UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

REGULATION OF PACING STRATEGY DURING ATHLETIC COMPETITION:

EVALUATION OF THE HAZARD SCORE HYPOTHESIS

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Clinical Exercise Physiology

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REGULATION OF PACING STRATEGY DURING ATHLETIC COMPETITION:

EVALUATION OF THE HAZARD SCORE HYPOTHESIS

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We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology

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ABSTRACT

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Regulation of energy expenditure is critical during endurance competition. The Hazard Score is a term that has been proposed to describe the likelihood that an athlete will decrease their velocity during the course of an endurance event, such as cycling or running. The Hazard Score is defined as the product of momentary Rating of Perceived Exertion (RPE) and the fractional distance remaining in the exercise bout. A higher Hazard Score is associated with a higher likelihood that an athlete will decrease velocity, while a low Hazard Score is associated with a higher likelihood that the athlete will increase velocity. Purpose: To determine the effect of a non-uniform pacing strategy utilizing two random 1-km bursts on Hazard Score and power output (PO) trends during 20-km cycling time trials. Methods: 10 subjects (8 males, 2 females) completed a maximal incremental exercise test, as well as one habituation, one steady state (SS) 20-km trial and two of four possible variations in non-uniform (BURST) pacing templates in order to compare the evolution of Hazard Score within trials. Each trial was separated by at least 48 hours. PO, heart rate (HR), and blood lactate were measured for each trial, as well as maximal oxygen consumption (VO_{2max}) during the incremental test. RPE was recorded at the end of each kilometer using the Category Ratio scale of RPE. Regression analysis was used to examine the relationship between Hazard Score and subsequent change in PO. Results: A moderate correlation (r= 0.36) was found between Hazard Score and change in PO across all trials. No significant difference was found between Hazard Score evolution during STEADY STATE and BURST trials. Conclusion: This study showed that Hazard Score is a moderately effective predictor of PO changes during a 20-km cycling event when utilizing a non-uniform pacing template.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

APPENDIX PAGE

INTRODUCTION

Regulating energy expenditure is of critical importance in all types of endurance competition, in which energy reserves are depleted or metabolites accumulated, which can lead to profound physiological challenges and homeostatic disturbances. In order to avoid these occurrences, athletes adopt different pacing strategies to optimally distribute energy reserves optimally (Foster et al., 2012). Development of pacing strategy is dependent upon duration, intensity, medium and mode of exercise, among other external factors. The goal of pacing has been described as achieving a desired outcome without fatigue interfering with the completion of the task or with the person's basic health (Foster et al., 2005). Several theories have been proposed as to how humans regulate pacing strategy, such as the peripheral fatigue model (MacLaren, Gibson, Parry-Billings & Edwards, 1989) and the central governor theory (Noakes, St Clair Gibson & Lambert, 2005).

The peripheral fatigue model suggests that decreases in pace and power output (PO) during exercise are due to metabolic factors in a muscle, such as the accumulation of hydrogen ions and inorganic phosphates or the depletion of adenosine triphosphate (ATP), intramuscular oxygen, phosphocreatine (PCr), and muscle glycogen, that impair muscle function (MacLaren, Gibson, Parry-Billings & Edwards, 1989). However, the central governor theory suggests that these changes in pace are due to a subconscious downregulation of muscle unit recruitment by the central nervous system (CNS), in an effort to maintain homeostasis (Noakes, St Clair Gibson & Lambert, 2005; Amman, 2011). While each of these models provide valuable insight regarding the mechanisms of fatigue, they seem to be incomplete (Weir, Beck, Cramer & Housh, 2006). In 1996, H.

V. Ulmer (1996) proposed a model of pacing called the anticipatory feedback model that takes into account afferent feedback from peripheral sensors, combined with knowledge of the endpoint of an activity and with prior experience from earlier exercise bouts to create a pre-exercise pacing template. This template is continuously monitored by the subconscious brain throughout the exercise session, which compares the expected Rating of Perceived Exertion (RPE) to the experienced RPE (Lambert, St Clair Gibson & Noakes, 2005; Joseph et al., 2008; Tucker, 2009). This comparison is then used to adjust the pacing template in an effort to distribute energy more optimally throughout the event.

The subconscious algorithm that is essential to creating a pacing template according to the anticipatory feedback model was described by de Koning et al. (2011) as an index that defines the likelihood that athletes will change their velocity. This index is referred to as the Hazard Score, and is the product of momentary RPE and fraction of the distance remaining in an event (de Koning et al., 2011), and describes how an athlete subconsciously regulates PO in an anticipatory manner. Traditional pacing strategies used in cycling include an "all-out" or positive strategy, an evenly paced strategy, a "U-shaped" or parabolic pacing strategy, a variable strategy and a negative strategy (Abbiss & Laursen, 2008). However, a non-uniform pacing strategy differs in that it requires changing PO at varying points throughout the event, often for tactical reasons. Non-uniform pacing strategies (e.g. break away efforts) are relatively common, but little research has been done on the effects of non-uniform pacing on PO or Hazard Score (Cohen et al., 2013).

Previous research seems to suggest that a relatively even pacing strategy is optimal for competitive distances longer than 2-km, although most athletes tend to display a somewhat parabolic pattern of PO (Foster et al., 1993; Foster et al. 2004). However, Cohen et al. (2013) evaluated differences in RPE and PO trends between self-paced 10-km cycling time trials and 10-km trials using a non-uniform pacing template. Following breakaway efforts, RPE rose above the trend seen in the control trial before returning to the normal trend. However, PO dropped below the normal trend and never fully recovered throughout the remainder of the ride. These results suggest that RPE and PO appear to change in a reciprocal manner throughout a 10-km cycling time trial, and that PO seems to be regulated by more than RPE alone.

The purpose of this study is to examine the effects of a non-uniform pacing template on Hazard Score and PO in a longer trial of 20-km, and with the implementation of two breakaway efforts. We hypothesized that the imposition of a non-uniform pacing strategy would not significantly affect the normal growth curve for the Hazard Score. Similarly, we hypothesized that Hazard Score would rise above the normal growth curve following the bursts, resulting in a reciprocal change in PO below the normal evolution of PO seen in the steady state trial.

METHODS

Subjects

Ten trained cyclists recruited from local and university triathlon and cycling clubs (8 men, 2 women) were included in this study. All were training systematically and were competitive at a local level. The study was completed during the winter, while subjects were in the off-season and performing relatively light training. Before the study, approval was obtained by the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects. All participants provided written informed consent prior to participating in the study. Subjects filled out the PAR-Q health history form in order to screen for contraindications to participation in the study. All 10 subjects successfully completed the testing protocol and are represented in the data analysis. Subject age, height, body mass, maximal oxygen uptake (VO_2max), peak PO (PPO) and body mass normalized PPO are presented in Table 1.

Table 1. Descriptive Characteristics of Subjects (n=10).

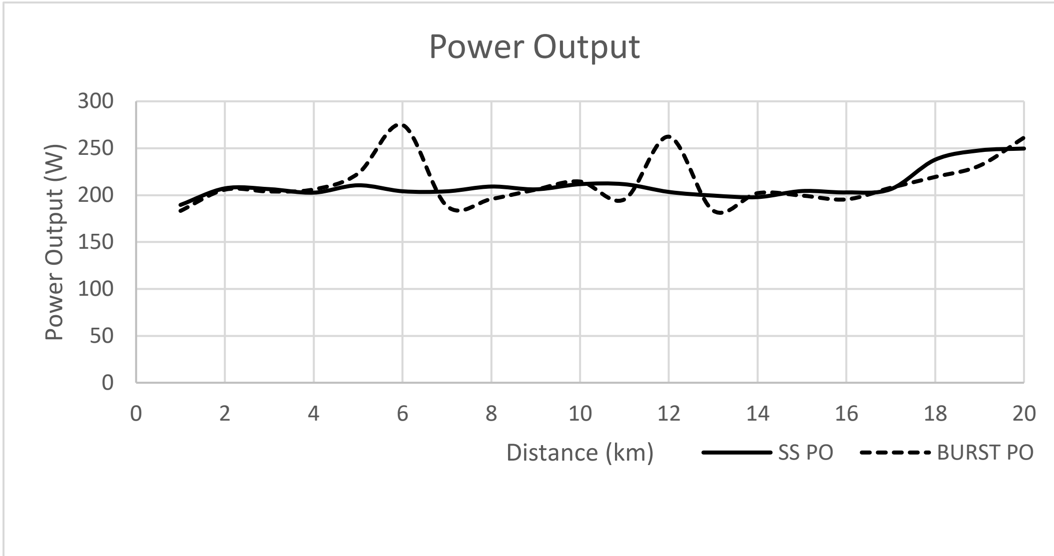
	Males (n=8)	Females (n=2)
Age (y)	33.5 ± 11.22	29.0 ± 8.49
Height (cm)	178.0 ± 4.43	162.6 ± 3.61
Body mass (kg)	78.9 ± 4.10	60.3 ± 3.82
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.7 ± 8.38	47.1 ± 14.00
Peak power output (W)	309 ± 46	250 ± 35
Peak power output ($W \cdot kg^{-1}$)	3.9 ± 0.5	4.2 ± 0.9

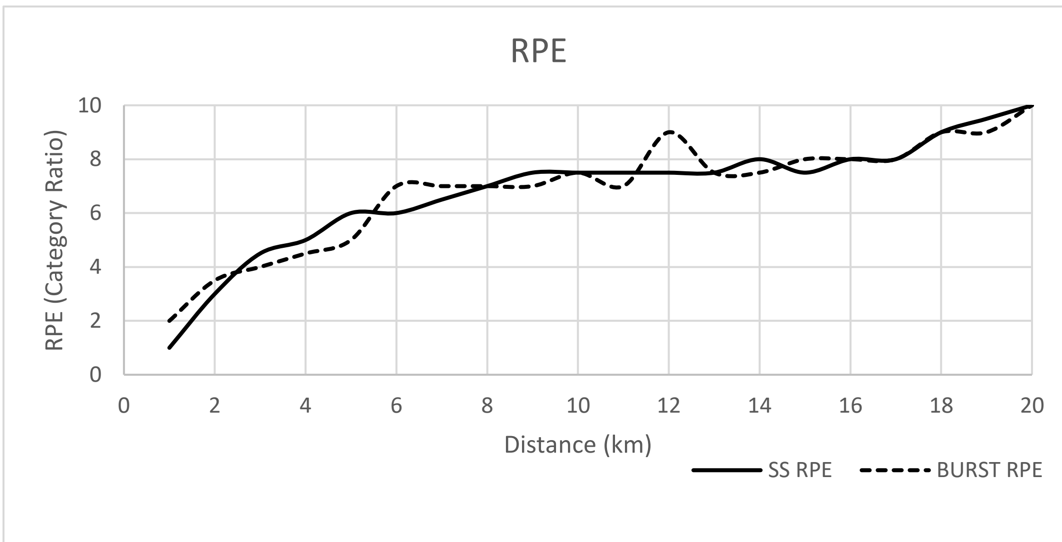
Values represent Mean ± S.D.

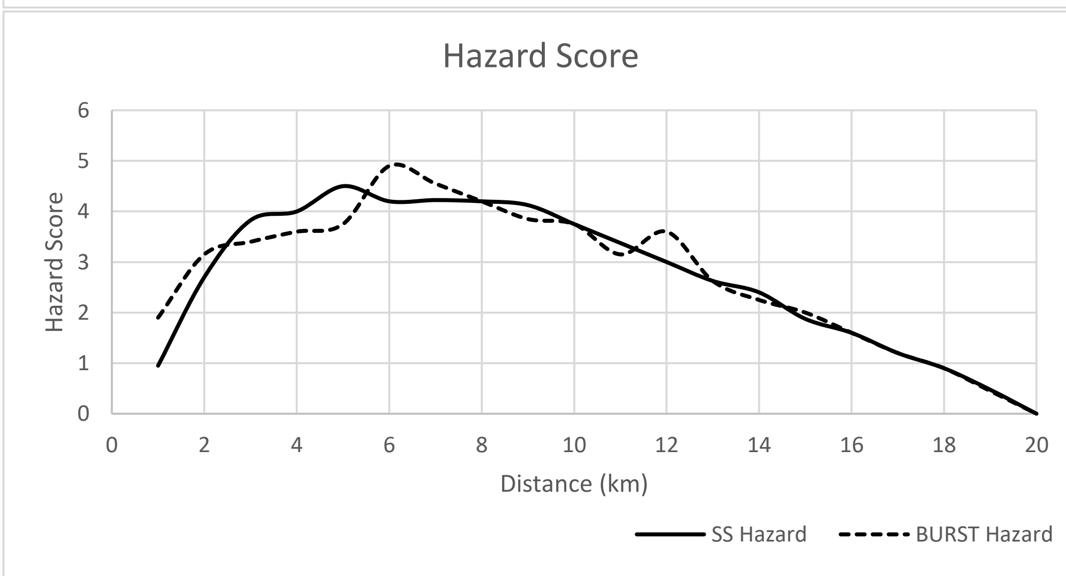
Experimental Design

Subjects performed a maximal incremental test (2 min at 100 W + 25 W every 2 min) on an electronically-braked cycle ergometer (Velotron, Racermate Inc., Seattle, WA). Subjects were asked during the last 10 seconds of each stage to provide RPE using the CR-10 scale (Borg, 1982). The test was concluded when the subjects indicated that they could no longer continue cycling. Respiratory gas exchange was measured using open-circuit spirometry with a metabolic cart (MOXUS, AEI Technologies, Pittsburgh, Pennsylvania). Heart rate (HR) was measured using radiotelemetry (Polar, Bethpage, NY), and PO was recorded throughout the test from the cycle ergometer. VO_2 was integrated over 30 second intervals.

Each subject subsequently performed a total of four 20-km time trials on the same cycle ergometer as the incremental test (Velotron, Racermate Inc., Seattle, WA). Subjects were asked to refrain from heavy exercise for 48 hours prior to each trial, and there were 48-96 hours between trials. Each trial was preceded by a standard 14-minute incremental warm-up based on PO during the maximal test. Participants started at 100 W for five minutes, increased to 50% (PPO) for five minutes, followed by 75% PPO for two minutes and a decrease to 100 W for the final two minutes. The first two trials were self-paced steady state (SS) trials, in which the subjects completed the 20-km distance in as little time as possible using their own pacing template. The first trial served as a familiarization trial. Trials 3 and 4 were randomized trials utilizing a non-uniform (BURST) pacing strategy. Before each BURST trial, the participants were informed that they may be asked to accelerate at some point during the test in order to simulate breaking away from the peloton in a cycling race. If asked to accelerate, the subjects had to increase PO to the maximum degree possible for 1-km. Upon completion of the burst, the subjects were asked to resume their own pacing strategy with the intent of finishing the remainder of the event in as little time as possible. Subjects had access to visual feedback regarding momentary velocity and PO from the ergometer console, as well as distance completed, just as they would in competition. Subjects were blinded to their HR data. The accelerations during the BURST trials were distributed in four variations: A) bursts at 5 km and 7 km, B) bursts at 11 km and 13 km, C) bursts at 5 km and 11 km, and D) bursts at 7 km and 13 km. This was done to mimic the range of breakaway efforts experienced during normal competition. Prior to BURST trials, subjects were asked to draw a card showing one of four letters, which coded for which combination of bursts were to be performed. Subjects were blinded to when the bursts would occur. Subjects were given feedback at 5-km, 10-km and 15-km, as well as prior to the completion of the trial, about how they were performing relative to their previous trials. Minimal verbal encouragement was given to control for the effect of extrinsic motivation on performance. Examples of SS and BURST data for PO, RPE, Hazard Score, blood lactate and HR from one subject completing a BURST trial (variation C) are displayed in Figure 1.


Power Output
Power Output (W)
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
Distance (km)
SS PO
BURST PO


RPE
RPE (Category Ratio)
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
Distance (km)
SS RPE
BURST RPE


Hazard Score
Hazard Score
6
5
4
3
2
1
0
0
2
4
6
8
10
12
14
16
18
20
Distance (km)
SS Hazard
BURST Hazard

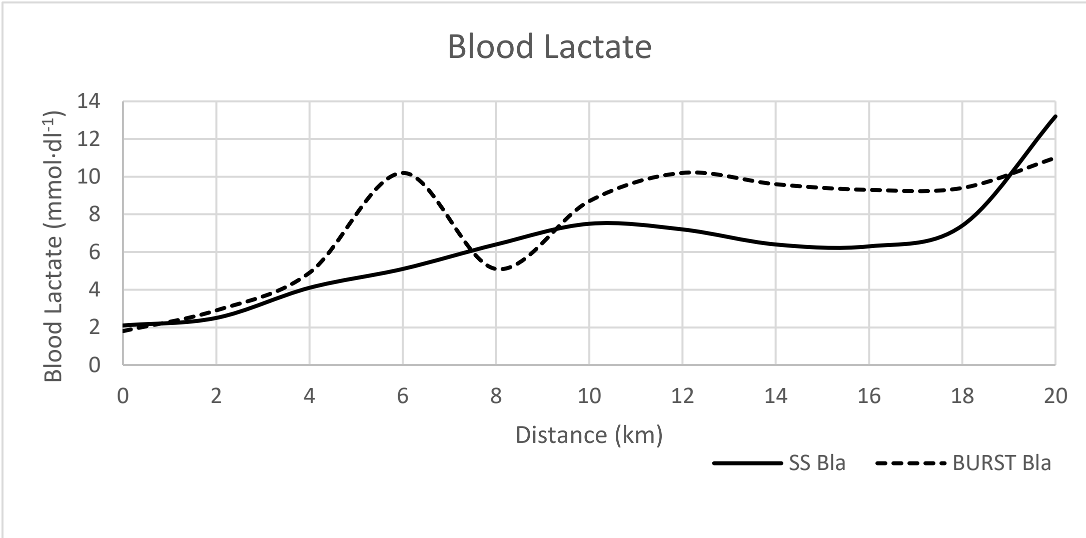


Figure 1. Changes in PO (A), RPE (B), Hazard Score (C), blood lactate (D) and HR (E) over 20-km for one representative subject performing bursts at 5-km and 11-km compared to steady state values.

PO was measured by a mechanically coupled power meter (SRM, Colorado Springs, CO) and integrated over each 1 km, and for 1 km following each acceleration, while management of race distance was managed by the electronically braked racing cycle (Velotron, Racermate Inc., Seattle, WA). RPE was recorded every 1 km using the

Category Ratio RPE scale. Blood lactate was measured in fingertip capillary blood using dry chemistry at the beginning of each trial, as well as every 2 km during the trial (Lactate Plus, Nova Biomedical, Waltham, MA). RPE and fractional distance remaining at each measurement were used to plot Hazard Score.

Statistical Analysis

Standard descriptive statistics were used to describe the subject population. To compare differences in Hazard Score development between SS and BURST trials, a paired t-test was used to determine if there were significant differences between correlation coefficients using the Statistical Package for Social Sciences (SPSS) 25.0 software (SPSS Inc., Chicago, IL, USA). The Hazard Score values were plotted against the subsequent changes in PO over 1-km using Microsoft Excel (2016; Microsoft Windows, Redmond, WA). Regression analysis was completed with a best fit correlation to examine the relationship between Hazard Score and PO. The average of individual coefficients across all subjects was obtained using linear regression of mean values for correlation coefficient across all trials. Alpha was set at .05 to achieve statistical significance.

RESULTS

Figure 2 shows mean data for all subjects regarding the relationship between Hazard Score and changes in PO integrated over the subsequent kilometer. A moderate correlation was found (r=0.36) between an increase in Hazard Score and a decrease in PO. This relationship is also described in Figure 3, which plots Hazard Score and PO data across all SS and BURST trials. A moderate correlation was also found (r=0.27) between Hazard Score and change in PO during the subsequent 1-km using this method. The time to finish was not significantly different between SS (2109.8 $\pm$ 215.66 s) and BURST (2105.6 $\pm$ 202.59 s).

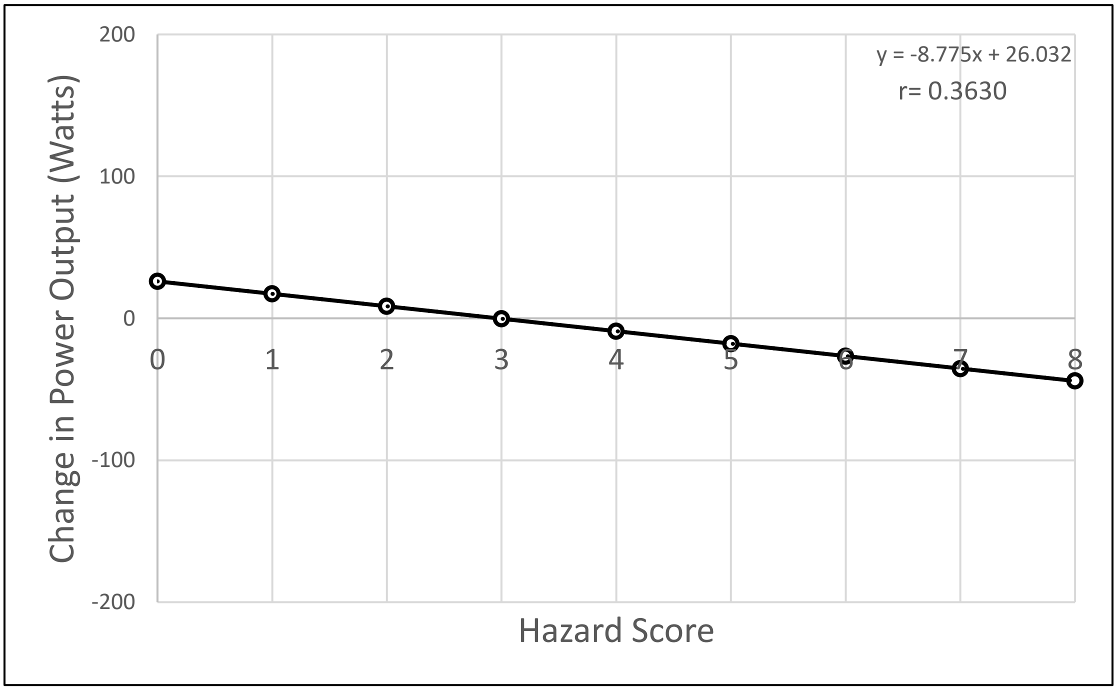


Figure 2. Mean correlation across all trials (e.g. the average slope and intercept for each subject) for change in PO as a function of Hazard Score.

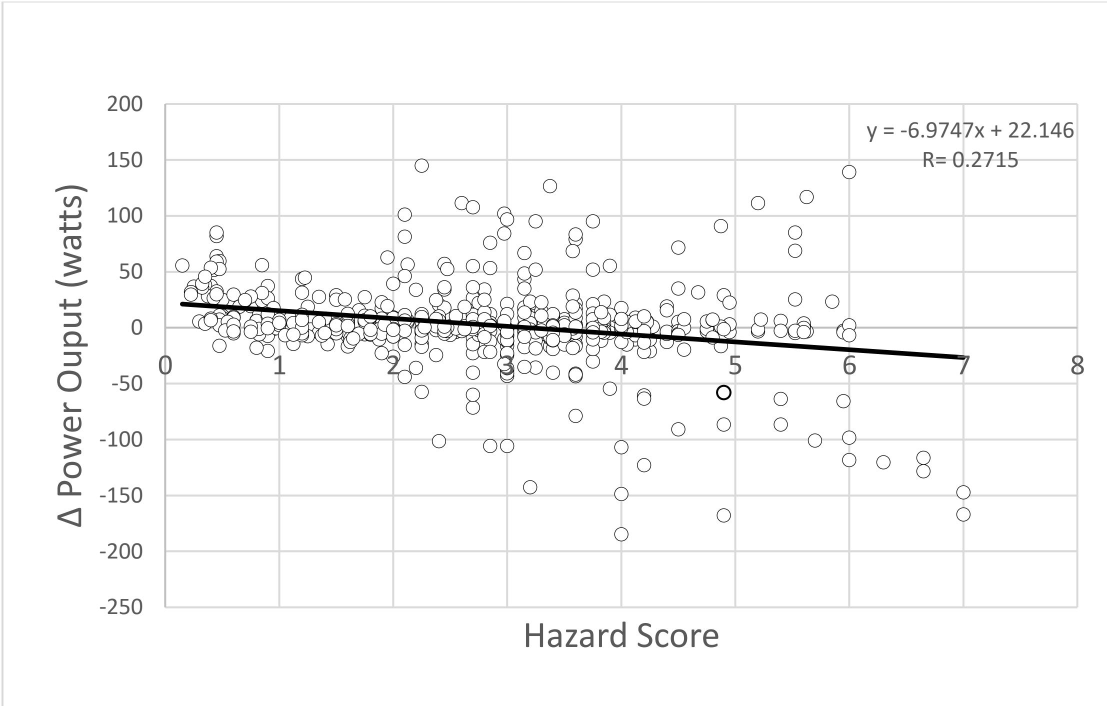
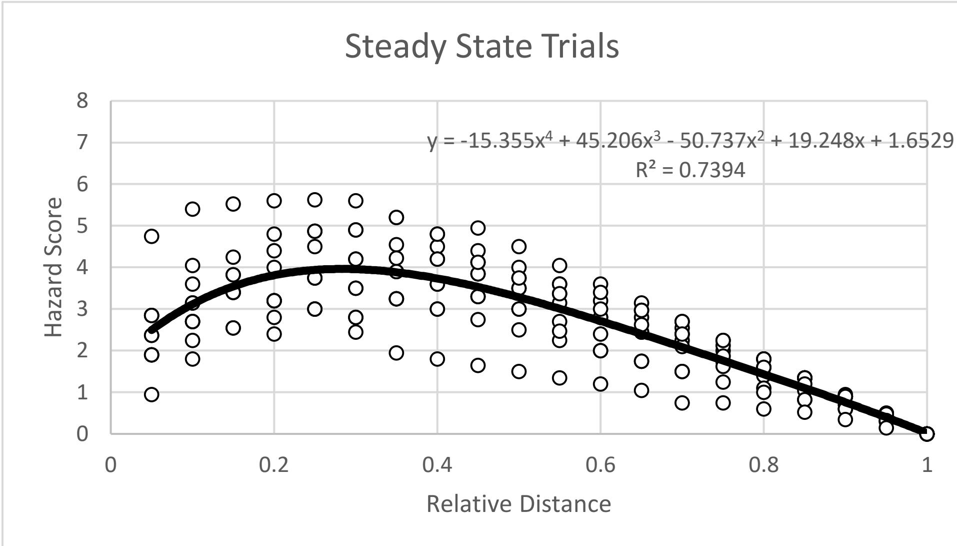


Figure 3. Data across all trials regarding changes in PO for as a function of Hazard Score.

Hazard Score patterns for SS and BURST trials with all subjects analyzed together are shown in Figure 4. While BURST trials led to higher individual values for Hazard Score (max=7) compared to SS (max=5.625), no significant difference was found between R^2 values (SS= .74, BURST= .74) for each condition.



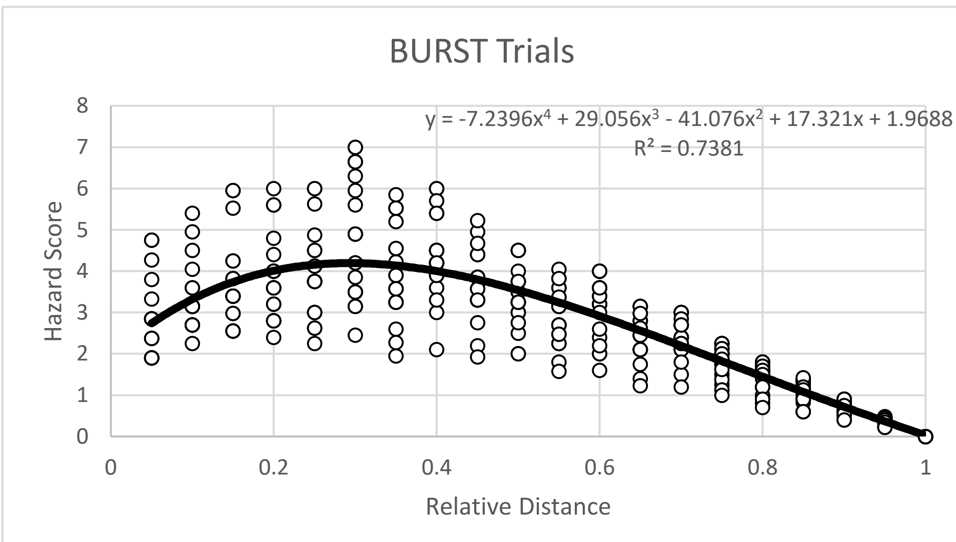


Figure 4. Changes in Hazard Score over relative distance for STEADY STATE (A) and BURST (B) trials. The BURST trials are combined.

DISCUSSION

The purpose of this study was to determine the effect of a non-uniform pacing strategy utilizing two random bursts on Hazard Score trends during 20-km cycling time trials. Subjects completed two of four possible variations in BURST templates, as well as a SS trial, to compare the evolution of Hazard Score between trials. The effect of Hazard Score on changes in PO was assessed to evaluate the hypothesis that a higher Hazard Score would result in a decrease in PO, while a lower Hazard Score would lead to increases in PO during BURST and SS trials.

The primary finding of this study was that changes in PO seem to be inversely correlated with Hazard Score during a cycling time trial, even in the presence of two mid-trial accelerations of 1-km. These results are consistent with the experimental hypothesis, as well as with findings from de Koning et al. (2011) which demonstrated that cyclists tend to change pace during trials based on momentary RPE and relative distance remaining in the event. This suggests that the calculation of a Hazard Score may be an effective predictor of subsequent changes in PO during competition, particularly during the 1-km following the value.

A secondary finding of this study was that trends in Hazard Score during BURST trials tended to increase above the path seen in SS during each burst, before normalizing toward the SS pattern later on in the trial. This is consistent with data from Cohen et al. (2013), which showed that RPE tends to normalize following 1-km bursts in a 10-km cycling time trial. These data suggest that there is an expected template of the evolution of Hazard Score that is defended by changes in PO, and that this template can be disrupted by bursts, but quickly normalizes afterwards.

Trends in PO during SS trials seemed to deviate from the "parabolic" pattern commonly seen in well-trained cyclists during self-paced events (Foster et al., 1993; Foster et al. 2004). In the current study, subjects tended to maintain a relatively even PO throughout the SS with a slight increase in PO in the last 1-km of the ride. Most literature suggests that competitive cyclists generate a relatively higher output at the beginning of events to overcome frictional forces and accelerate VO_2 kinetics (Hajoglou et al., 2005; Hulleman et al., 2007), as well as at the end with what is referred to as the end spurt. This deviation from the traditional pacing template suggests that the subjects in the current study may not have fully developed an optimal 20-km pacing template. This disparity could potentially have been resolved with the addition of another habituation trial. Foster et al. (2009) showed that the development of an ideal pacing template appears to be progressive with the number of previous similar exercise bouts. Swart et al. (2009) confirmed this idea, showing that in successive trials of the same distance cyclists demonstrated more aggressive pacing strategies, which typically displayed a higher PO early in the event. However, this learning effect seems to be less critical in well-trained cyclists (Foster et al., 2002; Foster et al., 2009). While subjects in the current study were all competitive at the local level, they were more familiar with a SS exercise pattern from participating in triathlons.

Another potential limiting factor for this study is the variety of BURST templates that were used. While these were useful in that they accounted for the tendency of competitors to break away from the peloton at relatively spontaneous points throughout an event, it creates problems when comparing BURST trials, as Hazard Score will naturally increase to a higher degree when bursts are placed at the beginning of the event as opposed to the end of the event, when the percent distance remaining is relatively low. We attempted to account for this by excluding any bursts within the first 4-km and the final 6-km of the trials. However, trials with earlier bursts (5-km, 7-km) led to a higher degree of variation in Hazard Score compared to SS.

Following each burst, Hazard Score necessarily increased along with RPE among subjects. This would suggest that PO over the following 1-km would be decreased, which was confirmed in all BURST trials. In a real competitive event, these decreases in PO may negate any potential advantage that would be gained by breaking away, as the peloton has the advantage of riding any absolute velocity at a lower PO due to decreases in drag effect up to 57% (Barry et al., 2015).

CONCLUSION

The current data suggests that Hazard Score is an effective predictor of PO over the subsequent 1-km during competitive 20-km cycling trials, even when utilizing a non-uniform pacing template. Higher Hazard Scores correlate with decreases in PO, while relatively low values seem to correlate with increases in PO. When breaking away from the peloton, Hazard Score increases along with RPE, which suggests that there will likely be a decrease in PO following such efforts that may negate the potential benefits from such a maneuver. These findings support the Hazard Score hypothesis proposed by de Koning et al. (2011) and supported by Cohen et al. (2013).

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APPENDIX A

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ____

SIGNATURE OF PARENT ____ WITNESS ____
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

APPENDIX B

INFORMED CONSENT

INFORMED CONSENT FOR "Regulation of Pacing Strategy During Athletic Competition: Evaluation of the Hazard Score Hypothesis"

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1. I, **__________________________**, give my informed consent to participate in this study designed to evaluate the effect of performing segments of relatively high power output intermittently throughout a 20-km cycling time trial on the likelihood that the athlete will accelerate throughout the event. I have been informed that the study is under the overall direction of Carl Foster, Ph.D. who is a Professor in the Department of Exercise and Sport Science at the University of Wisconsin-La Crosse. I consent to the presentation, publication and other release of summary data from the study which is not individually identifiable.

2. I have been informed that my participation in this study will require me to:

    a. Perform, on several occasions, a maximal incremental test or 20-km time trials, in which the pacing strategy will be experimentally manipulated by the investigators.

    b. Wear a snorkel-type breathing valve during maximal test.

    c. Wear a chest strap that transmits my heart rate via radio waves to a specialized wristwatch.

    d. Have several small blood samples taken from my fingertip.

3. I have been informed that there are no foreseeable risks associated with this study other than the fatigue associated with heavy exercise and the discomfort associated with providing the fingertip blood samples.

4. I have been informed that there are no primary benefits to myself other than gaining experience using several different pacing strategies that could influence cycling performance.

5. I have been informed that the investigator will answer questions regarding the procedures throughout the course of the study.

6. I have been informed that I am free to decline to participate or to withdraw from the study at any time without penalty.

7. Concerns about any aspects of this study may be referred to Patrick Reinschmidt at 507 421 3353. Questions about the protection of human subjects may be addressed to the Chair of the UW-L Institutional Review Board 608 785 6892.

____________________________ __________________

Signature of Participant Date

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Printed Name of Participant

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Signature of Witness Date

APPENDIX C

REVIEW OF RELATED LITERATURE

The purpose of this literature review is to discuss the use of a non-uniform pacing strategy on power output (PO) during 20-km closed-loop cycling and the Hazard Score Hypothesis.

Background of Pacing

Regulating energy expenditure is of critical importance in all species. Humans are unique in that they possess a conscious ability to monitor, describe and manipulate the patterns of our energy expenditure. This ability becomes important when discussing exercise and ambulatory activity, in which energy reserves are depleted at an increased rate. Uncontrolled rapid depletion of energy can lead to catastrophic physiological failures and homeostatic disturbances. In order to avoid these events during exercise, humans adopt different pacing strategies that distribute energy reserves optimally (Foster et al., 2012). These pacing strategies vary based on exercise duration, intensity, medium and mode, and are influenced by several other external factors. The goal of pacing has been described as "achieving a desired outcome without fatigue interfering with the completion of the task or with the person's basic health" (Foster et al., 2005). Several theories have been proposed as to how humans regulate pacing strategy.

The peripheral fatigue model suggests that decreases in pace and PO during exercise are due to "metabolic factors in a muscle", such as the accumulation of hydrogen ions and inorganic phosphates or the depletion of adenosine triphosphate (ATP), phosphocreatine (PCr), muscle glycogen and phosphates, that impair muscle function (MacLaren, Gibson, Parry-Billings & Edwards, 1989). However, the central governor theory suggests that these changes in pace are due to a subconscious downregulation of muscle unit recruitment by the central nervous system (CNS), in an effort to protect the integrity of muscle fibers and to maintain homeostasis (Noakes, St Clair Gibson & Lambert, 2005). While each of these models of fatigue provide valuable insight regarding the mechanisms of fatigue, they seem to be incomplete (Weir, Beck, Cramer & Housh, 2006). In 1996, H. V. Ulmer proposed the anticipatory feedback theory of pacing that takes into account afferent feedback from peripheral sensors, and combines it with knowledge of the endpoint of an activity and prior experience from earlier exercise bouts to create a pre-exercise pacing template (Ulmer, 1996). This template is continuously monitored by the subconscious brain throughout the exercise session, and compares the expected rate of perceived exertion (RPE) to the actual experienced RPE (Lambert, St Clair Gibson & Noakes, 2005; Tucker, 2009). This comparison is then used to adjust the pacing template in an effort to distribute energy more optimally throughout the event.

Hazard Score

The subconscious algorithm that is essential to creating a pacing template according to the anticipatory feedback model was described in a study by de Koning et al. (2011b) as an index that "defines the likelihood that athletes will change their velocity." This index is referred to as the Hazard Score, and is the product of momentary RPE and fraction of the distance remaining in an event (de Koning et al., 2011b). This index allows an athlete to subconsciously regulate PO in an anticipatory manner. In the study, data was combined from nine different experiments involving cyclists or runners performing competitive time trials in a laboratory. In each trial, RPE was measured using the Category Ratio scale at 10% increments throughout the event. Using the momentary RPE at different points throughout the trials, a Hazard Score curve was able to be formulated. The Hazard Score curve was then compared to PO, and the study found that scores of 1.5 or less were associated with an increase in pace, while scores of 3 or higher produced no changes in velocity. Athletes were much more likely to increase pace at the beginning of the event when RPE was relatively low, or at the end of the event when the fraction of the distance remaining was low. Subjects were less likely to accelerate during the middle of the trial, where Hazard Scores were relatively high.

Hazard Score is dependent on momentary RPE, therefore it is important to note that RPE seems to be a scalar unit of measurement, and appears to vary according to relative distance as opposed to absolute distance (Swart et al., 2009; Faulkner & Eston, 2008). A study done by Joseph et al. (2008) looked at the relationship between relative time trial distance and the growth rate of RPE, as well as the effects of exercising in hypoxic conditions among well-trained cyclists. Subjects completed practice trials, as well as experimental trials of 2.5, 5, and 10 kilometers (km) in normal conditions and a trial of 5 kilometers in hypoxic conditions. Growth of RPE was plotted according to relative distance, showing no significant difference at proportional differences across trials. In the hypoxic trials, decreases in PO were associated with a significantly increasing RPE at proportional differences. This supports the theory that RPE is a scalar quantity. This theory is also supported by St Clair Gibson et al. (2006), which suggested that the brain possesses a sort of scalar internal clock that monitors and predicts duration remaining in an exercise bout.

Hazard score and teleoanticipation are also dependent upon prior experience (Micklewright, Papadopoulou, Swart & Noakes, 2010), meaning that development of an optimal pre-exercise pacing template requires the completion of numerous trials of similar intensity and duration to the event at hand. Studies seem to suggest that the development of an ideal pacing template may take many trials to complete. In a study by Foster et al. (2009), relatively fit individuals completed repeated rowing and cycling time trials of varying distances in an effort to determine how pacing templates develop within individuals and the extent to which these templates affect performance. The greatest number of trials performed by subjects was six cycling trials. Subjects improved performance across trials, but did not display the optimal pacing strategy usually shown in elite rowers and cyclists. This suggests that it takes more than six previous trials to develop an ideal pacing template (Foster et al., 2009). Subjects did improve an average of 10% across trials, suggesting that relatively untrained individuals have a large learning effect. However, it has been suggested that this learning effect decreases over time and is insignificant in well-trained cyclists (Foster et al., 2002). The development of an ideal pacing template appears to require a relatively high number of previous similar exercise bouts among individuals with little specific event experience.

Pacing Strategies In Other Disciplines

The development of a pacing template takes a considerable amount of time, but the determination of this optimal strategy is affected by biomechanics, exercise duration and the medium in which the event is being performed. This means that in different sporting events, optimal pacing strategies are likely to differ. The current study will be investigating pacing among well-trained cyclists, but in order to better understand the varying pacing templates used in cycling it is beneficial to understand how pacing affects performance in other endurance competitions.

In swimming, large amounts of power are lost due to drag force in the water. This means that an early acceleration will result in a large amount of energy lost in order to overcome these forces and reach peak velocity (de Koning et al., 2011a). This suggests that an even-paced strategy is optimal for swimming events. In running events, a positive pacing strategy appears to be optimal. This is due to a decrease in drag force, which means that less energy will be lost due to frictional forces when reaching peak velocity (de Koning et al., 2011a). Cross-country skiers also tend to display a positive pacing pattern, and differences among elite skiers appear to be a greater decrease in velocity throughout the middle portion of the event. This suggests that an even pacing template may be better suited for skiers with less physical ability (Losnegard, Kjeldsen & Skattebo, 2016). Theoretically, a positive pacing strategy should be ideal for speed skaters performing middle distance events such as the 1500-m according to the energy flow model (Hettinga et al., 2011). However, there was found to be no significant difference between a positively paced strategy and a more even self-paced strategy.

Pacing Strategies During Cycling

The current study will examine how Hazard Score is affected by two different pacing strategies among well-trained cyclists. Traditional pacing strategies used in cycling include an "all-out" or positive strategy, an evenly paced strategy, a "U-shaped" or parabolic pacing strategy, a variable strategy and a negative strategy (Abbiss & Laursen, 2008). A positive strategy refers to a relatively high PO early in the event that gradually decreases over time. An evenly paced strategy requires maintaining a constant PO throughout the event. A parabolic pacing strategy refers to a relatively high PO at the start of the event that decreases to a somewhat constant pace, and is then followed by a terminal acceleration to the finish. The variable strategy involves manipulating PO throughout the bout based upon external factors such as terrain and wind resistance. A negative strategy is marked by a consistent increase in velocity throughout the event. The current study will compare a self-paced 20-km trial and a non-uniformly paced 20-km trial. A non-uniform pacing strategy requires increasing PO at varying points throughout the event. There are many different variations of non-uniform pacing strategy, but relatively little research has been done on the effects of non-uniform pacing on PO or Hazard Score. In order to determine the optimal strategies for completing a 20-km time trial, it is important to examine the mechanisms that determine pacing strategy.

Studies have shown that capacities for aerobic and anaerobic energy during exercise are fixed quantities. A study by Hettinga, de Koning, Meijer, Teunissen and Foster (2007) examined the effects of different pacing strategies on anaerobic work produced among well-trained cyclists. Subjects performed three time trials of 1500 meters (m) using either an even, positive or negative pacing strategy. Aerobic power was measured using oxygen uptake (VO_2) and respiratory exchange ratio (RER), while anaerobic power was measured using external PO and gross efficiency. No significant changes were found in total aerobic or anaerobic work produced, supporting the idea that aerobic and anaerobic capacities are relatively fixed within an individual (Hettinga et al., 2007).

While the amount of anaerobic power that can be produced seems to be unaffected by pacing strategy, the distribution of this anaerobic energy throughout an exercise bout appears to be critical in determining performance in cycling events. A study done by Hettinga, de Koning, Broersen, van Geffen and Foster (2006) examined the role of fatigue and changes in PO on pacing strategy. Eight male cyclists performed three time trials of 4000 m using varying pacing strategies. These strategies included a negative, a positive and an even pacing strategy. Total and anaerobic PO significantly increased during the negatively paced trials, while there was a significant decrease in total and anaerobic PO during even and positively paced trials (Hettinga et al., 2006). Aerobic PO increased throughout each trial, regardless of pacing strategy. This seems to suggest that anaerobic power is an important factor in determining pacing strategy.

In addition to variations in anaerobic PO, mean total PO also appears to be a critical factor in time trial performance. A study done by Hettinga, de Koning, Hulleman and Foster (2012) examined the effect of mean PO and pacing strategy on cycling performance among well-trained cyclists. Subjects were asked to complete four separate 1500-m time trials on the cycle ergometer. The fastest and slowest trials were then compared in terms of mean PO, aerobic peak power and anaerobic peak power. The impact of changes in mean PO on pacing strategy was calculated using the energy flow model. It was found that optimal pacing strategy was dependent upon distribution of anaerobic energy. The difference in total PO was more attributable to changes in anaerobic energy distribution (63%) than aerobic energy distribution (37%) (Hettinga et al., 2012). It was also found that faster performance in 1500-m time trials seems to be associated with a faster pace at the beginning of the event.

Optimal pacing strategy during cycling is dependent upon event duration. Events that are relatively short (≤ 1.5 minutes) in duration seem to be best performed using an "all-out" pacing strategy. This theory was examined by de Jong et al. (2015) in a study compared pacing strategy and PO during three short cycling time trials (250 m, 500 m, and 1000 m). Nine well-trained cyclists performed an incremental exercise test, a testing protocol to determine peak sprint power, and the three time trials. The peak power during the time trials was then compared to the peak sprint power. It was determined that, although a positive pacing strategy is referred to as an "all-out" strategy, the peak power during all trials was significantly less than the peak sprint power. Results also showed that subjects performed at high intensity for a significantly longer time during the 250 m trial than in the 500 m or the 1000 m trials. This suggests that pacing strategy becomes more aggressive as event duration decreases.

These findings were also supported by a study done by de Koning, Bobbert and Foster (1999) in which pacing strategies during different cycling races of either 1000 m or 4000 m were examined. Simulations were also used to determine theoretical optimal pacing strategies using the energy flow model. The simulations were then compared to the pacing strategies used during real competitive events. In both cases an "all-out" strategy was associated with faster times in the 1000 m and 4000 m races (de Koning et al., 1999). This was due to the higher PO needed to overcome frictional forces early in the event. Results also illustrated the importance of pacing strategy on performance, as even slight variations in pacing strategy were associated with significant changes in time to finish.

The anticipatory feedback model of fatigue suggests that a cyclist may monitor and adjust anaerobic PO during closed loop exercise based on knowledge of the endpoint and experienced RPE. This may be done in an effort to preserve some anaerobic capacity for a terminal acceleration. This is supported by a study done by Foster et al. (2004), in which well-trained cyclists were asked to perform time trials of 500 m, 1000 m, 1500 m and 3000 m. Pacing strategy and PO were observed and recorded during each randomized trial. In each trial, PO was and anaerobic energy utilization was relatively high and decreased to a constant value for most of the remainder of the event, although subjects appeared to reserve some of their anaerobic power for a terminal acceleration. While this is inconsistent with the idea of a pure “all-out” strategy as an optimal strategy for short cycling events, it does support the theory of teleoanticipation as a model for fatigue and pacing.

While most studies agree that a positive pacing strategy is optimal in short cycling events, there is evidence that an even pacing template may be ideal for middle distance races (Foster, Schrager, Snyder & Thompson, 1994). In a study by Foster et al. (1993), nine well-trained cyclists performed five 2 km time trials in order to determine optimal pacing strategy. The first kilometer of each trial was kept within 48-55% of best time in order to simulate a competitive racing event. Evenly paced trials produced the fastest times, suggesting that this strategy may be optimal for middle distance events lasting from two to four minutes in duration (Foster et al., 1993).

Non-uniform Pacing

The current study will include cycling time trials of 20-km, a relatively long distance compared to the studies discussed previously. Studies seem to suggest that a relatively even pacing strategy is optimal for such distances, although most athletes tend to display a somewhat parabolic pattern of PO (Foster et al., 1993; Foster et al. 2004). However, there is little research on the use of non-uniform pacing strategies for relatively long cycling events. The current study is based on a study done by Cohen et al. (2013), in which growth trends in RPE and PO were compared between self-paced 10-km cycling time trials and 10-km trials using a non-uniform pacing template. Ten well-trained cyclists completed a maximal incremental test on a cycle ergometer, followed by four 10-km time trials. Trials 1 and 2 were for habituation, while Trials 3 and 4 were randomized and included a self-paced trial (CONTROL) and a non-uniformly paced trial (BURST). In the non-uniform pacing trial, subjects were instructed to perform a 1-km “burst” in PO to simulate breaking away from the peloton in a competitive cycling race. This burst took place at the 4-km mark of the trial, and following the burst the subjects were asked to complete the trial in as little time as possible. RPE and PO were recorded along with blood lactate and heart rate. RPE and PO were plotted and compared between trials. CONTROL (16:36) was significantly faster than BURST (17:00) among subjects. Average PO during CONTROL was 240 watts (W), while the PO during BURST peaked at an average of 282 W during the surge before falling to an average of 220 W for the remainder of the trial (Cohen et al., 2013). During BURST, RPE increased above the normal growth pattern seen in CONTROL but returned to the expected curve following the surge. Blood lactate also spiked during BURST and remained elevated above the normal growth pattern for the duration of the trial. These results suggest that RPE and PO appear to grow in a reciprocal manner throughout a 10-km cycling time trial, and that PO seems to be regulated by more than RPE alone. The current study will also examine the use of a non-uniform pacing template compared to a self-paced template. However, it will use a longer distance of 20-km and will involve two bursts instead of one. RPE will be plotted against fractional distance remaining in the event and will be used to calculate a Hazard Score growth curve that will be compared between trials.

Factors Influencing Pacing Strategy and Endurance Performance

While studies have shown that optimal pacing strategies seem to exist for different endurance events, performance may also be influenced by a variety of internal and external factors. Many of these factors will not be directly measured within the current study, but it is important to consider the influence that they have on pacing.

Intrinsic drive and motivation seems to vary among individuals completing exercise events. In some cases an extraordinary amount of intrinsic motivation can be detrimental to the health of an individual, who may ignore afferent feedback from peripheral sensors and continue exercising in a state of catastrophic physiological failure, ultimately leading to a risk of collapse and life-threatening conditions (St Clair Gibson et al., 2013). The goal of a pacing template is to distribute energy in a way that avoids this type of peripheral fatigue and physiological damage. This means that, while rare, such high levels of intrinsic motivation may give unreliable data as to the effect of pacing strategy on RPE and fatigue. There seems to be limited research currently regarding factors that influence intrinsic drive, but it has been suggested that positive and negative self-talk may lead to differing degrees of physiological state awareness during endurance competition (St Clair Gibson & Foster, 2007). In theory, the neglecting of feedback from afferent sensors could lead to an altered pacing template that affects athletic performance, but further studies should be done regarding this topic.

Extrinsic motivation is also a relevant topic to the current study, particularly if monetary rewards are offered during the study. Extrinsic motivation is often quite high during athletic competition when individual achievement, monetary rewards and other goals are on the line. However, this level of motivation seems to be difficult to replicate in a laboratory setting. In a study by Hulleman, de Koning, Hettinga and Foster (2007), subjects completed four 1500-m cycling time trials in which a monetary reward of $100 was offered before the final trial for subjects if they could achieve their fastest time. This was done in an effort to simulate extrinsic motivation during competition and observe the effect on pacing template and performance. The study found that the monetary reward did not have a significant effect on time trial performance in 1500-m trials, which suggests that pacing patterns are relatively stable, at least during relatively short events (Hulleman et al., 2007).

Various environmental factors also appear to affect pacing strategy and performance. Studies show that hypoxic conditions lead to a decreased PO and an increased growth rate of RPE (Haseler, Richardson, Videen & Hogan, 1998). However, a study by Henslin Harris, Foster, de Koning, Dodge, Wright and Porcari (2013) found that the pre-exercise pacing template appears to have a strong effect on power distribution throughout exercise and that PO is not solely dependent on specific oxygen concentration. Local and environmental temperature also have been shown to influence exercise and task performance (Levels, de Koning, Foster & Daanen, 2012; Levels, de

Koning, Broehuijzen, Zwaan, Foster & Daanen, 2014; Levels, de Koning, Mol, Foster & Daanen, 2014). While the current study will be done in a laboratory setting, the effect of temperature on pacing should be taken into account before collecting data. A proper warm-up protocol is also important in determining time trial performance. A study done by Hajoglou, Foster, de Koning, Lucia, Kernozek and Porcari (2005) found that a warm-up significantly improved time trial performance among cyclists performing middle distance events, regardless of intensity. This was found to be due to an acceleration in VO_2 kinetics (Hajoglou et al., 2005), and suggests that the current study should incorporate a proper warm-up protocol prior to the onset of cycling time trials.

Summary

Athletic performance in endurance competitions relies on the utilization of an optimal pacing template. This template is created subconsciously using an algorithm that takes into account momentary RPE and prior exercise experience. This algorithm has been described as anticipatory feedback, and involves an internal negotiation that compares momentary RPE to expected RPE, as well as knowledge of distance remaining. It has been suggested that the idea of a Hazard Score (product of momentary RPE and percent distance remaining) is critical in distributing energy and PO throughout an event. This Hazard Score determines the likelihood that an individual will adjust their pacing strategy by increasing velocity. It is influenced by many factors, including the duration of the exercise bout and which pacing template has been selected. To our knowledge, there have been no studies examining the effect of a non-uniform pacing template on Hazard Score during 20-km cycling time trials. The current study will attempt to determine this relationship, and compare it to a self-chosen pacing template.

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