Aerobic and Anaerobic Contributions to Energy Production Among Junior Male and Female Cross-Country Skiers During Diagonal Skiing

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Purpose: Cross-country-ski races place complex demands on athletes, with events lasting between approximately 3 min and 2 h. The aim of the current study was to compare the aerobic and anaerobic measures derived from a short time trial (TT) between male and female skiers using diagonal cross-country skiing. Methods: Twenty-four highly trained cross-country skiers (12 male and 12 female, age 17.4 ± 1.4 y, body mass 68.2 ± 8.9 kg, height 174 ± 8 cm) participated. The submaximal VO2–speed relationship and VO2max were derived from an incremental ramp test to exhaustion (RAMP), while the accumulated oxygen deficit (AOD), peak VO2, and performance time were measured during a 600-m TT. Results: The female skiers took longer to complete the TT than the males (209 ± 9 s vs 166 ± 7 s, P < .001) and exhibited a lower relative anaerobic contribution (20% ± 4% vs 24% ± 3%, P = .015) and a higher fractional utilization of VO2max (84% ± 4% vs 79% ± 5%, P = .007) than males. Although there was no significant difference in AOD between the sexes (40.9 ± 9.5 and 47.3 ± 7.4 mL/kg for females and males, respectively; P = .079), the mean difference ± 90% confidence intervals of 6.4 ± 6.0 mL/kg reflected a likely practical difference (ES = 0.72). The peak VO2 during the TT was significantly higher than VO2max during the RAMP for all participants combined (62.3 ± 6.8 vs 60.5 ± 7.2 mL · kg⁻¹ · min⁻¹, P = .011), and the mean difference ± 90% confidence intervals of 1.8 ± 1.1 mL · kg⁻¹ · min⁻¹ reflected a possible practical difference (ES = 0.25). Conclusions: These results show that performance and physiological responses to a self-paced TT lasting approximately 3 min differ between sexes. In addition, a TT may provide a valid measure of VO2max.

Keywords: accumulated oxygen deficit, incremental ramp test, sex differences, maximal oxygen uptake, time trial

Due to the extensive involvement of both the upper and lower body, cross-country skiing is characterized by distinct physiological responses that differ from those associated with other types of continuous motion, such as running and cycling. Consequently, ski-specific laboratory tests (e.g., treadmill roller skiing using classic and skating techniques) are commonly used to simulate the particular demands of the sport. Unlike athletes in most other disciplines, cross-country skiers race over a range of distances, with International Ski Federation World Cup races lasting between approximately 3 minutes and 2 hours. This variation places complex demands on athletes, particularly in coordinating the development of highly anaerobic (i.e., maximal power and sprint speed) and oxidative (i.e., aerobic power and endurance) systems.

The 30-second all-out Wingate cycle test and incremental ramp tests to exhaustion are commonly used to assess maximal anaerobic and aerobic capacities, respectively. However, it is evident that 30 seconds is insufficient to fully deplete anaerobic energy reserves and that exhaustive tests lasting 2 to 3 minutes actually provide a more valid estimate of maximal anaerobic capacity. In addition, incremental ramp tests to volitional exhaustion, which differ from athletic events involving a fixed distance or time, have been described as lacking ecological validity. Moreover, exhaustive trials lasting 1 to 3 minutes appear to provide VO2max values similar to those obtained from a standard incremental ramp test. Therefore, such short-duration trials may be effective in providing valid measures of both VO2max and maximal anaerobic capacity.

Investigations involving treadmill and track running, cycling, kayaking, and cross-country skiing have revealed that the anaerobic energy contribution diminishes from ~40% to 16% during maximal efforts lasting between ~1.5 and 4 minutes. When comparing females and males during fixed-distance track running and kayaking, the anaerobic contributions are lower in females, which is likely due to the increased exercise duration for females. To date, however, the anaerobic contribution during a short time trial (TT) using classical skiing has not been examined, and the anaerobic and aerobic...
responses of male and female athletes during such a test have not been compared.

The purposes of the current study were to determine whether the relative anaerobic contribution to a 600-m diagonal-skiing TT and the calculated anaerobic capacity would differ between male and female skiers and whether the peak VO2 attained during a 600-m diagonal-skiing TT would differ from the VO2max attained during an exhaustive incremental ramp test to exhaustion (RAMP).

Methods

Participants

A group of 24 highly trained cross-country skiers was recruited from 2 specialist ski schools (12 males, 17.6 ± 1.4 y, 72.9 ± 5.2 kg, and 179 ± 5 cm; 12 females, 17.3 ± 1.4 y, 63.4 ± 9.4 kg, and 169 ± 7 cm). The participants all competed nationally, with 9 of the 24 also members of national junior development teams. During testing in the competition season the athletes were completing ~8 h/wk of endurance training and 2 gym-based strength sessions per week. All participants had experience of treadmill roller skiing and the test protocols as part of their seasonal training and performance monitoring. They were fully informed about the study before providing written consent to participate, and additional parental consent was obtained for those under 18 years. The study was preapproved by the regional ethical review board, Umeå University, Umeå, Sweden.

Study Overview

Participants arrived at the laboratory on the morning of testing in a fed and rested state. They were instructed to abstain from alcohol for at least 24 hours before testing and from caffeine on the day of the trial before testing. After height and body mass were measured (Seca 764, Hamburg, Germany) a RAMP and a 600-m TT were completed, separated by 2 to 3 hours of rest. All participants were familiarized to the TT twice in nonexperimental training sessions before testing. The RAMP tests commenced between 8 AM and 12 noon for all participants.

Equipment

All tests used the diagonal roller-skiing technique and the same pair of prewarmed roller skis (Pro-Ski Classic C2, Sterners, Dala-Järna, Sweden), to minimize variations in rolling resistance (mean ± SD rolling-resistance coefficient: .021 ± .001),19 as well as a safety harness around the waist connected to an automatic emergency brake above the treadmill. The RAMP and TT were completed on a motor-driven treadmill (Rodby RL 3000, Rodby, Vänge, Sweden) with lasers that automatically increased or decreased the speed if the athlete moved to the front or rear of the belt, respectively, maintaining a constant speed otherwise.20 Heart rate was monitored continuously (RS800CX, Polar Electro Oy, Kempele, Finland) and blood lactate concentration was measured from fingertip samples (Biosen 5140, EKF diagnostic GmbH, Magdeburg, Germany).

Expired-Air Collection

Respiratory variables were measured throughout the RAMP and TT using a mixed expired-air procedure with an ergospirometry system (AMIS 2001 model C, Innovation A/S, Odense, Denmark) equipped with a flowmeter. The gas analyzers were calibrated with a high-precision mixture of 16.0% O2 and 4.0% CO2 (Air Liquide, Kungsängen, Sweden), and the flowmeter was calibrated at 3 rates with a 3-L air syringe (Hans Rudolph, Kansas City, MO, USA). VO2, VCO2, and ventilation rate were monitored continuously, and VO2 values were calculated from 10-second epochs and reported as 30-second averages.

RAMP

The submaximal section of the RAMP was fixed at 7° and included a 4-minute warm-up followed by 4 × 4-minute continuous stages. The speeds of each of the 4 stages differed for individuals depending on age, sex, and skiing ability. The warm-up and first stage were completed at 5.2 to 7.0 km/h, and the speed was increased thereafter by either 0.8 or 1.0 km/h per stage to final speeds of 7.6 to 10.0 km/h. At the end of the submaximal section of the RAMP there was a 1-minute break before participants commenced the exhaustive phase, which involved increases in treadmill gradient, then speed, every minute until participants were unable to continue with the test.21 Depending on age, sex, and ability the starting speed was 10, 11, or 12 km/h and the initial gradient was 3° or 4°. The gradient was then increased by 1° every minute, up to a maximum of 9°, after which speed was increased by 0.4 km/h every minute. At the end of the test a rating of perceived exertion was recorded, and a fingertip blood sample was collected 3 minutes after the end of the test. The work rates during the 4 submaximal stages and the final minute of the RAMP were calculated as the sum of power against gravity and rolling resistance.22

600-m TT

After a 15-minute warm-up at a self-selected pace, including 4 × 30-second intervals to simulate prerace routines, participants were fitted with a mouthpiece and nose clip, and a 1-minute resting expired-air sample was collected. The treadmill gradient was 7° throughout the test, and the protocol began with the first 100 m fixed at 8.8 km/h for females and 10.8 km/h for males. This procedure was based on previous research and designed to avoid overpacing.18 The participants could see distance covered throughout the trial on a computer screen in front of the treadmill, and after the first 100 m the trial was self-paced for the remaining 500 m. Standardized verbal feedback and encouragement to complete the TT as fast as possible were provided continuously by the experimenter. A rating of perceived exertion was recorded immediately.
after the trial, and a fingertip blood sample was collected after 3 minutes. The average work rate during the TT was calculated as described previously. The coefficient of variation for a treadmill TT lasting 2 to 3 minutes has previously been reported to be 1.3%.

Calculations of Accumulated Oxygen Deficit

The linear relationship between treadmill speed at 7° and VO₂ during the final 30 seconds of each stage was derived for each individual from the 4 × 4-minute submaximal RAMP stages with the baseline VO₂ (at speed = 0 km/h) included in the model. This relationship was used to estimate the required VO₂ at the individual average speed during the TT (see Figure 1 in the Results). The accumulated oxygen deficit (AOD) was given by subtracting the accumulated VO₂ during the TT, as well as a stored O₂ component of 8.8 mL/kg from the accumulated estimated VO₂ requirement. The anaerobic and aerobic contributions were calculated as follows:

\[
\text{Anaerobic contribution} = \left( \frac{\text{accumulated estimated VO₂ requirement} - \text{accumulated VO₂ measured} - \text{stored O₂}}{\text{accumulated estimated VO₂ requirement}} \right) \times 100, \\
\text{Aerobic contribution} = \left( \frac{\text{accumulated VO₂ measured} + \text{stored O₂}}{\text{accumulated estimated VO₂ requirement}} \right) \times 100.
\]

Statistical Analyses

The Statistical Package for the Social Sciences 14.0 (SPSS Inc, Chicago, IL, USA) was used to carry out statistical analyses. The level of significance was set at \( P < .05 \), and data are expressed as mean ± SD. Independent-samples t tests were used to compare male and female responses, and paired t tests were used to compare the variables derived from the RAMP and the 600-m TT tests. Mean differences ± 90% confidence intervals (CIs) were calculated and expressed in qualitative probabilistic terms, and the magnitudes of the standardized differences were expressed as effect sizes (ES), whereby differences of <.2, <.6, and <1.2 were interpreted as trivial, small, and moderate, respectively. The bias ± 95% limits of agreement between RAMP and 600-m TT measurements were evaluated using Bland–Altman calculations. Pearson product–moment analyses were used to calculate correlation coefficients, and multiple-linear-regression analyses were carried out to determine which physiological variables best predict performance time.

Results

RAMP

The 4 submaximal stages of the RAMP, performed at 6.0 ± 0.7, 6.9 ± 0.7, 7.8 ± 0.8, and 8.7 ± 0.9 km/h (166 ± 33, 191 ± 37, 216 ± 42, and 241 ± 47 W), were associated with VO₂ values equal to 60% ± 6%, 70% ± 6%, 78% ± 7%, and 86% ± 5% of VO₂max, respectively (Figure 1[A]). The physiological variables associated with the exhaustive phase are displayed in Table 1.

600-m TT

The performance and physiological responses associated with the 600-m TT are displayed in Table 2, and a typical VO₂ response is shown in Figure 1[B]. Peak VO₂ (mL · kg⁻¹ · min⁻¹) during the 600-m TT was significantly higher than VO₂max for all participants combined (\( P = .011 \)) and for the females alone (\( P = .003 \)), but not for the males (\( P = .265 \)). The mean difference ± 90% CIs of 1.8 ± 1.1 mL · kg⁻¹ · min⁻¹ for all participants combined reflected

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**Figure 1** — (A) The mean ± SD linear relationship between treadmill speed and VO₂ during the submaximal stages of the incremental ramp test to exhaustion (RAMP) and estimated required VO₂ at the speed attained during the 600-m time trial. (B) A typical VO₂ response during the 600-m time trial illustrating the accumulated oxygen deficit (shaded area) and the VO₂max determined from the RAMP (dotted line).
Accumulated Oxygen Deficit and Diagonal Skiing

Table 2 Performance and Physiological Responses (Mean ± SD) During the 600-m Time Trial

<table>
<thead>
<tr>
<th></th>
<th>Males (n = 12)</th>
<th>Females (n = 12)</th>
<th>Combined (N = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time-trial time (s)</td>
<td>166 ± 7</td>
<td>209 ± 9***</td>
<td>187 ± 23</td>
</tr>
<tr>
<td>Peak VO_{2} (L/min)</td>
<td>4.97 ± 0.33</td>
<td>3.58 ± 0.58***††</td>
<td>4.28 ± 0.84†</td>
</tr>
<tr>
<td>Peak VO_{2} (mL · kg⁻¹ · min⁻¹)</td>
<td>68.2 ± 2.9</td>
<td>56.5 ± 3.6***††</td>
<td>62.3 ± 6.8†</td>
</tr>
<tr>
<td>Work rate (W)</td>
<td>384 ± 30</td>
<td>268 ± 43***</td>
<td>326 ± 70</td>
</tr>
<tr>
<td>Work rate (%RAMP)</td>
<td>95 ± 5</td>
<td>96 ± 6</td>
<td>95 ± 6</td>
</tr>
<tr>
<td>Time to peak VO_{2} (s)</td>
<td>118 ± 16</td>
<td>129 ± 26</td>
<td>123 ± 22</td>
</tr>
<tr>
<td>Peak respiratory exchange ratio</td>
<td>1.23 ± 0.06†</td>
<td>1.17 ± 0.03**††</td>
<td>1.20 ± 0.05††</td>
</tr>
<tr>
<td>Peak heart rate (beats/min)</td>
<td>197 ± 6†††</td>
<td>195 ± 7†††</td>
<td>196 ± 6†††</td>
</tr>
<tr>
<td>Postexercise blood lactate concentration (mmol/L)</td>
<td>11.5 ± 1.6</td>
<td>10.7 ± 1.8</td>
<td>11.1 ± 1.7</td>
</tr>
<tr>
<td>Rating of perceived exertion</td>
<td>18 ± 1</td>
<td>19 ± 1</td>
<td>18 ± 1</td>
</tr>
</tbody>
</table>

Significantly different from males: *P = .011, **P = .004, ***P < .001. Significantly different from the incremental ramp test to exhaustion value: †P < .05, ††P < .005, †††P < .001.

Aerobic and Anaerobic Contributions to Energy Production During the 600-m TT

The linear relationship (r² = .994 ± .012) between work rate and VO_{2} during the submaximal phase of the RAMP exhibited a slope of 4.92 ± 0.29 (mL · kg⁻¹ · min⁻¹)/(km/h) and a y-intercept of 8.35 ± 1.36 mL · kg⁻¹ · min⁻¹. Extrapolation to the TT speed (ie, 11.7 ± 1.5 km/h) resulted in an estimated VO_{2} requirement of 66.3 ± 7.4 mL · kg⁻¹ · min⁻¹ (Figure 1[A]), which corresponded to 110% ± 5% of the VO_{2max} during the RAMP. The resultant accumulated estimated VO_{2} requirement during the TT was 204 ± 9.6 mL/kg, while the accumulated VO_{2} during the TT was 151 ± 10.0 mL/kg (Figure 1[B]). Subtraction of the estimated stored O_{2} component (ie, 8.8 mL/kg) gave an AOD of 44.1 ± 8.9 mL/kg.

The females demonstrated a significantly lower anaerobic contribution to energy production than the males (20% ± 4% vs 26% ± 3%, P = .015; Figure 3), with the mean difference ± 90% CIs of 4% ± 3% reflecting a very likely practical difference (ES = 1.04; moderate). The fractional utilization of VO_{2max} was also significantly greater in the females (84% ± 4% vs 79% ± 5%, P = .007), with the difference of 5% ± 3% again reflecting a very likely practical difference (ES = 1.17; moderate).
Figure 2 — The bias (mean) ± 95% limits of agreement (1.96 SD) for the difference between the peak VO₂ measured during the 600-m time trial (TT) and the VO₂max during the incremental ramp test to exhaustion (RAMP).

Figure 3 — (A) The mean ± SD relative aerobic and anaerobic contributions to energy production during the 600-m time trial. (B) The mean ± SD oxygen uptake and accumulated oxygen deficit during the 600-m time trial. Significantly different from the corresponding value for males: *P = .015, ***P < .001.
The AOD was not significantly different between sexes (47.3 ± 7.4 vs 40.9 ± 9.5 mL/kg for the males and females, respectively; \( P = .079 \); Figure 3), although the difference of 6.4 ± 6.0 mL/kg reflected a likely practical difference (ES = 0.72; moderate).

### Predictors of Performance

No significant correlations were identified between performance (ie, time to complete the TT) and any of the physiological variables for the males (Table 3). By contrast, the TT time for females was significantly related to the RAMP VO\(_{2}\max\) and the peak VO\(_2\) during the TT (in mL \cdot kg\(^{-1}\) \cdot min\(^{-1}\)), the accumulated VO\(_2\) expressed relative to VO\(_{2}\max\), and the relative anaerobic contribution (\( P < .05 \), Table 3). The multiple-linear-regression analyses revealed that accumulated VO\(_2\) (in mL \cdot kg\(^{-1}\) \cdot min\(^{-1}\)), AOD (in mL/kg), and the relative anaerobic contribution (%) predicted 97.4% of the variance in TT time for the males (\( P < .001 \)) and 97.3% of the variance in TT time for the females (\( P < .001 \)). For the males, these independent variables were not significant when analyzed separately (Table 3). For the females, the relative anaerobic contribution alone was shown to explain 36.8% of the variance in TT time (\( P = .037 \)), while the other 2 variables were not significant (Table 3).

### Discussion

The current study has shown that (1) the anaerobic contribution during a TT lasting ~3 minutes using diagonal skiing is ~22%; (2) the time to complete a 600-m TT is longer for females than males, and this is coupled with a lower relative anaerobic contribution to energy production and a higher fractional utilization of VO\(_{2}\max\) among females but no significant difference in anaerobic capacity; and (3) a 600-m time trial may provide a valid measure of VO\(_{2}\max\) during diagonal treadmill skiing.

The slightly lower anaerobic contribution to the TT in the current study using diagonal skiing (22%), compared with previous data for skating (26%),\(^\text{18} \) may be due to differences in techniques. Although no study to our knowledge has directly compared economy or efficiency between diagonal and skate skiing at constant inclines, diagonal skiing at 4° appears more efficient than skating using gear 3 at 3°.\(^\text{28} \) Alternatively, the difference in mean TT time between the 2 studies may explain the differences in calculated anaerobic contributions (ie, 187 s vs 172 s). The different methods used to assess anaerobic contribution may also have contributed to the inconsistencies between studies. For example, a potentially more valid method was used in the current study, whereby the treadmill gradient was standardized at 7° for both the 4 × 4-minute submaximal stages and the TT (ie, only the speed differed between tests), while Losnegard et al\(^\text{18} \) used a method where both incline and speed differed between the submaximal and TT tests. In addition, the mix of sexes in the current study exaggerated the difference. That is, the values between the 2 studies are more similar when examining the males only (ie, 24% vs 26%). Overall, it appears that the anaerobic contribution to diagonal skiing is comparable to the values calculated for other exercise modes over similar durations, whereby elite runners have demonstrated a 22% anaerobic contribution during 181 seconds of exhaustive treadmill running\(^\text{29} \) and recreational athletes exhibited a 24% anaerobic contribution during 186 seconds of exhaustive cycle ergometry.\(^\text{30} \)

The difference in mean time to complete the TT between the sexes was ~43 seconds (ie, the females completed the 600-m effort in ~126% of the males’ time), and coupled with this was a significantly smaller

### Table 3  Correlation Coefficients Between the Time Taken to Complete the 600-m Time Trial (TT) and Physiological Variables Measured During the Incremental Ramp Test to Exhaustion (RAMP) and the 600-m TT

<table>
<thead>
<tr>
<th>Test</th>
<th>Measure</th>
<th>Males (n = 12)</th>
<th>Females (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAMP</td>
<td>VO(_{2}\max) (L/min)</td>
<td>.07</td>
<td>−.53</td>
</tr>
<tr>
<td></td>
<td>VO(_{2}\max) (mL \cdot kg(^{-1}) \cdot min(^{-1}))</td>
<td>.20</td>
<td>−.73**</td>
</tr>
<tr>
<td></td>
<td>Postexercise blood lactate concentration, mmol/L</td>
<td>.10</td>
<td>−.29</td>
</tr>
<tr>
<td>TT</td>
<td>Peak VO(_2) (L/min)</td>
<td>−.26</td>
<td>−.48</td>
</tr>
<tr>
<td></td>
<td>Peak VO(_{2}) (mL \cdot kg(^{-1}) \cdot min(^{-1}))</td>
<td>−.31</td>
<td>−.58*</td>
</tr>
<tr>
<td></td>
<td>Postexercise blood lactate concentration, mmol/L</td>
<td>.05</td>
<td>−.16</td>
</tr>
<tr>
<td></td>
<td>VO(_2) (mL \cdot kg(^{-1}) \cdot min(^{-1}))</td>
<td>−.08</td>
<td>−.43</td>
</tr>
<tr>
<td></td>
<td>VO(<em>2) (% VO(</em>{2}\max))</td>
<td>.43</td>
<td>.62*</td>
</tr>
<tr>
<td></td>
<td>Accumulated oxygen deficit, mL/kg</td>
<td>−.13</td>
<td>−.53</td>
</tr>
<tr>
<td></td>
<td>Anaerobic contribution, %</td>
<td>−.29</td>
<td>−.61*</td>
</tr>
</tbody>
</table>

\*\( P < .05 \). **\( P < .01 \).
anaerobic contribution for the females. While a longer exercise duration would be expected to result in a greater proportion of energy derived from aerobic metabolism, it is unclear whether exercise duration is the sole explanation for the difference in anaerobic contribution between the sexes. For example, there was a very likely (and statistically significant) chance of a greater fractional utilization of VO2max during the TT among the females. There was also a strong tendency for anaerobic capacity (ie, AOD) to be lower among the females, and this difference was deemed likely to be practical. Therefore, it is possible that a lower AOD among females drives a greater fractional utilization of VO2max and contributes to a greater aerobic contribution during a fixed workload, rather than exercise duration per se. The observations in the current study highlight the different demands on males and females during fixed-distance events, which may have implications for training and prerace preparation strategies across a variety of sports.

The AOD values for the males in the current study (44.1 ± 7.4 mL/kg) are somewhat lower than those reported previously (62.2 ± 16.8 and 60.2 ± 15.0 mL/kg) for males completing a 600-m cross-country skiing TT using 2 different skating techniques. This difference may be due to the younger age and lower performance level of the current participants, which would likely be associated with less muscle mass and a more limited anaerobic capacity. Alternatively, the stored O2 component of 8.8 mL/kg (which was subtracted from the accumulated estimated VO2 requirement) was originally derived from a group of senior male skiers and so may have been too large for these younger athletes. A previous study using middle-distance university runners included a stored O2 component of only 2.3 mL/kg. While this value would likely be too low for cross-country skiing, which involves a greater exercising muscle mass, any overestimation in the stored O2 component would lead to an underestimation of AOD.

Unlike Losnegard et al, who reported significant correlations between skating performance and AOD among male skiers, no significant correlations were identified between performance and any of the individual physiological parameters for the males in the current study. However, multiple-linear-regression modeling in the current study revealed that a prediction equation for performance incorporating accumulated VO2 (in mL · kg⁻¹ · min⁻¹), AOD (in mL/kg), and the relative anaerobic contribution (%) provided a high level of accuracy for both the males and the females (R² = .97). The female skiers in the current study also revealed a wider range of individual performance predictors, with higher VO2max, peak VO2 during the TT, accumulated VO2 expressed relative to VO2max (ie, fractional utilization), and anaerobic contribution all significantly associated with faster TT times. These sex differences may be reflective of the larger range of TT times among the females and, thus, greater heterogeneity (ie, 192–229 s [a 37-s difference] for the females and 156–181 s [a 25-s difference] for the males).

A secondary aim of the current study was to determine whether the VO2max attained during the RAMP and the peak VO2 attained during the TT would differ for male or female skiers. While the 2 values did not differ significantly for the males, the peak VO2 during the TT was significantly higher than VO2max for the females, as well as for all participants combined. These differences reflected likely practical differences for the females and possible practical differences for the males and all athletes combined, indicating that a TT test may not only be used to derive a measure of VO2max, but may also elicit higher VO2max values than a traditional RAMP. Indeed, a recent study has criticized the use of standard incremental exercise tests for the assessment of VO2max, suggesting that true maximal values are not necessarily elicited. In addition, maximal cycle-ergometer tests have consistently shown that VO2max can be attained during 3-minute all-out efforts. However, self-paced TTs have seldom been used in the laboratory to assess VO2max, despite being considered reliable for monitoring performance and more representative of racing conditions. While further examination is required and alternative protocols need to be tested, the current data suggest that a short, exhaustive, self-paced TT may be superior for determining VO2max.

The Bland–Altman plots showed a bias toward a higher peak VO2 during the TT compared with the VO2max during the RAMP (1.85 ± 6.37 mL · kg⁻¹ · min⁻¹ for all participants combined; range –4.4 to 7.1 mL · kg⁻¹ · min⁻¹), and with only 5 of the 24 participants eliciting higher values in the RAMP, the evidence appears to strongly favor the use of a TT for assessing VO2max. This is particularly so for the females, who all achieved a higher peak VO2 in the TT. The explanation for this difference is unclear but may be related to a lower muscle mass in females and/or different technical abilities, which could limit performance at greater inclines during a RAMP. Although the specific mechanisms leading to a higher peak VO2 during the TT compared with the RAMP are currently unclear and suggestions are speculative, motivation and effort appear not to be an issue since the ratings of perceived exertion at the end of the 2 tests were not different for the males, females, or all participants combined. Further investigations are required to elicit the underlying physiological mechanisms, as well as to extend the current findings to other exercise modes and populations.

**Practical Applications**

The current study demonstrates that there are physiological and performance differences between male and female athletes during short, self-paced, exhaustive bouts. These findings are important to consider when assessing mixed-sex groups, whereby the same test may elicit different physiological demands.

Current findings also suggest that a self-paced TT lasting ~3 minutes may provide a valid measure of VO2max for both male and female cross-country skiers.
This type of “closed-end” test may be preferable to a standard “open-ended” incremental test since it is more event-specific. Moreover, the TT used in the current study takes less time to complete than a standard incremental test, and the test duration more predictable, which is advantageous in test settings where time is both limited and costly. Self-paced, closed-end tests also remove the need for experimenters to self-select stage speeds and increments appropriate to individuals.

Conclusions

The current study has shown that the time taken to complete a 600-m TT at 7° using diagonal skiing was longer for females than males, the anaerobic contribution was lower for females, and the fractional utilization of VO2max was higher. Although unclear, the AOD may also be lower among junior female athletes compared with their male counterparts. A self-paced TT lasting ~3 minutes may also provide a measure of maximal aerobic capacity among cross-country skiers.

Acknowledgments

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References


