Physiological Responses to Exercise on Different Models of the Concept II Rowing Ergometer

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Purpose: The Concept II model C (IIC) rowing ergometer was replaced by the Concept II model D (IID), but the design modifications of the updated ergometer might alter resistance characteristics and rowing technique, thereby potentially influencing ergometer test results. This study evaluated the physiological response to rowing on the IIC and IID ergometers during a submaximal progressive incremental test and maximal-performance time trial. Methods: Eight national-level rowers completed submaximal and maximal tests on the IIC and IID ergometers separated by 48 to 72 h. Physiological responses and calculated blood lactate thresholds (LT1 and LT2) were compared between ergometer models (IIC vs IID) using standardized drag-factor settings. Results: Power output, oxygen consumption, rowing economy (mL O2 · min⁻¹ · W⁻¹), heart rate, blood lactate concentration, stroke rate, and rating of perceived exertion all displayed similar responses regardless of ergometer model. Calculated physiological values equivalent to LT1 and LT2 were also similar between models, except for blood lactate concentration at LT1, which displayed a small but statistically significant difference (P = .02) of 0.2 mmol/L. Conclusions: The physiological response when rowing on IIC and IID ergometers is nearly identical, and testing can therefore be carried out on either ergometer and the results directly compared.

Key Words: oxygen consumption, blood lactate, rowing economy
has determined whether there are physiological differences between the latest 2 models of the Concept II ergometer: model C (IIC) and model D (IID).

The Concept II air-braked rowing ergometer has been popular among researchers and competitive rowers as a sport-specific testing device and indoor trainer. Results from progressive incremental tests performed on Concept II ergometers are commonly used to interpret physiological adaptations to rowing training and to provide specific training-intensity recommendations. Many sport-science laboratories and training centers therefore have data from physiological tests conducted on the IIC ergometer. The introduction of the IID model, however, means that test results will be compared between ergometers when laboratories have upgraded to the IID ergometer or when rowers are tested at multiple locations using different Concept II ergometers. The IID rowing ergometer was introduced in 2003 to update and replace the IIC model. New features of the IID ergometer are an updated work-monitor unit, altered flywheel enclosure, and redesigned ergonomic handle. Although the latter changes reduce operational noise and improve the “feel” of the ergometer, flywheel-enclosure modifications might alter damping characteristics and therefore resistance, even though other resistance determinants such as flywheel moment of inertia and chain gearing have remained the same. Although any variations in resistance should be accounted for by the drag-factor setting, physiological differences might be apparent if the drag factors of the IIC and IID ergometers are different or the new handle design alters rowing technique. Any such difference would affect test results and confound comparisons between physiological data obtained on the different Concept II ergometer models. This study therefore determined whether the results from both ergometers are equivalent by comparing the physiological responses to incremental rowing to exhaustion on the IIC and IID ergometers.

**Methods**

**Subjects**

Eight experienced rowers (men, n = 6; women, n = 2) participated in the study. All had >5 years training experience and were members of a national-level training squad; 4 had been members of the Australian national team. Each rower and his or her coach provided informed consent to participate, and the experimental protocol had previously been approved by the Australian Institute of Sport Ethics Committee.

**Experimental Protocol**

Each participant completed 3 identical trials over 5 to 8 days. Trial 1 familiarized each rower with the IID ergometer and test protocol. Familiarization was not required for the IIC ergometer because all rowers had considerable experience with this model from prior indoor training and testing. A randomized crossover design then ensured that half the rowers performed trial 2 on the IID ergometer and half on the IIC ergometer before swapping ergometers for trial 3. All sessions were separated by 48 to 72 hours to allow complete recovery between tests, which were scheduled for the same time of day to control for diurnal variation. Subjects were instructed to eat similar meals and limit training to light workloads during the 24 hours before testing.
Incremental Rowing Protocol

The progressive incremental test protocol of Hahn et al\textsuperscript{5} was modified to comprise 5 × 4-minute submaximal stages and a single 4-minute maximal stage. The initial workload and progression of intensity were prescribed according to rower category (ie, male or female, lightweight or heavyweight). Men started with an initial workload of 150 W, with stage progressions of 40 W and 30 W for heavyweights and lightweights, respectively. Heavyweight women started at 125 W and progressed in 25-W increments. No lightweight women participated in this study. The submaximal stages were separated by 1-minute recovery periods, with a 5-minute rest before the maximal stage. Subjects were then instructed to complete as much distance as possible during the 4-minute maximal time trial. Blood lactate concentration (BLa; Lactate Pro, Arkray Inc, Shiga, Japan) was determined by analysis of capillary blood samples collected from the ear lobe: before the test, during each recovery period, immediately after maximal exercise, and 4 minutes after maximal exercise. Submaximal BLa was used to ensure that all subjects presented at the maximal stage in a “similar” physiological condition. If BLa exceeded 4 mmol/L before the fifth submaximal stage, the remaining submaximal stages were omitted and the 5-minute recovery period before the maximal stage began immediately. As a result of this condition, 3 of the 8 subjects completed only 4 × 4-minute submaximal stages and the single 4-minute maximal stage during each of the trials.

On arrival at the laboratory, subjects were weighed in minimal clothing on a calibrated digital scale (Teraoka Seiko Co, Tokyo, Japan) and allowed to perform preexercise stretches. Once they were comfortably seated on the ergometer, the drag factor was set to 130 for heavyweight men and 120 for heavyweight women and lightweight men. During exercise, mixed expired air passed through a Hans Rudolph R2700 valve (Kansas City, MO, USA) into aluminized 200-L Mylar collection bags that were connected to a fully automated indirect calorimetry system (AIS, Belconnen, ACT, Australia). This system has been described elsewhere.\textsuperscript{6} The Ametek (Applied Electrochemistry, Pittsburgh, PA, USA) O$_2$ and CO$_2$ analyzers were calibrated before each test using 3 precision-grade gases (BOC Gases Australia Ltd, Sydney, Australia) that spanned the physiological range of measurement. Both gas analyzers were also checked for drift after each test. Oxygen consumption (VO$_2$) and carbon dioxide production (VCO$_2$) were calculated at 30-second intervals throughout each stage. The VO$_2$ for each workload was defined as the highest O$_2$ consumption attained during 2 consecutive 30-second sampling periods. Our typical error for this measurement is 2.6%. Average power output, stroke rate, heart rate (HR), and rating of perceived exertion were recorded on completion of each workload. HR during each test was monitored using short-range telemetry (S610i, Polar Electro Oy, Kempele, Finland), and rating of perceived exertion was ascertained using the 15-point Borg scale.\textsuperscript{7} Automated software (ADAPT Software, AIS, Belconnen, ACT, Australia) determined lactate thresholds from the power output–BLa relationship using third-order polynomial regression. Lactate threshold 1 (LT$_1$; aerobic threshold) was defined as the point at which BLa began to increase above resting levels. Lactate threshold 2 (LT$_2$; anaerobic threshold) was defined as the point on the polynomial regression curve that yielded the maximum perpendicular distance to the straight line formed by joining LT$_1$ and peak BLa (modified Dmax). HR, power output, and VO$_2$ at LT$_1$ and LT$_2$ were subsequently determined using ADAPT.
Statistical Analyses

Because 3 subjects did not complete the required $5 \times 4$-minute submaximal workloads before displaying a BLu of 4 mmol/L, data from the first 4 submaximal stages were used for subsequent analyses for all subjects. Submaximal time-course data were analyzed using a $4 \times 2$ factorial-design ANOVA with repeated measures on both dimensions (Statistica for Windows, Tulsa, OK, USA). Maximal-performance data and physiological variables corresponding to LT$_1$ and LT$_2$ were compared between ergometer models using dependent $t$ tests. Statistical significance was set at the .05 level. All data are expressed as mean (SD).

Results

Descriptive Characteristics

The peak-performance characteristics for the subjects are listed in Table 1. Peak power ranged from 358 to 479 W for men and 254 to 318 W for women. The inclusion of heavyweight and lightweight rowers among the men’s group contributed to the broad range in peak power outputs.

Submaximal Performance

Figure 1 and Table 2 present data for both ergometer models during the $4 \times 4$-minute submaximal workloads and the $1 \times 4$-minute maximal-performance trial. Despite the trend for BLu and rowing economy (Figure 2) to be higher on the IID ergometer during submaximal exercise, there were no statistically significant differences for either of these variables. Only VCO$_2$ ($P < .001$) and respiratory-exchange ratio ($P = .03$) displayed statistically significant main effects for ergometer model. Despite these, the actual differences across all submaximal stages were only 0.08 to 0.12 L/min for VCO$_2$ and 0.01 to 0.03 for respiratory-exchange ratio and were therefore not physiologically significant.

Maximal Performance

There were no significant differences between results from the 4-minute maximal-performance trials on the IIC and IID ergometers. Performance between ergometers was very reproducible, with a mean difference of only 1.7 W (range –8.5 to 8.4 W).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Subject Description and Performance Characteristics During 4 Minutes of Maximal Ergometer Rowing for Men (n = 6, Mean [SD]) and Women (n = 2, Mean [Range])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>VO$_{2\text{peak}}$ (L/min)</td>
</tr>
<tr>
<td>Men</td>
<td>82.3 (11.3)</td>
</tr>
<tr>
<td>Women</td>
<td>80.8 (75.7–86.1)</td>
</tr>
</tbody>
</table>

Abbreviations: VO$_{2\text{peak}}$, peak oxygen consumption; P$_{\text{peak}}$, average power during the 4-minute maximal performance trial.
Figure 1 — (a) Blood lactate concentration and (b) heart rate during the incremental rowing protocol performed on Concept model IIC (white diamonds) and IID (black triangles) ergometers.
<table>
<thead>
<tr>
<th>Workload</th>
<th>Power (W)</th>
<th>SR (strokes/min)</th>
<th>RPE (6–20)</th>
<th>VO(_2) (L/min)</th>
<th>VCO(_2) (L/min)</th>
<th>RER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IIC</td>
<td>IID</td>
<td>IIC</td>
<td>IID</td>
<td>IIC</td>
<td>IID</td>
</tr>
<tr>
<td>1</td>
<td>145 (12)</td>
<td>145 (12)</td>
<td>17 (2)</td>
<td>17 (2)</td>
<td>7 (2)</td>
<td>7 (2)</td>
</tr>
<tr>
<td></td>
<td>2.65 (0.22)</td>
<td>2.65 (0.31)</td>
<td>2.20 (0.21)</td>
<td>2.28 (0.30)</td>
<td>0.83 (0.06)</td>
<td>0.86 (0.05)</td>
</tr>
<tr>
<td>2</td>
<td>177 (17)</td>
<td>176 (17)</td>
<td>18 (1)</td>
<td>18 (2)</td>
<td>10 (3)</td>
<td>9 (2)</td>
</tr>
<tr>
<td></td>
<td>3.08 (0.30)</td>
<td>3.14 (0.31)</td>
<td>2.74 (0.32)</td>
<td>2.86 (0.30)</td>
<td>0.89 (0.05)</td>
<td>0.91 (0.05)</td>
</tr>
<tr>
<td>3</td>
<td>209 (23)</td>
<td>208 (23)</td>
<td>19 (2)</td>
<td>19 (1)</td>
<td>12 (2)</td>
<td>12 (1)</td>
</tr>
<tr>
<td></td>
<td>3.54 (0.35)</td>
<td>3.57 (0.37)</td>
<td>3.29 (0.41)</td>
<td>3.37 (0.40)</td>
<td>0.93 (0.06)</td>
<td>0.94 (0.05)</td>
</tr>
<tr>
<td>4</td>
<td>241 (29)</td>
<td>242 (28)</td>
<td>21 (2)</td>
<td>21 (2)</td>
<td>14 (2)</td>
<td>14 (1)</td>
</tr>
<tr>
<td></td>
<td>3.94 (0.40)</td>
<td>3.97 (0.43)</td>
<td>3.78 (0.52)</td>
<td>3.87 (0.45)</td>
<td>0.96 (0.06)</td>
<td>0.98 (0.06)</td>
</tr>
<tr>
<td>Max</td>
<td>378 (71)</td>
<td>377 (68)</td>
<td>35 (4)</td>
<td>36 (2)</td>
<td>20 (0)</td>
<td>20 (0)</td>
</tr>
<tr>
<td></td>
<td>4.81 (0.51)</td>
<td>4.87 (0.57)</td>
<td>5.47 (0.92)</td>
<td>5.58 (0.78)</td>
<td>1.13 (0.09)</td>
<td>1.15 (0.08)</td>
</tr>
</tbody>
</table>

Abbreviations: SR, stroke rate; RPE, rating of perceived exertion; VO\(_2\), oxygen consumption; VCO\(_2\), carbon-dioxide production; RER, respiratory-exchange ratio.
Blood Lactate Thresholds

Table 3 contains the LT$_1$ and LT$_2$ BLa thresholds calculated from the third-order polynomial of the BLa–power output relationship and the value of selected physiological variables equivalent to LT$_1$ and LT$_2$. Apart from LT$_1$ BLa ($P = .02$), there were no statistically significant differences between the 2 ergometer models, although the practical significance of this 0.2-mmol/L difference is limited. LT$_1$ occurred at 65% of maximal VO$_2$ (VO$_2$ peak) and 79% of peak HR during the maximal stage (HRpeak), whereas LT$_2$ occurred at 86% of VO$_2$ peak and 92% of HRpeak.

Discussion

Our study is the first to show that the physiological responses to progressive exercise on the IIC and IID models of Concept II rowing ergometer are essentially identical despite the new design of the IID model. The current study evaluated the physiological responses to an incremental submaximal rowing test and maximal-performance trial on Concept IIC and IID ergometers. The results indicate that there are only minor differences between the models, with greatest variation seen during maximal performance. This therefore ensures that direct comparisons between the results from the 2 ergometer models are valid.

Differences between IIC and IID ergometers were less than or similar to those reported in the literature between other ergometer designs. Comparisons between Gjessing and early-model Concept II ergometers report mean power differences of 21.8 W$^1$ and 39.0 W$^2$ during simulated racing and incremental tests, respectively, compared with the 1.7-W difference (Table 2) during the maximal stage in the current investigation. Despite our small discrepancy in average power,
<table>
<thead>
<tr>
<th>Ergometer</th>
<th>LT₁</th>
<th>LT₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power (W)</td>
<td>BLa (mmol/L)</td>
</tr>
<tr>
<td>IIC</td>
<td>176 (27)</td>
<td>1.2 (0.4)</td>
</tr>
<tr>
<td>IID</td>
<td>180 (25)</td>
<td>1.4 (0.4)</td>
</tr>
</tbody>
</table>

Abbreviations: BLa, blood lactate concentration; VO₂, oxygen consumption; HR, heart rate.

* Significantly different from the Concept IIC ergometer (P = .02).
VO\textsubscript{2} peak differed by 0.06 L/min between the Concept II models compared with 0.04 L/min between ergometer designs.\textsuperscript{1} Response variables such as minute ventilation, HR, and BL\textsubscript{a} have also been compared across Concept II, Gjessing, and Rowperfect designs. Differences between these designs span 3.1 to 5.0 L/min for minute ventilation,\textsuperscript{1,3} 0.1 to 0.6 mmol/L for BL\textsubscript{a},\textsuperscript{1,3} and 0 to 4 beats/min for HR.\textsuperscript{1,3} Furthermore, maximal stroke rate is reported to be 1 point higher on the Gjessing than on the Concept II.\textsuperscript{1} Thus, with the exception of VO\textsubscript{2}, all variables in the current study displayed greater agreement between Concept IIC and IID models than that between ergometer designs. Despite our greater variation in VO\textsubscript{2} between the 2 ergometer models than previously reported,\textsuperscript{1} this value is well within the typical error for this measurement in our laboratory at maximal intensity (0.13 L/min) and thus represents normal test–retest variation.

**Practical Applications**

The present study attempted to replicate the conditions under which athletes present for routine testing. They were therefore asked to refrain from strenuous exercise in the preceding 24 hours and consume a similar meal, high in carbohydrate, before each test. In addition, all tests were undertaken at the same time of day, and the order effect for the final 2 ergometer trials was controlled by counterbalancing. Despite these intended controls, some subjects might have presented to the laboratory in a physiological state that was not consistent with previous trials. This might have affected the integrity of our HR and BL\textsubscript{a} measurements. This is the “real world” situation, however, and we should therefore be prepared to expect this variation for test–retest scenarios.

Another potential limitation was that power output was recorded directly from the ergometer display units and not by independent measurement of handle force and displacement. Directly measured power outputs of the Concept IIC and IID rowing ergometers demonstrate that their display units underestimate power by 5.1\%\textsuperscript{2} and 6.6\%,\textsuperscript{9} respectively. Although power output was not directly measured in our investigation, both Concept II ergometer models are reported to use the same algorithm to calculate power.\textsuperscript{9} Nevertheless, despite potential inaccuracy in calculated power, there appeared to be very little between-trials variation in the displayed power outputs during submaximal exercise and only slightly greater variation in peak power outputs during the maximal-performance trial. Indeed, the variation between ergometer models during the maximal-performance trial was well within the typical error of 2.8\% for this equipment in our laboratory and can therefore be explained by normal between-days variation in performance. In addition, because our investigation compared a used IIC model with a brand-new IID model, chain tension and the elasticity of the chain-return mechanism might have differed between ergometers, neither of which are accounted for in power-output or drag-factor calculations.\textsuperscript{9} Although there was no way to directly compare or control for these potential differences, both ergometers used throughout this investigation were well maintained, and the IIC model had experienced minimal operation because it had only been used for laboratory testing. Furthermore, the reproducibility of the measured physiological variables suggests that mechanical differences between the ergometers were negligible. Ideally, dynamic calibration
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of the Concept II ergometer would account for differences between true power and that displayed by the work-monitor unit, but such a calibration procedure would be exceedingly difficult for this style of ergometer.

Because the IID ergometer incorporates an altered flywheel enclosure and modified handle grip, resistance characteristics and rowing technique could potentially be changed. For example, because the leg drive along the slide and ultimate finish position are limited by leg length and practical limits to hip and trunk extension, many rowers (particularly heavyweight men) attempt to maximize stroke length at the front of the slide by allowing the handle to retract within several centimeters of the ergometer’s frame. Because the IID handle design positions the hands farther from the chain-handle interface, the same hand position at the catch results in less handle displacement and therefore shorter stroke length than with the IIC model. As such, close inspection of the IID model reveals that handle displacement would differ by a maximum of 4 cm only if the handle were allowed to touch the ergometer frame. Rowers would therefore be required to apply greater force at an identical stroke rate or a higher stroke rate at the same handle force to achieve the same power output on the IID as on the IIC model. We therefore anticipated that the design of the IID ergometer might have altered rowing-stroke mechanics and economy (mL O\textsubscript{2} · min\textsuperscript{-1} · W\textsuperscript{-1}), thereby resulting in an increased O\textsubscript{2} cost. When rowing economy was calculated, there were subtle differences between the 2 ergometer models in the anticipated direction (Figure 2), but none of them was large enough to be statistically significant. Except for the first submaximal stage, mean economy throughout all exercise intensities was better on the IIC model, with O\textsubscript{2} costs during maximal exercise of 12.9 mL O\textsubscript{2} · min\textsuperscript{-1} · W\textsuperscript{-1} on the IIC and 13.1 mL O\textsubscript{2} · min\textsuperscript{-1} · W\textsuperscript{-1} on the IID. Stroke rates during the corresponding submaximal and maximal workloads were also virtually identical (Table 2), thereby reinforcing the reproducibility of physiological responses when completing exercise on either ergometer model and rejecting our assertion that the different handle designs would alter stroke mechanics and O\textsubscript{2} cost. The observed discrepancy in rowing economy might therefore be the result of slight differences in intrastroke work output resulting from subtle between-trials deviations in stroke rate.

Differences between ergometer models were greatest during the maximal stage of the incremental test. This was largely because of within-subject standardization of average power during the submaximal stages. Unlike exercise tests performed on a treadmill or cycle ergometer, fixed constant power output cannot be predetermined on rowing ergometers: Control of power output therefore somewhat depends on the skill of the rower. Differences between ergometers at submaximal workloads are therefore mainly caused by the rower’s ability to self-pace. All subjects were skilled rowers with previous testing experience, but the most experienced athletes were better able to reproduce the target submaximal workloads. Rowers were not provided with target workloads during the maximal stage but were instructed to complete as much work as possible during the 4-minute stage. Although most rowers adopted a pacing strategy during the first half of the maximal trial, to ensure that they would be able to complete the entire stage, the potential for differences resulting from poor self-pacing was greater than in the submaximal stages. Therefore, although the response to maximal exercise was more variable than during submaximal workloads, it is likely that performance depended more on subject presentation and pacing than on the model of Concept II ergometer.
Conclusions

Incremental exercise performed on the Concept IID ergometer elicits a physiological response that is equivalent to that on the IIC model. Direct comparisons between test results obtained on these models of the Concept II rowing ergometer are therefore valid.

Acknowledgments

This investigation was funded by the National Sport Science Quality Assurance Program (Australian Institute of Sport, Belconnen, ACT, Australia 2616).

References