ROLE OF ENERGY SYSTEMS IN TWO INTERMITTENT FIELD TESTS IN WOMEN FIELD HOCKEY PLAYERS

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ABSTRACT. Lemmink, K.A.P.M., and S.H. Visscher. Role of energy systems in two intermittent field tests in women field hockey players. J. Strength Cond. Res. 20(3):682–688. 2006.—The energetics of 2 field tests that reflect physical performance in intermittent sports (i.e., the Interval Shuttle Sprint Test [ISST] and the Interval Shuttle Run Test [ISRT]) were examined in 21 women field hockey players. The ISST required the players to perform 10 shuttle sprints starting every 20 seconds. During the ISRT, players alternately ran 20-m shuttles for 30 seconds and walked for 15 seconds with increasing speed. Anaerobic and aerobic power tests included Wingate cycle sprints and a V̇O2max cycle test, respectively. Based on correlation and regression analyses, it was concluded that for the ISST, anaerobic energetic pathways contribute mainly to energy supply for peak sprint time, while aerobic energetic pathways also contribute to energy supply for total sprint time. Energy during the ISRT is supplied mainly by the aerobic energy system. Depending on the aspect of physical performance a coach wants to determine, the ISST or ISRT can be used.

KEY WORDS. Interval Shuttle Sprint Test, Interval Shuttle Run Test, maximal oxygen uptake, Wingate test, intermittent sport physiology

INTRODUCTION

Intermittent sports, such as field hockey, require a high degree of physical fitness (23). Time-motion analysis indicates that in women’s field hockey, about 20% of the game is spent in high-intensity activity, such as running and sprinting (18). These high-intensity activities of short duration (5 seconds, on average) are alternated with low-intensity activities such as walking and jogging (18 seconds, on average). The skill requirements and postural stress (semicrouched posture) are superimposed on the work rate demanded by the game and its pattern of play (23). It is therefore appropriate to view a field hockey game as aerobically demanding, with frequent, though brief, anaerobic efforts superimposed (21). High-intensity efforts rely predominantly on the immediate (adenosine triphosphate phosphocreatine) and short-term (anaerobic glycolysis) anaerobic energy systems. The aerobic energy system is important during prolonged intermittent exercise. Evidently, the energetics of field hockey require an interaction of all 3 energy systems, with each system playing a significant yet specific role in energy supply during the game (7, 21, 31).

A number of intermittent field tests have been developed to evaluate physical performance of players in invasion games such as field hockey and soccer (1–3, 5, 8, 12, 19, 28). In this line, we developed 2 field tests: the Interval Shuttle Sprint Test (ISST) and the Interval Shuttle Run Test (ISRT) (14–17). The ISST comprises 10 shuttle sprints, each shuttle sprint consisting of 2 × 6 m and 2 × 10 m of sprinting back and forth, starting every 20 seconds. The peak sprint time, the total sprint time, and the drop-off index express the performance. The ISRT consists of 30-second shuttle runs over 20 m, interspersed with 15-second walking periods at progressively increasing speeds until exhaustion. Intermittent field tests should challenge the energy systems in a manner that closely replicates the game situation. Therefore, it is important to investigate the relationship between anaerobic and aerobic energy systems and intermittent field test performances.

The relationship between intermittent sprint field tests (i.e., tests of repeated sprint ability) and measures of anaerobic and aerobic energy systems has been well documented, but study results show contradictory outcomes (1, 2, 5, 8, 28). Several reasons may be offered to explain these varying results. First, there is a diversity in repeated sprint test protocols (i.e., differences in sprint distances [20–40 m], number of repetitions [6–18], and recovery periods [15–25 seconds]). Second, there are a variety of laboratory tests to measure anaerobic power and capacity, such as all-out cycle ergometer sprints of 10, 30, and 90 seconds; all-out treadmill sprints; an intermittent cycle ergometer and treadmill test; and laboratory tests to measure aerobic capacity, such as maximal cycle ergometer and treadmill tests. Third, differences in homogeneity and performance levels of players may account for different study outcomes. Intermittent endurance field tests, such as the Intermittent Endurance Test (3) and, more recently, the Yo-Yo Intermittent Recovery Test (12), have been related to aerobic energy system measures. Results indicate moderate correlations between intermittent endurance field tests and V̇O2max.

Up until now, most research on the relationship between intermittent field tests and energy-producing systems has been limited to a comparison with only one of the energy systems as a criterion measure (1–4, 12). However, research should focus on the contribution of all energy systems at the same time, because the energetics of intermittent field tests are complex, with anaerobic and aerobic energy systems interacting and playing a specific role in energy supply during test performance. Therefore, the purpose of the present study was to evaluate the role of anaerobic and aerobic energy systems with regard to energy supply for 2 intermittent field tests (i.e., the ISST and the ISRT) by relating these field tests with laboratory tests for measuring anaerobic and aerobic performance. We hypothesized that anaerobic as well as aerobic performance would be related to the ISST and the ISRT. However, we expected the anaerobic and aerobic perfor-
Table 1. Physical characteristics (mean ± SD) of the women field hockey players (n = 21).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>21.5 ± 1.3 (19.0–24.0)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.4 ± 5.5 (162–180)</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>67.4 ± 8.0 (52.6–83.0)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>27.7 ± 5.9 (13.6–36.6)</td>
</tr>
</tbody>
</table>

mance to be most strongly related to the ISST and the ISRT, respectively.

Methods

Experimental Approach to the Problem

Two intermittent field tests (i.e., the ISST and ISRT) and 2 laboratory tests for measuring anaerobic and aerobic performance (i.e., the Wingate test and the Vo2max test) were conducted on separate days in a random order within a period of 2–4 weeks. Subjects were required to keep their training and eating and drinking habits constant during the test period (March and April) and to avoid heavy meals 3 hours prior to the tests. During the day preceding each test, the subjects refrained from high-intensity exercise.

The ISST and ISRT were administered on 2 separate occasions during normal training hours on the same synthetic field hockey playing surface with subjects wearing the same playing footwear both times. The environmental conditions during both tests were comparable (i.e., dry field, no high winds based on subjective observations, temperatures between −2 and −1°C, and humidity between 81 and 89%). Subjects performed a 15-minute warm-up consisting of jogging and stretching. The ISST was carried out individually, while the ISRT was conducted in a group with a maximum of 8 subjects. The other subjects performed field hockey exercises of low to moderate intensity.

The Wingate test and the Vo2max test, as measures of the anaerobic and aerobic energy systems, respectively, were administered on 2 different occasions at our laboratory under the supervision of a sports physician. The subjects were only given feedback on their performance after completing all tests.

Subjects

Twenty-one women field hockey players of the second highest skill level in The Netherlands participated in the study. Before testing, all subjects provided written informed consent and completed a medical questionnaire. The procedures were conducted in accordance with the ethical standards of the Medical Faculty of the University of Groningen. During the study the teams maintained their regular sports regimen (i.e., field hockey training twice a week for 150 minutes and 1 match per week). The subjects received no additional strength or conditioning training. Prior to the first test, height, weight, and body fat were determined. Body fat was predicted by means of leg-to-leg bioelectric impedance analysis (Valhalla, San Diego, CA) (20). This method proved to be reliable to measure body fat percentage, and results correlated with body fat percentages, as measured with underwater weighing and dual-energy X-ray absorptiometry in healthy adults. The physical characteristics of the subjects are presented in Table 1.

Physiological Measurements

Blood samples were taken from the ear lobe directly after completion of the tests (Minilet Lancets; Bayer, Mishawaka, IN) and were analyzed (YSI 2300 lactate analyzer; Yellow Springs, OH). Heart rate was recorded during all tests at 5-second intervals (Polar, Kempele, Finland). The highest rate for any 5-second interval was taken as the maximum test heart rate.

ISST

The ISST consisted of 10 maximal sprints of 32 m while the subject was carrying a hockey stick. Each 32-m sprint included a 6-m and a 10-m shuttle sprint. Timing procedures (timing gates) meant that the initial and final meter of the sprint was not timed, so data are based on 30-m distances (Figure 1).

The subject began standing with both feet behind line A (2 markers 2 m apart). On an auditory signal after a 5-second countdown (test CD), the subject sprinted 6 m to line B, crossed the line with both feet and then returned to line A, again crossing the line with 2 feet. The subject then sprinted 10 m to line C, crossed the line with 2 feet and then returned to finish over line A. The subject then tapered down, turned, and walked back to line A, waiting for the 5-second countdown to start the second sprint. The second sprint started exactly 20 seconds after the start of the first sprint.

Times were measured by photocell gates (Eraton, Wei, The Netherlands) placed at 1.05 m above the ground (approximately at hip height) and at 1 m behind line A. The photocells were linked to an electronic timer with a precision of 0.01 second. The following variables were recorded: peak sprint time = fastest sprint time (seconds), total sprint time = total sprint time of the 10 sprints (seconds), and drop-off index = decrement of the sum of the ideal total sprint time (=peak sprint time multiplied by 10) to the actual total sprint time (%) (8). Research has shown that the test-retest reliability of the test is satisfactory with intraclass correlation coefficients of 0.81, 0.80, and 0.79 for peak sprint time, total sprint time, and drop-off index, respectively, and no differences in mean time scores between test sessions (14).
ISRT

Subjects were required to run back and forth on a 20-m course while carrying a hockey stick with markers set 3 m before the turning lines (Figure 2). The frequency of the sound signals on a prerecorded CD increased in such a way that running speed was increased by 1 km·h⁻¹ every 90 seconds from a starting speed of 10 km·h⁻¹ and by 0.5 km·h⁻¹ every 90 seconds starting from 13 km·h⁻¹. Each 90-second period was divided into two 45-second periods in which subjects ran for 30 seconds and walked for 15 seconds. Running and walking periods were announced on the CD. During the rest periods subjects just had to walk back and forth to the 8-m line. The test stopped when the subject was unable to follow the pace (i.e., more than 3 m before the 20-m lines at 2 consecutive audio signals, or when the subject felt that she could not complete the run). The number of completed 20-m runs was recorded. Earlier studies have shown that the ISRT is reliable for repeated measurements with intraclass correlation coefficients of 0.91 and 0.94 in men and women, respectively, and with no systematic bias between test sessions (17). Furthermore, the ISRT discriminated for playing level of soccer players (15).

Wingate 10-Second Test

The Wingate 10-second ergocycle test relies entirely on the anaerobic pathways (7, 25). A 5-minute warm-up was completed to elicit heart rate increases to 150 b·min⁻¹. The subjects then rested for 5 minutes to eliminate any fatigue associated with the warming-up process. At the end of the resting period a 10-second countdown was given to warn the subjects that the test phase would follow immediately. The test phase started with full application of the predetermined workload (0.075 kp·kg⁻¹). Standing on the pedals during the first seconds was allowed. Verbal encouragement was given throughout the test. After 10 seconds, an active recovery period of 3 minutes was administered. As for the 10-second cycle test, absolute and relative PPO and MPO were recorded.

Vo₂max Cycle Ergometer Test

Vo₂max was assessed on a cycle ergometer (Lode Excalibur Sport) during a stepwise incremental protocol. Metabolic measurements were made using an online respiratory gas analysis system (Jaeger Oxycon Delta, Hoechberg, Germany). This system was calibrated with O₂ and CO₂ gases. During the test the subjects breathed room air through a rubber mouthpiece and wore a nose clip. All players were familiarized with the test procedures.

The subjects were told to pedal at 60–80 rpm throughout the test. After performing a 3-minute warm up at 50 W, the workload was increased by 50 W every 3 minutes up to 200 W and by 25 W every 3 minutes thereafter. Test performance was expressed as absolute (L·min⁻¹) and relative (ml·min⁻¹·kg⁻¹) Vo₂max. The individual's Vo₂max was determined as the highest Vo₂ in a 30-second period when at least 2 of the following criteria were achieved: (a) respiratory exchange ratio value of at least 1.1, (b) postexercise blood lactate concentration of at least 8.0 mmol·L⁻¹, (c) having attained 95% of the individual estimated maximal heart rate, and (d) exercising to volitional exhaustion (6).

Statistical Analyses

Descriptive data (mean, standard deviation, and range) were computed for all variables. Pearson product-moment correlation coefficients were used to determine the relationship between the various test performance indices. A stepwise multiple regression analysis was conducted to assess the contribution of the performance indicators of anaerobic and aerobic energy system measures to the variance of the field test scores. The level of statistical significance was set at p ≤ 0.05.

RESULTS

Overall results for the ISST and ISRT field tests and the Wingate and Vo₂max laboratory tests are presented in Table 2. The peak sprint time ranged from 8.5 to 10.9 seconds, with a mean drop-off index of 9.5 ± 2.7%. The total sprint time ranged from 95.2 to 116.6 seconds. Mean maximal heart rate and posttest blood lactate concentrations during the ISST were 190 ± 7 b·min⁻¹ and 9.0 ±
The aim of this study was to provide an image of the energetics of 2 intermittent field tests, the ISST and the ISRT, in women field hockey players. Since field hockey places a demand on both anaerobic and aerobic processes, the present study focused on the energy continuum of anaerobic and aerobic energetic pathways.

For the ISST, results showed significant correlations between relative PPO and MPO during 10-second and 30-second tests and the laboratory tests. Peak sprint times were correlated with relative PPO and MPO of the 10-second cycle sprint ($r = -0.43$ and $-0.44$, respectively; $p \leq 0.05$), absolute and relative PPO and MPO of the 30-second cycle sprint ($r = -0.66$ to $-0.39$; $p \leq 0.05$), and relative VO$_2$max ($r = -0.39$; $p \leq 0.05$). Total sprint times were correlated with both Wingate 10-second and Wingate 30-second relative PPO (W·kg$^{-1}$) ($r = -0.44$ and $r = -0.62$; $p \leq 0.05$), relative MPO of the 30-second cycle sprint ($r = -0.57$; $p \leq 0.05$), and relative VO$_2$max ($r = -0.64$; $p \leq 0.05$). Correlations were also observed between the drop-off index and absolute PPO and MPO of the 10-second and 30-second cycle sprints ($r = 0.39$–0.57; $p \leq 0.05$) and the relative MPO of the 30-second cycle sprint ($r = 0.39$; $p \leq 0.05$). The number of 20-m runs of the ISRT was correlated to the relative 10-second PPO ($r = 0.37$; $p \leq 0.05$), the relative 30-second PPO and MPO ($r = 0.37$ and 0.38, respectively; $p \leq 0.05$), and the relative VO$_2$max ($r = 0.74$; $p \leq 0.05$). The power values for the significant correlations ($p \leq 0.05$) ranged from 50.3% ($r = 0.37$) to 99.7% ($r = 0.74$).

The results of the stepwise multiple regression analyses for both interval shuttle tests, including the multiple $R$, $R^2$, standard error of prediction (SE), and $p$ values, are provided in Table 4. Relative MPO and absolute PPO of the 30-second cycle sprint were the only significant predictors of the peak sprint time, explaining 55% of the shared variance. Relative VO$_2$max and relative PPO of the 30-second cycle sprint contributed significantly to the prediction of total sprint times, with a percentage of explained variance of 58%. Absolute MPO of the 30-second cycle sprint was the only significant contributor to the drop-off index, explaining 33% of the shared variance. Finally, only relative VO$_2$max contributed significantly to the number of 20-m runs of the ISRT, with a percentage of shared variance of 54%.

**TABLE 3.** Pearson correlation coefficients between the Interval Shuttle Sprint Test (ISST), Interval Shuttle Run Test (ISRT), Wingate 10-second test (W10), Wingate 30-second test (W30), and the VO$_2$max test of the women field hockey players ($n = 21$).*

<table>
<thead>
<tr>
<th></th>
<th>ISST Peak (s)</th>
<th>ISST Total (s)</th>
<th>ISST Drop-off (%)</th>
<th>ISRT 20-m runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>W10 PPO (W)</td>
<td>-0.27</td>
<td>-0.09</td>
<td>0.39†</td>
<td>-0.09</td>
</tr>
<tr>
<td>W10 PPO (W·kg$^{-1}$)</td>
<td>-0.43†</td>
<td>-0.44†</td>
<td>0.16</td>
<td>0.37†</td>
</tr>
<tr>
<td>W10 MPO (W)</td>
<td>-0.31</td>
<td>-0.09</td>
<td>0.45†</td>
<td>-0.19</td>
</tr>
<tr>
<td>W10 MPO (W·kg$^{-1}$)</td>
<td>-0.44†</td>
<td>-0.34</td>
<td>0.33</td>
<td>0.10</td>
</tr>
<tr>
<td>W10 PPO (W)</td>
<td>-0.50†</td>
<td>-0.33</td>
<td>0.45†</td>
<td>-0.04</td>
</tr>
<tr>
<td>W30 PPO (W·kg$^{-1}$)</td>
<td>-0.59‡</td>
<td>-0.62‡</td>
<td>0.19</td>
<td>0.37†</td>
</tr>
<tr>
<td>W30 MPO (W)</td>
<td>-0.39‡</td>
<td>-0.12</td>
<td>0.57‡</td>
<td>-0.15</td>
</tr>
<tr>
<td>W30 MPO (W·kg$^{-1}$)</td>
<td>-0.66‡</td>
<td>-0.57‡</td>
<td>0.39‡</td>
<td>0.58‡</td>
</tr>
<tr>
<td>VO$_2$max (L·min$^{-1}$)</td>
<td>-0.21</td>
<td>-0.23</td>
<td>0.05</td>
<td>0.19</td>
</tr>
<tr>
<td>VO$_2$max (ml·min$^{-1}$·kg$^{-1}$)</td>
<td>-0.39†</td>
<td>-0.64‡</td>
<td>-0.23</td>
<td>0.74‡</td>
</tr>
</tbody>
</table>

* PPO = peak power output; MPO = mean power output.
† Significant ($p \leq 0.05$).
‡ Significant ($p \leq 0.01$).
second cycle sprints and the peak sprint time of the ISST ($r = -0.66$ to $-0.39$; $p \leq 0.05$). Although not significant, Baker et al. (2) reported a correlation of $-0.58$ between the absolute PPO on a 30-second cycle sprint and the peak sprint time ($8 \times 40$ m with 20-second recoveries). Multiple regression analysis showed that relative MPO and absolute PPO of the 30-second cycle sprint were significant predictors of the peak sprint time, explaining $55\%$ of the shared variance. In contrast to our expectations, correlations between the 30-second cycle sprint and the peak sprint time were slightly higher than for the 10-second cycle sprint. Since mean peak sprint time (9.3 seconds) was comparable with the time period of the 10-second Wingate test, we expected higher correlations with the 10-second test than with the 30-second test. Perhaps as a result of a pacing strategy, individual fastest sprint times were not always the sprint times on the first sprint. When peak sprint time was reached in a latter sprint, then the lactic anaerobic energy system and the aerobic energy system was more important for energy supply, resulting in a higher correlation with 30-second cycle test outcome values and a significant correlation with relative $V_{O_2 \text{max}}$ ($r = -0.39$; $p \leq 0.05$). Conversely, no correlation was found between $V_{O_2 \text{max}}$ and peak sprint time in the Aziz et al. (1) study ($8 \times 40$ m with 30-second rest). As a result of the longer rest periods, their sprint protocol is less sensitive for a pacing strategy. The design of the ISST, which includes slowing down, turning, and accelerating at 6-, 12-, and 22-m points, may have weakened the relationship with 10-second and 30-second cycle sprints.

Significant correlations ($p \leq 0.05$) existed between, on the one hand, relative PPO of the 10-second cycle sprint ($r = -0.44$), PPO and MPO of the 30-second cycle sprint ($r = -0.62$ and $-0.57$), and the relative $V_{O_2 \text{max}}$ ($r = -0.64$) and, on the other hand, the total sprint time of the ISST ($10 \times 30$ m). In addition, results of the multiple regression analysis showed that relative $V_{O_2 \text{max}}$ and relative PPO of the 30-second cycle sprint contributed to the prediction of total sprint times ($p \leq 0.05$), explaining $58\%$ of the shared variance. This illustrates that all energy systems are important for repeated sprint performance. The correlations between relative $V_{O_2 \text{max}}$ and total sprint time in our study ($r = -0.64$; $p \leq 0.05$) are higher than those found in other studies. Aziz et al. (1) reported a correlation of $-0.32$ ($p \leq 0.05$) between relative $V_{O_2 \text{max}}$ and total sprint time ($8 \times 40$ m with 30-second rest periods) in men field hockey and soccer players, whereas Dawson et al. (7) showed a correlation of $-0.49$ ($p \leq 0.05$) between relative $V_{O_2 \text{max}}$ and total sprint time (6 $\times$ 40 m, departing every 30 seconds) in competitive team and racquet sport players. In contrast, Wadley and Rossignol (28) found no correlation between relative $V_{O_2 \text{max}}$ and total sprint time ($12 \times 20$ m, departing every 20 seconds) in football players. The differences in number of sprints, sprint distance, and work–rest ratio may have influenced the strength of the relationship with $V_{O_2 \text{max}}$. The short recovery periods in our protocol (approximately 10 seconds) compared to the other protocols (approximately 15–30 seconds) may have increased the lactic anaerobic and aerobic energy contribution in adenosine triphosphate synthesis during the ISST, since replenishment of the phosphate stores and breakdown and removal of lactate during recovery was limited. The contribution of the lactic anaerobic energy system is supported by the high posttest blood lactate concentrations ($9.6 \pm 2.0$ mmol·L$^{-1}$).

Positive correlations between absolute power output values of the Wingate tests and the drop-off index of the ISST ($r = 0.39$–$0.57$; $p \leq 0.05$) indicate that the higher the power output, the higher the decrement in sprint times during the 10 consecutive sprints. Baker et al. (2) reported slightly higher correlations between PPO and MPO during a 30-second cycle sprint and the fatigue index (i.e., the difference between the mean of the fastest 2 and the slowest 2 sprints expressed as percentage of the fastest 2 sprints). Only absolute MPO of the 30-second cycle sprint in our study was a significant predictor of the drop-off index, with $33\%$ explained variance ($p \leq 0.05$). In agreement with the study of Baker et al. (2), there was a significant correlation between the peak sprint time and the drop-off index ($r = -0.61$; $p \leq 0.05$). This indicates that those subjects with the fastest sprint times and highest PPO and MPO during the cycle sprints also exhibited the greatest fatigue, perhaps as a result of a high proportion of fast-twitch fibers. In accordance with our findings, Wadley and Rossignol (28) reported no significant correlation between $V_{O_2 \text{max}}$ and percentage decrement for their repeated sprint ability test. In contrast, 2 other studies (1, 7) reported significant but modest correlations between absolute $V_{O_2 \text{max}}$ values and the percentage decrement in sprint times. Several explanations have been offered for these results, such as the relation of the drop-off index to the ability of the muscles to return to homeostasis quickly from the preceding sprints, or a greater proportion of slow-twitch fibers that lead to greater capillarization of the muscle fibers and a superior ability to utilize lactate aerobically (13). Since the reported significant correlations are low to moderate and are only for

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**Table 4.** Multiple regression analyses (stepwise) for the Internal Shuttle Sprint Test (ISST) and the Interval Shuttle Run Test (ISRT).*

<table>
<thead>
<tr>
<th>Criteria tests</th>
<th>Beta</th>
<th>$R$</th>
<th>$R^2$</th>
<th>SE</th>
<th>$p$</th>
</tr>
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<tbody>
<tr>
<td><strong>ISST</strong></td>
<td></td>
<td></td>
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<tr>
<td>Peak (s)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>W30 MPO (W·kg$^{-1}$)</td>
<td>-0.57</td>
<td>0.66</td>
<td>0.43</td>
<td>0.41</td>
<td>0.00</td>
</tr>
<tr>
<td>W30 PPO (W)</td>
<td>-0.36</td>
<td>0.74</td>
<td>0.55</td>
<td>0.37</td>
<td>0.04</td>
</tr>
<tr>
<td>Total (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{O_2 \text{max}}$ (ml·min$^{-1}$·kg$^{-1}$)</td>
<td>-0.48</td>
<td>0.64</td>
<td>0.41</td>
<td>3.61</td>
<td>0.01</td>
</tr>
<tr>
<td>W30 PPO (W·kg$^{-1}$)</td>
<td>-0.45</td>
<td>0.76</td>
<td>0.58</td>
<td>3.11</td>
<td>0.01</td>
</tr>
<tr>
<td>Drop-off (%)</td>
<td></td>
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<tr>
<td>W30 MPO (W)</td>
<td>0.57</td>
<td>0.57</td>
<td>0.33</td>
<td>2.23</td>
<td>0.01</td>
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<tr>
<td><strong>ISRT</strong></td>
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<tr>
<td>20-m runs</td>
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</tr>
<tr>
<td>$V_{O_2 \text{max}}$ (ml·min$^{-1}$·kg$^{-1}$)</td>
<td>0.74</td>
<td>0.74</td>
<td>0.54</td>
<td>8.28</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*Beta = standardized beta weights; $R = $ multiple-correlation coefficient; $R^2 = $ shared variance; SE = standard error of prediction; W30 = Wingate 30-second test; MPO = mean power output; PPO = peak power output.
absolute Vo\textsubscript{max}, further research is needed to clarify this relationship.

For the ISRT, relative Vo\textsubscript{max} was significantly correlated with the number of 20-m runs during the ISRT (r = 0.74; p ≤ 0.05) and contributed significantly to the prediction (explained variance 54%; p ≤ 0.05). This finding duplicates earlier data showing that the correlation between treadmill Vo\textsubscript{max} values and the ISRT performance was 0.77 (p ≤ 0.05) in Dutch soccer players (16). Recently, nearly the same correlation was reported by Krustrup et al. (12) between relative Vo\textsubscript{max} and the distance covered in the Yo-Yo Intermittent Recovery Test (r = 0.71; p ≤ 0.05). Despite the differences in test protocol (i.e., 30 seconds of 20-m shuttle run interspersed with 15 seconds of walking during the ISRT, compared to one 20-m shuttle run interspersed with 10 seconds of jogging during the Yo-Yo Intermittent Recovery Test), the aerobic energy contribution seems comparable. Bangsbo and Lindquist (3) reported a lower correlation coefficient between Vo\textsubscript{max} and their Intermittent Field Test score (i.e., the total distance during 10 minutes of high-intensity running, in 14 professional soccer players; r = 0.47; p ≤ 0.05). The duration of their test was 16.5 minutes, while the players alternated between high- and low-intensity exercise for 15 and 10 seconds, respectively. As a result of the differences in duration of high- and low-intensity exercise periods (15 and 10 seconds instead of 30 and 15 seconds), high-low intensity ratio (3 to 2 instead of 2 to 1), and type of activity in the low-intensity exercise periods (jogging instead of walking), the contribution of the aerobic energy production is probably lower than for the ISRT.

The significant correlations between the relative PPO of the 10-second and relative PPO and MPO of the 30-second cycle sprints and the number of 20-m runs indicate that a-lactic and lactic anaerobic energy systems contribute to ISRT performance. As a result of the intermittent character of the ISRT, phosphate stores can be partly replenished during the 15-second rest periods, increasing the role of the a-lactic energy system in the energy supply. To cover the energy needs of the muscles for the 30-second running periods, especially during the higher running speeds, the energy delivered by the aerobic energetic pathways is insufficient. Thus, the lactic anaerobic energy system makes an essential contribution to the energy supply of the muscles. This contribution is supported by the high posttest blood lactate concentrations (10.1 ± 2.1 mmol·L\textsuperscript{-1}).

Heart rate at the end (≥95% of the predicted maximal heart rate [220 minus age in years]) and postexercise blood lactate concentration (≥8 mmol·L\textsuperscript{-1}) are often used to confirm the maximal nature of a performance test (1, 29). Given the values for the maximal heart rate of the Vo\textsubscript{max} cycle test (187 ± 7.9 b·min\textsuperscript{-1}, 94.2% of predicted maximal heart rate) and the ISRT (197 ± 7.2 b·min\textsuperscript{-1}, 99.2% of predicted maximal heart rate) and the mean posttest blood lactate concentrations of the maximal cycle ergometer test (8.6 mmol·L\textsuperscript{-1}) and the ISRT (10.1 mmol·L\textsuperscript{-1}), we consider that both tests were conducted under maximal conditions. In addition, maximal heart rates at the end of the ISRT in our study are comparable with maximal heart rates during the ISRT and shuttle run tests in earlier studies (14, 15, 26, 30). Despite the fact that maximal heart rate and postexercise blood lactate concentration may not be the best indicators of maximal performance on anaerobic tests, such as the ISST and Wingate tests, their values demonstrate that the effort of the subjects was considerable and comparable to that expended in the other tests.

The difference in exercise mode between the laboratory and field tests may have negatively influenced the magnitude of the correlations. The anaerobic energy system indices were measured using Wingate tests, since reliable and valid treadmill running protocols to measure anaerobic energy system performances of sport players were not available. Wingate tests have been used extensively in the evaluation of anaerobic characteristics of athletes (7, 8, 10, 11, 25). The women field hockey players in our study obtained an absolute PPO of approximately 780 W during the 10-second cycle ergometer sprint and 760 W during the 30-second cycle sprint. These maximal values are in line with the results in other team-sports athletes (2, 10). Baker et al. (2) showed that the correlations between 40-m peak sprint time and PPO and MPO values of 30-second treadmill sprints and 30-second cycle sprints were comparable, indicating little influence of the exercise mode of anaerobic laboratory tests. In order to maintain consistency between our laboratory measurements, the Vo\textsubscript{max} was assessed during an incremental cycle ergometer test. The Vo\textsubscript{max} values ranged from 41.8 to 56.5 ml·min\textsuperscript{-1}·kg\textsuperscript{-1}, with a mean Vo\textsubscript{max} of 48.7 ml·min\textsuperscript{-1}·kg\textsuperscript{-1}. These findings show a resemblance to values observed in elite women hockey squads, ranging from 45 to 59 ml·min\textsuperscript{-1}·kg\textsuperscript{-1} (22, 24). In general, Vo\textsubscript{max} values assessed during cycling are somewhat lower than those obtained during running (9). However, since the pattern of Vo\textsubscript{max} values in a group of subjects will be more or less similar between cycling and running, the magnitude of the correlation will not be substantially affected.

In conclusion, results of the correlation and regression analyses indicate that anaerobic as well as aerobic energy systems contribute to the energy supply during the ISST. Anaerobic energetic pathways contribute mainly to energy supply for the peak sprint time, while aerobic energetic pathways also contribute to the energy supply for repeated sprint performance (i.e., total sprint time). The a-lactic and lactic anaerobic energy systems were positively related to the drop-off index, and there was no relationship between the aerobic energy system and the drop-off index. The energy during the ISRT is supplied mainly by the aerobic energy system. However, as a result of the interval character, anaerobic energy production also contributes to total energy requirement.

**Practical Applications**

Coaches and trainers of intermittent sports, such as field hockey and soccer, can use the ISST and ISRT, as these tests reflect the intermittent character of field hockey games and the interaction of anaerobic and aerobic energy systems. In addition, both tests can be administered easily within a short period of time and using limited test equipment. The ISRT and the ISST can be used to assess young athletic talent, to differentiate between players of different playing positions, and to monitor changes over time. If a coach wants to determine repeated sprint capacity of forwards or defenders, he or she can use the total sprint time during the ISST as a performance indicator. If a coach wants to determine midfielders’ interval endurance capacity (i.e., the capacity to perform moderate- to high-intensity activities frequently during a pro-
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