The Yo-Yo Intermittent Recovery Test: Physiological Response, Reliability, and Validity

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ABSTRACT

KRUSTRUP, P., M. MOHR, T. AMSTRUP, T. RYSGAARD, J. JOHANSEN, A. STEENSBERG, P. K. PEDERSEN, and J. BANGSBO. The Yo-Yo Intermittent Recovery Test: Physiological Response, Reliability, and Validity. *Med. Sci. Sports Exerc.*, Vol. 35, No. 4, pp. 697–705, 2003. **Purpose:** To examine the physiological response and reproducibility of the Yo-Yo intermittent recovery test and its application to elite soccer. **Methods:** Heart rate was measured, and metabolites were determined in blood and muscle biopsies obtained before, during, and after the Yo-Yo test in 17 males. Physiological measurements were also performed during a Yo-Yo retest and an exhaustive incremental treadmill test (ITT). Additionally, 37 male elite soccer players performed two to four seasonal tests, and the results were related to physical performance in matches. **Results:** The test-retest CV for the Yo-Yo test was 4.9%. Peak heart rate was similar in ITT and Yo-Yo test (189 ± 2 vs 187 ± 2 bpm), whereas peak blood lactate was higher ($P < 0.05$) in the Yo-Yo test. During the Yo-Yo test, muscle lactate increased eightfold ($P < 0.05$) and muscle creatine phosphate (CP) and glycogen decreased ($P < 0.05$) by 51% and 23%, respectively. No significant differences were observed in muscle CP, lactate, pH, or glycogen between 90 and 100% of exhaustion time. During the precompetition period, elite soccer players improved ($P < 0.05$) Yo-Yo test performance and maximum oxygen uptake ($\dot{V}O_{2max}$) by 25 ± 6 and 7 ± 1%, respectively. High-intensity running covered by the players during games was correlated to Yo-Yo test performance ($r = 0.71$, $P < 0.05$) but not to $\dot{V}O_{2max}$ and ITT performance. **Conclusion:** The test had a high reproducibility and sensitivity, allowing for detailed analysis of the physical capacity of athletes in intermittent sports. Specifically, the Yo-Yo intermittent recovery test was a valid measure of fitness performance in soccer. During the test, the aerobic loading approached maximal values, and the anaerobic energy system was highly taxed. Additionally, the study suggests that fatigue during intense intermittent short-term exercise was unrelated to muscle CP, lactate, pH, and glycogen. **Key Words:** MUSCLE METABOLITES, INTERMITTENT EXERCISE, FATIGUE, TIME-MOTION ANALYSIS, SOCCER PERFORMANCE

A number of laboratory and field tests have been developed to evaluate physical performance in sports such as treadmill tests for determination of maximum oxygen uptake and shuttle run tests performed in the field (23,28). In most tests, the type of exercise is continuous. However, in many sports such as ball games, the exercise is intermittent and performance is related to the athletes' ability to repeatedly perform intense exercise. For example, it has been demonstrated that the quality of soccer is associated with the amount of high-intensity running performed throughout a game (6,13,25). Therefore, in such sports, it seems logical to evaluate the athletes' ability to repeatedly perform intense exercise and with that his/her potential to recover from intensive exercise. Based on this rationale, the so-called Yo-Yo intermittent recovery test was developed (5). It consists of repeated exercise bouts performed at progressively increasing speeds, interspersed with 10-s active rest periods and performed until the subject is exhausted. The test is frequently used in a variety of sports, and test performance is closely related to the physical performance of top-class referees during a soccer match (21). However, the information about its reproducibility, sensitivity, and validity as a marker of athletic performance in intermittent sports is still limited. Furthermore, the characteristics of the physiological response during the test have been restricted to measurements of heart rate throughout the test.

It is still unclear what causes fatigue during intense repeated exercise. Studies using prior diet manipulation have shown that lowered muscle glycogen play a significant role in the development of fatigue during long-term intermittent exercise (3,4,9,30). However, to what extent muscle glycogen and factors such as muscle creatine phosphate (CP), lactate, and pH play a role in fatigue during short-term intense exercise is not clear. To further study these aspects

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the Yo-Yo intermittent recovery test can be used as an exercise model, when measurements are performed at various phases of the test.

Thus, the aims of the present study were 1) to examine the reproducibility and validity of the Yo-Yo intermittent recovery test and 2) to evaluate the physiological response during the test and to examine potential factors causing fatigue during repeated intense exercise.

MATERIAL AND METHODS

Subjects. Two groups of subjects were involved in the study. Seventeen male subjects, with a mean age of 28 (range: 25–36) yr, an average height of 182 (172–191) cm, an average body mass of 78.2 (68.4–91.2) kg, and a maximal oxygen uptake of 50.5 (42.1–60.8) $mL \cdot min^{-1} \cdot kg^{-1}$, were studied to provide information on test-retest reproducibility and the physiological response during the Yo-Yo test. In addition, 37 male professional elite soccer players, with a mean age of 26 (range: 22–32) yr, an average height of 181 (169–193) cm, and an average body mass of 75.4 (67.5–90.1) kg, were followed to obtain information on seasonal and positional differences in Yo-Yo test performance and its correlation with physical performance during match-play. They all had more than 4 yr of experience in the best national leagues of their respective countries. All participants were fully informed of experimental procedures and possible discomforts associated with the study before giving their written informed consent to participate. The study was approved by the Ethics Committee of Copenhagen and Frederiksberg communities.

The Yo-Yo intermittent recovery test. The Yo-Yo intermittent recovery test consists of repeated 2 × 20-m runs back and forth between the starting, turning, and finishing line at a progressively increased speed controlled by audio bleeps from a tape recorder (5). Between each running bout, the subjects have a 10-s active rest period, consisting of 2 × 5 m of jogging. When the subjects twice have failed to reach the finishing line in time, the distance covered is recorded and represents the test result. The test may be performed at two different levels with differing speed profiles (level 1 and 2). In the present study, we used the Yo-Yo intermittent recovery test, level 1, which consist of 4 running bouts at 10–13 $km \cdot h^{-1}$ (0–160 m) and another 7 runs at 13.5–14 $km \cdot h^{-1}$ (160–440 m), whereafter it continues with stepwise 0.5 $km \cdot h^{-1}$ speed increments after every 8 running bouts (i.e., after 760, 1080, 1400, 1720 m, etc.) until exhaustion (see Fig. 1). The test was performed indoor on running lanes, marked by cones, having a width of 2 m and a length of 20 m. Another cone placed 5 m behind the finishing line marked the running distance during the active recovery period. Before the test, all subjects carried out a warm-up period consisting of the first four running bouts in the test. The total duration of the test was 6–20 min. All subjects were familiarized to the test by at least one pretest.

Physiological response during the Yo-Yo test. A number of physiological measurements were performed while the subjects performed the Yo-Yo intermittent recovery test (Fig. 1). Before, during, and after the test heart rate (N = 17) was recorded in 5-s intervals using a Polar Vantage NV heart rate monitor weighing ~100 g (Polar, Kempele, Finland). Blood samples (N = 17) were collected from an antecubital vein catheter at rest, after the warm-up period, at the end of each speed level (i.e., 160, 440, 760, 1080, 1400, 1720 m, etc.), at exhaustion as well as 1, 2, 4, 6, and 15 min after the test. During the test, the blood samples were taken in the 10-s recovery periods between the running bouts. Muscle biopsies were taken at rest (N = 7) and at exhaustion (N = 13) from the medial part of m. vastus lateralis by using the needle biopsy technique with suction. On a separate occasion, a biopsy was obtained from six subjects immediately after a running distance corresponding to 90% of the individual peak Yo-Yo test performance (90%EXH). These six subjects had no resting biopsy taken in the main experiment, so every subject had two biopsies taken. Local anesthesia (20 $mg \cdot L^{-1}$ lidocaine without adrenalin) was given at rest, and an incision was made for obtainment of the resting and postexercise biopsies. This incision was covered by sterile Band-Aid strips and a thigh bandage during the test. The temperature of m. quadriceps femoris (N = 10) was measured by a needle thermistor (MKA08050-A, Ellab A/S, Rødovre, Denmark) at rest, after the warm-up, after 440 and 1080 m, and at exhaustion, as well as 5, 10, and 15 min after the test. All measurements were performed in m. vastus lateralis of the right leg at a muscle depth of ~3 cm, adjusting for the thickness of the skin fold using a Harpenden skin fold caliper (British Indicators Ltd., West Sussex, UK). The thermistors had a precision of 0.1°C and were all calibrated against a mercury thermometer. Fluid loss (N = 10) during the test was determined by weighing the subjects in dry shorts immediately before and after the test using a platform scale (model 1–10, OHAUS, Pine Brook, NJ). The subjects were allowed to drink water during the test and the water intake was recorded.

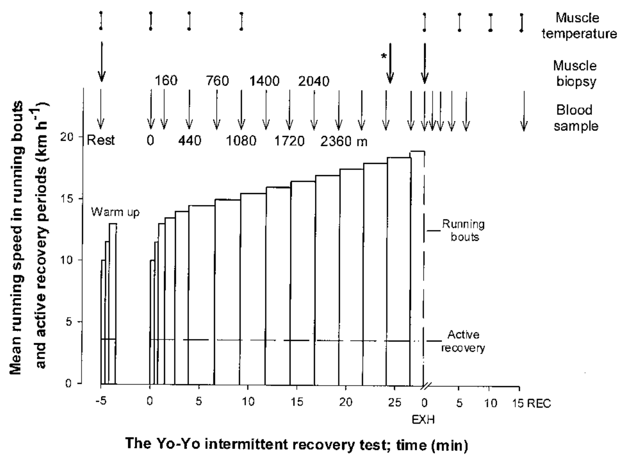

FIGURE 1—Schematic representation of the Yo-Yo intermittent recovery test including physiological measurements performed before, during, and after the test. The biopsy marked with (*) was taken on a separate day after 90% of individual exhaustion time.

Reproducibility of the Yo-Yo test. Thirteen of the subjects carried out an additional Yo-Yo test within 1 wk of the first test. The total distance covered was recorded. Heart rate was measured, and blood samples were collected as during the main experiment, whereas no biopsies were taken during the retest. Test-retest variation in quadriceps muscle temperature and fluid loss was determined in a total of seven subjects.

Laboratory treadmill test. Within one week of the Yo-Yo tests all subjects carried out a laboratory treadmill running protocol. The subjects ran at speeds of 10, 12, 14, and 16 $km \cdot h^{-1}$ in 6-min bouts separated by 2-min rest periods, followed by an incremental maximal test performed after 15 min of rest. The maximal test started at a running speed of 14 $km \cdot h^{-1}$ for 2 min and continued at 16 $km \cdot h^{-1}$ for 30 s with stepwise 1 $km \cdot h^{-1}$ speed increments every 30 s until exhaustion. Time to exhaustion was recorded as the test result. Heart rate was recorded in 5-s intervals during the entire protocol by a Polar Vantage NV heart rate monitor. Pulmonary oxygen uptake was measured during the last 3 min of each submaximal running speed and during the maximal test by a breath-by-breath gas analyzing system (MedGraphics CPX/D, Saint Paul, MN), which was calibrated before each protocol by a 3-L syringe as well as two gases of known O_2 and CO_2 concentrations. Individual peak heart rate (HR_{peak}) and maximal oxygen uptake ($\dot{V}O_{2max}$) were determined as the peak values reached in a 5- and 15-s period, respectively, at the end of the incremental maximal test. Blood samples were drawn from an antecubital vein before and after each exercise bout as well as 2, 4, 6, and 15 min after the incremental test for analysis of blood lactate and glucose as well as plasma potassium.

Blood analysis. All blood samples were collected in 2-mL syringes and immediately placed in ice-cold water until analyzed. Within 10 s of sampling 100 μL of blood was hemolyzed in an ice-cold 100-μL Triton X-100 buffer solution, and was later analyzed for lactate using an YSI 2300 lactate analyser (Yellow Spring Instruments, Yellow Springs, OH; 14). The rest of the blood sample was rapidly centrifuged for 30 s. Then, the plasma was collected and stored at −20°C until analyzed for insulin by using a fluorometric assay (24), for ammonia (NH_3) by using spectrophotometrical determination (22), as well as potassium by using a flame photometer (Radiometer FLM3, Copenhagen, Denmark) with lithium as the internal standard.

Muscle analysis. One part of the sample was immediately frozen in liquid N_2 and stored at −80°C for biochemical analysis. The frozen muscle samples were weighed before and after freeze drying to determine water content. The freeze-dried sample was dissected free of blood, fat, and connective tissue. A part of the muscle tissue (~2 mg d.w.) was extracted in a solution of 0.6 M perchloric acid (PCA) and 1 mM EDTA, neutralized to pH 7.0 with 2.2 M $KHCO_3$ and stored at −80°C until analyzed for CP and lactate by fluorometric assays (24). Muscle pH was measured by a small glass electrode (Radiometer GK2801) after homogenizing a freeze-dried muscle sample of about 2 mg d.w. in a nonbuffering solution containing 145 mM KCl, 10 mM NaCl, and 5 mM iodoacetic acid. In addition, 1–2 mg dry weight muscle tissue was extracted in 1 M HCl and hydrolyzed at 100°C for 3 h and the glycogen content was determined by the hexokinase method (24). The remaining portion of the sample for histochemical analysis was mounted in an embedded medium (OCT Compound Tissue-Tek, Sakura Finetek, Zoeterwoude, The Netherlands), whereafter it was frozen in isopentane which was cooled to the freezing point in liquid nitrogen. These samples were stored at −80°C until analyzed for fiber type distribution and fiber type specific glycogen content. Five serial 10-μm thick sections were cut at −20°C and incubated for myofibrillar adenosine triphosphate (ATPase) reactions at pH 9.4, after preincubation at pH 4.3, 4.6, and 10.3 (11). Based on the myofibrillar ATP staining, individual fibers were classified under light microscopy as ST, FTa, or FTb. To evaluate the relative glycogen content of individual fibers one 16-μm-thick transverse section was cut at −20°C and stained for glycogen by the periodic acid-Schiff (PAS) reaction (27). Under light microscopy, the staining intensity of the fibers was rated as full, partly full, almost empty, and empty and ranked from 3 to 0.

Testing of elite soccer players. A total of 37 male elite soccer players (9 central defenders, 7 fullbacks, 13 midfielders, and 8 attackers) carried out the Yo-Yo intermittent recovery test on two to four separate occasions. These tests were performed on artificial grass. Ten of these players performed the Yo-Yo intermittent recovery test and an incremental treadmill test (as described above) before the preparation phase of a season, in the middle of the preparation phase as well as in the start of and at the end of the season. The incremental treadmill test was used for determination of maximal oxygen uptake and performance during continuous incremental exercise. Within 2 wk of one of the tests performed during the competitive season, 12 players were videotaped during a total of 18 soccer matches in the national premier league to determine their locomotive activities. Each player was filmed close up by VHS movie cameras (NV-M50, Panasonic, Osaka, Japan) positioned at the side of the field, at the level of the midway line, at a height of about 15 m, and at a distance of about 30 m from the touch line. The videotapes were later replayed on a monitor for computerized recording of the movement pattern as described by Bangsbo et al. (6). The following locomotive categories were used: standing (0 $km \cdot h^{-1}$), walking (6 $km \cdot h^{-1}$), jogging (8 $km \cdot h^{-1}$), low-speed running (12 $km \cdot h^{-1}$), moderate-speed running (15 $km \cdot h^{-1}$), high-speed running (18 $km \cdot h^{-1}$), sprinting (30 $km \cdot h^{-1}$), and backward running (10 $km \cdot h^{-1}$). The locomotive categories were chosen in accordance with Bangsbo et al. (6). The match activities were afterward divided into four locomotive categories: 1) standing; 2) walking; 3) low-intensity running, defined as jogging, low-speed running, and backward running; and 4) high-intensity running, defined as moderate-speed running, high-speed running, and sprinting. The distance covered by each locomotive activity was determined as the product of total time and mean velocity for the activity. The total distance covered during a match was then calculated as the sum of the distances covered during each type of activity. Variations in results obtained by time

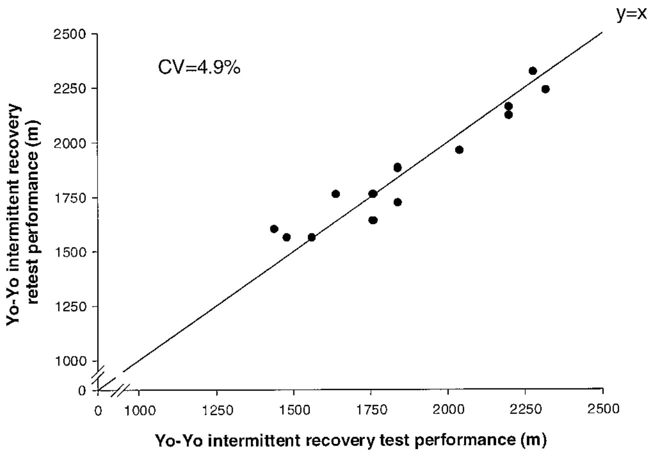

FIGURE 2—Test-retest reproducibility of the Yo-Yo intermittent recovery test. The correlation coefficient was 0.98 (N = 13, P < 0.05). *Full line* is the identity line (x = y).

motion analysis have previously been shown to be in the range of 1–5% in each of the individual activity categories (6,21). The 18 matches included in the present study were all analyzed by the same experienced observer.

Statistics. Differences in muscle metabolites and pH between different levels of time were evaluated by Student's paired *t*-test. Differences in fiber type specific glycogen content between rest and exhaustion were evaluated by a Wilcoxon signed rank test. Differences in oxygen uptakes, heart rates, and blood parameters during the tests as well as Yo-Yo test results during the season were evaluated by the one-way ANOVA on repeated measurement. 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 the Pearson's regression test. The coefficient of variance (CV) was used as a measure of reproducibility and calculated as SD of repeated measures divided by the mean and multiplied by 100 (1). A significance level of 0.05 was chosen. Data are presented as means ± SEM.

RESULTS

Performance. The distance covered in the Yo-Yo intermittent recovery test averaged 1793 ± 100 (range: 600–2320) m, which corresponds to a test duration of 14.7 ± 0.8 (5.1–18.6) min. No difference was found between performance in the first and second Yo-Yo test performed within 1 wk (1867 ± 72 vs 1880 ± 89 m; N = 13). The intra-individual difference between these tests averaged 13 ± 24 (−160 to 120) m, with a CV value of 4.9% (Fig. 2). A significant correlation was observed between Yo-Yo test performance and time to fatigue in the incremental running test (r = 0.79, P < 0.05, Fig. 3A) as well as maximal oxygen uptake (r = 0.71, P < 0.05, Fig. 3B). Also maximal oxygen uptake and time to fatigue in the incremental test were mutually correlated (r = 0.86, P < 0.05). The lactate concentrations immediately after treadmill running at 14 and 16 km·h^{-1} was inversely correlated to Yo-Yo performance (r = −0.46 and −0.65, respectively, P < 0.05), whereas this was not the case for running velocities of 10 and 12 km·h^{-1}.

Heart rates. Heart rate was 83 ± 2 (69–98) bpm immediately before the Yo-Yo test and increased (P < 0.05) to 158 ± 3 (145–168), 172 ± 3 (154–188), and 181 ± 3 (162–194) bpm after 440, 1080, and 1720 m, respectively. This corresponds to 83 ± 1 (77–89), 92 ± 1 (86–98), and 96 ± 1 (92–100)%, respectively, of peak heart rate (Fig. 4A). The peak heart rate reached during the Yo-Yo test was 187 ± 2 bpm, corresponding to 99 ± 1 (97–102)% of the peak heart rate reached during the treadmill test. During the recovery period, heart rate decreased (P < 0.05) to 148 ± 3 (127–164) and 121 ± 4 (73–139) bpm after 1 and 2 min, respectively, and decreased further (P < 0.05) to 98 ± 5 (81–109) bpm after 15 min. A significant inverse relationship was observed between the individual performance of the Yo-Yo test and percentage of maximal heart rate (%HR_{max}) reached after 6 and 9 min of the test (r = −0.81 and r = −0.75, respectively, P < 0.05) but not after 3 min (r = −0.34, NS). No systematic intra-individual differences were observed between test and retest heart rates, with mean values of 4 ± 2, −1 ± 2, 1 ± 2, 1 ± 1, and 0 ± 1 bpm before the test, after

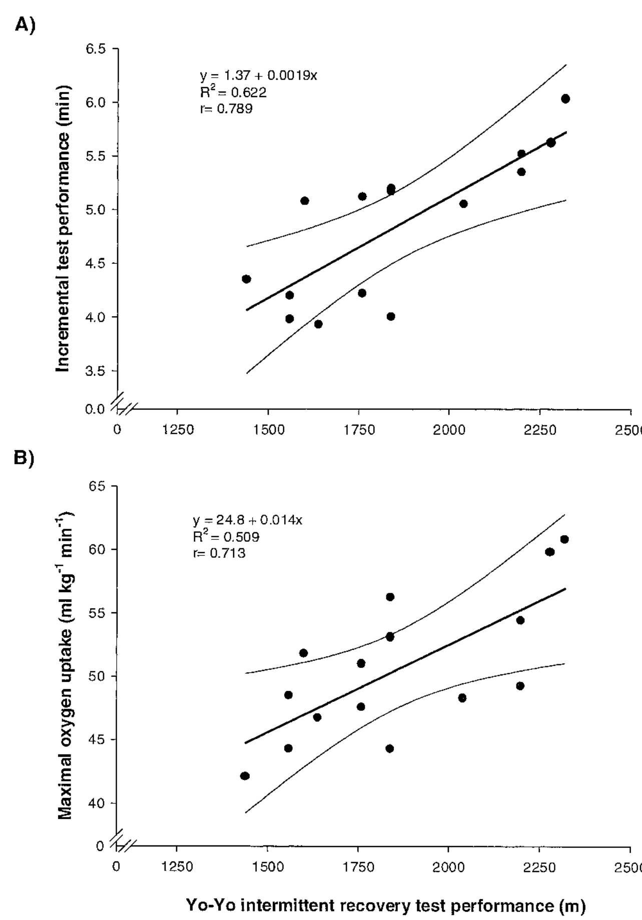

FIGURE 3—Interindividual relationship between the Yo-Yo intermittent recovery test and (A) time to fatigue in the incremental test (r = 0.79, N = 15, P < 0.05) and (B) maximal oxygen uptake (r = 0.71, N = 15, P < 0.05). The graphs show individual data points, the regression lines, and 95% confidence limits for the regression lines.

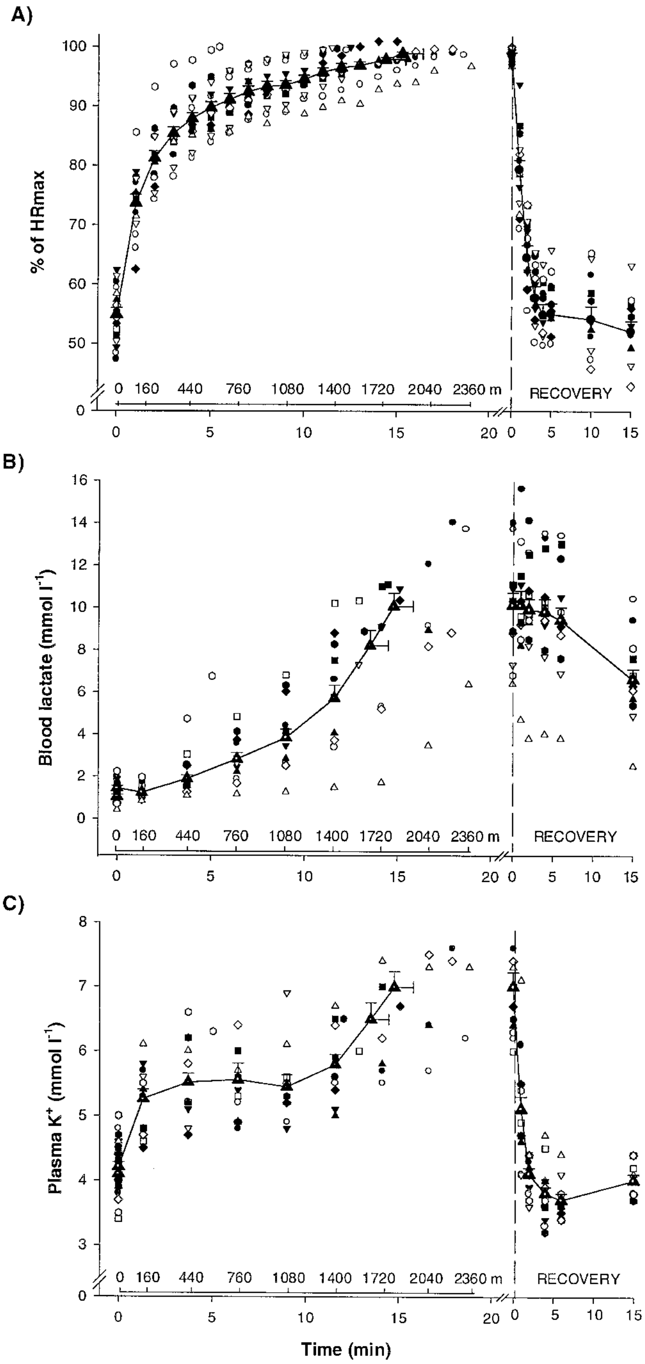

FIGURE 4—Heart rate, expressed in percentage of maximal heart rate (A), blood lactate (B), and plasma K^+ (C) before, during, and after the Yo-Yo intermittent recovery test. Values are means ± SEM as well as individual values.

440, 1040, and 1720 m and at exhaustion, respectively (CV: 7, 3, 3, 2 and 1%, respectively).

The oxygen uptake during the test, estimated by an individual relationship between heart rate and oxygen uptake obtained from the treadmill test, was 2.91 ± 0.06 (2.52–3.23), 3.36 ± 0.07 (2.94–3.79) and 3.56 ± 0.07 (3.04–4.03) $L \cdot min^{-1}$ after 440, 1080 and 1720 m, respectively, which corresponds to 76 ± 2 (69–91), 87 ± 1 (80–94), and 92 ± 1 (88–99) %, respectively, of $\dot{V}O_{2max}$. The estimated peak $\dot{V}O_2$ during the Yo-Yo test was 3.70 ± 0.09 (3.13–4.44) $L \cdot min^{-1}$ or 97 ± 1 (93–100) % of $\dot{V}O_{2max}$.

Muscle metabolites. Muscle metabolite concentrations, water content, and pH before and during the Yo-Yo test are presented in Table 1. Muscle CP was 82 ± 6 $mmol \cdot kg^{-1}$ d.w. at rest and 51% lower ($P < 0.05$) at exhaustion (40 ± 5 $mmol \cdot kg^{-1}$ d.w.). No difference was observed in CP values at 90%EXH and exhaustion. Muscle lactate was 51.2 ± 7.6 $mmol \cdot kg^{-1}$ d.w. at exhaustion and eightfold higher ($P < 0.05$) than at rest (6.8 ± 1.1 $mmol \cdot kg^{-1}$ d.w.). Muscle lactate at 90%EXH was not different from the value at exhaustion. Muscle pH was 7.16 ± 0.03 at rest and significantly lower ($P < 0.05$) at exhaustion (6.98 ± 0.04), which was not different from 90%EXH. Muscle water content was 76.8 ± 0.2% at rest, which was lower ($P < 0.05$) than at exhaustion 77.9 ± 0.6%. No difference was observed in muscle water content at 90%EXH and exhaustion. Muscle glycogen was 417 ± 10 $mmol \cdot kg^{-1}$ d.w. at rest and had decreased ($P < 0.05$) by 23% at exhaustion. Muscle glycogen at exhaustion was not different from at 90%EXH. The relative glycogen content of individual muscle fibers before and after the Yo-Yo test was evaluated by histochemical analyses ($N = 7$; Table 2). After the Yo-Yo test, 66 ± 9% of all fibers were rated as full with glycogen and 15 ± 7% as almost empty or empty of glycogen, which was different ($P < 0.05$) from before the test (75 ± 10% and 7 ± 5%, respectively). Fewer Type IIa fibers were rated as full with glycogen after than before the Yo-Yo test (67 ± 13 vs 91 ± 5%, $P < 0.05$), and more Type IIb fibers were rated as almost empty of glycogen (19 ± 5 vs 1 ± 1%, $P < 0.05$), whereas no significant differences was observed in relative glycogen content in Type I fibers after compared with before the Yo-Yo test.

Blood variables. Blood lactate concentration was 1.0 ± 0.1 (0.4–1.8) $mmol \cdot L^{-1}$ at rest and reached 10.1 ± 0.6 (6.4–14.0) $mmol \cdot L^{-1}$ at the end of the Yo-Yo test (Fig. 4B). During the first 6 min of recovery, blood lactate was unaltered but had decreased ($P < 0.05$) to 6.6 ± 0.5 (2.5–10.4) $mmol \cdot L^{-1}$ after 15 min of recovery (Fig. 4B). The blood lactate concentrations after 440, 760, 1080, 1400, and 1720 m were inversely correlated to Yo-Yo test performance ($r = -0.46$ to -0.81; $P < 0.05$). No systematic differences were observed in blood lactate concentrations between the test and retest trials (−0.1 ± 0.1, 0.4 ± 0.4, and 0.1 ± 0.6 $mmol \cdot L^{-1}$ at rest, after 1080 m, and at exhaustion, respectively), whereas large intra-individual variations were found (CV: 44, 39, and 17%, respectively). Plasma K^+ was 4.1 ± 0.1 $mmol \cdot L^{-1}$ at rest and increased ($P < 0.05$) to 7.0 ± 0.2 $mmol \cdot L^{-1}$ at exhaustion (Fig. 4c). After 6 min of recovery, plasma K^+ had decreased ($P < 0.05$) to 3.7 ± 0.1 $mmol \cdot L^{-1}$, whereafter it increased ($P < 0.05$) to resting levels after 15 min of recovery (Fig. 4C). The plasma K^+ during the test was not correlated to Yo-Yo test performance. No significant difference was found in test-retest plasma K^+ either at rest, after 1080 m, and at exhaustion (0.1 ± 0.1, −0.2 ± 0.2, and 0.0 ± 0.2 $mmol \cdot L^{-1}$), with CV values of 6, 11, and 7%, respectively. Plasma insulin was

TABLE 1. Muscle water content, CP, lactate, pH, and glycogen before and immediately after the Yo-Yo intermittent recovery test as well as after 90% of exhaustion time.

	Rest (N = 7)	Exhaustion (N = 13)	90% EXH (N = 6)	Exhaustion (N = 6)
Water content (%)	76.8 ± 0.2 (76.4–77.2)	77.9 ± 0.5* (76.2–81.1)	77.3 ± 0.4 (76.6–79.0)	77.7 ± 0.8 (76.3–81.1)
Muscle CP (mmol·kg^{-1} d.w.)	82 ± 6 (70–98)	40 ± 5* (19–73)	41 ± 6 (27–57)	41 ± 10 (19–73)
Muscle lactate (mmol·kg^{-1} d.w.)	6.8 ± 1.1 (1.6–9.9)	48.9 ± 6.1* (14.0–78.6)	41.0 ± 6.8 (28.5–64.9)	48.6 ± 9.0 (14.0–78.6)
Muscle pH (−log H$^+$)	7.16 ± 0.03 (7.01–7.21)	6.98 ± 0.04* (6.77–7.13)	6.98 ± 0.04 (6.90–7.14)	7.03 ± 0.05 (6.81–7.13)
Muscle glycogen (mmol·kg^{-1} d.w.)	417 ± 10 (398–457)	320 ± 20* (215–482)	346 ± 44 (208–515)	354 ± 38 (215–482)

Values are mean ± SEM.
* Significantly different (P < 0.05) from resting value.

11.4 ± 2.4 μU·mL^{-1} at rest and decreased (P < 0.05) to 6.4 ± 1.2 and 6.9 ± 0.5 μU·mL^{-1} after 1080 m and at exhaustion, respectively. Plasma NH_3 was 47 ± 6 μmol·L^{-1} at rest and increased (P < 0.05) to 172 ± 37 μmol·L^{-1} after 1080 m and 229 ± 24 μmol·L^{-1} at exhaustion. When comparing peak values reached during the Yo-Yo test and the incremental treadmill test no difference was observed in plasma K^+ (7.0 ± 0.2 vs 6.9 ± 0.1 mmol·L^{-1}), whereas peak blood lactate and peak plasma NH_3 were higher (P < 0.05) after the Yo-Yo test (10.9 ± 0.1 vs 10.3 ± 0.1 mmol·L^{-1} and 314 ± 22 vs 240 ± 16 μmol·L^{-1}, respectively).

Muscle temperature. Quadriceps muscle temperature was 36.6 ± 0.1 (36.0–37.3)°C before the test and increased (P < 0.05) to 38.7 ± 0.1 (37.9–39.2) and 39.9 ± 0.1 (39.2–40.7)°C after 440 and 1080 m, respectively, with a further increase (P < 0.05) to 40.6 ± 0.2 (39.7–41.4)°C at exhaustion. During the recovery period, muscle temperature decreased (P < 0.05) by 1.0 ± 0.2 and 1.3 ± 0.1°C, respectively, during the first 5 min and next 10 min, reaching 38.4 ± 0.1 (37.8–38.7)°C after 15 min of recovery. No significant intra-individual difference was observed in test-retest muscle temperature at rest, after 1080 m and at exhaustion (0.1 ± 0.2, −0.1 ± 0.1 and 0.0 ± 0.1°C, respectively), with CV values being 2, 1 and 0%, respectively.

Fluid loss. The fluid loss during the Yo-Yo test was 0.47 ± 0.03 (0.34–0.56) L, which corresponds to 0.6 ± 0.0 (0.4–0.7) % of the body mass. The fluid loss in the test and retest trial was not significantly different (0.47 ± 0.03 and 0.52 ± 0.03 L, respectively), with a CV value of 19%.

Seasonal changes in physical performance of soccer players. The Yo-Yo test performance of 10 elite soccer players was 1760 ± 59 m before the seasonal preparation period and was 25 ± 6% better (P < 0.05) at the start of the season (2211 ± 70; Fig. 5A). At the end of the season, the mean distance covered in the Yo-Yo test was not significantly altered (2103 ± 68 m), but large inter-individual performance changes were observed during the season (Fig. 5A). Thus, the mean intra-individual difference in test result between the start and end of season was −108 ± 107 (−640 to 280) m, with a CV value of 15%. The mean heart rate after 6 and 9 min of the test performed at the start of the season was 165 ± 3 and 171 ± 3 bpm, respectively, which at both time points was 9 ± 2 bpm lower (P < 0.05) than before the seasonal preparation period (Fig. 5B). No significant differences in heart rate response during the Yo-Yo test were observed during the season (Fig. 5B). The maximal oxygen uptake (N = 10) was 55.2 ± 0.9 mL·min^{-1}·kg^{-1}, at the start of the season, which was 7 ± 1% higher (P < 0.05) than before the seasonal preparation period. Time to exhaustion in the incremental test increased (P < 0.05) by 14 ± 3% during the seasonal preparation phase (331 ± 11 vs 293 ± 11 s). The maximal oxygen uptake and time to exhaustion in the incremental test was not significantly altered during the season with intra-individual CV values being 9 and 8%, respectively.

Positional differences in Yo-Yo test performance. A grouping of the 37 players into four categories according to their playing position demonstrated that full-backs (N = 7) had the highest Yo-Yo test performance during the season averaging 2241 ± 25 (1920–2680) m. This was 17% longer (P < 0.05) than for central defenders (1919 ± 47 (1160–2280) m, N = 9) and 14% longer than for attackers (1966 ± 30 (1480–2320) m, N = 8, Fig. 6). Midfielders (N = 13) covered a Yo-Yo test distance of 2173 ± 23 (1840–2560) m, and this was 13% longer (P < 0.05) than for the central defenders (Fig. 6).

Yo-Yo test and physical performance during a soccer match. A significant correlation was observed between the Yo-Yo test result and the amount of high

TABLE 2. Relative glycogen content in type I, IIa, and IIb fibers before and immediately after the Yo-Yo intermittent recovery test.

		Glycogen Depletion Pattern				
	Fiber Type Distribution (%)	Full (3) (%)	Partly Full (2) (%)	Almost Empty (1) (%)	Empty (0) (%)	Average Rating (n)
Rest						
Type I	57 ± 7 (39–80)	62 ± 14 (14–100)	26 ± 9 (0–54)	10 ± 7 (0–50)	1 ± 1 (0–6)	2.50 ± 0.21 (1.64–3.00)
Type IIa	33 ± 5 (19–49)	91 ± 5 (70–100)	8 ± 4 (0–30)	1 ± 1 (0–8)	0 ± 0 (0–0)	2.90 ± 0.06 (2.67–3.00)
Type IIb	10 ± 2 (0–12)	78 ± 10 (44–100)	21 ± 10 (0–56)	1 ± 1 (0–5)	0 ± 0 (0–0)	2.77 ± 0.11 (2.44–3.00)
All fibers	100 ± 0 (100–100)	75 ± 10 (33–100)	19 ± 6 (0–38)	6 ± 5 (0–33)	0 ± 0 (0–2)	2.67 ± 0.14 (2.00–3.00)
Exhaustion						
Type I	59 ± 8 (21–80)	68 ± 12 (9–94)	19 ± 4 (5–32)	11 ± 9 (0–60)	2 ± 2 (0–10)	2.53 ± 0.21 (1.29–2.94)
Type IIa	25 ± 6 (9–51)	67 ± 13* (22–100)	20 ± 9 (0–60)	13 ± 7 (0–44)	0 ± 0 (0–0)	2.54 ± 0.19 (1.78–3.00)
Type IIb	16 ± 4 (3–29)	59 ± 9 (37–100)	22 ± 7 (0–44)	19 ± 7* (0–43)	0 ± 0 (0–0)	2.40 ± 0.15* (2.04–3.00)
All fibers	100 ± 0 (100–100)	66 ± 9* (22–82)	20 ± 2 (17–28)	13 ± 7* (1–52)	1 ± 1 (0–7)	2.50 ± 0.18 (1.56–2.81)

Values are mean ± SEM (N = 7).
* Significantly different (P < 0.05) from resting value.

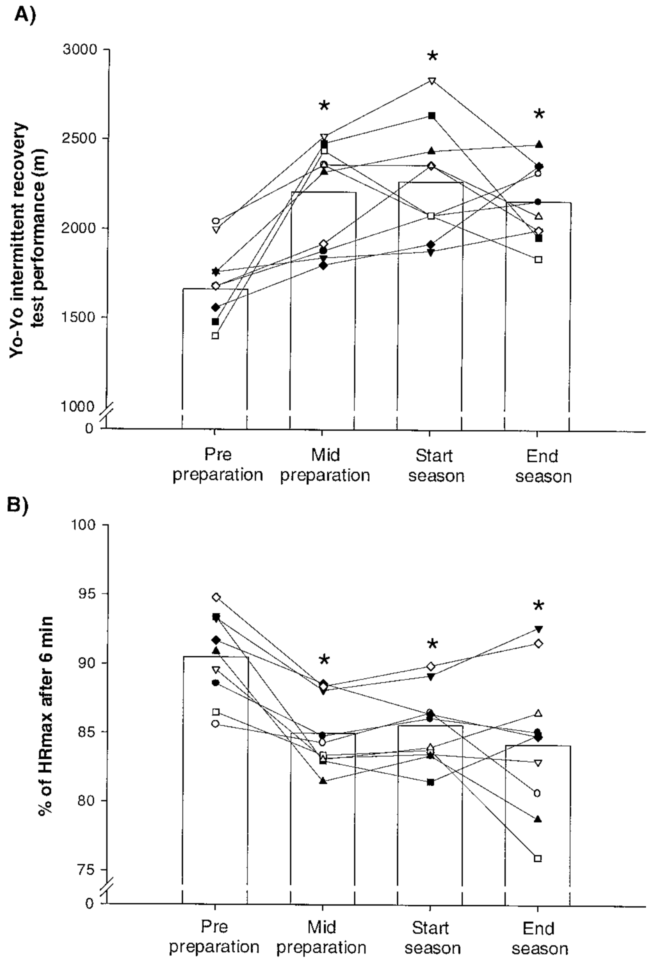

FIGURE 5—Seasonal changes in (A) Yo-Yo intermittent recovery test performance and (B) heart rate, expressed as % of maximal heart rate, after 6 min of the Yo-Yo intermittent recovery test. Values are means ± SEM as well as individual values. # Denotes significant difference (P < 0.05) from prepreparation period.

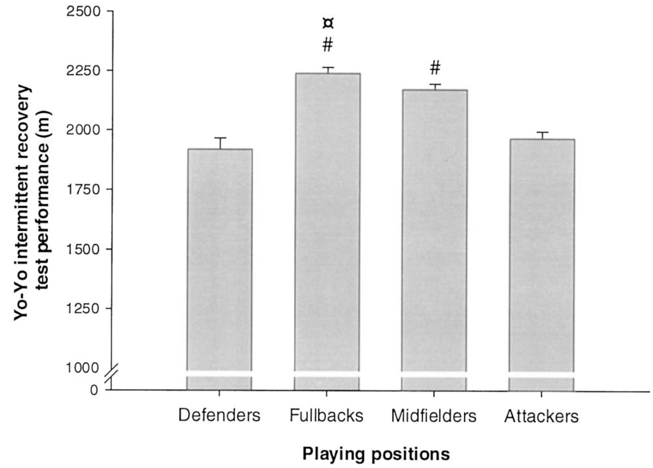

FIGURE 6—Yo-Yo intermittent recovery test performance for soccer players in relation to playing position (i.e., central defenders (N = 9), fullbacks (N = 7), midfielders (N = 13), and attackers (N = 8)). Values are means ± SEM. ¤ Denotes significant difference from attackers. # Denotes significant difference from central defenders.

intensity running (>15 km·h^{-1}) during a soccer match (r = 0.71, P < 0.05, Fig. 7). The Yo-Yo test performance was also correlated to the sum of high-speed running and sprinting during the game (r = 0.58, P < 0.05) as well as the total distance covered during a game (r = 0.53, P < 0.05). A significant correlation was found between maximal oxygen uptake and total distance covered in a match (r = 0.52, P < 0.05), whereas no significant correlation was found between maximal oxygen uptake and high-intensity running during a game (r = 0.38, P > 0.05). The performance of the incremental treadmill test to exhaustion was not correlated to either high intensity running (r = 0.26, P > 0.05) or total distance covered (r = 0.43, P > 0.05) during a game.

DISCUSSION

The major findings in the present study were that the Yo-Yo intermittent recovery test had a high reproducibility and that test performance was closely related to match performance in soccer. In addition, the test had a high sensitivity allowing for a detailed analysis of differences between and seasonal changes of the physical capacity of soccer players. The physiological measurements showed that aerobic energy turnover reached maximal values and that the anaerobic energy system was highly taxed toward the end of the test. Of interest is also that the development of fatigue during intense short-term intermittent exercise did not appear to be related to low muscle pH, CP, glycogen levels, or high muscle lactate concentrations.

A significant correlation was observed between the Yo-Yo intermittent recovery test performance and the amount of high-intensity exercise during a soccer game, which has been suggested to be a precise measure of physical performance during a soccer game (6,8,13,25). Thus, the test appears to be useful to evaluate match-related physical capacity of a soccer player. It should be noted that the amount of high-intensity exercise varies between matches, as also illustrated in Fig. 7, due to factors like tactical limitations, the quality of the opponent, and the degree of

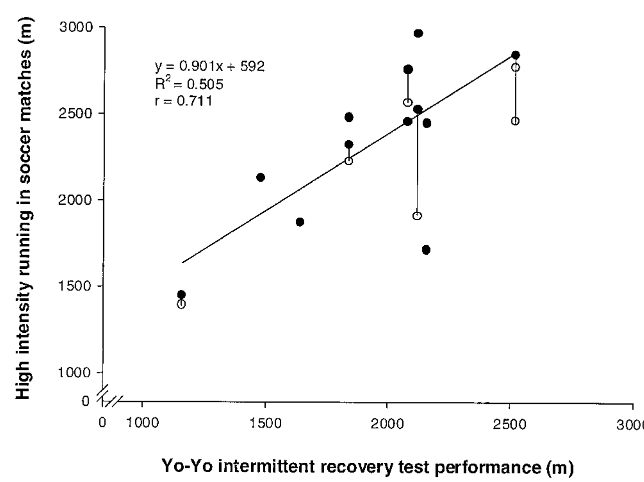

FIGURE 7—Interindividual relationship between the Yo-Yo intermittent recovery test performance and the amount of high-intensity running (>15 km·h^{-1}) during elite soccer matches (r = 0.71, N = 18, P < 0.05). The *connected symbols* represent values of high intensity running for the same player in subsequent matches.

motivation. Anyway, the positive relationship between the Yo-Yo test result and match performance is in agreement with the finding from a study performed on top-class soccer referees (21) and suggest that the test provide a valid measure of physical performance in intermittent sports such as soccer. In accordance with this, it was shown that elite soccer players in different playing positions had marked differences in Yo-Yo test performance. Thus, fullbacks and midfielders performed 14–17% better in the Yo-Yo test than central defenders, which corresponds well with the finding that fullbacks and midfielders cover a much longer distance with high-intensity running during top-class soccer games than central defenders (25). Another important finding also supporting the use of the test was that the elite soccer players had a major improvement in test performance during the precompetitive season (25%), which was considerably larger than the reproducibility of the test (CV = 5%). In addition, large individual alterations in test performance was observed during the season although average values was unaltered in this period (CV = 15%). These findings illustrate that the test is sensitive and can be used to detect differences between players as well as seasonal changes in "soccer fitness".

Significant correlations were observed between the Yo-Yo intermittent recovery test performance and time to exhaustion at the treadmill test and $\dot{V}O_{2max}$, which could lead to the suggestion that the two latter measures could as well be used in soccer. However, neither treadmill performance nor $\dot{V}O_{2max}$ was correlated to high-intensity exercise performance during a game. Furthermore, even though correlations were found between the Yo-Yo test, $\dot{V}O_{2max}$, and treadmill test performance, large interindividual differences were observed. For example, four individuals with almost the same $\dot{V}O_{2max}$ of 48–49 $mL \cdot min^{-1} \cdot kg^{-1}$ had very different Yo-Yo test performance (1560, 1760, 2040, and 2200 m, see Fig. 3B). In addition, the preseasonal changes in Yo-Yo test performance of 25% greatly exceeded those of $\dot{V}O_{2max}$ for soccer players in the present and similar studies (3–11%; 5,18,20,26). When taking into account that the amount of high-intensity running in elite soccer varies markedly in relation to time of the season (CV = 24%; 25), it seems as if the Yo-Yo test performance is a more sensitive measure for variations in soccer performance than $\dot{V}O_{2max}$. The latter notion is supported by the finding that top-class soccer referees improved their Yo-Yo test performance by 31% and the amount of high-intensity running during competitive matches by 23% after 8 wk of intense intermittent exercise training, with a negligible change in $\dot{V}O_{2max}$ (3%; NS) (21). Other advantages of the Yo-Yo test are that it can be accomplished at low cost (no treadmill, no metabolic cart) and rapidly. Thus, at least 30 athletes can be tested within 20 min.

The heart rate and the corresponding estimated $\dot{V}O_2$ increased progressively during the test and reached almost maximal levels. The heart rate response during the last phase of the test was similar to the levels observed during the intense parts of a soccer match (5,13). Furthermore, the high blood and muscle lactate levels toward the end of the test show that the rate of glycolysis is high during the test as also occasionally observed during a soccer game (6,13). Together, the test allows a determination of the ability to recover from exercise periods of an intensity similar to that obtained in soccer. Another interesting aspect is that the test can be used to determine an athlete's maximal heart rate. Thus, the peak heart rate reached during the Yo-Yo test corresponded to 99% of that reached in a standardized maximal heart rate test and for 14 of 17 subjects the test result differed less than 3 bpm.

The heart rates, expressed in percentage of individual maximal values, obtained at fixed time points of the test (i.e., 6 and 9 min) inversely correlated to the performance of the Yo-Yo test. However, this relationship was not established after 3 min, suggesting that the test should be longer than 3 min. Of note is also that submaximal heart rate values were consistently lower throughout the tests performed during the season compared with the preseason (9 bpm or 5%; Fig. 5). Together, these observations suggest that heart rate measurements during a submaximal version of the Yo-Yo test may also provide information about soccer fitness. It has the advantage that the athletes do not have to work to exhaustion but the disadvantage that equipment for measurements of heart rate is needed. Also blood lactate obtained during the test was inversely correlated to the Yo-Yo test performance. This relationship was present from 4 to 14 min of the test but not after 1.5 min. Thus, although the invasiveness of the procedure has to be taken into consideration, blood samples taken during a submaximal version of the Yo-Yo test can add to the information about the physical status of an athlete.

It has been suggested that elevated muscle lactate and lowered muscle pH are the cause of fatigue during intense exercise and repeated intense exercise (12,17,29). However, our observations that muscle lactate and pH were the same 1.5 min before the end of the test (90%EXH) as at exhaustion suggest that fatigue is not caused by accumulation of hydrogen ions or lactate. These findings are in accordance with observations obtained in studies of repeated intense exercise using a knee-extensor model, which showed that fatigue was established at different levels of muscle lactate and pH (10). Low muscle CP has also been suggested to cause fatigue, because it has been observed that performance of intense intermittent exercise is improved by a period of creatine intake (2,16). However, muscle CP was not changing in the last phase of exercise, and the absolute CP levels were higher than at exhaustion after intense continuous exercise and intermittent sprint exercise (15,19). Thus, muscle fatigue during short-term intermittent exercise does not seem to be related to low muscle CP.

Studies using prior diet manipulation have shown that lowered muscle glycogen could play a significant role in the development of fatigue during long-term intermittent exercise (3,4,9). In these latter studies, performance was markedly lowered after a low-carbohydrate diet resulting in initial muscle glycogen levels below 200 $mmol \cdot kg^{-1}$ d.w. In the present study all subjects had postexercise glycogen contents above this value (215–480 $mmol \cdot kg^{-1}$ d.w.), and based on the PAS-staining, it was observed that more than 85% of the individual fibers were full or partly full with glycogen at exhaustion and that essentially no fibers were glycogen depleted (Table 2). In addition, another study using intermittent short-lasting exercise has shown no differences in the rate of glycolysis in a range of muscle glycogen levels between 250 and 650 $mmol \cdot kg^{-1}$ d.w. and no effect on performance of diet manipulated above-normal muscle glycogen contents (7). Altogether, this suggests that glycogen availability is sufficient during short-term intermittent exercise for subjects on a normal diet.

In summary, the present study showed that the Yo-Yo intermittent recovery test has a high reproducibility and is a valid measure of physical performance in soccer. During the test, both aerobic and anaerobic energy systems are highly taxed, and the test evaluates an individual's ability to recover from intense exercise. Thus, it can be used to examine seasonal changes in the physical capacity of athletes in intermittent sports. The observations in the study also indicate that development of fatigue during intense repeated short-term exercise is not related to factors such as lowered muscle pH, CP, and glycogen or high muscle lactate.

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