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Title: Influence of Upright Versus Time Trial Cycling Position on Determination of Critical Power and W' in Trained Cyclists

Submission Type: Original Investigation

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Abstract

Body position is known to alter power production and affect cycling performance. The aim of this study was to compare mechanical power output in two riding positions, and to calculate the effects on critical power (CP) and W' estimates. Seven trained cyclists completed three peak power output efforts and three fixed-duration trials (3-, 5- and 12-min) riding with their hands on the brake lever hoods (BLH), or in a time-trial position (TTP). A repeated-measures analysis of variance showed that mean power output during the 5-min trial was significantly different between BLH and TTP positions, resulting in a significantly lower estimate of CP, but not *W'*, for the TTP trial. In addition, TTP decreased performance during each trial and increased the percentage difference between BLH and TTP with greater trial duration. There were no differences in pedal cadence or heart rate during the 3-min trial; however, TTP results for the 12-min trial showed a significant fall in pedal cadence and a significant rise in heart rate. The findings suggest that cycling position affects power output and influences consequent CP values. Therefore, riders and coaches should consider the cycling position used when calculating CP.

Keywords: Body position, laboratory testing, mechanical power, critical power, power-duration

Introduction

Previous research has demonstrated how different riding positions (i.e., upright or aerodynamic) alter physiological responses and mechanical capabilities during cycling (Jeukendrup & Martin, 2001; Jobson, Nevill, George, Jeukendrup, & Passfield, 2008; Millet, Tronche, Fuster, & Candau, 2002). For example, when riding outdoors, energy expenditure is known to increase with travelling velocity as a consequence of the greater power output required to overcome air resistance (Ashe et al., 2003). To reduce the energy cost, a rider can alter their body position to lessen their frontal area and therefore aerodynamic drag (Fintelman, Sterling, Hemida, & Li, 2016) . This is achieved by a rider a) adopting a tucked position with forearms placed on aerodynamic handlebars, typically used during time-trials, or b) placing the hands on the dropped portion of the handlebars. However, Jobson et al. (2008) highlighted that in the absence of this drag component in the laboratory, an upright position is frequently adopted when performing similar performance trials indoors.

Mechanistic explanations for the effect of body position on cycling performance under laboratory conditions include alterations to the control of leg movement and muscle recruitment patterns (Fintelman et al., 2016; Too, 1990; Welbergen & Clijsen, 1990). Specifically, changes in joint angles may affect the shortening velocities of the muscles across the joints and their ability to produce power (Elmer, Barratt, Korff, & Martin, 2011). Differences in average power output between upright and aerodynamic body position during laboratory-based 40.23-km cycling have previously been reported (Jobson et al., 2008). Jobson et al. (2008) suggested that replicating adopted cycling positions between laboratory visits was most important for consistency. While this is a worthwhile recommendation for assessing changes over time, the results of any assessment performed in a non-race-specific position may not translate to real-world performance capabilities.

Most laboratory-based studies have focused on the physiological responses to body position during time-trial based tasks. However, the findings are equivocal. Some researchers have found no significant differences in ventilatory and metabolic responses (Dorel, Couturier, & Hug, 2009; Grappe, Candau, Busso, & Rouillon, 1998; Origenes, Blank, & Schoene, 1993). Others have reported that riding in an aerodynamic position (i) increases oxygen consumption, heart rate and respiratory exchange ratio (Grappe et al., 1998), (ii) contributes to a lower power output (Jobson et al., 2008) , (iii) is more costly during steady-state cycling, and (iv) restricts ventilation during maximal exercise (Ashe et al., 2003). We are unaware of any study that has assessed the effect of body position on mechanical capabilities when completing maximal, fixed-duration cycling trials. This information has potentially important implications for athletes, coaches and practitioners who wish to accurately assess the power-duration relationship and predict performance capabilities.

An increasingly used form of exercise testing in the laboratory and field is to use several fixed-duration trials to determine a rider's power-duration profile (Karsten et al., 2016; Parker Simpson & Kordi, 2016). These tests yield data for two parameters: 1) the power-asymptote of the hyperbolic power-duration relationship 'critical power' (CP); and 2) the curvature constant, termed W'. If altering body position affects the physiological and thus mechanical response to cycling, a rider's power-duration profile may be affected. Thus the purpose of the present investigation was to assess power-duration parameters in both the upright and time-trial cycling positions. It was hypothesised that power output during maximal, fixed-duration cycling trials in the time-trial position would be attenuated when compared to the more upright cycling position. The hypothesised reduction in power output in the time-trial position would lead to a lower CP while W' would remain unaffected.

Methods

Participants

Seven (6 male and 1 female) healthy, well-trained cyclists (mean ± SD: age 31 ± 4 yrs; body mass 64.7 ± 10.5 kg; height 1.77 ± 0.16 m) participated in the study, which was conducted during the competitive racing season. All participants were competitive amateur team road cyclists, at least British Cycling Category 2 standard, with a minimum weekly training volume of 14 h and competed regularly in both road and 'time trial' races. Prior to testing, each cyclist gave written informed consent to participate in the investigation which had institutional ethics approval from the University of Kent.

Study Design

Using a repeated-measures within-subjects design, each participant visited the laboratory on four occasions, separated by at least 1 d and no more than 7 d. Visits 1 and 2 involved riding in the upright position with hands resting on the brake lever hoods (BLH), which were positioned on the widest, upper most part of the handlebars of a road bike. On visit 1, participants performed (i) three peak power output (PPO) efforts; (ii) a 3-min and (iii) a 12-min maximal volitional effort. Visit 2 involved a 5-min maximal volitional effort. On visits 3 and 4, participants performed the same trials as visit 1 and 2, but on their personal Time Trial bikes and performed the testing in their specific time trial position (TTP). In the TTP, elbows are tucked in and positioned closer to the body and the forearms rest on the time trial handlebars which are positioned in the centre of the bike handle bars. The protocol is summarised in Figure 1.

All participants had previously completed three supervised familiarisation sessions which were identical to the first experimental testing session. All cyclists were asked to bring their road racing and time-trial bikes to the relevant testing sessions. The rear wheel was replaced with a calibrated power meter (PowerTap G3 wheel, CycleOps, Madison, USA) to measure mechanical power output and cadence. The bikes were then attached to a custom-made turbo trainer (United Kingdom Sport Innovations). Before beginning each trial, the zero-offset of the powermeter was set according to the manufacturer's instructions. In addition, all participants wore a heart rate monitor (Garmin International, Kansas, USA) throughout all experimental visits.

Participants were instructed to refrain from performing heavy exercise 24 h prior to each testing session and to report to the laboratory at the same time of day (+/- 2 h). All testing sessions were preceded by a self-prescribed 20-minute warm-up in the specific cycling position in which that trial was going to be performed. Pedal cadence and gear selection were freely self-adjustable throughout all test sessions.

Fixed-duration maximal time trial efforts (TT): Details of these experimental procedures are provided elsewhere (Parker Simpson & Kordi, 2016). Briefly, all TT efforts began with participants increasing power output in the 10- to 15-s period prior to the start of a TT toward their pre-effort target power (see below for further information about 'TT target powers'). On each occasion, participants were instructed to average the highest power they could for the respective duration (3-, 5- or 12-min) of the trial and to finish the trial with nothing more to give ("empty the tank"). To help achieve this, participants were allowed to self-select gear ratios and cadences throughout each trial. To maximise ecological validity, participants had access to elapsed- and remaining-time, real-time power output and cadence feedback throughout each trial.

TT target powers:

3-min TT: Participants were offered a guide power output not to exceed at the beginning of the 3-min trial. This guide was issued to help avoid a power profile resembling an ‘all-out’ pacing strategy.

12-min TT: To guide the power output for the 12 min TT effort, a conservative estimate of W′ was subtracted from the 3-min TT average power output, providing a likely overestimate of CP. This value (± 10 W) was suggested as the ‘target power’ first ~1-3 min of the 12-min TT.

5-min TT: The 5-min power guideline was simply to not exceed the average power achieved during the 3-min TT at the start of the 5-min TT trial.

Data Acquisition and Analysis

Throughout all exercise trials, power output and pedal cadence were recorded every second using a wireless ANT+ cycle computer (Garmin Edge 500, Garmin International, Kansas, USA). The highest 1-s, 3-, 5-, and 12-min power output windows were found (Golden Cheetah training software, goldencheetah.org) and CP & W′ estimated using both the work-time and power-time^{-1} linear models (equation 1). Cadence (RPM) and heart rate (HR) were recorded for the 3- and 12-min efforts, only.

[Eq. 1] $P = (W'/t) + CP$

t = time or tolerable duration and P = power output.

Statistical Analysis

All statistical tests were conducted using SPSS statistical software package (IBM SPSS Inc., Chicago, IL.). A two-way repeated measures analysis of variance (ANOVA) was used to analyse body position (2) x Trial Duration (4) differences in mean power output. Pairwise comparisons (Bonferroni, *post-hoc*) were computed to detect where differences in power output occurred for trial duration. Data were first examined using the Shapiro-Wilks’ normality test. Sphericity was checked using Mauchly’s Test of Sphericity, and where assumptions were violated, Greenhouse-Geisser correction was used to adjust the degrees of freedom. Paired samples *t*-tests were used to identify any differences in CP and *W’* estimates and for differences in cadence and HR between the 3- and 12-min TT efforts. In accordance with Paton and Hopkins (2001), any difference in mean power output between BLH and TTP position greater than 1% was noted as a meaningful change in physiological performance. Significance was set at $P = 0.05$ and all data are reported as mean ± SD and effect sizes as partial eta squared ($\eta_p{}^2$).

Results

CP and W′ estimates between two cycling positions are presented in Table 1.

3-, 5- & 12-min TT performance:

Repeated measures ANOVA showed no significant difference for body position on mean power output of the TT efforts $F(1,6) = 4.982$, $p = .067$, $\eta_p{}^2 = .45$. However, there was a significant difference for trial duration $F(1.008, 6.048) = 112.562$, $p = .000$, $\eta_p{}^2 = .95$, with

Bonferroni post-hoc tests revealing that only power output for the 5 min trial differed between body positions (357 ± 66 W vs. 345 ± 63 W; $p = 0.014$). There were no differences for Body Position x Trial Duration, $F(1.64, 9.87) = .327$, $p = .688$, $\eta_p^2 = .05$.

All three TT efforts performed in the TTP showed more than a 1% reduction in average power output when compared with the corresponding BLH TT trial (Figure 2). Power output for the 3-, 5- and 12-min TT reduced by 1.6%, 3.3% and 3.9%, respectively.

For the 3-min TTs, no significant difference between cadence (105 ± 5 vs. 102 ± 3 RPM; $p = 0.276$) or HR (171 ± 12 vs. 172 ± 9 BPM; $p = 0.87$) was observed between positions. However, the 12-min effort exhibited both a significant decrease in cadence (95 ± 4 vs. 92 ± 4 RPM; $p = 0.04$) and increase in HR (171 ± 10 vs. 176 ± 9 BPM; $p = 0.01$) in the TTP when compared to the BLH.

Power-Duration Parameters:

CP was significantly different when calculated from the TTP position compared to the BLH position (276 ± 54 W vs. 290 ± 66 W respectively; $p < 0.05$). However, no difference was observed for *W'* between the TTP and BLH cycling positions 20.5 ± 4.2 vs. 19.4 ± 6.4 kJ; $p = 0.61$) (Figure 3).

Discussion

The primary findings of the present study, and partly in accordance with our hypothesis, are that CP was significantly lower when performed in the TTP compared to BLH, whereas *W'* remained similar irrespective of riding position. In the TTP, only mean power for the 5-min TT was significantly reduced when compared with BLH. However, mean power output over the 3-, 5- & 12-min TTs progressively declined with increasing TT duration (figure 3). While the curvature constant of the power-duration relationship between BLH and TTP remained consistent, the depreciation in performance over extending TT durations affected the asymptote (CP) of this relationship.

The CP represents an important fatigue threshold and an inherent characteristic of the aerobic energy system (Poole, Ward, Gardner, & Whipp, 1988); Jones et al., 2010; Poole et al., 2016). Any reduction in pulmonary or local oxygen availability (Dekerle, Mucci, & Carter, 2012; Foster et al., 1999; Simpson, Jones, Skiba, Vanhatalo, & Wilkerson, 2015) would have a deleterious effect on CP. Exercise intensity and torso angle have been shown to affect stroke volume, cardiac output muscle blood flow, deoxygenation and gross efficiency (Fintelman et al., 2016; Foster et al., 1999; Hettinga, Konings, & Cooper, 2016). Recently, Fintelman et al. (2016) showed that lowering torso angle whilst cycling at 70% maximal aerobic power increased oxygen consumption, breathing frequency, minute ventilation and decreased gross efficiency. In speed skating, where athletes also adopt ‘aggressive’ aerodynamic positions with low torso angles, similar observations have been made. Foster, Rundell, Snyder et al. (1999) found a ‘lower’ skating position resulted in reduced stroke volume and cardiac output at maximal voluntary exertion along with higher heart rates at all sub-maximal skating velocities. Hettinga et al. (2016) observed greater deoxygenation of the *m. vastus lateralis* when speed skating in a ‘lower’, more aggressive position. They attributed this increased desaturation to higher intramuscular forces and thus reduced muscle blood flow when skating with a lower torso angle. In speed skating there appears to be a neutral trade-off between the compromised physiological response and the enhanced aerodynamic properties of a lower torso angle (DeKoning, De Boer, De Groot, & Schenau, 1987; Tamaki et al., 1987) making somewhat debateable whether to adopt a lower racing position. In cycling however, the 'trade-off' appears more clear-cut. Fintelman et al (2016) calculated that although a lower torso angle (0° vs. 16°) increased metabolic cost by 2%, frontal area was reduced by 10%, tipping the scales in favour of a faster performance velocity irrespective of the reduced physiological capabilities when adopting a lower torso angle (Peterman, Lim, Ignatz, Edwards, & Byrnes, 2015).

The present study shows that if physiological capabilities from the BLH position were simply applied to the TTP, the 'real world' performance predictions would likely overestimate that capable by a given athlete. Therefore, our data highlight the importance of assessing that physiological capabilities of cyclists in the position in which they compete.

Given the increasing relative reduction in power output across the 3-, 5- & 12-min TTs (Figure 3), some consideration should be given to event duration when attempting to optimise propulsive and resistive variables for a given event. Naturally, longer-duration events rely more heavily of aerobically derived variables (e.g. CP) when compared with shorter-duration events. Indeed, over shorter-duration events, the reduced CP, observed as a consequence of adopting a TTP has less of an impact on the mechanical power output achievable due to the relatively larger contribution from W′. It is noteworthy that the W′ was unaffected by body position, supporting the notion that the W′ may represent some tolerable limit of fatigue-implicated metabolite accumulation within the exercising muscle (Jones & Vanhatalo, 2017; Vanhatalo, Fulford, DiMenna, & Jones, 2010).

As this was an observational study, our main interest was to compare the effects of BLH and TTP body positions on mechanical parameters used to assess a rider's fitness and performance. Other than mechanical power output, cadence and HR were the only other variables that were monitored. Previous work has suggested that, for supramaximal efforts (~3 mins), power output is significantly higher in an upright position compared to a time trial position (Welbergen & Clijsen, 1990). The positional set up of the TTP requires the rider keeping his/ her trunk parallel with the ground and the elbows closely tucked in and close to each other and close to the chest with forearms rested on time-trial bars. Whilst the primary goal of this position is to reduce frontal area, and thus drag, such positions where the rider has little reach could compress the diaphragm and make it harder to breathe. Welbergen and Clijsen measured oxygen uptake in the 3-min supramaximal trial, with no significant difference in VO_2 max between positions reported. Although several studies have reported an effect for body position on a range of biomechanical contributions (Too, 1990). Future research should assess the effect of TTP position on pulmonary diffusing capacity.

Although the present study extends previous findings showing a difference in cycling performance as a result of adopting different cycling positions, it is important to note some study limitations. This study recruited only 7 well-trained cyclists for participation. This small number of participants leads to larger standard error in group means and thus the potential to lack sufficient statistical power to detect differences; especially in regard to each TT duration.

In conclusion, the study identified that riding in a TTP position significantly reduced CP, but did not alter the *W'*. These findings suggest that meaningful comparsions of performance cannot be made using different riding positions. Importantly, these differences could provide researchers with opportunities to gain further insight into the mechanistic basis of CP. From an applied perspective, scientists, coaches and athletes should consider cycling position when using CP as a training and performance parameter.

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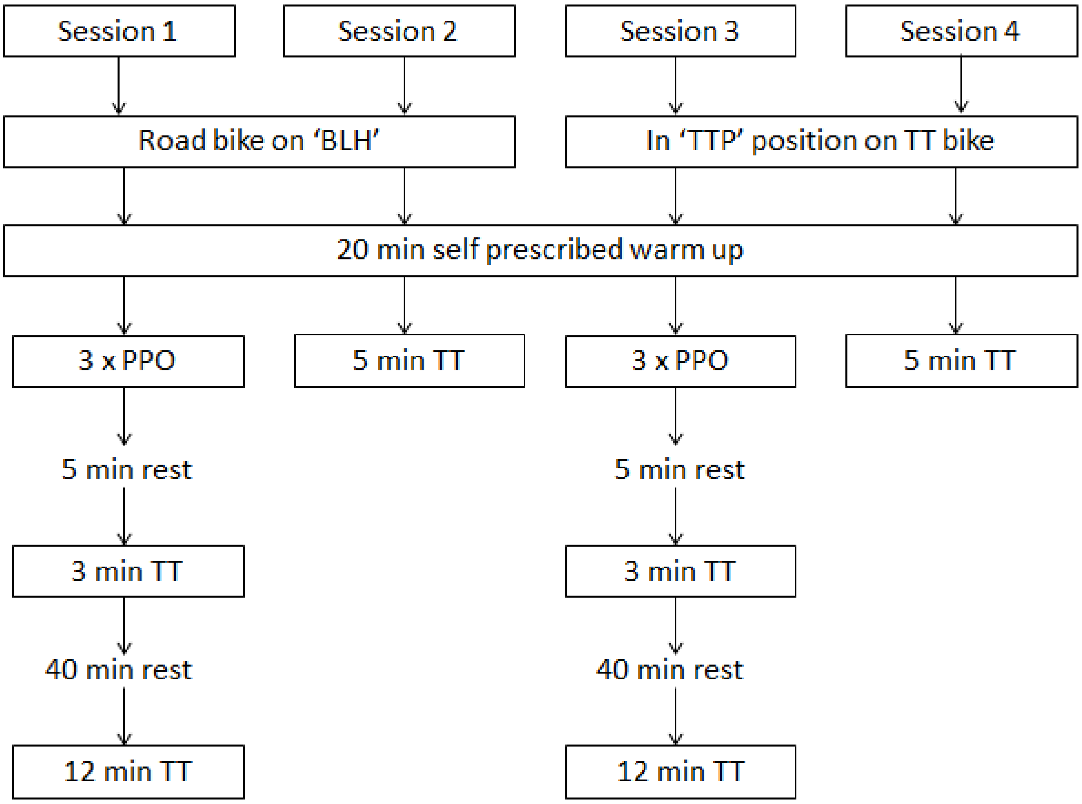
Figure 1: An overview of the study design.



After the familiarisation sessions, participants performed the peak power output (PPO), 3- and 12-min time trials (TT) in the first visit and a 5 min TT on the second visit on the a road bike and whilst adopting the brake lever hood (BLH) position. The final two visits were identical but the TT efforts were performed on time-trial bikes in the racing time-trail position (TTP).

Figure 2: Percentage difference in power output between time trail position (TTP) and break leaver hood (BLH) positions for each of the 3-, 5- and 12-min time trail.

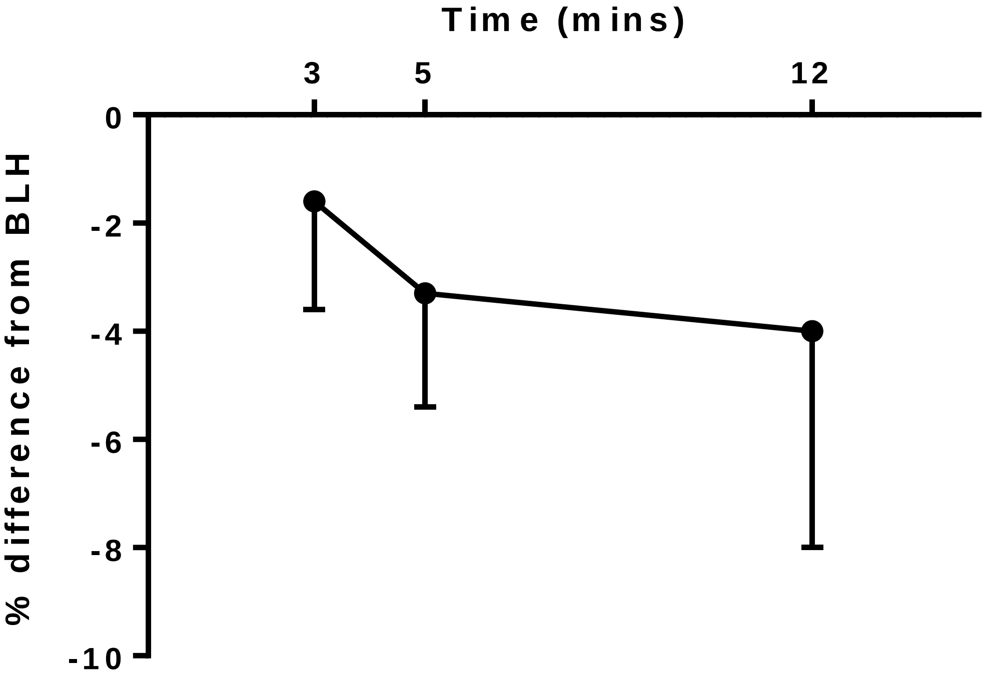
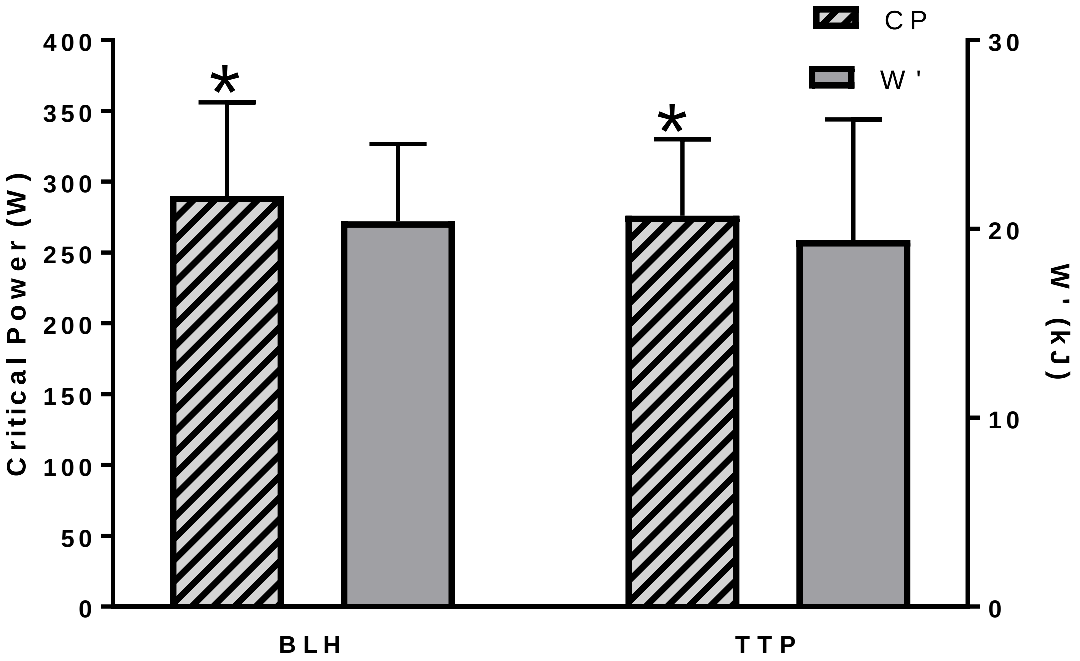


Figure 3: Critical Power and *W'* when performed on the brake lever hoods cycling position (BLH) vs. time-trial cycling position (TTP).



* denotes significant difference between BLH and TTP.

Table 1: Individual and mean power outputs for each TT and corresponding CP & W′ when performed in the time trial position (TTP) and on the brake lever hoods (BLH).

	TTP							BLH						
Participant	**PPO**	**3 min**	**5 min**	**12 min**	**CP (W)**	***W’* (J)**	**R^2**	**PPO**	**3 min**	**5 min**	**12 min**	**CP (W)**	***W’* (J)**	**R^2**
1	1054	372	318	277	246	22218	0.99	1060	382	342	296	285	24440	0.99
2	1210	408	357	313	281	22742	0.99	1278	417	370	319	237	29418	0.99
3	950	354	316	273	245	20348	0.99	981	403	333	278	266	21664	0.99
4	970	410	370	329	301	19999	0.99	944	400	370	326	381	15480	0.99
5	968	460	420	382	356	18999	0.99	1035	460	438	402	300	19413	0.99
6	620	260	233	208	191	12608	0.99	617	252	233	210	195	10674	0.99
7	958	453	401	347	311	26232	0.99	939	448	412	386	366	14368	0.99
Mean	961	388	345*	304	276	20449	0.99	979	395	357	317	290	19351	0.99
SD	177	68	63	57	54	4196		197	69	66	65	67	6425	

*Significantly different to BLH (*P* < 0.05)