Effect of Blood Lactate Sample Site and Test Protocol on Training Zone Prescription in Rowing

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Purpose: To assess the effect of sample site (earlobe vs toe) and incremental exercise protocol (continuous vs discontinuous) on training zone prescription in rowing. Methods: Twenty-six rowers performed two incremental exercise tests on an ergometer: (1) a five-step discontinuous test with 4-min stages and 30-W increment, with blood samples taken from the earlobe and toe at the start of the 1-min break between steps; (2) a continuous test, with 2-min stages and 30-W increment, with blood samples taken from the right first toe at the end of each stage. Blood was analyzed for lactate concentration. Results: At a lactate concentration of 2 mmol·L⁻¹, the mean (95% CI) power output was 8.1 (±15.4) W greater for the continuous protocol, the random error between the methods (1.96 × SD of differences) was ±58.8 W, and there was no evidence of any relationship between power output and error between methods. At a lactate concentration of 4 mmol·L⁻¹, the mean (95% CI) power output was 24.2 (±17.0) W greater for the continuous protocol, and the random error was ±64.8 W. At 4 mmol·L⁻¹, systematic bias between methods increased with high power outputs. Conclusions: The continuous protocol with toe sampling led to higher power outputs for a given lactate concentration compared with the discontinuous protocol with earlobe sampling. This was partly due to the choice of sample site and largely due to the choice of protocol. This bias, and also random variability, makes direct comparison of these tests inappropriate.

Keywords: ergometry, discontinuous exercise, continuous exercise, toe-tip sampling

Measurement of blood lactate concentration during exercise tests is a well-documented method of assessing an individual athlete’s training status, and can be used in the subsequent prescription of a training regimen for that individual.1–6 The world governing body of rowing, the Fédération Internationale des Sociétés d’Aviron (FISA), has provided training and assessment guidelines that involve prescription of the intensity of training sessions according to blood lactate levels.1 Training zones are described, where the “utilisation 1” (UT1) training zone is defined as the work rates that elicit blood lactate concentrations of between 3 and...
4 mmol·L\(^{-1}\). Similarly, an athlete is said to be exercising in the “utilisation 2” (UT2) zone if their blood lactate is between 2 and 3 mmol·L\(^{-1}\). It is common in high-level rowing, therefore, for athletes to perform incremental exercise tests to define the training zones for each individual. These tests involve blood sampling and subsequent analysis for lactate concentration.

Common sample sites for capillary blood sampling are the earlobe and fingertip.\(^7\)–\(^11\) The vigorous body movement during rowing ergometry means that taking blood samples from these sites during the exercise is impossible, and so a discontinuous incremental protocol is the one used by many laboratories.\(^12\)–\(^15\) The toe of a rower provides a potential site for blood sampling during exercise as the foot remains relatively stationary during the rowing action. This was recognized by Forsyth and Farrally\(^9\) who compared blood lactate concentration in plasma collected from the toe, ear, and fingertip after simulated rowing. They claimed that lactate concentrations did not differ significantly from site to site.

This is not a universal view, however. Dassonville et al.\(^7\) compared lactate at different sample sites during cycle ergometry, and found that lactate values from the earlobe were lower than from the fingertip. They speculated that this difference might be at least partly attributable to the local production of lactate by the hand muscles gripping the handlebars rather than the muscles producing the external work. It could be hypothesized, therefore, that measurement of lactate in capillary blood taken from the toe during rowing might be higher than simultaneous measurements at the earlobe due to contraction of the muscles of the feet and lower limbs.

Bland and Altman\(^16\) have elaborated their methods for appraisal of the agreement between methods. Together with the conventional explorations of systematic and random error between methods, they outlined how to examine whether these two components of error depend on the size of the measured value. Regression methods were cited as useful tools for exploring whether the systematic error is uniform over the range of measurements.

Lactate profiles provide the basis of exercise program prescription for many rowers, and therefore accurate assessment is crucial. The aim of this study was to compare two incremental protocols used for prescription of training zones in rowing—a novel continuous protocol and an established discontinuous protocol—including an assessment of the effect of sample site and protocol on blood lactate determination.

**Method**

Fourteen men and 12 women gave their written informed consent to participate. Mean \(\pm\) standard deviation age, height, and weight for the men were: 22 \(\pm\) 4 years, 1.85 \(\pm\) 0.08 m, 86 \(\pm\) 16 kg; and for the women were: 23 \(\pm\) 7 years, 1.74 \(\pm\) 0.08 m, 69 \(\pm\) 11 kg. Twenty-two subjects were competitive rowers and four subjects were well-trained recreational athletes who used the ergometer as part of a fitness regimen. This study was approved by the local Ethics Advisory Committee, and conformed to the principles outlined in the Declaration of Helsinki.
Each subject performed one maximal 2000-m time trial on a rowing ergometer (Model C; Concept II, Morrisville, VT, USA), to determine appropriate work rates for the discontinuous incremental protocol described below. Subsequently, on separate days not more than 1 week apart and at the same time of day, each subject performed between two and four incremental tests. Each test was either discontinuous or continuous (DIS or CON), with the type of test selected randomly.

For the incremental tests, subjects rowed each stroke of each stage as closely as possible to a prescribed work rate. Average work rate and stroke rate for each stage was measured. The first time an athlete performed an incremental test, they self-selected their stroke rate for each stage. On subsequent repetitions of the same test, athletes rowed with the rating profile chosen in the earlier test.

**Continuous Test**

Subjects immersed their right foot in water at 42°C for 10 minutes. After removal from the water, subjects began exercising at a work rate of 60 W, with 30-W increases in workload every 2 minutes (Figure 1A). This protocol thus closely mimics the standard “ramp” protocol employed in many other investigations, where a steady-state is never achieved and instead there is a relatively smooth increase in work rate. Ramp protocols are usually employed in cycle ergometry, where it has been shown that this increment of 15 W·min⁻¹ (or 30 W every 2 minutes) is suitable for determination of gas exchange thresholds and maximal oxygen uptake, for example. Blood was sampled at 2-minute intervals from the right first toe for the duration of this continuous protocol (CONtoe). The test was terminated when the subject was not able to maintain the required work rate.

During the test, strategies were employed to keep the foot warm and ensure good blood flow, with the combination used being determined by individual subject preference. These strategies were: the use of fan heater expelling warm air toward the right foot; the placement of preheated gel pads on the foot; and the use of socks and shoes with the toe cut out.

**Discontinuous Test**

The other incremental test involved five 4-minute exercise bouts with a 1-minute break between stages, when blood was sampled at the right earlobe (DISear; Figure 1B). The fifth stage was set at a work rate 30 W below the average work rate achieved in the 2000-m time trial, and each preceding stage was ramped down by 30 W (Figure 1B). For eight athletes, blood was also sampled from the toe as described above (DISToe) by a second experimenter, simultaneously with the earlobe sample.

**Lactate Analysis**

Small samples of capillary blood were collected from a puncture wound on the toe or earlobe for immediate measurement of lactate concentration using an automated
Figure 1 — Schematic diagrams illustrating: (A) the continuous protocol, with 30-W increments every 2 minutes, starting from 60 W; and (B) the discontinuous protocol, with five stages of 4 minutes, with a 1-minute interval between stages (this profile is representative of a rower who achieved a time of 386 s, average work rate 390 W, for the 2000-m time trial).
portable lactate analyser (Lactate Pro LT-1710; Arkray, Kyoto, Japan) that has previously been shown to have good validity and reliability.17–19

Data Analysis

For each of the protocols, the work rates corresponding to lactate concentrations of 2 and 4 mmol·L−1 were determined from interpolation of the blood lactate versus power curves. Paired Student’s t-tests were performed (level of significance set at \( P < .05 \)) and 95% confidence intervals (CI) were calculated, to assess:

1. Test–retest reliability for like tests (number of tests for CONtoe = 16, DIStoe = 16, DISear = 40).

2. The effect of sampling site on threshold work rates (number of tests for DISear vs DIStoe = 16).

3. The effect of protocol on threshold work rates for toe blood lactate sampling (number of tests for DIStoe vs CONtoe = 16).

4. The effect on threshold work rates of the established protocol compared with our novel protocol (number of tests for DISear vs CONtoe = 34).

Limits of agreement (LOA) analysis was performed to investigate bias and random error of the measurements, and any relations of these error components to the size of the measured value, following the recommendations of Bland and Altman16 and Atkinson and Nevill.20

Results

The average number of stages completed in the CON test was eight (range 6 to 11), therefore peaking at 270 (range 210 to 360) W in 16 (range 12 to 22) minutes, providing appropriate and sufficient data for threshold discrimination.

The reliability tests show that repeat measurements at the same sample site for the same protocol are reliable (Table 1, rows 1 to 3), with the highest average test–retest difference being less than 4 W for the DIStoe repeatability, which reflects a small test–retest variability in both the subject and the sample method. However, systematic and random errors were larger when different sample sites (Table 1, row 4) or protocols (Table 1, row 5) or a combination of both (Table 1, row 6) were compared. The effect of different sample site (DISear vs DIStoe) was smaller than the effect of different protocol (DIStoe vs CONtoe), as shown by the smaller values for test–retest difference and random error in rows 4 and 5 of Table 1. Systematic and random errors were at their largest when both sample site and protocol were changed (DISear vs CONtoe; Table 1, row 6).

These errors are illustrated further in the LOA plots shown in Figure 2. Because these comparisons can be made in various permutations, four separate tests per individual would be needed in order for all 26 subjects to contribute to each comparison. However, most subjects performed only two tests, which is why there are fewer than 26 data included in each plot in Figure 2.

The comparison of the established protocol (DISear) and the novel protocol (CONtoe) is of most interest. At a lactate concentration of 2 mmol·L−1, the mean power output was 151.4 W for DISear and 159.5 W for CONtoe, ie, 8.1 (95% CI = −7.3 to 23.5) W greater for CONtoe (Table 1). The random error between the
Table 1  Comparisons of Repeated Measurements to Assess Test–Retest Reliability

<table>
<thead>
<tr>
<th></th>
<th>At 2 mmol·L⁻¹</th>
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<th>At 4 mmol·L⁻¹</th>
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<tr>
<td></td>
<td>Test–retest mean (W)</td>
<td>Test–retest difference (W)</td>
<td>95% CI (W)</td>
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<td>CONtoe vs CONtoe</td>
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<td>0.0</td>
<td>0.6</td>
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<td>DIStoe vs DIStoe</td>
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<tr>
<td>DISear vs CONtoe</td>
<td>156</td>
<td>−8.1</td>
<td>15.4</td>
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*Indicates statistical significance at \( P < .05 \). CON indicates the continuous test and DIS discontinuous. 95% CI is the 95% confidence interval. Negative test–retest differences indicate a higher work rate for the CON test.
methods (1.96 × SD of differences) was ± 58.8 W (95% CI = 43.7 to 89.6 W), and there was no evidence of any relationship between power output and systematic or random error between methods (Figure 2).

At a lactate concentration of 4 mmol·L⁻¹, the mean power output was 194.3 W for DISear and 218.5 W for CONtoe, ie, 24.2 (95% CI = 7.2 to 41.2) W greater for CONtoe (Table 1). The random error was ± 64.8 W (95% CI = 48.2 to 98.4 W). There was evidence that systematic bias between methods increased with the subjects who recorded particularly high power outputs. Regression analysis was employed to describe the slope of this increase in bias.¹⁶ The regression equation for the relationship between power output and bias between methods was:

\[ Y = -0.5x + 82 \quad r^2 = 0.2 \]

The regression equation can be interpreted as meaning that for every 10-W change in individual power output the systematic bias between the two methods would increase by approximately 5 W (ie, the coefficient of \( x = -0.5 \)).
There was a difference in measurements due to choice of sample site—shown by the simultaneous measurements from the ear and toe (DISear and DIStoe). When each pair of measurements is considered (N = 65 pairs), the average blood lactate concentration at the toe was 3.9 mmol·L⁻¹ and 4.3 mmol·L⁻¹ at the ear. This difference of 0.4 mmol·L⁻¹ (95% CI = ± 0.3 mmol·L⁻¹) was significant (P = .002). LOA analysis reveals that the measurements made at the toe are higher than the ear at low blood lactate concentrations, but the opposite is true at high blood lactate concentrations (Figure 3).

**Discussion**

These data show good repeatability for identical tests, in determining work rate at 2 and 4 mmol·L⁻¹ blood lactate concentration (Table 1). Systematic differences occur when comparing nonidentical (in blood sample site and/or protocol) tests. Some of this difference is due to choice of sample site, as these data have shown differences between measurements at the toe and the ear (Table 1, Figures 2 and 3). A more substantial source of systematic difference is in the choice of protocol, with the differences becoming larger when comparing the established and novel protocols, as these differ in both sample site and protocol (Table 1, Figure 2).

The novel continuous protocol with blood sampling from the toe resulted in lactate-prescribed training zones at a higher work rate than the established discontinuous protocol. At 4 mmol·L⁻¹ blood lactate, the average difference was 24 W, but this systematic error could be as high as 40 W for particularly fit subjects (rowers who might record a power of 250 W at 4 mmol·L⁻¹)—the subject population most likely to undergo such testing. The application of the methods proposed

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**Figure 3** — Limits of agreement plot comparing lactate measurements taken simultaneously from the toe-tip and earlobe, over the full range of work-rates completed by the subjects.
by Bland and Altman\textsuperscript{16} is common in sport and exercise sciences. For the first time in exercise-related measurement data, we found an increase in systematic error with an increase in size of the measured value (in this case, power output at 4 mmol·L\(^{-1}\) blood lactate concentration). The size of the difference in training zone prescription (up to 40 W) is likely to be practically significant, and it could be speculated that this difference would lead to different training sessions and training adaptations.

Importantly, not only was there a difference between protocols in the average power output at the thresholds, but the 95\% limits of agreement were very wide (Figure 2). At 4 mmol·L\(^{-1}\) it would be possible, even if systematic error was eradicated, to have individuals who would show as much as a ±65-W difference in their training zone prescription, depending on the protocol employed. It would be inappropriate, therefore, for laboratories to substitute these two tests, and investigators should ensure that they adhere to the same protocol when performing test–retest comparisons for the same subject at different points in the training cycle, or when comparing different subjects.

Forsyth and Farrally\textsuperscript{9} provided the first evidence that the toe is a practical alternative site to the earlobe for blood sampling during rowing. They measured lactate levels simultaneously at the finger, toe, and earlobe, for constant load rowing ergometer exercise at 76\% and 92\% of maximal heart rate (HR\textsubscript{max}), and found no statistically significant difference between sites. However, the data provided in Forsyth and Farrally’s paper\textsuperscript{9} can be reconstructed to calculate LOAs. A comparison of toe and earlobe sampling sites results in LOAs of 1.6 mmol·L\(^{-1}\) at 76\% HR\textsubscript{max} and 3.0 mmol·L\(^{-1}\) at 92\% HR\textsubscript{max}. It is clear that agreement between sites was poor, with the possibility of subjects showing as much as ±3 mmol·L\(^{-1}\) difference between the toe and earlobe at the higher exercise intensity, and variation in sites worsened as lactate concentration got higher—ie, at the higher exercise intensities. These patterns were also evident for comparisons between the finger and earlobe, and between the finger and toe, and choice of site was therefore also likely to result in nonidentical prescription of training zones.

The results of the current study agree with previous similar work.\textsuperscript{8,21–23} Ferry, Duvallet, and Rieu\textsuperscript{8} measured blood lactate from the earlobe for cycle ergometry and employed two protocols: one continuous incremental with 30-W increments, and one discontinuous incremental, with 1-minute breaks in-between 30-W increments. They found that the continuous protocol resulted in a higher work rate estimation at 4 mmol·L\(^{-1}\) lactate—a similar finding to the current study. Bentley, McNaughton, and Batterham\textsuperscript{21} determined lactate threshold during two incremental cycle protocols of different stage duration (3 and 8 minutes) and found that for well-trained cyclists, the shorter stage duration resulted in a higher work rate at lactate threshold. It should be remembered that blood lactate response is not only dependent on work rate, but is also dependent on exercise duration and exercise performed immediately before blood sampling. There is a delay between muscle lactate production and appearance in the sampled blood. Two minutes (the stage duration in this study) may not be long enough for the lactate concentration to reflect the work rate that the subject’s muscles are working at in the continuous protocol, leading to an overestimation of the exercise intensity at these thresholds. In addition, a steady state of blood lactate concentration may not even be attainable...
at high work rates. These factors could conceivably account for the discrepancy in this study between the work rates determined for the two tests at 4 mmol·L⁻¹, and are mechanisms also suggested by Ferry, Duvallet, and Rieu. The sample site may also explain why our protocols do not show good agreement. Dassonville et al. measured blood lactate in samples taken from the earlobe and fingertip during cycling ergometry. They found that lactate values were higher when measured at the fingertip and speculated that this may be due to local production of lactate by muscles in the arm and hand involved in gripping the handlebars. A similar process may be involved in rowing—many muscle groups are active, and the pattern of muscle recruitment may result in local differences in blood lactate concentration. However, we found that on average, and particularly at the higher intensities, blood lactate concentrations were lower at the toe than at the earlobe (Figure 3). This contradicts the hypothesis that local muscle contraction in the foot will lead to higher local lactate concentration.

**Practical Applications**

It is surprising that the toe has not proved a more popular site for blood sampling in rowing. Every subject in this study reported that sampling from the toe was easily tolerated. The toe benefits from being available while the subject exercises and is available for site cleaning and preparation between sampling. One potential disadvantage is that there is lower blood flow to the toe. We encouraged blood flow to the toe by heating the foot before and during the test, although this may not have been essential in every case. It may also be possible to insert cannulae in the back of the foot for the sampling of venous rather than capillary blood.

It is very common to use electromagnetically braked cycle ergometers for studies of basic exercise physiology, such as studies of oxygen uptake kinetics, control of ventilation or effects of dietary supplementation. These studies have employed intermittent, incremental and steady-state protocols. Cycle ergometers are able to provide smooth controlled changes in work rate, and allow easy access to blood vessels in the stationary arms and hands. Cycling is therefore often the mode of choice for many investigators. It could be argued that the mechanisms investigated in these cycling studies could and should also be investigated using ergometers that employ different muscle masses and muscle groups, different duty cycles, and different ventilatory patterns. However, few other ergometers allow smooth increases in work rate and access to a suitable blood-sampling site. One such ergometer is the rowing ergometer, where the subject controls (and can adjust) the work rate, and the stationary feet provide a site for blood sampling. However, only one study has employed rowing ergometry in this way. A secondary aim of the current study was to investigate the possibility of using rowing ergometers for such studies, and it is clear that further work in this area is necessary.

**Conclusions**

This study suggests that the toe is a practical sampling site for capillary blood, allowing rowers to continue exercising while sampling. This opens up the possibility of simultaneous assessment of other physiological responses such as
gas exchange. It should be noted, however, that lactate measurements at the toe were not in good agreement with measurements at the ear. In addition, in the applied context of training zone determination using FISA's guidelines, there are differences between the measured lactate for a given work rate when comparing the continuous and discontinuous protocols, and only the discontinuous protocol with earlobe sampling should be used for this purpose.

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References