UNIVERSITY OF WISCONSIN- LA CROSSE

Graduate Studies

MUSCLE OXYGENATION PATTERNS DURING MAXIMAL INCREMENTAL CYCLING AND 20-KM TIME TRIALS

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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Clinical Exercise Physiology

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MUSCLE OXYGENATION PATTERNS DURING MAXIMAL INCREMENTAL CYCLING AND 20-KM TIME TRIALS

By Cassie Pratt

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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Pacing strategies are necessary during endurance events in which the goal is to finish in as little time as possible. Both anaerobic and aerobic energy systems are utilized during cycling and running competitions. The Rating of Perceived Exertion (RPE) scale increases linearly as heart rate (HR), and power output (PO) increases. Muscle oxygen (O_2) saturation within the working muscles typically mirrors this pattern. These components help determine the amount of energy an athlete can expend over the course of an event. Purpose: To determine how muscle O_2 saturation changes with changes in PO during incremental and non-incremental exercise (20-km time trials). Methods: 9 subjects (8 male, 1 female) completed a maximal incremental exercise test, as well as a habituation 20-km trial, followed by a steady state (SS) 20-km time trial and two 20-km time trials with variations in nonuniform pacing. One variation had bursts separated by 2-km while the other was separated by 4-km. Athletes had 48-96 hours between trials. Muscle O_2 saturation, PO, and HR were measured. RPE was recorded each kilometer. Repeated measures analysis of variance (RMANOVA) was used to determine the magnitude of differences between burst trials (2-km vs. 4-km rest). Results: There was no significant difference ($p<.05$) between the finishing times amongst the various 20-km protocols. Conclusion: This study revealed that the experimental intervals caused reciprocal changes in the magnitude of muscle oxygen and PO in the working muscle that are larger than the changes in a normally paced time trial.

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INTRODUCTION

It is believed that pacing in athletic events is experience-driven, and that the optimal pacing strategy may be influenced by previous training, and competitions. Pacing became of popular interest during the 1990's and has been defined as the distribution of energy throughout an event needed to sustain a level of exercise before critical homeostatic disturbances occur (Foster, et al., 2012). Athletic events requiring pacing are generally based on time to completion and finishing in as little time possible, while avoiding the physiological disturbances that occur when fatigue accumulates (Cohen, et al., 2013). Homeostatic changes during endurance exercise have traditionally been described in terms of muscle and blood lactate as well as changes in ventilation, heart rate (HR) and Rating of Perceived Exertion (RPE). Research suggests that these values can be used to guide an individual's training (Van der Zwaard, et al., 2016). The homeostatic disturbances occurring from inappropriate pacing may cause harm to the individual and result in a negative performance outcome, although there is limited evidence of harm (St. Clair Gibson, et al., 2006; Amann, 2011).

Experimental findings suggest that the relationship between intrinsic and extrinsic feedback regulates motor unit activation as well as exercise intensity during physical activity (Amann, 2011; St. Clair Gibson et al., 2006). Together this complex system may help predict how much energy to expend over varying distances and varying durations of exercise (Faulkner, Arnold, & Eston, 2008; Foster, et al., 2004; Joseph et al., 2008). During endurance events, oxygen delivery to the muscles must be efficient for longer durations of time compared to sprinting events (Van der Zwaard, 2017). The ability to use and create ATP for energy is primarily dependent on the presence of oxygen, and the type of activity. When exercising at very high intensity or to exhaustion, muscles become oxygen depleted which then demands heavy use of non-oxidative ATP generation. Anaerobic systems create relatively little ATP and are utilized only during high intensity activities when the muscle is in an oxygen deficient environment. This elicits the accumulation of lactate, a marker of muscle fatigue (anaerobic metabolism). In contrast, longer durations of lower intensity exercise allow a steadier supply and demand of ATP to the skeletal muscles as oxygen consumption increases, delaying the onset of fatigue (aerobic metabolism). In most events, it is likely that both aerobic and anaerobic pathways are utilized. Sprinting during an endurance event could allow an athlete to take the lead, challenging the body to provide both aerobic and anaerobic sources of ATP (Van der Zwaard, 2017). This physiological flexibility may contribute to varying levels of fatigue and recovery within a single effort and could influence the outcome of the event. The RPE can be utilized as a major predictor of pace, and once exercise has started the individual makes adjustments in PO based on their perception of how they feel and what is yet to come for the remaining portion of the activity (Joseph et al., 2008; Schallig et al., 2016). Falkner et al. (2008) found that competitive runners utilized RPE to adjust and control energy expenditure over several distances. Multiple studies have been conducted experiments to observe self-pacing, anticipated work load, and overall pace regulation including those that had subjects exercise with varying distances and duration feedback commands (Faulkner et al., 2010; Micklewright, Papadopoulou, Swart, & Noakes, 2009). These studies suggest that the amount of energy needed to complete a task can be anticipated prior to starting activity (Faulkner et al., 2008).

An objective approach to estimating the adequacy of oxidative energy production can be achieved using near-infrared spectroscopy (NIRS) to track oxygen saturation in the working muscles (Van der Zwaard et al., 2016). NIRS technology measures the association between the absorption of light by compounds such as oxyhemoglobin and deoxyhemoglobin. NIRS is non-invasive and may be beneficial for training studies and in clinical settings. One study found that NIRS technology was a useful tool when using a low intensity incremental cycling protocol, but higher intensity increments have not been explored (Crum et., 2017). To our knowledge there are no data regarding how muscle oxygen saturation behaves in non-incremental exercise, such as a time trial or during interval exercise.

It has been suggested that a rider's power output (PO) is inversely related to muscle oxygen (O_2) saturation while exercising (Crum et al., 2017). Therefore, we predict that oxygen desaturation will occur during bursts at higher PO occurring during time trials. Using well-trained cyclists, it is further predicted that finishing times will vary between a spontaneously paced trial compared to one with bursts of intensity. It is also hypothesized that as riders begin increasing PO, O_2 saturation in their muscles will decline, but will return to normal following the burst. Fatigue may cause an athlete to unintentionally decrease PO, but decreases in PO in an effort to conserve energy may be done on purpose to finish the remaining portion of the trial faster than his/her component (de Koning et al., 2011). Instances of higher PO can be seen concluding endurance races. We predict that the second burst during the two incremental time trials will produce a less pronounced spike in PO and decrease in muscle O_2 saturation as muscle fatigue sets in. Based on previous studies there is evidence that with variations in pacing strategies, the relationship between RPE and pacing, and the influence of previous experience may impact overall performance (Cohen et al., 2013). The purpose of this study is to determine if muscle O_2 saturation will influence the self-selected pace along with the total time it takes to complete 20-kilometer cycling time trials which include high intensity breakaway efforts.

METHODS

Participants

Nine well-trained cyclists including eight males and one female were recruited from local cycling clubs. The cyclists had all previously participated in competitive cycling events and ranged from 20-46 years of age (33.7 ± 10.51 years). All riders gave written informed consent and to were asked to complete a physical activity readiness health questionnaire (PAR-Q). After approval from the Institutional Review Board for the Protection of Human Subjects, all testing took place in the University of Wisconsin-La Crosse's human performance lab and all participants successfully completed all element of the study. Participant descriptive characteristics for the participants are presented in Table 1.

Table 1. Subject Characteristics, (n=9)

Variable	Mean ± SD	Range
Age (y)	33.7 ± 10.51	(20.0-46.0)
Weight (kg)	76.7 ± 8.10	(57.7-85.9)
Height (cm)	176.5 ± 0.99	(25.6-28.5)
VO_{2max} (ml/kg/min)	55.4 ± 10.40	(37.2-75.1)
HR_{max} (bpm)	164.3 ± 14.60	(146.4-178.4)
PO_{max} (W)	305.6 ± 44.70	(250.0-375.0)

Values represent Mean ± SD
VO_{2max}: maximal oxygen consumption
HR_{max}: maximal heart rate

PO_{max}: maximal power output

Materials

Using an electronically braked cycle ergometer (Velotron, Racermate, Seattle, WA), HR (radio telemetry), and power output (PO) were recorded during each trial. Trials were pre-programed on the Velotron, while PO was measured with an SRM power meter (SRM Training Systems, Colorado Springs, CO) attached to the chain ring of the cycle. Subjects were free to bring in their own pedals and/or handlebars as long as they were used for all trials. HR was measured using radio telemetry (Polar, Bethpage, NY). The Moxy Monitor (Moxy, Fortiori Design LLC, Hutchinson, MN) was used to track muscle oxygen saturation in the working muscle. The small, non-invasive monitor emits near-infrared light to measure the amount of oxygenated hemoglobin and myoglobin in the muscle tissue.

Procedure

Before the maximal incremental test, a large blood pressure cuff was placed around the upper leg for five minutes. The Moxy sensor was secured by an elastic sports tape on the lower third of the vastus lateralis before applying 200 mm Hg pressure to the cuff for five minutes. This process occluded blood flow to the limb providing resting baseline data for the localized deoxygenated muscle, resembling a state of muscle fatigue during a hard effort. Control measures at the fully oxygenated state were made immediately prior to inflating the cuff. Following the release of cuff pressure, subjects were given three minutes for normal blood flow to return. Ten minutes of active recovery were allowed prior to the maximal cycling test to eliminate any physiological interferences.

Using open-circuit spirometry, maximal oxygen consumption (VO_{2max}) was measured using a metabolic cart (MOXUS, AEI Technologies, Pittsburg PA). Every participant performed an initial test VO_{2max} to gauge each rider's maximum PO. This final value was used to develop an individualized warm-up protocol. During the maximal incremental test, PO began at 100 W and was increased by 25 W every two minutes. At each two-minute stage, the subject was asked to rate their exertion using the RPE scale (Borg, 1982). The test was concluded when the subject could not continue.

All subjects had 48-96 hours of recovery between laboratory sessions, during which they were asked to refrain from heavy exercise. Following the maximal incremental test, each subject performed a self-paced (SS) 20-kilometer time trial for habituation and another 20-km time trial as a baseline. Each subject subsequently performed experimental 20-km trials. In all time trials the goal was finishing in as little time possible. A standard warm-up was performed by each rider based on their incremental test. The habituation trial allowed the rider to become familiar with the trial length and wearing the Moxy monitor while cycling. The experimental tests included two randomly placed 1-kilometer bursts (A: 5k & 7k; B: 11k & 13k; C: 5k & 11k; D: 7k & 13k). The order of burst trials was random. Burst trials were designed to be treated like a "break away" in a cycling race.

To control for extrinsic motivation, the only feedback provided was at every 5-kilometer marker. Feedback included previous time trial times which allowed the rider to compete against their own previous time trial time. During burst trials, riders were told to maximally increase their speed and power output when they reached the designated 1-kilometer interval. Upon finishing each burst, they were told to settle back into their normal 20-kilometer pace. We refrained from any outside encouragement and cheering during the trials to create a more realistic self-paced time trial environment, promote consistency, and minimize biases.

Statistical Analysis

Repeated measures analysis of variance (RMANOVA) was used to determine the magnitude of differences between burst trials. If significance was found ($P < 0.05$) an unpaired t-test was used to identify the specific difference between groups.

RESULTS

During the self-paced (SS) 20-km time trial PO was nearly constant, except for an end spurt during the final 2-km. HR and RPE increased progressively. The O_2 saturation in the muscle decreased rapidly at the beginning of SS, and then decreased slowly but progressively throughout the trial (Figure 1).

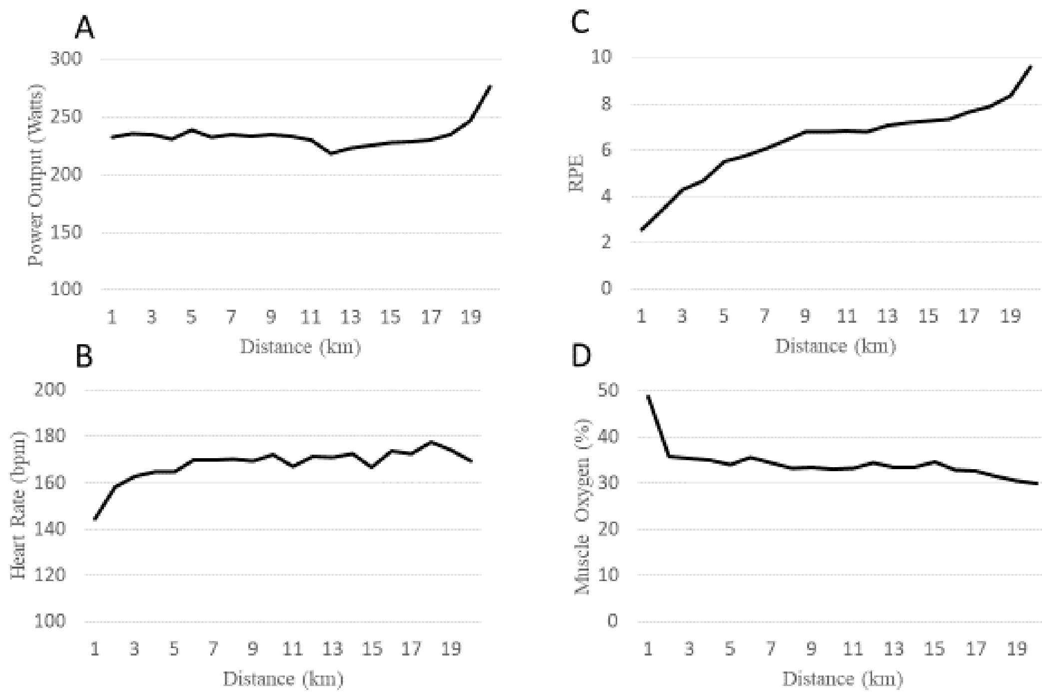

Figure 1. 4-panel summary of the steady state 20-km time trial; (A) represents PO, (B) represents HR, (C) displays RPE, and (D) muscle O_2 saturation.

During the burst trial with a short (2-km) recovery (Figure 2) the overall PO decreased slowly across the trial, except for an increase with the end spurt. In both early and late bursts, the second burst in each group was smaller than the first. HR and RPE grew throughout the trial, with more rapid increases during the bursts. Muscle O_2 saturation decreased rapidly at the beginning of the trial. During the bursts there was a further decreased in muscle O_2 saturation which recovered somewhat during the recovery after the burst. The directional changes in PO and muscle O_2 saturation were reciprocal in nature.

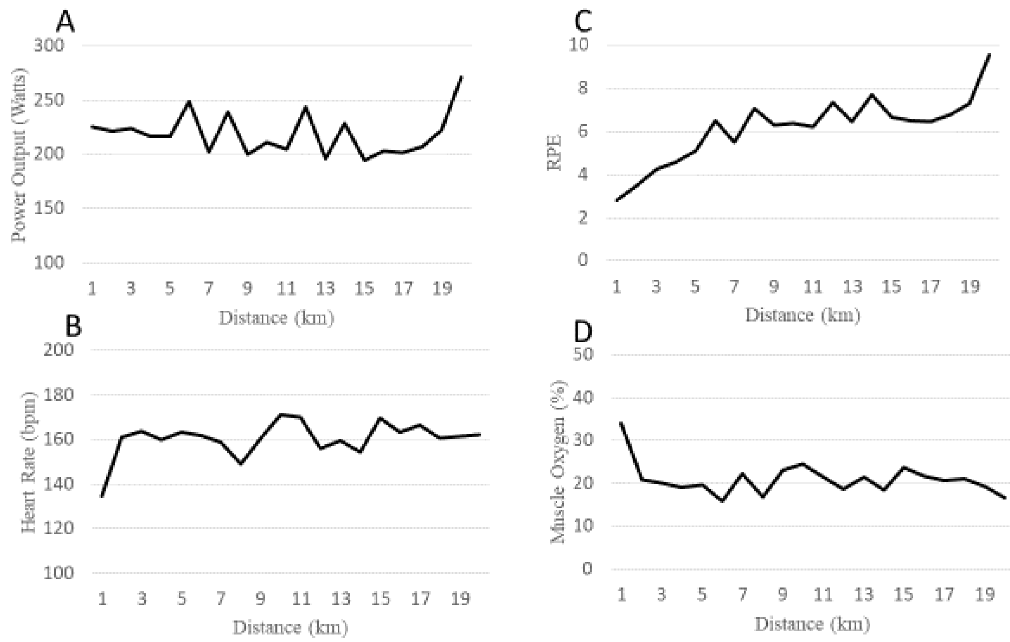

Figure 2. 4-panel summary of the group 1 burst trial (burst A and B with 2-km rest); (A) represents PO, (B) represents HR, (C) displays RPE, and (D) muscle O_2 saturation.

Burst trials with a longer recovery (4-km) recovery (Figure 3) showed a decrease in PO throughout the trial, but PO during each burst remained higher than trials with less recovery (2-km). Muscle O_2 saturation remained virtually consistent for the entire trial with minor decreases during bursts and minor increases following the bursts.

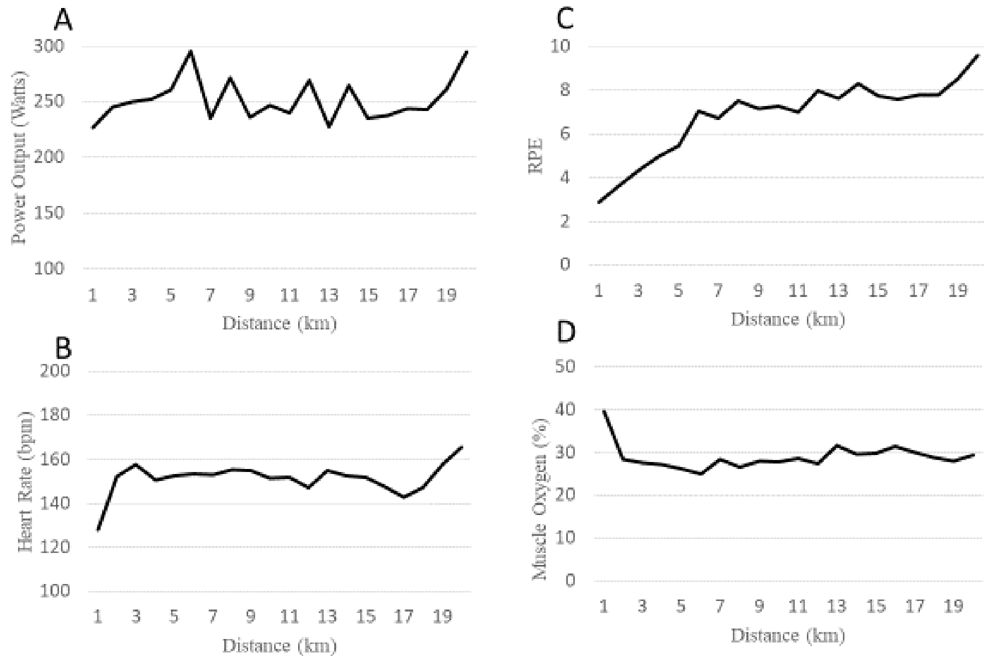

Figure 3. 4-panel summary of the group 2 burst trial (burst C and D with 4-km rest); (A) represents PO, (B) represents HR, (C) displays RPE, and (D) muscle O_2 saturation.

Each burst trial showed reciprocal changes in percent PO and percent muscle O_2 saturation regardless of the location of each burst (Figure 4). Trials with longer recovery (4-km; Trial C and D) displayed matching PO and muscle O_2 saturation increases and decreases for burst one and two. On the other hand, trials with less recovery (2-km; Trial A and B) displayed larger increases in PO for the first burst compared to the second burst.

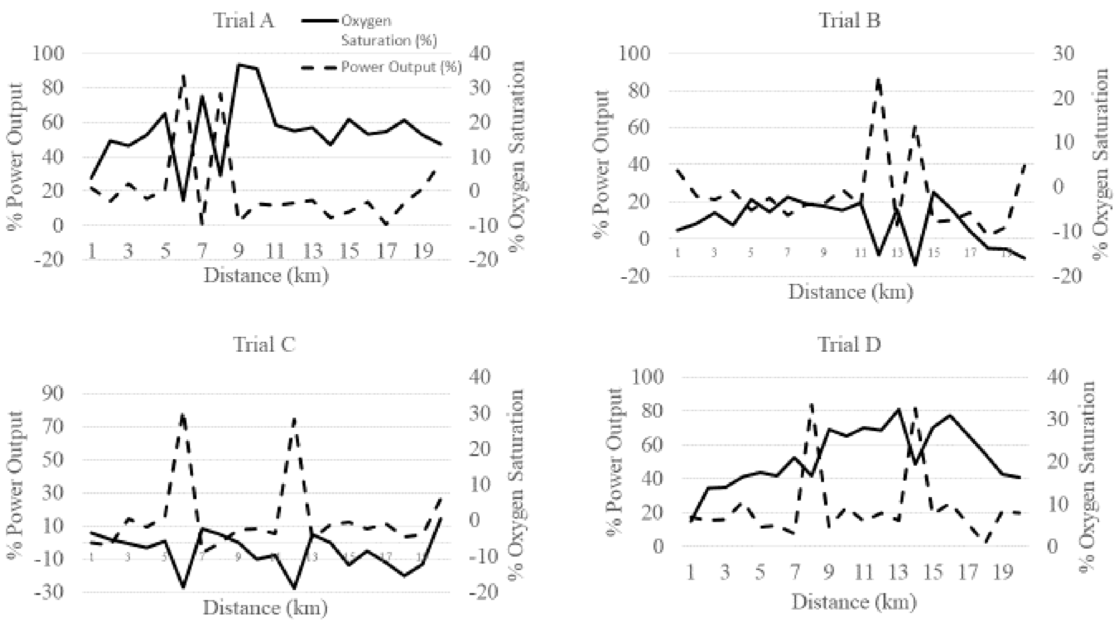

Figure 4. 4-panel summary representing relationship between percent PO and percent muscle O_2 during each type of experimental burst trial; (A) bursts at 5-km and 7-km, (B) bursts at 11-km and 13-km, (C) bursts at 5-km and 11-km, (D) bursts at 7-km and 13-km.

Table 2. Overall Results for Various 20-Kilometer Cycling Protocols, (n=9)

	SS	Group 1 (2-km rest)	Group 2 (4-km rest)
Finish Time	33:47 ± .133	35:32 ± .166	33:30 ± .064

Burst one and burst two during Trials A and B (2-km recovery) showed significantly different PO and muscle O_2 saturation (Figure 5). The first burst presented larger PO values with reciprocal decreases in muscle O_2 saturation compared to burst two. Recovery after burst two showed a larger PO than during burst one.

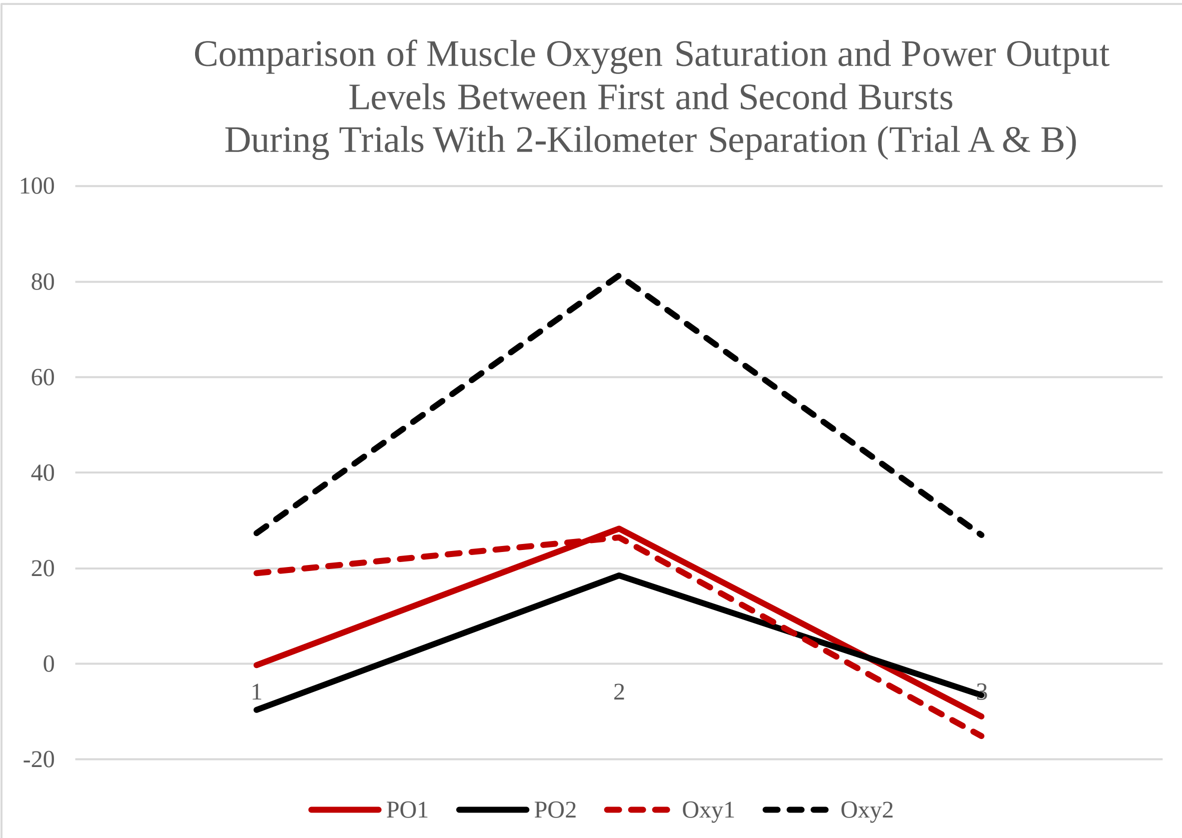

Figure 5. Differences between first burst and second burst during the trials with only 2-kilometer recovery (Burst A & B). Graph shows kilometer before, during, and after burst.

When comparing each burst during Trials C and D (4-km recovery), PO and muscle O_2 saturation were similar between bursts (Figure 6). PO was larger during burst one and similarly, muscle O_2 saturation was lower. Immediately following burst two, PO was greater than the kilometer proceeding burst one. Likewise, burst two produced a lower muscle O_2 saturation value as well.

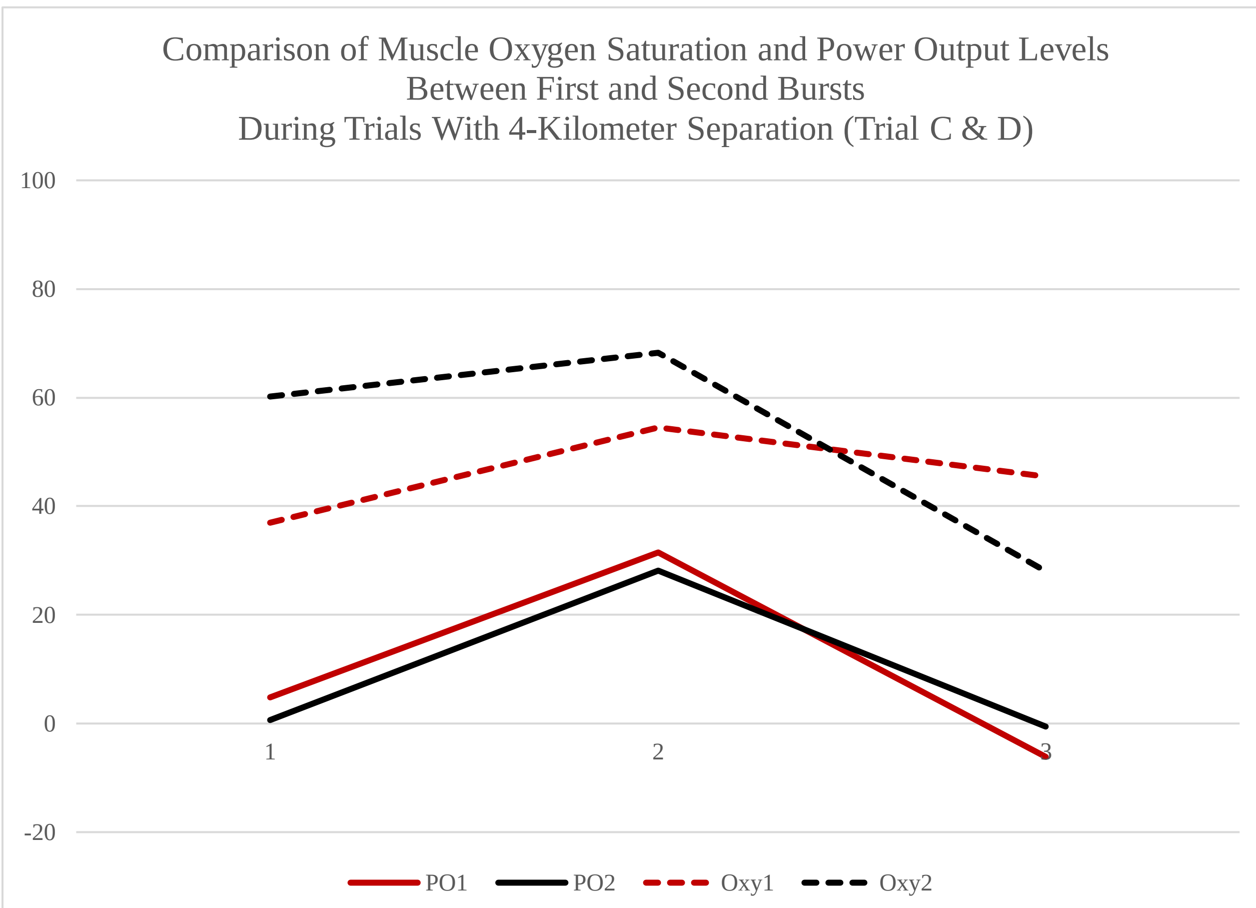

Figure 6. Differences between first burst and second burst during the trials with 4-kilometer recovery (Burst C & D). Graph shows kilometer before, during, and after burst.

DISCUSSION

The purpose of this study was to identify the relationship between the magnitude of muscle O_2 saturation and PO during variations of steady state and interval cycling protocols. The recovery time between bursts was important in establishing the rate at which the magnitude of muscle O_2 saturation declined and returned to each rider's normal level. The primary finding was that muscle saturation in the working muscle was reciprocal with changes in PO, meaning that as PO increased or decreased, the magnitude of O_2 saturation decreased or increased.

HR and RPE followed similar patterns to PO and muscle O_2 saturation in all 20-km time trials. During the SS ride, RPE and HR progressively increased with the duration of the trial. This would suggest that near the end of a time trial, physiological fatigue is higher than it was at the beginning and may also represent a final increase in intensity to beat a competitor or finish within a range of time. During the experimental trials, HR and RPE increased during and after burst intervals, and subsequently decreased as the rider re-established a steady-state pace again. In figures 1-4, each panel displays almost identical graphs. These findings establish an important relationship between the perception of effort and the physiological reaction to incremental energy expenditure during varying cycling protocols.

The location of the 1-kilometer bursts demonstrated the important aspect of recovery between bursts as the trials with bursts separated by 4-kilometers (Group 2) versus 2-kilometers (Group 1) were characterized by nearly full recovery in the second burst (3% vs. 10% PO decrement, respectively). Differences in PO and muscle O_2 saturation varied between the two types of trials (2-km rest v. 4-km rest) based on location of each burst (Figure 5 and Figure 6). The PO upon starting the first burst was higher compared to the latter with reductions in PO and muscle O_2 saturation as the kilometer ended. Interestingly, while PO had started lower during the second bursts for each type of trial, riders displayed a higher end PO compared to their first burst. Variations between the two groups showed a larger impact on the muscle oxygen saturation as the group with less time to recover had muscle O_2 saturation that remained elevated (Figure 5) when starting the second burst. Trials C and D where the intervals were further apart showed more even oxygen saturation results during each burst (Figure 6).

The increase in PO during each burst coincides with a decrease in muscle O_2 saturation, suggesting the use of a more anaerobic energy system during the burst efforts. Subjects were able to perform a second burst confirming that recovery between intervals permitted sufficient ATP production. However, these findings also indicate that when riders had more time to settle back into a steady pace, they could produce a second burst that more closely mirrored their first burst (Figure 6). Subjects with little time to return to a normal pace showed a decline in PO and O_2 saturation during their second burst (Figure 5). Trials that displayed a longer break between bursts represented more uniform oscillations in PO and O_2 levels demonstrating the benefits of a long-term energy system during incremental and steady-state time trials.

In addition, we observed how each finishing time differed from one protocol to the other (Table 2). With varying types of time trials all at which were self-paced, it was seen that most riders progressively decreased time to finish for each session, but no distinct trial type was notably faster than the others. This supports the idea that pacing is a learned experience (Foster et al., 2009), and it is likely that riders were able to rapidly sense how much energy to expend during each burst regardless of where they occurred in each burst trial. Using trained cyclists, it is plausible that competing at high levels of intensity and for different durations of time allowed them to better regulate pace. This supports the findings of Amann (2011) on nerve blocked time trials.

Incentive to “compete” against the rider’s previous trial and simulate a race-like situation was based on internal motivators as they were unaware of how other subjects had performed. Some findings suggest that without a competitor present, physiological disturbances caused by fatigue are perceived as a greater detriment to the outcome of a ride. Since pace regulation is dictated by multiple factors including extrinsic and intrinsic motivation as well as afferent feedback in the working muscles, it was important to note how finishing times fluctuated as sessions progressed. Overall trial times seemed to decrease, but we did not witness any large improvements. As subjects felt more comfortable on the cycle ergometer and were made aware of their previous results, motivation to finish faster in each proceeding trial was apparent. Another notable finding was that the two incremental time trials compared to the steady state time trial were almost identical in completion time supporting that the influence of muscle fatigue during high-intensity efforts and the absence of motivational factors played a role in preventing significant improvements.

In conclusion, finishing times between steady-state, and incremental time trials varied slightly, but only between the different types of incremental rides (Group 1 and Group 2). While there was no significant difference in finishing times, those that had 4-kilometer of rest between bursts rather than only 2-kilometer, had completed the time trials in the least amount of time. This information supports the idea that riders can be self-motivated when they are aware of their end point and as the finish approaches. Low-intensity incremental studies using NIRS technology have confirmed the reliability of the Moxy monitor (Crum et al., 2017), and this study aimed to uncover its consistency during high-intensity rides.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT FOR "Muscle Oxygen Saturation Patterns During Maximal Incremental Cycling and 20-km Time Trials"

Principal Investigator: **Cassie Pratt**

UW-La Crosse

133 Mitchell Hall

La Crosse, WI 54601

651-494-8142

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. Wear a small, computer device on my leg that measures muscle oxygen desaturation via infrared lights.

e. 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 Cassie Pratt at 651 494 8142. 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
____________________________	
Printed Name of Participant	
____________________________	__________________
Signature of Witness	Date

APPENDIX B

REVIEW OF RELATED LITERATURE

In endurance sports, optimal performance is dictated by strategic pacing, previous experience, and the influence of intrinsic and extrinsic factors. Pacing can be defined as the distribution of energy throughout the body needed to sustain a level of maximal exercise before critical homeostatic disturbances in the body occur (Foster et al., 2012). Long-distance competitions such as cycling and running races entail both steady state efforts as well as incremental efforts where the goal is to finish as quickly as possible. The development of fatigue and other physiological disturbances during exercise drive intensity and duration of activity (Tucker et al., 2009). Measuring heart rate (HR), ventilation, and blood lactate may provide an outline for quality training and improved performance (Van der Zwaard, S., et al., 2016).

Experimental findings suggest that the relationship between intrinsic and extrinsic feedback received by the body regulates motor unit activation as well as exercise intensity during physical activity. Together this complex system may help predict how much energy to expend over a variety of distances and varying durations of exercise (Faulkner, Arnold, & Eston, 2008). During endurance events, oxygen delivery to the muscles must be efficient for longer durations of time compared to sprinting events (Van der Zwaard, 2017). An athlete may perform both sprinting and steady state efforts as a means of strategy and there for utilize the complex interaction between both aerobic and anaerobic energy systems (Van der Zwaard, 2017). This physiological flexibility may contribute to varying levels of fatigue and recovery throughout a single ride and influence the outcome of the event. The Rate of Perceived Exertion (RPE) scale has been identified as a major predictor of pace (Borg, 1982). Falkner et al. (2008) found that competitive runners used RPE to gauge how much energy they could expend over several distances. Just as RPE can provide verbal markers to describe how an athlete is feeling, near-infrared spectroscopy (NIRS), HR, and ventilation can narrate direct physiological components during exercise.

Multiples studies have conducted experiments to observe self-pacing, anticipated work load, and overall pace regulation including those that had subjects exercise with varying distances and duration feedback commands (Faulkner et al., 2010; Micklewright, Papadopoulou, Swart, & Noakes, 2009). These studies suggest that the amount of energy needed to complete a task can be anticipated before any movement even begins (Faulkner et al., 2008). The influence of external feedback, known duration of exercise, as well as prior experience may impact the physiological changes made within the body during training and how the athlete perceives effort, and pacing strategies.

The purpose of this study is to determine if a cyclist's power output (PO) and muscle oxygen (O_2) saturation during 20-km time trials is influenced by a series of high intensity bursts, and minimal external feedback. PO is suggested to be a main determinant in pacing strategy and increases during competitive athletic events (Black et al., 2015) Black et al. (2015) found that the length of time an athlete is willing to tolerate exercise at a higher intensity decreases as PO increases.

Another key component of this study is to utilize a near-infrared (NIRS) device to observe the fluctuation in muscle O_2 saturation as the riders complete each trial. Using trained cyclists on a cycling ergometer, it is predicted that finishing times will vary only slightly between a non-incremental trial compared to one with varying bursts of intensity and that times will decrease as the riders become more aware of the task at hand in each proceeding trial. It is also predicted that as riders begin rating higher values on the RPE scale, the magnitude of O_2 saturation in the working muscle will also grow. Based on previous studies there is evidence that the variations in pacing strategies, the relationship between RPE and pacing, and previous experience may all impact overall performance.

Theories Behind Self-Selected Pacing

Self-selection of pace requires influence from the central nervous system and peripheral nervous system. Earlier evidence suggested that a "central programmer" as described by H.V. Ulmer (1996) sorts through external and internal feedback to moderate the onset of fatigue by regulating exercise intensity. Signals from the peripheral system during times of fatigue when there is potential physiological harm to the athlete may provide evidence of a protective mechanism (St. Clair Gibson, Swart, & Tucker, 2017). Other motives for the selection of a certain pace occur as the brain calculates the anticipated energy expenditure based on the distance and duration remaining. (St. Clair Gibson et al., 2006). Mickelwright, et al. (2009) found that after giving varying amounts of feedback to cyclists during a series of 20 km time trials, those who had received even small amounts of information were able to select more appropriate pacing tactics. These findings suggested that both afferent and efferent feedback as well as previous experience tie closely together. St. Clair Gibson et. al (2006) mentions the existence of an 'internal clock' that would allow reproducible pacing experiences, and the ability to make continuous PO adjustments during exercise to efficiently finish the task with little physiological harm.

Further discussing the internal time clock, it is important to recognize that its scalar time properties are likely based on prior experience and will progressively improve as training bouts continue (St Clair Gibson et al., 2006). Physiological markers such as increased skin and core temperatures, depletion of glycogen reserves, as well as cognitive factors including mental drive and motivation are all associated with previous experiences that would strengthen one's internal clock (Tucker & Noakes, 2009).

Based on these anticipatory findings, it would be predicted that the athlete would have a set pace in mind upon the start of an event, but studies have also introduced the presence of a feedforward mechanism. This proponent suggests that regardless of the initial calculated PO needed for exercise, modifications in pace are made when external factors interfere (Tucker & Noakes, 2006). The ability to adjust pacing on the spot indicates that not all pacing strategies are absolute from start. In conclusion, an individual is capable of choosing a self-selected pace before starting exercise, and can later regulate based on unaccountable factors.

Variations in Pacing Dependent on Event

While the use of anticipatory feedback systems, and reliance on previous experiences dictate pace, it is important to note the diverse strategies used during competition. The goal of choosing the appropriate pacing strategy is to maximize energy expenditure while also delaying fatigue and other homeostatic disturbances to achieve an optimal performance. Information regarding PO, O_2 consumption, and duration of activity help guide the selection of pace (Faulkner et al., 2008). Abbiss, and Laursen (2008) highlight six universally observed pacing strategies including positive and negative, all-out, parabolic-shaped (resembling a U, J, or reversed J-shape on a graph) pacing, variable pacing, and even pacing.

"Positive" and "negative" pacing strategies occur when an athlete employs a different pace earlier in the competition as compared to the latter portions of the event. Positive pacing would indicate that a faster starting pace was used and gradually became slower throughout the duration of the event. Evidence of early onset fatigue and increased oxygen consumption (VO_2) resulting from positive pacing is what leads to the decrease in exercise intensity. This form of pacing is often observed during breakaways, misjudged duration of exercise, uncertainty of being able to maintain a certain speed, or because of non-idealistic goals limited by the athlete's physiological capacities (Abbiss, & Laursen, 2008; Renfree, Martin, Micklewright, & St. Clair Gibson, 2013). Faulkner et al. (2010) found that when athletes are presented with uncertainty regarding trial length and duration, they often adopt a slower start to conserve energy stores. On the other hand, the opposite approach in which the athlete becomes progressively faster as their event unfolds, better known as negative pacing. Studies have shown that by starting at a slower pace, there is a significant delay in fatigue and stress on the body allowing the athlete to prolong activity. As the known endpoint becomes clearer to the athlete, power output increases and is typically seen as a final 'kick' where all remaining energy reserves are used for that last portion. How and when an athlete chooses to engage in their final end-spurt can be specific to the individual's physiological capabilities (Abbiss, and Laursen, 2008).

Due to the high energy demand of an "all-out" pace, this strategy is typically seen during short duration events. Evidence has found that an all-out mechanism is ideal when most of an activity is being spent accelerating and the total energy cost to maintain a one pace would be below that of the energy it takes to accelerate; shorter events benefit from holding that initial acceleration through the finish as anything less than submaximal would produce a less than optimal performance (Faulkner et al., 2008)

"Parabolic" and "variable" pacing incorporates both positive and negative pacing. Parabolic pacing may take the form of a U, J, or reverse J when plotted on a graph as the athlete progressively decreases speed over time, but later increases speed as they anticipate a nearing endpoint. Evidence indicates that parabolic pacing may be based on anticipatory feedback and is often experience-driven (Faulkner et al., 2008). Like parabolic pacing, variable pacing is used to offset outside factors influencing pace. It is difficult to simulate a true competitive situation with the presence of outside factors influencing a race such as wind, hills, obstacles, elevation, and length of duration. When faced with one or more of these factors, the athlete must manipulate their PO rather than velocity to maintain efficient energy expenditure (Faulkner et al., 2008).

"Even" pacing unlike positive and negative pacing has been seen during longer durations of exercise when strategic variations in speed are not as critical compared to shorter length activities (Abbiss et al., 2008). Traditional theories about kinetic energy and the laws of motion support the notion that an athlete will perform best if the amount of accelerations and decelerations are limited as these changes in power and velocity will greatly deplete energy reserves (Abbiss et al., 2008). While some studies have found even pacing to produce the most optimal performance outcomes, other research has indicated differently. One study done by Thomas, Stone, St. Clair Gibson, Thompson, & Ansley (2013) recruited well-trained cyclists and had them complete self-paced trials as well as even-paced trials to exhaustion with their fastest self-paced trial determining their subsequent even-paced trial. Results indicated that trying to withhold an even pace may pose more challenges for the athlete as mentally maintaining a fixed pace with the constant, unchanging physiological stress is likely to derail the even pace. True racing is often more stochastic and done in a parabolic or variable form (Thomas et al., 2013).

Role of Perceived Exertion on Pacing

It is evident that pacing occurs as a mechanism for sparing the body from homeostatic disasters, and selection of pace not only appears to be anticipated as noted earlier but also felt and described with RPE. The sensory feedback that one receives from the selection of a pace too fast or too conservative for the given task drive an individual to make more accurate pacing decisions the next time around.

Research has found that RPE is lower at the beginning of an exercise activity compared to the end, and the use of this scale can gauge energy expenditure and prevent adverse physiological disturbances (Swart et al., 2009). Varying markers of intensity correspond to different RPE ratings allowing an athlete to quickly express how they are physically feeling. When comparing two running races of varying distances, Faulkner (2008) showed that RPE and time shared a scalar linear relationship where despite the race differences RPE was selected based off race duration. The subjects participating in the shorter race followed a similar linear increase in RPE as they did during the longer races. Swart (2009) found that RPE is dynamic rather than fixed where situations of uncertainty cause ratings to quickly change. This dynamic characteristic is supported as physiological responses such as PO, HR, O_2 consumption, and blood lactate concentrations tend to follow a pattern like RPE (Tucker, & Noakes, 2009). PO The progression in RPE was seen with increases in PO as a group of cyclists were told to complete a normally paced time trial as well as a time trial that included “bursts” of speed. The results suggested that once a significant burst of power is made by a rider, the RPE increases and later declines with the onset of fatigue (Cohen et al., 2013). Frequent use of RPE during training and competition help develop future performance templates and anticipatory feedback models. Experience and repetition of activity have been found to increase performance results as RPE is not always determined from “afferent sensory feedback but may be set at the beginning of the exercise bout as part of a feedforward control mechanism” (Crewe, Tucker, Noakes, 2008, p. 570).

Outside Factors Impacting Pacing

Anticipating the duration of an event, selecting an optimal pacing strategy, and being prepared for the task at hand could be impacted by external factors such as heat, elevation, the presence of competition, and pharmacological interventions. The onset of environmental and behavioral changes may require the body to adjust energy expenditure to maintain homeostasis. This suggests that fatigue may occur as interpretations of external factors are regulated in the brain (Crewe et al., 2008).

Experiments manipulating the external temperatures have suggested that pacing becomes more difficult in hot conditions compared to cooler temperatures as shown in elevated RPE levels (Crew, et al. 2008). Core temperature regulation is a key component in maintaining homeostasis and can be used to predict exercise intensity prior to competition (Roelands, de Koning, Foster, Hettinga, & Meeusen, 2013). One study found that subjects reduced power throughout trials in the heat, and therefore suggested that as temperature increased self-selected pacing began at a lower PO. These findings display that the anticipation of higher RPE ratings during heated settings turns on the body's inhibitory mechanisms before core temperature exceeds its limit (Roelands et al., 2013).

While environmental aspects were clearly found to cause modifications in pacing, the addition of certain pharmacological interventions were also shown to influence overall pacing techniques. Dopamine and noradrenaline neurotransmitters while beneficial for motivation and arousal during activity can cloud thermoregulation. Higher levels of dopamine allow an individual to endure hotter temperatures by blocking the protective mechanisms of the RPE template (Roelands et al., 2013; Ross & Noakes, 2009).

Muscle Oxygen (O_2) Saturation During Exercise

It is suggested that a rider's PO and muscle O_2 saturation while exercising display reciprocal patterns (Crum et al., 2017). Using near-infrared spectroscopy, local O_2 saturation and total hemoglobin (Hb) can be measured in the muscle tissue (Crum et al., 2017) Muscle O_2 saturation can valuable data for the development of training programs just as HR, and ventilatory threshold measurements are also used to guide exercise intensity.

In this study, the Moxy monitor (Moxy, Fortiori Design LLC, Hutchinson, MN) will measure the magnitude of muscle O_2 saturation during steady-state and burst trials. The monitor will calculate the amount of light absorbed at varying wavelengths representing oxygenated Hb and deoxygenated Hb. From this information, we can identify the amount of O_2 remaining in the working muscle before, during, and after 20-km time trials. Van der Zwaard et al. (2016) found that adipose tissue thickness interfered with NIRS data, normalizing change in O_2 to O_2 at maximal exercise significantly reduced this affect. Crum et al. (2017) found that the monitor was consistent during low to moderate intensity, and research regarding high-intensity experiments with the Moxy are lacking.

Summary

Pacing, while seemingly simple is a complex and multi-faceted concept. The human body uses primitive, physiological mechanisms of protection to combat catastrophic homeostatic imbalances from increased exercise intensity. The combination of afferent and efferent signals influences an individual's ability to anticipate the onset of fatigue. Modifications of exercise can then be made to override setbacks from environmental, physiological and psychological factors. The capacity to regulate pace and RPE, as well as develop performance templates prior to exercise invites research to challenge how quick these pre-anticipated pace selections can be created. An abundance of research has tested subjects during time trials when presented with deceptive distance feedback, multiple environmental factors, and other obstacles. It is hypothesized that athletes will display reciprocal PO and muscle O_2 saturation patterns when performing self-paced 20-km time trials and burst trials. It is also hypothesized that time to completion will not vary between the different types of trials as PO and intensity will be adjusted based on the trial. We conclude that RPE and HR will rise, and fall based on burst locations and the amount of recovery between bursts.

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