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Original Research

Examination of Resistance Settings Based on Body Weight for the 3-Minute All-Out Critical Power Test

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ABSTRACT

International Journal of Exercise Science 11(4): 585-597, 2018. There are conflicting suggestions regarding the most valid resistance (3-5% of body weight) to use for the critical power (CP) 3-min all-out (CP_{3min}) test to estimate CP and anaerobic work capacity (AWC). The purpose of this study was to determine if the CP and AWC estimates from the CP_{3min} test were affected by the percentage of body weight used to set the resistance on a Monark cycle ergometer. Ten recreationally trained participants (mean ± SD: Age: 22.2 ± 2.2 yrs.) completed the CP_{3min} test at resistances of 4.5% ($CP_{4.5\%}$) and 3% ($CP_{3\%}$) of body weight to determine the CP and AWC. There were no significant differences between the $CP_{4.5\%}$ (167 ± 34 W) and $CP_{3\%}$ (156 ± 36 W) estimates. The $AWC_{3\%}$ (5.6 ± 2.5 kJ) estimates were significantly lower than the $AWC_{4.5\%}$ (9.0 ± 4.0 kJ). The CP and AWC estimates from the $CP_{4.5\%}$ were consistent with values reported in the literature, however, the AWC estimate from the $CP_{3\%}$ was lower than typically reported. These findings suggested that a resistance set at 3% of body weight for the CP_{3min} test may be too low to accurately estimate AWC, but 3% and 4.5% resulted in the same estimation of CP. Thus, the principal finding of this study was that a resistance of 4.5% of body weight for $CP_{3\text{-}min}$ in recreationally trained participants resulted in more accurate estimates of AWC, compared to a resistance of 3%, and supports the use of 4.5% body weight resistance to measure both CP and AWC.

KEY WORDS: Aerobic exercise, anaerobic exercise, bicycling, exercise evaluation

INTRODUCTION

The critical power (CP) concept developed (16) for a single muscle or muscle group and applied to whole-body cycle ergometry exercise (17), provides estimates of two separate parameters, CP and the anaerobic work capacity (AWC). The critical power represents the highest sustainable power output and AWC the total amount of work that can be performance above CP using only energy sources stored within the working muscle (phosphocreatine, adenosine triphosphate, glycogen, and the oxygen bound to myoglobin) (17). Theoretically, CP demarcates the heavy and severe exercise intensity domains (3,12) and reflects the highest power output where $\dot{V}O_2$ and blood lactate reach steady state values (12). Critical power is a more important predictor of endurance performance than the gas exchange threshold (GET) and $\dot{V}O_{2peak}$ (11). The AWC has been shown (18) to be highly related to the total work completed during the Wingate 30 s all-out test and useful in the prediction of endurance performance (6). Specifically, the inclusion of AWC, in addition to aerobic parameters, significantly improved endurance performance predictions in an otherwise homogenous aerobically trained population. Thus, previous studies (6,11,18) have shown the CP and AWC parameters from the CP test are valid estimations of aerobic and anaerobic capabilities, respectively, and have practical implications in the prediction of performance.

One of the primary applications the CP parameter is the demarcation of the exercise intensity domains (12,21). Gaesser and Poole (12) described three distinct exercise intensity domains; moderate, heavy, and severe. The moderate domain includes exercise intensities that result in $\dot{V}O_2$ and blood lactate response that reach steady state values within 2-3 min and exercise can be maintained for at least 60 min (12,21). The gas exchange threshold (GET) demarcates the moderate from heavy domains (12). Continuous exercise performed above the GET, within the heavy domain, results in a gradual rise in $\dot{V}O_2$ and blood lactate beyond the third min, but eventually reach a delayed steady-state and exercise can typically be maintained beyond 20 to 30 min (12,21). Exercise intensities performed within the severe domain result in continuous increases in $\dot{V}O_2$ and blood lactate until exhaustion is reached, typically within 20 min (14,21). Poole et al. (21) suggested that CP demarcates the heavy from the severe exercise intensity domains. Specifically, the authors (21) showed that subjects could complete a 24 min constant power output ride at CP, but 7 of 8 subjects could not complete a 24 min ride at CP + 5% of the maximal power. In addition, the blood lactate and $\dot{V}O_2$ responses stabilized during the ride at CP, but continued to rise during the ride at CP + 5%. Recently, it has been suggested (3) that the respiratory compensation point (RCP), measured during an incremental test, may represent a similar intensity as CP. Therefore, taken together, previous studies (3,21) indicated CP and the RCP may reflect a similar exercise intensity and demarcate the heavy and severe exercise intensity domains.

Originally, the CP test required the measurement of the amount of work (W_{lim}) completed during a series of 3 to 4 exhaustive, constant power outputs and the time to exhaustion (T_{lim}) (16,17). The multiple, exhaustive work bouts required for the CP test may limit the application of the model. Therefore, several studies (4,13) have examined different methodological variations of the number of work bouts required to determine CP. Housh et al. (13) showed that both CP and AWC could be estimated from two constant power output rides to exhaustion using the linear, total work versus T_{lim} model. More recently, a methodological change to the CP test was developed utilizing a single, 3-min all-out test (CP_{3min}) (7,22). The 3-min duration was selected because it allowed enough time to yield a stable power output during the last 30 s of the test, termed the end test power (EP), and hypothesized to reflect CP. In addition, the work performed above the EP (W′ which is analogous to AWC) could be calculated. Vanhatalo et al. (22) reported no difference between the EP estimated from the CP_{3min} test and CP estimated from the original multiple work bout model or between W′ and AWC. Thus, the authors (22) concluded that CP and AWC could be accurately estimated from a 3-min all-out test.

The CP_{3min} test of Burnley et al. (7) and Vanhatalo et al. (22) provided a less physically demanding protocol compared with the traditional multiple workbout model. The authors (7,22) methodology, however, required an incremental test to exhaustion prior to the CP_{3min} test to determine the $\dot{V}O_2$ peak and GET. These parameters were used determine the resistance setting for the 3-min all-out test. Thus, the CP_{3min} test proposed by Burnley et al. (7) and Vanhatalo et al. (22) was not truly a single workbout test. In an attempt to improve the applicability of the CP_{3min} test, Bergstrom et al. (2) hypothesized that a single 3-min all-out test with resistance set as a percentage of body weight could be used to estimate CP and AWC. The authors (2) reported the CP and AWC estimates from the CP_{3min} test, with the resistance set at 4.5% body weight, were not significantly different from CP and AWC estimates from the multiple workbout total work versus T_{lim} model. These findings (2) indicated that CP and AWC could be determined from a single work bout, with the resistance set based on body weight, without the need to measure gas exchange parameters during an incremental exercise test to exhaustion.

Recently, Clark et al. (8) further examined the CP_{3min} test protocol. The authors (8) developed criteria for setting the resistance for the CP_{3min} based on a percentage of body weight that was dependent upon an individuals' activity level; 3% for recreationally trained individuals, 4% for anaerobic/aerobic sport athletes, and 5% for endurance athletes. The authors (8) reported no difference between the CP estimates from the test with a resistance set based on body weight and activity level, and the CP estimates from a CP_{3min} test of Burnley et al. (7) and Vanhatalo et al. (22). Thus, currently there are 3 separate recommendations (2,9,10,31) for estimating CP and AWC from a CP_{3min} test for recreationally trained participants. The actively level dependent resistance setting recommendation for recreationally trained participants (3%), however, was made in a small sample (n = 3) and no comparison was made between parameter (CP and AWC) estimates from the CP_{3min} test completed at other percentages of body weight resistance (8). Previous evidence (2) examining the CP_{3min} test with the resistance set at 3.5% and 4.5% percentage of body weight indicated no significant difference between parameter estimates (CP or AWC) in recreationally trained participants. The 3.5% resistance setting, however, resulted in an AWC estimate that was significantly lower than the original multiple work bout model (24), but no differences were reported among the CP values from the weight resistance protocols (3.5 and 4.5%) and original multiple work bout model (17). No previous studies, however, have compared estimates of CP and AWC from the 3-min all-out test with the resistance set at 4.5% of body weight, as recommended by Bergstrom et al. (2) and the resistance set as a percent of body weight dependent upon activity level (3% for recreationally trained participants), as recommended by Clark et al. (8). Thus, it is still unclear if separate recommendations that are dependent upon activity level are necessary for setting the body weight resistance for the CP_{3min} test in recreationally trained participants. Therefore, the purpose of this study was to determine if the CP and AWC estimates from a single, 3-min all-out test are affected by the percentage of body weight used to set the resistance on a mechanically braked cycle ergometer in recreationally trained individuals. Based on previous studies (2,7,8,22), we hypothesized that the resistance setting (3% or 4.5%) for the CP_{3min} test would have no effect on the CP estimates, but a resistance of 3% would result in significantly lower AWC estimates than 4.5%.

METHODS

Participants

Ten recreationally trained participants (6 women, 4 men; mean ± *SD* age: 22.2 ± 2.2 yrs; body mass: 71.9 ± 19.3 kg) were recruited for this study (Table 1). Recreationally trained was defined according to the American College of Sports Medicine, as an individual who engages in 150 $min \cdot wk^{-1}$ of moderate intensity exercise (19). Specifically, the participants' reported participation in physical activities that included running (n = 4), cycling (n =4), weightlifting (n= 3), kickboxing (n = 2), swimming (n = 1), and recreational sports (e.g., soccer, rugby, basketball etc.) (n = 6). The participants had no known cardiovascular, pulmonary, metabolic, muscular and/or coronary heart disease. This study was approved by the University Institutional Review Board for Human Participants. All participants completed a health history questionnaire and signed a written informed consent document before testing. The participants were asked to refrain from strenuous exercise and caffeine consumption for at least 24 hours prior to testing. The testing was conducted at the same time of day for each participant.

Table 1. Mean ± *SD* for the participant demographics.

Age (years)	Height (cm)	BM (kg)	BF (%)	LBM (kg)	$\dot{V}O_2$ Peak ($mL \cdot kg^{-1} \cdot min^{-1}$)
22.1± 2.5	170.6± 8.7	70.8± 18.5	25.0±9.9	50.7± 15.0	46.5± 7.3

BM = body mass; BF = body fat; LBM = total lean body mass

Protocol

The participants visited the laboratory on three occasions. During the first visit, resting heart rate and blood pressure were taken manually prior to resting electrocardiogram (ECG) (Nihon Kohden, ECG-1550A) to ensure participants were free from cardiovascular disease risk factors. Following the ECG, the participants performed an incremental cycle ergometer test to exhaustion for the determination of GET, RCP, and $\dot{V}O_2$ peak. Before either the second or third visit all participants completed a total body dual-energy X-ray absorptiometry (DXA) scan for the determination of body composition parameters. During visits two and three, the participants performed one of two, randomly ordered, CP_{3min} tests to estimate CP and AWC. The resistance for the CP_{3min} was set at 3% body weight ($CP_{3\%}$) or at 4.5% body weight ($CP_{4.5\%}$).

An incremental test to exhaustion was performed on a calibrated Lode electronically-braked cycle ergometer (Corival, Groningen, The Netherlands) for the determination of $\dot{V}O_2$peak, GET, and RCP. Prior to testing, the seat height of the ergometer was adjusted so that the participant's legs were near full extension at the bottom of the pedal revolution. The test was completed at a pedal cadence of 70 $rev \cdot min^{-1}$ and toe cages were used to maintain pedal contact throughout the test. The participants were fitted with a nose clip and breathed through a two-way valve (Hans Rudolph 2700 breathing valve, Kansas City, MO). A calibrated TrueMax 2400 metabolic cart (ParvoMedics, Sandy, UT) was used to collect and analyze the expired gas samples. The gas analyzers were calibrated with room air and gases of known concentration prior to all testing sessions. The O_2, CO_2, and ventilatory parameters were expressed as 30 s averages. In addition, the heart rate was recorded with a Polar Heart Rate Monitor (Polar Electro Inc., Lake Success, NY) that was synchronized with the metabolic cart. The test began at 50 W and the power output increased by 30 W every 2 min until voluntary exhaustion or the participant's pedal rate decreased below 70 rev·min^{-1} for more than 10 s, despite verbal encouragement. Verbal encouragement was provided throughout the test. This protocol was selected so that subjects would exhaust within 8 to 12 min (20). The $\dot{V}O_{2peak}$ was defined as the highest 30 s average $\dot{V}O_2$ value recorded during the test. The power output associated with $\dot{V}O_{2peak}$ ($P\dot{V}O_{2peak}$) was determined from the regression equation developed from the power output versus $\dot{V}O_2$ relationship.

The GET was determined from the $\dot{V}CO_2$ versus $\dot{V}O_2$ relationship using the V-slope method described by Beaver et al. (1). The RCP was determined using the $\dot{V}E$ versus $\dot{V}CO_2$ relationship described by Beaver et al. (1). The power outputs at the GET and RCP were determined from a regression equation derived from the power output versus $\dot{V}O_2$ relationship during the incremental test.

The CP_{3min} test was performed on the Monark 894E cycle ergometer (Monark Exercise AB, Vansbro, Sweden). The cycle ergometer was calibrated according to the manufacturers instructions prior to testing. A 5 min warm-up at ~50 W, followed by 5 min of rest was provided prior to the test. The participants then completed 3 min of unload cycling. In the last 5 s of the unloaded phase, the participants were instructed to reach a cadence as high as possible. The resistance was applied to the flywheel when the cadence was > 110 rev·min^{-1}. The resistances were randomized between $CP_{3\%}$ and $CP_{4.5\%}$ of body weight. The participants were instructed to maintain their cadence as high as possible for 3 min. Verbal encouragement was provided to the participants, but they were not aware of the elapsed time, cadence, power output, or heart rate. The power output during the test was recorded with the Monark ATS Software (Monark Exercise AB, Vansbro, Sweden). The CP and AWC parameters from the CP_{3min} tests were estimated from the power versus time relationships (Figure 1). The CP was the average power output over the final 30 s of the test and the AWC was calculated as the work done above CP using the following equation (8): AWC = 150 s (P_{150} – CP), where AWC is expressed in joules and P_{150} is the mean power output for the first 150 s of the test, and P_{150} and CP are expressed in watts. The test-retest reliability for the CP and AWC parameters from our laboratory indicated the ICC values were R = 0.91 and R = 0.79, respectively, with no significant mean differences between test and retest.

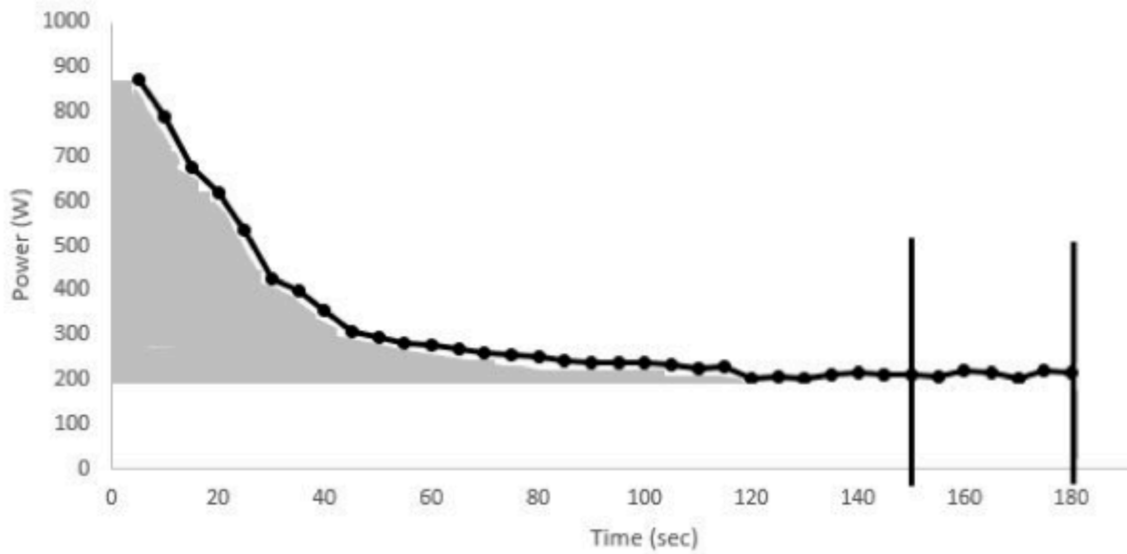

Figure 1. Schematic representation of the 3-min all-out critical power (CP_{3min}) test response to estimate the critical power (CP) and anaerobic work capacity (AWC). The gray area under the curve represents the AWC and was estimated from the equation AWC = ([mean power (MP) (average power during first 150 seconds) – CP] x 150) / 100. The black vertical lines represent CP, which was the average power during the last 30 sec of the test.

Each participant underwent a single total body DXA scan to provide measures of body composition for the descriptive characteristics of the subjects. Total body DXA scans were performed using a Lunar Prodigy iDXA (Lunar Inc., Madison, WI) bone densitometer. A urine pregnancy test was administered immediately prior to the DXA scan to ensure the female participants were not pregnant. The participants were instructed to remove all objects such as jewelry or eyeglasses and wore t-shirt and shorts containing no metal during the scanning procedure. All scans were analyzed by a single trained investigator using the Lunar software version 13.10. DXA fat mass (kg), DXA mineral-free lean mass (LBM; kg), and DXA percent fat (%Fat) were assessed (23). Prior to each visit, the participants were weighed on a stadiometer scale (Detecto®- 439-Physician Scale, Webb City, MO). The participants' body weight was used to set the resistance for the CP_{3min} tests (3% and 4.5% of body weight).

Statistical Analysis

The mean differences between CP and AWC estimates from the $CP_{4.5\%}$ and the $CP_{3\%}$ were examined using separate paired samples t-tests. In addition, the mean differences between the peak power output (highest five s average power output during the test) from the $CP_{4.5\%}$ and the $CP_{3\%}$ were examined using separate paired samples t-tests. The relationship between the two estimates of CP and AWC (from the $CP_{4.5\%}$ and $CP_{3\%}$ tests) were described using separate Pearson product-moment correlation coefficients. Separate Bland and Altman analyses (5) were used to assess the agreement between the $CP_{3\%}$ and $CP_{4.5\%}$ as well as the $AWC_{3\%}$ and $AWC_{4.5\%}$. The 95% limits of agreement (LOA) were calculated. Mean differences among the $CP_{3\%}$, $CP_{4.5\%}$, GET, and RCP were examined using separate, one-way repeated measures ANOVAs with Bonferroni corrected pairwise comparisons. A zero order correlation matrix was used to examine the relationship among $CP_{3\%}$, $CP_{4.5\%}$, GET, RCP, $AWC_{3\%}$, and $AWC_{4.5\%}$. An Alpha level of $p < 0.05$ was considered statistically significant for all statistical analyses. All statistical analyses were performed with Statistical Package for the Social Sciences software (v.23.0 IBM SPSS Inc., Chicago, Illinois, USA).

RESULTS

Table 2 displays individual participant values for $CP_{3\%}$, $CP_{4.5\%}$, $AWC_{3\%}$, and $AWC_{4.5\%}$ as well as the mean (± *SD*) for the groups. There was no statistically significant difference ($t(9) = 1.793$, $p = 0.106$) between $CP_{3\%}$ (156 ± 36 W; 76 ± 16% $P\dot{V}O_{2peak}$) and $CP_{4.5\%}$ (167 ± 34 W; 81 ± 14% $P\dot{V}O_{2peak}$) and there was a high correlation between the two variables ($r = 0.866$, $p = .001$). There was, however, a statistically significant difference ($t(9) = 5.712$, $p < .001$) between $AWC_{3\%}$ (5.6 ± 2.5 kJ) and $AWC_{4.5\%}$ (9.0 ± 4.0 kJ), but a high correlation between the two variables ($r = 0.924$, $p < 0.001$). The 95% LOA for the $CP_{3\%}$ and $CP_{4.5\%}$ estimates ranged from -25.45 to 50.88 W, and there was a moderately high, but not statistically significant relationship ($r = 0.105$, $p = 0.773$) between the difference ($CP_{4.5\%}$-$CP_{3\%}$) and the mean of the two measures (Figure 2). The 95% LOA for the $AWC_{3\%}$ and $AWC_{4.5\%}$ estimates ranged from -0.35 to 7.30 kJ. There was a statistically significant, moderately high correlation ($r = 0.764$, $p = 0.010$) between the mean difference ($AWC_{4.5\%}$ - $AWC_{3\%}$) and the mean of the two measures (Figure 3). The patterns of responses for the $CP_{3\%}$ and $CP_{4.5\%}$ tests are presented in Figure 4. There was a statistically significant difference ($t(9) = 3.857$; $p = 0.004$) between the $CP_{3\%}$ peak power (455 ± 162 W) and $CP_{4.5\%}$ peak power (531 ± 161 W).

The results of the one-way repeated measures ANOVA for the fatigue thresholds ($CP_{4.5\%}$, $CP_{3\%}$, GET, and RCP) indicated there were statistically significant differences among the power outputs ($F(3, 27) = 20.12$, $p < 0.001$, partial $\eta^2 = 0.691$). The follow-up pairwise comparisons indicated a statistically significant lower power output at the GET (104 ± 24 W) compared to the $CP_{3\%}$ (156 ± 36 W; $t = 5.150$; $d = 1.29$), $CP_{4.5\%}$ (167 ± 34 W; $t = 4.087$; $d = 1.63$), and the RCP (165 ± 32 W; $t = 6.134$; $d = 1.940$). There were, however, no statistically significant differences among power outputs for $CP_{3\%}$, $CP_{4.5\%}$, and RCP (Table 2). Table 3 displays the zero-order correlation matrix for $CP_{3\%}$, $CP_{4.5\%}$, GET, RCP, $AWC_{3\%}$, and $AWC_{4.5\%}$. There was a statistically significant, moderately high correlation between the RCP and $CP_{3\%}$ ($r = 0.782$) and a high correlation between RCP and $CP_{4.5\%}$ ($r = 0.860$). There were no statistically significant correlations between the GET and any of the CP test parameters or RCP and the correlation coefficients ($r = 0.118 – 0.377$).

Table 2. Individual participant values (mean ± *SD*) for critical power (CP) and anaerobic work capacity (AWC) from the 3-min all-out CP test with the resistance set at 3% ($CP_{3\%}$) or 4.5% ($CP_{4.5\%}$) of body weight.

Participant	$CP_{3\%}$ (W)	$CP_{4.5\%}$ (W)	$AWC_{3\%}$ (kJ)	$AWC_{4.5\%}$ (kJ)	GET (W)	RCP (W)
1	137	154	4.1	5.0	84	130
2	133	125	4.1	9.8	75	122
3	131	146	4.1	5.9	88	127
4	158	154	5.9	9.9	82	168
5	209	213	11.9	18.0	124	191
6	147	161	6.9	10.1	143	171
7	107	158	4.5	7.1	110	163
8	220	241	6.0	11.6	85	226
9	181	167	6.2	8.3	125	181
10	141	149	2.7	4.5	121	174
Mean	**156**	**166**	**5.6***	**9.0**	**104**	**165**
SD	**36**	**34**	**2.5**	**4.0**	**24**	**32**

*Significantly lower ($p < 0.05$) than the AWC from the $CP_{4.5\%}$ test.

Table 3. Correlations among parameters of the 3-min all-out critical power (CP) test (CP and anaerobic work capacity [AWC]) with the resistance set at 4.5% ($CP_{4.5\%}$) and 3% ($CP_{3\%}$) of body weight, gas exchange threshold (GET), and respiratory compensation point (RCP) for this sample of recreationally trained participants.

	$CP_{4.5\%}$	$CP_{3\%}$	GET	RCP	$AWC_{4.5\%}$
$CP_{3\%}$	0.866*				
GET	0.143	0.118			
RCP	0.860*	0.782*	0.377		
$AWC_{4.5\%}$	0.631	0.711*	0.199	0.506	
$AWC_{3\%}$	0.620	0.678*	0.415	0.490	0.924*

*Significant correlation at $p \leq 0.05$

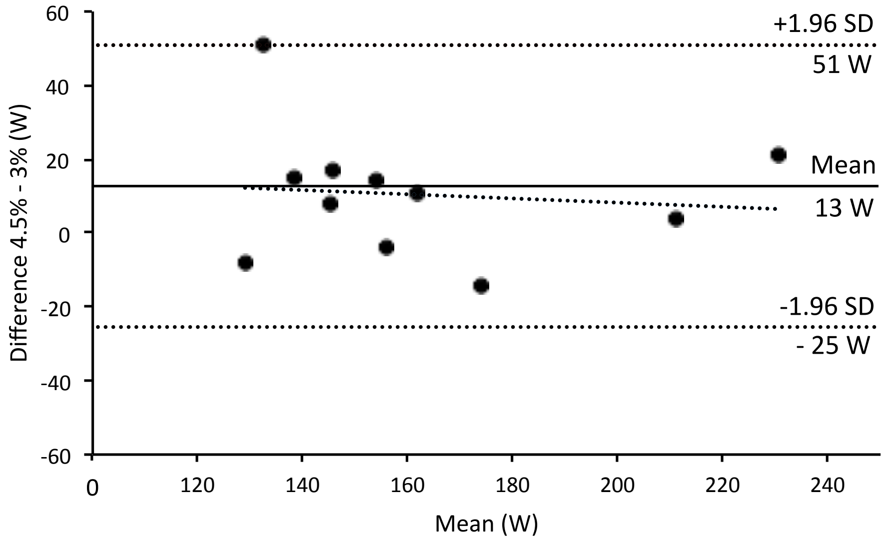

Figure 2. Bland Altman analysis of agreement between the critical power (CP) estimates from the 3-min all-out critical power (CP_{3min}) test with resistance set at 4.5% and 3% for recreationally trained subjects. The middle solid line represents the mean of the difference between the CP estimates from the two methods (p = 0.106). The upper and lower dotted lines represent the bias ±1.96 SD (95% Limits of Agreement). The $r^2 = 0.011$, $p = 0.773$.

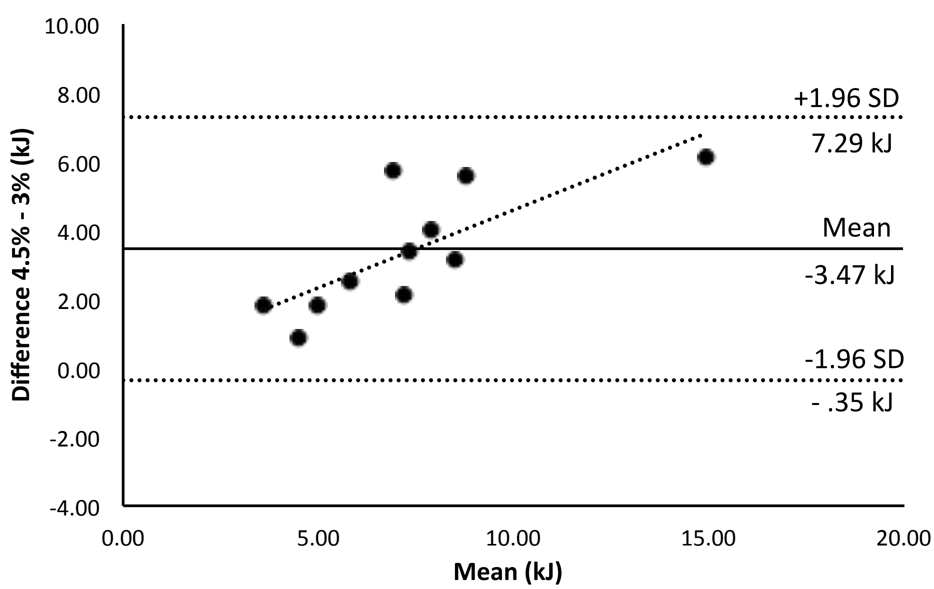

Figure 3. Bland Altman analysis of agreement between anaerobic work capacity (AWC) estimates from the critical power (CP) test with resistance set at 4.5% and 3% for recreationally trained subjects. The middle solid line represents the mean of the difference between the AWC estimates from the two methods (p < 0.001). The upper and lower dotted lines represent the bias ±1.96 SD (95% Limits of Agreement). The $r^2 = 0.584$, $p = 0.010$.

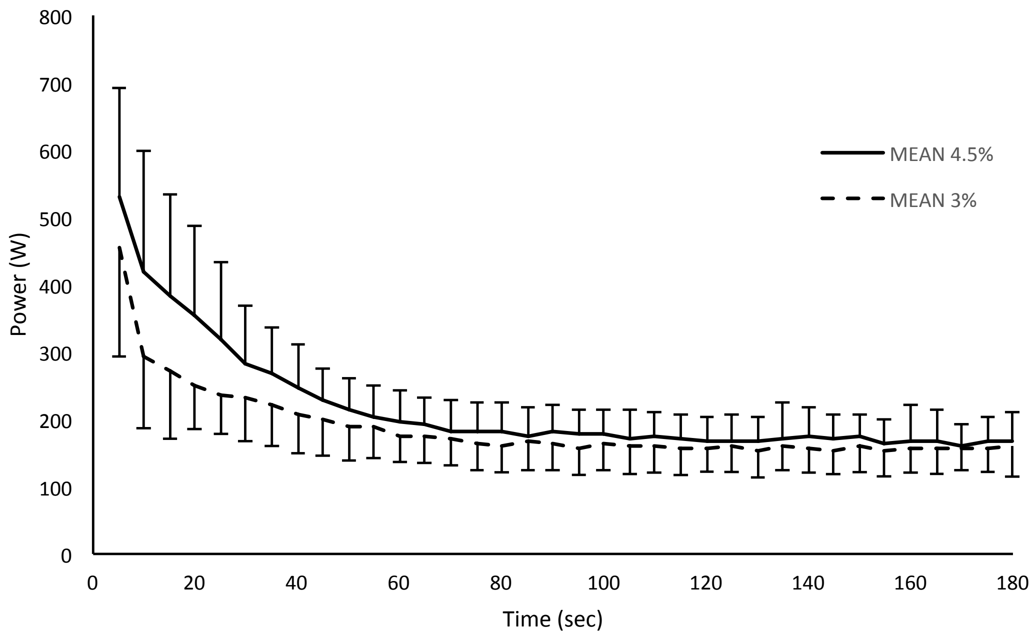

Figure 4. The mean ± SD pattern of response for the 3-min all-out critical power (CP_{3min}) test with the resistance set at 4.5% (solid line) and 3% (dashed line) of body weight.

DISCUSSION

The mean (± *SD*) $P\dot{V}O_{2peak}$ from the incremental test to exhaustion (212 ± 49 W) and $\dot{V}O_2$ peak (46.5 ± 7.3 mL·kg^{-1}·min^{-1}; men = 49.8 ± 9.9 mL·kg^{-1}·min^{-1}; women = 44.4 ± 4.7 mL·kg^{-1}·min^{-1}) for the participants in the present study were similar to the mean $P\dot{V}O_{2peak}$ (225 ± 58 W) and $\dot{V}O_2$ peak values (43.0 ± 7.4 mL·kg^{-1}·min^{-1}) previously reported for recreationally trained participants (2). The mean $\dot{V}O_2$ peak values for the men and women in this study resulted in classifications of "good" and "excellent", respectively (19). The GET occurred at 53 ± 9% of $\dot{V}O_2$ peak, and was similar to the range of GET values previously reported (54 – 75% $\dot{V}O_2$ peak) for recreationally trained individuals (2,9,10). The RCP occurred at 79 ± 11% (165 ± 32 W) of peak power, which was within the range (70 – 84% peak power) previously reported for healthy participants (10). Thus, the $P\dot{V}O_{2peak}$, the $\dot{V}O_2$ peak, GET, and RCP values for the participants in this present study were consistent with recreationally trained participants (2,4,9,10). Furthermore, the power output at the RCP was not different from $CP_{4.5\%}$ or $CP_{3\%}$ (81 ± 15% and 76 ± 16% peak power, respectively), but the RCP and CP (4.5% and 3%) were greater than the GET. Previous studies (3,21) have suggested that the CP and RCP represent a similar intensity, that is greater than the GET, and demarcate the heavy from severe exercise-intensity domains. Thus, the current findings were consistent with the findings of others (3,21), and indicated that the CP and RCP may reflect similar exercise intensities.

In the present study, the $CP_{4.5\%}$ and $CP_{3\%}$ tests resulted in patterns of responses (Figure 4) for the power output versus time relationships that were consistent with the patterns of responses previously reported (2) for the CP_{3min} test with the resistance set at 4.5% of body weight. The patterns for power output versus time relationships for the $CP_{3\%}$ and $CP_{4.5\%}$ displayed initial increases in power output during the first 5 to 10 s, followed by steep declines during the first two min of the tests. The final min of the tests resulted in gradual decreases and plateaued during the final 30 s. A qualitative analysis of the patterns of responses for the two separate intensities in Figure 4 demonstrated a lower initial power output and more rapid initial decline in power output for the $CP_{3\%}$ test compared to the $CP_{4.5\%}$ test. In addition, the initial 5-s peak power output was significantly greater for the $CP_{4.5\%}$ (531 ± 161 W) than the $CP_{3\%}$ (455 ± 162 W) tests. The participants reported post-$CP_{3\%}$ that the resistance felt too light and resulted in a sensation of their momentum or inertia getting ahead of them causing them to slow their cadence to meet the resistance on the flywheel. Thus, the results of the present study indicated the $CP_{3\%}$ and $CP_{4.5\%}$ tests resulted in a pattern of response for the power output versus time relationship that were consistent with the patterns previously reported (2,8,31), but the $CP_{3\%}$ test resulted in a lower 5-s peak power output which suggested the resistance may be too low for participants to reach and maintain a maximal cadence throughout the test.

It has been suggested (8) that the percentage of body weight resistance for the CP_{3min} test should differ, depending on the training status of the participant. Specifically, resistances of 3, 4, and 5% were recommended for recreationally trained participants, anaerobic athletes, and endurance athletes, respectively (8). The recommendation for recreationally trained participants, however, was made in a small sample (n = 3) comparing the parameter estimates from the CP_{3min} test with a resistance set at 3% body weight to those from the CP_{3min} test on an electronically braked cycle ergometer using the linear factor (GET + 50% $\Delta/[70 \text{ rev} \cdot \text{min}^{-1}]^2$) to set the resistance (7). Previous evidence (2) examining the CP_{3min} test with the resistance set at 3.5% and 4.5% percentage of body weight indicated no significant difference between parameter estimates (CP or AWC) in recreationally trained participants, although the CP and AWC estimates from the $CP_{3.5\%}$ test were 7 and 15% lower than the CP and AWC, respectively, from the $CP_{4.5\%}$ test. In addition, the authors reported (2) the mean CP from the body weight resistance protocols (3.5 and 4.5%) were not different from the original multiple work bout model (17), but the AWC from the $CP_{3.5\%}$ test was significantly lower. Therefore, we hypothesized that the resistance setting on the cycle ergometer would have no effect on the CP, but the 3% resistance setting would underestimate the AWC. The current findings indicated that the $CP_{3\%}$ (156.4 ± 36.1 W; 76 ± 16% peak power) was ~7% lower than the $CP_{4.5\%}$ (166.8 ± 34.3 W; 81 ± 15 % peak power), but the mean difference between the two estimates was not statistically significant (Figure 4). These findings, were consistent with those of Bergstrom et al. (2) who reported an ~7% lower estimate of CP from the CP_{3min} test with the resistance set at 3.5% compared to 4.5%, but no statistically significant mean difference between the two estimates. Thus, the results of this study supported our hypothesis, and indicated that the resistance setting (3% or 4.5%) had no significant effect on the estimates of CP from the CP_{3min} test.

The results of this study indicated the $CP_{3\%}$ (5.6 ± 2.5 kJ) test significantly underestimated the AWC from the $CP_{4.5\%}$ (9.0 ± 4.0 kJ) test by ~38% (Table 2). These findings were similar to those of Bergstrom et al. (2) who reported that, although not significantly different, the AWC was 15% lower when the resistance was set at 3.5%, compared to 4.5%. In addition, it was previously reported (2) that the AWC from the test with the resistance set at 3.5% was significantly lower (~38%) than the original multiple work bout model (17), but the AWC from the test with resistance set at 4.5% was not. Based on their findings, the authors (2) suggested, "Even though there were no significant mean differences between the CP and AWC values from the $CP_{3.5\%}$ and $CP_{4.5\%}$ tests, the $CP_{4.5\%}$ test is recommended because of its similarities to the [original, multiple workbout model]…" (p. 662). In this study, the mean AWC estimate from the test with the resistance set at 4.5% (9.0 ± 4.0 kJ) was similar to the mean AWC previously reported (9.84 ± 4.39 kJ and 10.4 ± 2.6 kJ) for recreationally trained participants, but the mean AWC estimate from the test with the resistance set at 3% (5.6 ± 2.5 kJ) was not (2,4). Therefore, these findings indicated that the CP and AWC estimates from the $CP_{4.5\%}$ were consistent with values previously reported for recreationally trained participants (2,4), but the AWC estimate from the $CP_{3\%}$ was lower than previously reported. The significantly lower AWC values for the $CP_{3\%}$ test were likely related to the ~14% lower peak power output and more rapid decline in power output, when compared the $CP_{4.5\%}$ test (Figure 4). Thus, the current findings supported our hypothesis and indicated that the resistance set at 3% of body weight resulted in an estimate of AWC that was significantly less than the AWC with the resistance set at 4.5%.

In conclusion, the results of the present study for both CP and AWC suggested that a resistance set at 3% of body weight for the CP_{3min} test may be too low to accurately estimate AWC, but 3% and 4.5% resulted in the same estimation of CP. Thus, the principal finding of this study was that a resistance of 4.5% of body weight for the $CP_{3\text{-}min}$ test in recreationally trained participants resulted in more accurate estimates of both CP and AWC, than using a resistance of 3%, when compared to the parameters of the CP tests previously reported (2,7,22).

Currently, there are conflicting suggestions regarding the most valid resistance setting (3-5% of body weight) (2,7,8,22) for estimating CP and AWC from a CP_{3min} test for recreationally trained participants. This study determined if the CP and AWC estimates from a single 3-min all-out test were affected by the percentage of body weight used to set the resistance on a Monark cycle ergometer. There was no difference between the CP estimates from the test performed at a resistance of 3% or 4.5% of body weight, however, the AWC values from the $CP_{3\%}$ test were significantly lower than the AWC values from the $CP_{4.5\%}$ test and were not consistent with AWC values previously reported (2) in recreationally trained participants. These findings indicated that a resistance set at 3% of body weight for the CP_{3min} test may be too low to accurately estimate AWC, but 3% and 4.5% resulted in the same estimation of CP. Therefore, the principal finding of this study was that a resistance of 4.5% of body weight for CP_{3min} test may be more accurate to estimate AWC than using a resistance of 3% of body weight. These findings support the use of a common percentage of body weight to set the resistance (4.5% of body weight) for the CP_{3min} test protocol in recreationally trained participants.

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