Journal of Science and Medicine in Sport (2008) 11, 202—208

ELSEVIER

Journal of Science and Medicine in Sport

www.elsevier.com/locate/jsams

ORIGINAL PAPER

The Yo—Yo intermittent recovery test in basketball players

Carlo Castagna[a,b,*], Franco M. Impellizzeri[c], Ermanno Rampinini[c], Stefano D'Ottavio[b], Vincenzo Manzi[b]

[a] *Scuola Regionale dello Sport delle Marche, Italian Olympic Commitee (CONI), Italy*
[b] *School of Sport and Exercise Sciences, University of Rome Tor Vergata, Italy*
[c] *Human Performance Laboratory, S.S. MAPEI, Italy*

Received 4 August 2006; received in revised form 23 February 2007; accepted 26 February 2007

KEYWORDS
Field testing;
Shuttle running;
Intermittent exercise;
Line drill;
Fatigue

Summary The purpose of this study was to examine the physiological correlates of the Yo—Yo intermittent recovery test level 1 (Yo—Yo IR1) in basketball players. Twenty-two male basketball players (means ± S.D., body mass 72.4 ± 11.4 kg, height 181.7 ± 6.9 cm, age 16.8 ± 2.0 years) were tested for maximal oxygen uptake (VO_{2max}), ventilatory threshold (VT) and running economy (RE) on a motorized treadmill. Lower limb explosive strength and anaerobic-capacity was assessed using vertical jumps (CMJ), 15 m shuttle running sprint (15 mSR) and line drill (LD), respectively. The same test battery was replicated after an experimental basketball game in order to assess selective effect of fatigue on physical performance. Pre to post-game CMJ (40.3 ± 5.7 versus 39.9 ± 5.9 cm) and 15 mSR (5.80 ± 0.25 versus 5.77 ± 0.22 s) performances were not significantly different ($p > 0.05$). LD performance decreased significantly post-game (from 26.7 ± 1.3 to 27.7 ± 2.7 s, $p < 0.001$). Yo—Yo IR1 performances (m) were significantly related to VO_{2max} ($r = 0.77$, $p = 0.0001$), speed at VO_{2max} ($r = 0.71$, $p = 0.0001$) and $\%VO_{2max}$ at VT ($r = -0.60$, $p = 0.04$). Yo—Yo IR1 performance was significantly correlated to post-game LD decrements ($r = -0.52$, $p = 0.02$). These findings show that Yo—Yo IR1 may be considered as a valid basketball-specific test for the assessment of aerobic fitness and game-related endurance.

Introduction

Competitive basketball is an intermittent high-intensity physical activity that requires a well-developed aerobic and anaerobic fitness.[1] Although basketball performance is thought to be mainly dependent on players' anaerobic ability, high aerobic fitness is also important for improved performance.[2,3] Specifically maximal aerobic power (VO_{2max}) is considered to improve the ability to recovery from the anaerobic efforts during the

* Corresponding author.
E-mail address: castagnac@libero.it (C. Castagna).

1440-2440/$ — see front matter © 2007 Sports Medicine Australia. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsams.2007.02.013

game.[4] Furthermore, aerobic conditioning has been suggested to be important for preparing players to be able to sustain an appropriate training load volume for basketball.[2]

Aerobic fitness (VO_{2max}, lactate thresholds, and running economy) can be accurately evaluated using a variety of laboratory protocols.[5] Although the values obtained with laboratory testing are considered the ''gold standard'' for the measurement of aerobic fitness, the procedures involved are time consuming and require trained personnel and expensive equipment. For these reasons, some continuous field-tests[6,7] involving shuttle running over 20 m (approximately court length) have been proposed as practical alternatives to laboratory assessments in basketball.[8] The validity of these tests is based on their correlations with VO_{2max} (criterion validity)[6,7] and displacement specificity (logical validity). However, due to the intermittent nature of basketball,[1] the exercise continuity considered in these tests[6,7] may considered as a potential threat to the logical validity and content validity.[9]

Recently Bangsbo[10] developed the Yo—Yo intermittent recovery test (Yo—Yo IR1) as a field test for assessing performance for team-sport players. Yo—Yo IR1 consists of 2 m × 20 m bouts of progressive speed shuttle-running, interspersed by 10 s of active recovery, performed until exhaustion.[10,11] Recent research has shown that Yo—Yo IR1 elicits maximal aerobic responses while significantly stressing the anaerobic energy system,[11] demonstrating that the physiological demands of the Yo—Yo IR1 are similar to those taxed during competition.[11] Furthermore, Yo—Yo IR1 scores have been reported to be significantly correlated with VO_{2max} assessed in laboratory, confirming its validity as measures of aerobic-fitness in soccer players.[12] Despite its logical validity and popularity no study has been performed in order to test Yo—Yo IR1 validity as measures of aerobic fitness in basketball players (population validity).[9]

The first aim of this study was to examine the relationship between the Yo—Yo IR1 and traditional physiological parameters of aerobic-fitness assessed in the laboratory, in a population of trained basketball players. The second aim was to examine the association between Yo—Yo IR1 performance and selected aspects of game-performance[1,13] in order to make possible statements of test specificity.[14] Due to the intermittent high-intensity nature of Yo—Yo IR1[11] it was hypothesized that significant associations may occur among maximal-intensity components of aerobic-fitness and anaerobic-endurance with Yo—Yo IR1 performance.[12] An improved understanding of these relationships may provide useful information for fitness assessment and training prescription in basketball players.

Material

Subjects

Twenty-two male junior basketball players (body mass 72.4 ± 11.4 kg, height 181.7 ± 6.9 cm, and age 16.8 ± 2 years) from the same basketball club (Stamura Basket, Ancona, Italy) were involved in the study. All players had official medical clearance according to national law. Written informed consent was received from all players and parents after verbal and written explanation of the experimental design and potential risks of the study. Participants were told they were free to withdraw from the study at any time without penalty. The local Institutional Review Board approved this study design.

The assessments were performed at the same time of the day (from 5.00 to 7.00 p.m. for field tests and from 4.00 to 8.00 p.m. for laboratory tests) and subjects were blinded about the aims of the study. All of the testing procedures were completed in June one week after the play-off phase of the basketball competitive season. During the competitive season the training schedule consisted in five training sessions (~90 min each session) with a competitive game played during the weekend.

Experimental approach to the problem

In the present investigation, a descriptive design was used. Criterion validity was evaluated examining Yo—Yo IR1 performance relationship with VO_{2max}, ventilatory threshold (VT), running economy (RE) and speed attained at VO_{2max}. Test relevance was also assessed by examining the relationship between Yo—Yo IR1 performance and score decrements of basketball-specific tests performed before and at the end of an experimental basketball game.[13] It was assumed that the occurrence of significant pre-to-post game test variations[8,15,16] were consequence of selective game related fatigue.[13] To achieve this, other common basketball-specific performance tests (i.e. the vertical countermovement jump (CMJ), 15 m shuttle running sprint (15 mSR) and line drill (LD)), were completed in a random order before and after a competitive basketball match.

Testing sessions took place over three separate days (at least 72 h a part). The testing sessions consisted as follows:

1. Treadmill-testing;
2. Yo—Yo IR1;
3. Experimental game.

Yo—Yo intermittent recovery test

Yo—Yo intermittent recovery test features two levels differing with respect to starting speed.[10] In this investigation, the level 1 version was completed according to previously described methods.[11] All players were familiar with the testing procedures being part of their usual fitness assessment program. Yo—Yo IR1 test consisted of 20-m shuttle runs performed at increasing velocities (Table 1) with 10 s of active recovery between runs until exhaustion. The end of the test was considered when the participant twice failed to reach the front line in time (objective evaluation) or he felt not able to cover another shuttle at the dictated speed (subjective evaluation). The total distance covered during the Yo—Yo IR1 was primary performance measure[10] and the speed attained during the last 2 m × 20 m bout was considered as V_{max}.[12] All field testing sessions were performed on the same basketball court where players usually trained. Reliability of the Yo—Yo test calculated as a CV is 4.9% for the total distance covered during the test.[11]

Aerobic fitness assessment

Maximum oxygen uptake was determined using an incremental running test on a motorized treadmill (RunRace, Technogym, Gambettola, Italy). After an individually adjusted warm-up (5 min) subjects run for 6 min at 8 km h^{-1}, and the velocity was increased by 1 km h^{-1} every minute until 16 km h^{-1} was attained. Thereafter exercise intensity was increased through increasing the treadmill grade by 1° min^{-1} until exhaustion, that was reached in 8—12 min. Achievement of VO_{2max} was considered as the attainment of at least two of the following criteria: (1) a plateau in VO_2 despite increasing speeds, (2) a respiratory exchange ratio above 1.10, (3) a heart rate (HR) ± 10 beats min^{-1} of age-predicted maximal HR (220-age). Expired gases were analyzed using a breath-by-breath automated gas-analysis system (K4b^2, COSMED, Rome, Italy). Reliability, accuracy and validity of the K4b^2 gas analyzer system has been reported elsewhere.[17,18]

Before each test flow and volume were calibrated using a 3-L capacity syringe (Sensormedics, Yorba Linda, CA). Gas analyzers were calibrated using gases of (O_2 and carbon dioxide) known concentrations (Sensormedics, Yorba Linda, CA). Ventilatory threshold (VT) was assessed according to Beaver et al.[19] Running economy was considered as average VO_2 during the final minute of the 6 min run at 8 km h^{-1}. Maximal aerobic speed was calculated using the relationship between VO_2 and running speed.[20] Maximal HR (HR_{max}) was considered as the highest 5 s mean during the treadmill test.

Explosive-strength and anaerobic-capacity field tests

Countermovement jump,[21] 15 mSR and LD performance were measured 20 min before and immediately after the experimental game in ran-

Table 1 Yo—Yo intermittent recovery (level 1) test protocol

Stage	Speed (km h^{-1})	Shuttle bouts (2 m × 20 m)	Split distance	Accumulated distance
1	10	1	40	40
2	12	1	40	80
3	13	2	80	160
4	13.5	3	120	280
5	14	4	160	440
6	14.5	8	320	760
7	15	8	320	1080
8	15.5	8	320	1400
9	16	8	320	1720
10	16.5	8	320	2040
11	17	8	320	2360
12	17.5	8	320	2680
13	18	8	320	3000
14	18.5	8	320	3320
15	19	8	320	3640

After each 2 m × 20 m shuttle-run bout players perform 10 s of active recovery jogging round a cone set 5 m apart from the starting line.

domized order. Pre-test warm-up consisted in 10 min basketball skills practice conducted at self selected intensity followed by sub-maximal CMJs (2–3 repetitions) and shuttle-run sprints. No stretching exercises were allowed prior to the test. Countermovement jump performance (jump height) was measured using a switch-mat connected to a computer (Muscle Lab, Bosco System, Rieti, Italy). Subjects were asked to keep hands on their hips to prevent influence of arm movements on vertical jump performance.[21] Each subject performed at least two maximal CMJs starting from a standing position, with 1 min recovery in-between. Players were asked to jump as high as possible. The best jump height was used for calculations.

Fifteen-meter shuttle running sprint performance was assessed with the aid of a photocell beam connected to a personal computer (Microgate Polifemo, Bolzano, Italy). Photocell beam height was set at 45 cm from ground level with players starting from a line set 50 cm from the photocell beam. The best of two 15 mSR trials was used for calculation (2 min passive recovery between trials). The LD[15,22] performance was measured using a hand-held stopwatch (Casio, HS-30W, Japan). The reliability of CMJ, 15 mSR and LD (reported as CV%) were assessed during the week before the commencement of the study in the same players ($n = 22$) and ranged between 0.5 and 0.9%. The variations (CV%) within the measurements trials for CMJ and 15 mSR on the experimental day were less than 1%.

Experimental basketball-game

Twenty players performed two basketball games each lasting two match play periods of 10 min interspersed by a 2 min interval (mean total play time 30.5 min). This time duration was chosen as this is the average playing time[12] for the competitive level of the players in this study (unpublished data). During the experimental games no substitution was allowed in order to have all players observed for the same amount of playing time and only man to man defense was allowed. In order to evaluate exercise intensity HR was monitored throughout the game with a HR monitor system (Polar Team System, Polar Electro Oy, Kempele, Finland). Post-hoc HR analyses were performed using Polar Precision System SW 3.0 software (Polar Electro Oy, Finland). Furthermore blood lactate concentration measurements were performed sampling players' ear lobe blood randomly during the matches (Lactate Pro, Arkray, Tokyo, Japan).

Statistical analyses

Data are reported as mean ± standard deviation (S.D.). Before using parametric tests, the assumption of normality was verified using the Shapiro–Wilk W test. Pearson's product–moment correlations and linear regression analysis were used to examine the relationships between the Yo–Yo IR1 performance (m) and VO_{2max}, VT speed, RE, speed at VO_{2max} and LD post-game performance decrement. One-way ANOVA was used to examine possible differences between Yo–Yo IR1 maximal speed, speed at VO_{2max} and VT speed. Comparisons between field-test variable means was performed using paired t-tests. Unpaired t-tests were performed to examine players' game-role differences over test variables. Significance was assumed at 5% ($p \leq 0.05$) a priori. Statistical analyses were performed using Statistica package (6.0 version, Statsoft, California, USA).

Results

Values of the aerobic-fitness variables considered in this study are shown in Table 2. Speed at VT, speed at VO_{2max} and Yo–Yo IR1 speed at exhaustion were significantly different from each other ($p = 0.002$). Yo–Yo IR1 performance was significantly correlated with VO_{2max} ($r = 0.77$, $p = 0.0001$) and speed at VO_{2max} ($r = 0.71$, $p = 0.0001$). However, no significant correlation was found between Yo–Yo IR1 and VT speed and RE ($r = -0.12$, $p > 0.05$).

Results of the pre-post experimental-game tests are shown in Table 3. During the first and the second half of the experimental game, players attained 86 ± 5 and 87 ± 4% of the individual HR_{max}, respectively ($p = 0.42$). Experimental-games blood lactate

Table 2 Physiological characteristics of the basketball players ($n = 22$)

Variables	Mean ± S.D.
VO_{2max} (mL kg^{-1} min^{-1})	60.4 ± 5.1
VT VO_2 (mL kg^{-1} min^{-1})	40.2 ± 4.7
RE (mL kg^{-1} min^{-1})	31.5 ± 4.3
Yo–Yo IR1 distance (m)	1678 ± 397
Yo–Yo IR1 velocity (km h^{-1})	15.7 ± 0.7
Speed at VO_{2max} (km h^{-1})	17.1 ± 1.8
vVT (km h^{-1})	11.6 ± 1.3
HR_{max} (beats min^{-1})	198 ± 6

RE: VO_2 at 8 km h^{-1}, VT VO_2: VO_2 at ventilatory threshold; vVT: speed at ventilatory threshold, HR_{max}: maximal heart rate.

Table 3 Pre-post experimental-game test performances ($n = 20$)

Variables	Pre-game	Post-game
CMJ height (cm)	39.9 ± 5.9	40.3 ± 5.7
15 mSR	5.80 ± 0.25	5.77 ± 0.22
Line drill	26.7 ± 1.3	27.7 ± 2.7[a]

[a] Significance at $p \leq 0.001$.

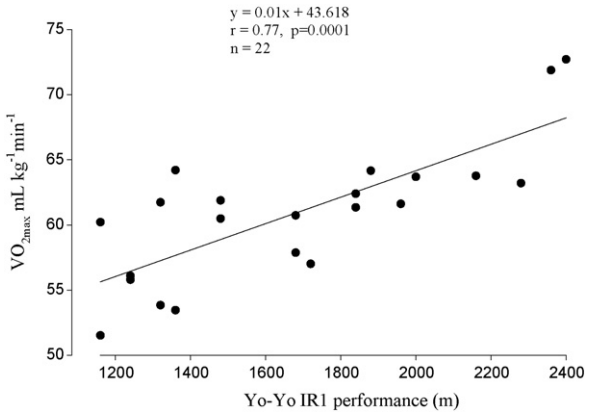

Figure 1 Scatter plot of VO_{2max} (mL kg^{-1} min^{-1}) vs. Yo—Yo IR1 test performance (m).

concentration was 3.7 ± 1.4 mmol l^{-1}. Players were sampled for blood lactate concentration a minimum of two times per match (45 blood samplings).

Significant correlations were found between pre-post LD decrements and Yo—Yo IR1 performance ($r = -0.52$, $p = 0.02$). No significant correlations were observed between the Yo—Yo IR1 test performance and game mean HR or first versus second half HR variations (Figs. 1 and 2).

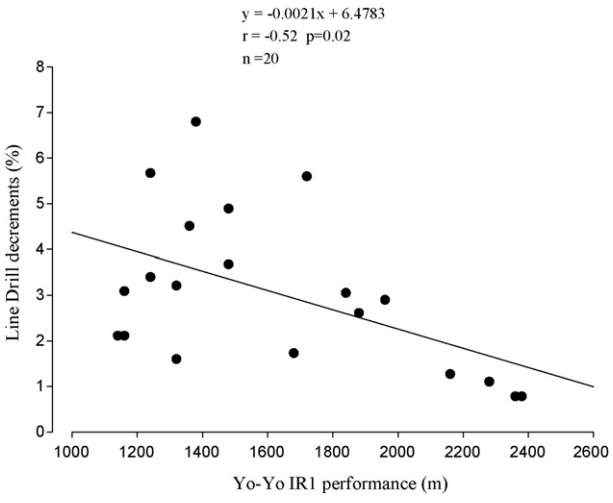

Figure 2 Scatter plot of line drill decrements (%) vs. Yo—Yo IR1 test performances (m).

Discussion

This is the first study that demonstrates the validity of Yo—Yo IR1 test as measure of aerobic-fitness in basketball players and its specificity as measure of basketball-specific endurance. This is of particular interest for sport scientists as Yo—Yo IR1 test has been proposed as suitable for basketball players but validated in soccer players only.[12]

This study showed that Yo—Yo IR1 test performance and VO_{2max} values were significantly related, with 59% of shared variance. This is similar to previous research that reported a moderate correlation ($r = 0.71$, $p < 0.05$) in a group ($n = 15$) of habitually active subjects (VO_{2max} 50.5 mL kg^{-1} min^{-1}).[11] Although the strength of this association confirms the validity of Yo—Yo IR1 test as generic measure of aerobic fitness, it is not sufficiently high to demonstrate its predictive validity.[9]

The present results revealed that of the planned comparisons only VO_{2max} and speed at VO_{2max} were associated with Yo—Yo IR1 test performance. Therefore the finding of a significant relationship between speed at VO_{2max} and Yo—Yo IR1 test performance suggests that this test is influenced by other components of aerobic-performance than just VO_{2max}.[20,23,24] Moreover, the Yo—Yo IR1 test performance was also inversely related to the percentage of VO_{2max} attained at VT ($r = -0.60$, $p = 0.04$), partially supporting the hypothesis of a more complex influence of aerobic-components to Yo—Yo IR1 test performance.

The Yo—Yo IR1 performance observed in this sample of basketball players (1678 ± 397 m) was lower than those observed in professional soccer players at the beginning (1760 ± 59 m) and during the competitive season (2211 ± 70 m).[11] Higher Yo—Yo IR1 performances were also reported in regional level soccer players (2138 ± 364).[12] However, the mean Yo—Yo IR1 performance found in this study was higher than that reported for female top-level soccer players (1379 m)[25] and for state level (840—1049 m) and recreational level (1010—1048 m) Australian team-sport athletes.[26] Unfortunately, to the best of this study author's knowledge no information is available in the international scientific literature regarding Yo—Yo IR1 test performance in basketball players.

Differences in Yo—Yo IR1 performance have been reported to be consequence of fitness status, period of the competitive season, and playing role within a team.[11] In this study players were tested after the completion of a successful competitive season and as consequence of that possessing a good physical fitness. Indeed, the basketball players

showed a VO_{2max} (60.4 ± 5.1 mL kg^{-1} min^{-1}) higher than what usually reported for basketball players competing at elite level.[27] Furthermore, CMJ (40.3 ± 5.7 cm) and LD (26.7 ± 1.3 s) performances were similar or even higher to what reported in elite basketball teams of the same age. Specifically, Apostolidis et al.[27] and Hoffman et al.[15] reported LD performances of 27.92 ± 1.04 s and 28.3 ± 0.9 s for junior players of the Greek and Israeli National teams, respectively. Moreover, the CMJ performance of the players in this study were similar to those reported in professional adult players (43.9 ± 4.0)[28] and in junior elite players (40.1 ± 3.7 cm).[27] Given the good physical performances showed by this sample of basketball players the Yo—Yo IR1 test performance here reported may represent a valid reference for competitive basketball.

In order to assess possible role dependent effects over Yo—Yo IR1 test performance[11,29] players were grouped according to main playing assignments in two groups: Forwards (Centers-Wings and Guards-Playmakers, $n = 11$ each). Results showed no significant positional effects on Yo—Yo IR1 test performance, pre to post match performances and physiological variables. These findings are most likely due to homogeneity of the performance levels and/or training status of the basketball players used in this study.

A field test cannot be considered sport-specific until a direct association between some aspects of match performance and the field test investigated has been determined.[14] In line with this, we attempted to assess the specificity of the Yo—Yo IR1 test by examining the relationships between the changes in basketball-specific field tests undertaken before and just after an experimental basketball-game with distance covered during the Yo—Yo IR1 test.[13,30,31] We assumed that variations in test scores (CMJ, 15 mSR and LD) may directly reflect the fatigue effects of match play.[13,30,31] Due to this, it was imperative that the game intensity obtained in this study was specific to that encountered in actual competitive basketball match play. Although observations were made using an experimental-game, the intensity attained by players during competition are similar to game intensities in professional basketball games.[1] These results provide further support the validity of the research design in this investigation.

The preplanned correlation analysis revealed that Yo—Yo IR1 test performance was only significantly related to the pre to post experimental-game LD decrements, but not the changes in the 15 mSR and CMJ. The finding that explosive short term maximal efforts (<6 s) did not vary as consequence of match play agrees with previous research on competitive soccer players.[13,31] In the Hoffman et al.[13] study no changes in CMJ performance were observed following a competitive soccer match. It was speculated that CMJ performance (Power) was maintained through the match because of elevated catecholamine levels during match play that have been shown to positively affect anaerobic power development.[32] Conservation of short-term maximal performance has been reported also by others who demonstrated no changes in isokinetic strength following soccer match play.[33,34]

More recently Krustrup et al.[31] found that repeated sprint performance (5 m × 30 m with 25 s active recovery) changed following experimental soccer-match. In particular these authors reported no changes in the initial sprint of the repeated sprint bout during the first half of the match. However, sprint bout performance was found to decrease following the third sprint after an intense exercise period in the first half. In contrast, to the first half measures, sprint performance decreased from the first sprint bout compared to the control condition. In the present study, the basketball players reported a significant decrement in LD after the experimental game, showing that basketball playing may induce fatigue patterns (repeated sprint) similar to those induced by a soccer match just after approximately 20 min of match play (~30 min of total playing). We suggest that the relationship between Yo—Yo IR1 test and game related LD decrements may be due to selective glycogen depletion patterns in lower limbs fast-twitch fibers.[11,31] Combined with previous research,[31] the present results provide useful information that can be used to develop basketball specific training strategies. Moreover, the significant although moderate association between Yo—Yo IR1 test performance and LD decrements suggest that the Yo—Yo IR1 test may be a useful field test for assessing endurance performance in basketball players. However in order to fully assess test ecological validity, the relationship between Yo—Yo IR1 test and selected game-activities should be examined through physical performance assessment within a competitive match.

This study is the first to report on the validity of the Yo—Yo IR1 test and aerobic fitness measures and match-related performance decrements in basketball players. The present findings suggest that the Yo—Yo IR1 test may be considered a valid field-test to assess aerobic-fitness and game preparedness of basketball players.

Practical implications

- The Yo—Yo intermittent recovery test (level 1) is a valid test to assess aerobic fitness in male young basketball players.
- The ability to perform short-term (~30 s) maximal-intensity exercise decreases as consequence of basketball playing.
- The Yo—Yo intermittent recovery test (level 1) performance is related to post-game decrement in short-term (~30 s) basketball-specific maximal anaerobic-performance.

References

1. McInnes SE, Carlson JS, Jones CJ, et al. The physiological load imposed upon basketball players during competition. *J Sports Sci* 1995;**13**:387—97.
2. Stone WJ, Steingard PM. Year-round conditioning for basketball. *Clin Sports Med* 1993;**12**(2):173—91.
3. Stone WJ, Kroll WA. *Sports conditioning and weight training*. 3rd ed. Dubuque, Iowa: WmC Brown Publishers; 1991.
4. Tomlin DL, Wenger HA. The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports Med* 2001;**31**(1):1—11.
5. Pate RR, Kriska A. Physiological basis of the sex difference in cardiorespiratory endurance. *Sports Med* 1984;**1**(2):87—98.
6. Ramsbottom R, Brewer J, Williams C. A progressive shuttle run test to estimate maximal oxygen uptake. *Br J Sports Med* 1988;**22**(4):141—4.
7. Leger L, Gadoury C. Validity of the 20 m shuttle run test with 1 min stages to predict VO_{2max} in adults. *Can J Sport Sci* 1989;**14**(1):21—6.
8. Stapff A. Protocols for the physiological assessment of basketball players. In: *Physiological tests for elite athletes*. Champaign, IL: Human Kinetics Publishers; 2000.
9. Thomas JR, Nelson JK, Silverman J. *Research methods in physical activity*. 5th ed. Champaign, IL: Human Kinetics; 2005.
10. Bangsbo J. *Yo-yo test*. Ancona: Kells; 1996.
11. Krustrup P, Mohr M, Amstrup T, et al. The Yo—Yo intermittent recovery test: Physiological response, reliability, and validity. *Med Sci Sports Exerc* 2003;**35**(4):697—705.
12. Castagna C, Impellizzeri FM, Chamari K, et al. Aerobic fitness and yo-yo continuous and intermittent tests performances in soccer players: a correlation study. *J Strength Cond Res* 2006;**20**(2):320—5.
13. Hoffman JR, Nusse V, Kang J. The effect of an intercollegiate soccer game on maximal power performance. *Can J Appl Physiol* 2003;**28**(6):807—17.
14. Boddington MK, Lambert MI, Waldeck MR. Validity of a 5-m multiple shuttle run test for assessing fitness of women field hockey players. *J Strength Cond Res* 2004;**18**(1):97—100.
15. Hoffman JR, Epstein S, Einbinder M, et al. A Comparison between the wingate anaerobic power test to both vertical jump and line drill tests in basketball players. *J Strength Cond Res* 2000;**14**(3):261—4.
16. Hoffman JR, Stavsky H, Falk B. The effect of water restriction on anaerobic power and vertical jumping height in basketball players. *Int J Sports Med* 1995;**16**:214—8.
17. McLaughlin JE, King GA, Howley ET, et al. Validation of the COSMED K4 b2 portable metabolic system. *Int J Sports Med* 2001;**22**(4):280—4.
18. Duffield R, Dawson B, Pinnington HC, et al. Accuracy and reliability of a Cosmed K4b2 portable gas analysis system. *J Sci Med Sport* 2004;**7**(1):11—22.
19. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. *J Appl Physiol* 1986;**60**(6):2020—7.
20. Billat V, Koralsztein JP. Significance of the velocity at VO_{2max} and time to exhaustion at this velocity. *Sports Med* 1996;**22**:90—180.
21. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. *Eur J Appl Physiol* 1983;**50**:273—82.
22. Semenick D. Tests and measurements: The line drill test. *NSCA J* 1990;**12**(2):47—9.
23. Morgan DW, Baldini FD, Martin PE, et al. Ten kilometer performance and predicted velocity at VO_{2max} among well-trained male runners. *Med Sci Sports Exerc* 1989;**21**(1):78—83.
24. Noakes TD, Myburgh KH, Schall R. Peak treadmill running velocity during the VO_{2max} test predicts running performance. *J Sports Sci* 1990;**8**(1):35—45.
25. Krustrup P, Mohr M, Ellingsgaard H, et al. Physical demands during an elite female soccer game: importance of training status. *Med Sci Sports Exerc* 2005;**37**(7):1242—8.
26. Thomas A, Dawson B, Goodman C. The Yo—Yo test: reliability and association with a 20-m shuttle run and VO_{2max}. *Int J Sports Physiol Perform* 2006;**1**:137—49.
27. Apostolidis N, Nassis GP, Bolatoglou T, et al. Physiological and technical characteristics of elite young basketball players. *J Sports Med Phys Fitness* 2004;**44**(2):157—63.
28. Häkkinen K. Effects of the competitive season on physical fitness profile in elite basketball players. *J Human Mov Stud* 1988;**15**:119—28.
29. Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci* 2003;**21**:519—28.
30. Bangsbo J. The physiology of soccer - with special reference to intense intermittent exercise. *Acta Physiol Scand* 1994;**151**(Suppl. 619):1—155.
31. Krustrup P, Mohr M, Steensberg A, et al. Muscle and blood metabolites during a soccer game: implications for sprint performance. *Med Sci Sports Exerc* 2006;**38**(6):1165—74.
32. Kraemer WJ, Patton JF, Knuttgen H, et al. Effects of high-intensity cycle exercise on sympathoadrenal-medullary response patterns. *J Appl Physiol* 1991;**70**(1):8—14.
33. Ekblom B. Applied physiology of soccer. *Sports Med* 1986;**3**:50—60.
34. Kirkendall DT. Physiology of soccer. In: *Exercise and sport science*. Philadelphia: Lippincott Williams & Wilkins; 2000.