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Physiological and Performance Test Correlates of Prolonged, High-Intensity, Intermittent Running Performance in Moderately Trained Women Team Sport Athletes

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Abstract. Sirotic, A.C., and A.J. Coutts. Physiological and performance test correlates of prolonged, high-intensity, intermittent running performance in moderately trained women team sport athletes. *J. Strength Cond. Res. 21(1):138–144. 2007.*—A large number of team sports require athletes to repeatedly produce maximal or near maximal sprint efforts of short duration interspersed with longer recovery periods of submaximal intensity. This type of team sport activity can be characterized as prolonged, high-intensity, intermittent running (PHIIR). The primary purpose of the present study was to determine the physiological factors that best relate to a generic PHIIR simulation that reflects team sport running activity. The second purpose of this study was to determine the relationship between common performance tests and the generic PHIIR simulation. Following a familiarization session, 16 moderately trained ($\dot{V}O_2max$ = 40.0 ± 4.3 ml·kg^{-1}·min^{-1}) women team sport athletes performed various physiological, anthropometrical, and performance tests and a 30-minute PHIIR sport simulation on a nonmotorized treadmill. The mean heart rate and blood lactate concentration during the PHIIR sport simulation were 164 ± 6 b·min^{-1} and 8.2 ± 3.3 mmol·L^{-1}, respectively. Linear regression demonstrated significant relationships between the PHIIR sport simulation distance and running velocity attained at a blood lactate concentration of 4 mmol·L^{-1} (LT) ($r = 0.77$, $p < 0.05$), 5 × 6-second repeated cycle sprint work ($r = 0.56$, $p < 0.05$), 30-second Wingate test ($r = 0.61$, $p < 0.05$), peak aerobic running velocity (V_{max}) ($r = 0.69$, $p < 0.05$), and Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) distance ($r = 0.50$, $p < 0.05$), respectively. These results indicate that an increased LT is associated with improved PHIIR performance and that PHIIR performance may be monitored by determining Yo-Yo IR1 performance, 5 × 6-second repeated sprint cycle test work, 30-second Wingate test performance, V_{max}, or LT. We suggest that training programs should focus on improving both LT and V_{max} for increasing PHIIR performance in moderately trained women. Future studies should examine optimal training methods for improving these capacities in team sport athletes.

Key Words. lactate threshold, match simulation, Yo-Yo test

Introduction

Most team sports require athletes to regularly repeat short high-intensity bouts of exercise, interspersed with longer intervals of submaximal exercise over a prolonged period of time (i.e., ≥30 minutes) (26). This type of activity can be characterized as prolonged, high-intensity, intermittent running (PHIIR). To date, relatively little research has examined the physiological capacities that are related to improved PHIIR. Similarly, there are few data on the validity of performance tests as a means of monitoring adaptation to training for team sport athletes who undertake PHIIR (17).

Most of the previous studies that have examined the relationships between physiological measures, performance test measures, and PHIIR performance have used time and motion analysis during competitive match play to measure criterion PHIIR performance (2, 6–8, 18, 22). Unfortunately, the use of time and motion analysis as the criterion measure of running performance during team sport matches is limited, because this measurement method usually has relatively low levels of test-retest reliability (12). In addition, others have reported that the relationships between physiological factors, performance test results, and running performance measures from time and motion analysis may be spurious, because running patterns during competitive match play may be affected by the influence of the opposition, weather, team tactics, match score, or the referee during a competitive match (8, 24, 25). Combined, these factors suggest that a more accurate measure of the relationships between physiological and performance test measures with PHIIR is required.

The recent development of a PHIIR sport simulation specific to the work demands of most team sports (1, 11) and the earlier development of a nonmotorized treadmill (NMT) (19) now allows scientists to replicate a field game in a research laboratory. This development is very significant, because the NMT ergometer permits a more accurate measurement of running performance and also has the ability to control the experimental conditions (11). At present, the NMT is the only known ergometer that allows an almost instantaneous change of speed, near-maximal running speed (19), and any decline in power output to be detected with the onset of fatigue (9). These characteristics of the NMT are vital for a valid replication of PHIIR demands during team sport match play and allow for accurate measurement of PHIIR in a laboratory.

Although previous studies have examined the relationships between physiological components, performance tests, and PHIIR performance on elite-level male athletes (2, 6–8, 22), to date there have been relatively few studies conducted that have examined these relationships for female team sport athletes (18, 22). Krustrup et al. (18) recently demonstrated that high-intensity running during soccer match play was related significantly to maximal pulmonary oxygen uptake ($\dot{V}O_2max$), running speed at 2 mmol·L^{-1} blood lactate concentration ([BLa$^-$]), and

TABLE 1. Subject physical characteristics (mean ± *SD*).

	Age (y)	Body mass (kg)	Height (cm)	Σ9 skinfolds (mm)	$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})
Mean	20.9 ± 1.8	59.7 ± 9.3	162.6 ± 7.2	121.7 ± 40.3	40.0 ± 4.3
Range	16.0–23.0	41.6–82.0	151.4–172.5	75.0–211.9	32.9–45.9

performance during level 1 of the Yo-Yo Intermittent Recovery (Yo-Yo IR1) test, respectively, in 14 elite women soccer players. In addition, this study also demonstrated that total distance covered during the 90-minute soccer match was significantly related to running speed at 2 mmol·L^{-1} blood lactate and Yo-Yo IR1 performance. Interestingly, no relationship was found between total distance covered during the 90-minute soccer match and $\dot{V}O_2$max. These findings show that measures of aerobic fitness are important for PHIIR during elite soccer match play in women; however, the relationship between other fitness measures such as anaerobic capacity has not yet been determined.

To our knowledge, no research has attempted to determine the relationship between physiological variables, performance tests, and PHIIR performance using an NMT simulation specific to team sport energetic requirements (i.e., running for ≥30 minutes) in a controlled environment. Therefore, the primary purpose of the present study was to determine the physiological factors that best relate to a generic PHIIR simulation that reflects team sport running activity. The second purpose of this study was to determine the relationship between common performance tests and the generic PHIIR simulation in a group of moderately trained women team sport athletes.

METHODS

Experimental Approach to the Problem

At present, there is limited information on the physiological capacities that allow for improved performance in women's team sports that require PHIIR. This study examined the relationship between a battery of various common physiological and performance test measurements in a group of moderately trained women team sport athletes with a criterion standard PHIIR performance test on an NMT. Linear regression analysis allowed us to evaluate the relationship between the various physiological factors and practical performance tests and team sport running performance. Based on the findings of previous studies that have examined PHIIR sports performance in elite women soccer players using time and motion analysis, we hypothesized that $\dot{V}O_2$max (18) and lactate threshold (LT) (18) would be the best physiological determinants related to PHIIR performance. Furthermore, we also hypothesized that the Yo-Yo IR1 performance would correlate also with PHIIR performance.

Subjects

Sixteen moderately trained ($\dot{V}O_2$max = 40.0 ± 4.3 ml·kg^{-1}·min^{-1}) women team sport athletes participated in this study. Subjects were all regional-level team sport athletes in their chosen sport (9 touch football, 2 soccer, 3 netball, and 2 field hockey). Table 1 shows subject physical characteristics. Prior to the commencement of the study, all participants received a clear explanation of the study informing them of all risks and benefits associated with participation, and informed consent was obtained by players and a legal guardian where required. Ethical approval was granted by the University Human Research Ethics Committee for all experimental procedures.

Training History

To be eligible for inclusion in this study, all subjects were required to have been training and competing on a regular basis in at least a regional-level team-based field sport competition for a minimum of 12 months prior to testing. All subjects were in the competitive phase of the training season while undergoing all testing procedures. In the 3 weeks prior to testing, all subjects completed a daily training diary that included daily measures of training duration (minutes) and a global rating of perceived exertion (10-grade scale) (16). Training loads were calculated from the diary measures using Foster's session rating of perceived exertion method (16). Table 2 shows the weekly and total training duration and training loads for the 3-week period. In the 3-week period, all subjects completed a team training session either once or twice a week. In addition to team training, all subjects completed 2–4 physical training sessions a week that consisted of interval training, distance running, and weight training. Each subjects also participated in a competitive match once a week in her respective sport.

Experimental Procedures

Research Design. All subjects completed the following tests during the study: a direct measurement of maximal oxygen consumption ($\dot{V}O_2$max); a 5 × 6-second repeated sprint ability (RSA) cycle test; a 10-second maximal cycle sprint; a 30-second Wingate cycle test, a 30-minute PHIIR sport simulation on an NMT and a Yo-Yo IR1 test. The $\dot{V}O_2$max test was carried out on visit 1; the 5 × 6-second RSA cycle, 10-second maximal cycle sprint, and 30-second Wingate cycle tests were performed on visit 2; the 30-minute PHIIR sport simulation on visit 3; and the Yo-Yo IR1 test on visit 4. There were at least 2 days for recovery between each visit.

Each subject was asked to standardize their diet and to complete only low-volume, low-intensity training in the 24 hours prior to all testing sessions. In the week prior to commencement of the testing sessions, all subjects were screened for contraindications to exercise and gave informed consent. In this same week, all subjects completed familiarization of all laboratory tests and the Yo-Yo IR1 test. Familiarization was completed to minimize the learning effect associated with performing the testing

TABLE 2. Mean (± *SD*) weekly training load and duration for the 3-week period prior to testing.*

Week	Training load (AU)	Training duration (h)
1	1,135 ± 162	4.8 ± 0.7
2	1,174 ± 150	4.4 ± 0.6
3	1,754 ± 190	5.1 ± 0.9
Total	4,063 ± 189	14.4 ± 0.8

* AU = artibrary units.

procedures for the first time. Anthropometric measures of height, body mass, and skinfolds were measured during the familiarization session.

Maximal Oxygen Uptake. Each subject completed a $\dot{V}O_2$max test that involved a discontinuous, incremental treadmill run to exhaustion. The test was completed on a motorized treadmill (Startrac 4500, Star Tracer, Irvine, CA). Maximal oxygen uptake was measured using open-circuit spirometry (Physio-Dyne Gas Analysis System, Quogue, NY), which was calibrated before and after each test with reference and calibration gases of known concentrations according to the manufacturer's specifications. The pneumotach was calibrated with ambient air using a 3-L syringe (Hans Rudolph, Kansas City, MO).

Following a 5-minute warm-up at 7 km·h^{-1}, the protocol commenced at the same workload of 7 km·h^{-1}. The treadmill speed was increased by 1.5 km·h^{-1} every 4 minutes until a [BLa$^-$] of 4 mmol·L^{-1} was reached. At the completion of every 4-minute stage, each subject had a 1-minute rest period to allow for collection of [BLa$^-$], heart rate (HR), and rate of perceived exertion. Once [BLa$^-$] reached 4 mmol·L^{-1}, the speed was increased by 0.5 km·h^{-1} every minute until volitional fatigue. The maximal oxygen uptake was considered to be the highest oxygen volume (30-second average) recorded during the last minute of exercise. The criteria for attaining $\dot{V}O_2$max included any 2 of the following: (a) volitional exhaustion; (b) a respiratory exchange ratio equal to or greater than 1.15; and (c) a plateau in oxygen consumption (increase $<$2 ml·kg^{-1}·min^{-1}) with increased exercise intensity. The reliability of $\dot{V}O_2$max measures for this laboratory was previously determined to be acceptable (technical error of measurement [*TEM*] = 1.4 ml·kg^{-1}·min^{-1}, *TEM%* = 2.7, and intraclass correlation coefficient [ICC] = 0.96). The peak running velocity during the $\dot{V}O_2$max test (V_{max}) was determined as the highest treadmill speed maintained for a complete minute. In this study, all participants reached V_{max} at the lowest treadmill speed at which $\dot{V}O_2$max was elicited. The intersession reliability of V_{max} in this laboratory using this protocol was *TEM* = 0.4 km·h^{-1} or *TEM%* = 2.4, and ICC = 0.97.

Lactate Threshold. LT was determined using the [BLa$^-$], HR, velocity, and oxygen consumption data collected from the discontinuous incremental treadmill run to exhaustion. These data ([BLa$^-$], HR, velocity, and oxygen consumption) were then input into the Lactate Analysis macro add-in program in Microsoft Excel (SASI, South Australian Institute of Sport, Adelaide, Australia), which calculated LT as the running velocity at a [BLa$^-$] of 4 mmol·L^{-1}. The reliability for this method of LT measurement for this laboratory was previously determined to be moderate (*TEM* = 0.8 km·h^{-1}, *TEM%* = 5.9, and ICC = 0.80).

Blood Buffering Capacity. Blood buffering capacity (β_{blood}) was determined from 100-μl capillarized blood samples taken from the subject's fingertip using the iSTAT Portable Clinical Analyzer (Abbott Diagnostics iSTAT Corporation, East Windsor, NJ) both at rest and following the completion of the discontinuous, incremental treadmill run to exhaustion. Blood buffering capacity was determined from the relationship between [BLa$^-$] and pH (4). Expressed in units called *slykes* (mmol·L^{-1}·pH unit), β_{blood} was defined as the increase in [BLa$^-$] corresponding to a decrease in pH of 1.0 unit. The equation for calculating β_{blood} is shown below:

$$\beta_{blood} = [BLa^-]_{post} - [BLa^-]_{pre}/[pH]_{b,post} - [pH]_{b,pre}$$

Reliability trials for the determination of β_{blood} previously determined in our laboratory was *TEM* = 16.3 slykes, *TEM%* = 9.7%, and ICC = 0.71.

5 × 6-Second RSA Cycle Test. The 5 × 6-second RSA cycle test was chosen because it contained a minimal skill component and, therefore, could provide a good measure of physiological work during repeated sprint bouts. The 5 × 6-second RSA cycle test was performed according to the methods of Bishop et al. (5). After a 5-minute warm-up (cycling at a constant load of approximately 90–100 W followed by 3 practice sprint starts), each participant completed a 10-second maximal sprint test on a magnetically braked cycle ergometer (SRM Indoor Trainer, Königskamp, Germany). The total work recorded in the first 6 seconds of the 10-second maximal sprint was used as the criterion score during the subsequent 5 × 6-second RSA cycle test. Upon completion of the 10-second maximal sprint test, subjects rested for 5 minutes before performing the 5 × 6-second RSA cycle test. All sprints were performed in the standing position. RSA work was defined as the total amount of work (kJ) performed in all 5 sprints combined. This test has previously been reported to be both a valid (5) and reliable (15) test of RSA.

30-Second Wingate Cycle Test. The Wingate cycle test consisted of a 30-second 'all-out' cycle sprint on a magnetically braked cycle ergometer (SRM Indoor Trainer). This test was used to determine the anaerobic capacity of each subject and included very little skill or learning effect. Subjects performed the 30-second Wingate cycle test 20 minutes after the completion of the 5 × 6-second RSA cycle test. Five seconds prior to the commencement of the sprint, subjects were instructed to assume the ready position and await the start signal. Upon commencement of the test, the subject was instructed to cycle at a maximal rate for 30 seconds with the buttocks off the cycle seat. Anaerobic work was defined as the total amount of work (kJ) performed in the 30-second period.

PHIIR Sport Simulation. The 30-minute PHIIR sport simulation (2 × 15-minute periods) used in the present study was based on time and motion analysis studies of various PHIIR sports such as soccer, field hockey, rugby union, and rugby league (3, 13, 21, 25, 28). Two 15-minute activity profiles were performed succinctly throughout the PHIIR sport simulation. Included in these activity profiles were 6 running speeds: standing still (0% of maximal sprint speed [MSS]), walking (20% of MSS), jogging (35% of MSS), running (50% of MSS), fast running (70% of MSS), and sprinting (100% of MSS). These 6 movement categories were divided into aerobic and anaerobic activities based on the intensity of the movement. Aerobic activities consisted of standing, walking, jogging, and running, whereas anaerobic activities included fast running and sprinting. Based on the contribution of aerobic and anaerobic metabolism utilized in an actual sport match (17, 23), the aerobic-to-anaerobic ratio for the activity profile, with respect to time for this protocol, was 9.5:1. The 6 movement categories (stand, walk, jog, run, fast run, and sprint) also were designated a particular duration based on time and motion data from team sports (17). The time duration assigned to each movement category is displayed in Table 3. The percentage of total time spent in each movement category and the activity changes that occurred during the PHIIR sport simulation also are shown in Table 3.

Customized software then was used to randomize the movement duration data so that a set protocol that replicated the general running demands of a team sport

TABLE 3. The time duration, percentage of total time designated to each movement category, and the frequency of changes in activity for the 30-minute prolonged, high-intensity, intermittent running sport simulation.

Category	Duration of each activity (s)	Time spent in each activity (%)	Activity changes
Stand	8	17	29
Walk	8	34	44
Jog	8	27	50
Run	6	13	31
Fast run	4	4	12
Sprint	3	5	18
Total			184

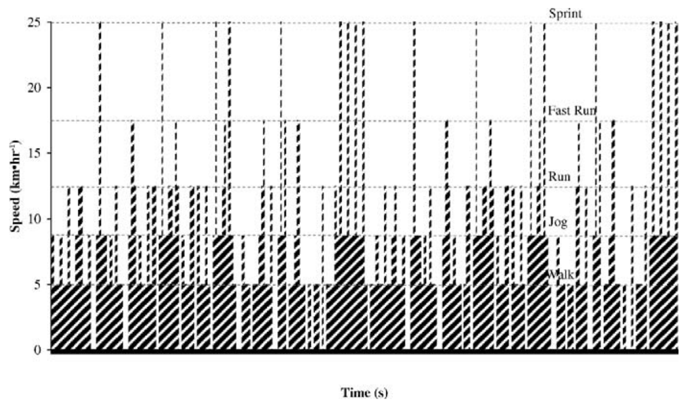

FIGURE 1. The 30-minute prolonged, high-intensity, intermittent running activity profile for a participant with a maximal speed of 25 km·h^{-1}. Two 15-minute periods were completed with 2 minutes recovery after completion of the first 15-minute activity profile.

match was created. The software was programmed with specific rules so that the running sequences replicated the specific movement patterns that occur during team sport match play. For example: (a) each sprint would always be preceded and followed by a jog; (b) a maximum of 3 individual movements could be grouped consecutively (i.e., 3 jogs in a row), to simulate the stop-start nature of team sport match play by avoiding excessively long periods without a change in speed; and (c) there would be a set number of 3- and 6-second sprints, which replicates the duration of sprints in typical PHIIR match play, where the majority of sprints last between 1 and 3 seconds (3, 13, 21, 28).

A 4 × 6-second RSA test, separated by 16 seconds of jogging, was incorporated at the end of the two 15-minute activity profiles. This 4 × 6-second RSA test was used to assess a bout of repeated sprints in a prefatigued state during PHIIR performance. The ability to repeat sprints or high-intensity activities is considered vital to the outcome of a PHIIR match, because most of these activities are associated with important events during a match (28). The result was two 15-minute activity profiles that comprised 93 and 91 activity changes, respectively (184 activity changes during the 30-minute PHIIR sport simulation). Figure 1 shows the activity profile for a participant with a maximal sprinting speed of 25 km·h^{-1}.

All subjects completed the PHIIR sport simulation (2 × 15-minute periods) on an NMT (Woodway Force 3.0 Treadmill, Waukesha, WI). To avoid intersubject variability, subjects completed a peak speed assessment using the methods of Abt et al. (1) to determine the speed of each movement category (stand, walk, jog, run, fast run, sprint). Subjects completed 3 maximal 6-second sprints separated by 2 minutes of active recovery. Each speed category (stand, walk, jog, run, fast run, sprint) was then determined relative to each participant's MSS. A speed chart displaying target speed was placed at eye level for each subject to follow the activity profile. The athlete's current speed was shown on the visual display unit. A computer-generated audio signal was used to instruct subjects to change speed using an IBM-compatible personal computer. Three audible tones were played, starting 3 seconds prior to the change in speed. Immediately following the third tone, a recorded voice was played that informed the participant of the upcoming speed. Equal verbal encouragement was given to each subject to sprint as fast as possible when required and to ignore the display screen. At all other times, each subject was verbally instructed to match her speed with the target speed displayed.

Treadmill running-belt velocity, distance, and horizontal forces measured during each PHIIR sport simulation were collected at a sampling rate of 10 Hz via the XPV7 PCB interface (Fitness Technology, Adelaide, Australia) and were analyzed using Force 3.0 software (Innervations, Joondalup, Australia). Collected data then were exported to Microsoft Excel to be synchronized with the PHIIR sport simulation starting time. The data then were reduced to 1-second averages (i.e., for each second, the mean of 10 samples was used). Both the total distance and sprint distance covered during the PHIIR sport simulation were then determined. Reliability trials of the total distance covered during the PHIIR sport simulation previously determined in our laboratory revealed that *TEM* = 68.0 m, *TEM%* = 2.0, and ICC = 0.74. Similarly, the intersession reliability of sprint distance covered during the PHIIR simulation previously determined in our laboratory was *TEM* = 11.3 m, *TEM%* = 2.7, and ICC = 0.93.

Physiological Responses to the PHIIR Sport Simulation. Mean HR during the PHIIR sport simulation was measured using Polar Vantage NV recordable HR monitors (Polar Electro Oy, Kempele, Finland) and analyzed with the Polar Precision Performance SW version 4.02 HR analysis software package (Polar Electro Oy).

Blood lactate concentrations were determined from 25-μl capillarized blood samples taken from hyperemic fingertips collected in heparinized capillary tubes. Samples were drawn from all subjects every 5 minutes during and immediately following the PHIIR sport simulation. All samples were taken with subjects in a standing position and were analyzed by an Accusport Portable Lactate Analyzer (Boehringer Mannheim, Mannheim, Germany) immediately following each sample being taken. The Accusport Portable Blood Lactate Analyzer has been reported to be accurate up to at least 18.7 mmol·L^{-1} and reliable at both high (14.4 mmol·L^{-1}) and low (1.7 mmol·L^{-1}) concentrations (14).

Yo-Yo Intermittent Recovery Test. The Yo-Yo IR1 test was performed according to the methods of Krustrup et al. (17) and consisted of repeated 20-m runs forward and back, keeping in time with a series of audio signals from a compact disc. After completion of two 20-m intervals, all subjects had 10 seconds of active recovery, which consisted of 10 m of jogging around a cone placed 5 m away from the starting point. The running speed was progressively increased until the subjects reached volitional ex-

Table 4. Physiological, anthropometrical, and performance variables related to the total distance covered during the 30-minute prolonged, high-intensity, intermittent running (PHIIR) sport simulation.*

Variable	Mean ± *SD*	Range	Correlation with PHIIR
NMT distance (m)	2,557 ± 272	2,055–2,906	
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	40.0 ± 4.3	32.9–45.9	0.17
LT ($km \cdot h^{-1}$)	11.5 + 1.2	9.0–13.5	0.77†
β_{blood} (slykes)	74.7 ± 24.4	41.5–107.0	0.37
V_{max} ($km \cdot h^{-1}$)	14.6 ± 1.2	12.5–16.5	0.69†
RSA work (kJ)	15.8 ± 1.9	11.4–18.2	0.56†
10 s work (kJ)	3.6 ± 0.4	3.0–4.3	0.47
30 s work (kJ)	12.5 ± 1.7	8.5–15.7	0.61†
Body mass (kg)	59.7 ± 9.3	42.4–82.0	0.26
Σ9 skinfolds (mm)	121.7 ± 40.3	75.0–211.9	0.20
Yo-Yo IR1 (m)	958 ± 368	480–1,840	0.50†

* NMT = nonmotorized treadmill; LT = lactate threshold; RSA = repeated sprint ability; Yo-Yo IR1 = performance level 1 Yo-Yo intermittent recovery test.
† All correlations significant ($p < 0.05$).

haustion. The Yo-Yo IR1 test performance was taken as the total distance covered upon volitional fatigue. This test has previously been reported to be both a reliable and valid test of physical performance in team sports such as soccer (17).

Statistical Analyses

Standard statistical methods were used for the calculation of means, *SDs*, Pearson product-moment correlation coefficients and ICCs. Statistical significance was set at $p \leq 0.05$. SPSS (SPSS, Inc., Chicago, IL) was used for all statistical calculations.

Results

The mean HR and [BLa^-] during the PHIIR sport simulation were 164 ± 6 $b \cdot min^{-1}$ and 8.2 ± 3.3 $mmol \cdot L^{-1}$, respectively. The physiological, anthropometrical, and performance characteristics of the subjects and the correlation coefficient of the variables to PHIIR performance are shown in Table 4. The results of correlation analysis between the important physiological variables and PHIIR sport simulation distance also are shown in Table 4. In addition to these, LT also was related significantly to total sprint distance ($r = 0.71$, $p < 0.05$) during the PHIIR sport simulation. There were no other significant correlations between the physiological measures and sprint distance during the PHIIR sport simulation. In terms of performance tests, the Yo-Yo IR1 test was moderately related to PHIIR sport simulation distance ($r = 0.50$, $p < 0.05$).

Discussion

The primary purpose of the present study was to determine the physiological factors that best relate to a generic PHIIR simulation that reflects team sport running activity in women team sport athletes. The second purpose of this study was to determine the relationship between common performance tests and the generic PHIIR sport simulation in moderately trained women team sport athletes. In this study, LT, V_{max}, 5 × 6-second RSA cycle work, 30-second Wingate cycle work, and Yo-Yo IR1 distance all moderately correlated with the total distance covered during the PHIIR sport simulation. No other physiological measures were significantly related to PHIIR performance.

The PHIIR sport simulation used in this study was effective in eliciting HR and blood lactate responses that were similar to those reported from match play in a variety of team sports (2, 4, 10, 18, 20, 27). The mean intensity during the PHIIR sport simulation was 86.1 ± 3.2% of maximal heart rate, which is similar to match play intensity in high-level referees (8), semiprofessional rugby league players (10), basketballers (20), and both male and female professional soccer players (2, 18). Additionally, the mean blood lactate response during the PHIIR sport simulation in this study was 8.2 ± 3.3 $mmol \cdot L^{-1}$, which is also similar to the values reported in high-level team sport athletes during match play (2, 27). These physiological responses combined with the frequency of activity changes (~10 seconds) and distance covered during the PHIIR sport simulation show that this test is similar to the work demands of many team sports.

The present finding of a significant correlation between LT and PHIIR sport simulation distance ($r = 0.77$, $p < 0.05$) is in agreement with previous research reporting a moderate correlation between LT and the total distance covered during a match in elite Italian soccer referees ($r = 0.73$, $p < 0.05$) (7). Similarly, Bangsbo and Lindquist (2) also reported that the average oxygen uptake corresponding to [BLa^-] 3 $mmol \cdot L^{-1}$ in 20 professional Danish soccer players correlated to distance covered during a match ($r = 0.58$, $p < 0.05$) and also intermittent endurance running test performance that required PHIIR ($r = 0.69$, $p < 0.05$). A recent study also demonstrated a moderate relationship between running velocity at 2 $mmol \cdot L^{-1}$ [BLa^-] and total distance covered during a competitive soccer match ($r = 0.64$, $p < 0.05$) in 14 elite women Danish soccer players. These results demonstrate that LT is an important physiological capacity for PHIIR performance in team sport athletes.

In agreement with some (8, 17, 18), but not all, previous research (2, 27), we found that $\dot{V}O_2max$ expressed relative to body mass (i.e., $ml \cdot kg^{-1} \cdot min^{-1}$) was not significantly correlated with the total distance covered during PHIIR. Previous studies have shown poor and insignificant relationships between $\dot{V}O_2max$ and distance covered during a match in 8 Serie A elite soccer referees (8), intermittent endurance running test performance in 14 professional male soccer players (2), and distance covered during competitive match play in 14 elite Danish women soccer players (18), respectively. However, in contrast to our findings, others have reported a significant relationship between $\dot{V}O_2max$ expressed relative to body mass and the total distance covered during various competitive team sport matches ($r = 0.60$–0.64, $p < 0.05$) (2, 27). It is possible that the lack of a significant relationship between distance covered during the PHIIR sport simulation and $\dot{V}O_2max$ in this study may be due to the shorter duration of exercise used in this study.

The lack of consensus regarding the strength of the relationship between physiological measures of aerobic fitness and PHIIR performance with some of these previous studies may be due to the subtle differences in the running demands of referees and soccer players (7), or it may be due to methodological issues associated with using time and motion analysis data, rather than a standardized running test, as a criterion measure of PHIIR (12, 24). The advantage of the methods used in the present study is that a standardized PHIIR protocol specific to team sport work requirements was completed in a laboratory, without the influence of opponents, tactics, and referees. Additionally, the measurement accuracy of this latter method is greater than that of time and motion analysis that has been used in most previous similar studies (2, 6–8, 18, 22). Therefore, we suggest that the results from this study provide an improved understanding of the relationships between physiological measures and the potential for PHIIR performance, because the influence of external factors such as opponents and tactics are removed.

Previous studies have shown that RSA is important for improved performance in team sport athletes (5). The present study demonstrated that the 5 × 6-second RSA cycle test was significantly correlated ($r = 0.56$, $p < 0.05$) with the total distance covered during the PHIIR sport simulation. To date, only one study has examined the relationship between simulated team sport play and the 5 × 6-second RSA cycle test (5). In agreement with the present results, this previous study demonstrated that total work completed during the 5 × 6-second RSA cycle test was significantly correlated to the total sprint times for 5-, 10-, and 15-m sprints ($-0.86 < r < -0.76$, $p < 0.05$) that were completed as part of a repeated sprint test circuit that was designed to replicate movement patterns of field hockey. These previous results also indicate that the 5 × 6-second RSA cycle test provides some valuable information relating to PHIIR performance in team sport athletes.

The ability to repeat sprints in close succession is suggested to be an important physical component of PHIIR performance, often contributing to the final outcome of a competitive match (5, 28). The present study, however, failed to show a significant relationship between the total work completed during the 5 × 6-second RSA cycle test and either the total 4 × 6-second RSA NMT distance or the total sprint distance in the PHIIR sport simulation. The lack of relationship between these variables shows that the 5 × 6-second RSA cycle test when completed without any prefatiguing exercise is not a good indicator of repeated sprint bout performance completed *during* simulated team sport match play. In agreement, Bishop et al., (5) reported low and insignificant relationships between the 5 × 6-second cycle RSA test performance and repeated sprint decrement measures (for 5-, 10-, and 15-m sprints) completed during a 45-minute hockey match running simulation in 10 moderately trained men. Collectively, the present finding demonstrates that although the 5 × 6-second RSA cycle test is related to global PHIIR performance, it may not be a valid indicator of 'prefatigued' repeat sprint performance during simulated team sport play.

Significant correlations were observed between both V_{max} ($r = 0.77$, $p < 0.05$) and the 30-second Wingate cycle test ($r = 0.61$, $p < 0.05$) and the PHIIR sport simulation distance. This result may be explained by the anaerobic contribution to high-intensity activities, such as fast running and sprinting, that were incorporated in the PHIIR sport simulation. The present results indicate that these tests could be used to monitor performance changes in PHIIR. However, because these tests are usually completed in a research laboratory, where only 1 athlete can be assessed at any one time, we suggest that these tests may not be as practically useful as the Yo-Yo IR1 test for monitoring PHIIR performance in the field setting.

In this study, the Yo-Yo IR1 test performance was moderately related to the total distance covered during the PHIIR sport simulation ($r = 0.50$, $p < 0.05$). The present result agrees with previous studies demonstrating that the Yo-Yo IR1 test is an effective tool for monitoring training adaptations in soccer players (17, 18). For example, Yo-Yo IR1 test performance values from elite women ($r = 0.56$, $p < 0.05$) (18) and men ($r = 0.53$, $p < 0.05$) (17) soccer players have been shown to be moderately correlated to total distance covered during a 90-minute soccer match. These correlations indicate that the Yo-Yo IR1 test may be a valid performance predictor of PHIIR performance and a useful practical test for detecting changes in PHIIR performance.

PRACTICAL APPLICATIONS

The results of the present study indicate that LT is an important physiological capacity related to PHIIR performance. This finding demonstrates the importance of increasing LT to improve performance during competitive team sports. A higher LT may allow athletes to perform at a higher intensity for a longer duration, permitting these players to be more active and, therefore, closer to the ball during a competitive game. Thus, we suggest that physical fitness training programs should focus on increasing LT. The present results also show that PHIIR performance can be monitored through the utilization of Yo-Yo IR1 test, 5 × 6-second RSA cycle test, 30-second Wingate cycle test, or determination of V_{max} or LT. However, due to its simplicity and specificity to PHIIR, we recommend the use of the Yo-Yo IR1 test for monitoring changes in team sport athletes.

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