THE EFFECTS OF A RACE TIMER ON THE 3 MINUTE ALL-OUT TEST FOR CRITICAL POWER

By

Paul Mandell

A Thesis Presented to

The Faculty of Humboldt State University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Kinesiology: Exercise Science

Committee Membership

Dr. Taylor Bloedon, Committee Chair

Dr. Boe Burrus, Committee Member

Dr. Whitney Ogle, Committee Member

Dr. Justus Ortega, Committee Member

Dr. Taylor Bloedon, Program Graduate Coordinator

May 2019

Abstract

THE EFFECTS OF A RACE TIMER ON THE 3 MINUTE ALL-OUT TEST FOR CRITICAL POWER

Paul Mandell

Maximal exercise testing is commonly employed by exercise scientists in order to assess an athlete's' capabilities and inform future training goals and tactics. The Critical Power (CP) concept provides a novel perspective on the physiological capacity of an individual to perform work. The 3 Minute All-Out Test (3MT) for critical power was developed by Vanhatalo, Doust, & Burnley in 2006. Concerns about pacing during the test lead to the development of protocol which blinds participants to time during the test. Twelve healthy active males were recruited to participate in the current study on the effects of a race timer on the 3MT. Participants completed one $\dot{V}O_{2peak}$ test and one 3MT familiarization trial before completing one standard 3MT and one 3MT with the presence of a countdown race timer. The presence of a race timer produced significant differences in CP & WEP, but not in PPO or total work between trials. These differences may be explained by the effect of knowledge of time on information processing and decision making during the 3MT. Future research should focus on the effects of a race timer on the 3MT in trained cyclists, and may be adapted to other modes of exercise.

Table of Contents

List of Tables

List of Figures

Introduction

Maximal exercise testing is commonly employed by exercise scientists in order to assess an athlete's' capabilities and inform future training goals and tactics. The Critical Power (CP) concept provides a novel perspective on the physiological capacity of an individual to perform work. CP represents the maximal rate of work at which an individual can sustain exercise through continuous, stable utilization of available substrates (Burnley, Doust, & Vanhatalo, 2006; Jones & Vanhatalo, 2017; Poole, Burnley, Vanhatalo, Rossiter, & Jones, 2016). Work Prime (W'), which represents exercise capacity above critical power, is established during CP testing, allowing for precise quantification of anaerobic work capacity (Jones & Vanhatalo, 2017). By establishing both CP and W', athletes, trainers, and coaches are able to create a profile which provides insights into race pacing as well as the duration and/or distance at which work above CP can be sustained (Poole et al., 2016). The variables obtained through a CP test hold the potential to influence race tactics in a number of endurance sports, as well as allowing for the creation of customized, and highly accurate interval training programs (Jones & Vanhatalo, 2017).

Critical Power & the 3MT

Critical Power represents the delineation point between the heavy and severe intensity domains of exercise (Lucas, Souza, Costa, Grossl, & Guglielmo, 2013; Poole et al. Jones, 2016; Jones, Wilkerson, Dimenna, Fulford, & Poole, 2008). The heavy exercise domain, occurring at and below critical power, is characterized by a sharp increase in values for V̇O, lactate, [Cr+], and increased [H+] at the onset of exercise. Subsequent stabilization of all values occurs shortly after exercise begins, indicating an ability to continue exercise until substrate depletion occurs (Jones et al., 2007). The severe intensity exercise domain is characterized by a sharp rise in lactate & V̇O at the onset of exercise, which continues to rise until fatigue is reached. Inorganic phosphate accumulates progressively while muscle phosphocreatine [PCr] decreases and muscle [H+] accumulates, leading to fatigue (Vanhatalo et al., 2016). In theory, exercise at 5% above CP would lead to volitional fatigue.

The basis for the CP model is the work-time relationship. Maximal work capacity at a given intensity is a product of energy use and reconstitution for a limited time period (Moritani, Nagata, deVries, & Muro, 1981; Jones & Vanhatalo, 2017). The traditional methodology for establishing CP consists of a series of constant work rate (CWR) tests on a cycle ergometer (Moritani, Nagata, deVries, Muro 1981; Hill DW 1993). While practical for the establishment of CP & W*, the CWR hyperbolic method is time consuming and requires multiple laboratory sessions and personnel (Vanhatalo, Doust, & Burnley, 2006; Bergstrom, et. al., 2012; Black, Jones, Kelly, Bailey, & Vanhatalo, 2016; Jones & Vanhatalo, 2017). A better test to determine CP, W*, PPO was needed if the CP concept was to be efficiently utilized.

Vanhatalo, Doust, & Burnley (2008) developed and validated the 3MT in which participants are instructed to pedal all-out against a fixed resistance for three minutes. The 3MT is a practical, efficient, and non-invasive method for determining both CP and W' as well as determining $\dot{V}O_{2peak}$ and maxHR (Burnley, Doust, & Vanhatalo, 2006). This method requires fewer laboratory visits, and because it is sensitive to changes in training status, the 3MT presents a novel and time conscious way to evaluate athletes (Cheng, Yang, Lin, Lee, & Wang, 2011; Cheng, Hsu, Kuo, Shih, & Lee, 2016; Bergstrom, et. al., 2012; Karsten, Jobson, Hopker, Stevens, & Beedie, 2014; Poole et al., 2016; Jones & Vanhatalo, 2017).

Factors Affecting Pacing, Cadence, & Power Output During Exercise

Sport and exercise performance is influenced by internal and external sensory input, which informs an athlete about the current exercise session and informs decision making for future actions (Hampson, Gibson, Lambert, & Noakes 2001; Ulmer, Schneider, & Freitag 2002; Tucker, 2009; Pageaux 2014). Performance outcomes in the 3MT are similarly sensitive to a number of external and internal factors. These factors include, but are not limited to; internal and external sensory feedback, perception of fatigue, prior knowledge of exercise mode, knowledge of distance/time remaining during exercise, mood state, and anticipation (Hampson, Gibson, Lambert, & Noakes 2001; Ulmer, Schneider, & Freitag 2002; Tucker, 2009, Pageaux 2014; Smitts et. Al. 2014; Smits, Polman, Otten, Pepping, & Hettinga 2016).

Teleoanticipation theory suggests that exercise performance is precisely regulated based primarily on duration and/or distance as well as intensity and RPE (Ulmer, Schneider, & Freitag 2002). Prior knowledge of the exercise and associated intensity further refine the ability to regulate performance by introducing an anticipatory component. Ulmer, Schneider, & Freitag (2002) supported this idea by demonstrating that swimmers were able to precisely judge and monitor exercise intensity and power output for a known duration and distance. This theory was later refined by Noakes (2009), who absorbed the anticipatory template into the Central Governor Theory (CGT), and offered a broader explanation of autoregulation across a wider variety of exercise intensities. CGT posits that the nervous system precisely monitors work output and exercise intensity as a protective mechanism in order to maintain homeostasis (Tucker, 2009). The proposed mechanisms of the CGT rely on a number of internal physiological factors such as respiratory rate, heart rate, $\dot{V}O$, blood lactate & [H+] accumulation, skin and core temperature, and mechanical strain, which provide afferent neural feedback in order to help establish Rate of Perceived Exertion (RPE) (Tucker, 2009; Hampson, Gibson, Lambert, & Noakes, 2001). This explanation relies heavily on the idea that exercise performance is largely dependent on the participants ability to tolerate discomfort. One major limitation of the CGT is that it approaches the brain and nervous system as a black box. CGT fails to account for a person's previous experience, information acquisition from both internal and external environmental stimuli, decision making skills, and the coupling of afferent feedback and efferent output during exercise.

Maybe a transition before this paragraph The Affordance Competition Theory (ACT) further revises the CGT by taking into account affordances offered by an individual's environment (Smits, Hettinga, & Pepping, 2014). Affordances are environmental stimuli that inform a person about possibilities for specific future actions, and are in constant competition with one another (Smits et. Al. 2014). These potential actions are weighed against external influences such as risk, reward, and metabolic reserves/cost. Indeed, there is evidence to suggest that pacing is a decision based process and that athletes of different experience levels rely on different sources of input to inform their decision-making process (Parry, Chinnasamy, & Micklewright 2012; Smitts, Pepping, Hettinga, 2014; Smitts, Polman, Otten, Pepping, & Hettinga 2016; Boya et. al.

2017). The ACT also lends credibility to the Psychobiological Model for Endurance Exercise, which accounts for the cognitive-motivational factors (cognitive-motivational affordances) that influence decision based pacing strategies. This model lists knowledge of distance and time remaining/covered, RPE, motivation, and previous experience as the leading cognitive-motivational factors for decision based pacing (Pageaux, 2014).

Previous research using the 3MT has followed a protocol designed and validated by Vanhatalo, Doust, & Burnley (2006), which relies on the blinding of participants to time and power output during the 3MT. Typically, participants undertaking the 3MT complete one familiarization session prior to testing sessions, thereby providing a partial anticipatory template for future testing sessions. While the logic behind a preventative pacing strategy in the 3MT is sound, blinding the participants to time may actually be of detriment to the accuracy of the results. The current protocol may prevent participants from achieving a true all-out effort by dismantling the anticipatory template for the session and leading to inaccuracies in the decision-making process during the 3MT (Tucker, 2009; Pageaux, 2014; Smitts, Pepping, Hettinga, 2014). It is possible that the introduction of a time component to the 3MT may result in higher and more accurate values for PPO, CP, and W’ in participants with knowledge of test duration based on a refined ability to monitor exercise intensity.

To date, there has been no research investigating what effects knowledge of time may have on outcomes of the 3MT. Therefore, the purpose of this study is to investigate the effects of incorporating a race timer in the 3MT on CP, work above end power (WEP, a measure of W') PPO, Mean power, Total work, $\dot{V}O_{2peak}$, & HRmax. This study aims to further refine the body of knowledge surrounding the Critical Power Concept and to contribute to the 3MT as a performance measurement for establishing critical power.

Methods

12 healthy active males (Age: 24.9 years +/- 2.2, Height: 180.4cm +/- 7.5, Weight: 78.1kg +/- 6.6, V̇O2peak: 53.9ml.kg.min +/- 6.1) were recruited to participate in this study, which followed a randomized and counterbalanced design (IRB 18-064). Participants completed an exercise history questionnaire to establish their experience with high intensity exercise before being invited to participate in the study. All participants had routinely engaged in high intensity exercise such as Olympic lifting, resistance training, power training, or HIIT 2-3x weekly for at least three months prior to the study. Participants were determined to be free from any injuries, medical issues, or risk for metabolic disease prior to enrollment.

Experimental Design

Experimental protocol consisted of four visits to the laboratory with a minimum of 48 hours between each session, as shown in figure 1. Visit 1, participants completed the informed consent, exercise habits questionnaire, PAR-Q, anthropometric measures, and an incremental ramp test to determine $\dot{V}O_{2peak}$ and gas exchange threshold (GET). Visit 2 consisted of a 3MT familiarization trial used to accustom participants to the protocol and to help control for a learning effect, although data was not included in the data analysis. Visits 3 and 4 took place in a randomized and counterbalanced format. One standard 3MT was completed, serving as the control, while the other test consisted of a modified 3MT which served as the experimental trial.

$\dot{V}O_{2peak}$ Procedure

All cycling sessions took place on a Velotron electronically braked cycle ergometer (Racermate, Inc. 2017, Seattle, WA). The handlebars and the seat on the cycle ergometer were adjusted for comfort. The same measurements were replicated for all the following sessions to ensure the same bike fit for all session. The $\dot{V}O_{2peak}$ protocol consisted of 3 minutes of unloaded cycling followed by a 30 watt/min increase until volitional fatigue. Participants were instructed to maintain their preferred cadence for as long as possible. The test was concluded when cadence dropped 10rpm below their specified preferred cadence for more than 10 consecutive seconds, despite strong verbal encouragement. Verbal encouragement was standardized so as not to reveal or allude to any metrics including elapsed time, power output, or metabolic data. The same phrases (e.g. “Push!” “Dig Deep!” “Don't let your cadence drop!”) were used at regular intervals throughout each test by the same research assistants. $\dot{V}O_{2peak}$ was determined from the highest 10-second average achieved at any point during the test (Vanhatalo, Doust, & Burnley, 2007).

Determining GET

GET was estimated using the 10 second averaged data from the $\dot{V}O_{2peak}$ test according to the V-slope method (Vanhatalo, Doust, & Burnley, 2006; Vanhatalo, Doust, & Burnley, 2007). Consensus between three qualified researchers was reached concerning the point at which GET and the corresponding power output. Flywheel resistance for subsequent 3MT trials was determined by obtaining the power output corresponding to halfway (50%) between GET & $\dot{V}O_{2peak}$ divided by preferred cadence squared (Dicks, Jamnick, Murray, & Pettitt 2016, Beaver, Wasserman, & Whipp 1986).

Gas collection and analysis was completed via Parvomedics TrueOne 2400 Metabolic Measurement System and software (Parvo Medics 2013, Sandy, UT) paired with Hans Rudolph Metabolic Mask (Hans Rudolph, 2018, Shawnee, KS). Heart rate was analyzed using a Polar H3 heart rate sensor paired to a Polar RS800 (Polar USA, 2018, Bethpage, NY) heart rate monitor. Participants were equipped with Shimano RO65 road shoes and accompanying Shimano PDR540 SPD pedals (Shimano INC, 2018, Irvine, CA).

3MT Procedure

Participants began each testing session by completing a five-minute warmup at 100W followed by five minutes rest period. Following the rest period, participants completed three minutes of unloaded cycling followed by a three-minute all-out effort.

Participants were instructed to increase their cadence to approximately 110 rpm during the final five seconds of unloaded cycling. Strong verbal encouragement was being given for the duration of the test. Participants were instructed to avoid pacing and to give maximum effort during the session, as well as to maintain the highest cadence they can in order to ensure all-out effort. Participants were blinded to elapsed time during the test (Burnley, Doust, & Vanhatalo, 2006; Vanhatalo, Doust, & Burnley, 2007).

Modified 3MT

The modified 3MT followed the same procedures as the standard 3MT test, however in this session participants were made aware of elapsed time through the use of a Programmable Gym Timer (Invech Holdings Inc, China) positioned immediately in front of the cycle ergometer. The timer was set to count down from three minutes, with a 10 second countdown prior to the beginning of the test. Warm up, rest, and testing procedures remained the same as in the 3MT.

Statistical Analysis

Paired T-Tests will be used to compare $\dot{V}O_{2peak}$, HRmax, PPO, WEP, CP, Mean Power, and Total Work between standard and timer conditions. 30-second average cadences, peak RPM, pedal velocity, and time at PPO (tPPO) will compared between conditions.

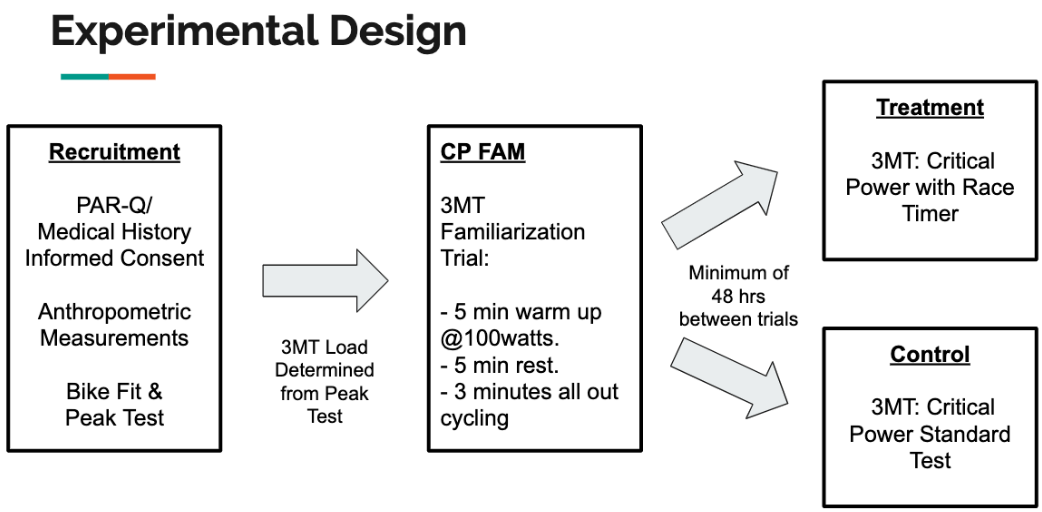

Figure 1. Experimental Design.

Participants were randomized and counterbalanced to control for a learning effect. A minimum of 48 hours rest was taken between trials.

Results

There was a significant difference in CP between timer and standard conditions (*P* = 0.021), as well as a significant difference in WEP between timer and standard (*P* = 0.004). There was also a significant difference in tPPO between standard and timer conditions (*P* = 0.046) (Table 1.). There were no significant differences in $\dot{V}O_{2peak}$ HRmax, PPO, or Mean Power between trials (Table 4.).

Cadences were averaged into six 30-second sections across the duration of the 3MT and were compared between timer and standard conditions (Table 2.). There was a significant difference between groups in Average #6 (2:30-3:00) of the 3MT (*P* = 0.011), as well as a difference between groups in pedal velocity during the final 30-second average (*P* = 0.010). There were no significant differences in Averages #1-5. Additionally, there was no significant difference in peak RPM or Pedal Velocity between groups (Table 3.).

Tables

Table 1. Work During the 3MT

Measure	Standard Trial		Timer Trial		t-test
	Mean	SD	Mean	SD	
CP (W)	267.51	44.54	276.7	49.6	-2.684*
WEP (kJ)	13.71	4.34	12.47	4.01	3.675*
PPO (W)	597.33	150.66	598.25	155.76	-.164
Mean Power (W)	340.54	50.11	347.88	54.91	-1.808
Total Work	61847.78	9205.63	62589.18	9881.0	-1.443

* *$p < 0.05$ CP: Critical Power. WEP: Work above End Power. PPO: Peak Power Output*

Table 2. 30 Second Average Cadences

Time	Standard Trial		Timer Trial		t-test
	Mean	SD	Mean	SD	
0:00-0:30	146.85	8.82	147.12	9.09	-.380
0:31-1:00	106.52	17.86	106.3	16.23	.232
1:01-1:30	88.82	18.64	88.86	16.00	-.031
1:31-2:00	81.9	18.32	82.64	15.94	-.630

Time	Standard Trial		Timer Trial		t-test
	Mean	SD	Mean	SD	
2:00-2:30	78.10	17.47	79.77	16.35	-1.638
2:30-3:00	75.86	16.36	78.26	15.94	-3.092*

* *$p < 0.05$. Time represented in individual 30-second averages across the 3MT.*

Table 3. CP Pedal Velocity & Time at PPO

Measure	Standard Trial		Timer Trial		t-test
	Mean	SD	Mean	SD	
Pedal Velocity (m/s)	1.38	.298	1.43	.293	-3.092*
Time at PPO(s)	7.14	2.14	5.96	3.09	2.25*

* *$p < 0.05$*

Table 4. $\dot{V}O_{2peak}$ & HR_{max}

Measure	Standard Trial		Timer Trial		t-test
	Mean	SD	Mean	SD	
$\dot{V}O_{2peak}$	52.98	4.49	52.83	5.38	.187
HR_{max}	174	8.75	175.6	8.54	-1.727

* *$p < 0.05$* $\dot{V}O_{2peak}$ *expressed in ml.kg.min.*

Figures and Alternate Text

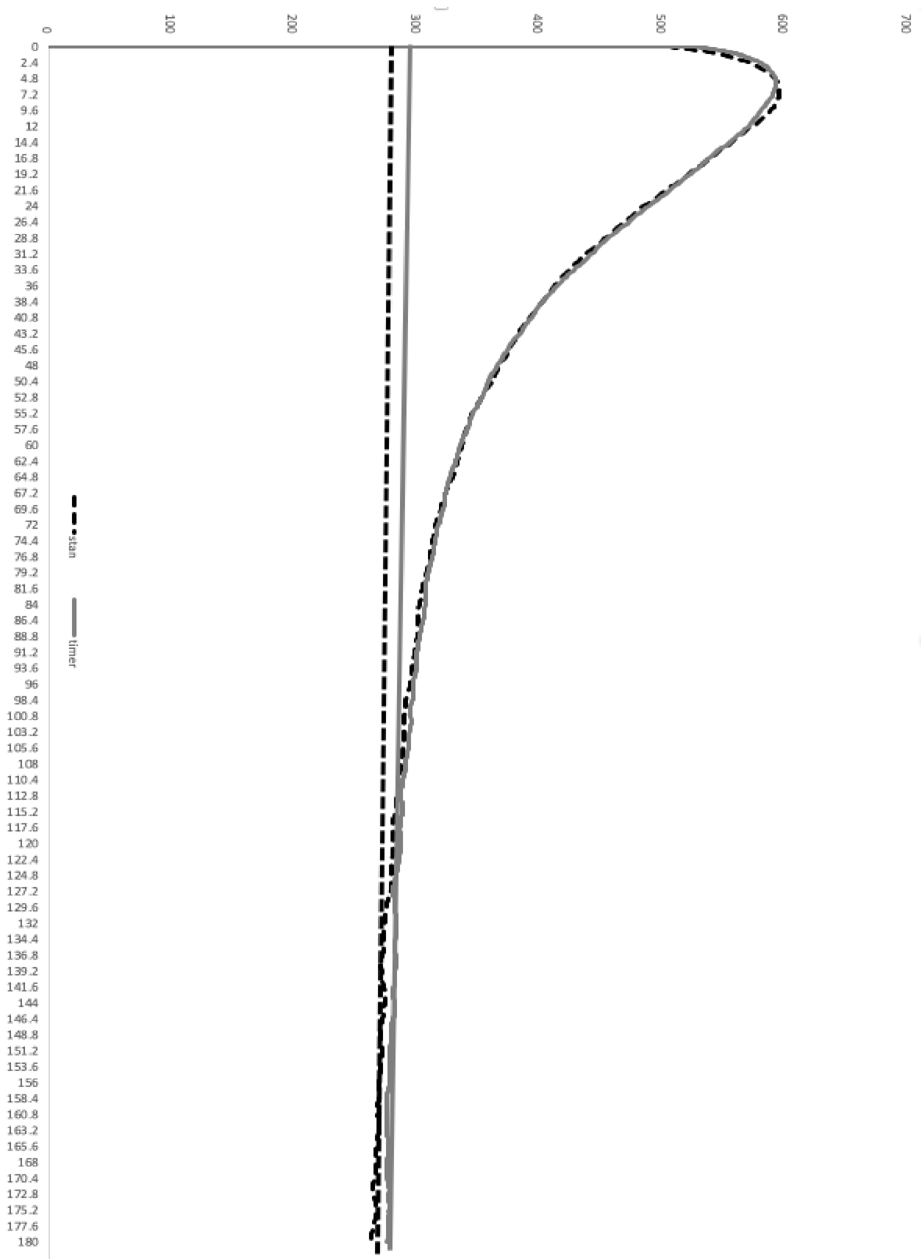

Figure 2. Mean Power Curves Between Groups.

Standard trial represented by block dotted line. Mean CP Standard Trial: 267.5 watts.
Timer trial represented by solid grey line. Mean CP Timer Trial: 267.8 watts.

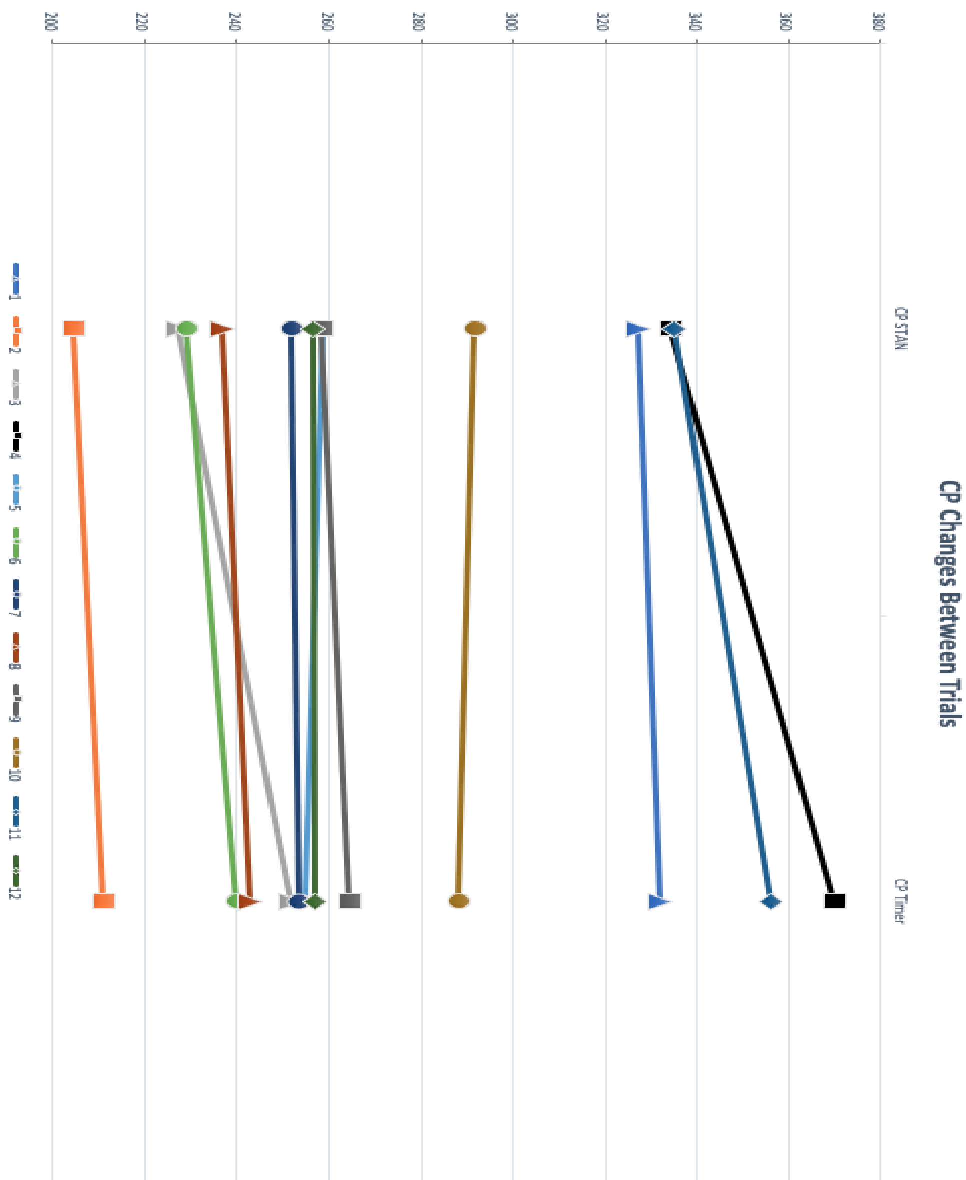

Figure 3. Individual Differences in CP between trials.

Discussion

It was hypothesized that the introduction of a race timer to the 3MT would result in higher values for CP, PPO, and WEP. This hypothesis was only partially supported through the results of this study. While CP was significantly higher in the timer condition, PPO was not significantly different between trials, and WEP was significantly greater in the standard trial. Both Mean Power and Total Work failed to reach significance between conditions. These findings suggest that the introduction of a race timer did have a significant effect on the outcome of the 3MT, but whether this is of any benefit to the test remains unclear. While CP was higher in the timer group, WEP was significantly lower, suggesting that participants may have “borrowed” from their WEP in order to sustain CP at a higher output during the timer condition. This is consistent with the concerns of Vanhatalo et. al (2007) who designed the 3MT protocol to blind participants to time. However, the lack of a significant difference between PPO, Mean Power, and Total Work between groups prompted further exploration.

Based on the lack of a difference in PPO, Peak RPM, and Peak Pedal Velocity between conditions, it would appear that participants did not adopt a pacing strategy from the start of the test. Furthermore, the lack of a significant difference in Mean Power and

Total Work in the 3MT suggest that the higher values for CP are representative of a revised distribution of available energy from one section of the test to another. Another finding of interest is the difference in time at PPO between tests. Participants in the timer condition reached their PPO significantly faster than they did in the standard condition. This difference in timing may represent a more refined distribution of work across the 3MT.

Further analysis of cadence revealed a significant difference during the final 30 seconds (CP Cadence), as well as a higher pedal velocity during the final 30 seconds. These results are expected due to the linear relationship between cadence and power output of the 3MT, and provide the mechanical basis for the higher CP in the timer condition. No significant difference was seen in 30-second average cadence between trials from 0:00-2:30, suggesting that participants maintained the same power output over the duration of the test between trials. It is evident from these observations that a pacing strategy was adopted during the final 30 seconds of the test. However, this idea fails to account for the similarities in PPO, Mean Power, and Total Work between trials, since holding PPO and cadence constant while increasing CP would result in a higher value for Total Work in the timer trial. The increase in CP resulted in a lower WEP, while total work between groups remained the same.

Vanhatalo et. Al (2007) examined the effects of altered cadence at the beginning of the 3MT on “end power”, or CP. They determined that end power was robust to lower cadences at the outset of the test, but not to higher cadences (corresponding to 130% power output from a prior peak test). Those findings lend credibility to concerns about pacing, however the present study has a number of notable differences that should dispel any concerns about end power. Flywheel resistance was the same in each trial while cadence, and power profiles in both trials remained similar throughout the first two minutes and thirty seconds. WEP was significantly lower in the timer trial, but this is due to the higher end power. Because the power profiles in both tests are nearly identical, increasing CP reduces the area under the curve used to measure WEP, as was observed by Vanhatalo et. Al (2007). Whether the higher CP value and lower WEP values represent a more accurate measure of each remains unclear and more research is needed before any concrete conclusions can be made. However, holding all other variables constant, it seems reasonable that a higher CP in the timer trial may represent a more accurate measure of CP and WEP. unclear.

One possible of explanation for this is found in the ACT. It may be that knowledge of elapsed time was an affordance of particular importance to participants during the 3MT, and allowed them to refine their anticipatory exercise template. The introduction of additional information may have also lead to differences in the decision-making process between conditions, which may account for the difference in energy distribution between trials.

The ACT has a number of benefits over the CGT. The CGT is rooted in biology and only partially accounts for the psychological aspects of sports performance. The CGT hypothesizes a feed-forward control to anticipate exercise duration, RPE, & power output during exercise. The CGT accounts for previous experience and arousal in the context of a predetermined RPE & exercise template for the session (Hampson, et al. 2001; Tucker, 2009). It approaches exercise as though performance for a given session is determined before the session even begins. This is one of the major limitations to the CGT, because does not take into account the continuous flow of sensory information and the subsequent coupling of perception and action, or the selection of an appropriate pacing strategy for the session (Smitts et al., 2014). Importantly, the individual decision-making processes inherent to interactions in and with the environment during exercise are not addressed by the CGT. The ACT posits that individuals must determine in the moment whether RPE is acceptable, and make a decision to reduce, maintain, or increase power output based on a number of internal and external factors. There is still speculation as to whether this occurs consciously or subconsciously (Tucker, 2009; Smits et al., 2014).

The GCT argues that RPE is the deciding factor for downregulating power output when intensity is deemed unacceptable (Hampson et al., 2001; Tucker, 2009). If this were true then CP would be the same for both trials via downregulation of power output, since flywheel resistance was the same in both trials. The introduction of a timer supports the theory of decision based performance through the adoption and maintenance of a higher CP cadence in the timer trial. This may have been accomplished through the refinement of the anticipatory framework of exercise by adding a known endpoint (time), or additional cognitive motivational factors related to performance within a refined set of parameters.

Conclusions

This study was the first to examine the effects of a race timer on the 3MT. The introduction of a time component to the 3MT did illicit a pacing strategy, as was evident in the distribution of work across the test. While CP and WEP were different between trials, the total work and peak power output were not. These results lend credibility to the explanation that the observed differences were due to a refined anticipatory template and an improved ability to make decisions during the test.

One of the major limitations of this study was the selection of novice healthy active males as participants. It has been previously that experienced cyclists rely less on distance/duration feedback than novice cyclists, and this area warrants further exploration. (Boya et. al. 2017).

There are also some concerns about participant adherence to recovery and exercise guidelines outside of the laboratory sessions. Performance is sensitive to a number of influential factors such as mental fatigue, sleep, nutrition, hydration, and motivation (Tucker, 2009; Hampson, et al. 2001; Pageaux, 2014; Salam, et al. 2017). Participants were given a set of guidelines for recovery and exercise between laboratory sessions in order to ensure adequate recovery for the following testing sessions. As well, the opportunity to ask any questions was made available during each session.

Unfortunately, there can be no guarantee that all participants adhered to the nutrition and exercise guidelines given to them, which may have impacted the outcomes of each testing session.

RPE also presents a limitation to this study. While care was taken to record RPE for each testing session, the decision was made not to include RPE in the analysis due to a large degree of variability within participants RPE. Theoretically, RPE during maximal intensity exercise should correspond to 10 on the Borg-10 scale (Hampson, et al. 2001), however this was not observed in the present study. Many participants reported that their RPE for the session was lower than that of maximal effort, despite data which supported maximum or near maximum values for heart rate and $\dot{V}O_{2peak,}$ and directly contradicted their self-assessment of perceived effort.

Future research should aim to recruit more experienced cyclists or endurance athletes. The effects of a race timer on the 3MT in both trained and novice cyclists warrants further exploration, as do the potential for performance differences between those groups. Even so, this study has provided an initial new perspective on the 3MT by examining the effects of a timer on anticipation, sensory input, and decision making during a maximum effort test.

References

Abbiss, C. R., Peiffer, J. J., & Laursen, P. B. (2009). Optimal cadence selection during cycling. International SportMed Journal, 10(1), 1-15. Retrieved February 9, 2018.

Ansley, L., Robson, P. J., Gibson, A. S., & Noakes, T. D. (2004). Anticipatory Pacing Strategies during Supramaximal Exercise Lasting Longer than 30 s. Medicine & Science in Sports & Exercise, 36(2), 309-314. doi:10.1249/01.mss.0000113474.31529.c6

Baden, D. A. (2005). Effect of anticipation during unknown or unexpected exercise duration on rating of perceived exertion, affect, and physiological function * Commentary. *British Journal of Sports Medicine,39*(10), 742-746. doi:10.1136/bjsm.2004.016980

Bergstrom, H. C., Housh, T. J., Zuniga, J. M., Camic, C. L., Traylor, D. A., Schmidt, R. J., & Johnson, G. O. (2012). A New Single Work Bout Test to Estimate Critical Power and Anaerobic Work Capacity. Journal of Strength and Conditioning Research,26(3), 656-663. doi:10.1519/jsc.0b013e31822b7304

Beaver, W. L., Wasserman, K., & Whipp, B. J. (1986). A new method for detecting anaerobic threshold by gas exchange. *Journal of Applied Physiology,60*(6), 2020-2027. doi:10.1152/jappl.1986.60.6.2020

Boya, M., Foulsham, T., Hettinga, F., Parry, D., Williams, E., Jones, H., . . . Micklewright, D. (2017). Information Acquisition Differences between Experienced and Novice Time Trial Cyclists. *Medicine & Science in Sports & Exercise,49*(9), 1884-1898. doi:10.1249/mss.0000000000001304

Burnley, M., Doust, J. H., & Vanhatalo, A. (2006). A 3-min All-Out Test to Determine Peak Oxygen Uptake and the Maximal Steady State. Medicine & Science in Sports & Exercise,38(11), 1995-2003. doi:10.1249/01.mss.0000232024.06114.a6

Black, M. I., Jones, A. M., Kelly, J. A., Bailey, S. J., & Vanhatalo, A. (2016). The constant work rate critical power protocol overestimates ramp incremental exercise performance. European Journal of Applied Physiology,116(11-12), 2415-2422. doi:10.1007/s00421-016-3491-y

Cheng, C., Hsu, W., Kuo, Y., Shih, M., & Lee, C. (2016). Caffeine ingestion improves power output decrement during 3-min all-out exercise. *European Journal of Applied Physiology,116*(9), 1693-1702. doi:10.1007/s00421-016-3423-x

Cheng, C., Yang, Y., Lin, H., Lee, C., & Wang, C. (2011). Determination of critical power in trained rowers using a three-minute all-out rowing test. European Journal of Applied Physiology, 112(4), 1251-1260. doi:10.1007/s00421-011-2081-2

Dicks, N. D., Jamnick, N. A., Murray, S. R., & Pettitt, R. W. (2016). Load Determination for the 3-Minute All-Out Exercise Test for Cycle Ergometry. International Journal of Sports Physiology and Performance, 11(2), 197-203. doi:10.1123/ijspp.2015-0116

Faria, E. W., Parker, D. L., & Faria, I. E. (2005). The Science of Cycling. Sports Medicine, 35(4), 285-312. doi:10.2165/00007256-200535040-00002

Hampson, D. B., Gibson, A. S., Lambert, M. I., & Noakes, T. D. (2001). The Influence of Sensory Cues on the Perception of Exertion During Exercise and Central Regulation of Exercise Performance. Sports Medicine, 31(13), 935-952. doi:10.2165/00007256-200131130-00004

Hopker, J. G., Coleman, D. A., Gregson, H. C., Jobson, S. A., Haar, T. V., Wiles, J., & Passfield, L. (2013). The influence of training status, age, and muscle fiber type on cycling efficiency and endurance performance. Journal of Applied Physiology, 115(5), 723-729. doi:10.1152/japplphysiol.00361.2013

Jones, A. M., & Vanhatalo, A. (2017). The ‘Critical Power’ Concept: Applications to Sports Performance with a Focus on Intermittent High-Intensity Exercise. Sports Medicine, 47(S1), 65-78. doi:10.1007/s40279-017-0688-0

Jones, A. M., Wilkerson, D. P., Dimenna, F., Fulford, J., & Poole, D. C. (2008). Muscle metabolic responses to exercise above and below the “critical power” assessed using 31P-MRS. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 294(2). doi:10.1152/ajpregu.00731.2007

Karsten, B., Jobson, S. A., Hopker, J., Stevens, L., & Beedie, C. (2014). Validity and reliability of critical power field testing. European Journal of Applied Physiology, 115(1), 197-204. doi:10.1007/s00421-014-3001-z

Lucas, R. D., Souza, K. D., Costa, V., Grossl, T., & Guglielmo, L. (2013). Time to exhaustion at and above critical power in trained cyclists: The relationship between heavy and severe intensity domains. Science & Sports,28(1). doi:10.1016/j.scispo.2012.04.004

Lucas, R. D. (2018). Discussion of "Can measures of critical power precisely estimate the maximal metabolic steady-state?" – Is it still necessary to compare critical power to maximal lactate steady state? *Applied Physiology, Nutrition, and Metabolism,43*(1), 94-95. doi:10.1139/apnm-2017-0501

Maturana, F. M., Keir, D. A., McLay, K. M., & Murias, J. M. (2016). Can measures of critical power precisely estimates the maximal metabolic steady-state? Applied Physiology Nutrition and Metabolism. doi:10.1139/apnm-2016-0248

Moritani T, Nagata A, deVries HA, Muro M (1981) Critical power as a measure of physical work capacity and anaerobic threshold. Ergonomics 24:339–350

Nikolopoulos, V., Arkinstall, M. J., & Hawley, J. A. (2001). Pacing strategy in simulated cycle time-trials is based on perceived rather than actual distance. *Journal of Science and Medicine in Sport,4*(2), 212-219. doi:https://doi.org/10.1016/S1440-2440(01)80031-1

Pageaux, B. (2014). The Psychobiological Model of Endurance Performance: An Effort-Based Decision-Making Theory to Explain Self-Paced Endurance Performance. Sports Medicine,44(9), 1319-1320. doi:10.1007/s40279-014-0198-2

Parry, D., Chinnasamy, C., & Micklewright, D. (2012). Optic Flow Influences Perceived Exertion during Cycling. *Journal of Sport and Exercise Psychology, 34*(4), 444-456. doi:10.1123/jsep.34.4.444

Poole, D. C., Burnley, M., Vanhatalo, A., Rossiter, H. B., & Jones, A. M. (2016). Critical Power. Medicine & Science in Sports & Exercise, 48(11), 2320-2334. doi:10.1249/mss.0000000000000939

Salam, H., Marcora, S. M., & Hopker, J. G. (2017). The effect of mental fatigue on critical power during cycling exercise. European Journal of Applied Physiology. doi:10.1007/s00421-017-3747-1

Smits, B. L., Pepping, G., & Hettinga, F. J. (2014). Pacing and Decision Making in Sport and Exercise: The Roles of Perception and Action in the Regulation of Exercise intensity. *Sports Medicine,44*(6), 763-775. doi:10.1007/s40279-014-0163-0

Smits, B. L., Polman, R. C., Otten, B., Pepping, G., & Hettinga, F. J. (2016). Cycling in the Absence of Task-Related Feedback: Effects on Pacing and Performance. *Frontiers in Physiology,7*. doi:10.3389/fphys.2016.00348

Tucker, R. (2009). The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. British Journal of Sports Medicine, 43(6), 392-400. doi:10.1136/bjsm.2008.050799

Ulmer, H. V., Schneider, A., Neumahr, S., & Frietag, W. (1996). PRECISION OF TIME AND VELOCITY ESTIMATION AS A BASE OF TELEOANTICIPATION. *European Journal of Physiology, 431*. Retrieved March 15, 2019.

Vanhatalo, A., Doust, J., & Burnley, M. (2006). Determination of critical power using a 3-min all-out cycling test.

Vanhatalo, A., Doust, J. H., & Burnley, M. (2007). Robustness of a 3-min all-out cycling test to manipulations of power profile and cadence in humans. Experimental Physiology,93(3), 383-390. doi:10.1113/expphysiol.2007.039883

Vanhatalo, A., Black, M. I., Dimenna, F. J., Blackwell, J. R., Schmidt, J. F., Thompson, C., . . . Jones, A. M. (2016). The mechanistic bases of the power-time relationship: muscle metabolic responses and relationships to muscle fiber type. The Journal of Physiology, 594(15), 4407-4423. doi:10.1113/jp271879

Wittekind, A. L., Micklewright, D., & Beneke, R. (2009). Teleoanticipation in all-out short-duration cycling. *British Journal of Sports Medicine, 45*(2), 114-119. doi:10.1136/bjsm.2009.061580

Appendices

Appendix A. 1. Participant Screening

Participant Screening

Thank you for your interest in our Critical Power research study. If you have a few minutes I would like to ask you a couple questions to ensure that you are eligible to participate. All questions and answers will remain confidential and will be destroyed immediately if you don't advance in the study. If you do continue in the study, a code number will be used to protect your identity and put on the sheet to record your responses. Data from the study will be stored in a locked file cabinet in the Human Performance Laboratory for 5 years.

Before we begin, do you have any questions for me?

Are you a male above the age of 18? ……………………………………...Y N

Do you currently participate in aerobic, anaerobic, or resistance
training exercise 2 or more days/ week? …………………………………Y N

Are you experienced and comfortable with pushing your physical
and psychological limits during exercise?..Y N

Have you maintained these exercise habits regularly
over the last 6 months?...Y N

Are you free of cardiovascular, metabolic, respiratory,
and orthopedic conditions?..Y N
If yes, what condition:____________________

Are you currently using cholesterol/blood pressure lowering ……………Y N
medication?

Are you willing to come into the lab on four separate
occasions over the course of two weeks?..Y N

The total time commitment to come into the lab is about 3 hours. Are you able to commit to this amount of time? …………………Y N

Do you wish to continue with this study?..Y N

The next session will include filling out questionnaires about your physical activity & health status. We will also record your height, weight and body composition. Then a VO2peak test will occur. This should take about an hour to 1.5 hours of your time.

Appendix A. 2 Participant Instructions

Participant Instructions – Critical Power Study

-Please Follow these Guidelines Prior to Each Session

- Report to the lab dressed for exercise (Shorts & T-Shirt)
- Eat a snack or small meal 2 hours prior to each session
- Drink ½-1 oz of water for each pound you weigh for 24 hours prior to the session
- Eat a well balanced diet including protein, fats, and carbohydrates from a variety of whole-food sources & maintain similar eating habits 24 hours prior to each session
- Obtain 7-9 hours of sleep prior to, and after each session

-Please Avoid the Following Prior to Each Session

- Strenuous/heavy exercise 36-48 hours prior to the testing session
- Use of alcohol 24 hours prior to the testing session
- Use of caffeine at least 3 hours prior to the testing session
- Consuming a large meal at least 2 hours prior to the testing session
-

Session 1 – Informative Session/ VO2Peak Test

In this session we will inform you about the specific requirements of the study and answer any questions you may have. We will conduct a skinfold test to measure body composition (body fat), and fit you to the bike. Following bike fitting we will conduct an incremental ramp test in order to determine VO2peak.

Session 2 - Critical Power Familiarization

In this session, we will conduct a Critical Power Familiarization test in order for each participant to get a better understanding of how the test is conducted and to practice for the next two sessions. Data from this test will not be analyzed. Participants will have the opportunity to ask any questions and make any necessary adjustments

Sessions 3 & 4 - Critical Power Tests

In sessions 3 & 4, each participant will conduct one critical power testing session. Data from these sessions will be analyzed.

Following Each Session:
A carbohydrate snack will be provided to aid in recovery following each Critical Power Test. Please do your best to continue hydrating & consume a quality meal containing protein, fat, and carbohydrate within 1.5 hours of finishing the test. It is also important to obtain enough sleep following each test in order to ensure adequate recovery. If you have any questions pertaining to recovery or recovery nutrition, please direct them to Paul Mandell (pkm80@humboldt.edu)