Development of Race Profiles for the Performance of a Simulated 2000-m Rowing Race

Michael D. Kennedy¹ and Gordon J. Bell²

Catalogue Data

Key words: maximal oxygen consumption, critical power, pacing strategy, critical velocity, accumulated oxygen deficit
Mots-clés: consommation maximale d’oxygène, puissance critique, stratégie de course, vélocité critique, déficit d’oxygène accumulé

Abstract/Résumé
The purpose of this study was to determine the race profile for a 2000-m simulated rowing race as well as the effect of training and gender on the race profile. Nineteen men and 19 women undertook a 2000-m simulated rowing race before and after 10 weeks of a typical off-season training program for rowing. Velocity was calculated every 200 m and the deviation in velocities from the mean race velocity (MRV) was plotted every 200 m to produce race profiles for each gender before and after training. The three fastest male rowers varied approximately 0.02 m·s⁻¹ from the MRV after training and displayed a constant-pace model. The fastest female rowers displayed an all-out strategy after training, producing large deviations from MRV. Average squared deviations from the mean (SDM) determined that all groups except the fastest females had a reduction in MRV deviation after training. These results suggest that the optimal race profile for a simulated 2000-m rowing race may be different between genders. Training reduces SDM and influences both male and female pacing patterns such that both exhibit a pacing strategy that is more similar to that of elite athletes in other events of similar and shorter duration.

Le but de cette étude est d’établir le profil de course pour une compétition d’aviron sur 2000 m ainsi que d’évaluer l’effet de l’entraînement et l’incidence du sexe sur ce profil.

¹Faculty of Rehabilitation Medicine, and ²Faculty of Physical Education and Recreation, E407 Van Vliet Center, University of Alberta, Edmonton, AB, T6G 2H9.
Dix-neuf femmes et autant d’hommes participent à une épreuve simulée sur 2000 m avant et après 10 semaines d’un entraînement hors saison typique. Afin d’établir le profil de course pour les femmes et les hommes, avant et après le programme d’entraînement, la vitesse est calculée à chaque tranche de 200 m de même que l’écart relatif à la vitesse moyenne (MRV). La performance des trois meilleurs rameurs après le programme d’entraînement présente une variation d’environ 0,02 m·s⁻¹ et s’avère constante. La performance des meilleures rameuses révèle une allure à fond de train, ce qui causa des écarts importants du MRV. Le calcul de la moyenne des écarts types (SDM) permit d’établir que tous les groupes à l’exception des femmes les plus rapides présentaient une diminution de leur MRV après l’entraînement. D’après ces observations, le profil optimal de course des hommes au cours d’une épreuve simulée sur 2000 m semble différent de celui des femmes. L’entraînement cause une baisse du SDM et modifie le profil de course des deux groupes: leur stratégie de course est similaire à celles des athlètes d’élite dans des épreuves comparables et de plus courte durée.

Introduction

A product of certain maximal sport performance (race, time trial) is the “race profile” created by that performance. A race profile is one method of describing the spontaneous pacing behavior (Foster et al., 1994) of athletes during a race. It can be described in time or velocity per lap or interval, providing a simple yet descriptive graphical representation of pacing. The “optimal race profile” (ORP) has been previously described (Wilberg and Pratt, 1988) as the pattern of deviation from mean lap time of cyclists on a 333.3-m velodrome and is only optimal because this is the pacing pattern that the fastest riders exhibit (Wilberg and Pratt, 1988). This ORP is similar to the pacing pattern of elite athletes observed in other sports of similar total time (Foster et al., 1994). The attention sport science has given to athlete pacing strategy is significantly less than other factors known to affect performance (Foster et al., 1993). There has been little systematic observation of spontaneous pacing strategy in the sport of rowing, despite the fact that rowing may be a sport which could greatly benefit from scientific pacing strategies (Foster et al., 1993).

Previous studies that have analyzed race performances illustrate a common deceleration during the latter half of certain events such as cycling (Foster et al., 1994; Wilberg and Pratt, 1988) and speed skating (Foster et al., 1994). Part of this deceleration may stem from exertional related fatigue (Foster et al., 1994) due to the maximal intensity of these sports. Given the high intensity of a 2000-m rowing race on water (Steinacker, 1993) and simulated race on land (Gillies and Bell, 2000), it is possible that the associated metabolic fatigue and decreased power transfer may combine to produce a deceleration (similar to track cycling or speed skating) over the latter half of the race. The simulated dry-land rowing race may exhibit smaller decreases in velocity, with associated decreases in power output due to fatigue, as a result of the wind resisted fly wheel on a rowing machine producing less drag than water (Foster et al., 1993). Despite this limitation, the benefit of the dry-land rowing race model is the controlled environment, ensuring that all spontaneous pacing behavior is indicative of physical exertion. As well, competitive rowers use indoor rowing machines to monitor training and performance (Gillies and Bell), and 2000-m indoor rowing competitions have been established as a world competition (Concept II, 1998).
Therefore, observations of race profiles from spontaneous pacing behavior of rowers in a closed environment would be a logical first step in describing the pacing pattern of rowing. To our knowledge, there is little published research involving the effect of training on pacing behavior in rowing or other sport. As well, there have been few comparisons between men and women with regard to pacing behavior, although both Foster et al. (1993) and Wilberg and Pratt (1988) used both genders in their samples. Previous research from our lab indicates that women exhibit some unique differences compared to men during a 2000-m simulated rowing race (Gillies and Bell, 2000), thus it was also of interest to determine pacing behavior of our female subjects compared to our male subjects.

Thus the primary purpose of this study was to create race profiles from actual performances of a 2000-m simulated rowing race to determine spontaneous race strategy. As well, the effect of training and a gender comparison on the race profile were examined. It was hypothesized that: (a) the rowing race profile would be similar in overall profile to those seen in other events of similar duration; (b) training would have an effect on reducing variability and the pattern of the race profile; and (c) the degree of variability and pattern in simulated 2000-m race profiles may differ between men and women.

**Methods**

**SUBJECTS AND EXPERIMENTAL DESIGN**

Subjects (19 M, 19 F) were recruited from the local university and club rowing communities. To be included in this study, subjects had to be actively training for the preceding 3 months at least twice a week on rowing machines, and strength training once a week. The sample consisted of 7 male and 11 female novice (<1 year) rowers, and 12 male and 8 female experienced (>1 year) rowers. Subject characteristics (mean ± SD) for males were, age 25.1 ± 4.8 yrs; Ht 179.8 ± 6.9 cm; body mass 79.3 ± 8.2 kg; for females, age 25.2 ± 4.6 yrs; Ht 169.2 ± 5.8 cm; body mass 68.0 ± 11.5 kg. All subjects signed an informed consent form prior to testing, and the study received ethics approval from the Faculty of Physical Education and Recreation at the University of Alberta.

**2000-M SIMULATED ROWING RACE**

The 2000-m simulated rowing race was performed on a Concept II Model C rowing machine (Morrisville, VT) in a controlled lab setting where each subject was instructed to race over the 2000-m distance to reach the lowest possible time. Time, distance, stroke rate, and 500-m split time were displayed on the rowing machine and could be observed by each subject throughout the race. Heart rate, split time/500-m time, and stroke rate were recorded every 200 m for the entire 2000-m simulated rowing races both before and after training. Prior to the test, the subjects performed their own warm-up routines which included rowing and stretching. The test began on the command of, “Are you ready? Row.” The subjects were required to complete 2000 m of rowing as fast as possible using their own race strategy; consistent verbal encouragement was provided. This protocol has been previously described (Kennedy and Bell, 2000).
DETERMINATION OF AEROBIC FITNESS

Before and after the training program, all subjects were required to undergo an incremental combined ventilatory threshold (VT) and maximal oxygen consumption (\(\dot{V}O_2\)max) test to volitional exhaustion on a Concept II Model C rowing machine as previously described (Gillies and Bell, 2000). Briefly, the test began with 2 minutes of rowing at a power output (PO) of 100 watts for men and 50 watts for women, followed by increments in PO by 50 watts every 2 min for both genders. This continued until the RER value exceeded 1.05, after which time the subject was required to increase the power output to a maximum for as long as possible until volitional exhaustion. VT was determined as the lowest point on the \(\dot{V}E/\dot{V}CO_2\) vs. power output curve prior to a systematic increase previously described (Bhambhani and Singh, 1985).

The criterion for \(\dot{V}O_2\) max was a peak and/or plateau in \(\dot{V}O_2\) with increasing exercise time, which was observed in all subjects using this protocol. Corresponding secondary criteria were the achievement of an RER >1.15, attainment of known or age-predicted maximum heart rate (HR max), and volitional exhaustion. Expired air was collected into a calibrated Horizon metabolic measurement cart (Sensor Medics, Yorba Linda, CA, U.S.) for analysis of ventilation and respiratory gases (15-s average). The metabolic cart was calibrated with known gas concentrations before and after each test, and correction to \(\dot{V}O_2\) max was performed if the \(O_2\) or \(CO_2\) gas concentrations were out by more than 0.05%. All subjects wore a heart rate monitor (Polar Electro, Kempele, Finland) that was set to record heart rate to memory every 5 sec.

PHYSIOLOGICAL TRAINING PROGRAM

The training was performed from mid-off-season to completion of the off-season (January–March) and consisted of strength training twice a week and rowing training 4 days a week on separate days for 10 weeks. The strength training program included six upper body exercises (seated row, flat bench press, lat pulldowns, shoulder press, biceps curl, triceps extension) and four lower body exercises (bilateral incline leg press, knee extension, knee flexion, calf raise). The number of sets ranged from 2 to 6, number of repetitions ranged from 4 to 12, and mean intensity based on a percentage of predicted 1-RM ranged from 65 to 90%.

The program was individually prescribed and periodized so that a progressive overload occurred throughout the 10-week program using a computer software program (Power 5.1, Hudson, FL, U.S.). To do this, each subject had to undertake a multiple repetition maximum (mRM) strength test that determined how much weight he or she could lift to volitional failure between 8 and 10 repetitions on each exercise using a protocol previously described (Gillies and Bell, 2000). Rowing training was completed on Concept II rowing machines and included 3 days a week of continuous rowing training and 1 day a week of interval training. Two continuous rowing sessions were performed at a set intensity, equivalent to a heart rate of 5 beats per minute below VT (see above). The other continuous rowing session was performed at an intensity equivalent to a heart rate at VT.

The continuous sessions began with rowing 5000 m per session in addition to a 1000-m warm-up and 1000-m cool-down, and the distance rowed was gradu-
ally increased every 2 weeks until a total of 11,000 m of rowing was completed per session. The interval session involved four repeats of 500 m of high intensity rowing equivalent to the 500-m split time achieved during the 2000-m rowing test and was gradually increased every 2 weeks until eight repeats were completed. The intensity of the interval sessions was increased as well by decreasing the split time by 5 sec after 5 weeks of training. All rowing session intensities were individually prescribed based on the physiological testing, and each subject wore a heart rate monitor for all rowing training. Training logs were kept for both strength and aerobic work, and all rowing machine sessions were supervised.

DATA PROCESSING

A Concept IIIC rowing machine can display stroke rate, time, distance, power output, and the mean split time to complete 500 m, depending on the selected computer display mode. In this study the subjects were allowed to view stroke rate, time, distance, and split time for 500 m. All variables were manually recorded every 200 m (from 200 m to 2000 m) from the Concept II monitor during the 2000-m test. The race profiles were created for each subject’s 2000-m trial before and after training. Velocity was calculated every 200 m and averaged to create a mean race velocity (MRV) for the entire 2000 m.

Each subject’s MRV was subtracted from his or her interval velocities to produce difference scores (deviation) from MRV every 200 m. These deviations from MRV were then plotted relative to the MRV that was defined as the zero point to create the race profile. Therefore the rowers’ performance was equated such that their 200-m interval velocities could be compared directly, interval by interval (Wilberg and Pratt, 1988).

The fastest three rowers (as constituted by the fastest time over 2000 m) and the slowest three rowers (as constituted by the slowest time over 2000 m) for both genders were grouped for comparison both before and after training. Average squared deviation from the mean (SDM) for each interval was computed. An overall SDM average for men and women before and after training, as well as the slowest and fastest groups before and after training, was then calculated from the individual SDM of each interval. \( T \)-tests for dependent measures were used to compare gender and training responses for all physiological measurements, with alpha set at \( p < 0.05 \) (Bonferroni correction factor \( p < 0.0042 \)).

Results

Table 1 describes the changes in physiological characteristics before and after training. There was significant improvement in all physiological parameters (except male and female maximum HR) with training in both genders (\( p < 0.0042 \); Table 1). Table 2 presents the MRV for the simulated 2000-m rowing race for each gender before and after training, as well as the fastest and slowest rowers (\( n = 3 \)) after training.

Figure 1 displays the deviation in rowing velocity from MRV for both genders and the effects of training on the race profile. The pattern of pacing response indicated in Figure 1 shows that the subjects initiated the test at a pace faster than...
Table 1  Physical Measures Before and After Training (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Female Before</th>
<th>Female After</th>
<th>Male Before</th>
<th>Male After</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic Performance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO$_2$max  (ml·kg$^{-1}$·min$^{-1}$)*</td>
<td>36.9 ± 5.2</td>
<td>45.1 ± 5.9</td>
<td>46.1 ± 7.1</td>
<td>55.6 ± 5.4</td>
</tr>
<tr>
<td>VO$_2$max (L·min$^{-1}$)*</td>
<td>2.5 ± 0.4</td>
<td>3.1 ± 0.4</td>
<td>3.6 ± 0.5</td>
<td>4.3 ± 0.4</td>
</tr>
<tr>
<td>Max HR (beats·min$^{-1}$)</td>
<td>187.9 ± 9.5</td>
<td>187.2 ± 10.0</td>
<td>191.6 ± 8.8</td>
<td>188.3 ± 6.2</td>
</tr>
<tr>
<td>2000 m (sec)*</td>
<td>539.4 ± 42.3</td>
<td>495.9 ± 29.7</td>
<td>458.1 ± 30.7</td>
<td>426.3 ± 20.0</td>
</tr>
<tr>
<td><strong>Strength</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inclined leg press (kg)*</td>
<td>148.3 ± 62.9</td>
<td>186.5 ± 50.5</td>
<td>296.9 ± 45.8</td>
<td>347.8 ± 57.9</td>
</tr>
<tr>
<td>Bench press (kg)*</td>
<td>17.9 ± 4.0</td>
<td>20.3 ± 4.0</td>
<td>77.6 ± 14.7</td>
<td>83.5 ± 13.3</td>
</tr>
</tbody>
</table>

* Significant difference before and after training for each gender, $p$ $\leq$ 0.0042.

Note: VO$_2$max = maximal oxygen consumption; 2000 m = time to complete 2000-m simulated rowing race.

Table 2  Velocity (m·s$^{-1}$) for Male and Female Groups and Fastest and Slowest Rowers (mean ± SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before training</td>
<td>4.02 ± 0.06; $N$ = 38</td>
<td>4.35 ± 0.06; $n$ = 19</td>
</tr>
<tr>
<td>After training</td>
<td>4.36 ± 0.06; $N$ = 38</td>
<td>4.71 ± 0.06; $n$ = 19</td>
</tr>
<tr>
<td>Fastest rowers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>after training</td>
<td>5.03 ± 0.02; $n$ = 3</td>
<td>4.34 ± 0.15; $n$ = 3</td>
</tr>
<tr>
<td>Slowest rowers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>after training</td>
<td>3.96 ± 0.20; $n$ = 3</td>
<td>3.38 ± 0.09; $n$ = 3</td>
</tr>
</tbody>
</table>

MRV for approximately the first 400 m (male before) to 800 m (female before, male and female after), and then slowed to a pace below MRV in the middle portion of the 2000-m race. Before training, both genders showed a marked increase in velocity with 400 m to finish, and then finished with rowing velocities greater than MRV. In comparison, the after-training male and female groups exhibited a small increase in velocity at 1800 m, and only the females achieved a final velocity slightly greater than MRV. Before-training deviation over the last 200-m interval were 0.143 and 0.090 m·s$^{-1}$ for men and women, respectively, compared to after-training deviation of −0.042 and 0.012 for men and women, respectively (Figure 1).
The fastest male rowers deviated approximately 0.02 m·s\(^{-1}\) from MRV in the after-training 2000-m race. This fastest group of males exhibit a constant-pace model of intensity compared to the fastest female rowers and the slowest male and female rowers after training (Figure 2). The before-training profile for fastest males exhibited greater deviation over the duration of the 2000-m race, whereas the female fastest group displayed a much more consistent pattern of pacing compared to their after-training pattern and was also similar to the fastest male before-training pattern. Both male and female slow groups had marked differences in their pacing pattern after training, with smaller deviations and a more even profile. The fastest males after training had an SDM of less than 0.01, the slowest males had the greatest decrease in SDM after training, and the female group had the least change in SDM before and after training (Figure 3).

**Discussion**

Sporting events that involve covering a particular distance in the shortest time possible are dependent on a variety of factors that would be at least physiological, biomechanical, and psychological in nature. Pacing strategies are also important, and race profiles can be developed that reveal the nature of an athlete’s perfor-
mance in a particular event. For example, optimal race profiles (ORP) have been developed for cycling (Wilberg and Pratt, 1988) that reflect the pacing pattern of the fastest cyclists. This type of information is valuable for descriptive purposes, as most sports (including rowing) which are short-term and high intensity in nature have little quantitative support for an “optimal” profile to plan pacing strategy. Second, generating an optimal profile for comparative purposes may have a direct impact on the way rowers approach the 2000-m race, whether it be an indoor simulated race or an actual on-water race, enabling a systematic change to their individual profile to match the theoretical optimum for reaching the fastest time.

The rowing race profile of both genders in the present study was similar in many respects to profiles observed in international short-duration cycling (1000 m; mean time = 1 min 6 sec) or speed skating (1500 m; mean time = 1 min 54 sec) events (Foster et al., 1994). In general terms, this type of race profile is characterized by the first half of the race being faster than the mean, followed by a marked deceleration in the latter half (Foster et al., 1994). Compared to before training, the after-training profiles of both genders in our study exhibited this short-duration pacing pattern with a faster first half, a deceleration over the latter half of the race, and little recovery of velocity in the final 200 m (Figure 1). This suggests that men and women may have evolved with training to exhibit a pattern of pacing indicative of improved knowledge of how much energy expenditure is required in a particular portion of the simulated 2000-m race (altered pace strategy). Thus both

Figure 2. Comparison of race profiles for fastest male and female rowers to slowest male and female rowers both before and after training. Note: Fastest males after training exhibit a constant-pace model and fastest females after training exhibit an all-out start strategy.
improved fitness and strategy may have combined to contribute to the faster performance velocity after training (+0.36 m/s or –35.2 sec for men; +0.32 m/s or –42.6 sec for women).

It was hypothesized that the rowing race profile would be similar to other race profiles observed in events of similar duration such as elite cycling and speed skating. The data indicates that the fastest men in our study showed a pacing pattern similar to other elite calibre events of similar length, but this was not the case for the fastest women (Figure 2). The pacing pattern of the fastest men was considered optimal, leading to the fastest velocities, as defined by Wilberg and Pratt (1988), as well as constant, indicating that the race profile in this fastest group of male rowers adhered to a constant-pace model.

The race profile observed before training for the fastest male rowers in the present study did not completely conform to the constant-pace model produced after training (Figure 2), despite still being the three fastest times. In comparison, the results of the fastest females after training exhibited a pattern similar to an all-out-start strategy as described by Bishop et al. (2002) in the sport of flatwater kayaking. The all-out start in our study resulted in a 5% decrease in velocity over the final 1000 m of the race. Conversely, the fastest female rowers exhibited more of a constant-pace model prior to training, and this more conservative approach to the 2000-m simulated rowing race before training may have been indicative of a less evolved pacing strategy (deKoning et al., 2002).
As noted, the fastest men produced a race profile similar to a constant-pace model after training. This constant pace was the main difference in comparison to all other groups examined in the present study, and was most similar to the range of deviations as well as the pattern of pacing in international-caliber events for 4000-m cycling (van Ingen Schenau et al., 1992) and 5000-m speed skating (van Ingen Schenau et al., 1990). The mean time for the fastest males after training in this study was similar to other research displaying constant-pace profiles (fastest three male 2000-m rowing time = 6 min 38 sec; 4000-m cycling = 4 min 32 sec; 5000-m speed skating = 6 min 58 sec). However, the fastest women exhibited a different pace strategy (all-out) compared to the fastest men (constant pace) after training, which was similar to events of shorter duration (Bishop et al., 2002). Thus our results suggest that men and women may differ in pacing strategy as a result of training, and gender-specific strategies may be needed to optimize a simulated 2000-m rowing race. Whether the women in the present study would have performed even faster after training if they had been able to adhere to a constant-pace model is not known. Further research and analysis of elite and international-caliber rowers of both genders may provide some answers.

Despite the improvements in aerobic fitness and strength for both genders in the present study, the benefit of training relative to reducing variability in velocity was probably also due to learning and the ability to gauge the intensity of effort needed to perform this type of event. Figure 1 shows that the ability for either gender to maximize velocity in the mid-portion of the race improved with training. This was also confirmed by the fact that velocity during the final 200 m of the simulated 2000-m race was –0.012 m·s⁻¹ from mean race velocity in both genders after training, compared to a deviation of 0.115 m·s⁻¹ before training. This increase in rowing velocity during the final 200 m may indicate poor energy distribution during earlier parts of the race before training. This is in contrast to after training, when the group was better able to distribute maximal energy expenditure and resist fatigue over the duration of the race.

Further analysis of the data showed that average squared deviation from mean race velocity after training was significantly lower for both genders (Figure 3). Both the slower velocity in the final 200 m and the reduced mean deviation after training are indicative of a shift toward an improved pacing strategy for both genders. The greater rowing experience and training adaptations may have contributed to better confidence and physiological ability to perform the 2000-m simulated rowing race (deKoning et al., 2002; Laursen and Jenkins, 2002). Furthermore, it has been shown that an improved pacing strategy may be learned in as little as three maximal trials of the same distance (deKoning et al., 2002). Thus the combined benefits of continuous constant-pace training and interval training performed at race pace over 10 weeks likely combined to reduce the total time for male and female groups, contributing to a more evolved pacing strategy in addition to the physiological adaptations to training.

SUMMARY AND CONCLUSIONS

The present study examined the pacing strategy used by male and female rowers to undertake a simulated 2000-m rowing race on a rowing machine. Two pacing models emerged with the analyses of our data—a constant pace model and an all-
out pace model. The fastest male rowers adhered to the constant-pace model, especially after training, to optimize their simulated 2000-m rowing race profile. This was in contrast to the fastest female rowers, who employed more of an all-out strategy to reduce their race time after training. Physical training helped produce faster times for the simulated 2000-m rowing race in both genders, and the race profile of both after training reflected a different distribution of energy for the entire race compared to before training. Training reduced the SDM of the male rowers and most of the female rowers except for the fastest female rowers. The fastest female rowers after training exhibited a pacing strategy representative of much shorter time events (≤ 2 min).

The main benefit of the present research is that it provides the predominate race profile used by rowers in pursuit of the fastest 2000-m simulated rowing race time. This research should now be extended to examining race profiles of more elite rowers and during on-water 2000-m rowing races at international competitions so as to determine the accuracy and robustness of the pacing profiles generated from the present study.

References


Received April 18, 2002; accepted in final form November 1, 2002.