the endurance athlete, however, it is not as clear. Elite endurance athletes consistently test higher than nonelite athletes in running economy, anaerobic threshold, and VO_{2max}.

Keywords: elite versus nonelite athlete; performance characteristics; endurance athlete

The ability to distinguish elite from nonelite athletes is not clearly defined. Traditionally, those athletes drafted in higher rounds or playing in higher divisions are elite. Differentiating these levels is a multifaceted process.

Several variables have been investigated to define the elite athlete, including anthropometric and physiologic characteristics,[2,3,33-35,45,61,62,66,77,74,92] balance,[44] the role of the athlete on the team,[11,77] length of training,[45] type of performance training,[13,24,44,46,65] talent development and maturation,[1,3,19,66,74,88] and physical performance.[7,15,91] The multiple variables attest to the complexity of the elite athlete.

Confounding the delineation is the question of which performance characteristics are most predictive of success. Are elite athletes simply of a different genetic makeup than nonelite athletes? Can performance variables such as strength, power, endurance, and agility be trained at a level sufficient to make one an elite athlete?

Successful performance in sport during childhood and adolescence is affected by a wide range of physical and physiologic factors that operate in a sport-specific manner.[3] While training specific performance variables engenders future success for some young children and adolescents,[3,66] a more comprehensive analysis insinuates that the interaction between genetic and training factors promotes elite performance.[88]

OPERATIONAL DEFINITION

The studies analyzed used a wide array of definitions for an elite athlete.[8,20,26,29,34,63,80,82] For the endurance athlete, the determination is even more complicated because of the inconsistency in defining what variables (eg, anaerobic threshold [AT], maximal oxygen uptake [VO_{2max}]) determine elite performance. For this article, an elite athlete is defined as follows:

1. drafted or drafted in high rounds versus those undrafted or drafted in later rounds;
2. perceived as having greater performance ability than that of their peers in the same sport;
3. play at a higher level within a sport (division I vs II, professional vs amateur); and
4. for endurance, greater variables (eg, running economy, AT, VO_{2max}).

CHARACTERISTICS OF ANAEROBIC FIELD AND COURT SPORT ATHLETES

American football requires a variety of mental and physical attributes to be successful. Elite American football players typically possess superior anthropometric height and weight measurements[37,64] compared with nonfootball individuals. In addition, they demonstrate a variety of physical performance characteristics for numerous movement patterns. The National Football League combine assesses 8 physical performance tests.[79] Despite the effort to choose athletes with the best physical attributes, actual performance varies considerably.

A recent study examined the combine performance differences between drafted and undrafted players.[83] Players were divided into 3 position groups: skill players (wide receivers, running backs, and defensive backs), big skill players (fullbacks, linebackers, tight ends, and defensive ends), and linemen (centers, offensive tackles, offensive guards, and defensive tackles). For skill players, those drafted performed significantly better than nondrafted players on the 40-yard dash, vertical jump height, proagility shuttle, and 3-cone drill.[83] In the big skill group, drafted players performed significantly better on the 40-yard dash and the 3-cone drill. Finally, the 40-yard dash, 225-lb bench press test, and the 3-cone drill were significantly better in the drafted versus undrafted linemen.

An evaluation of anatomic and physiologic characteristics to determine those that best predict American football ability found the only test that predicted football ability was the Margaria-Kalamen power test (athlete propels up a flight of 12 stairs, 3 at a time, as quickly as possible), which also related to a better 40-yard dash.[4] In division I-A football, football playing ability was significantly correlated with vertical jump for all positions.[80] A study of 46 college football players found that the 36.6-m sprint and 18.3-m shuttle run predicted football playing ability, while physical characteristics such as height, weight, and percentage body fat did not.[26]

Based on the available studies, it appears that regardless of position, power, speed, and agility are most relevant to actual performance in the National Football League, and anthropometric characteristics such as height and weight are less important.[26,37,79,80,83] Interestingly, it is not known which characteristics of undrafted or late-round picks indicate success in American football.

Similar to American football, rugby requires a wide variety of physical fitness qualities.[8] To compete at a high level, athletes must demonstrate tactical abilities in addition to physical performance measures.[8] Recent research compared elite division I National Rugby League players with division II state league rugby players.[8] Twenty athletes from each league were assessed on the basis of the 1-repetition squat maximum, power output of a jump squat, 10-m and 40-m sprints, cone agility drill, and sprint momentum (body mass × average velocity during 10-m sprint test). Elite players were significantly bigger (height, weight) and stronger (maximum strength) than division II players. They were also significantly more powerful (explosive). Increased size and strength allowed elite players to produce greater momentum compared with their nonelite peers. The findings suggest that lower body strength relative to body mass is an indicator of success in rugby, as heavier, faster players would be able to drive forward better and, conversely, be able to repel their opponents drive forward.

Elite junior rugby players were compared with subelite players across anthropometric and physical ability measures to analyze predictors of tackling ability.[32] Forty-one players were assessed on the basis of height, weight, and skinfold measurements as well as lower body muscular power. Each player performed 6 tackling drills and was evaluated by 2 expert coaches with a standardized grading system. Elite players ranked better in all anthropometric and physiologic measures. The strongest individual predictors of tackling ability were acceleration and lower extremity muscular power; acceleration alone was predictive of tackling ability in a regression analysis.

The relationship among isokinetic knee strength, single-sprint performance, and repeated-sprint ability in soccer and rugby players found the strongest correlation between relative knee extensor torque at 240° and the initial acceleration phase (0-10 m) of the single-sprint performance. Results suggest that factors other than strength (in this case, power) contribute to repeated-sprint ability.[67]

Studies in other sports also highlight the relationship of power to specific sport demands. In elite-level ice hockey players, higher peak anaerobic power output is an important predictor of higher round picks in all positions.[20] Furthermore, greater standing long jump distance was a significant predictor for overall hockey potential. With regard to weight and playing level, greater horizontal leg power (off-ice sprint and 3-hop jump) was the best predictor of skating performance.[29]

In elite volleyball players, sport-specific jumps are directly related to depth jump performance, indicating that the stretch-shortening cycle and tolerance of high stretch loads are critical to performance.[82] In a study of elite Serbian basketball players, anaerobic power was higher in the center position than in guards and forwards.[70]

Acceleration (a critical component of sprinting) separates elite athletes from their nonelite peers.[8,34,37,63,79,83] Lacrosse, soccer, and field hockey have similar characteristics to rugby and football.[63] Investigators analyzed sprinting ability in soccer players with tests for power, strength, and leg stiffness to differentiate elite from nonelite athletes.[63] Subjects were divided into 2 groups based on sprint speed. Faster accelerating athletes demonstrated shorter ground contact times and higher

step frequencies than the slower group. Higher strength and power measures were also found in the faster group.

Success in sports requires a variety of physical factors that many athletes strive to attain. While some variables, such as ambition, drive, and mental toughness, are difficult to quantify for research purposes, measures of height, mass, strength, speed, acceleration, agility, and power are identifiable and measureable. On multiple levels, physical performance measures differentiate elite athletes from those who are not.[8,34,37,63,79,83] Unfortunately, success cannot be defined by physical performance measures alone.

PERFORMANCE CHARACTERISTICS OF ELITE ENDURANCE ATHLETES

Several key physiologic and training variables correlate with elite endurance performance, including VO_{2max}, running economy, AT, anthropometry, and an array of training characteristics, and distinguish elite from nonelite endurance athletes.

Maximal Oxygen Uptake

VO_{2max} is the maximum rate that oxygen can be taken from ambient air and transported to cells for cellular respiration during physical activity.[40] VO_{2max} in triathletes ranges from 39 to 49 mL/kg/min during tethered swimming,[62,73] 57 to 61 mL/kg/min during cycle ergometry,[68,71,72] and 61 to 85 mL/kg/min during treadmill running.[42,68,72,73] These variances allude to the reality that variables correlated with endurance performance are dependent on individual sports.

Genetic factors, in addition to environmental and training factors, have an effect on an athlete's VO_{2max}. A study of 268 Bolivians concluded that 20% to 25% of the variability in aerobic capacity at high altitude can be explained by genetic factors. In 172 dizygotic and monozygotic twins, the genetic effect for VO_{2max} was 40%.[17] Other studies suggest a genetic contribution to VO_{2max} and endurance running.[84,88]

VO_{2max} measured via a crank arm ergometer and tethered swimming showed weak correlations to triathlon swimming.[21,27,73] More significant relationships have been demonstrated between VO_{2max} and cycling and total triathlon time.[62,68,72,91] Evidence indicates that factors such as thermal regulation, fluid homeostasis, and energy balance have an increasingly larger impact on performance than VO_{2max}, as the length of the triathlon increases.[59]

Elite marathon runners typically have VO_{2max} values ranging from 70 to 85 mL/kg/min.[49] VO_{2max} is considered a significant physiologic determinant of middle- and long-distance running performance.[18,31,77] As such, VO_{2max} has been used to predict the upper limits of marathon performance.[47,48] Moreover, VO_{2max} accounts for up to 59% of the variance in times for "top-class" marathon runners.[12] End-stage treadmill velocity in a VO_{2max} test also is a predictor of performance,[25] and it may be the best predictor of 5000-m performance in untrained and trained individuals.[86]

While VO_{2max} undoubtedly correlates with the performance of endurance athletes, this association should be tempered with the knowledge that maximal aerobic power may vary.[73] The inability of VO_{2max} to predict endurance sport performance entirely necessitates inclusion of other physiologic variables, such as running economy.[48]

Running Economy

Running economy (efficiency) is expressed as the steady-state submaximal oxygen uptake at a given running velocity.[48] The lower the oxygen consumption at a given submaximal running speed, the better the economy. A higher proportion of slow-twitch fibers is associated with better running economy.[16,50,89] A study of collegiate cross-country team members discovered that the combined analysis of a runner's VO_{2max} and running economy could account for 92% of the variance in performance during an 8000-m race.[43] Running economy, like VO_{2max}, has been used to estimate a marathon pace in elite runners.[47,48] However, male marathon runners' oxygen cost at marathon velocity may not correlate with performance time.[12] In fact, the average running economy of 10 top-class marathoners (210 ± 12 mL/kg/km) was significantly higher than that of 10 high-level marathoners (195 ± 4 mL/kg/km).[12] Therefore, running economy alone may not be a conclusive predictor of elite endurance performance, although it is undoubtedly correlated.

Anaerobic Threshold

While the VO_{2max} of an endurance athlete separates elite from nonelite athletes, the ability to sustain a high percentage of VO_{2max} is perhaps even more predictive of endurance performance. This ability is related to the AT.[22,91] AT is the oxygen consumption during exercise, above which there is a sharp increase in anaerobic energy production resulting in a significant increase in lactic acid levels.[22,91] Similar to VO_{2max}, genetic factors may have an impact on AT.[36] Measures of ATs during cycling for triathletes have ranged from 61% to 88% of the VO_{2max}.[58,72,85,91] An athlete's AT is the greatest predictor of race performance in endurance cycling[14,22,23] and running events.[30,75,76,78] AT also correlates with triathlon performance over Olympic distances.[28,91] When each variable is examined independently, AT is more telling of endurance performance than VO_{2max} or running economy.

Anthropometry

An endurance athlete's anthropometric characteristics, including body height, weight, and skinfold thickness, correlate with performance.[5,41] Body mass positively correlates with race times for novice and experienced marathoners.[39,41,51] Moreover, low body fat percentages are associated with faster race times.[9,10,52,57] The mean percentage of body fat for elite female and male runners combined is 8.0%, compared with 10.7% and 12.1% for "good" and "average" runners, respectively.[9]

Low measures of select skinfold thickness also correlate with increased endurance performance.[5,52] Elite endurance athletes generally have a slim physique high in ectomorphy compared with lower level athletes[10] or sedentary groups.[9] At the same time, conflicting studies demonstrate no association between anthropometry and endurance performances in recreational ultratriathletes, recreational ultrarunners, and ultraendurance cyclists.[53,54]

Training Characteristics

Several training characteristics predict endurance performance.[10,38,55,73] Among ultratriathletes, personal best triathlon times correlate with future triathlon performance.[54] Personal best marathon time, longest training session, training intensity, and training volume all correlate with performance in recreational ultrarunners.[53] Training speed, frequency, duration, and previous finishes in cycling marathons correlate with performance in ultraendurance cyclists; training speed is the most predictive variable.[56] Moreover, several other studies support the correlation between these training variables and improved endurance performance.[10,38,55,73]

Highly competitive endurance athletes who perform resistance training in addition to routine endurance training demonstrate improved performance.[90,98] Six or more weeks of sport-specific, explosive resistance training or heavy weight resistance training improves running economy by up to 8% and performance in 3- and 5-km runs by 2.9%.[90] Highly trained cyclists can improve by implementing high-intensity explosive resistance exercises.[90] Resistance training enhances endurance by transforming type IIb muscle fibers into type IIa muscle fibers—a muscular adaptation also induced by endurance training.[87]

The necessity for the inclusion of training parameters, such as intensity, frequency, duration, and performance history, when attempting to characterize endurance athletes is considerable. Given the variability of VO_{2max}, running economy, AT, and anthropometric characteristics among high-level endurance athletes, training parameters may be the most reliable predictors of endurance performance. Furthermore, when sport-specific, explosive resistance training is correlated with increased endurance performance, an athlete's muscular power must be considered.

Elite East African Endurance Runners

In 2010, 41 of the 50 fastest marathons were run by Kenyans or Ethiopians, and 84 of the top 100 competitive marathon rankings were owned by Kenyan or Ethiopian runners in 2012.[6] Genetic studies of elite African athletes do not show a unique genetic makeup; however, environmental and social factors likely play a role.[81] Kenyan runners are from a distinct environmental background (higher altitudes) and commute farther by foot than other populations. A study within Kenya discovered that a higher percentage of elite runners ran to school each day (national athletes, 73%; international athletes,

81%; controls, 22%), in addition to covering greater distances. Seventy-five percent of controls traveled fewer than 5 km to school each day, compared with 49% of international athletes.[69] East Africans possess several previously mentioned factors that combine to create an elite endurance athlete: sizeable VO_{2max}, running economy, and ideal anthropometric characteristics.[60]

CONCLUSION

Defining elite performance remains elusive owing to the wide array of descriptors utilized. No single characteristic has been defined as the main predictor of performance in elite endurance athletes. Elite athletes in anaerobic sports are more powerful and explosive than their counterparts.[4,8,26,30,34,37,63,67,79,80,82,83] The focus of performance training in the anaerobic athlete should be on increasing power production, which has a direct correlation with speed and agility. Physical characteristics such as height, weight, percentage body fat, and flexibility are not as important in athletic performance.[4,26,37,79,80,83]

REFERENCES

1. Ahmetov II, Rogozkin VA. Genes, athlete status and training: an overview. *Med Sport Sci.* 2009;54:43-71.
2. Aouadi R, Jlid MC, Khalifa R, et al. Association of anthropometric qualities with vertical jump performance in elite male volleyball players. *J Sports Med Phys Fit.* 2012;52(1):11-17.
3. Armstrong N, McManus AM. Physiology of elite young male athletes. *Med Sport Sci.* 2011;56:1-22.
4. Arnold JA, Brown B, Micheli RP, Coker TP. Anatomical and physiologic characteristics to predict football ability: report of study methods and correlations, University of Arkansas, 1976. *Am J Sports Med.* 1980;8(2):119-122.
5. Arrese AL, Ostariz ES. Skinfold thicknesses associated with distance running performance in highly trained runners. *J Sports Sci.* 2006;24(1):69-76.
6. Association of Road Racing Statisticians. http://www.arrs.net. Accessed April 22, 2012.
7. Augustsson J, Thomee R. Ability of closed and open chain kinetic chain tests of muscular strength to assess functional performance. *Scand J Med Sci Sports.* 2000;10(3):164-168.
8. Baker DG, Newton RU. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *J Strength Cond Res.* 2008;22(1):153-158.
9. Bale P, Bradbury D, Colley E. Anthropometric and training variables related to 10km running performance. *Br J Sports Med.* 1986;20(4):170-173.
10. Bale P, Rowell S, Colley E. Anthropometric and training characteristics of female marathon runners as determinants of distance running performance. *J Sports Sci.* 1985;3(2):115-126.
11. Ben Abdelkrim N, Chaouachi A, Chamari K, Chtara M, Castagna C. Positional role and competitive-level differences in elite-level men's basketball players. *J Strength Cond Res.* 2010;24(5):1346-1355.
12. Billat VL, Demarle A, Slawinski J, Paiva M, Koralsztein JP. Physical and training characteristics of top-class marathon runners. *Med Sci Sports Exerc.* 2001;33(12):2089-2097.
13. Bishop D, Girard O, Mendez-Villanueva A. Repeated-sprint ability: part II. Recommendations for training. *Sports Med.* 2011;41(9):741-756.
14. Bishop D, Jenkins DG, Mackinnon LT. The relationship between plasma lactate parameters, peak and 1-h cycling performance in women. *Med Sci Sports Exerc.* 1998;30(8):1270-1275.
15. Blackburn JR, Morrissey MC. The relationship between open and closed chain strength of the lower limb and jumping performance. *J Orthop Sports Phys Ther.* 1998;27(6):430-435.
16. Bosco C, Montanari G, Ribacchi R, et al. Relationship between the efficiency of muscular work during jumping and the energetics of running. *Eur J Appl Physiol Occup Physiol.* 1987;56(2):138-143.

17. Bouchard C, Lesage R, Lortie G, et al. Aerobic performance in brothers, dizygotic and monozygotic twins. *Med Sci Sports Exerc*. 1986;18(6):639-646.

18. Brandon LJ. Physiological factors associated with middle distance running performance. *Sports Med*. 1995;19:268-277.

19. Burgess DJ, Naughton GA. Talent development in adolescent team sports: a review. *Int J Sports Physiol Perform*. 2010;5(1):103-116.

20. Burr JF, Jamnik RK, Baker J, et al. Relationship of physical fitness test results and hockey playing potential in elite-level ice hockey players. *J Strength Cond Res*. 2008;22(5):1535-1543.

21. Butts NK, Henry BA, Mclean D. Correlations between VO2max and performance times of recreational triathletes. *J Sports Med Phys Fitness*. 1991;31(3):339-344.

22. Coyle EF. Integration of the physiological factors determining endurance performance ability. *Exerc Sport Sci Rev*. 1995;23:25-63.

23. Coyle EF, Feltner ME, Kautz SA, et al. Physiological and biomechanical factors associated with elite endurance cycling performance. *Med Sci Sports Exerc*. 1991;23(1):93-107.

24. Cronin J, Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Med*. 2005;35(1):213-234.

25. Daniels J, Scardina N, Hayes J, Foley P. Elite and subelite female middle- and long-distance runners. In: Landers DM, ed. *Sport and Elite Performers*. Champaign, IL: Human Kinetics; 1984:55-72.

26. Davis DS, Barnette BJ, Kiger JT, et al. Physical characteristics that predict functional performance in division I college football players. *J Strength Cond Res*. 2004;18(1):115-120.

27. Dengel DR, Flynn MG, Costill DL, et al. Determinants of success during triathlon competition. *Res Q Exerc Sport*. 1989;60(3):234-238.

28. De Vito G, Bernardi M, Sproviero E, et al. Decrease of endurance performance during Olympic triathlon. *Int J Sports Med*. 1995;16(1):24-28.

29. Farlinger CM, Kruisselbrink LD, Fowles JR. Relationships to skating performance in competitive hockey players. *J Strength Cond Res*. 2007;21(3):915-922.

30. Farrel PA, Wilmore JH, Coyle EF, et al. Plasma lactate accumulation and distance running performance. *Med Sci Sports*. 1979;11(4):338-344.

31. Foster C. VO2max and training indices as determinants of competitive running performance. *J Sports Sci*. 1983;1:13-22.

32. Frisancho AR, Frisancho HG, Milotich M, et al. Developmental, genetic, and environmental components of aerobic capacity at high altitude. *Am J Phys Anthropol*. 1995;96(4):431-442.

33. Gabbett TJ, Jenkins DG, Abernethy B. Correlates of tackling ability in high-performance rugby league players. *J Strength Cond Res*. 2011;25(1):72-79.

34. Gabbett TJ, Jenkins DG, Abernethy B. Physiological and anthropometric correlates of tackling ability in junior elite and subelite rugby league players. *J Strength Cond Res*. 2010;24(11):2989-2995.

35. Gabbett T, Kelly J, Pezet T. Relationship between physical fitness and playing ability in rugby league players. *J Strength Cond Res*. 2007;21(4):1126-1133.

36. Ge RL, Chen QH, Wang LH, et al. Higher exercise performance and lower VO2max in Tibetan than Han residents at 4,700 m altitude. *J Appl Physiol*. 1994;77(2):684-691.

37. Ghigiarelli JJ. Combine performance descriptors and predictors of recruit ranking for the top high school recruits from 2001 to 2009: differences between position groups. *J Strength Cond Res*. 2011;25(5):1193-1203.

38. Gulbin JP, Gaffney PT. Ultraendurance triathlon participation: typical race preparation of lower level triathletes. *J Sports Med Phys Fitness*. 1999;39:12-15.

39. Hagan RD, Smith MG, Gettman LR. Marathon performance in relation to maximal aerobic power and training indices. *Med Sci Sports Exerc*. 1982;13(3):185-189.

40. Hill AV, Lupton H. Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Q J Med*. 1923;16:135-171.

41. Hoffman MD. Anthropometric characteristics of ultramarathoners. *Int J Sports Med*. 2008;29(10):808-811.

42. Holly RG, Barnard RJ, Rosenthal M, et al. Triathlete characterization and response to prolonged strenuous competition. *Med Sci Sports Exerc*. 1986;18(1):123-127.

43. Houmard JA, Craib MW, O'Brien KF, Smith LL, Israel RG, Wheeler WS. Peak running velocity, submaximal energy expenditure, VO2max, and 8 km distance running performance. *J Sports Med Phys Fitness*. 1991;31(3):345-350.

44. Hrysomallis C. Balance ability and athletic performance. *Sports Med*. 2011;41(3):221-232.

45. Hrysomallis C, Buttifant D. Influence of training years on upper-body strength and power changes during the competitive season for professional Australian rules football players. *J Sci Med Sport*. 2012;15(4):374-378.

46. Impellizzeri FM, Rampinini E, Castagna C, et al. Validity of a repeated-sprint test for football. *Int J Sports Med*. 2008;29(11):899-905.

47. Joyner MJ. Modeling: optimal marathon performance on the basis of physiological factors. *J Appl Physiol*. 1991;70(2):683-687.

48. Joyner MJ, Coyle EF. Endurance exercise performance: the physiology of champions. *J Physiol*. 2008;586(1):35-44.

49. Joyner MJ, Ruiz JR, Lucia A. The two-hour marathon: who and when? *J Appl Physiol*. 2011;110(1):275-277.

50. Kaneko M. Mechanics and energetics in running with special reference to efficiency. *J Biomech*. 1990;23:57-63.

51. Knechtle B, Dugg B, Welzel U, Kohler G. Body mass and circumference of upper arm are associated with race performance in ultraendurance runners in a multistage race—the Isarrun 2006. *Res Q Exerc Sport*. 2009;80(2):262-268.

52. Knechtle B, Knechtle P, Barandun U, Rosemann T, Lepers R. Predictor variables for half marathon race time in recreational female runners. *Clinics (Sao Paulo)*. 2011;66(2):287-291.

53. Knechtle B, Knechtle P, Rosemann T, Lepers R. Personal best marathon time and longest training run, not anthropometry, predict performance in recreational 24-hour ultrarunners. *J Strength Cond Res*. 2011;25(8):2212-2218.

54. Knechtle B, Knechtle P, Rosemann T, Senn O. Personal best time, not anthropometry or training volume, is associated with total race time in a triple iron triathlon. *J Strength Cond Res*. 2011;25(4):1142-1150.

55. Knechtle B, Knechtle P, Rosemann T, Senn O. Sex differences in association of race performance, skin-fold thicknesses, and training variables for recreational half-marathon runners. *Percept Mot Skills*. 2010;111(3):653-668.

56. Knechtle B, Knechtle P, Rust CA, Rosemann T, Lepers R. Finishers and nonfinishers in the "Swiss Cycling Marathon" to qualify for the "Race Across America." *J Strength Cond Res*. 2011;25(12):3257-3263.

57. Knechtle B, Wirth A, Knechtle P, Rosemann T. Moderate association of anthropometry, but not training volume, with race performance in male ultraendurance cyclists. *Res Q Exerc Sport*. 2009;80(3):563-568.

58. Kohrt WM, O'Connor JS, Skinner JS. Longitudinal assessment of responses by triathletes to swimming, cycling, and running. *Med Sci Sports Exerc*. 1989;21(5):569-575.

59. Kreider RB. Physiological considerations of ultraendurance performance. *Int J Sports Nutr*. 1991;1(1):3-27.

60. Larsen HB, Christensen DL, Nolan T, Sondergaard H. Body dimensions, exercise capacity and physical activity level of adolescent Nandi boys in western Kenya. *Ann Hum Biol*. 2004;31(2):159-173.

61. Lidor R, Ziv G. Physical characteristics and physiological attributes of adolescent volleyball players: a review. *Pediatr Exerc Sci*. 2010;22(1):114-134.

62. Lidor R, Ziv G. Physical and physiological attributes of female volleyball players: a review. *J Strength Cond Res*. 2010;24(7):1963-1973.

63. Lockie RG, Murphy AJ, Knight TJ, Janse de Jonge XAK. Factors that differentiate acceleration ability in field sport athletes. *J Strength Cond Res*. 2011;25(10):2704-2714.

64. Mall NA, Matava MJ, Wright RW, Brophy RH. Relation between anterior cruciate ligament graft obliquity and knee laxity in elite athletes at the National Football League combine. *Arthroscopy*. 2012;28(8):1104-1113.

65. McGuigan MR, Wright GA, Fleck SJ. Strength training for athletes: does it really help sports performance? *Int J Sports Physiol Perform*. 2012;7(1):2-5.

66. McManus AM, Armstrong N. Physiology of elite young female athletes. *Med Sport Sci*. 2011;56:23-46.

67. Newman MA, Tarpenning KM, Marino FE. Relationships between isokinetic knee strength, single-sprint performance, and repeated-sprint ability in football players. *J Strength Cond Res*. 2004;18(4):867-872.

68. Noakes TD, Goodwin N, Rayner BL, et al. Water intoxication: a possible complication during endurance exercise. *Med Sci Sports Exerc*. 1985;7:370-375.

69. Onywera VO, Scott RA, Boit MK, Pitsiladis YP. Demographic characteristics of elite Kenyan endurance runners. *J Sports Sci*. 2006;24(4):415-422.

70. Ostojic SM, Mazic S, Dikic N. Profiling in basketball: physical and physiological characteristics of elite players. *J Strength Cond Res*. 2006;20(4):740-744.

71. O'Toole ML. Training for ultraendurance triathlons. *Med Sci Sports Exerc*. 1989;21(5):209-213.

72. O'Toole ML, Douglas PS, Hiller WD. Lactate, oxygen uptake, and cycling performance in triathletes. *Int J Sports Med*. 1989;10(6):413-418.

73. O'Toole ML, Hiller DB, Crosby LO, et al. The ultraendurance triathlete: a physiological profile. *Med Sci Sports Exerc*. 1987;19(1):45-50.

74. Pearson DT, Naughton GA, Torode M. Predictability of physiological testing and the role of maturation in talent identification for adolescent team sports. *J Sci Med Sport*. 2006;9(4):277-287.

75. Peronnet F, Thibault G, Rhodes EC, et al. Correlations between ventilatory threshold and endurance capability in marathon runners. *Med Sci Sports Exerc*. 1987;19:610-615.

76. Petit MA, Melson CM, Rhodes EC. Comparison of a mathematical model to predict 10km performance from the Conconi test and ventilatory threshold measurements. *Can J Appl Physiol*. 1997;22(6):562-572.

77. Pollock ML, Jackson AS, Pate RR. Discriminant analysis of physiological differences between good and elite distance runners. *Res Q Exerc Sport*. 1980;51:521-532.

78. Rhodes EC, McKenzie DC. Predicting marathon time from anaerobic threshold measurements. *Phys Sport Med*. 1984;12(1):95-99.

79. Robbins DW. The National Football League (NFL) combine: does normalized data better predict performance in the NFL draft? *J Strength Cond Res*. 2010;24(11):2888-2899.

80. Sawyer DT, Ostarello JZ, Suess EA, Dempsey M. Relationship between football playing ability and selected performance measures. *J Strength Cond Res*. 2002;16(4):611-616.

81. Scott RA, Pitsiladis YP. Genotypes and distance running: clues from Africa. *Sports Med*. 2007;37(4-5):424-427.

82. Sheppard JM, Cronin JB, Gabbett TJ, et al. Relative performance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *J Strength Cond Res*. 2008;22(3):758-765.

83. Sierer SP, Battaglini CL, Mihalik JP, et al. The National Football League combine: performance differences between drafted and non-drafted players entering the 2004 and 2005 drafts. *J Strength Cond Res*. 2008;22(1):6-12.

84. Sjodin B, Svendenhag J. Applied physiology of marathon running. *Sports Med*. 1985(2):83-99.

85. Sleivert GG, Wenger HA. Physiological predictors of short-course triathlon performance. *Med Sci Sports Exerc*. 1993;25(7):871-876.

86. Stratton E, O'Brien BJ, Harvey J, et al. Treadmill velocity best predicts 5000-m run performance. *Int J Sports Med*. 2009;30(1):40-45.

87. Tanaka H, Swensen T. Impact of resistance training on endurance performance: a new form of cross-training? *Sports Med*. 1998;25(3):191-200.

88. Watanabe T, Mutoh Y, Yamamoto Y. Genetic variance in age-related changes in running performance and growth during adolescence: a longitudinal twin study. *Am J Hum Biol*. 2001;13(1):71-80.

89. Williams KR, Cavanagh PR. Relationship between distance running mechanics, running economy, and performance. *J Appl Physiol*. 1987;63(3):1236-1245.

90. Yamamoto LM, Klau JF, Casa DJ, Kraemer WJ, Armstrong LE, Maresh CM. The effects of resistance training on road cycling performance among highly trained cyclists: a systematic review. *J Strength Cond Res*. 2010;24(2):560-566.

91. Zhou S, Robson SJ, King MJ, et al. Correlations between short-course triathlon performance and physiological variables determined in laboratory cycle and treadmill tests. *J Sports Med Phys Fitness*. 1997;37(2):122-130.

92. Ziv G, Lidor R. Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players. *Sports Med*. 2009;39(7):547-568.