AN ABSTRACT OF THE THESIS OF

Cameron B. Jones for the degree of Master of Science in Kinesiology presented on June 8, 2020.

Title: Does Fatigue Influence the Assessment of Critical Speed when Multiple Test Trials are Conducted in a Single Session?

Abstract approved:

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The Critical Power - W' model has many advantages compared to the traditional VO_{2max} test, including tracking fitness changes over time in well trained athletes, predicting performances due to its discrete aerobic and high intensity tolerance variables, and prescribing exercise intensities with increased accuracy. However, a major disadvantage of this model is the length of time in which testing can take, spanning over two weeks in the traditionally used protocol. Efforts have been made to shorten the testing duration by conducting multiple time to exhaustion runs within a single testing day, over the course of two testing days. There is concern, however, that this shorter protocol may introduce fatigue in consecutive testing trials when performing multiple trials within a single day. This study aimed to perform a secondary analysis on the two-day testing protocol, investigating the possible effect of multiple trials on residual error from a line of best fit when calculating CS and W'. A mixed effects model was used to calculate the estimated marginal means for trial/day combinations to determine if any single trial was different from the line of

best fit. Results of this analysis revealed no significant differences between any day or trial ($p > 0.05$). These results demonstrate that the two-day critical power testing protocol did not introduce systematic fatigue into the testing protocol. Future research should further establish the validity of the two-day protocol by a direct comparison of this testing methodology with the traditional protocol.

Does Fatigue Influence the Assessment of Critical Speed when Multiple Test Trials are Conducted in a Single Session?

by
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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 8, 2020
Commencement June 2021

Master of Science thesis of Cameron B. Jones presented on June 8, 2020

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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CHAPTER 1: INTRODUCTION

Maximal aerobic power (VO_{2max}) is the most common measure used to assess cardiorespiratory fitness and is considered the 'gold standard' of measuring cardiovascular fitness[1]. As such, VO_{2max} is a strong predictor of performance in endurance sports[2] and has been used to track changes in aerobic fitness over time[3]. VO_{2max} tests typically consist of either an incremental test protocol (i.e., workload increased at set time intervals), or a ramp test protocol (i.e., continuous increase in workload). During an incremental test, VO_{2max} is achieved when an individual reaches a plateau in oxygen consumption (VO_2) that no longer increases despite subsequent increases in workload. This phenomenon reflects that the energy required to meet the new, increased workload demand is being met via substrate level phosphorylation[4].

The VO_{2max} plateau has been described as an increase in VO_2 of less than 2.1 mL/kg/min between the final two stages of an incremental test;[5] however, it is estimated that 47% of cyclists and 24% of runners reach volitional exhaustion without achieving a VO_2 plateau [6]. In these scenarios, additional criteria are used to verify that a true VO_{2max} was achieved. Verification methodologies include: 1) The completion of a supramaximal "verification stage", where test participants attempt to exercise at a higher workload – following a short rest – than the last successful stage [8] and 2) physiological criteria, such as a respiratory exchange ratio of >1.1, and a near maximal heart rate, typically calculated as your age subtracted from 220 or 208 - .7 * age [6,7]. Verification stages are often difficult for individuals to complete due to the exhaustive nature of the VO_{2max} test, and many of the commonly used additional criteria tend to lead to an underprediction of an individual's true VO_{2max}, as these measures can be influenced by variables outside of the test and may not always be within control of the test administrator [7]. Taken together, the difficulty of the verification stage and the lower accuracy associated with the

additional criteria used to determine VO_{2max} likely contribute to the lack of a VO_2 plateau in some individuals [7,8].

Another challenge with using VO_{2max} to track aerobic fitness and/or predict performance is that VO_{2max} values stabilize over a prolonged period of endurance training despite continued improvements in performance [9]. Improvements in workload at anaerobic threshold and endurance economy may help explain these performance gains beyond those described by changes in VO_{2max}[10, 11]. While considered a primarily aerobic task, VO_{2max} test performance is also likely influenced by anaerobic pathways, however, the relative contribution of these pathways is difficult to quantify in a standard VO_{2max} test. Even events that may be considered primarily endurance based, such energy sources are an important factor to consider when predicting performance and tracking fitness changes over time due to the role anaerobic metabolism can play in ATP availability in such events, [10, 11].

The critical power (CP) concept is one possible solution to challenges intrinsic to the use of VO_{2max} tests. Critical Power (CP) refers to the highest intensity in which steady-state exercise can be achieved. Because CP naturally represents the threshold between steady-state exercise and non-steady-state exercise, CP provides a superior method for prescribing exercise intensity for training[14,15]. Additionally, CP has the potential for tracking changes in fitness over time, as CP would improve with further training of aerobic metabolism. The CP concept also predicts high-intensity exercise tolerance (W'), which may be particularly useful for explaining differences in exercise performance [12, 13]. Both CP and W' have shown to have a strong relationship with endurance performance, and both explain variability in performance across individuals with similar VO_{2max} values, as VO_{2max} loses its predictive power when comparing individuals with similar training backgrounds [12, 13, 14]. Together CP and W' can describe overall endurance capacity in terms of aerobic (CP) and anaerobic (W') components, and although W' is

better understood as a measure of high intensity exercise tolerance, using these variables together provides a more complete picture of an individual's reliance on different energy systems.

The CP and W' concepts were first examined by Monod & Scherrer (1965), who wished to observe "maximal work (W_{lim}) and the maximal time (T) over which the work was performed until the onset of local muscular exhaustion." Monod & Scherrer used intermittent isometric contractions at various resistances to test time until fatigue at different work intensities. Additionally, they used blood cuff occlusion to stop oxygen delivery, and showed that time until fatigue in this case was not zero, meaning some form of non-aerobic energy reserve existed. With these two tests Monod & Scherrer were able to demonstrate that maximal work (W_{lim}) resulted from the use of an energy reserve (a) and a maximal energy reconstitution rate (b) (energy reserve representing anaerobic and maximal energy reconstitution rate representing aerobic contributions to work done, respectively) and could be expressed in the following equation:

$$W_{lim} = a + bT_{lim.}$$

With this equation they described a relationship in which any intensity above the energy reconstitution rate could be maintained for only a limited time, and that some energy reserve is depleted during this time, ultimately leading to exhaustion. The onset of exhaustion occurs at a rate directly proportional to the workload required. While only applied to local muscular fatigue, the foundations of CP and W' come from these discrete maximal energy reconstitution rate and energy reserve concepts presented by Monod & Scherrer..

This same relationship has been observed in full body dynamic exercise. First confirmed by Moritani et al. (1981), the researchers used a cycle ergometer to control power output and had participants cycle for three-to-four different constant power output trials until exhaustion. They

discovered that a similar relationship (i.e. a direct, positive relationship between workload and time to exhaustion) existed for a whole-body exercise as the localized muscular fatigue phenomenon described by Monod and Scherrer. The ability to carefully control power output with cycle ergometry has led to extensive examination of the intensity power relationship in cycling [18, 19].

For a given power (P), time to exhaustion (TE) can be estimated by the following equation:

$$TE = W' / (P - CP)$$

In this relationship, CP is represented by the horizontal asymptote of the P–TE curve (see figure 1.1) [18,20]. Mathematically, CP is a point of exercise intensity that could be maintained indefinitely; however, in reality TE at CP may be relatively short before an individual becomes exhausted, depending on the individuals muscular endurance to maintain exercise as well their familiarity and comfort with exercise. CP has more practically been defined as the highest maximal metabolic steady-state that can be achieved and the threshold between the heavy and severe intensity domains, above which achieving VO_{2max} is imminent, but steady-state is unachievable due to the slow VO_2 component caused by a loss of skeletal muscle contractile efficiency at such high intensities [15, 23].

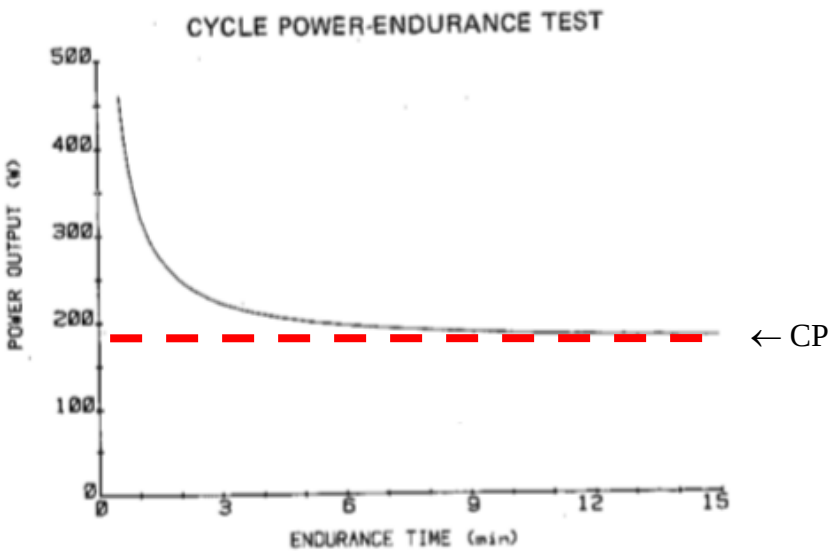

Figure 1.1: Conceptual figure representing the relationship between Endurance Time (min) and Power Output (W) with dashed line representing CP asymptote (Hughson, 1984)

The variable W' (the curvature constant in the P-TE relationship) has been defined as the work that can be performed at intensities greater than CP, within the severe intensity domain [17,18,19]. Viewed graphically, W' is represented by the area under the P-TE curve, but above the CP value (see figure 1.2). Often equated to anaerobic work capacity, W' more accurately represents high-intensity exercise tolerance, as W' does not appear to be related to any one muscle fiber type [21].

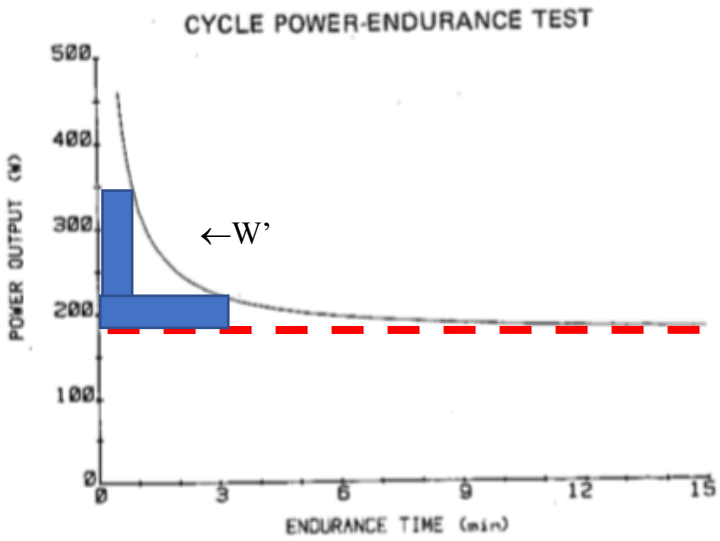

Figure 1.2: Conceptual figure representing the relationship between Endurance Time (min) and Power Output (W) with rectangles showing W', area under the curve (Hughson, 1984).

While the power-time relationship is well established due to the fine control of power afforded by cycle ergometry, exercise modalities such as running do not lend themselves well to the power-time relationship, as it is difficult to precisely measure power output directly in a running individual. As a proxy, running speed can be used in lieu of power output, due to the direct positive relationship between lower extremity power and running speed [20]. Hughson et al. (1984) first used this relationship to describe the CP and W' variables in runners (known as Critical Speed (CS) in a running task)[20]. Participants in this study performed six running trials at six different speeds calculated to elicit exhaustion in 2-12 minutes. Each trial was separated from the others by 48 hours of rest. The velocity and time to exhaustion for all six trials were used to plot a speed-time to exhaustion curve (S-TE), with CS and W' determined from this curve for each participant. Hughson et al. collected VO_{2max} data from the test participants and found a strong, positive correlation between this established CS and VO_{2max} of $r = 0.84$ ($p<0.05$).

CP (or CS) and W' are unlikely to represent a specific physiological mechanism, as both are calculated through performance outcomes rather than direct measurement of physiological phenomena[18]. Nevertheless, these measurements can offer many advantages over the traditional and widely used VO_{2max} test. One of the greatest advantages to CP is its ability to track changes in fitness over time, even after prolonged periods of training and plateaus in VO_{2max}[15,19,23]. This is largely due to discrete aerobic and "anaerobic" contributions that CP and W' represent, respectively, as well as the ability to discern improvements in aerobic economy, which VO_{2max} fails to capture. In combination with its strong relationship with VO_{2max}, CP offers more insight into physiological and performance capabilities than the traditional VO_{2max} test.

Additionally, CP can be an effective way to describe training intensities[15,16]. It is widely understood that exercise at different intensities acts as a stimulus for different metabolic pathways, cardiorespiratory responses, and fatigue. Should training be performed chronically, such training will elicit specific physiological adaptations[17, 22, 23]. To this end, it is important to accurately train at the appropriate intensity for such adaptations. Currently the American College of Sports Medicine (ACSM) recommends the use of % maximum heart rate (%HRmax), percent reserve oxygen consumption (%VO_2R) , and % heart rate reserve (%HRR) to identify training intensity due to the lack of need for specialized equipment. However, due to natural daily variability in HR and VO_2, these indirect measurements may lead to overestimation or underestimation of workload compared to the targeted intensity[5,16]. CP may offer an advantage as a method of prescribing exercise intensities due its behavior as a distinct threshold between the heavy and severe intensity domains, at least for higher exercise intensities.

Currently, maximal lactate steady state (MLSS) is considered the gold standard for defining the threshold between heavy and severe domains of intensity. MLSS is defined as the highest power output at which increase in blood lactate is less than 1mmol/L between 10 and 30

minutes of continuous exercise, and is typically measured at several difference intensities over the course of several days. Even with this established standard, there is disagreement over the seemingly arbitrary length of time between measurements, as well as the magnitude of change (1 mmol/L), and there does not seem to be a strong rationale for these traditionally used values [15, 23]. In addition to these concerns, common blood lactate analyzers show an error of .2 - .4 mmol/L, a seemingly wide range when the window for determining MLSS is 1 mmol/L, leaving a good chance for error when determining MLSS[15]. Furthermore, MLSS can be affected by disturbances in an exercise bout, which are often necessary for the collection of a blood sample. In contrast CP has been established with a performance-based procedure that better demarcates steady state exercise intensities (heavy) and non-steady state exercise intensities (severe)[15]. Evidence of this increased utility can been seen across seven studies that have compared the intensities determined for MLSS and CP and have found that CP on average is 7% higher (1-16% across 7 studies)[15] while still representing steady-state exercise. This reflects the underestimation of MLSS compared to CP, which indicated CP more closes represents the threshold between heavy and severe intensities. Due to these findings, athletes would likely want to use CP as opposed to MLSS when determining training intensities, as it may provide a more accurate target for training within the severe domain of exercise.

Despite the many distinct advantages of CP and W', the traditional test protocol (which includes a series of four to six constant power TE trials separated by 24-48 hours of rest) is a heavy test participant burden, and this often deters the use of CP and W' compared to the less demanding alternatives available. An effort has been made to shorten the CP/W' test protocol from approximately two weeks (with four to six testing days) to three to four days (with two testing days). In this shorter protocol, three running trials to exhaustion, at different constant speeds, were conducted on each test day[24]. Test trials on the same day were separated by enough

recovery time so that heart rate (HR) returned to within 20 bpm of resting HR (approximately 10-20 minutes). When this protocol was used to calculate CS and W' in healthy, moderately trained individuals, multiple regression analysis revealed significant squared semi-partial correlations between CS and VO_{2max} ($sr^2 = 0.803$; $p < 0.001$), as well as between W' and VO_{2max} ($sr^2 = 0.095$; $p < 0.01$)[20]. The overall regression model linking CP and W' to VO_{2max} yielded an R^2 value of 0.828 ($p < 0.001$). However, it is unclear whether using multiple trials within a single day had an effect on the resulting estimates of CS and W', as all three trials to exhaustion were performed in a relatively short amount of time.

Therefore, this study aimed to perform a secondary analysis on the data collected by Seipel et al (2018), investigating the possible effect of multiple trials in a single day on residual error from a line of best fit when calculating CS and W'. Should the same day trials in the shorter, two-day protocol prove to be too exhaustive for inadequate recovery, a trend of greater residual error in later trials would be observable, with a negative impact on the overall estimations of CS and W'. The information from the analysis at hand will clarify the validity of this shorter, two-day protocol used to estimate CS and W', and will be useful for future researchers and exercise professionals when developing tests designed to assess critical speed and/or W'.

CHAPTER 2: METHODS

PARTICIPANTS

Thirty-six individuals (20 male, 16 female) volunteered to take part is this study. Four of the male volunteers were unable to complete all required testing sessions within the six-week window for testing. One male and one female volunteer did not qualify to based on health history screening and risk factors for cardiovascular disease. The remaining thirty participants (15 male, 15 female) between the age of 18 and 32 years old (average age = 22 ± 3.2 years) reported one or fewer risk factors for cardiovascular disease.

All participants reported running at least three times a week for at least 30 minutes or more during a typical training week (average time = 189.2 ± 96.9 total weekly minutes). Twenty-one participants consistently engaged in one or more additional modes of endurance exercise (n = 21; average time = 255.8 ± 164.3 total minutes). Nineteen participants consistently engaged in some form of resistance exercise (n =19; average time = 87.7 ± 55.8 total minutes). Despite all participants running on a regular basis, participants had a range of fitness (male VO_{2max} = 54.3 – 73.9 mL/kg/min; female VO_{2max} = 37.3-56.8 mL/kg/min) and experience levels (2 months – 15 years of aerobic training). Participant demographic characteristics can be viewed in the Table 2.1.

Table 2.1 Demographic characteristics of study participants

	Overall (n = 30) Mean ± SD	Men (n = 15) Mean ± SD	Women (n = 15) Mean ± SD
Age (years)	22.0 ± 3.2	21.9 ± 3.0	22.1 ± 3.7
Height (cm)	173.8 ± 9.6	182.1 ± 4.3	165.5 ± 4.9
Weight (kg)	69.3 ± 10.7	76.9 ± 6.9	61.7 ± 8.0
Body Fat (%)	18.7 ± 7.4	13.7 ± 3.1	23.8 ± 6.9
Aerobic Exercise Experience (years)	4.7 ± 4.0	5.7 ± 3.6	3.8 ± 4.4
Weekly Running Time (min)	189.2 ± 96.9	170.7 ± 75.5	207.8 ± 114.1

PROCEDURES

Each participant completed three separate testing sessions at the Oregon State University Human Performance Laboratory (Corvallis, Oregon). In total, participants completed one maximal graded exercise test (GXT_{max}) to determine VO_{2max}, and six TE trials split over two days to calculate CS and W'. During the first testing session, each participant completed an informed consent form, health history questionnaire, and a training history questionnaire as a part of the screening process. Participants were also given the opportunity to ask clarifying questions about the study as well as questions about testing protocols. Participants then had their height, weight, and body composition assessed. InBody 770 multifrequency bioelectrical impedance analysis system (InBody, Cerritos, CA) was used to assess weight and body composition. All participants who met the eligibility requirements continued onto their first exercise test. If a physician's approval was needed for participation, testing was postponed to a later date after approval was obtained.

ParvoMedics TrueMax 2400 metabolic cart was used to measure VO_2 (parvoMedics, Sandy, UT). Heart rate was recorded using a Polar HR monitor (Polar, Lake Success, NY). TrackMaster treadmill (Full Vision, Newton, KS) was used for all laboratory testing.

During all laboratory testing, temperature and humidity were kept at comfortable levels (temperature = 22.7 ± 1.4 C; humidity = 35.8 ± 6.0%). Barometric pressure was noted at the beginning of each testing session (755.9 ± 7.2 mmHg), which was necessary for calibration of the metabolic cart.

Maximal Graded Exercise Test

Before the GXT_{max}, participants were fitted with a nose clip and a mask containing two one-way valves that connected to the metabolic cart. This allowed for the collection of expired gases without any leaking back into the environment. Starting speed was set between 8.0 – 11.0 kph, based on participants reported fitness level, to achieve a test duration of 12 to 15 minutes. Participants were instructed to perform a 3-minute warm up at a 0% gradient. Following the warm-up, grade was increased to 3%, signifying the start of the test. Stages for this test were 1 minute in duration, with rating of perceived exertion (RPE) recorded halfway through each minute, and either speed or incline being increased at the end of each stage. Speed was adjusted by 0.8 kph at the end of every minute until the participant reached an RPE of 13. After participants expressed an RPE of 13, speed was maintained while grade was increased by 1% at the end of stage until the participant was unable to continue.

The main criteria for a test to be considered ‘maximal’ was plateau in VO_2 of less than 2.1 mL/kg/min in minute average oxygen consumption between the final two stages. If the VO_2 achieved this plateau VO_{2max} was taken as the maximum minute average VO_2 recorded for any completed stage. If the VO_2 plateau was not achieved, a verification stage was performed

following a similar protocol as Mier et al [15]. Following a 10-minute active recovery period, speed and grade were increased gradually over a two-minute period until the speed and grade of the final stage of the GXT_{max} were reached. After one minute at this intensity, grade was again increased by 1%, a workload the participants were instructed to maintain for two minutes. If the participant was able to maintain this higher intensity for at least one complete minute, and if the final minute average VO_2 for this verification stage measured within the 2.1mL/kg/min of the last complete stage of the initial GXT_{max}, the test was deemed maximal. If the participant completed the verification stage but a VO_2 plateau was again not observed, the verification stage was repeated, but with an increase of 2% grade in the final two minutes. The maximum minute average VO_2 attained during this second verification stage was considered to be the participant's VO_{2max}.

CS-W' Trials to Exhaustion

Critical speed and W' were evaluated after six timed run-to-exhaustion (TE) trials that were conducted over two laboratory visits, as previously reported[20]. Briefly, after participants arrived in the lab, they were fitted with a HR monitor and were asked to lay supine on a table for 5-10 munities to determine pre-exercise heart rate. They were then allowed a warm-up of up to 10 minutes, which consisted of running on the treadmill. Warm-up intensity was self-selected, but participants were instructed not to exceed an RPE of 17 during this period.

For each TE trial, starting treadmill speed was estimated based on previous test performance and/or self-reported running performances. The speed for each trial was selected with the goal of eliciting exhaustion in approximately two, three, four, five, eight, or ten minutes. The order of these TE trials was randomized to minimize the potential error associated with fatigue. Each trial began with the participant straddling the treadmill belt with one foot on each

side of the belt. Once the treadmill reached testing speed, participants used the treadmill handrails to transfer onto the belt and maintain balance. Upon achievement of a balanced running gait, participants were instructed to release the handrails. Participants were instructed to again grab the handrails and straddle the belt upon volitional exhaustion, ending the trial. Trial time was the duration after the handrails were initially released until handrails were again used upon exhaustion. Participants were blinded to elapsed time and speed during all trials but were told that each trial length would range from roughly 2 to 12 minutes. Blinding participants to the elapsed time was done to discourage participants from stopping the trial before volitional exhaustion. Vigorous verbal encouragement was provided to all participants throughout the test trials.

If participants reached 12 minutes without achieving volitional exhaustion, they were instructed to stop and begin the recovery process. Trials in which participants met or exceeded 12 minutes were not included in the analysis, as data points beyond 12 minutes were beyond the scope of the W' curvature constant. If a participant's time for any trial was shorter than a trial performed at a faster speed, the trial was assumed to represent a submaximal effort and was also excluded from the analysis. All CS-W' calculations were performed with a minimum of four successful trials.

At the end of each TE trial, participants were given the opportunity to walk for a self-selected period of time, before recovering in a supine position. Heart rate (HR) was monitored throughout the recovery and used to determine when the next trial began. Participants began the next trial when HR returned to within 20 beats per minute (bpm) of the pre-exercise level. In the event that a participant's HR plateaued at a value above that described by the this criteria, three consecutive readings within a three beat-per-minute range (taken at least one minute apart) were used as alternate criteria for adequate recovery.

STATISTICAL ANALYSES

Demographic data were calculated and are displayed in table 2.1 as mean and standard deviation (i.e., height, weight, age, body fat percentage, relative VO_{2max}, CS, W', weekly running time, years of aerobic training experience).

To address the research aim, the magnitude of a participants individual trial W' residuals (i.e. the distance between a measurement and the best-fit line generated to estimate W' and CS) were compared using mixed-effects modelling with a random intercept for each participant and a random slope for day. Residual W' was used rather than W' , as W' for each individual can be expected to be inherently different, and while W' can be compared within a single individual it does not allow for comparison across individuals. W' residuals were calculated by finding the difference between estimated W' and single trial W'. Single trial W' was calculated by first converting CS into meters per second, and then calculating the expected distance covered attributable to this CS. This "distance at CS" value was subtracted from actual distance covered during the trial of interest, with the resulting value representing single trial W'. The estimated W' and single trial W' were then compared using estimated marginal means for all day/trial combinations. Estimated marginal means were calculated using RStudio, fit to the mixed-effects model, and used to compare these residuals across trial-day combinations to test for differences in W' between the trials. T-tests were used to verify the results of the estimated marginal means.

Excel (Microsoft, Redmond, WA) and RStudio (RStudio, Boston, MA) were used for all statistical procedures.

CHAPTER 3: RESULTS

The results of the statistical analysis did not reveal any significant differences for day/trial W' residual values ($p > 0.05$). This finding demonstrates that no W' residuals (differences between the measured trial W' and overall estimated W') showed significant disagreement from one another, regardless of the day of testing or trial number within the day of testing. As a result of these similarities in residuals among the trials and days, it can be concluded that W' performances for each trial were consistent across participants. It should be noted, however, that the analysis consistently returned lower p-values for Day 2 comparisons, and this trend should likely not be ignored. It is possible this trend could represent an effect of motivation or effort from participants on Day 2 that did not generate a W' residual of sufficient magnitude to be captured by the present analysis.

Table 3.1: Results of the statistical analysis comparing differences in residual W' between days and trials.

Day	Trial	Estimated Marginal Means	SE	Lower CI	Upper CI	T	p value
1	1	-0.383	4.565	-9.719	8.954	-0.084	0.934
1	2	3.289	4.473	-5.859	12.438	0.735	0.468
1	3	1.393	4.386	-7.577	10.364	0.318	0.753
2	1	-6.894	4.227	-15.539	1.750	-1.631	0.114
2	2	6.303	4.565	-3.034	15.640	1.381	0.178
2	3	7.221	4.227	-1.423	15.866	1.709	0.099

CHAPTER 4: DISCUSSION

To the best of our knowledge, this is the first study to provide direct evidence in support of the validity of a shorter, 2-day protocol used by Seipel (2018). No significant differences between individual trial W' and overall estimated W' across days and trials were found ($p > 0.05$), indicating that trial performances for test participants were consistent with respect to W'.

A major concern after the initial data collection was that participants fatigued across the three trials within a single testing day, introducing error in the estimation of critical speed. This error would be evident in trials performed later in the day, and would not represent the full capabilities of the test participant due to reduced contributions of W', and thus result in shorter distances covered during the trial. Significantly greater estimated marginal means (representing a larger residual values) would have been observed for Trial 3 on Days 1 and 2, with the possibility of a similar trend for Trial 2 on Days 1 and 2. However, the absence of these findings in this analysis highlight that the recovery criteria between trials in this two-day protocol was adequate to prevent fatigue from significantly altering W' values, and as such, minimizing this source of error in the estimation of CS.

While W' values were consistent across trials, it is possible that some test participants "held back" or paced themselves across all trials. If participants had exhibited such behavior, it would ultimately result in underestimation of CS and W' values for that participant. However, it seems unlikely that test participants engaged in such a strategy, as a strong, positive correlation was observed between CS and VO_{2max} using the same data (R^2 value of 0.828 ($p < 0.001$)).

Due to the results of this analysis, the conclusions made by Seipel (2018) appear to be valid. These include a strong correlation between CS and VO_{2max} ($sr2 = 0.803$; $p < 0.001$), which was not surprising as CS generally represents the magnitude of aerobic metabolism available to

an individual and is correlated to VO_{2max} [18]. Interestingly, these data also show W' (generally attributable to anaerobic metabolism) contributed to approximately 10% of the variance observed between the CS-W' measurements and VO_{2max}. Seipel hypothesized that this relationship was due to W' acting as a mechanism to allow the ultimate achievement of VO_{2max}, as VO_{2max} can only be obtained in the non-steady-state domain of intensity (higher intensity than CS). These results provide further evidence that CS and W' can provide a more complete picture of energy systems at higher exercise intensities than traditional VO_{2max} values, and as such, may be beneficial when tracking fitness and targeting various training adaptations.

One of the main reasons for conducting CS testing with a shortened protocol as described by Seipel (2018) is to reduce the time commitment by the test participant, as well as shorten the window for changes within the participant that may affect outcome performances. Such variables can include changes in health, diet, and stress. While many of these variables can be controlled, it is at the cost of further burden to the participant. Additionally, testing over too long of a time period can also introduce error due to fitness changes in participants that continue to train. To this end, using a shortened two-day protocol is protective against these variables that can influence measured outcomes in CS-W' testing.

While this study provides evidence of the validity of the two-day protocol, it does not directly assess the criterion-based validity of the two-day protocol by comparing it to the traditional protocol. Future research should directly compare the CS and W' estimates from the two-day protocol and those generated by the traditional protocol to better compare the ability of the two-day protocol to assess these physiological variables

In conclusion, the main finding of this analysis is that a shorter two-day CS testing protocol did not reveal any significant differences in W' residuals between days and trials, indicating consistent performances across the three testing trials and two testing days.

Researchers and practitioners can cautiously use the two-day protocol in place of the longer, traditional method for assessing CS and W'. A direct comparison of these two test methodologies is warranted to best assess the utility of the two-day protocol when administering a test of CS.

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APPENDIX A: INFORMED CONSENT FORM

CONSENT FORM

Project Title: **Addressing Error in the Cooper 12-Minute Run**
The Influence of Exercise Tolerance Parameters

Principal Investigator: Jason Penry, Ph.D.
Student Researcher: Aaron Seipel, Morgan Anderson, Stephanie Baxter, Micah White, Arthur Chan
Co-Investigator(s):
Sponsor: none
Version Date: 10/12/17

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1. WHAT IS THE PURPOSE OF THIS FORM?

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

2. WHY IS THIS RESEARCH STUDY BEING DONE?

The purpose of this research study is to investigate the role of critical speed and severe domain distance capacity in influencing performance during the Cooper 12-minute run test. The 12-minute run is commonly used as a field test for estimating maximal oxygen consumption. This estimation does not factor in other predictors of endurance performance. As such, the assumed relationship may simply be the result of interaction with other physiological variables. The information acquired in this study will improve understanding of maximal oxygen consumption's utility in predicting endurance performance potential. Moreover, it will allow for more informed interpretation of 12-minute run test results by coaches and athletes.

Up to 50 participants may be invited to take part in this study. The investigators intend to publish these findings in a peer-reviewed journal and present these results at a professional conference in the near future. This study will also serve as the masters thesis research for Aaron Seipel, one of the student investigators named above.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are between the age of 18 and 35 years old, currently run at least 3 days per week, and are not currently injured, pregnant, or lactating. Additionally, you believe that you are capable of completing maximal aerobic exercise, and have no more than one cardiovascular disease risk that you are aware of.

WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

During this study, you will participate in one 12-minute run test, six treadmill runs to volitional fatigue, one maximal graded exercise test, and one body composition test. Each test day will be followed by at least 24 hours of rest and you will be asked to complete all tests within a six-week period. Your total time commitment is approximately 4 hours.

You are asked to maintain your current activity level and refrain from structured exercise for the period of 24 hours before each test. In addition, we ask that you refrain from eating for at least 2 hours prior to the test and consume the same meal prior to each test. We will ask you about each of these considerations each time you visit the lab for a testing session. Each testing session will be separated by a minimum of 48 hours.

Descriptions of each test follow below:

Maximal graded exercise test. This is an exercise test that progresses from low to high intensity to measure the maximal rate at which your body can use oxygen during physical activity. This test will be conducted on a treadmill in the Oregon State University Human Performance Laboratory and will require you to run for 12-18 minutes. You will wear a mask to collect the air you breathe out during the test. During this test, speed or gradient will increase every minute until you can no longer continue. Speed will be increased first, and gradient will be increased in the latter stages of the test. In some cases, an additional 5-minute stage will be necessary at your maximal effort. The fatigue experienced following this test will be similar to that felt after completing a five-kilometer running race.

Volitional exhaustion treadmill runs. These tests will be conducted on a treadmill in the Oregon State University Human Performance Laboratory and will be conducted over two visits. You will select your own warm up intensity for 10 minutes. Speeds will be selected to elicit fatigue between one and ten minutes. Upon exhaustion, you will be given the opportunity to rest and recover until your heart rate decreases to within less than 20 beats per minutes above pre-test levels. When you feel adequately recovered and heart rate recovery criteria have been met, the test will be repeated at a different speed. Three trials will be performed per visit to the laboratory with the same recovery protocol used between each trial. After completing the third trial, you may cool down as you wish.

12-minute run. This test will be conducted at an all-weather 400-meter running track in the greater Corvallis area. You will select your own warm up intensity for 10 minutes. Following a warm up, you will be asked to run as far as possible in a 12-minute period. While you will not be permitted to wear a watch, we will provide a whistle signal 3-, 6-, and 9-minutes into the run. A final whistle signal will be given at the 12-minute mark, at which point you must stop immediately. Once an investigator has marked your ending point, you will be permitted to cool down as you wish.

Body composition test. This test will be conducted in the Oregon State University Human Performance Laboratory and involves measuring your body composition by bioelectrical impedance. In order to get accurate results, you cannot eat or exercise for 2 hours before this test and need to be well hydrated. You will stand stationary barefoot on two electrodes, while holding two electrodes at your side. This test should take approximately 15 minutes.

WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

You can expect to experience short-term fatigue when completing the volitional exhaustion treadmill runs and the maximal exercise test. There is also a very remote chance that you may suffer a heart attack during a maximal running effort. For physically active individuals with one or fewer cardiovascular disease risk factors, this is considered a low risk. If further screening classifies you as greater than low risks, you will be ineligible to participate in the study. As such, the risk associated with any exercise testing performed will be low. In addition, every effort will be made to ensure that the areas in which the tests are conducted are free of obstacles that may cause injury.

The possible risks and/or discomforts associated with the exercise testing in the study include:

- Acute exercise may present a risk of sudden death
- Cardiovascular event (i.e., heart attack or cardiac arrhythmia)
    - Overall risk of cardiac events is about 6 events per 10,000 tests
- Serious injury
- Falling
- Physical discomfort from the test and equipment
- Fatigue
- Muscle aches, cramps, joint pain
- Muscle strain and/or joint injury
- Delayed muscle soreness
- Abnormal blood pressure/heart rate
- Shortness of breath
- Lightheadedness, fainting
- Dizziness
- Nausea

There are no anticipated risks from the body composition assessment using bioelectrical impedance.

4. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. If you think that you have been injured as a result of being in this study, please contact the researchers immediately via Dr. Jason Penry, Principal Investigator, at 541-737- 3265 or jay.penry@oregonstate.edu.

5. WHAT ARE THE BENEFITS OF THIS STUDY?

We do not know if you will benefit from being in this study. However, you will receive information concerning your maximal aerobic capacity, critical speed, and gas exchange threshold heart rate as a result of participating in this study. In addition, you will receive an estimate of your current body composition and basal metabolic rate. Moreover, in the future, other people might benefit from this study, as it will allow coaches, other athletes or researchers to better understand the utility of maximal oxygen consumption in predicting endurance performance potential. This will be particularly useful in identifying the appropriate tests for assessing and tracking improvements in endurance athletes.

6. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study.

7. WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You **will not** be charged for any tests that are being performed for the purposes of this study. You will be responsible for travel costs to the study site.

8. WHO IS PAYING FOR THIS STUDY?

The Oregon State University Human Performance Laboratory fund is paying for this research.

9. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you. To help ensure confidentiality, we will use identification code numbers on data forms instead of your name, and will keep all personal information and study data in a locked filing cabinet. Any digital files that are created will be secured via password protection.

During the 12-minute run and volitional exhaustion treadmill runs, two to four subjects may be tested simultaneously to encourage maximal effort during all these trials. While participation in the study will not be completely confidential amongst subjects due to this, your personal information will not be disclosed to other participants. To minimize the risk of your results being disclosed to other participants during these tests, no results will be given until completion of all tests. In the event that other participants are present during your final test, results will be shared privately at a later time or via email based on your personal preference.

We will make every effort to protect your identity but there is a risk that information, which identifies you, could be accidentally disclosed.

If the results of this project are published, your identity will not be made public.

WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

10. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please email Jason Penry (jay.penry@oregonstate.edu) or Aaron Seipel (seipela@oregonstate.edu).

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

11. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: Delete this line only if the study is exempt. The IRB will insert the appropriate date when the consent form is approved.

Participant's Name (printed): _____

_____ _____
(Signature of Participant) (Date)

_____ _____
(Signature of Person Obtaining Consent) (Date)

APPENDIX B: HEALTH HISTORY SCREENING

Mark all *true* statements.

SECTION1:

History:

Participant has had:

__ a heart attack
__ heart surgery
__ cardiac catheterization
__ coronary angioplasty (PTCA)
__ pacemaker/implantable cardiac defibrillator/rhythm disturbance
__ heart valve disease
__ heart failure
__ heart transplantation
__ congenital heart disease

Symptoms:

__ Participant has experienced chest discomfort with exertion.
__ Participant experiences unreasonable breathlessness.
__ Participant experiences dizziness, fainting, blackouts.
__ Participant takes heart medications.

Other health issues:

__ Participant has musculoskeletal problems.
__ Participant has concerns about the safety of exercise.
__ Participant takes prescription medication(s).
__ Participant is pregnant.

If any statements in this section are marked, a physician or appropriate health care provider should be consulted before engaging in exercise and documentation of this consultation should remain on file.

SECTION 2: CARDIOVASCULAR RISK FACTORS

__ Participant is a man older than 45 years.
__ Participant is a woman older than 55 years or has had a hysterectomy or is post-menopausal.
__ Participant smokes.
__ Participant's blood pressure is > 140/90.
__ Participant's blood pressure is not known.
__ Participant takes blood pressure medication.
__ Participant's blood cholesterol level is > 240 mg/dl.
__ Participant's cholesterol is not known.
__ Participant has a close blood relative who had a heart attack; before age 55 if father or brother or before age
65 if mother or sister.
__ Participant is physically inactive (< 30 minutes of physical activity on at least 3 days per week).
__ Participant is > 20 pounds overweight.

If 2 or more statements in this section are marked, a physician or appropriate health care provider

should be consulted before engaging in exercise and documentation of this consultation should remain on file.

SECTION 3: NO HISTORY, SYMPTOMS, HEALTH ISSUES, OR CARDIOVASCULAR RISK FACTORS

__ None of the items in sections 1 and 2 above are true.

Participant should be able to exercise safely without consulting their healthcare provider.

Study Team Member Completing Form:

_____

APPENDIX C: SUPPLEMENTAL HEALTH HISTORY

The purpose of this questionnaire is to obtain information regarding your health prior to conducting physiological testing. Please answer all questions to the best of your knowledge.

Thank you for your honest answers!

SECTION 1: ADDITIONAL HEALTH HISTORY

Are you a former smoker?
_____Yes If yes, please specify approximate quit date _____
_____No

Are you diabetic?
_____Yes If yes, please specify list medications taken:
_____No

Do you have any respiratory problems (example: asthma, emphysema)?
_____Yes If yes, please specify:
_____No

Please explain any other significant medical problems that you consider it important for us to know:

Are you taking any supplements or over the counter mediations?
_____Yes If yes, please list:
_____No

Are you currently suffering from any cold, flu, or allergy symptoms?
_____Yes, please specify:
_____No

Do you ***currently*** have any muscular injury(s) that will prevent you from exercising?
_____Yes If yes, please explain the ***type of injury(s)*** and the ***length of time*** it has persisted:
_____No

Do you currently have any muscle or joint pain?
_____ Yes If yes, is this pain mild, moderate or severe? (please circle one)
_____ No Mild Moderate Severe

Have you had any muscular injury(s) in the ***past***?
_____Yes If yes, please report how long ago you had the injury(s):
_____No

Have you had any surgeries in the ***past***?
_____ Yes If yes, please specify the type of surgery you have had, the year of surgery and
_____ No your age at the time:

Do you ***currently*** have any bone or joint injury(s) that will prevent you from exercising?
_____Yes If yes, please report how long ago you had the injury(s):
_____No

Do you ***currently*** have any soft tissue injury(s) that would prevent you from exercising?
_____Yes If yes, please report how long ago you had the injury(s):
_____No

If you've ***recently*** (within the past 6 months) suffered any other type of injury(s) that prevent you from exercising? Please list them here.

Is there the **one** primary sport or physical activity you participate in?

Please list any other sports or physical activity you participate in regularly.

Please complete the following about your exercise program (if applicable):
Aerobic Exercise (e.g., running, swimming, biking, etc.):

Type of exercise

a.
b.
c.
d.
e.

Minutes/Session

a.
b.
c.
d.
e.

Intensity/Pace

a.
b.
c.
d.
e.

Times/Week

a.
b.
c.
d.
e.

Resistance Exercise _____ _____ _____
Type of Training Minutes/session Times/Week

Do you intend to change your training status while participating in this study? _____

How long have you participated in an aerobic exercise program? _____

How long have you participated in a resistance exercise program? _____

Females only:
What was the date of your last period? _____
Do you menstruate regularly?
_____ Yes
_____ No

Do you plan to become pregnant during the course of your participation in this study?
_____ Yes
_____ No

SECTION 2: EMERGENCY CONTACT

Please provide us with emergency contact information.

Name: _____ Relation:

_____

Home/Cell Phone: _____ Work Phone:

_____

Study Team Member Completing Form:
_____