

The Yo-Yo IR2 Test: Physiological Response, Reliability, and Application to Elite Soccer

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ABSTRACT

KRUSTRUP, P., M. MOHR, L. NYBO, J. MAJGAARD JENSEN, J. JUNG NIELSEN, and J. BANGSBO. The Yo-Yo IR2 Test: Physiological Response, Reliability, and Application to Elite Soccer. *Med. Sci. Sports Exerc.*, Vol. 38, No. 9, pp. 1666–1673, 2006. **Purpose:** To examine the physiological response, reliability, and validity of the Yo-Yo intermittent recovery level 2 test (Yo-Yo IR2). **Methods:** Thirteen normally trained male subjects carried out four Yo-Yo IR2 tests, an incremental treadmill test (ITT), and various sprint tests. Muscle biopsies and blood samples were obtained, and heart rate was measured before, during, and after the Yo-Yo IR2 test. Additionally, 119 Scandinavian elite soccer players carried out the Yo-Yo IR2 test on two to four occasions. **Results:** Yo-Yo IR2 performance was 591 ± 43 (320–920) m or 4.3 (2.6–7.9) min. Test–retest coefficient of variation in distance covered was 9.6% ($N = 29$). Heart rate (HR) at exhaustion was 191 ± 3 bpm, or $98 \pm 1\%$ HR_{max}. Muscle lactate was 41.7 ± 5.4 and 68.5 ± 7.6 mmol·kg⁻¹ d.w. at 85 and 100% of exhaustion time, respectively, with corresponding muscle CP values of 40.4 ± 5.2 and 29.4 ± 4.7 mmol·kg⁻¹ d.w. Peak blood lactate was 13.6 ± 0.5 mM. Yo-Yo IR2 performance was correlated to ITT performance ($r = 0.74$, $P < 0.05$) and $\dot{V}O_{2max}$ ($r = 0.56$, $P < 0.05$) but not to 30- and 50-m sprint performance. Yo-Yo IR2 performance was better ($P < 0.05$) for international elite soccer players than for moderate elite players (1059 ± 35 vs 771 ± 26 m) and better ($P < 0.05$) for central defenders ($N = 21$), fullbacks ($N = 20$), and midfielders ($N = 48$) than for goalkeepers ($N = 6$) and attackers ($N = 24$). Fifteen elite soccer players improved ($P < 0.05$) Yo-Yo IR2 performance by $42 \pm 8\%$ during 8 wk of preseasonal training. **Conclusion:** This study demonstrates that the Yo-Yo IR2 test is reproducible and can be used to evaluate an athlete's ability to perform intense intermittent exercise with a high rate of aerobic and anaerobic energy turnover. Specifically, the Yo-Yo IR2 test was shown to be a sensitive tool to differentiate between intermittent exercise performance of soccer players in different seasonal periods and at different competitive levels and playing positions. **Key Words:** HEART RATE, LACTATE, CREATINE PHOSPHATE, LEVEL OF COMPETITION, PLAYING POSITION, SEASONAL PERIODS

The activity profile and physical demands of ball games such as basketball and soccer have been studied extensively over the last decade (9,14,15,18,19,21,25,29). It is now well established that these sports are of intermittent nature, with activity changes every 3–5 s, and are physically demanding because of multiple brief, intense actions involving jumps, turns, tackles, high-speed runs, and sprints (15,19,21). Furthermore, heart rate recordings and the collection of muscle and blood samples have shown that the aerobic loading is high throughout basketball and soccer matches and that the anaerobic energy turnover is very high during periods of the game (3,9,15,19). The conclusion regarding a high rate of anaerobic energy turnover during periods of elite soccer games is further supported by the recent finding that international elite soccer

players perform twice as much high-intensity running in the most intense 5-min period as the game average (21) and that sprinting ability is temporarily reduced after an intense exercise period (15).

A number of physical tests have been used to evaluate the training status of elite soccer players according to differences in age, playing position, and elite level (5,8,10,13,14,16,24). Most of them consist of continuous exercise, and the relevance of these tests in ball games has been questioned (2,7,12,13). On the other hand, two intermittent field tests, the Yo-Yo intermittent recovery level 1 test (Yo-Yo IR1) and the shuttle sprint test, have been found to be related to the total amount of high-intensity exercise during soccer games (10,12–14). These tests have also been shown to have a high reproducibility and to be sensitive to training adaptations (4,5,10,12,13). However, because the Yo-Yo IR1 test consists of 10–20 min of repeated bouts of high-intensity aerobic work, and because the multiple shuttle test consists of six 6- to 7-s sprints interspersed with 20-s rest periods, neither of these tests is optimal for evaluating the ability to perform high-intensity exercise with a large rate of anaerobic energy production in combination with a high aerobic energy turnover.

One intermittent field test that may meet the requirements of simultaneous stimulation of the aerobic and anaerobic energy system is the Yo-Yo intermittent recovery level 2 test (Yo-Yo IR2 test) (2). This test lasts 2–10 min and consists of

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20-m shuttle runs at rapidly increasing speeds interspersed with 10-s periods of active recovery. The Yo-Yo IR2 test has been used for testing in a number of sports, such as basketball (22) and Australian football (28), but the test has not yet been investigated in terms of physiological response and reproducibility. Likewise, the test still needs to be examined to determine whether it is a sensitive tool to evaluate the intense intermittent exercise performance of soccer players in different seasonal periods, at different competitive levels, and in different playing positions.

Thus, the aims of the present study were to examine the physiological response and reliability of the Yo-Yo IR2 test and to evaluate its application to elite soccer.

METHODS

Subjects. Thirteen healthy, male subjects with a mean age of 25 (range: 22–30) yr, an average height of 1.82 (1.70–1.93) m, an average body mass of 77.9 (64.5–92.0) kg, and a maximal oxygen uptake of 52.9 (43.3–57.2) mL·min⁻¹·kg⁻¹ participated in the study. The quadriceps muscle fiber-type distribution was 58.6% (30.2–86.3) type I fibers, 32.7% (8.5–50.4) type IIa fibers, and 8.6% (0.0–20.6) type IIx fibers. The quadriceps muscle citrate syntase (CS), 3-hydroxyacyl-CoA dehydrogenase (HAD), creatine kinase (CK), and phospho frukto kinase (PFK) activity were 26 (15–37), 27 (19–42), 4.6 (3.8–5.3), and 144 (105–169) mmol·kg⁻¹ d.w.·min⁻¹, respectively. The subjects were habitually active, but none of them trained for competition. All subjects were informed of any risks and discomforts associated with the experiment before giving their written consent to participate. Moreover, 119 Scandinavian male, elite soccer players with a mean age, height, and weight of 23 (17–35) yr, 1.81 (1.69–1.98) m, and 74.9 (62.7–93.4) kg, respectively, participated in the study. The sample of players consisted of international elite players (*N* = 35), First Division players (*N* = 36), Second Division players (*N* = 15), and elite youth players (*N* = 21). The players represented all playing positions, that is, goalkeepers (*N* = 6), central defenders (*N* = 21), fullbacks (*N* = 20), central midfielders (*N* = 22), lateral midfielders (*N* = 26), and attackers (*N* = 24). The study conforms with the code of ethics of the World Medical Association (Declaration of Helsinki) and was approved by the ethics committee of Copenhagen and Frederiksberg municipalities.

The Yo-Yo IR2 test. The Yo-Yo IR2 consisted of repeated two 20-m runs at a progressively increased speed controlled by audio bleeps from a tape recorder as seen in Figure 1 (2). Between each running bout the participants had a 10-s rest period. When the participant failed to reach the finishing line in time twice, the distance covered was recorded and represented the test result. The test was performed indoor (habitually active males) or on artificial turf (soccer players) on a 2-m-wide and 20-m-long running lane marked by cones.

Physiological response to the Yo-Yo IR2 test. The subjects carried out the Yo-Yo IR2 test on four occasions at least 48 h apart. The first two Yo-Yo IR2 tests were

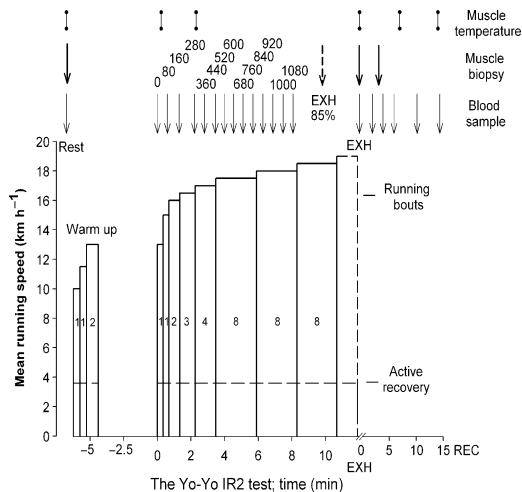


FIGURE 1—Experimental protocol.

performed to establish test–retest reproducibility. The third test was used for invasive measurements. After 15 min of rest in the supine position, the subjects had a Polar Vantage NV heart rate monitor (Polar Electro Oy, Kempele, Finland) placed around the chest for continuous heart rate recordings throughout the test. A catheter (18 G, 32 mm) was placed in an antecubital vein and covered by a wrist bandage. In preparation for obtainment of needle biopsies in the m. vastus lateralis, an incision was made through the skin and muscle fascia under local anesthesia (20 mg·L⁻¹ lidocain without adrenalin). The incisions were covered by sterile band aid strips and thigh bandages. A resting blood sample and muscle biopsy was obtained approximately 5 min prior to the warm-up period (Fig. 1). The warm-up consisted of the first 2 min of the Yo-Yo IR1 test as described by Krustup et al. (13). Subsequently, the subjects rested for 4 min before they performed the Yo-Yo IR2 test. Blood was sampled immediately prior to and during the test (i.e., after 80, 160, 280, 360, 440, 520, 600, 680, 760, 840, 920 m, etc.) and at exhaustion (Fig. 1). Blood samples were also collected in the recovery period after the test (i.e., after 2, 4, 6, 10, and 15 min). During the test, blood samples were taken in the 10-s recovery periods between the intervals (13). Another two muscle biopsies were obtained from the m. vastus lateralis at exhaustion and at 3 min into recovery. Muscle temperature was measured at a depth of 3 cm in the vastus lateralis muscle at rest, before the start of exercise, after 280 m, at exhaustion, and after 7.5 and 15 min of recovery (Fig. 1).

A fourth Yo-Yo IR2 test was performed on a separate occasion within 1 wk of the first invasive test. The test was terminated at 85% of exhaustion time during the first invasive Yo-Yo IR2 test. Heart rate was measured throughout the test, and blood samples were obtained as during the first part of the first invasive Yo-Yo IR2 test. A muscle biopsy was collected from m. vastus lateralis immediately after exercise (Fig. 1). On the testing days the subjects reported to the laboratory in the morning after consuming a light meal. Intake of caffeine on the day of the experiment, as well as alcohol consumption and heavy physical activity on the day prior to the test, were avoided.

The laboratory treadmill test. The laboratory treadmill test consisted of 6-min running bouts at 10, 12, and 14 km·h⁻¹ separated by 2-min rest periods. After 15 min of recovery an incremental maximal test was performed. This test started at a running speed of 14 km·h⁻¹ for 2 min and continued at 16 km·h⁻¹ for 30 s with a stepwise 1-km·h⁻¹ speed inclination every 30 s until exhaustion. Time to exhaustion was recorded. Heart rate was recorded in 5-s intervals during the entire test by a Polar Vantage NV monitor (Polar Electro Oy, Kempele, Finland). Pulmonary oxygen uptake was measured during each submaximal running speed and during the maximal test by a MedGraphics CPX/D breath-by-breath gas-analyzing system (Saint Paul, MN). This system was calibrated with two gases of known O₂ and CO₂ concentration, and the tube flowmeter (23) was calibrated by a 3-L syringe prior to each protocol. Individual $\dot{V}O_{2\max}$ and HR_{max} were determined as the peak values reached in 15-s and 5-s periods, respectively.

Sprint tests. The subjects also completed a repeated sprint test on a running track. Each sprint test consisted of five 30-m sprints, separated by periods 25-s of active recovery, during which the subjects jogged back to the starting line. The sprint times were recorded in seconds by infrared light sensors with the precision of 0.01 s (Time It, Eleiko Sport, Halmstad, Sweden). In addition, the subjects performed two 50-m sprints. They performed the test twice, separated by approximately 5 min, and the best time was chosen as the test result. All the tests included in the study were preceded by pretests to familiarize the subjects with the tests.

Blood analyses. Within 10 s of a 2-mL blood sampling, 100 μ L of blood was hemolyzed in an ice-cold 100- μ L Triton X-100 buffer solution and was later analyzed for lactate and glucose using a YSI 2300 lactate analyzer (Yellow Spring Instruments, Yellow Springs, OH) (11). The rest of the sample was rapidly (< 30 s) centrifuged, and subsequently, plasma was collected and stored at -20°C for later analysis. Plasma potassium concentration was measured using a flame photometer (Radiometer FLM3) with lithium as internal standard.

Muscle metabolites analysis. The muscle tissue was immediately frozen in liquid N₂ and stored at -80°C. The frozen sample was weighed before and after freeze-drying to determine water content. After freeze-drying, the muscle samples were dissected free of blood, fat, and connective tissue, and about 1 mg d.w. of tissue was extracted in a solution of 0.6 M of perchloric acid (PCA) and 1 mM of EDTA, neutralized to a pH of 7.0 with 2.2 M of KHCO₃, and stored at -80°C until being analyzed for CP and lactate by a fluometric assay (17). Another 1–2 mg d.w. of muscle tissue was extracted in 1 M of HCl and hydrolyzed at 100°C for 3 h, and the glycogen content was determined by the hexokinase method (17). Muscle pH was measured by a small glass electrode (Radiometer GK2801, Copenhagen, Denmark) after homogenizing a freeze-dried muscle sample of about 2 mg d.w. in a nonbuffering solution containing 145 mM of KCl, 10 mM of NaCl, and 5 mM of iodoacetic acid.

Muscle enzymes analysis. About 3 mg d.w. of muscle tissue was homogenized (1:400) in a 0.3-M phosphate

buffer adjusted to a pH of 7.7 and containing 0.5 mg·mL⁻¹ of bovine serum albumin. Citrate synthase (CS) activity and 3-hydroxyacyl-CoA dehydrogenase activity was determined by fluometric methods with NAD–NADH coupled reactions (17). Homogenates for phosphofructokinase (PFK) were prepared in 100 mM of potassium buffer phosphate (pH 8.2) containing 10 mM of glutathione, 0.5 mM of ATP, 5 mM of MgSO₄, and 30 mM of NaF. Creatine kinase (CK) activity was determined fluometrically on muscle homogenized in a triethanolamine acetate–bovine serum albumin (TEA–BSA) buffer (17).

Muscle fiber-type analysis. A part of the resting biopsies was mounted in an embedded medium (OCT Compound Tissue-Tek, Sakura Finetek, Zoeterwoude, The Netherlands), frozen in isopentane that was cooled to the freezing point in liquid N₂, and stored at -80°C. Five serial 10- μ m-thick sections were cut at -20°C and incubated for myofibrillar adenosine triphosphate (ATPase) reactions at a pH of 9.4, after preincubation at a pH of 4.3, 4.6, and at a pH of 10.3 (6). Based on the myofibrillar ATP staining, each fiber was classified under light microscopy as slow-twitch (ST), fast-twitch a (FTa), or fast-twitch x (FTx) fiber.

Statistics. Changes in muscle metabolites, blood metabolites, and heart rate during the Yo-Yo IR2 test were evaluated by the one-way analysis of variance (ANOVA) with repeated measures. An ANOVA test was also used to evaluate group differences in Yo-Yo IR2 test performance between playing positions. When a significant interaction was detected, data were subsequently analyzed using a Newman–Keuls *post hoc* test. Correlation coefficients were determined and tested for significance using Pearson's product–moment test. The coefficient of variation (CV) was used as a measure of test–retest reproducibility and calculated as the SD of the difference between the test and retest scores divided by the mean test score and multiplied by 100 (1). The significance level was set to $P < 0.05$. Values are presented as means \pm SEM.

RESULTS

Test–Retest Reproducibility

No difference was found in performance of two Yo-Yo IR2 tests performed within 1 wk (688 \pm 46 and 677 \pm 47 m, $P > 0.05$, $N = 29$). The intraindividual difference between these tests averaged 1 \pm 12 (-80 to 160) m, with a CV value of 9.6% (Fig. 2). No significant differences were observed between test and retest blood lactate values immediately prior to the test and after 80, 160, and 280 m (2.1 \pm 0.2 vs 2.4 \pm 0.2, 2.3 \pm 0.3 vs 2.3 \pm 0.2, 2.6 \pm 0.3 vs 2.7 \pm 0.3, and 4.0 \pm 0.4 vs 4.5 \pm 0.7 mmol·L⁻¹), with CV values of 31, 23, 22, and 34%, respectively. Likewise, no significant differences were observed between test and retest plasma K⁺ values immediately prior to the test and after 80, 160, and 280 m (4.1 \pm 0.1 vs 4.1 \pm 0.1, 4.5 \pm 0.1 vs 4.4 \pm 0.1, 4.9 \pm 0.1 vs 5.0 \pm 0.1, and 5.2 \pm 0.1 vs 5.2 \pm 0.1 mmol·L⁻¹), with CV values of 11, 9, 11, and 12%, respectively.

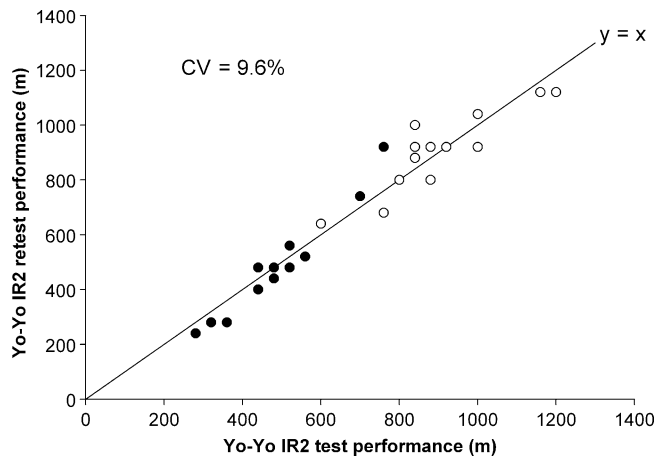


FIGURE 2—Test–retest reproducibility of the Yo-Yo intermittent level 2 recovery test ($N = 29$). The filled symbols represent normally trained subjects ($N = 16$), and the open symbols represent elite soccer players ($N = 13$). The full line is the identity line ($x = y$).

Test Performance

The distance covered in the Yo-Yo IR2 test was 591 ± 43 (320–920) m for the 13 subjects that took part in the invasive procedures, which corresponds to a test duration of 4.3 ± 0.3 (2.6–7.9) min (Fig. 1). Performance in the incremental treadmill test was 4.54 ± 0.20 (3.45–6.07) min. The heart rate at running speeds of 10, 12, and 14 $\text{km}\cdot\text{h}^{-1}$ was 149 ± 4 , 166 ± 3 , and 182 ± 3 bpm, respectively, which corresponds to 76 ± 2 , 85 ± 1 , and $93 \pm 1\%$ of maximum heart rate (HR_{max}). The 50-m sprint test performance was 7.07 ± 0.12 (6.43–7.53) s. A significant correlation was observed between Yo-Yo IR2 test performance and time to fatigue in the incremental running test ($r = 0.74$, $P < 0.05$) as well as maximal oxygen uptake ($r = 0.56$, $P < 0.05$). A significant negative correlation was observed between Yo-Yo IR2 test performance and percent HR_{max} during treadmill running at 14 $\text{km}\cdot\text{h}^{-1}$ ($r = -0.64$, $P < 0.05$) but not at 10 or 12 $\text{km}\cdot\text{h}^{-1}$ ($r = -0.41$ and -0.51 , $P > 0.05$). No correlations were observed between the Yo-Yo IR2 test performance and 50-m sprint performance ($r = 0.21$, $P > 0.05$), repeated sprint performance (5×30 m, $r = 0.26$, $P > 0.05$), quadriceps muscle PFK activity ($r = 0.30$, $P > 0.05$), CK activity ($r = 0.04$, $P > 0.05$), CS activity ($r = -0.03$, $P > 0.05$), HAD activity ($r = -0.05$, $P > 0.05$), or the quadriceps muscle fraction of FT fibers ($r = 0.24$, $P > 0.05$).

Physiological Response to the Yo-Yo IR2 Test

Heart rate. Heart rate was 109 ± 5 bpm immediately before the test and increased ($P < 0.05$) to 157 ± 4 , 176 ± 4 , and 184 ± 3 bpm after 80, 160, and 280 m, respectively, corresponding to 80 ± 2 , 88 ± 2 , and $93 \pm 1\%$ of the highest measured heart rate (HR_{max} ; Fig. 3A). At exhaustion, heart rate was 191 ± 3 (179–203) bpm, or 98 ± 1 (95–100) percent of HR_{max} . No systematic differences were observed in the peak heart rate reached during the Yo-Yo IR2 test and the incremental treadmill test (193 ± 3 vs 193 ± 2 bpm), with a coefficient of variance of 4%. During the recovery

period, heart rate decreased ($P < 0.05$) to 147 ± 6 , 127 ± 4 , 109 ± 3 , and 104 ± 3 bpm after 1, 2, 5, and 15 min, respectively (Fig. 3A). No relationship was observed between Yo-Yo IR2 test performance and percentage of maximal heart rate after 1, 2, or 3 min of the test ($r = -0.19$, -0.49 , and -0.40 , respectively, $P > 0.05$).

Muscle metabolites. Muscle metabolite concentrations, water content, and pH before and during the Yo-Yo IR2 test are presented in Table 1. Muscle CP was 77.6 ± 2.7 $\text{mmol}\cdot\text{kg}^{-1}$ d.w. at rest and had decreased ($P < 0.05$) to 52% of the resting level at 85% EXH and 38% at exhaustion (Fig. 4A). This corresponds to an average rate of CP breakdown of 10.0 ± 1.3 and 13.8 ± 5.0 $\text{mmol}\cdot\text{kg}^{-1}$ d.w. min^{-1} during the first and last parts of the test, respectively. Muscle CP increased ($P < 0.05$) by 30.5 ± 2.4 $\text{mmol}\cdot\text{kg}^{-1}$ d.w. to 80% of resting level during the first 3 min of recovery (Fig. 4A). Muscle lactate was 5.4 ± 0.6 $\text{mmol}\cdot\text{kg}^{-1}$ d.w. at rest and had increased ($P < 0.05$) about 8- and 12-fold at 85% EXH and at exhaustion in the Yo-Yo IR2 test, respectively, which corresponds to an average rate of lactate accumulation of 9.8 ± 1.3 and 27.8 ± 7.9 $\text{mmol}\cdot\text{kg}^{-1}$ d.w. min^{-1} in the first and last phases of the test, respectively (Fig. 4B). Muscle lactate decreased ($P > 0.05$) by 19.5 ± 1.7 $\text{mmol}\cdot\text{kg}^{-1}$ d.w. during the first 3 min of recovery (Fig. 4B).

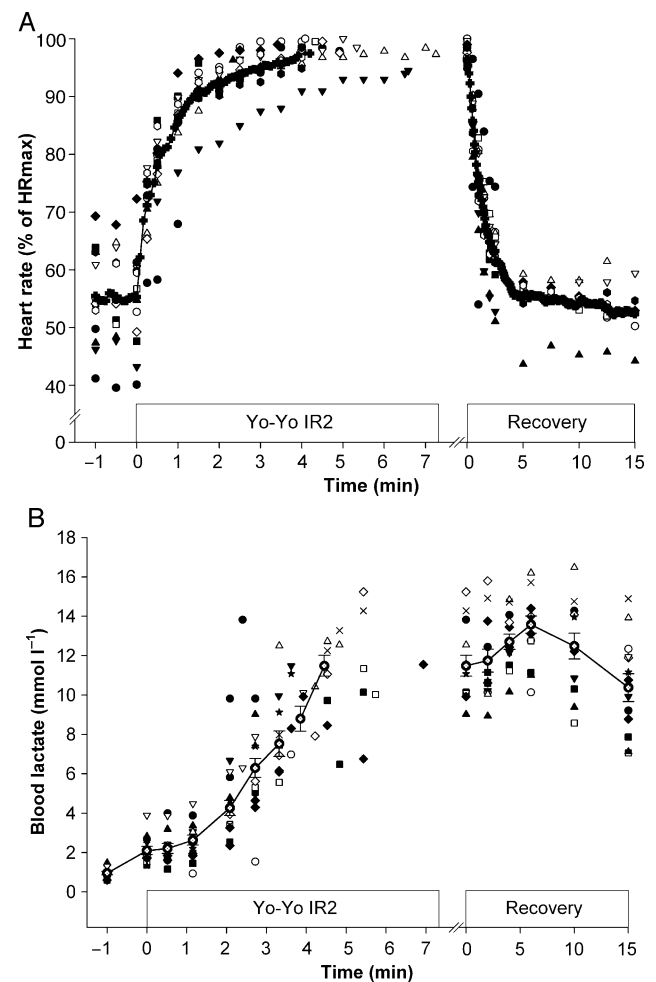


FIGURE 3—Heart rate (A) and blood lactate (B) before, during, and after the Yo-Yo IR2 test. Means (full line) and individual values are presented.

TABLE 1. Muscle CP, lactate, pH, and glycogen at rest, after 85% exhaustion time, at exhaustion, and after 3 min of recovery in the Yo-Yo IR2 test.

	At Rest (N = 13)	85% (N = 11)	At Exhaustion (N = 13)	3 min into Recovery (N = 13)
Muscle CP (mmol·kg ⁻¹ d.w.)	77.6 ± 2.7 (62.9–95.9)	40.4 ± 5.2* (19.3–67.6)	29.4 ± 4.7* (5.9–64.2)	59.9 ± 6.3*‡ (9.6–80.1)
Muscle lactate (mmol·kg ⁻¹ d.w.)	5.4 ± 0.6 (2.8–9.0)	41.7 ± 5.4* (13.5–70.5)	68.5 ± 7.6*† (37.9–128.2)	49.0 ± 8.9*‡ (20.5–125.5)
Muscle pH (–log·H ⁺)	7.07 ± 0.01 (6.98–7.13)	6.87 ± 0.04* (6.69–7.13)	6.80 ± 0.04*† (6.55–7.07)	6.91 ± 0.03*‡ (6.67–7.03)
Muscle glycogen (mmol·kg ⁻¹ d.w.)	399 ± 24 (287–599)	378 ± 9 (320–442)	363 ± 26* (275–538)	352 ± 25* (214–552)

Values are means ± SEM. * Significant different from rest; † significant difference between 85 and 100% of exhaustion time; ‡ significant difference between exhaustion and recovery.

Muscle pH was 7.07 ± 0.01 at rest and decreased ($P < 0.05$) to 6.87 ± 0.04 and 6.80 ± 0.04 at 85% EXH and at exhaustion, respectively. During the first 3 min of recovery, muscle pH increased ($P < 0.05$) to 6.91 ± 0.03. Muscle glycogen was 399 ± 24 mmol·kg⁻¹ d.w. at rest and decreased ($P < 0.05$) by 36 ± 16 mmol·kg⁻¹ d.w. during the test.

Blood variables. Blood lactate was 2.4 ± 0.2 mmol·L⁻¹ immediately before the test and increased ($P < 0.05$) to 5.1 ± 0.8 mmol·L⁻¹ after 280 m, 8.8 ± 0.6 mmol·L⁻¹ at 85% EXH, and 11.5 ± 0.5 mmol·L⁻¹ at exhaustion (Fig. 3B). Blood lactate peaked at 13.6 ± 0.5 mmol·L⁻¹ 6 min into the recovery period, after which it decreased ($P < 0.05$) to 10.4 ± 0.7 mmol·L⁻¹ after 15 min of recovery (Fig. 3B). The blood lactate concentrations after 80, 160, and 280 m were inversely correlated to Yo-Yo test performance ($r = -0.55$,

–0.72, and –0.50, respectively, $P < 0.05$). No correlation was observed between peak blood lactate and Yo-Yo IR2 test performance ($r = 0.25$, $P > 0.05$).

Plasma K⁺ was 4.1 ± 0.1 mmol·L⁻¹ immediately before the test and increased ($P < 0.05$) to 5.3 ± 0.1 mmol·L⁻¹ after 280 m and further to 6.3 ± 0.2 mmol·L⁻¹ at exhaustion. Plasma K⁺ decreased ($P < 0.05$) to 4.2 ± 0.1 mmol·L⁻¹ after 2 min and 3.5 ± 0.1 mmol·L⁻¹ after 4 min of recovery; thereafter, it increased ($P < 0.05$), reaching resting level after 15 min of recovery. The plasma K⁺ concentration after 280 m was inversely correlated to Yo-Yo IR2 test performance ($r = -0.70$, $P < 0.05$), whereas this was not the case for plasma K⁺ obtained after 80 m ($r = 0.21$, $P > 0.05$) or 160 m ($r = 0.48$, $P > 0.05$).

Blood glucose concentration was 4.6 ± 0.1 mmol·L⁻¹ immediately before the test, increased ($P < 0.05$) to 5.4 ± 0.2 mmol·L⁻¹ at exhaustion, and increased further to 6.5 ± 0.1 mmol·L⁻¹ after 6 min of recovery.

Muscle temperature. Quadriceps muscle temperature was 36.5 ± 0.1 (35.5–37.2)°C at rest and 37.7 ± 0.1 (36.9–38.6)°C immediately before the test. The muscle temperature increased ($P < 0.05$) to 38.5 ± 0.1 (37.8–39.4)°C after 280 m and further to 39.4 ± 0.1 (38.9–40.0)°C at exhaustion. After 7.5 and 15 min of recovery, muscle temperature had decreased ($P < 0.05$) to 38.4 ± 0.1 (37.9–39.0) and 37.8 ± 0.1 (37.0–38.5)°C, respectively.

Yo-Yo IR2 Test Performance of High-Level Soccer Players

Yo-Yo IR2 test performance in relation to level of competition. The international elite players performed 37% better ($P < 0.05$) in the Yo-Yo IR2 test than the Second Division players (1059 ± 35 vs 771 ± 26 m) (Fig. 5). Only 2 of 35 international elite players performed < 760 m in the Yo-Yo IR2 test, whereas this was the case for 8 of 36 First Division players, 9 of 15 players in the Second Division team, and 6 of 21 elite youth players (Fig. 5).

Positional differences in Yo-Yo IR2 test performance. It was observed that the central defenders (985 ± 43, $N = 21$), fullbacks (978 ± 40, $N = 20$), lateral midfielders (984 ± 41, $N = 26$), and central midfielders (968 ± 48, $N = 22$) had a higher ($P < 0.05$) Yo-Yo IR2 test performance than the attackers (894 ± 47 m, $N = 24$) and goalkeepers (602 ± 27 m, $N = 6$) (Fig. 6).

Yo-Yo IR2 test performance during a season. For a group of 15 First Division players, the Yo-Yo IR2 test performance was 928 ± 21 and 1033 ± 45 m in the middle and at the end of the preparation phase, which, respectively, was 27 ± 4 and 42 ± 8% better ($P < 0.05$) than at the start of the preparation period (Fig. 7). The Yo-Yo IR2 test performance at the end of the first half of the season was 964 ± 39 m,

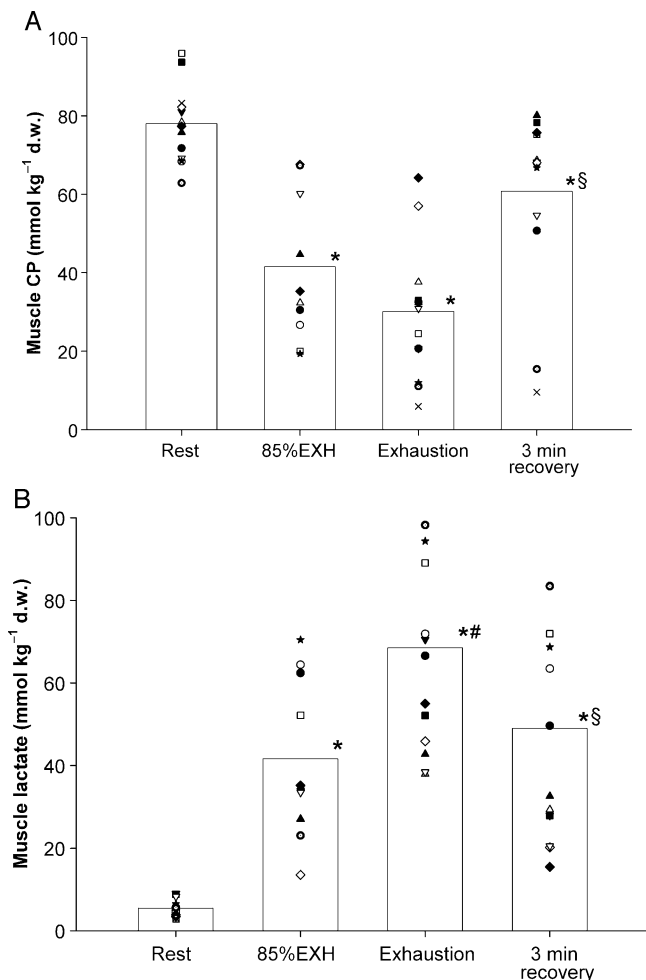


FIGURE 4—Muscle CP (A) and lactate (B) at rest, after 85% of exhaustion time and at exhaustion in the Yo-Yo IR2 test, as well as after 3 min of recovery. Means and individual values are presented. * Significantly different from rest; # significantly different from 85% EXH; § significantly different from exhaustion.

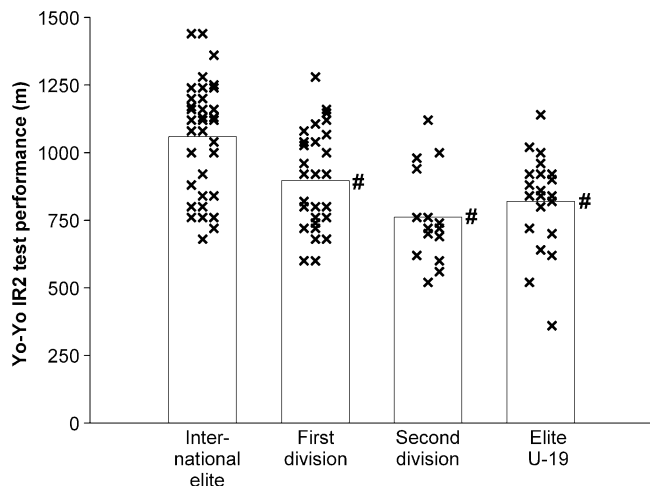


FIGURE 5—Yo-Yo IR2 test performance for professional soccer players at different competitive levels, that is, international elite players ($N = 35$), First Division players ($N = 36$), Second Division players ($N = 15$), and elite youth players ($N = 21$). Means and individual values are presented. # Significantly different from international elite level.

which was not significantly different from the start of the season. Only four players improved their Yo-Yo IR2 test performance during the season, whereas nine players had decreases in performance ranging from 40 to 440 m. The coefficient of variance between performances at the start and the end of the season was 14% (Fig. 7). For another group of First and Second Division players ($N = 20$), the Yo-Yo IR2 test performance was observed to be 873 ± 43 m at the end of the season and $11 \pm 5\%$ lower before the seasonal preparation (780 ± 35 m) (Fig. 7).

DISCUSSION

The present study demonstrates that the Yo-Yo IR2 test can be used to evaluate an athlete's ability to perform intense intermittent exercise with a high aerobic energy production and a significant contribution of the anaerobic energy system.

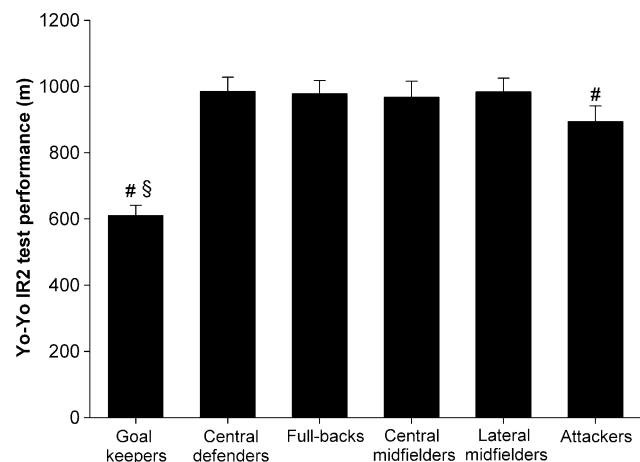


FIGURE 6—Yo-Yo IR2 test performance of elite soccer players at different playing positions, that is, goalkeepers ($N = 6$), central defenders ($N = 21$), fullbacks ($N = 20$), central midfielders ($N = 22$), lateral midfielders ($N = 26$), and attackers ($N = 24$). Values are means \pm SEM. # Significantly different from central defenders, fullbacks, and midfielders; § significantly different from attackers.

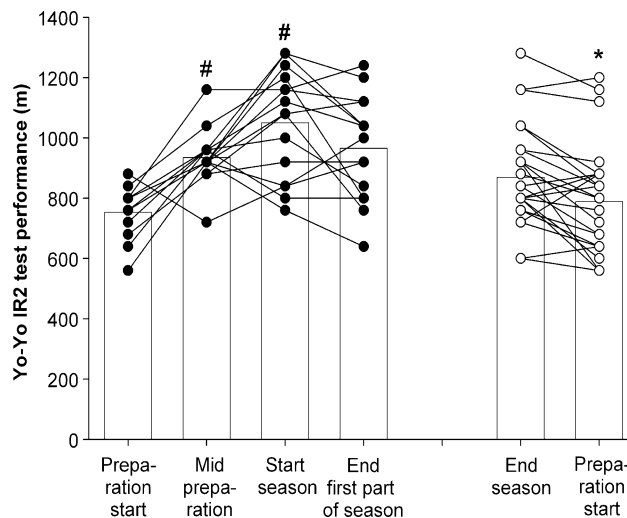


FIGURE 7—Yo-Yo IR2 test performance for elite soccer players at various stages of the season. Means and individual values are presented. * Significantly different from the end of the season; # significantly different from start of preparation.

The test has a high reproducibility and sensitivity and can be used to examine changes in intermittent exercise performance of athletes such as soccer players.

The Yo-Yo IR2 test appears to be optimal for evaluating the ability to perform repeated intense exercise because both the aerobic and anaerobic systems are heavily stimulated. The peak heart rate during the Yo-Yo IR2 test was the same as the peak heart rate observed during the exhaustive treadmill test in which the participants reached their maximal oxygen uptake. A similar response was obtained when the Yo-Yo IR1 test was evaluated (13). The crucial difference between the two tests was the stimulation of the anaerobic system. In the Yo-Yo IR2 test the CP level at the end of the test was lower and the rate of CP utilization in the last phase of the test was significantly higher compared with the IR1 test (Table 2). Furthermore, the muscle lactate concentration at the end of the test was higher in the Yo-Yo IR2 than in the IR1 test, and the rate of lactate accumulation in the last phase of the test was about five times larger. Accordingly, muscle pH was lower at exhaustion in the Yo-Yo IR2 than in the IR1 test. In addition, in the Yo-Yo IR2 test, the rate of lactate accumulation in the blood during the last phase of the test and the peak blood lactate concentration were higher compared with the Yo-Yo IR1 test. In general, the rate of anaerobic energy production and, specifically, the rate of lactate production towards the end of the Yo-Yo IR2 test were high. Also, the higher average rate of muscle glycogen utilization during the Yo-Yo IR2 compared with the Yo-Yo IR1 test (10 ± 3 vs 6 ± 3 $\text{mmol} \cdot \text{kg}^{-1} \cdot \text{d.w.} \cdot \text{min}^{-1}$) suggest that the rate of glycolysis was more pronounced during the Yo-Yo IR2 test. The blood lactate concentrations were at the same level as observed during basketball games (19) and occasionally during soccer games (3,9,15), suggesting that the metabolic responses observed during the test represents those observed in periods of ball games. Thus, whereas the Yo-Yo IR1 test focuses on the ability to repeatedly perform aerobic high-intensity work, the Yo-Yo IR2 test examines

TABLE 2. Physiological responses to the Yo-Yo IR1 and Yo-Yo IR2 test.

	Yo-Yo IR1 (N = 13)	Yo-Yo IR2 (N = 13)
Subject characteristics		
Age (yr)	28 (25–36)	25 (22–30)
Height (m)	1.82 (1.72–1.91)	1.82 (1.70–1.93)
Body mass (kg)	78.2 (68.4–91.2)	77.9 (64.5–92.0)
$\dot{V}O_{2\max}$ (mL·min ⁻¹ ·kg ⁻¹)	50.5 (42.1–60.8)	52.9 (43.2–57.2)
Treadmill test performance (min)	4.86 (3.89–6.01)	4.54 (3.45–6.07)
Test duration (min)	14.7 ± 0.8	4.3 ± 0.3
HR _{peak} (bpm)	187 ± 2	193 ± 3
HR _{peak} (% HR _{peak} treadmill)	99 ± 1	100 ± 1
Blood lactate at exhaustion (mmol·L ⁻¹)	10.1 ± 0.6	11.5 ± 0.5
Peak blood lactate (mmol·L ⁻¹)	10.9 ± 0.1	13.6 ± 0.5*
Blood lactate after 15 min of recovery (mmol·L ⁻¹)	6.6 ± 0.5	10.4 ± 0.7*
Peak blood K ⁺ (mmol·L ⁻¹)	7.0 ± 0.2	6.4 ± 0.2*
Muscle lactate at exhaustion (mmol·kg ⁻¹ d.w.)	48.9 ± 6.1	68.5 ± 7.6
Muscle CP at exhaustion (mmol·kg ⁻¹ d.w.)	40.3 ± 4.9	29.4 ± 4.7
Muscle pH at exhaustion	6.98 ± 0.04	6.80 ± 0.04*
Muscle temperature at exhaustion (°C)	40.6 ± 0.2	39.4 ± 0.1*
Rate of muscle lactate accumulation (mmol·kg ⁻¹ ·min ⁻¹)		
Whole test	3 ± 1	16 ± 5*
Last part	6 ± 2	28 ± 8*
Rate of muscle CP accumulation (mmol·kg ⁻¹ ·min ⁻¹)		
Whole test	3 ± 1	13 ± 2*
Last part	0 ± 1	14 ± 4*
Rate of net blood lactate degradation (mmol·L ⁻¹ ·min ⁻¹)		
Whole test	0.6 ± 0.1	2.8 ± 0.4*
Last part	1.5 ± 0.3	3.7 ± 0.9*

Values are means ± SEM (N = 13), except for data regarding the last part of the test (Yo-Yo IR1, N = 6; Yo-Yo IR2, N = 11). * Significant different between the Yo-Yo IR1 and Yo-Yo IR2 tests.

the capacity to perform intense intermittent exercise with a large anaerobic component in combination with a significant aerobic contribution.

The muscle lactate level was still high 3 min into recovery, and the blood lactate concentration peaked after 6 min and was high 15 min after the test (10.4 mM). Despite high muscle lactate concentrations after the test, the average rate of muscle lactate release was only 6.5 mmol·kg⁻¹ d.w.·min⁻¹ during the first 3 min of recovery. These findings confirm the observation from continuous exercise that the clearance of both muscle and blood lactate are slow processes, with the rate of lactate removal from the blood being slower than the rate of muscle lactate decrease. It becomes important to take such differences into account when making interpretations of blood lactate values obtained during and after competitions in sports where intermittent exercise is performed.

Soccer at a high level is characterized by a large amount of high-intensity exercise being performed during a game. Thus, players at an international elite level have been shown to perform 25% more high-intensity running and 35% more sprinting during competitive games than professional players at a moderate elite level (21). When comparing the performance of players from an elite team with players at lower levels, it was also clear that elite players performed better on the Yo-Yo IR2 test (Fig. 5). However, within each group there was a significant variation, reflecting a great difference in the ability to perform repeated intense exercise. Nevertheless, only 2 of 35 players in the international teams had

values below 760 m, suggesting that a basic level of fitness is needed to perform at a high level. The comparison between players in different positions revealed that the central defenders, fullbacks, and midfielders had better performance than the attackers and goalkeepers (Fig. 6). The finding that the central defenders were as good as the fullbacks and midfield players was in contrast to what was observed in terms of $\dot{V}O_{2\max}$ (2,20,26) and when their performance was compared in the Yo-Yo IR1 test (13) as well as an incremental treadmill test to exhaustion (2,20). This observation indicates that the Yo-Yo IR2 test, with its high rate of anaerobic energy turnover, was better at reflecting the work of the central defenders in a soccer game than the other measures. Thus, the Yo-Yo IR2 test examines an area of intermittent exercise performance that has not been studied before. Accordingly, the Yo-Yo IR2 test was not correlated with sprint performance. Similarly, the lack of correlations among the Yo-Yo IR2 test, muscle enzymes, and fiber-type distribution suggest that no single factor determined a subject's ability to perform this type of exercise.

It was observed that the soccer players had a 27% improvement in Yo-Yo IR2 test performance during the first 4 wk of a preparation period for a new season and a 42% improvement during the entire 8-wk period of preparation. Thus, it appears that the players' ability to perform repeated high-intensity exercise was changing considerably and that the test was sensitive to such changes. These changes may be compared with the small increases in $\dot{V}O_{2\max}$ observed during the preseasonal preparation for top-class referees (3%, NS) (12) and elite soccer players (7%) (13). Furthermore, the findings that four players had a 4–19% improvement in Yo-Yo IR2 test performance and that nine players had a 3–33% decrease in performance during the first part of the season also suggest that the test can be used to evaluate individual changes in performance during the season. The finding of a decrease in Yo-Yo IR2 performance for 60% of the players may also suggest that the players are not performing enough aerobic and anaerobic training during the season (2). This notion is supported by the finding that the players in the other group only had a 11% decrease in Yo-Yo IR2 test performance from the end of the season to the start of the preparation period, which may be compared with the 42% increase observed during the preparation period. Apparently, the level of fitness at the end of the season was lower than at the start of the season.

In summary, the Yo-Yo IR2 test examines the ability to perform repeated high-intensity exercise with an almost maximum aerobic energy production and a high rate of anaerobic energy turnover. The test has a high reproducibility and sensitivity. Thus, individual differences and changes in performance of athletes in sports using intense intermittent exercise can be examined in a simple manner.

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