A Prediction Model for Peak Power Output From Different Incremental Exercise Tests

Hans Luttikholt, Lars R. McNaughton, Adrian W. Midgley, and David J. Bentley

Context: There is currently no model that predicts peak power output (PPO) thereby allowing comparison between different incremental exercise test (EXT) protocols. In this study we have used the critical power profile to develop a mathematical model for predicting PPO from the results of different EXTs. Purpose: The purpose of this study was to examine the level of agreement between actual PPO values and those predicted from the new model. Methods: Eleven male athletes (age 25 ± 5 years, VO2max 62 ± 8 mL · kg⁻¹ · min⁻¹) completed 3 laboratory tests on a cycle ergometer. Each test comprised an EXT consisting of 1-minute workload increments of 30 W (EXT30/1) and 3-minute (EXT25/3) and 5-minute workload increments (EXT25/5) of 25 W. The PPO determined from each test was used to predict the PPO from the remaining 2 EXTs. Results: The differences between actual and predicted PPO values were statistically insignificant (P > .05). The random error components of the limits of agreement of ≤30 W also indicated acceptable levels of agreement between actual and predicted PPO values. Conclusions: Further data collection is necessary to confirm whether the model is able to predict PPO over a wide range of EXT protocols in athletes of different aerobic and anaerobic capacities. Key Words: physical work capacity, aerobic fitness, critical power, fatigue

There are a number of physiological variables determined from an incremental exercise test to exhaustion (EXT), such as maximal oxygen consumption (VO2max) and the lactate threshold, which are useful in determining endurance capacity or as indicators of metabolic disease.¹,² An EXT is also now commonly used by scientists to determine maximum workload, which has been used to predict VO2max or assist in prescribing endurance training.⁴,⁶

In cycling exercise, an EXT is used to determine peak power output (PPO), which has been shown to predict performance in endurance cycling tasks.⁷,⁸ However, there is considerable variation in an EXT protocol by way of differences in starting workload, stage duration (minutes), and magnitude of workload increment—each with different outcomes.³ In studies comparing various EXTs of trained cyclists, the PPO attained during an EXT is lower as the length of stages

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increases.\textsuperscript{10-12} For example, it has been shown that the difference in PPO (W) from an EXT comprising stages of 60 seconds in duration with that obtained in an EXT with stages of 3 minutes in duration can be in the range of 60 to 100 W.\textsuperscript{11} This factor has been shown to influence the relationship between PPO, VO\textsubscript{2max}, and endurance performance.\textsuperscript{10-11} Those EXTs that use stages of between 60 seconds and 5 minutes in duration are commonly used for monitoring the effects of training, for talent ID, or for prescription of training intensity.\textsuperscript{5} However, variation of EXT protocol may influence subsequent PPO results and the purpose for which they are being used. For example, an athlete who achieves ~500 W in an EXT that comprises 1-minute stages may achieve a value of ~400 W in an EXT with stages of 3 minutes in duration. If the outcome of the testing is to prescribe power output in training, then submaximal or supramaximal values will be different when expressed as percentages of PPO, as in typical “interval” training programs.\textsuperscript{13} This could affect the acute physiological responses to that kind of training and also subsequent long-term adaptation. Indeed, a recent review article\textsuperscript{14} has highlighted the considerable difference in EXT protocol and PPO results appearing in the literature and also how this might affect comparison of PPO values for performance diagnostics.

Despite the physiological significance of PPO for performance diagnostics and the large variation in EXTs, there is currently no procedure that predicts PPO between EXTs and thereby allows comparison and standardization among EXT protocols. The objective of this study is to present a new model allowing the prediction of PPO. We also examined the level of agreement between actual PPO values obtained from 3 different EXTs completed by trained cyclists and values predicted by the new model.

\section*{Methods}

\subsection*{Theoretical Development of the Prediction Model}

An EXT involves a series of progressively increasing workloads, each sustained for a set duration until exhaustion of the tested individual. Fatigue will occur with increasing power output owing to a variety of biochemical and neurological factors.\textsuperscript{15} In line with these effects, the prediction model was developed assuming the typical metabolic or neurological fatigue response that occurs during an EXT. Time to exhaustion at a certain workload (TTE\textsubscript{WL}) reflects the duration (in minutes) until fatigue occurs when sustaining this workload. In the prediction model, sustaining a workload for the duration of a given stage (SD) of an EXT will contribute to fatigue in proportion to the ratio SD:TTE\textsubscript{WL} (%):

\[ \text{CTF (WL)} = \frac{\text{SD}}{\text{TTE}_{\text{WL}}} \times 100 \]  

(Eq. 1)

where CTF is the contribution to fatigue of sustaining a given WL and SD is the stage duration (in minutes) of the EXT.

During a continuous EXT, there is no recovery from consecutive stages. Any fatigue induced during a stage of an EXT will carry over to the next higher workload. In turn, the remaining exercise capacity and hence the effective TTE at that higher workload are reduced. The moment where the EXT terminates is represented in Equations 2 and 3.
\[
\text{SUM}_{i=1 \ldots n-1} (\text{CTFW}_{L_i}) + \text{CTFW}_{L_n} = 100 \quad \text{(Eq. 2)}
\]

where WL\(_i\) is the starting workload of the EXT, and

\[
\text{CTFW}_{L_n} = \frac{t}{\text{TTE}_{L\text{final}}} \times 100 \quad \text{(Eq. 3)}
\]

where \(t\) is the duration over which the last workload is maintained (minutes) and \(t \leq \text{SD}\). Subsequently, PPO is calculated as

\[
\text{PPO}(a/SD) = WL_{\text{full}} + \left(\frac{t}{\text{SD}}\right) \times a \quad \text{(Eq. 4)}
\]

where WL\(_{\text{full}}\) is the value of the highest workload (W) completed for the full stage duration and \(a\) is the workload increment (W).

Critical power (CP) is defined as the maximum average power output sustained for a set duration.\(^{16}\) In the prediction model, the TTE\(_{WL}\) is derived from the critical power profile. A subject’s CP profile (or power-duration profile) can be determined by performing a series of separate time trials (TTs) of various durations and determining the sustained power output (W) during those trials.\(^{17}\) For the purpose of the prediction model, reference CP profiles A and B (see Figure 1) were developed from actual PPOs in a variety of EXTs and from data of power output for various durations collected on a large number of well-trained male cyclists (height 175 to 185 cm, body mass 70 to 75 kg at 10% to 15% body fat). The power-duration curve B lies above power-duration curve A at WLs < MAP. At supramaximal WLs

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Reference power-duration profiles A and B reflecting a range of anaerobic and aerobic abilities of well-trained cyclists. Power-duration profile A represents better anaerobic capacity than power-duration profile B. Power-duration profile B represents better aerobic endurance than profile A.}
\end{figure}
Prediction of Peak Power Output

Table 1  Example of the Contribution to Fatigue (CTF) of Sustaining Workloads During Incremental Exercise Test 25/5, Comprising Stages of 5 Minutes Duration With 25-W Increments

<table>
<thead>
<tr>
<th>Workload</th>
<th>Time to exhaustion* (min)</th>
<th>CTF at full 5-min stage duration†</th>
<th>SUM CTFs at 5-min stage duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>225 W</td>
<td>170</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>250 W</td>
<td>100</td>
<td>5.0</td>
<td>7.9</td>
</tr>
<tr>
<td>275 W</td>
<td>38</td>
<td>13.2</td>
<td>21.0</td>
</tr>
<tr>
<td>300 W</td>
<td>15</td>
<td>33.3</td>
<td>54.3</td>
</tr>
<tr>
<td>325 W</td>
<td>7</td>
<td>71.4</td>
<td>125.8‡</td>
</tr>
</tbody>
</table>

*Derived from the power-duration profile A in Figure 1.
†Determined by applying Equation 1.
‡SUM CTFs > 100 when including CTF of the workload at 325 W. Conclusion is that 325 W cannot be sustained for the full stage duration.
Rearranging Equation 3,

\[ t = \frac{\text{CTF}_{wL_{\text{final}}} \times TTE_{wL_{\text{final}}}}{100} = 45.7 \times \frac{7}{100} = 3.2 \text{ minutes} \]

Applying Equation 4,

\[ \text{PPO}_{25/5} = 300 + \left(\frac{3.2}{5}\right) \times 25 = 300 + 16 = 316 \text{ W} \]

In the above example, the lowest workload taken into consideration is 65% of \(\text{MAP} = 0.65 \times 345 = 225 \text{ W}\). Lower starting workloads will not have a relevant effect on \(\text{PPO}\). For example, TTE at a workload of 200 W is estimated at 275 minutes, and the corresponding \(\text{CTF}\), assuming a stage duration of 5 minutes, will be \(5/275 \times 100 = 1.8\). In analogy with the above example, \(\text{PPO}_{25/5}\) can be calculated to be 315 W (compared with 316 W). From Equation 1, it follows that in an EXT with stages of less than 5 minutes in duration, the effect of neglecting workloads below 225 W will be even less. Note that the lowest workload to be taken into consideration will be proportionally higher or lower when the actual CP profile has higher or lower absolute power output compared with the reference profiles A and B.

Table 2 demonstrates predicted \(\text{PPO}\) from EXT30/1, EXT25/3, and EXT25/5 calculated from profiles A and B in Figure 1. Table 3 shows the \(\text{PPO}\) ratios between EXT30/1, EXT25/3, and EXT25/5 derived from the predicted \(\text{PPO}\) in Table 2. These ratios are independent of absolute power attained in the EXT. In default of the personal aerobic/anaerobic balance, the mean of the \(\text{PPO}\) ratios from profiles A and B in Table 3 are used to predict \(\text{PPO}\) from the result’s actual EXT.

**Table 2**  Predicted Peak Power Output (PPO) From Different Incremental Exercise Tests (EXT) Calculated From Reference Critical-Power Profiles A and B (See Figure 1)

<table>
<thead>
<tr>
<th>EXT</th>
<th>PPO* calculated using reference profile A (W)</th>
<th>PPO calculated using reference profile B (W)</th>
<th>Average PPO (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/1</td>
<td>412</td>
<td>412</td>
<td>412</td>
</tr>
<tr>
<td>25/3</td>
<td>335</td>
<td>347</td>
<td>341</td>
</tr>
<tr>
<td>25/5</td>
<td>317</td>
<td>332</td>
<td>325</td>
</tr>
</tbody>
</table>

*\(\text{PPO}\) determined by solving Equation 2 and applying Equation 4.

**Table 3**  Ratio for Peak Power Output (PPO) Between Incremental Exercise Tests 30/1, 25/3, and 25/5 Derived From the Predicted PPO in Table 2

<table>
<thead>
<tr>
<th>PPO</th>
<th>Profile A</th>
<th>Profile B</th>
<th>Mean of profiles A and B</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPO30/1:PPO25/3</td>
<td>1.229</td>
<td>1.187</td>
<td>1.208</td>
</tr>
<tr>
<td>PPO30/1:PPO25/5</td>
<td>1.299</td>
<td>1.241</td>
<td>1.267</td>
</tr>
<tr>
<td>PPO25/3:PPO25/5</td>
<td>1.056</td>
<td>1.045</td>
<td>1.049</td>
</tr>
</tbody>
</table>
Testing the Model

**Subjects.** To test the validity of the model for predicting PPO, the level of agreement was determined between the results of a series of EXTs and PPO values predicted from the results of each EXT. To achieve this, 11 male athletes were recruited from the local cycling fraternity and asked to participate in the study. The subjects were of various ability levels and were age 25 ± 5 years, height 180 ± 5 cm, and VO$_{2\max}$ 62 ± 8 mL O$_2$ · kg$^{-1}$ · min$^{-1}$. All the subjects were competing in regional- and national-level cycling and triathlon events. The experimental procedures were explained to the subjects verbally and in writing. The experimental procedures were approved by the institutional research ethics committee.

**Incremental Exercise Testing.** Each subject completed 3 different continuous and progressive EXTs to exhaustion in a randomized order on 3 separate days interspersed by a minimum of 48 hours of recovery. The starting workload for each EXT was ~150 to 200 W depending on body mass and the subject’s ability level (each subject had performed similar EXTs and hence we were familiar with their potential PPO value). The EXT30/1 increased by 30 W every minute until exhaustion. The 2 remaining tests increased by 25 W every 3 minutes (EXT25/3) or 5 minutes (EXT25/5) until exhaustion. In all cases a 5-minute warm-up at 100 W was allowed before the commencement of the test. All the tests were performed on a stationary cycle ergometer (SRM, Jülich, Germany), and the reliability and validity of this device for measuring PPO in cycling has previously been examined.$^{21-22}$ The tests were completed under similar laboratory environmental conditions (temperature 20°C, relative humidity 50%). Within the experimental period, the subjects were asked to adhere to a carbohydrate-rich diet and to standardize the volume and intensity of endurance training in the 48 hours before the test so as to improve the reliability of the EXT procedures.

**Determination of PPO and HR$_{\text{max}}$.** During each EXT, heart-rate data (HR, beats/min) was collected every 1 second via a portable HR monitor (Polar, Kempele, Finland) belt attached to the chest of the subject and integrated to the power control unit of the SRM system. Power output (PO, W) was also sampled every 1 second during each EXT using the SRM crank system. The maximum HR (HR$_{\text{max}}$) was measured as the highest consecutive HR value obtained. The actual PPO in each of the EXT PPO30/1, PPO25/3, and PPO25/5 was calculated as the highest power output averaged (using the SRM software) for 60 seconds, 3 minutes, or 5 minutes, depending on the EXT completed.$^{23}$ The PPO value obtained from each EXT was then used to predict (using the theoretical prediction model) the PPO value from the other tests. For example, the prediction model was used to predict PPO30/1 and PPO25/5 from the actual PPO25/3 value.

**Statistical Analyses**

The agreement between predicted and actual PPOs from the different EXTs was determined using the 95% limits of agreement (95% LoA) method.$^{24}$ The assumptions of normality for the distribution of the individual differences between the predicted and actual values and that of homoscedasticity (ie, the size of the prediction errors are independent of the magnitude of the actual values) were confirmed using the Shapiro–Wilk test and 2-tailed Pearson correlation coefficients, respectively.
Systematic bias between the actual and predicted PPO values from each EXT was tested using 2-tailed paired t tests. Absolute measurement error was also determined by the coefficient of variation for repeated measures. The coefficient of variation was calculated by dividing the standard deviation of the differences by the square root of 2 and dividing the answer by the grand mean and was expressed as a percentage. Relative reliability, or the degree to which individuals maintain their position within the group on retesting, was determined using the intraclass correlation coefficient (2-way random model with the systematic variance excluded from the denominator variance). The single rater value was reported for the intraclass correlation coefficient and is based on the assumption that future test values will be derived from predicted values only. Analyses were completed using SPSS for Windows software (release 11.5.0; SPSS Inc, Chicago, Ill). The alpha level for significance testing was set a priori at .05.

Results

Comparisons between actual PPOs and those predicted from each EXT are shown in Table 4. Mean differences between actual and predicted PPOs were insignificant (P > .05), except that the modeling of the PPO from EXT25/5 significantly underpredicted the actual PPO for EXT30/1 (P = .04). The PPOs were significantly higher in the EXT that consisted of the shorter stages (EXT30/1) compared with tests incorporating longer stage durations (EXT25/3 and EXT25/5) for both the actual and predicted PPO. The 95% LoA demonstrated that there was good agreement between actual and predicted PPO (Figure 2). The repeated-measures coefficient of variation ranged between 1.7% and 3.3%, and the ICC, between .91 and .98 (Table 5). There was no significant difference in HRmax for each EXT (185 ± 10, 183 ± 10, and 181 ± 10 for EXT30/1, EXT25/3, and EXT25/5, respectively).

Discussion

The purpose of this study was to develop and test a new model that enables prediction of PPO in an EXT from the PPO obtained from an EXT of a different protocol. The main finding is that the level of agreement between actual and predicted PPOs for any given EXT was sufficiently high for the modeling procedure to be of practical use in future research. Atkinson and Nevill stressed the importance of using analytical goals for future research to evaluate the results of any reliability analysis. If we apply this suggestion to the context of our study, the level of agreement between predicted and actual PPO should be high enough to improve the validity of conclusions from a review or meta-analysis that has attempted to interpret studies that have used EXTs with different stage durations or increments.

The highest random-error component of the LoA for any actual predicted PPO comparison was 30 W. This is interpreted as suggesting that 95% of the prediction errors would be 30 W or less when applying the model to PPO data previously reported by studies that incorporated cycle-ergometer EXTs. When considering that the mean difference in actual PPOs between EXT30/1 and EXT25/3 (200% increase in stage duration) was 66 W and between EXT30/1 and EXT25/5 (400% increase in stage duration) was 82 W, this indicates that the modeling procedure
Table 4  Comparison of Actual PPOs Determined During the 3 EXTs and the Predicted PPOs for Each Incremental Test Calculated From the Modeling of the PPO of a Different EXT (N = 11)*

<table>
<thead>
<tr>
<th>EXT</th>
<th>Actual PPO</th>
<th>Predicted PPO From Actual PPO of EXT(30/1)</th>
<th>Predicted PPO From Actual PPO of EXT(25/3)</th>
<th>Predicted PPO From PPO of EXT(25/5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(30/1)</td>
<td>399 ± 41</td>
<td>—</td>
<td>—</td>
<td>395 ± 47, —4, —15.6, 15, 390 ± 41, —9, —19.0, 14</td>
</tr>
<tr>
<td>(25/3)</td>
<td>333 ± 39</td>
<td>331 ± 35, —2, —12.9, 16</td>
<td>—</td>
<td>334 ± 35, 1, —4.7, 8</td>
</tr>
<tr>
<td>(25/5)</td>
<td>317 ± 33</td>
<td>312 ± 32, —5, —15.5, 14</td>
<td>315 ± 37, —2, —6.4, 8</td>
<td>—</td>
</tr>
</tbody>
</table>

*EXT indicates incremental exercise test (the values in parentheses refer to the stage increments in watts and stage duration in minutes, respectively); PPO, peak power output; SD, standard deviation of the mean; Mean diff, mean difference between actual and predicted PPOs; 95% CI, lower and upper bounds of the 95% confidence interval for the mean difference; and Sd, standard deviation of the individual differences between actual and predicted PPOs.

†Significant difference between actual and predicted values (P = .04).
Figure 2 — Bland–Altman plots demonstrating the individual differences between the actual peak power output (PPO) for a particular incremental test and the predicted PPO from modeling of the PPO of another incremental test plotted against the individual mean values. The upper and lower horizontal dashed lines represent the 95% limits of agreement.
would be of practical use in interpreting studies using different EXT stage durations. However, the mean difference in actual PPOs for EXT25/3 and EXT25/5 (67% increase in stage duration) was only 16 W and was identical to the random-error component of the LoA when using both of these EXTs for predictions (ie, predicting PPO EXT25/3 from EXT25/5 or predicting EXT25/5 from EXT25/3). The results therefore suggest that the model corrections for PPO become more important as the percentage difference in stage duration increases. This point may be especially important if PPO values from EXT with stage durations of between 5 and 7 minutes (40% increase) or 6 and 7 minutes (17% increase) were compared, because differences in actual PPO are likely to be very small. However, irrespective of the prediction error, it may be questionable whether such potentially small differences in PPO are quantitatively important to warrant correction, and further research is required to determine what these differences are before a decision can be made. The practical and statistically insignificant (except 1 comparison) systematic bias between actual and predicted PPO values also supports the premise that the modeling procedure used in this study provides levels of agreement that are sufficiently high to be of practical use.

In calculating the CTF of a workload, the TTE at that workload is derived from the CP profile. Each individual will have his or her own specific personal CP profile depending on such factors as training status and specific physiological abilities, such as anaerobic and aerobic endurance, the lactate threshold (as a percentage of

<table>
<thead>
<tr>
<th>Actual – predicted</th>
<th>CV (%)</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPO30/1 – PPO25/3</td>
<td>2.7</td>
<td>.94</td>
</tr>
<tr>
<td>PPO30/1 – PPO25/5</td>
<td>2.4</td>
<td>.95</td>
</tr>
<tr>
<td>PPO25/3 – PPO30/1</td>
<td>3.3</td>
<td>.91</td>
</tr>
<tr>
<td>PPO25/3 – PPO25/5</td>
<td>1.7</td>
<td>.98</td>
</tr>
<tr>
<td>PPO25/5 – PPO30/1</td>
<td>3.2</td>
<td>.91</td>
</tr>
<tr>
<td>PPO25/5 – PPO25/3</td>
<td>1.7</td>
<td>.98</td>
</tr>
</tbody>
</table>

*CV indicates coefficient of variation for repeated measures; ICC, intraclass correlation coefficient (2-way random model for a single rater, systematic error not included in the denominator variance of the estimated ICC); and EXT, incremental exercise test.
maximum performance), and muscle efficiency (gross efficiency). Note that the CP profile of an individual is not constant in time but will vary during a training season depending on the type of training the person is undergoing. The predictive validity of the present model should therefore ideally be tested knowing the CP profiles of the tested individuals. This requires multiple testing days and was outside the scope of this present investigation. That aside, future experiments examining the validity of this model should also quantify the CP profile of each subject in conjunction with other PPO results.

The prediction model uses reference CP profiles established from a range of trained cyclists. Differences between the reference CP profile and the actual personal CP profile will become manifest predominantly at higher workloads of an EXT at which CTF exponentially increases as TTE approaches the stage duration (see also Table 1). Because stage duration appears in the denominator of the CTF definition (see Equation 1), EXTs with relatively short stage durations (e.g., 1 minute) will be even more sensitive for such differences than EXTs with relatively longer stage durations (e.g., 5 minutes). PPO25/3 and PPO25/5 predicted from actual PPO30/1 and PPO30/1 predicted from actual PPO25/3 and PPO25/5 are likely to result in a lower level of agreement with the respective actual PPOs. This is confirmed by the standard deviation of the differences and the LoA reported in Table 4.

Another factor in the context of the results that generally should be considered is whether the PPO values are truly reflective of the cyclist’s best effort. Obtaining the highest PPO value depends not only on physiological capacity but also to a certain extent on psychological factors. The true best effort is given when \( \sum_{i=1}^{n-1} (CTF_{W_{Li}}) + CTF_{WL_n} = 100 \) (see Equation 4). Two subjects who participated in this experiment demonstrated a very small difference (≤2 W) between actual PPO(25/3) and actual PPO(25/5), where the average difference of the 11 tested persons is 17 W. This is a strong indication that these individuals did not or could not give their best effort in EXT25/3. On reflection, these subjects were not as experienced or as trained as the other athletes in this cohort and this factor may have influenced their capacity to exert fully in the latter stages of the EXT. Hence the important consideration is that premature fatigue and not obtaining a “best effort” might have influenced the actual PPO values and the LoA statistics presented. These results aside, the insignificant systematic bias between predicted and actual values suggests that the modeling would be of practical use. Furthermore, it is possible that this model can be used to establish (in combination with other physiological results such as HRmax) whether subjects have given their best effort in an EXT.

Table 3 provides an overview of the ratios between PPO30/1, PPO25/3, and PPO25/5 based on profile A, profile B, and the average of profiles A and B. Based on these ratios it can be derived that using profile A instead of the average of A and B for predicting PPO(25/5) from actual PPO(30/1) would lead to a difference in predicted PPO of 1.299/1.267 × 100% = 2.5%. Similarly, using profile A instead of the average of profiles A and B for predicting PPO(25/5) from PPO(25/3) would lead to a difference in predicted PPO of 1.056/1.049 × 100% = 1.0%. The agreement between predicted and actual PPOs would have been better if the training status had been taken into consideration in choosing the CP reference profile. For example, if knowing that a cyclist has been doing little anaerobic (aerobic) training, then profile B (profile A) would be more appropriate for making predictions instead of the average of profile A and profile B. However, this hypothesis needs to be confirmed with measures of anaerobic/aerobic capacity. In subjects of a higher
caliber and/or greater body mass (or of lower caliber and/or lower body mass) than the well-trained cyclists of 70 to 75 kg, the power-duration curves will be at higher (or lower) absolute powers for any given duration. In order to test to what extent PPO ratios are dependent on absolute power, we calculated PPO30/1, PPO25/3, and PPO25/5 and the corresponding PPO ratios, assuming power-duration profiles with 25% higher and 20% lower absolute powers compared with reference power-duration profile A (Tables 6 and 7).

The results in Table 7 suggest that PPO ratios between EXTs depend on absolute power. PPO ratios can differ up to 4%; for example, the ratio PPO30/1:PPO25/3 at 20% lower absolute powers than reference profile A is 4% \((1.25/1.23 \times 100)\) higher than that PPO ratio at the powers of reference profile A. Confirming this effect of absolute higher and lower powers on predicted PPO would require further research. Note that in testing the predictive validity of the prediction model, the PPO ratios

<table>
<thead>
<tr>
<th>Incremental exercise test</th>
<th>PPO based on reference power-duration profile A</th>
<th>PPO based on a power-duration profile with 25% higher CP compared with reference power-duration profile A</th>
<th>PPO ratios based on a power-duration profile with 20% lower CP compared with reference power-duration profile A</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/1</td>
<td>412 W</td>
<td>498 W</td>
<td>344 W</td>
</tr>
<tr>
<td>25/3</td>
<td>335 W</td>
<td>416 W</td>
<td>275 W</td>
</tr>
<tr>
<td>25/5</td>
<td>317 W</td>
<td>395 W</td>
<td>259 W</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incremental exercise test</th>
<th>PPO ratios based on reference power-duration profile A</th>
<th>PPO ratios based on a power-duration profile with 25% higher CP compared with reference power-duration profile A</th>
<th>PPO ratios based on a power-duration profile with 20% lower CP compared with reference power-duration profile A</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPO30/1: PPO25/3</td>
<td>1.230</td>
<td>1.197</td>
<td>1.250</td>
</tr>
<tr>
<td>PPO30/1: PPO25/5</td>
<td>1.300</td>
<td>1.260</td>
<td>1.328</td>
</tr>
<tr>
<td>PPO25/3: PPO25/5</td>
<td>1.056</td>
<td>1.053</td>
<td>1.060</td>
</tr>
</tbody>
</table>
between different EXTs equal the mean of the PPO ratios of profiles A and B (see Table 3) and are independent of the absolute PPO values.

The reference CP profiles are based on the physiological performance range of well-trained cyclists. World-class or moderately trained cyclists might have physiological capabilities corresponding with profiles that fall outside the range defined by profiles A and B. Future studies are necessary to verify this.

Another factor that deserves mention is that the EXTs are assumed to have fixed workload increment and stage duration and not to have passive recovery intervals between workloads. The practice of having a recovery interval between workload stages during an EXT is not uncommon. At the same time, other EXT protocols commence with initial stages of one duration and then in the later stages the workload duration is reduced. However, the majority of EXTs are completed in a continuous manner with the same workload duration. That aside, this model has considered only continuous incremental protocols. Hence, applying this prediction model to results of discontinuous EXTs will affect prediction of PPO.

**Practical Applications and Conclusions**

This investigation developed and tested a model that allows prediction of PPO from one EXT to another. The practical implication of this model is that PPO values appearing in the scientific literature or those used for performance diagnostics can be compared. Researchers and sports scientists often use EXTs with different stage increments or durations because of personal preference or because they are interested in determining other physiological or performance variables besides the PPO. This procedure may require a specific stage duration or increment. It is improbable that in the future a standardized EXT protocol will be developed, and this highlights the importance of modeling procedures such the one presented in this investigation that allows valid comparisons of PPO from studies that have used different EXT stage durations or increments. The model can also be used for predicting submaximal power output where the duration of the trial is known. A number of investigations also perform set workload exercise before a time trial.29-30 The model presented in this investigation could be used to estimate the effect on average time trial power of the preceding submaximal effort. However, further studies are required to confirm the current results using cyclists of different ability levels to predict PPO from different EXT designs.

**References**


