

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

CHANGE IN PACE DURING TIME TRIALS IN RELATION TO HAZARD SCORE

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

Corey Speaker

College of Exercise and Sport Science
Clinical Exercise Physiology

December, 2011

CHANGE IN PACE DURING TIME TRIALS IN RELATION TO HAZARD SCORE

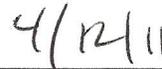
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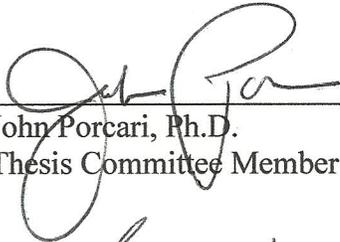
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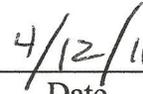
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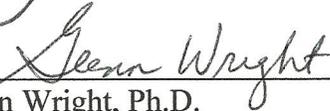
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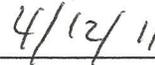
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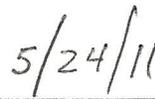


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Thesis accepted



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ABSTRACT

Speaker, C. Change in pace during time trials in relation to Hazard Score. MS in Clinical Exercise Physiology, December 2011, 36pp. (C. Foster)

Background: Pacing strategies are developed to avoid critical homeostatic disturbances. These disturbances can be monitored using the Rating of Perceived Exertion (RPE) scale. To maintain homeostasis and have optimal rate of increase in RPE athletes compute a ‘hazard’ score to determine whether or not it’s time to increase or decrease speed. The purpose of this study was to determine if the integration of momentary RPE and percent distance remaining (Hazard Score) explain these changes that can occur in pace.

Methods: Eleven cyclists performed a maximal exercise test and five 10km time trials (TT). Two trials were for habituation and to obtain a baseline pace. Pace was manipulated for the first 2km of the three subsequent randomized experimental TTs, after which the remaining distance was completed as fast as possible. RPE, HR, power output (PO), and blood lactate concentration was measured. **Results:** Hazard Scores between each trial were significant ($p < 0.05$). Hazard Scores of less than 1.0 indicated an increase in PO, whereas scores of greater than 3.0 indicated a decrease in PO. **Conclusion:** The Hazard Score seems to predict change in pace. This finding may become a helpful tool in terms of understanding how humans regulate their behavior during intense activity.

ACKNOWLEDGEMENTS

Many thanks to Carl Foster for the time and effort spent on guiding me in this project. Your help and input was much appreciated. Also, thanks to my committee members John Porcari and Glenn Wright for their time, effort, and attention to detail for this entire project. A special thanks to Jose Rodríguez-Marroyo for all of the time spent helping with data collection. Finally, thanks to Jana Hagen for helping recruit subjects for this study. The partial funding received for this work from UW-L resources is gratefully acknowledged

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INTRODUCTION

For centuries competition has been an integral part of human society whether for entertainment (non-athletes) or personal fulfillment (athletes). Since the early days of the Olympics, athletes have been searching for ways to attain optimal performance. For events that have a cyclical motion (i.e., swimming, running, cycling) the athletes pacing strategy is a major factor in determining outcome (1,7,10,11,20). During many races the competitor can be seen making either large accelerations near the end of the race (endspurt) or can be seen decelerating even if they know it will be detrimental to finishing successfully.

There are at least five main pacing strategies that have been identified, each dependant on the duration/distance of the exercise bout. For very short duration exercises ($\leq 30s$) an 'all-out' pacing strategy is typically used (1,3). This involves reaching the highest total power output as quickly as possible. For events that are between 0.5 minutes to 4 minutes or for ultra endurance events, a 'positive' pacing strategy is typically used (1,6,9,11). This is much like the all-out strategy where peak power is reached early during the bout, but has a gradual decrease. In events lasting longer than 4 minutes, but shorter than typical ultra endurance events, either an 'even' or 'negative' pacing strategy is utilized (1,11,20). The even strategy only has minimal fluctuations in power resulting in a relatively constant velocity for the entire duration of the bout. Negative pacing tends to start out like the even strategy, but usually ends with an endspurt or a large increase in velocity. The final pacing strategy that has been observed

is the 'parabolic' strategy. When plotted on a velocity versus percent distance completed graph, the data shows either a U-shaped or J-shaped curve.

For the most part, scientists have come to an agreement that humans develop pacing strategies in a way designed to avoid critical homeostatic disturbances. Along with this, the current physiological state of the athlete seems to influence the development of the strategy (21). During short duration exercise (1-30 min) decreases in power seem to be affected by substrate depletion or metabolite accumulation (7,9,12). For mid duration exercise (20-120 min) body or brain temperature seems to be a key determinant (15,17). Finally, for long duration exercise (>90 min) carbohydrate availability for oxidation is important (14). Depending on the duration of the exercise, these different elements will overlap.

It appears that the level of imbalance caused by these physiological disruptions can be monitored using the Rating of Perceived Exertion (RPE) scale. This scale has been considered an excellent tool for getting perceptual feedback on work capacity (2). It also seems to be a linear function of relative distance completed during exercise (5,13,16,18). Essentially the closer you are to the endpoint of a bout the higher the RPE. Utilizing RPE and the concept of 'teloanticipation', Tucker (19) developed a model showing how continuous afferent feedback interpretations and anticipatory calculations help athletes to determine the optimal rate of increase in RPE and work rate to attain the desired outcome (8,22). It is also apparent that the interpretation of afferent feedback is mainly dependant on remaining exercise duration. Thus, throughout a race the athlete is constantly compared to how they expected to feel relative to how much of the race is left. If a high RPE is reached too soon in the race then that athlete will have to decrease power

output and if the RPE is too low for that point in the race, the power output will most likely increase.

Considering the idea that athletes are basically trying to predict if they are able to speed up or have to slow down in a race, distance remaining seems to play a key role. We also know that RPE appears to be driven by an anticipatory response linked to perceptual feedback and is a key tool in the regulation of work rate. During a race, athletes apparently compute a 'hazard' score to determine whether or not it's time for an endspurt or if it's time to slow down. This score is computed using the following equation, $Hazard\ Score = RPE \times \% Distance\ Remaining$. So, if an athlete rates their RPE at 5 and has 50% of the race remaining their Hazard Score would be 2.5 ($5 \times .5 = 2.5$). Does the integration of momentary RPE and percent of distance remaining (Hazard Score) help explain these changes that can occur in pace?

Recently de Koning et al. (4) reviewed nine experiments, the results of which suggested the use of the Hazard Score. The studies were a combination of published and unpublished work involving cycling and running. The bouts performed ranged from 4 to 60 minutes and had performances of positive, negative, and u-shaped pacing strategies. In all of the studies they found a similar linear trend with RPE and percent distance remaining. When they computed the Hazard Scores for these studies an upside down J-shaped curve was found when Hazard Score was plotted against distance completed.

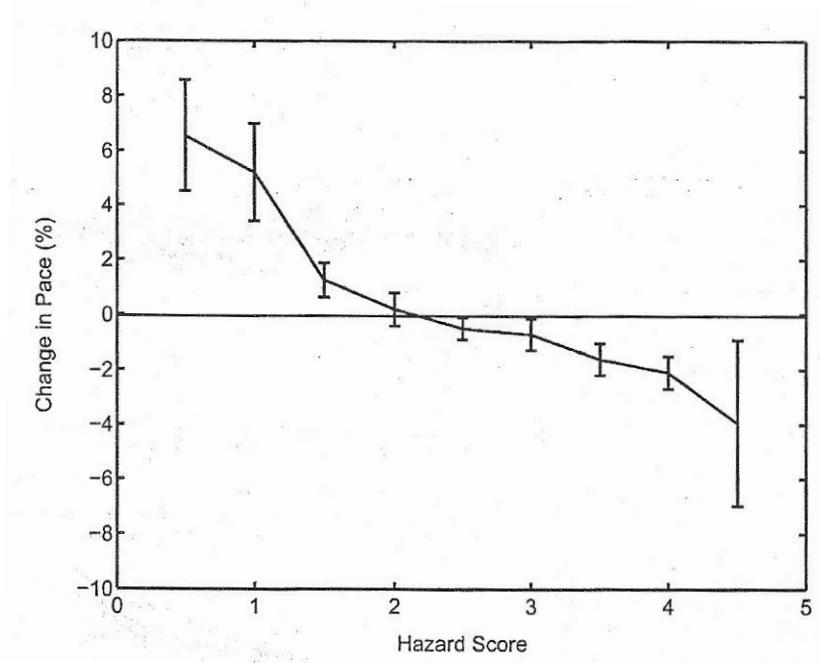


Figure 1. Data from de Koning et al. (4) showing the change pace in relation to Hazard Score

The main findings were that when the Hazard score was less than 1, an increase in power output or velocity was observed. Scores between 1 and 3 elicited no change in pace and Hazard scores above 3 showed a decrease in pace. These published data used for the most part, spontaneously paced time trials. However, athletes often use non-optimal pacing strategies for competitive reasons. The present study was designed to test the Hazard Score hypothesis by manipulating Hazard Score using fast, slow, and self-selected (SS) starting pace. We hypothesize similar findings with a low score resulting in an increase in velocity and a high score resulting in a decrease in velocity when pacing strategy is manipulated using a wide range.

METHODS

Subjects

Eleven recreational cyclists, male (n=4) and female (n=7), were recruited for this study. Table 1 shows the descriptive data for the subjects.

Table 1. Subject Characteristics

	Women (7)	Men (4)
Age (years)	23.2 ± 7.8	32.8 ± 7.8
Height (cm)	166.8 ± 4.7	179.2 ± 4.7
Weight (kg)	62.1 ± 5.1	83.1 ± 21.5
Rel. VO ₂ Max (ml/kg/min)	44.7 ± 5.7	51.8 ± 9.4
Abs. VO ₂ Max (L/min)	2.8 ± 0.4	4.1 ± 0.4
Max PO (watts)	225.9 ± 32.1	325.0 ± 35.4

Each participant completed the PAR-Q to assess state of health and ability to participate in the study. They also provided written informed consent prior to the study. This study was approved by the UWL Institutional Review Board for the Protection of Human Subjects.

Procedures

Prior to the experimental trials, subjects performed a maximal incremental exercise test (GXT) and two 10 km time trials (TT) on a Velotron cycle to allow for subject characterization and habituation. Participants were given a rest period of at least 72 hours between trials to allow for adequate recovery. They were also asked to refrain from vigorous activity during the rest period and maintain a similar diet before each trial.

The average velocity of the second 10 km trial (baseline pace) was recorded for each subject for use as a reference (base) in the experimental trials. For the three experimental trials, participants were assigned pacing strategies for each of the randomly ordered experimental 10 km TTs. Two of the three trials started off with a preselected pace for the first 2 km. For the last 8 km participants were instructed to finish the TT as fast as possible. Each participant performed one fast start trial (e.g. base+5% PO) and one slow start (e.g. base-5% PO) trial. For the other trial the subject was instructed to perform at a self-selected pace. Just prior to the 10 km bout the subject completed a 15 minute warm-up at varying percentages of max PO reached during the GXT. See figure 2 for the trial process.

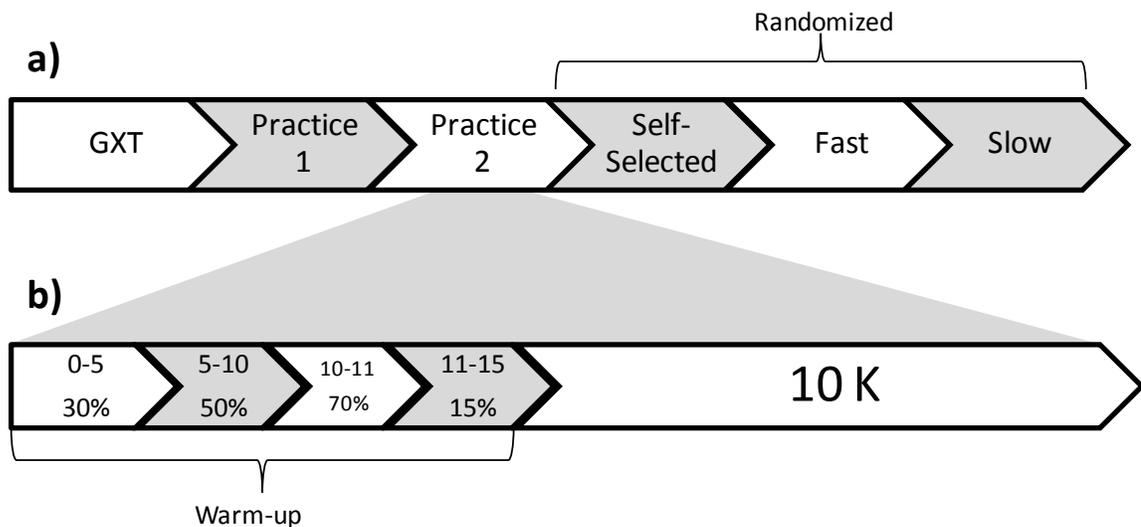


Figure 2. a) The process of the entire experiment from start to finish. b) The process of each individual 10 K trial. Percentages pertain to maximum PO attained during the GXT

During the experimental TTs heart rate (HR; Polar Vantage XL) and momentary RPE was recorded every 0.5 km. Simultaneously, power output (PO) was continually monitored and integrated every 0.5 km. RPE was measured using Borg's 0-10 category

ratio RPE scale (2). Every 2 km capillary blood was obtained from a fingertip was measured using dry chemistry (Lactate Plus, NOVA). Before each experimental TT the participant was informed that they would receive a small monetary reward if they improved over their baseline time (e.g. practice #2). This was intended to create a more competitive state of mind. However, the incentive option was not revealed to the participant until after the practice trials so that a negative bias could be avoided. Hazard Scores were computed every 0.5 km using the previously mentioned equation. Repeated measures ANOVA was used to analyze the measured data.

RESULTS

There was no main effect on time (Figure 3) or PO for the fast, slow, and SS pacing strategies.

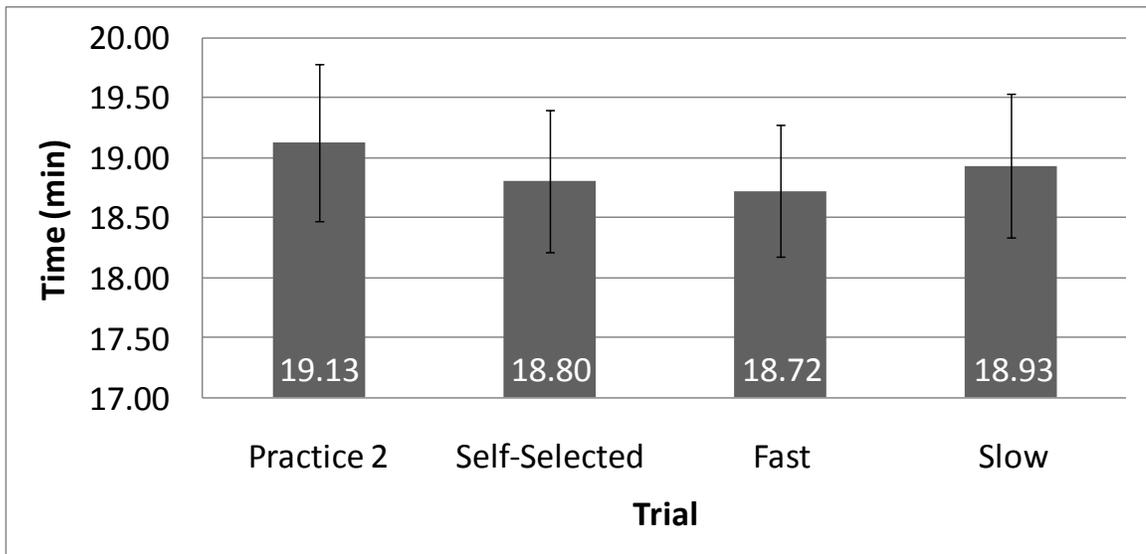


Figure 3. Overall times for the three experimental trials and baseline (Practice 2)

However, a significant main effect was found within PO for distance in the different trials as well as an interaction effect between strategy and distance ($p < 0.05$). The main effect for distance and the interaction effect can be observed in Figure 4 by looking at the difference in PO at the beginning of each trial in (~2 km).

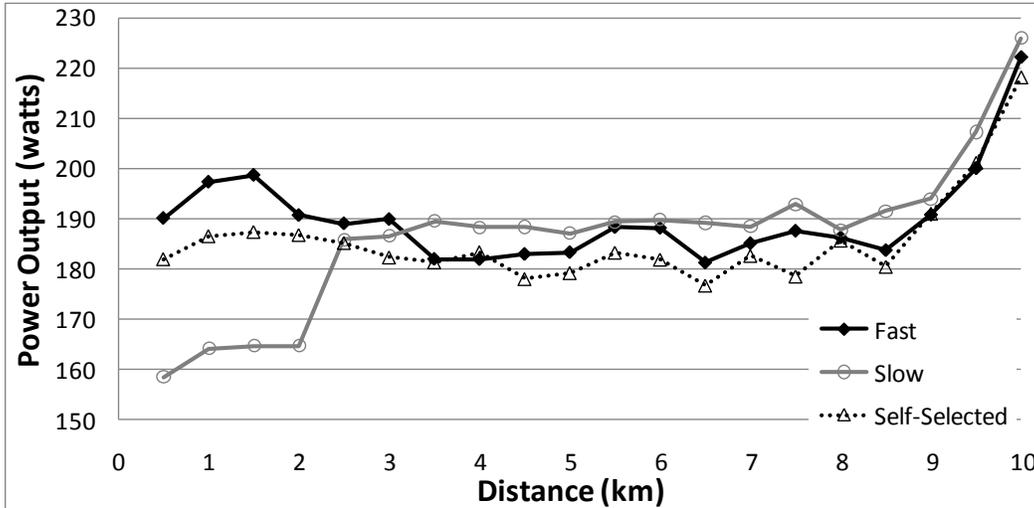


Figure 4. PO for the three possible pacing strategies

HR increased throughout each trial and stayed relatively similar to the SS trial. No main effect was found between pacing strategy. However, a significant main effect was found within HR for distance in the different trials as well as an interaction effect between strategy and distance ($p < 0.05$). The HR response for the 3 strategies can be seen in Figure 5.

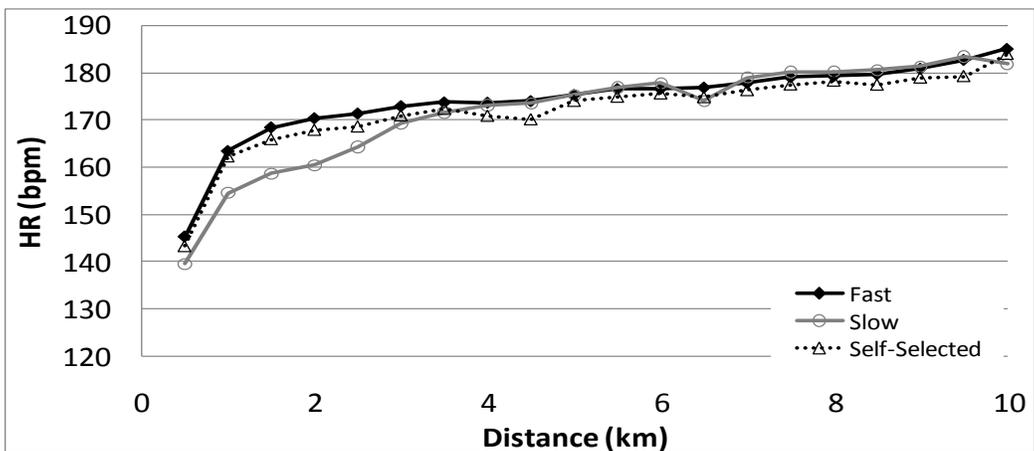


Figure 5. HR response during the three different trials

RPE had an overall positive linear progression throughout each trial, which can be seen in Figure 6. Overall RPE had a significantly different main effect related to strategy between the

three trials ($p < 0.05$). A significant main effect was also found within RPE for distance in the different trials as well as an interaction effect between strategy and distance ($p < 0.05$). This significant difference was mainly caused by a constantly elevated RPE during the Fast trial.

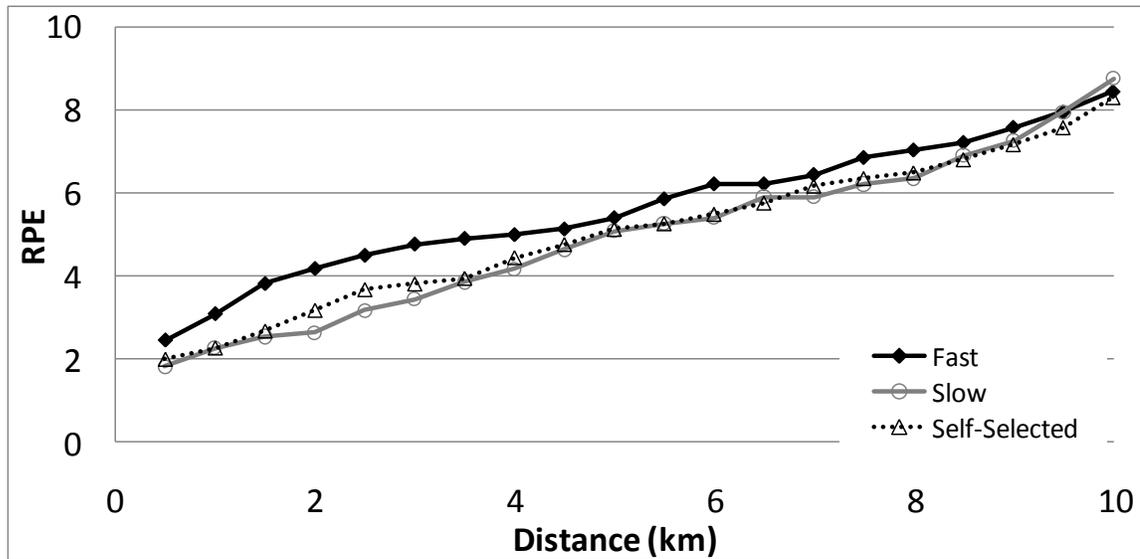


Figure 6. RPE measurements during each of the three different trials

Figure 7 shows the blood lactate concentration throughout each trial. All three trials had a similar linear increase in blood lactate. A main effect was not found for pacing strategy. However, a significant main effect was found within blood lactate for distance in the different trials as well as an interaction effect between strategy and distance ($p < 0.05$). Again, most of these differences are caused during the beginning of the trial due to the adopted pacing strategy.

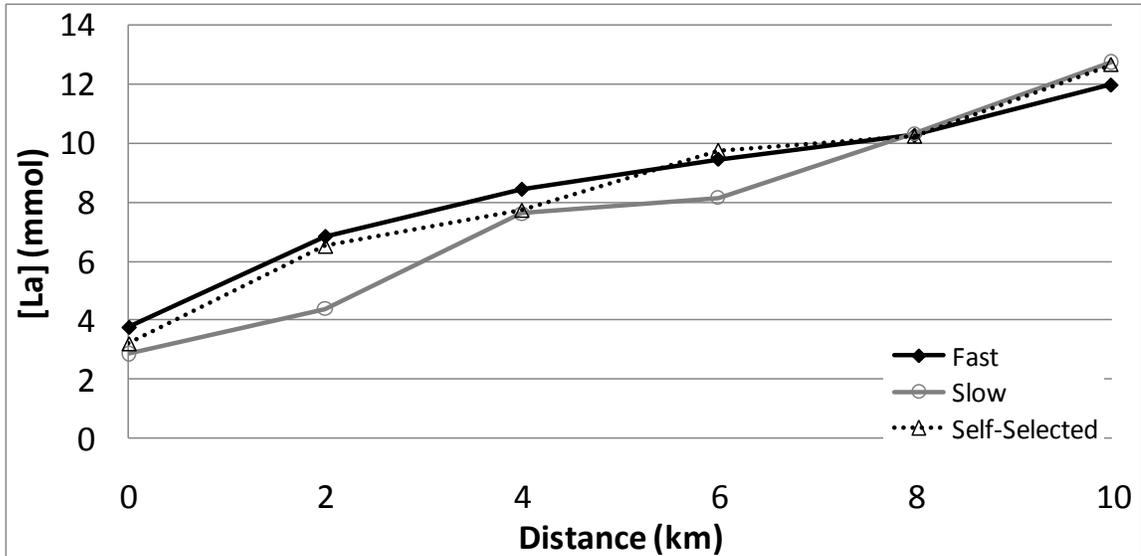


Figure 7. Blood lactate concentration during the each of the trials

Average Hazard scores ranged from 0 to 3.4. Overall Hazard Scores had a significantly different main effect between the three trials ($p < 0.05$). A significant main effect was also found between Hazard Scores for distance in the different trials as well as an interaction effect between strategy and distance ($p < 0.05$). This significant difference was similar to the RPE results by mainly being caused by a constantly elevated RPE during the Fast trial. Figure 8 depicts the Hazard score throughout each of the three types of trials. Three upside down J-shaped curves can be seen with a little spread between each during the beginning of the trials. Eventually the curves merged together around five km and terminated at a Hazard score of zero.

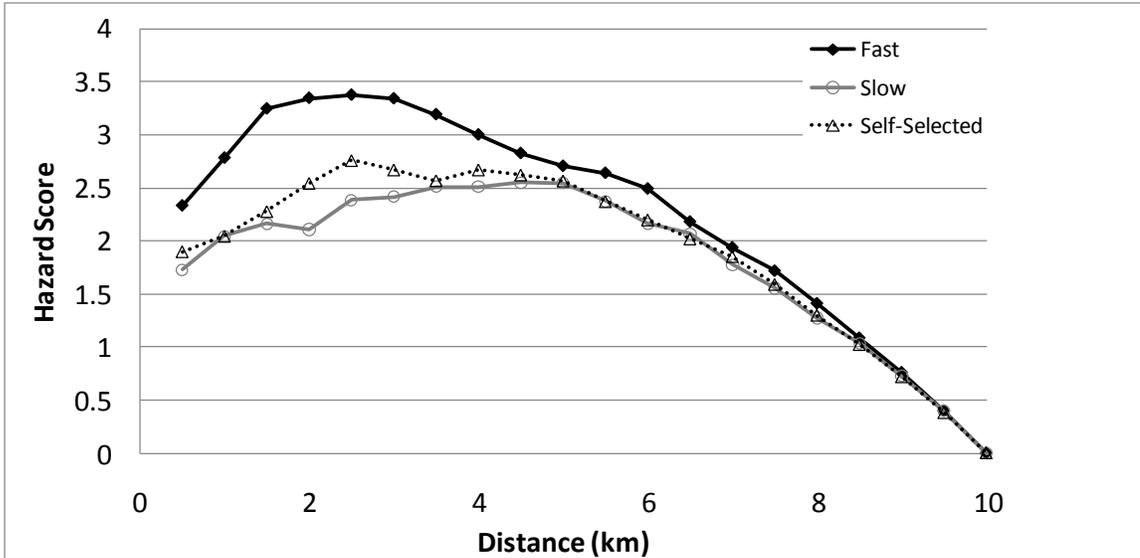


Figure 8. Fast, Slow and SS Hazard scores throughout each trial

A significant main effect was found for Δ PO for all three trials ($p < 0.05$). Also, a significant main effect was found for Δ PO in terms of distance and an interaction effect between strategy and distance ($p < 0.05$). It was observed that when Hazard Scores were less than 1.0 PO increased. Conversely, when Hazard Scores were greater than 3.0 PO generally decreased (Figure 9).

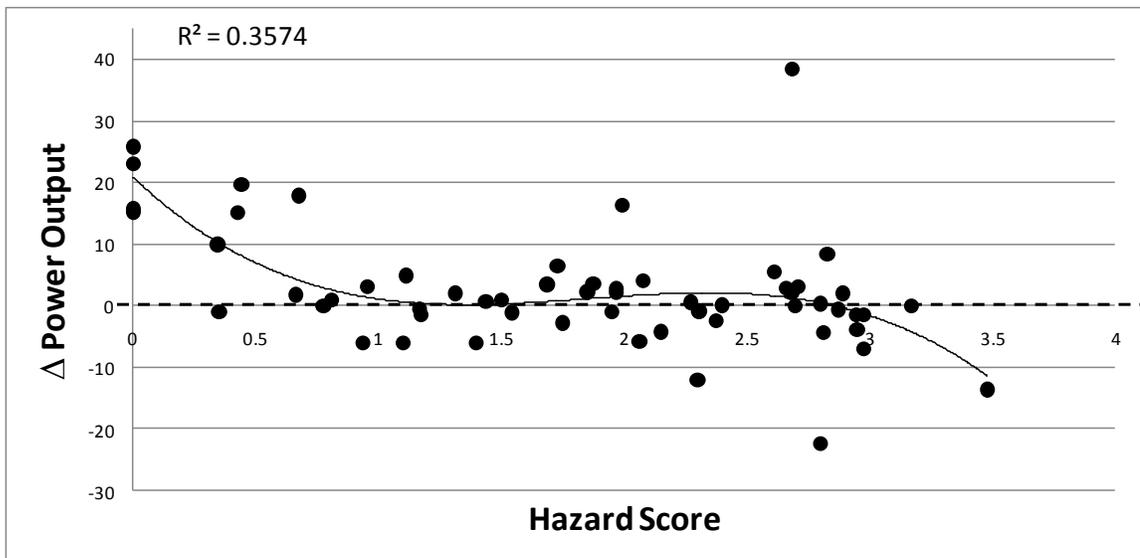


Figure 9. Change in power output as a function of Hazard score.

DISCUSSION

Even though pacing strategy had no effect on time or average PO of the trials, the main effect for distance suggests that PO was properly manipulated during the start of each trial to get a statistical difference in pacing strategy. It should be noted that even though time was not significantly different, practically, a faster time would be a more desirable outcome. Therefore, the Fast pacing strategy had the best outcome, followed by SS then the Slow strategy. Since average time and PO was unaffected overall HR was unaffected as well. The differences observed seemed to be mainly limited to the slow trials since HR was blunted during the first couple kilometers. The similar HR and lactate response from the different strategies reiterates that the body adapts to the strategy to avoid large homeostatic disturbances so that the desired outcome may be attained (21).

RPE followed the expected linear progression (5,13,16,18). The difference found with overall RPE reinforces the fact that the chosen pacing strategy was manipulated properly, at least from a perceptual perspective. It seemed that the starting pace drastically altered the outcome of RPE mainly during the Fast trial. The linear rise in RPE and the difference found between each of the three trials suggests that the subjects developed a template using teloanticipation to attain an optimal increase in RPE. (8, 21, 22).

Since the Hazard Score in all three trials became similar during the second half of the trials, there may be a limitation to the Hazard Score. As mentioned earlier athletes are mainly seen performing endsprints or slow way down at the end of a race, so the Hazard Score would be most useful during this part of the race. Unfortunately, all of the

scores become similar and during any event all eventually reach a score of 0 (refer to Figure 8). So, an alteration to the equation may be needed in the way the Hazard Score is calculated for the second half of a trial. This alteration would have to increase the sensitivity to detect the subtle differences in RPE when approaching the end of the race.

The outcome of change in PO as a function of Hazard Score yielded results similar de Koning et al. (4). The present study adds to their findings by looking more closely at pace manipulation in relation to Hazard Score in a laboratory setting. Overall, the study suggests that the integration momentary RPE in relation to percent distance remaining shows correlation to change in pace when starting pace is experimentally manipulated. This finding may become a helpful tool in terms of understanding how humans regulate their behavior during intense physical activity. More research is needed however to explore this concept in competitive level athletes.

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APPENDIX A
INFORMED CONSENT

Protocol Title: Change in Pace During Time Trials in Relation to Hazard Score

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La Crosse, WI 54601
218-235-1428

Emergency Contact: Carl Foster, Ph.D.
133 Mitchell Hall
University of Wisconsin-La Crosse
608-785-8687

- ***Purpose and Procedure***

- The purpose of this study is to see if the combination of rate of perceived exertion (RPE) and percent of distance remaining in a time trial help explain changes in pace within the trial.
- As a preliminary test, I will do a maximal incremental test to familiarize me with the lab and to document my exercise capacity.
- I will do two practice 10 km time trials on a cycle so an average performance can be found.
- I will then do three more 10 km time trials with a starting speed that's at my average speed, a little faster, or a little slower.
- After 3-5 km I will be allowed to go at the speed that I choose with the goal of finishing as rapidly as possible.
- During the time trials, I will wear a heart monitor around my chest.
- During testing, blood will be taken from my fingertip every few minutes to measure blood lactate.
- Throughout the test I will be asked how hard I am working using a 0-10 scale.
- I will have at least 72 hours of rest between time trials and will refrain from any hard activity during that time.
- Testing will take place in room 225 Mitchell Hall, UW-L and each session will last 60 min (5 hours total).

- ***Potential Risks***

- I may experience finger and muscle soreness and substantial fatigue.
- Individuals trained in CPR, Advanced Cardiac Life Support and First Aid will be in the laboratory, and the test will be terminated if complications occur.
- The risk of serious or life-threatening complications, for healthy individuals, like myself, is near zero.

- ***Rights & Confidentiality***

- My participation is voluntary.
- I can withdraw from the study at any time for any reason without penalty.
- The results of this study may be published in scientific literature or presented at professional meetings using grouped data only.

- All information will be kept confidential through the use of number codes. My data will not be linked with personally identifiable information.
- **Possible Benefits**
 - I may better understand the use of different pacing strategies and its effect on my performance.

Questions regarding study procedures may be directed to Corey Speaker (218-235-1428), the principal investigator, or the study advisor Dr. Carl Foster, Department of Exercise and Sport Science, UW-L (608-785-8687). Questions regarding the protection of human subjects may be addressed to the UW-La Crosse Institutional Review Board for the Protection of Human Subjects, (608-785-8124 or irb@uwlax.edu).

Participant _____

Date _____

Researcher _____

Date _____

APPENDIX B
REVIEW OF LITERATURE

LITERATURE REVIEW

For centuries competition has been an integral part of human society whether for entertainment (non-athletes) or personal fulfillment (athletes). Since the early days of the Olympics, athletes have been searching for ways to attain optimal performance in their chosen event. For events that have a cyclical motion (i.e., swimming, running, cycling) the athletes pacing strategy seems to be a major factor in determining outcome (1, 7, 10, 12, 22). During many races the competitor can be seen making either large accelerations during the middle of the race (endspurt) or can be seen decelerating even if they know it will be detrimental to finishing successfully.

Pacing Strategies

There are at least five main pacing strategies that have been identified, each dependant on the duration/distance of the exercise bout. For very short duration exercises (≤ 30 -60s) an ‘all-out’ pacing strategy is typically used (1, 3). De Koning et al. (3) explored the effect of a variety of pacing strategies during 1000 m and 4000 m cycling time trials (TT). The data collected indicated that in both TTs optimal performance was obtained when the highest total power output was reached immediately.

For events that are between 0.5 minutes to 4 minutes or for ultra endurance events a ‘positive’ pacing strategy is typically used (1, 6, 10, 12, 19). This is much like the all-out strategy where peak power is reached early during the bout, but has a more gradual decrease throughout since peak power isn’t quite as high, nor sustained quite as long. Sandals et al. (19) observed that the top 2% of elite runners during 800 m competitions adopted this strategy. The athlete’s speed throughout these events had dropped from 107.4% of average speed in the first lap to 97.5% of average speed in the last lap. Tucker et al. (22) observed a significant ($P <$

0.00005) decrease in speed during the second lap of 26 world record 800 m races from 1912-1997. Some researchers have observed this same pacing strategy in ultra-endurance events (>4 hours), however more research is needed to further investigate if this is the most effective strategy (1).

In events lasting longer than 4 minutes, but shorter than typical ultra-endurance events, either an 'even' or 'negative' pacing strategy is utilized (1, 12, 22). The even strategy only has minimal fluctuations in power resulting in a relatively constant velocity for the entire duration of the bout. Negative pacing tends to start out like the even strategy, but usually terminates with an endspurt or a large increase in velocity. Tucker et al. (22) analyzed pacing strategies of world record times for 5000 m and 10,000 m events from 1921-2004 and found that an overall negative pacing strategy was utilized. However, it was apparent that an even strategy was used for up to the last km for each event, at which time the athlete had a significant burst of speed or endspurt, causing an overall negative pacing strategy.

The final pacing strategy that has been observed is the 'parabolic' strategy. When plotted on a velocity versus percent distance completed graph, the data shows either a U-shaped or J-shaped curve. Garland (11) found a reverse J-shaped relationship for rowers during a 2000 m race. The speed of the rowers started fast, gradually became slower and then ended with a slight increase in speed. Garland (11) concluded that since most of the rowers (both 'losers' and 'winners') adopted this pacing strategy that others should as well, at least in 2000 m rowing. Another parabolic shaped pacing strategy is the inverted U-shaped, where peak power is reached during the middle of a race. This strategy was experimented on with cyclists however it was found to be ineffective during mid-duration events (10).

Physiological Response to Pacing Strategies

For the most part, scientists have come to an agreement that humans develop pacing strategies in a way designed to avoid critical homeostatic perturbations or disturbances while still allowing optimal performance. Along with this, the current physiological state of the athlete seems to influence the development of the strategy (23). During short duration exercises (1-30 min) decreases in power seem to be affected by substrate depletion or metabolite accumulation (7, 9, 13). Apparently, athletes tend to utilize energy sources in a way that allows maintained muscular power output from anaerobic energy expenditure throughout the entire bout (7).

For mid duration exercises (20-120 min) body or brain temperature seems to be a key determinant (16, 18). A case study done on a 35-year-old male tri-athlete reported a decrease in speed during the run phase (50 min) of the event. This change in speed was thought to be brought on by a large increase in core temperature and unusual reduction in blood sodium levels, which lead to cramping even though no signs of dehydration were present (16). The onset of fatigue brought about by hyperthermic conditions seems to be related to cerebral temperature rather than muscle temperature (18). Nybo et al. (18) found that electroencephalograms of the prefrontal cortex seem to be the best predictor of Rating of Perceived Exertion (RPE) during ~50 min long cycling bouts in hot conditions. They also noted that no alterations were observed for frequency or amplitude during electromyography between normal and hot conditions. Finally, for long duration exercises (>90 min) carbohydrate availability for oxidization is important (15). Karlsson et al. (15) experimented with two different types of diets and its effect on performance on 30 km runs. One diet was high in carbohydrates while the other was a mixed diet. All of the runners performed better with the special high carbohydrate diet, most likely due to the increased

availability of muscle glycogen. Overall, depending on the duration of the exercise, these different elements of physiological state will overlap.

Rating of Perceived Exertion and Pacing

It appears that the level of imbalance caused by these physiological disruptions can be monitored using the Rating of Perceived Exertion (RPE) scale. This scale has been considered an excellent tool for getting perceptual feedback on work capacity (2). It also seems to be a linear function of relative distance completed during exercise (5, 14, 17, 20). Essentially the closer you are to the endpoint of a bout the higher your RPE will be (Figure 1). Faulkner et al. (2008) suggested that this linear relationship exists despite differences in heart rate response, the athlete's velocity, course elevation, and pacing strategy.

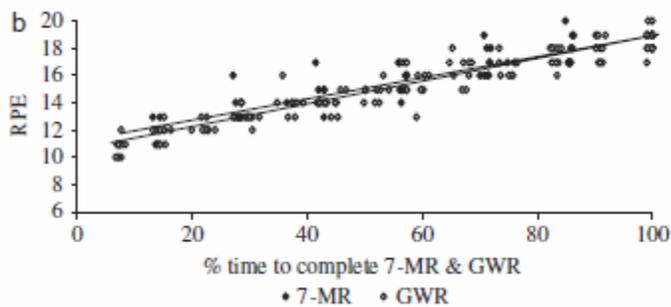


Figure 1. Faulkner et al. (5) data showing the linear relationship between RPE and percent distance remaining.

Joseph et al. (14) added to these findings by suggesting that this relationship exists even with varying distances.

To avoid early exhaustion, athletes monitor their exertion in a teloanticipatory way so that performance is based on the end point (24). Because of this athletes seem to develop a template before the beginning exercise (8). This template becomes better with habituation, ultimately increasing performance. Utilizing RPE and the concept of 'teloanticipation', Tucker (21)

developed a model showing how continuous afferent feedback interpretations and anticipatory calculations help athletes to determine the optimal rate of increase in RPE and work rate to attain the desired outcome (8, 24). It is also apparent that the interpretation of afferent feedback is mainly dependant on remaining exercise duration. Thus, throughout a race the athlete is constantly comparing how they feel relative to how much of the race is left. If a high RPE is reached too soon in the race then that athlete will have to decrease power output and if the RPE is too low for that point in the race, the power output will most likely increase.

Hazard Score

Considering the idea that athletes are basically trying to predict if they are able to speed up or have to slow down in a race, distance remaining seems to play a key role. We also know that RPE appears to be driven by an anticipatory response linked to perceptual feedback and is a key tool in the regulation of work rate. During a race, athletes essentially have to compute a ‘hazard’ score to determine whether or not it’s time for an endspurt or if it’s just time to put on the brakes. So, does the integration of momentary RPE and percent of distance remaining (Hazard Score) help explain these changes that can occur in pace?

Recently de Koning et al. (4) reviewed nine experiments the results of which suggest the use of the Hazard Score. The studies were a combination of published and unpublished work involving cycling and running. The bouts performed ranged from 4 to 60 minutes and had performances of positive, negative, and u-shaped pacing strategies. In all of the studies they found a similar linear with the product of RPE and percent distance remaining predicting changes in velocity. When they computed the Hazard Scores for these studies an upside down J-shaped curve was found when Hazard Score was plotted against distance completed.

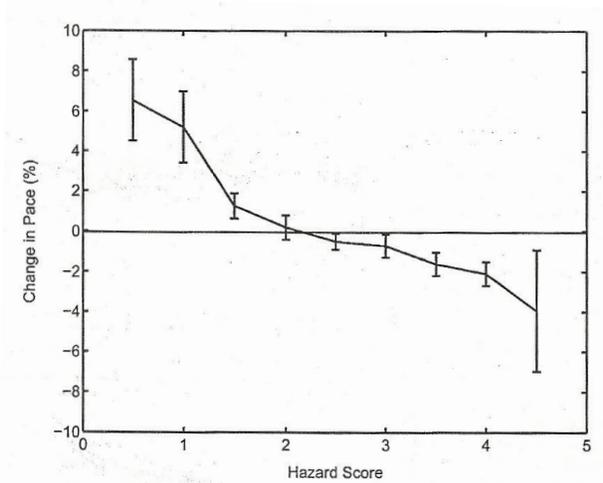


Figure 2. Data from de Koning et al. (4) showing the change pace in relation to Hazard Score.

The main findings were that when the Hazard score was less than 1, an increase in power output or velocity was observed. Scores between 1 and 4 elicited no change in pace and Hazard scores above 4 showed a decrease in pace (figure 2). We hypothesize similar findings with a low score resulting in an increase in velocity and a high score resulting in a decrease in velocity when pacing strategy is manipulated using a wide range.

Conclusion

By manipulating pacing strategy of the athletes we should see a corresponding change in Hazard score. Also, we would expect to see a similar linear correlation between RPE and relative distance remaining. Since athlete's seem to develop templates in an anticipatory manner and also strive for an optimal rate of increase in RPE and work rate, the Hazard Score may be beneficial in having a way to predict a change in pace. Overall, the development of the Hazard Score may become a helpful tool in terms of understanding how humans regulate their behavior during vigorous physical activity.

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