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Jonathan R. Switalla
Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, KY.

M. Travis Byrd
Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, KY

Mark G. Abel
Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, KY

Bradley S. Fleenor
Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, KY

Haley C. Bergstrom
Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, KY

Correspondence
Haley C. Bergstrom
Department of Kinesiology and Health Promotion, University of Kentucky, 100 Seaton Building Lexington, KY

Can experienced runners accurately estimate performance capabilities to derive the parameters of the critical velocity model?

Jonathan R Switalla, M Travis Byrd, Mark G Abel, Bradley S Fleenor and Haley C Bergstrom

Abstract
This study examined the accuracy of estimated performance times to define the parameters of the critical velocity (CV) model. Twelve subjects provided an estimated time to complete (ET_{com}) maximal-effort runs at four different distances (400m, 800m, 1600m, and 3200m). The CV and anaerobic running capacity (ARC) were derived from the total distance (TD) versus ET_{com} relationship. The equation: predicted time to completion ([PT_{com}] = ARC/(velocity - CV)) was used to determine the PT_{com} for runs at three different distances (200m, 600m, and 1000m). The PT_{com} was validated against the actual time to complete (AT_{com}) runs at the same three distances. The TD versus ET_{com} relationship was highly linear and indicated a close relationship between running distance and time. The PT_{com} overestimated the AT_{com} at 200m, but there were no significant differences between the PT_{com} and AT_{com} at 600m and 1000m. There were, however, no significant relationships between PT_{com} and AT_{com} at any of the three distances. These findings indicated that the CV model could be applied to estimated running times to derive the CV and ARC parameters, but the parameters of the test could not be used to accurately estimate individual performance times above CV using the equation PT_{com} = ARC / (V – CV).

Keywords: Fatigue Threshold, Performance Estimations, Aerobic Exercise, Anaerobic Exercise

1. Introduction

The critical velocity (CV) model was developed [1] as the treadmill analog to the critical power (CP) model for cycle ergometry. Running velocity and the time to exhaustion (T_{lim}) conformed to the same hyperbolic relationship that had previously been shown for power output versus T_{lim} during cycle ergometry [1]. The CV model provides estimates of two separate parameters, CV and anaerobic running capacity (ARC), that are defined as the slope and the y-intercept of the total distance (TD) and T_{lim} relationship, respectively. It has been suggested [2] that CV represents the highest sustainable (at least 30 min) running velocity, where metabolic responses (VO_2 and blood lactate) reach steady state values. The ARC parameter reflects the total amount of work that can be performed using only the energy stores within the working muscle (phosphocreatine, adenosine triphosphate, glycogen, and the oxygen bound to myoglobin [3, 4], and is limited by the accumulation of metabolic byproducts and ions [5]. Thus, the CV model provides estimates of two separate parameters, CV and ARC, which reflect the aerobic and anaerobic capabilities, respectively.

One potential application of the CV model is the prediction of performance for intensities above the CV [3]. Currently, there are conflicting data regarding the ability of the CV model to accurately predict performances. For example, Pepper *et al*. [6] indicated the CV model accurately predicted the time to exhaustion at 115% of CV, but it was over predicted at 100 and 130%. During cycle ergometry, however, the time to exhaustion was accurately predicted at all power outputs above CP [7]. Thus, the results of previous studies [6, 7] indicated there is conflicting evidence regarding the ability of the CP/CV model to provide an accurate estimate of the subjects' performance capabilities at power loadings greater than CP or CV.

Typically, the CV test parameters are determined from multiple, constant power output or velocity work bouts, performed to exhaustion. The total distance (TD) is then plotted against the time to exhaustion (T_{lim}) to derive CV and ARC.

Recently, Black *et al.* [8] suggested that, in comparison with the conventional constant work rate protocol, a self-selected pacing, time-trial strategy could be used to estimate the CP and AWC during cycle ergometry. These findings [8] indicated performance variables (i.e., time trials), rather than times to exhaustion, may provide accurate estimates of the CP test parameters. No previous studies, however, have examined the validity of CV and ARC derived from estimated performance capabilities at predetermined distances during track running.

The CV test is physically demanding, requiring multiple, exhaustive work bouts. To improve the applicability of the test, previous studies have examined the number of trials necessary to accurately estimate the test parameters. During cycle ergometry, it was reported that only two constant work rate tests are necessary to accurately estimate CP and AWC [4]. In addition, a single 3-minute all-out test has also been developed for cycling [4, 9, 10], rowing [11], swimming [12], and running [13]. Although a single, 3-min all-out test reduced the number of workbouts required to determine CV/CP and ARC/AWC, many athletes and coaches do not have access to the necessary equipment and may not be willing to alter training schedules to complete the test. A protocol that utilizes estimated performance times to determine the parameters of the CV test would improve the applicability of the test. Therefore, the purposes of this study were to: 1) determine if estimated performance times at four different distances can be used to accurately define the parameters of the CV test; and 2) if the CV test parameters could be used to accurately predict performance at intensities above CV. Based on previous studies [7, 8], we hypothesized that; 1) CV and ARC would be accurately estimated from estimated performance times; and 2) the estimated CV and ARC parameters could be used to predict performance above CV.

2. Materials and Methods

2.1 Experimental Design

The subjects completed a total of seven visits with a minimum of 24 hours between each visit. During the first visit, the subjects performed a graded treadmill test to exhaustion to determine maximal oxygen uptake ($\dot{V}O_{2peak}$) and the velocity associated with $\dot{V}O_{2peak}$ ($v\dot{V}O_{2peak}$). The subjects were asked to estimate their maximal-effort times to complete (ET_{com}) four different distances (400m, 800m, 1600m, and 3200m). The ET_{com} was used to derive the CV and ARC from the linear-total distance versus T_{lim} model. During the remaining six visits, the subjects performed maximal-effort runs at distances of 200m, 600m, and 1000m. Each distance was performed twice, in a randomized order, and the time to complete (AT_{com}) the run was recorded. The predicted time to complete (PT_{com}) three distances (200, 600, and 1000m) was derived using the CV and ARC estimates from the TD versus ET_{com} relationship. The PT_{com} and AT_{com} for the maximal-efforts runs were used to access the validity of the equation: PT_{com} = ARC / (V – CV) for predicting performance, utilizing the CV parameters derived from the predicted times. In addition, the reliability of the performance at each distance (200, 600, and 1000m) was determined.

2.2 Subjects

Twelve (6 males, 6 females, age: 23.5 ± 3.6 years, height: 174.1 ± 8.0 cm, weight: 66.7 ± 9.0 kg) trained runners with experience in running distances, between 15 to 45 miles per week were recruited for this study. The study was approved by the University's Institutional Review Board for Human Subjects. All subjects completed a medical history questionnaire and signed a written informed consent document prior to testing. Twelve runners completed the incremental treadmill test and provided estimates of their ET_{com} for four distances (400m, 800m, 1600m, and 3200m). Two subjects, however, were removed from the analyses because they provided estimates of ET_{com} that resulted in negative anaerobic running capacity (ARC) values derived from the total distance versus ET_{com} relationship. Therefore, the analyses included 10 subjects (5 males, 5 females, age: 22.6 ± 3.2 years, height: 173.7 ± 8.7 cm, weight: 64.2 ± 7.4 kg).

2.3 Body Composition Assessments

Body composition assessments were completed with Bioelectrical Impendence Analysis (BIA; Bodystat QuadScan 4000) prior to the exercise testing during visit 1. The BIA device was calibrated before measurements were taken and subjects were instructed to lay in a supine position on a non-conductive surface. The impedance at all frequencies provided (5, 50, 100 & 200 kHz), percent body fat, and total body water were determined from the manufacture's prediction equation and recorded for each subject.

2.4 Determination of peak values

During visit 1, the subjects completed a graded treadmill test to exhaustion for the determination of $\dot{V}O_{2peak}$ and $v\dot{V}O_{2peak}$. Prior to the test, each subject completed a 3 min warm-up on the treadmill at a velocity of 4.8 km·h^{-1} and 0% grade, followed by a 3 min passive recovery. Following the warm-up, each subject was fitted with a nose clip and had to breathe through a 2-way valve (Hans Rudolph 2700 breathing valve, Kansas City, MO, USA). Expired gas samples were collected and analyzed using a calibrated TrueMax 2400 metabolic cart (Parvo Medics, Sandy, UT, USA). The gas analyzers were calibrated with room air and gases of known concentration prior to all testing sessions. The O_2, CO_2, and ventilator parameters were recorded breath-by-breath and expressed as 20 s averages [14]. In addition, HR was recorded with a Polar Heart Rate Monitor (Polar Electro Inc., Lake Success, NY) that was synchronized with the metabolic cart. Heart rate was recorded continuously throughout the test and expressed as 20 s averages. Each subject gave a rating of perceived exertion (RPE) during the last 10 s of each minute using the Borg 6-20 RPE scale [15]. The incremental test began at a treadmill velocity of 6.4 km·h^{-1} and 0% grade. Following the 14.4 km·h^{-1} stage, the velocity no longer was increased, however, the treadmill grade was increased by 2% every 2 min until the subject no longer could maintain the running velocity and grasped the handrails to signal exhaustion. The $\dot{V}O_{2peak}$ was defined as the highest 20 s average $\dot{V}O_2$ value recorded during the test. The velocities performed at 0% grade (6.4 to 14.4 km·h^{-1}), were plotted against $\dot{V}O_2$ and the regression equation derived was used to determine the $v\dot{V}O_{2peak}$.

2.5 Estimated Performance Times and CV Parameter Determination

Following the graded treadmill test, each subject completed a written survey asking them to provide the ET_{com} for maximal-effort runs at 400m, 800m, 1600m, and 3200m. The TD was plotted against ET_{com} for each of the four distances. The CV and ARC were defined as the slope and y-intercept of the regression line, respectively, of the TD versus ET_{com} relationship.

2.6 Determination of PT_{com}

The PT_{com} for three distances (200, 600, and 1000m) was derived using the CV and ARC estimates from the TD versus ET_{com} relationship, along with the average running velocities (V) calculated for each distance from the AT_{com} ($V = TD / AT_{com}$). The PT_{com} values were derived for each of the standard distances using the equation: $PT_{com} = ARC / (V - CV)$.

2.7 Examination of the Estimated CV and ARC Parameters

During visits 2 – 7, the PT_{com} values for the 200m, 600m, and 1000m distances, obtained from the TD versus ET_{com} relationship, were validated against the AT_{com} runs at 200m, 600m, and 1000m. All of the runs were conducted outside on a measured running loop on a city block. The subjects performed a standardized running warm-up. Following the warm-up, a rest period of 10 min was given prior to beginning the max-effort run. The maximal-effort runs at each of the three distances were performed on separate days, and each distance was performed twice, in a randomized order with a minimum of 24 h of recovery between runs for the determination of the test-retest reliability (ICC) at each distance. The AT_{com} was recorded by the tester using a stopwatch. The subjects were given strong verbal encouragement during each run and were not aware of how much time had elapsed. The faster of the two trials at each distance was used to compare to the PT_{com} derived from the CV model.

2.8 Statistical Analysis

The mean differences between the PT_{com} determined from the TD versus ET_{com} relationship and the fastest recorded AT_{com} for each distance were analyzed using paired samples t-tests. The relationship between the PT_{com} and AT_{com} were assessed using Pearson correlations, coefficients of determination, and the standard error of the estimates (SEE). In addition, the relationships among CP, ARC, and AT_{com} for each distance (200, 600, and 1000 m) were examined using a Pearson product correlation matrix. The relative reliability of AT_{com} for each distance was examined using the intraclass correlation coefficients (ICC), with the inclusion of systematic error 2,1 and 2,k equations [16]. Absolute reliability of AT_{com} for each distance was examined using the standard error of the measurement (SEM). Bland-Altman plots were used to assess the agreement between: 1) PT_{com} and AT_{com} at each distance (200, 600, and 1000m); and 2) the first and second set of performance trials for each distance (200, 600, and 1000m).

3. Results

The mean ± SD and range of values derived from the incremental treadmill test and body composition analyses are presented in Table 1. The ET_{com} for the four distances (400m, 800m, 1600m, and 3200m) used to determine the CV and ARC ranged from 60 s to 1080 s. The r^2 values for the TD versus ET_{com} relationship ranged from 0.996 to 1.000. The mean (± SD) CV and ARC were 14.3 ± 2.9 $km \cdot h^{-1}$ (81.3% of $v\dot{V}O_{2peak}$) and 125.07 ± 32.43 m, respectively.

The mean ± SD and range of values for the PT_{com} and AT_{com} for the 200, 600, and 1000m runs are presented in Table 2. There was a significant difference ($t_{(9)} = 6.90$, $p < 0.001$) and no significant relationship ($r^2 = 0.02$, SEE = 4.79 s, p = 0.72) between the PT_{com} (53.77 ± 9.28 s) and AT_{com} (32.40 ± 4.55 s) at 200m (Figure 1). The results of the Bland-Altman analyses are presented in Figure 2. The PT_{com} was not significantly different from the AT_{com} at 600 m (PT_{com} = 111.16 ± 19.14 s and AT_{com} = 119.90 ± 20.35 s; $t_{(9)} = -1.10$, p = 0.30) or 1000 m (PT_{com} = 198.52 ± 127.44 s and AT_{com} = 213.30 ± 32.40 s; $t_{(9)} = -0.34$, p = 0.74), and there was no significant relationship between PT_{com} and AT_{com} at either distance (600 m: $r^2 = 0.04$, SEE = 21.18 s, p = 0.59 and 1000 m: $r^2 = 0.05$, SEE = 33.47 s, p = 0.53) (Figures 3 and 4). The results of the Bland-Altman analyses for 600 m and 1000 m are presented in Figures 5 and 6. The relationships among CV, ARC, and AT_{com} for each distance are presented in Table 3.

The test-retest reliability at each distance (200, 600, and 1000m) resulted in ICC values of R = 0.98 – 0.99. The SEM values for 200, 600, and 1000 m runs were 0.12 s, 0.87 s, and 0.69 s, respectively. Furthermore, there were no mean differences (p = 0.081 – 0.965) between test-retest for any of the distances.

Table 1: Subject demographics, body composition (% body fat), and maximal aerobic capacity ($\dot{V}O_{2max}$) for 5 male and 5 female subjects.

Variable	Mean ± SD	Range
Age (yrs)	22.6 ± 3.24	19-29
Height (cm)	173.7 ± 8.9	162.6-188.0
Weight (kg)	64.3 ± 7.4	48.6-75.5
Body Comp (% Fat)	14.2 ± 9.2	1.4-28.1
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	63.96 ± 12.39	48.69-82.71

Table 2: Mean ± SD for predicted (PT_{com}) and actual (AT_{com}) times to completion for the 200, 600, and 1000m runs for 5 male and 5 female subjects.

Distance	PT_{com} (s)	AT_{com} (s)
200 m	53.77 ± 9.28*	32.40 ± 4.55
600 m	111.16 ± 19.14	119.90 ± 20.35
1000 m	198.52 ± 127.44	213.30 ± 32.40

*Significantly ($P < 0.05$) greater than the actual time to completion

Table 3: Correlation matrix for the critical velocity (CV), anaerobic running capacity (ARC), and the actual times to complete (AT_{com}) running trials at 200, 600, and 1000m (n = 10).

	CV	ARC	AT_{com} 200	AT_{com} 600	AT_{com} 1000
CV	1.00				
ARC	-.188	1.00			
AT_{com} 200	-.906*	-.093	1.00		
AT_{com} 600	-.888*	-.167	0.960*	1.00	
AT_{com} 1000	-.869*	-.151	0.917*	0.982*	1.00

*r significant at $p \leq 0.05$

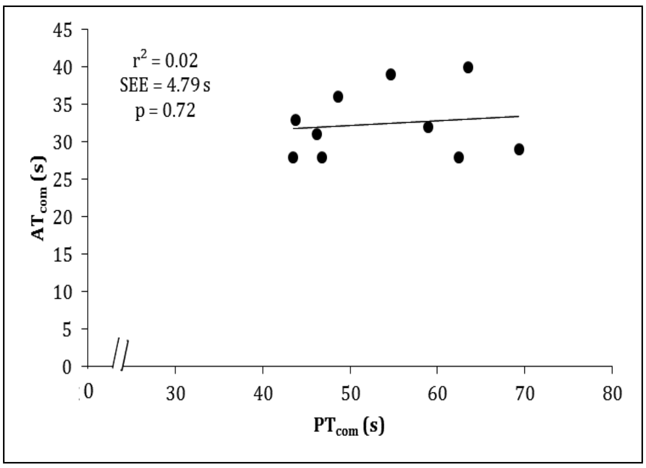

Fig 1: The relationship between the actual time to completion (AT_{com}) versus the predicted times to completion (PT_{com}) for the 200m run

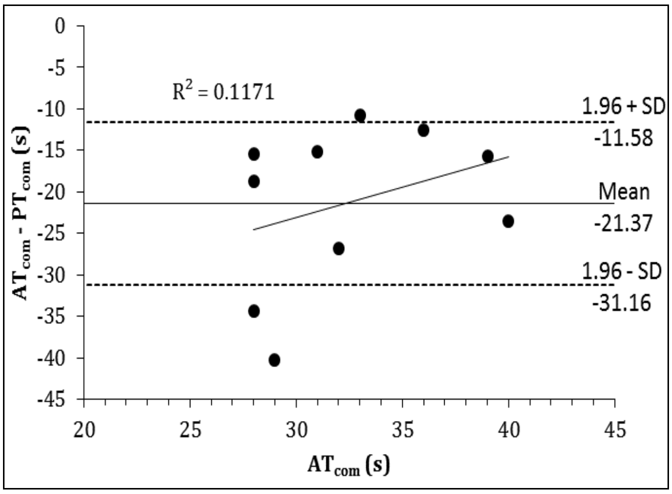

Fig 2: Bland Altman analysis of agreement between the actual (AT_{com}) minus predicted (PT_{com}) and actual time for the 200m. The middle solid line represents the mean of the difference of the actual time and predicted time. The upper and lower dotted lines represent the bias ±1.96 SD (95% Limits of Agreement). The $r^2 = 0.1171$; $P > 0.05$

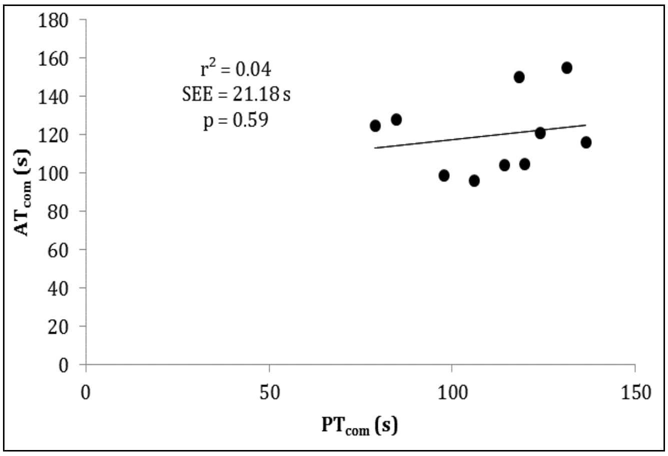

Fig 3: The relationship between the actual time to completion (AT_{com}) versus the predicted time to completion (PT_{com}) for the 600m run

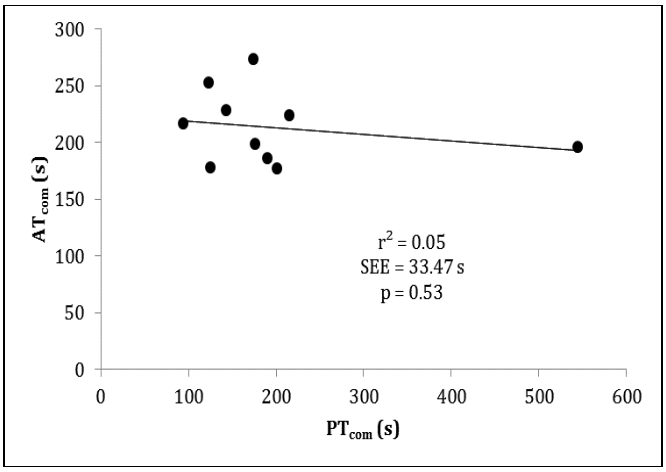

Fig 4: The relationship between the actual time to completion (AT_{com}) versus the predicted times to completion (PT_{com}) for the 1000m run

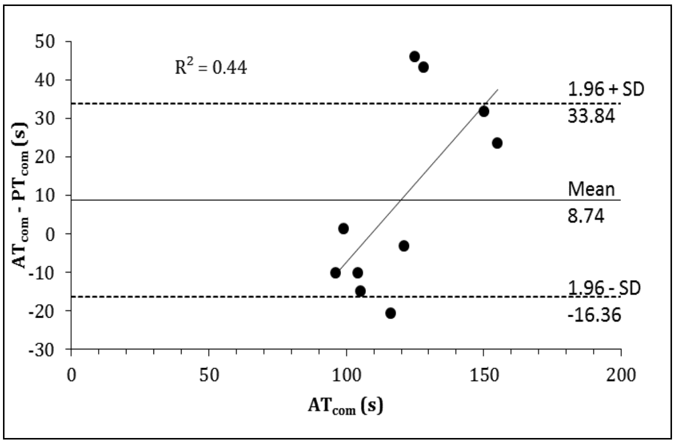

Fig 5: Bland Altman analysis of agreement between the actual (AT_{com}) minus predicted (PT_{com}) and actual time for the 600m. The middle solid line represents the mean of the difference of the actual time and predicted time. The upper and lower dotted lines represent the bias ±1.96 SD (95% Limits of Agreement). The $r^2 = 0.44$; $P > 0.05$

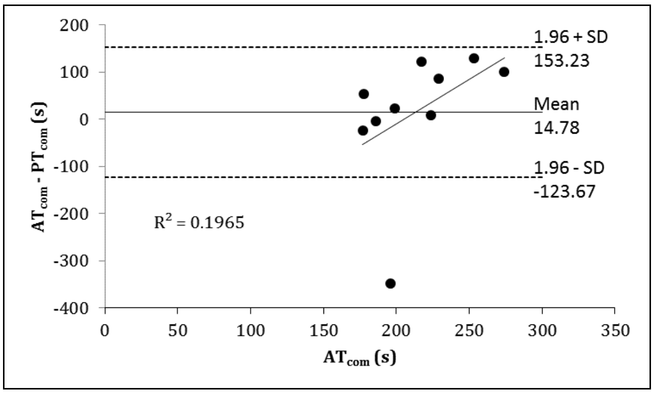

Fig 6. Bland Altman analysis of agreement between the actual (AT_{com}) minus predicted (PT_{com}) and actual time for the 1000m. The middle solid line represents the mean of the difference of the actual time and predicted time. The upper and lower dotted lines represent the bias ±1.96 SD (95% Limits of A.

4. Discussion

The primary purpose of the present study was to determine if estimated performance times at four different distances can be used to accurately define the parameters of the CV test. The TD was plotted as a function of the ET_{com} for four running distances (400, 800, 1600, and 3200m). The r^2 values for the TD versus T_{lim} (0.996 – 1.000) relationship were consistent with the r^2 values (0.987 – 0.999) reported in previous studies of recreationally trained subjects [6, 7], and indicated a close relationship between running distance and time. These findings suggested that the mathematical model used to derive the CV parameters (CV and ARC) from times to exhaustion during constant velocity running, was also applicable to estimated performance times at specified distances.

The mean ± SD and range of CV (14.3 ± 2.9 km·h^{-1}; 10.2 – 17.9 km·h^{-1}) and ARC (0.13 ± 0.032 km; 0.09 – 0.11 km) values in the present study were higher and lower, respectively, than the mean and range of CV (13.43 ± 2.04 to 13.7 ± 1.1 km·h^{-1}; 10.43 – 17.85 km·h^{-1}) and ARC (0.20 ± 0.063 km; 0.11 – 0.23 km) values previously reported for recreationally trained subjects [6, 17]. These differences in CV and ARC values may be related to the training status of the subjects. Specifically, the subjects in the present study, although not elite, were experienced runners and had a greater aerobic capacity (63.96 ± 12.39 ml·kg^{-1}·min^{-1}), than previous samples of subjects who exercised regularly, but were not highly trained runners (48.6 ± 7.1 to 54.4 ± 6.6 $ml \cdot kg^{-1} \cdot min^{-1}$). Thus, the ARC and CV values in this present study were slightly lower and higher, respectively, compared with previous studies examining recreationally trained subjects [6, 17]. These differences may be related to the slightly greater aerobic capacity and the mode specific training adaptations of the current sample of experienced runners, compared with generally active individuals previously reported [6, 17].

One unique application of the CV model is the ability to predict the time to exhaustion (PT_{com}) at any velocity greater than CV using the equation: $PT_{com} = ARC / (V – CV)$ [3]. In the present study, the accuracy of the PT_{com} estimated from the CV and ARC parameters derived from the TD versus ET_{com} relationship was examined for three distances (200, 600, and 1000m). At 200m (~150% of CV) the PT_{com} overestimated the AT_{com}, while the PT_{com} for the 600m (125% of CV) and 1000m (118% of CV) were not significantly different from the AT_{com}. There were, however, no significant relationships between the AT_{com} and PT_{com} for any of the distances. Currently, there are conflicting data regarding the accuracy of performance prediction for intensities above CV or CP [6, 7]. For example, Pepper *et al.* [6] reported no significant differences and significant relationships between the predicted and actual times to exhaustion at 85% and 115% of CV, however, the time to exhaustion was over predicted at 100% and under predicted at 130% of CV. In addition, during cycle ergometry, there were no differences and significant relationships ($r = 0.84 – 0.89$, $p < 0.05$) between the predicted and actual times at power loadings above CP [7]. At CP, however, the actual time to exhaustion was significantly less than the predicted time [7]. The discrepancy between actual and predicted times for intensities greater than 130% of CV in the present study, as well as previous studies [6], may be related to the limitations of the mathematical model. Typically, the CV model is determined from work bouts ranging from 1 to 20 min [2, 18] and in the present study the range of times used to determine CV and ARC was 1 to 18 min. The prediction of the 200m time required extrapolation outside the range of values used to determine the parameters of the CV test. Thus, the significant difference between the PT_{com} and AT_{com} at higher intensities (>130% of CV) may be related to the limitations of the mathematical model to predict performance outside the range of values used for the CV and ARC parameter estimations.

The non-significant differences between PT_{com} and AT_{com} at 600m and 1000m, reflecting 125% and 118% of CV, respectively, in the present study was consistent with previous data indicating no significant differences between actual and estimated times at 115% of CV [6]. The lack of relationship between PT_{com} and AT_{com} (Figures 1, 3, and 4), however, was not consistent with previous research [6, 7] and indicated significant individual variability in the performance predictions. In addition, the SEE values for the three runs indicated a possible error in prediction of 4.8 s for a 32.4 s run (14.8% of mean), 21.2 s for a 2 min run (17.7% of mean), and 33.5 s for a 3.55 min (15.7% of mean) run. These SEE values indicated an error that was too large to be of practical value when predicting performance at these distances. Thus, the current findings, in conjunction with those of others [6, 7], indicated that the prediction of performances utilizing the CP and CV models tend to under or overestimate the actual times to exhaustion for high intensity, shorter duration trials (>130% of CV), and resulted in SEE values for all three distances that were too great to provide accurate estimates of performance. The lack of correlation between actual and predicted times may be related to the non-significant relationship between the independent variables (CP and ARC) used to estimate running performance and the non-significant relationships between ARC and any of the running distances. Because ARC was not related to running performance in the present study, but is used in the equation to derive the PTcom, it may reduce the accuracy of the model. Therefore, the current findings did not support the validity of the equation $PT_{com} = ARC / (V – CV)$.

5. Conclusions

In conclusion, the purpose of this study was to determine if estimated performance times at four different distances can be used to accurately define the parameters of the CV test. The TD versus ET_{com} relationship was highly linear ($r^2 = 0.996 – 1.000$) and indicated a close relationship between running distance and time. These findings suggested that the mathematical model used to derive the CV parameters (CV and ARC) from times to exhaustion during constant velocity running, was also applicable to estimated performance times at specified distances. The comparisons of the PT_{com} versus the AT_{com} indicated the PT_{com} overestimated the AT_{com} for the 200m. There were no significant differences between the PT_{com} and AT_{com} for the 600 and 1000m, however, there were no significant relationships between PT_{com} and AT_{com} at any of the distances. These findings were consistent with other studies that also found a discrepancy between actual and predicted times utilizing the CP and CV model [6, 7]. In addition, the SEE values for all three distances indicated error in prediction that was too great to be of practical values for the 200m, 600m, and 1000m distances. Therefore, the principal findings of this study were that the CV model could be applied to estimated performance times during outdoor running to derive the CV and ARC parameters, but the parameters of the test could not be used to accurately estimate performance times above CV using the equation $PT_{com} = ARC/ (V – CV)$.

6. References

1. Hughson RL, Orok CJ, Staudt, LE. A high velocity treadmill running test to assess endurance running potential. Int J Sports Med. 1984; 5(1):23-25.
2. Poole DC, Ward SA, Gardner GW, Whipp BJ. Metabolic and respiratory profile of the upper limit for prolonged exercise in man. Ergonomics, 1988; 31(9):1265-1279.
3. Moritani T, Nagata A, Devries HA, Muro M. Critical power as a measure of physical work capacity and anaerobic threshold. Ergonomics. 1981; 24(5):339-350.
4. Vanhatalo A, Doust JH, Burnley M. Determination of critical power using a 3-min all-out cycling test. Med Sci Sports Exerc. 2007; 39(3):548-555.
5. Jones AM, Wilkerson DP, DiMenna F, Fulford J, Poole DC. Muscle metabolic responses to exercise above and below the “critical power” assessed using 31P-MRS. Am J Physiol Regul Integr Comp Physiol. 2008; 294(2):R585-R593.
6. Pepper ML, Housh TJ, Johnson GO. The accuracy of the critical velocity test for predicting time to exhaustion during treadmill running. Int J Sports Med. 1992; 13(2):121-124.
7. Housh DJ, Housh TJ, Bauge SM. The accuracy of the critical power test for predicting time to exhaustion during cycle ergometry. Ergonomics. 1989; 32(8):997-1004.

8. Black MI, Jones AM, Bailey SJ, Vanhatalo A. Self-pacing increases critical power and improves performance during severe-intensity exercise. Appl Physiol Nutr Metabol. 2015; 40(7):662-670.
9. Bergstrom HC, Housh TJ, Zuniga JM, Camic CL, Traylor DA, Schmidt RJ, *et al.* A new single work bout test to estimate critical power and anaerobic work capacity. J Strength Cond Res. 2012; 26(3):656-663.
10. Burnley M, Doust, JH, Vanhatalo A. A 3-min all-out test to determine peak oxygen uptake and maximal steady state. Med Sci Sports Exerc. 2006; 38(11):1995-2003.
11. Cheng CF, Yang YS, Lin HM, Lee CL, Wang CY. Determination of critical power in trained rowers using a three-minute all-out rowing test. Eur J Appl Physiol. 2012; 112(4):1251-1260.
12. Kalva-Filho CA, Zagatto AM, Araújo MI, Santiago PR, Da Silva AS, Gobatto CA, *et al.* Relationship between aerobic and anaerobic parameters from 3-minute all-out tethered swimming and 400-m maximal front crawl effort. J Strength Cond Res. 2015; 29(1):238-245.
13. Pettitt RW, Jamnick N, Clark IE. 3-min all-out exercise test for running. Int J Sports Med. 2012; 33(6):426-431.
14. Robergs RA, Dwyer D, Astorino T. Recommendations for improved data processing from expired gas analysis indirect calorimetry. Sports Med. 2010; 40(2):95-111.
15. Borg G. Perceived exertion as an indicator of somatic stress. Scand J Rehabil Med. 1970; 2(2):92-98.
16. Weir, JP. Quantifying test-retest reliability using the intraclass correlation coefficient and SEM. J Strength Cond Res. 2005; 19(1):231-240.
17. Housh TJ, Cramer JT, Bull AJ, Johnson GO, Housh DJ. The effect of mathematical modeling on critical velocity. Eur J Appl Physiol. 2001; 84(5): 469-475.
18. Bull AJ, Housh TJ, Johnson GO, Rana SR. Physiological responses at five estimates of critical velocity. Eur J Appl Physiol. 2008; 102(6):711-720.