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The Yo-Yo Intermittent Recovery Test

A Useful Tool for Evaluation of Physical Performance in Intermittent Sports

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Contents

Abstract

The two Yo-Yo intermittent recovery (IR) tests evaluate an individual's ability to repeatedly perform intense exercise. The Yo-Yo IR level 1 (Yo-Yo IR1) test focuses on the capacity to carry out intermittent exercise leading to a maximal activation of the aerobic system, whereas Yo-Yo IR level 2 (Yo-Yo IR2) determines an individual's ability to recover from repeated exercise with a high contribution from the anaerobic system. Evaluations of elite athletes in various sports involving intermittent exercise showed that the higher the level of competition the better an athlete performs in the Yo-Yo IR tests. Performance in the Yo-Yo IR tests for young athletes increases with rising age. The Yo-Yo IR tests have shown to be a more sensitive measure of changes in performance than maximum oxygen uptake. The Yo-Yo IR tests provide a simple and valid way to obtain important information of an individual's capacity to perform repeated intense exercise and to examine changes in performance.

The activity profile and physical demands of many sports involving intermittent exercise, such as basketball and soccer, have been studied extensively over the last decade.[1-10] It is well established that such sports have high physical demands due to multiple brief intense activities, such as jumps, turns, tackles, high-speed runs and sprints.[1,2,5,7,8] Physiological determinations, such as heart-rate recordings as well as metabolic measurements of muscle and blood samples collected during competition, have furthermore shown that in many of these sports the aerobic loading is high throughout the

competition and that the anaerobic energy turnover is extensive during periods of competition.[1-3,5,7] The aerobic and anaerobic capacity of an athlete may determine the outcome of the competition and it is therefore important to evaluate the athletes' ability within these areas. Traditionally, the capacity of an athlete has been evaluated using continuous exercise tests, including the Legér shuttle-run test,[11] a 12-minute running test or a maximum oxygen uptake ($\dot{V}O_{2max}$) test. However, the relevance of these tests to intermittent sports has been questioned,[12-15] leading to the development of the Yo-Yo intermittent recovery (IR) tests.[16] The Yo-Yo IR tests have rapidly become some of the most extensively studied fitness tests in sports science. Due to their specificity and practicality, the tests have also been widely applied in many team sports to assess players' abilities to repeatedly perform high-intensity exercise.

The development of the test was inspired by the Legér multistage fitness test. As in the Legér test, the participants in the Yo-Yo IR tests are running 20m shuttles; however, each shuttle is interspersed with a recovery period. Thus, the Yo-Yo IR tests consist of 2×20m shuttle runs at increasing speeds, interspersed with a 10-second period of active recovery (controlled by audio signals from a compact-disc player). An individual is running until he/she is not able to maintain the speed, and the distance covered at that point is the test result. There are two levels to the test. Level 1 (Yo-Yo IR1) starts at a lower speed and with the increases in speed being more moderate than for the level 2 (Yo-Yo IR2) test (figure 1). For a trained person, the Yo-Yo IR1 test lasts 10–20 minutes and is mainly focusing on an individual's endurance capacity, whereas the Yo-Yo IR2 test lasts 5–15 minutes and aims at evaluating a trained person's ability to perform a repeated intense exercise bout with a high anaerobic energy contribution. The Yo-Yo IR1 test fulfils these criteria for a less trained person.

Since their introduction, the Yo-Yo IR tests have been extensively used for testing in society,[16,18] for example, schools, and in a high number of sports, such as basketball,[19] soccer,[4,8,15,17,20-29] rugby,[30] Australian football[10,31] and running.[32] After >15 years of application, it appears appropriate to evaluate the potential and use of the tests. The present article presents and discusses data collected in scientific studies that have either examined the Yo-Yo IR test or used the tests to evaluate the performance level of individuals. In addition, a significant amount of unpublished data are presented. The article deals with various aspects such as the physiological response to the Yo-Yo IR tests, the use of the tests in sports analysis, the effect of age on test performance, the use of the tests to examine seasonal variations in performance and how to utilize a reduced version of the tests.

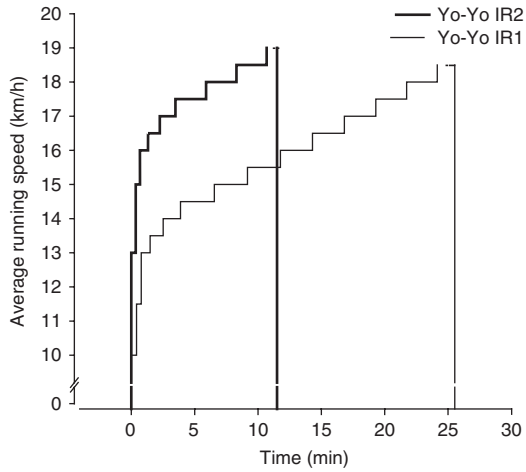

Fig. 1. Schematic representation of the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) and level 2 (Yo-Yo IR2) tests (reproduced from Krustrup et al.,[15,17] with permission).

1. The Physiological Response to the Yo-Yo Intermittent Recovery (IR) Tests

In this section, the physiological response to the Yo-Yo IR tests will be described and the difference between performing the Yo-Yo IR1 and IR2 test will be discussed.

The heart rate increases progressively during both tests reflecting an increasing oxygen uptake ($\dot{V}O_2$), but faster in the IR2 test (figure 2a). At the end of the Yo-Yo IR1 and IR2 test the heart rate (± standard error of the mean [SEM]) was observed to be 100 ± 1% and 99 ± 1%, respectively, of the

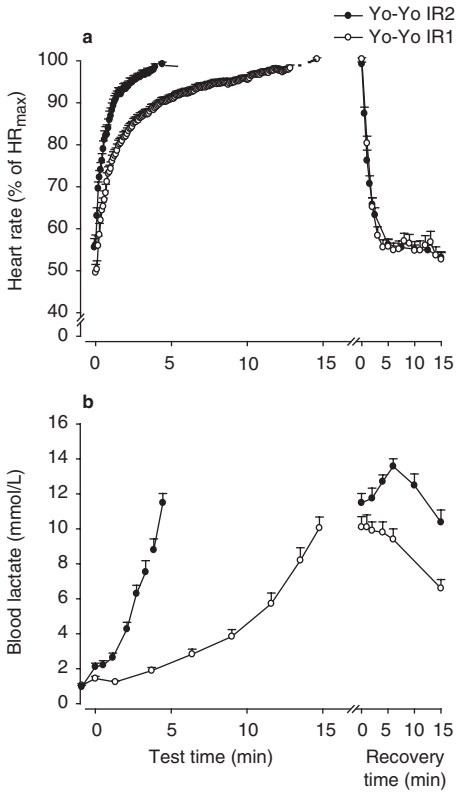

Fig. 2. Heart rate expressed as a percentage of (**a**) maximal heart rate (HR_{max}) and (**b**) blood lactate before, during and after the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) and level 2 (Yo-Yo IR2) tests. Values are mean ± standard error of the mean (reproduced from Krustrup et al.,[15,17] with permission).

peak heart rate reached during a treadmill test in which the participants reached their $\dot{V}O_{2max}$.[15,17] Thus, both Yo-Yo IR tests can be used to rapidly determine the maximal heart rate of an individual. Such measurements are useful in the evaluation of heart rates obtained during training.[33,34]

Both tests are therefore stimulating the aerobic system maximally; the major difference between the two tests is the degree of activating the anaerobic system. Muscle biopsies and blood samples have been collected before, during and immediately after the Yo-Yo IR tests, among other things to provide information about the anaerobic energy production during the tests.[15,17] In the Yo-Yo IR2 test, the creatine phosphate (CP) level at the end of the test was lower than in the IR1 test and the rate of CP utilization both in the first and last phase of the test was significantly higher compared with the IR1 test (figure 3).[15,17] Furthermore, the muscle lactate concentration at the end of the test was higher in the Yo-Yo IR2 than in the IR1 test,[15,17] and the rate of muscle lactate accumulation during the test was about 5 times larger (figure 3). Accordingly, muscle pH was lower at exhaustion in the Yo-Yo IR2 than in the IR1 test (6.80 vs 6.98).[15,17] In addition, in the Yo-Yo IR2 test, the rate of lactate accumulation in the blood during the test and the peak blood lactate concentration was higher compared with the Yo-Yo IR1 test (figure 2b). 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, a higher average rate of muscle glycogen utilization reported during the Yo-Yo IR2 test[15,17] suggests that the rate of glycolysis is more pronounced than during the Yo-Yo IR1 test.

After both the Yo-Yo IR1 and the IR2 tests, muscle glycogen was only moderately lowered (23% and 9%, respectively).[15,17] More importantly, a significant number of muscle fibres had markedly reduced glycogen levels. After the Yo-Yo IR1 test, 14% of all fibres were rated as almost empty or empty of glycogen, which was different from before the test (6%).[15] Also, more fast twitch (FT)a fibres and more FTx fibres were almost empty of glycogen (13% vs 1% and 19% vs 1%, respectively; $p < 0.05$).[15] The lowering of muscle glycogen in some

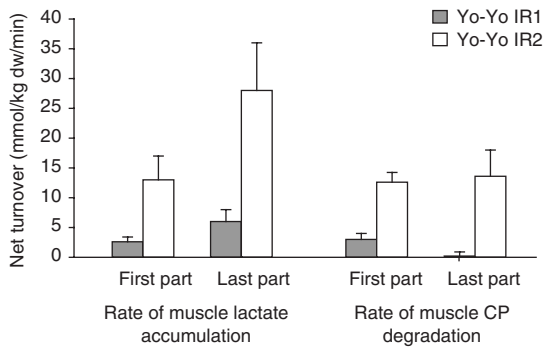

Fig. 3. Rate of muscle lactate accumulation and creatine phosphate (CP) degradation during the first and the last part of the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) and level 2 (Yo-Yo IR2) tests. Values are mean ± standard error of the mean.[15,17] **dw** = dry weight.

fibres may have contributed to the development of fatigue. Thus, studies using prior diet manipulation have shown that lowered muscle glycogen could play a significant role in the development of fatigue during repeated intense exercise.[35-37]

In summary, whereas the Yo-Yo IR1 test focuses on the ability to repeatedly perform aerobic high-intensity work, the Yo-Yo IR2 test examines the capacity to perform intense intermittent exercise with a large anaerobic component in combination with a significant aerobic contribution.

2. Reproducibility of the Yo-Yo IR Tests

Several studies have evaluated the reproducibility of the Yo-Yo IR tests. Krustrup et al.[15] observed that performance of the Yo-Yo IR1 test was the same when the test was repeated within a week (1867 ± 72 vs 1880 ± 89m; n = 13), and the coefficient of variation (CV) was 4.9%. In accordance, Thomas et al.[31] measured the test-retest reliability of the Yo-Yo IR1 test in 16 recreationally active subjects and found a correlation coefficient (r) of 0.95 ($p < 0.01$) with CV being 8.7%. Figure 4 shows data for 28 subjects, who have performed two Yo-Yo IR1 tests separated by about 1 week, with r = 0.93 and a CV of 8.1%.

For the Yo-Yo IR2 test, Krustrup et al.[17] found no difference in two tests performed within 1 week (688 ± 46 and 677 ± 47m; $p > 0.05$; n = 29). The intra-individual difference between these tests averaged 1 ± 12m, with a CV of 9.6%. Similarly, Impellizzeri observed a CV of 7.1% based on three Yo-Yo IR2 test performances (590 ± 46, 547 ± 38 and 567 ± 33m) of 12 junior basketball players (Impellizzeri FM, personal communication). Thomas et al.[31] found a CV of 12.7% when testing 17 recreationally active subjects twice within 6 days (325 ± 107 and 339 ± 113m) and Iaia et al. (unpublished observation) detected a significant correlation (r = 0.99; $p < 0.05$; n = 11) between the distances covered during two Yo-Yo IR2 tests performed within a week by trained endurance runners with a CV of 8.5%. Figure 4 shows the relationship (r = 0.97; $p < 0.05$) for 53 subjects with a CV of 10.4%.

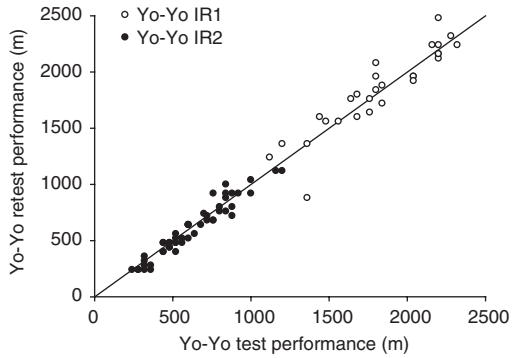

Fig. 4. Test-retest reproducibility of the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) and level 2 (Yo-Yo IR2) tests. The correlation coefficient and coefficient of variation are 0.93 and 8.1% for the IR1 (n = 28), and 0.97 and 10.4% for the Yo-Yo IR2 (n = 53), respectively. The solid line is the line of identity (x = y) [reproduced from Krustrup et al.,[15,17] with permission].

In summary, both tests have reasonably high reproducibility considering that an exhaustive test involves psychological components, which may vary and affect performance differently on a daily basis.

3. Performance of Different Groups of Athletes

Various studies have examined the performance of athletes in the Yo-Yo IR tests. Top-elite male soccer players, playing matches at the highest international level, had a higher performance level on the Yo-Yo IR1 test (2420m; n = 25) than other elite players playing at a lower level (moderate-elite; 2190m; n = 71) and sub-elite players (2030m; n = 89) as well as moderately trained soccer players (1810m; n = 29; figure 5a) [Rossi H, Tschopp M and Tunstall H, personal communication].[8,15,20,22,23,29] Similarly, data were obtained for female soccer players with the performance levels of top-elite, moderate-elite and sub-elite players being 1600 (n = 44), 1360 (n = 74) and 1160m (n = 63), respectively (figure 5b) [Tschopp M and Tunstall H, personal communication].[4,25,26] The latter group had a similar performance as young, high-level female badminton players (aged 21 years: 1200m; and aged 17 years: 1080m; Meibom J, personal communication) and considerably better performance than under 21

years state-level female hockey players (840m; n = 15).[31] The same pattern as for soccer players was observed for male soccer referees (figure 5a; unpublished observation).[13,14,38] Performance of elite rugby players (1656m; n = 23) was less than observed for elite soccer players, with the level of the elite rugby players being almost the same as sub-elite players (1564m; n = 27; figure 5a).[30] Some data also exist for cricket (n = 27) and for recreational individuals (n = 45)[18,31] who clearly have lower values than those observed for soccer and rugby players (figure 5a).

For the Yo-Yo IR2 test, the difference between top-elite (1260m; n = 54; unpublished observation),[24] moderate-elite (1050m; n = 130; unpublished observation),[17,21,27] sub-elite (840m; n = 72; Rossi H, personal communication)[17,25] and moderate-trained male soccer players (n = 57) was greater

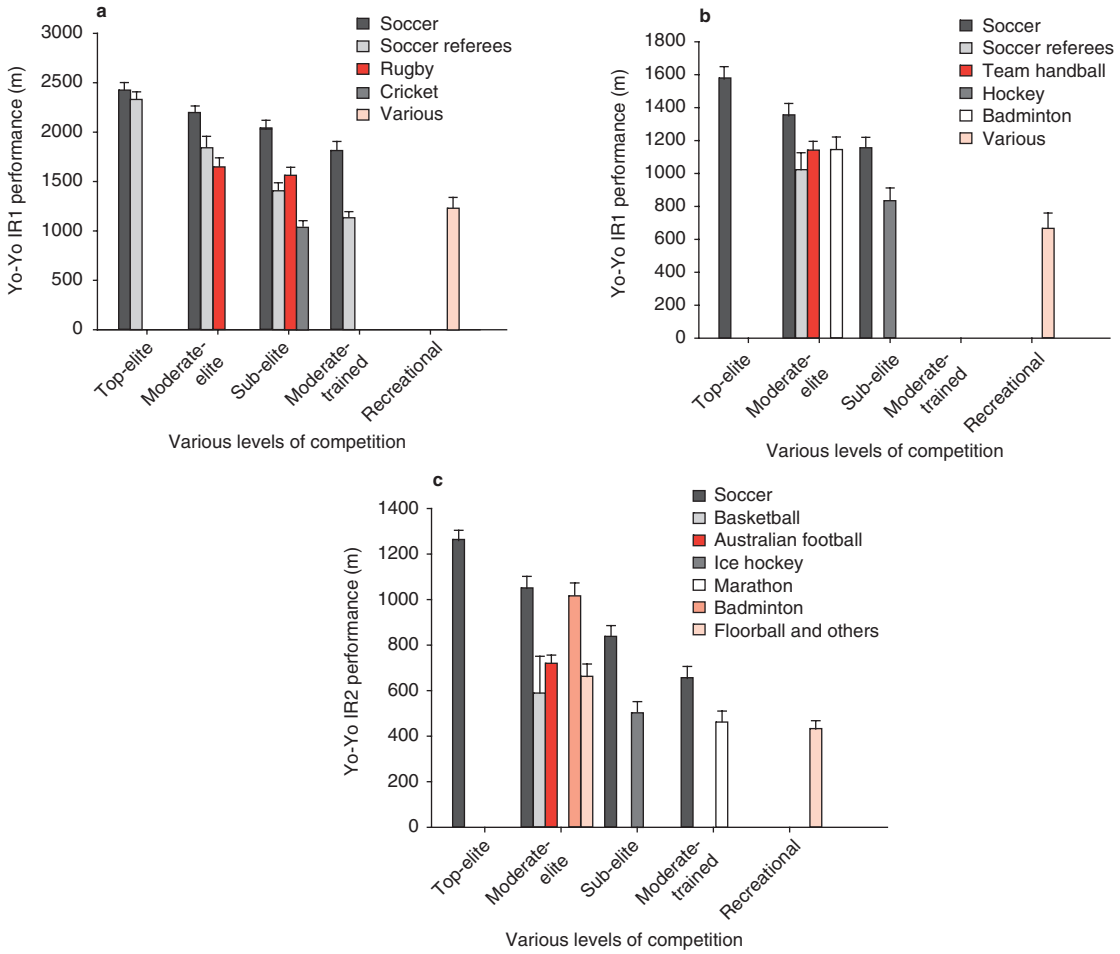

Fig. 5. Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1) performance for (**a**) male and (**b**) female athletes and Yo-Yo IR2 test performance for (**c**) male athletes in relation to their competitive level and to the type of sport practiced. Values are mean ± standard error of the mean. (**a**) Top-elite (n = 12), moderate-elite (n = 31), sub-elite (n = 46) and moderate-trained (n = 83) soccer referees[13,14,38] (unpublished observation). (**b**) Elite badminton players (n = 17; Meibom J, personal communication). Elite soccer referees (n = 10; unpublished observation). Elite team handball players (n = 96; Bencke J, personal communication). Under-21 state-level hockey players (n = 15).[31] Various recreationally active subjects (n = 26; unpublished observation). (**c**) Sub-elite ice-hockey players (n = 13; unpublished observation). Moderate-trained marathon runners (n = 16; unpublished observation).

than for the Yo-Yo IR1 test (20%, 33% and 49% vs 8%, 11% and 25%; figure 5),[17,21,24,25,27,39] illustrating that the ability to perform repeated high-intensity exercise is of great importance in elite soccer, as also observed in match analysis.[4,8] 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.[8] In the Yo-Yo IR2 test, young high-level male badminton players had the same level (1020m; n = 20; unpublished observation) as moderate-elite soccer players, whereas elite Australian football players in the Yo-Yo IR2 test (720m; n = 35)[10,31] had a similar level as sub-elite soccer players (figure 5b). Sub-elite ice-hockey players (510m; n = 13; unpublished observation), elite (n = 13) and recreational floorball players (n = 19) players, as well as 12 junior players of a professional basketball club (590m; Impellizzeri FM, personal communication) had significant lower values. Interestingly, performance of 16 moderately trained marathon runners ($\dot{V}O_{2max}$: 55.6 ± 1.4 mL/min/kg; time of a marathon: 3 hours 12 minutes; unpublished observation) was significantly (81%; $p < 0.01$) below the level observed for sub-elite soccer players, highlighting the specificity of the test to intermittent sports (figure 5c).

In team sports, such as soccer, basketball and rugby, a large variability in the test results within a team is often found. Nevertheless, a certain minimum standard may be set in a sport. For example, in soccer, very few players at an international level had a value below 760m in the Yo-Yo IR2 test,[17] suggesting that such a basic level of fitness is needed to perform at a high level. The differences in performance are to some extent related to the position in the team or rather players are selected to a position in a team due to certain physical characteristics. When comparing the performance on the Yo-Yo IR1 test of soccer players in different positions, a clear picture is given for both females and males (figure 6a). Goalkeepers do not perform as well as outfield players, with central defenders and attackers covering less distance than midfield players and full-backs in the IR1 test.[4,8,15]

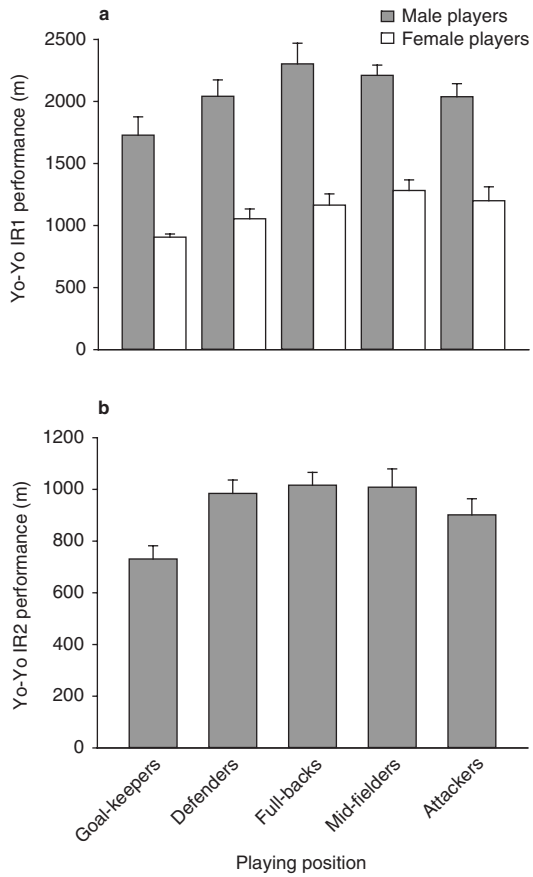

Fig. 6. Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test of male and female soccer players (**a**) and Yo-Yo IR2 performance of male soccer players (**b**) at different playing positions. (**a**) Male players: goalkeepers (n = 5), defenders (n = 58), fullbacks (n = 39), midfielders (n = 75) and attackers (n = 49). Female players: goalkeepers (n = 3), defenders (n = 11), fullbacks (n = 9), midfielders (n = 19) and attackers (n = 12)[4,8,15] [unpublished observation, Rossi H, Tschopp M and Tunstall H, personal communication]. (**b**) Goalkeepers (n = 18), defenders (n = 44), fullbacks (n = 38). Midfielders (n = 92) and attackers (n = 46)[17,21,27] [unpublished observation, Rossi H and Rostgaard T, personal communication]. Values are mean ± standard error of the mean.

For the Yo-Yo IR2 test, no differences between the groups of outfield male soccer players were observed except that the performance of attackers tended to be lower[17,21,27] (figure 6b). The finding of the central defenders being as good as the full-backs and midfield players is in contrast to what has been observed for the Yo-Yo IR1 test (figure 6a), $\dot{V}O_{2max}$[12,40,41] and an incremental treadmill test to

exhaustion.[12,40] This finding indicates that the Yo-Yo IR2 test, with its high rate of anaerobic energy turnover, is better reflecting the work of the central defenders in a soccer game than the other measures. It also shows that the Yo-Yo IR2 test examines an area of intermittent exercise performance, which is not covered in the other tests. Noteworthy, there are significant differences within a category of players, for example, the range of performance on the Yo-Yo IR2 test of elite midfield soccer players was 800–1320m. In rugby, the defenders and midfield players had the same performance in the IR2 test (743 and 747m, respectively), which was slightly higher than for forwards.[10]

A considerable number of young soccer players have performed the Yo-Yo IR tests (Tschopp M, Tunstall H, personal communication).[25] The data presented in figure 7 are mainly soccer players from the youth national teams of New Zealand (Tunstall H, personal communication) and the US.[25] The level of performance in the Yo-Yo IR tests progresses with a corresponding increase in age. At the age of 17–18 years, female athletes had already achieved a Yo-Yo IR1 performance level similar to that obtained by adult female players, which was not the case for male adult soccer players (figure 7). In accordance, the Yo-Yo IR2 test performance of 16-to 17-year-old male players was observed to be about 30% lower than that found for the older elite players in the same club (680 vs 940m, unpublished observation).

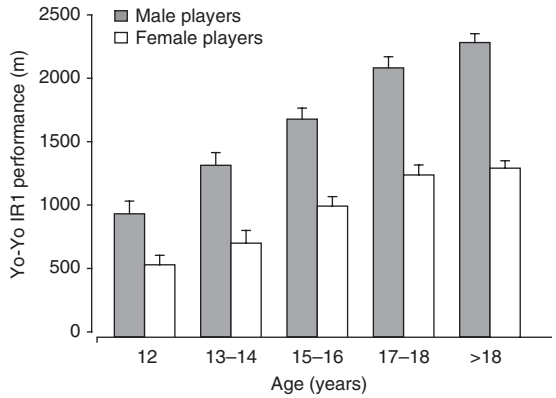

Fig. 7. Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test performance in relation to age (12, 13–14, 15–16, 17–18, >18 years) for male (n = 58, n = 60, n = 94, n = 58, n = 72, respectively)[8,15,20,25] [Tschopp M and Tunstall H, personal communication] and female players (n = 30, n = 58, n = 47, n = 84, n = 114, respectively)[4,25] [unpublished observation, Tschopp M and Tunstall H, personal communication]. Values are mean ± standard error of the mean.

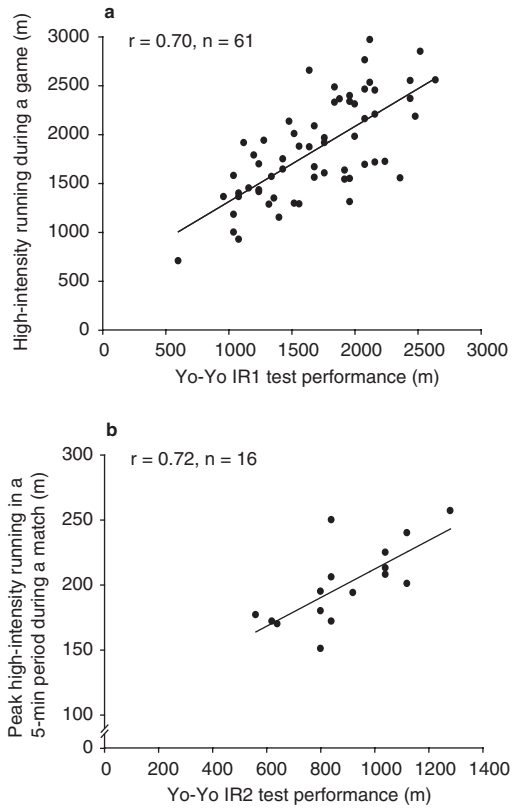

Fig. 8. Relationship between (**a**) the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test performance and the amount of high-intensity running (>15 km/h) during a soccer game ($p < 0.05$) and (**b**) the Yo-Yo IR2 performance and the peak high-intensity distance covered in a 5-minute period during a match for professional soccer players ($p < 0.05$).

In summary, it is clear that not only performance of elite athletes is higher than for non-elite athletes in both Yo-Yo IR tests, but differences are also observed among elite athletes, with the performance level being closely related to the standard of the athletes. The performance of elite athletes in the Yo-Yo IR tests provides information about the physical demands in the sport the athletes are taking part in, and a clear difference is observed between sports. Performing both Yo-Yo IR tests allows a more complete picture about an athlete's characteristics

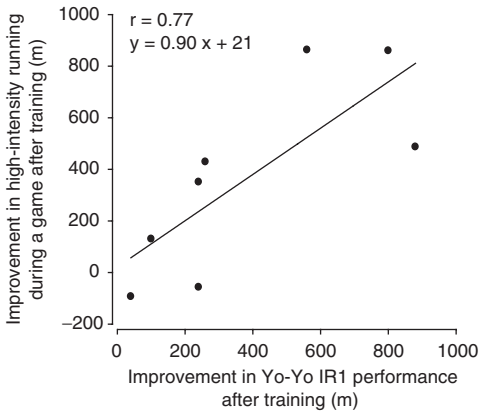

Fig. 9. Relationship between the improvement in Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test performance and the amount of high-intensity running (>15 km/h) of elite referees during a soccer game after a period of intermittent exercise training (n = 8; $p < 0.05$).[14]

and serves as a tool to monitor and evaluate an athlete's development over time.

4. Performance in the Yo-Yo IR Test in Relation to Performance during Competition

Few studies have examined whether there is any relationship between performance of the Yo-Yo IR tests and performance in competition.[4,14,15] It should be emphasized that these types of comparisons are complicated by the fact that in most sports it is difficult to obtain a precise measure of physical performance. Nevertheless, in soccer, a significant correlation was observed between Yo-Yo IR1 performance and the amount of high-intensity exercise for professional players during a game (figure 8a), which has been suggested to be the best measure of endurance performance during a soccer game.[2-4,42] In the study by Krustrup et al.,[4] Yo-Yo IR1 performance of elite female soccer players was also observed to be significantly correlated (r = 0.81; n = 14) with the amount of high-intensity running performed at the end of each half of a game. Thus, the test appears to be useful to evaluate match-related physical capacity of a soccer player. Similarly, a positive relationship between the Yo-Yo IR1 test result and match performance was observed for top-class soccer referees.[14] In addition, for these referees, a 31% increase in performance of Yo-Yo IR1 test after a 12-week training period was associated with a 23% higher amount of high-intensity work during a game as well as a significant reduction in the fall in high-intensity running towards the end of the game. It was also observed that the referees having the greatest improvement in Yo-Yo IR1 performance had the largest training-induced increase

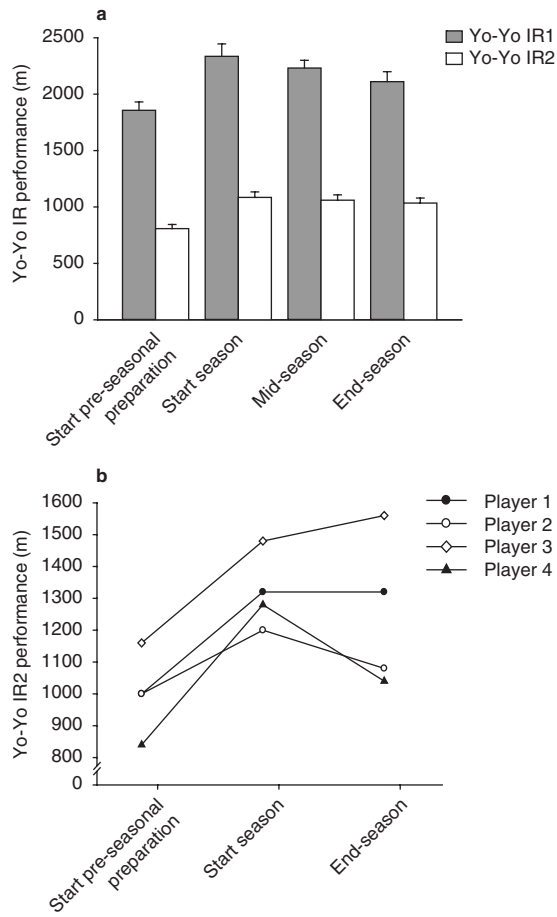

Fig. 10. Mean seasonal changes in (**a**) Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test performance (n = 85, n = 28, n = 56, n = 46, respectively)[15,20,29] [Tunstall H, personal communication] and Yo-Yo IR2 performance (n = 96, n = 42, n = 79, n = 44, respectively)[17,24,27] [unpublished observation, Rostgaard T, personal communication] and (**b**) individual (n = 4) seasonal changes in Yo-Yo IR2. In graph (**a**), values are mean ± standard error of the mean.

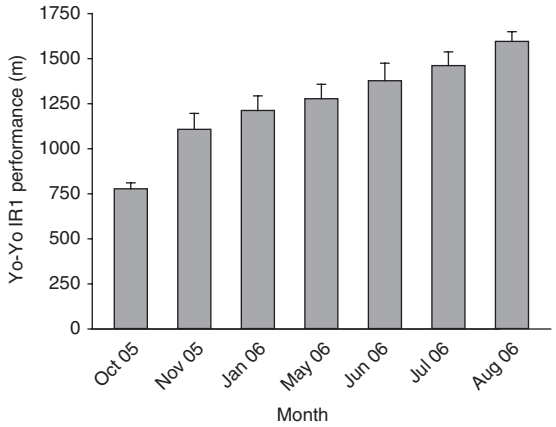

Fig. 11. Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test performance of under 20 years (U20) national female soccer players (n = 17–20) throughout a 1-year period. Start of World Cup (WC) squad selection process (Oct 2005); end of phase 1 development (Nov 2005); end of phase 2 development (Jan 2006); post-qualification – start of WC preparation (May 2006); mid-WC preparation (Jun 2006); late WC preparation (Jul 2006); final squad for U20 WC (Aug 2006) [Tunstall H, personal communication]. Values are mean ± standard error of the mean.

in high-intensity exercise during games (r = 0.77; n = 8; figure 9).

For the Yo-Yo IR2 test, a significant relationship between performance and the highest distance covered in a 5-minute period during a game was observed (figure 8b). It appears logical since the Yo-Yo IR2 test is focusing on evaluating the abilities to perform intense exercise and to recover, which are essential components during the intense periods a game. Nevertheless, these results underline the accuracy of the tests to evaluate these aspects.

In summary, the few studies that have compared the Yo-Yo IR test results with a performance measure during competition, have found a relationship suggesting that each of the tests performance provides valid information about an athlete.

5. Seasonal Changes in Performance

A high number of studies have focused on preseason and seasonal changes in Yo-Yo IR test performance (table I). Summaries of data obtained for male soccer players in our laboratory for the Yo-Yo IR tests are shown in figure 10a. It is clear that the players in both the Yo-Yo IR1 and IR2 tests had a significant (25% and 42%, respectively) improvement in the pre-season test performance as would be expected. Thus, it appears that the players' ability to perform repeated high-intensity exercise was changing considerably and that the test was sensitive enough to detect such alterations. During the season, the levels were, on average, lower. However, it is not possible to generalize since there were major individual variations. Figure 10b shows Yo-Yo IR2 test performance data for four soccer players. All players had an improvement in the pre-season, but there are major differences in the response during the season: one of the players had a slight improvement, one remained stable, whereas two players had a major drop in performance during the season. In another study using the Yo-Yo IR2 test, four players improved their test performance during the season, whereas nine players had a decrease in performance ranging from 40 to 440m.[17] The CV between performance at the start and the end of the season was 14%. These results also illustrate that the Yo-Yo IR tests can detect changes in performance level of the players during the season. A different picture was observed when preparing a national under 20 years female team for the World Cup. Through a 1-year

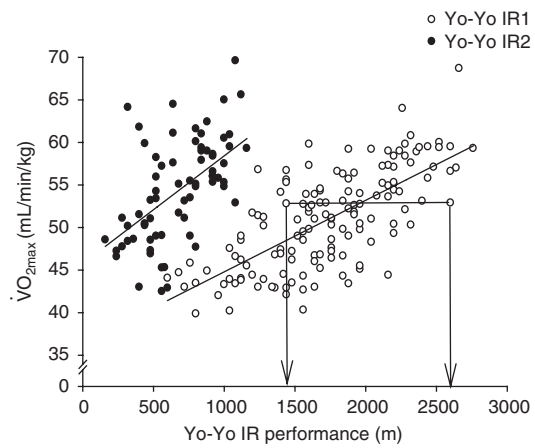

Fig. 12. Individual relationship between maximal oxygen uptake ($\dot{V}O_{2max}$) and performance during the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) [n = 141; r = 0.70; p < 0.05] and Yo-Yo IR2 (n = 71; r = 0.58; p < 0.05) tests. The graph shows individual data points and the regression lines. The two vertical arrows indicate the variation of the Yo-Yo IR1 test performance for a given $\dot{V}O_{2max}$ of 53 mL/min/kg.

Table I. Change in Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) and level 2 (Yo-Yo IR2) test performance as an effect of training/de-training in different sports

Study	n	Sport/level/gender	Training type/protocol/period	Frequency (no. sessions per week)	Duration (no. of weeks)	Yo-Yo IR test		$\dot{V}O_{2max}$ (mL/min/kg)	Change (%)
						distance (m)	performance change (%)		
Yo-Yo IR1									
Barbero Alvarez and Barbero Alvarez[20]	9	Professional male soccer players	Soccer training Pre-season preparation			1875 ± 95	+28*	55.3 ± 1.3[a]	+6.0
Krustrup et al.[15]	10	Elite male soccer players	Soccer training Pre-season preparation	5–7	6	1760 ± 59	+25 ± 6*	51.3 ± 1.1	+7 ± 1*
Unpublished observation	14	Elite male soccer players	Soccer training During competitive season	6	7–8	1883 ± 56	+14.4*		
Tunstall[b]	21	U20 elite male soccer players	Soccer and interval training Tour preparation	3–5	7	2125 ± 52	+12.7*		
	17	U20 elite female soccer players	Soccer and interval training Final World Cup preparation	4	8	1278 ± 80	+24.9*		
Ferrari Bravo et al.[23,39]	13	Sub-elite male soccer players	Interval training (4 × 4 min 90–95% HR_{max} – 3-min rest)[c]	2	7	1846 ± 91	+12.5*	52.8 ± 0.9	+6.6*
	13	Sub-elite male soccer players	Repeated sprint: 3 × (6 × 20 + 20m sprints – 20-sec rest)/3-min rest[c]	2	7	1917 ± 121	+28.1*	55.7 ± 0.6	+5.0*
Krustrup and Bangsbo[14]	10	Elite male soccer referees	Intermittent training (run >90% HR_{max})	3–4	12	1345 ± 62	+31.1*	46.5 ± 1.7	+3.4
Weston et al.[38]	12	Top-class male soccer referees	Intermittent high-intensity training (85–95% HR_{max})	3	68–70	1720 ± 80	+35.5*		
	7	Elite male soccer referees	Intermittent high-intensity training (85–95% HR_{max})	3	68–70	1290 ± 154	+53.9*		
Yo-Yo IR2									
Hasegawa[24]	16	Professional male football players	Daily football practice		10	717 ± 33	+52.3*		
Krustrup et al.[17]	20	Sub-elite male soccer players	End of season/de-training after summer holidays	0–1	4	873 ± 43	−11 ± 5*		
	15	Elite male soccer players	Soccer training Pre-season preparation	5–7	8	730 ± 41	+42 ± 8*		
Unpublished observation	10	Elite male soccer players	Soccer training Pre-season preparation	6–7	6	1116 ± 62	+13.5*		
McHughes et al.[27]	16	Professional male soccer players	Soccer training Pre-season preparation			911 ± 58	+18.4*		

Continued next page

Table I. Contd

Study	n	Sport/level/gender	Training type/protocol/period	Frequency (no. sessions per week)	Duration (no. of weeks)	Yo-Yo IR test distance (m)	Yo-Yo IR test performance change (%)	$\dot{V}O_{2max}$ (mL/min/kg)	Change (%)
Rostgaard[b]	14	Elite male soccer players	Soccer training Mid-season rebuilding	6	5	849 ± 33	+31.7*		
	12	Elite male soccer players	Soccer training Pre-season preparation	5–7	5	880 ± 45	+26.1*		
Iaia et al.[32]	8	Trained male endurance runners	Speed endurance: 8–12 × 30-sec run ~95% vmax, 3-min rest	3	4	440 ± 58	+19.0*	55.3 ± 1.8	−2.2
Mohr et al.[43]	6	Healthy active males	Sprint training: 15 × 6-sec runs at 95% vmax, 1-min rest	3–5	8	520 ± 54	+9.9*	51.9 ± 2.7	+0.9
	7	Healthy active males	Speed endurance: 8 × 30-sec runs 130% $\dot{V}O_{2max}$ − 90 sec rest	3–5	8	483 ± 61	+28.7*	49.0 ± 1.6	+2.4

a Estimated $\dot{V}O_{2max}$.

b Personal communication.

c Training carried out during competitive season.

HR_{max} = maximal heart rate; **U20** = under 20 years; **vmax** = maximal speed achieved during a 30-sec[32] and a 6-sec[43] all-out running effort; **$\dot{V}O_{2max}$** = maximal oxygen uptake; * indicates significant difference from pre-training level ($p < 0.05$).

period, the team had a progressive improvement in Yo-Yo IR1 test performance (figure 11; Tunstall H, personal communication), mainly due to more focus on the fitness training and probably also reflecting that the starting level of the female players was low.

Studies have frequently used the Yo-Yo IR tests to evaluate the effect of a training period or a detraining period. After a 6- to 8-week training period focusing on aerobic high-intensity or speed endurance training,[34] most studies found a 15–35% and 15–45% improvement in the Yo-Yo IR1 and IR2 test performance, respectively, as shown in table I.

In summary, athletes in team sports show large improvements in Yo-Yo IR test performance during the pre-season; whereas during the season, varying responses are observed within a team. The Yo-Yo IR tests can effectively evaluate changes in performance and identify athletes for whom fitness training should be a priority.

6. Relationship Between the Yo-Yo IR Tests and Maximal Oxygen Uptake

An often asked question is whether $\dot{V}O_{2max}$ can be estimated from the Yo-Yo IR test results. Based on analysis of 141 subjects, a significant correlation ($p < 0.05$) was obtained between Yo-Yo IR1 and $\dot{V}O_{2max}$ with a correlation factor of $r = 0.70$ (figure 12). Correspondingly, a significant relationship ($p < 0.05$) was obtained for Yo-Yo IR2 ($r = 0.58$; $n = 71$; figure 12). Thus, theoretical $\dot{V}O_{2max}$ can be estimated for both the Yo-Yo IR1 and Yo-Yo IR2 test from the following equations, respectively:

Yo-Yo IR1 test:

$$\dot{V}O_{2max}\ (mL/min/kg) = IR1\ distance\ (m) \times 0.0084 + 36.4$$

Yo-Yo IR2 test:

$$\dot{V}O_{2max}\ (mL/min/kg) = IR2\ distance\ (m) \times 0.0136 + 45.3$$

However, the relationship between the Yo-Yo IR tests and $\dot{V}O_{2max}$ represented a scattered picture (figure 12). For example, individuals with almost the same $\dot{V}O_{2max}$ of 53 mL/min/kg had a range of Yo-Yo IR1 test performance of 1450–2600m as indicated in figure 12. Thus, the estimation of

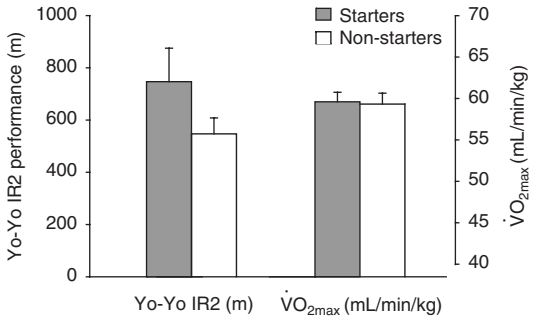

Fig. 13. Yo-Yo intermittent recovery level 2 (Yo-Yo IR2) test performance and estimated maximal oxygen uptake ($\dot{V}O_{2max}$) in professional starters (n = 12) and non-starters (n = 4) in Australian football.[10]

$\dot{V}O_{2max}$ from the IR test results is not accurate. This is to be expected, since the Yo-Yo tests are to a great extent also evaluating the anaerobic response during exercise as well as recovery processes. Thus, the test is better reflecting the ability to perform repeated intense exercise than $\dot{V}O_{2max}$.[14,15,23,32,39,43] It is also illustrated by the observation that $\dot{V}O_{2max}$, in contrast to the Yo-Yo IR1 test, was not correlated with the amount of high-intensity exercise during a soccer match.[15] That the Yo-Yo tests are more specific for intermittent sports is also supported by an interesting finding by Young et al.[10] studying Australian football players. They observed that there was no difference in $\dot{V}O_{2max}$ between those players starting in the team and the substitutes, but performance on the Yo-Yo IR2 test of the regular players was 37% better than for the substitutes (figure 13). Generally, too much focus has been on the need of obtaining $\dot{V}O_{2max}$ determinations of individuals, since the measure only to a limited extent expresses a person's working capacity. In accordance, it has been observed that the Yo-Yo IR tests provide more sensitive measures of change in performance in intermittent sports than $\dot{V}O_{2max}$. Thus, a considerable number of studies have demonstrated much greater changes in IR test performance compared with change in $\dot{V}O_{2max}$ (figure 14).[14,20,23,32,39,43] For example, a study of endurance runners improved their Yo-Yo IR2 test performance by 18% and the time to fatigue during a repeated supra-maximal treadmill run to exhaustion by 25% after 4 weeks of intense intermittent exercise training, without any change in $\dot{V}O_{2max}$.[32] It should also be added that $\dot{V}O_{2max}$ determinations are time consuming and expensive. In contrast, the Yo-Yo tests can be operated rapidly at low cost, for example, 30 athletes can be tested in <20 minutes by using only three markers and a compact-disc player.

In summary, after a period of training in team sports, changes in performance of the Yo-Yo IR tests are considerably greater than those observed for $\dot{V}O_{2max}$, and the Yo-Yo test results are more accurately reflecting alterations in the ability to perform repeated intense exercise.

7. Non-Exhaustive Testing

Some individuals (e.g. elderly people and injured athletes during rehabilitation) may not be able to complete a Yo-Yo IR test. For such subjects and for frequent testing, useful results can be obtained by performing a non-exhaustive (submaximal) version of the IR tests, i.e. the subject is running a given time, with heart rate response as a measure of capacity. The advantage of not forcing the athletes to work to exhaustion must be weighed against the disadvantage that equipment for the measurement of heart rate is needed.

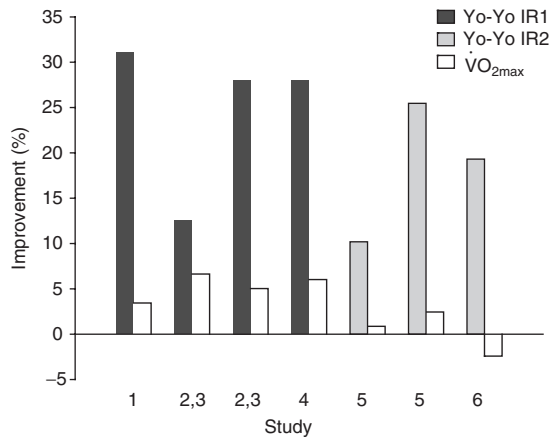

Fig. 14. The effect of different types of training on the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) and Yo-Yo IR2 test performance as well as maximal oxygen uptake ($\dot{V}O_{2max}$). Data from Krustrup et al.[14] (study 1); Ferrari Bravo et al.[23,39] (studies 2 and 3); Barbero Alvarez and Barbero Alvarez[20] (study 4); Mohr et al.[43] (study 5); Iaia et al.[32] (study 6).

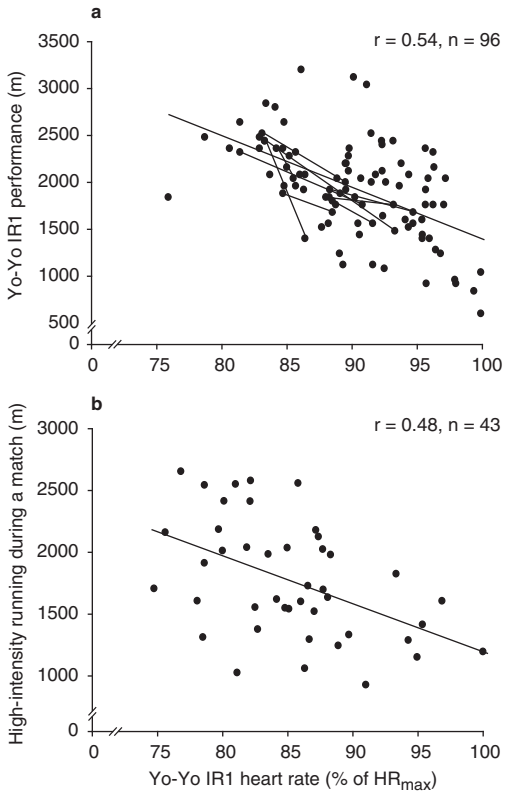

Fig. 15. The relationship between heart rate after 6 minutes in the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test, expressed as a percentage of individual maximal values and (**a**) the Yo-Yo IR1 performance ($p < 0.05$) as well as heart rate after 5 minutes in the Yo-Yo IR1 test expressed as a percentage of individual maximal values, and (**b**) the amount of high-intensity running (>15 km/h) during a game ($p < 0.05$). In (**a**), values for the same subject obtained at different times are connected. **HR_{max}** = maximal heart rate.

The heart rate, expressed as a percentage of individual maximal values obtained after 6 minutes of the Yo-Yo IR1 test, has been observed to be inversely correlated to the performance of the Yo-Yo test (figure 15a, unpublished observations). Such a relationship was not established after 3 minutes. These findings suggest that the test can provide information about the capacity of an individual, if the test is of sufficient duration. That heart rate measurements can be utilized is supported by the observation that the heart rate, expressed as a percentage of maximal heart rate, during the Yo-Yo IR1 test was inversely related to work performed at a high intensity during a soccer game (figure 15b). In accordance, for 17 Danish elite soccer players, the heart rate values were consistently higher throughout a Yo-Yo IR1 test performed at the start of the pre-season compared with the start of the competitive season (6 minutes: 10 ± 2 beats/min or 6%; figure 16).[15] Similarly, heart rate of the Danish National soccer players preparing for EURO2004 was significantly higher at the start of the preparation period compared with after 2 and 4 weeks of preparation.[44] Collectively, these observations suggest that heart rate measurements during a submaximal version of the Yo-Yo IR1 test provide useful information about the fitness level of an individual.

8. Conclusions

The Yo-Yo IR1 test evaluates an individual's ability to repeatedly perform intermittent exercise with a high aerobic component towards the end of the test; whereas during the Yo-Yo IR2 test, both the aerobic and anaerobic energy systems are highly taxed. Both evaluate the individual's ability to recover from intense exercise.

A number of studies have shown the sensitivity of the Yo-Yo tests in discriminating players' performance at various competitive levels, between different playing positions, and after periods of dif-

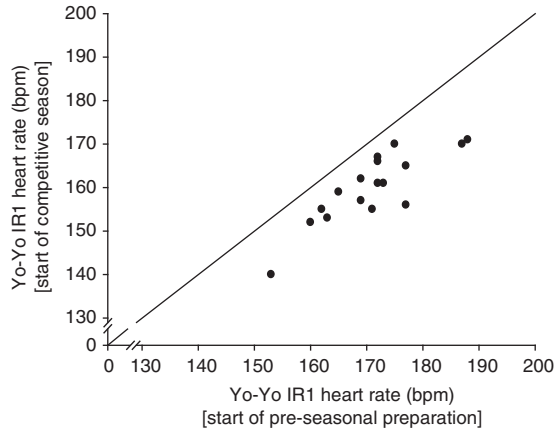

Fig. 16. Heart rate after 6 minutes of the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test, expressed in beats per minute (bpm), at the start of pre-seasonal preparation and at the start of the competitive season for 17 Danish elite soccer players. The solid line is the line of identity (x = y).[15]

ferent types of training. In addition, their reliability and validity are well known and strong correlations were found, for example, between Yo-Yo test performance and the amount of high-intensity running during a soccer game, which was not the case for other tests such as repeated sprint tests, a $\dot{V}O_{2max}$ test or the Legér multistage fitness test.

The Yo-Yo IR tests can be used to determine an athlete's ability to perform intense intermittent exercise. Sports characterised by intermittent exercise can examine seasonal changes in athlete physical capacity in a simple and effective manner.

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