Original Article

Management of metabolic resources for a 20-km cycling time-trial using different types of pacing

DINESHEN CHUCKRAVANEN [1] ✉, SUJAN RAJBHANDARI [2]

[1] *School of Life Sciences, University of Northumbria at Newcastle, UK*

[2] *Faculty of Engineering, Oxford University, UK*

ABSTRACT

Chuckravanen, D., & Rajbhandari, S. (2015). Management of metabolic resources for a 20-km cycling time-trial using different types of pacing. *J. Hum. Sport Exerc., 10*(1), pp.95-103. Pacing is crucial for improving human performance in time-trial physical exercise. This study examined the effect of different types of pacing (self pace, variable pace and even pace) on the energy expended from the aerobic system and anaerobic system for a 20-km time-trial cycling exercise. In addition, the degree of homeostatic disturbance caused by each type of pacing was analysed to find out the effect of pacing on the human body. Furthermore, the relationship between the Ratings of Perceived Exertion (RPE) and blood lactate concentration was investigated, and associated to these types of pacing. Here, in this study, we showed that even pace was aerobic energy system dependent, and variable pace was anaerobic energy system dependent. Also, the Hazard Score index demonstrated that the variable pace time-trial caused the greatest homeostatic disturbance and there was a positive relationship between RPE and blood lactate concentration. **Key words**: AEROBIC SYSTEM, ANAEROBIC SYSTEM, HAZARD SCORE INDEX, HOMEOSTATIC DISTURBANCE, PACING STRATEGY, SPORTS PERFORMANCE.

✉ **Corresponding author.** School of Life Sciences, University of Northumbria at Newcastle, UK
E-mail: dineshen2013@gmail.com
Submitted for publication November 2013
Accepted for publication October 2014
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2015.101.08

INTRODUCTION

Pacing is a key component to strategy for any race and it plays an important role for athletic competition. The aim in racing is to cover the distance between the start and the finish lines or required distance as fast as possible provided one's conditioning levels and talent (Fitzgerald, 2009). In order to reach this goal, a racer such as a runner or a cyclist should be aware of the quickest pace he can maintain throughout the full race distance, and also the ability to adjust the pace along the way based on how he feels during the race so as to complete that race successfully (Ulmer, 1996). Pacing strategy is also critical during the training process of the racer and comprises of a distribution of efforts across a range of submaximal intensities (high and low) (Fitzgerald, 2009). Couple with that, pacing enables the available metabolic resources to be used efficiently so that the physical activity can be completed successfully and also in the minimum time possible (Ulmer, 1996). Pacing especially in time-trial exercise can be evaluated in terms of energy efficiency or metabolic demand. Very few studies focused on the energy production from aerobic and anaerobic metabolic pathways during prolonged physical exercise bouts (Hettinga, et al., 2006; Hettinga et al., 2007). Therefore, there is a need to investigate the energy generated from the aerobic and the anaerobic metabolic processes for various common types of pacing that are self pace, variable pace and even pace for a 20-km cycling time-trial physical exercise.

MATERIAL AND METHODS

Participants

Ten well-trained and healthy male cyclists took part in this research study. The mean (± standard deviation) of their Body Mass Index (BMI), height, measured work capacity and measured maximum oxygen uptake ($\dot{V}O_{2max}$) were 24.2 (±1.8) $kg \cdot m^{-2}$, 1.77 (±0.06) m, 353 (±30) W, 4.89 (±0.32) $L \cdot min^{-1}$ respectively. The participants' age varied from 25.5 to 40.1 years.

Study protocol

This research study was approved by the School of Life Sciences Ethics Committee at the University of Northumbria at Newcastle. The cyclists had to perform a 20-km cycling time trial exercise in the minimum time possible using three common types of pacing that were self pace, variable pace and even pace. In the self pace time-trial exercise, the cyclists were required to cycle as hard as they felt they could at any moment in time. For the even pace time trial exercise, the cyclists used the mean power output from their self pace cycling time trial exercise and for the variable paced strategy, the cyclists used 70% and 140% of their respective self pace power outputs (Palmer et al., 1999; deKoning et al., 2011). The participants performed these three types of pacing on three different days separated by at least one week apart to allow them to recover and also to prevent any training effect (Flynn et al., 1994).

Data collection

Physiological data including heart rate measured in beats per minute (BPM) were recorded using a data acquisition system (Powerlab, ADI Instruments, Australia), and volume of oxygen consumption ($\dot{V}O_2/L \cdot min^{-1}$) was measured using an online gas analyser (Cortex Metalyser, Cortex Biophysik, Germany). Power outputs were recorded at a frequency rate of 11 Hz using Velotron 3D software which was interfaced with the Cycle Ergometer (VelotronPRO, RacerMate Inc., USA) that was used for all cycling time trials. The Rating of Perceived Exertion (RPE) was used as a subjective measure for the sensation of fatigue the cyclists felt during the 20-km cycling time trial, and these RPE scores were obtained at every 2-km interval. RPE is a means of measuring the intensity of the physical activity level and the perceived exertion in facts represents how hard one feels like one's body is working. The RPE subjective measure provides a good estimate on the physical sensations a person feels while performing a physical exercise which include increased heart rate, increased breathing rate or respiration, increased muscle fatigue and sweating (Borg, 1970; Borg, 1998). The higher the RPE subjective measure value, the higher the level of intensity or work-out felt by the subject while performing a physical activity. In addition, blood samples were collected for every 4-km interval from the cyclists to determine blood lactate concentration ($mmolL^{-1}$). Generally, the blood lactate concentrations during exercise are commonly used to evaluate the effects of training in order to set the intensity of training and also to predict the performance of endurance exercise. Therefore, blood lactate concentration would help in evaluating the effect different types of pacing employed in this study. The data were collected by the research team of School of Life Sciences, and then these data were analysed using Matlab software platform version R2008a.

Furthermore, SPSS v17 software was used for subsequent statistical analysis. All the collected and computed data were tested for parametricity using Kolmogorov-Smirnov (K-S) test to find out whether they follow a normal distribution so as to ensure suitable statistical tests were identified for comparison purposes (Fasano & Franceschini, 1987; Lopes et al., 2007).

Data analysis
In order to analyse the energy expenditure for the different pacing trials, the metabolic aerobic power (P_{met}) was determined (Hettinga et al., 2006) from the measured volume of oxygen consumption ($\dot{V}O_2$), and the respiratory exchange ratio (*RER*) which is the ratio of the amount of carbon dioxide produced by the cyclist to the amount of oxygen consumed by the cyclist as shown in Equ. 1. Then, the Gross Mechanical Efficiency (*GME*) was calculated from the ratio of the power output (P_{tot}) to the metabolic aerobic power (P_{met}). Also, the anaerobic mechanical power (P_{an}) during the time-trial was computed as the difference between the power output and the aerobic mechanical power P_{ae} as shown in Equ. 2.

$$P_{met}\ (\mathrm{W}) = \dot{V}O_2\ (L \cdot min^{-1}) \times \{(4940 \cdot RER + 16040)/60\} \qquad \text{…Equ. 1}$$
$$P_{an} = P_{tot} - P_{ae} \qquad \text{…Equ. 2}$$

In this analysis, the respiratory exchange ratio (RER) in excess of 1.00 was assumed to occur due to the buffering of lactate by bicarbonate (Hettinga et al., 2006; Hettinga et al., 2007). The lactate represents the body's buffering agent that neutralizes the acid that accumulates in the working muscles (Brooks, 2001; Robergs et al., 2004).

Moreover, the Hazard Score index (deKoning et al., 2011), which is the product of the momentary rating of perceived exertion (RPE) and the fraction of the remaining distance, has the ability to show the likelihood that the cyclists would change their power outputs or their velocities during the cycling time-trial. This hazard score index would also show indirectly how the power outputs of the cyclists were regulated (deKoning et al., 2011). The calculated anaerobic and aerobic powers for the various pacing trials were then tested for parametricity using Kolmogorov-Smirnov (K-S) test (Fasano and Franceschini 1987), and then One Way Analysis of Variance (ANOVA) with repeated measures was used to compare the mean data between the time trials (Field, 2009). When significant F ratios were found ($p < 0.05$) in the statistical analysis, the means of the tested variables were consequently compared using a Tukey's post-hoc test. When testing for statistical significance, the p-value represents the probability of reaching the test statistic value (*e.g.* the mean of a population sample) as extreme as the observation value (Berger & Casella, 2001). The F-ratio is a test statistic in finding whether the difference between two or more independent variables is statistically significant or stable by computing the ratio of the variance between groups and the variance within groups (Lomax, & Hahs-Vaughn, 2012; Sawilowsky, 2002). The parametric statistical test, Pearson product moment correlation coefficient (*r*) was used to analyse relationship (if any) between the variables (Cohen, 1988) as the data variables were found to be normally distributed.

RESULTS

Total work done by all the cyclists for all the pacing time-trials

The mean (± standard deviation) of total work done by all the cyclists for self pace, even pace and variable pace were 5.14 (±0.01) MJ, 5.15 (±0.01) MJ and 5.13 (±0.01) MJ respectively (See Table 1).

Table 1. The total work (W_r), work through anaerobic capacity (W_{Anae}) and work through aerobic capacity (W_{Ae}) are displayed for each pacing trial

Participant Number	Self Pace (x 10^5 / J)			Even Pace (x 10^5 / J)			Variable Pace (x 10^5/ J)		
	W_T	W_{Anae}	W_{Ae}	W_T	W_{Anae}	W_{Ae}	W_T	W_{Anae}	W_{Ae}
1	5.569	0.979	4.591	5.559	0.637	4.922	5.569	2.047	3.522
2	5.568	0.999	4.569	5.568	0.881	4.687	5.571	2.143	3.428
3	5.566	1.592	3.973	5.571	0.578	4.993	5.537	2.052	3.485
4	5.317	0.802	4.515	5.323	0.559	4.764	5.282	1.994	3.289
5	5.157	1.067	4.090	5.149	0.526	4.623	5.072	1.945	3.127
6	5.109	0.784	4.325	5.105	0.665	4.440	5.105	1.891	3.214
7	5.010	1.244	3.766	5.007	0.863	4.144	5.004	2.083	2.921
8	5.013	1.170	3.843	5.015	0.724	4.290	5.009	2.028	2.981
9	4.731	1.071	3.660	4.733	0.788	3.946	4.735	2.033	2.701
10	4.399	0.873	3.526	4.434	0.664	3.770	4.370	1.751	2.618
Mean values	**5.144**	**1.058**	**4.086**	**5.146**	**0.689**	**4.458**	**5.125**	**1.997**	**3.129**

As shown in Table 1, it was found that there was no significant difference between W_T ($p > 0.05$). However, there were significant differences among anaerobic capacities, and aerobic capacities for all pacing trials ($p < 0.01$). Each row of the table (from the 3rd row onwards, that is from participant number 1 onwards) corresponds to the work done by a cyclist in increasing order of time performance except for the last row (bold) which represents the average of these variables. As expected, these results confirmed that there was no significant difference ($p > 0.05$) in the total work done by all the cyclists for each of the three different pacing trials. Furthermore, there was no significant difference ($p > 0.05$) in the total power which is the sum of the aerobic and anaerobic powers for each athlete for each pacing trial. Also, the total energy used by each cyclist for each pacing trial was practically constant despite the large variation in the amount of energy produced via the anaerobic energy system and the aerobic energy system for each pacing trial.

Anaerobic power, Aerobic power and Total power

Figure 1 shows the mean total power of all the cyclists for 5-km cycling interval. The average even pace power was about 265 W which was constant throughout the time trial while both self pace power and variable pace power decreased between 5 km to 15 km followed by endspurts (increase in power outputs) between 15 km to 20 km of the cycling time trial. Moreover, the mean gross mechanical efficiencies for self pace, even pace and variable pace were 17.9±1%, 18.1±0.9% and 18.3±1.1% respectively. In addition, it was found that there was no significant difference ($p > 0.05$) in the gross mechanical efficiency between the different pacing time-trials.

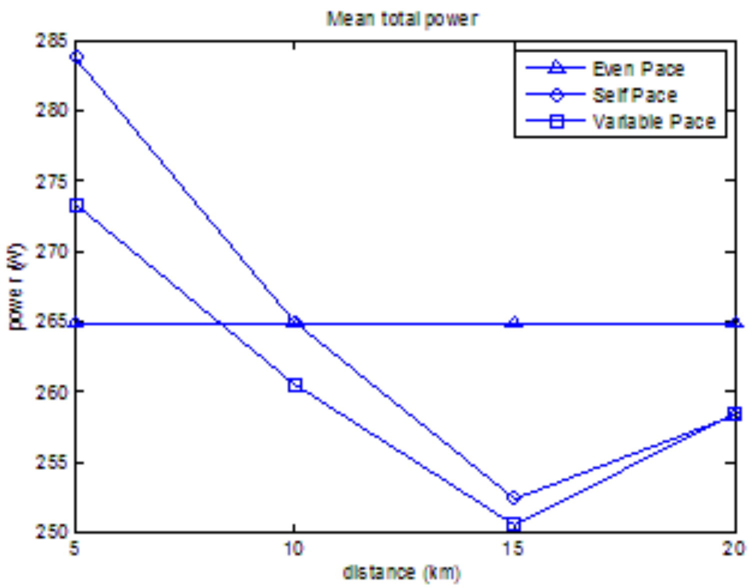

Figure 1. The average total power (W) for al the cyclists for 5km interval for even pace, self pace and variable pace trials

Mean aerobic and anaerobic powers at 5-km cycling interval

The aerobic and anaerobic powers for all cyclists were computed for each 5-km interval, and for each type of pacing (See Figures 2, 3). The data in Figure 2, showed that for self pace trial, the mean aerobic power increased to a peak until the mid-point of the time trial (*i.e.* 10-km), then decreased slowly from 10-km towards the end of the cycling race. In even pace and variable pace time trials, however, the mean aerobic power for all cyclists increased monotically to a "plateau". Interestingly, it was found that there was a significant difference ($p < 0.01$) between the estimated aerobic powers for all pacing trials. In Figure 2, the difference in the absolute values for each pacing aerobic power occurred because there was a large variability in the energy produced by the aerobic system from the ten cyclists.

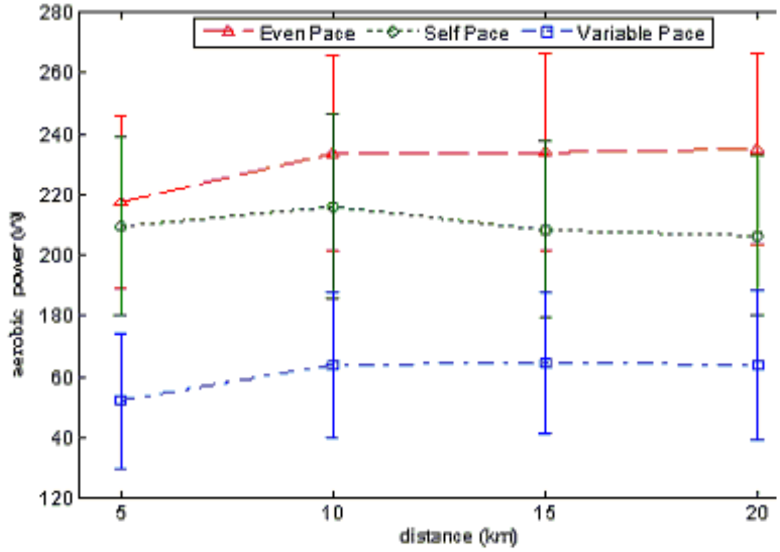

Figure 2. Aerobic power measured in watts (y-axis) for the participants (n=10) for the 20-km cycling time trials for even pace, self pace and variable pace (p<0.01)

Figure 3 describes the mean anaerobic power vs. distance (km) for the participants for the 20-km cycling time trial for even pace, self pace and variable pace at 5-km interval. It was found that there was a significant difference (p < 0.01) between the anaerobic powers for all pacing trials. Furthermore, the endspurts were clearly observed by the increase in the anaerobic powers between the 15-km to the 20-km of the cycling race for both variable pace and even pace trials. In Figure 3, the difference in the absolute values for each pacing anaerobic power occurred because there was a large variability in the energy produced by the anaerobic system from all the ten cyclists.

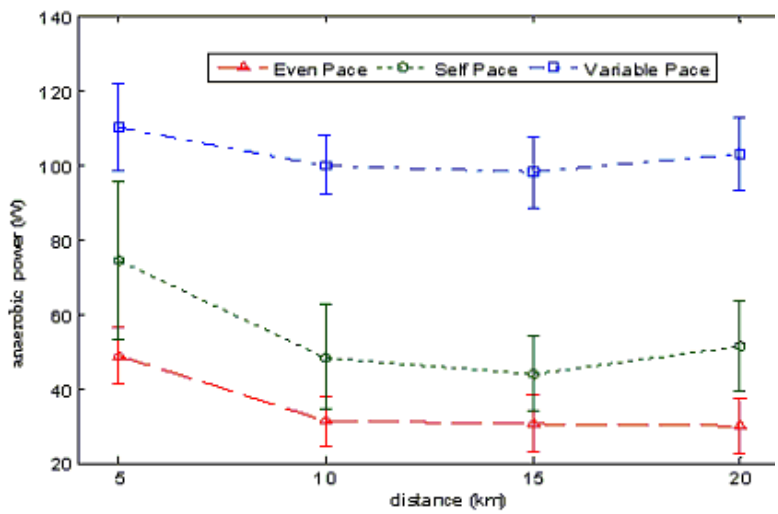

Figure 3. Anaerobic power measured in watts (y-axis) for the participants (n=10) for the 20-km cycling time trials for even pace, self pace and variable pace at 5-km interval (p<0.01)

Hazard Score index of the cyclists for the different types of pacing time trials

It was observed that the cyclists obtained the highest hazard score for the variable pace and least in self pace. Hence, variable pace caused greatest homeostatic disturbances in the physiological systems of the cyclists. In addition, all the hazard score graphs increased to a maximum and then decrease to zero resembling the arousal state inverted-U model or behaviour of the cyclists at a particular distance. This observation follows the Yerkes-Dodson law concerning arousal and performance (Yerkes & Dodson, 1908).

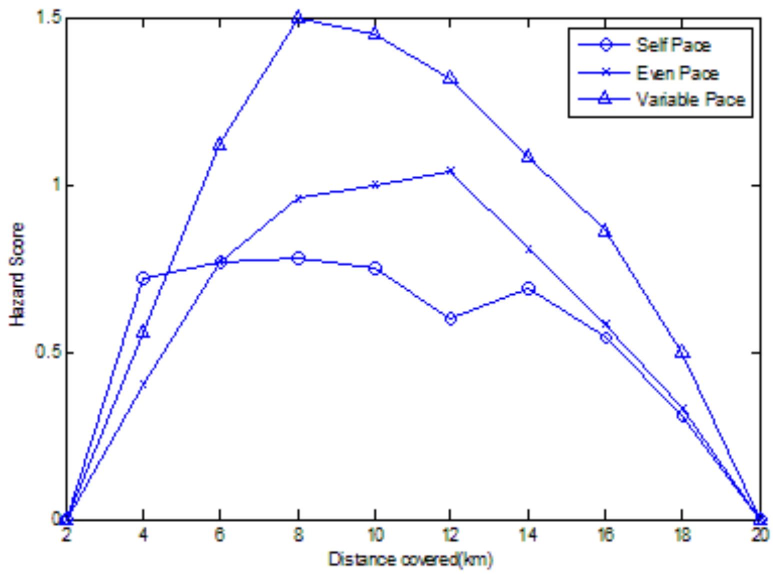

Figure 4. Hazard Score of the cyclist for each pacing time-trial vs. Distance covered (Hazard score = momentary RPE x Percentage of remaining distance).

Rating of perceived exertion and blood lactate concentration

The mean ratings of perceived exertion (RPE) for self pace, even pace and variable pace for that time trial endurance exercise were 15.4 (±1.3), 13.9 (±1.1) and 15.2 (±1.2) respectively. In addition, the mean blood lactate concentration was highest in the variable pace time trial with 5.8 (± 1.7) $mmolL^{-1}$ followed by self pace (5.0±1.7) $mmolL^{-1}$ and least in even pace time trial with a concentration of (4.1 ±1.3) $mmolL^{-1}$. The association between blood lactate concentration and rating of perceived exertion was found using the Pearson product moment correlation coefficient (r) which was +0.681. This means that there was a strong positive relationship (Cohen, 2002) between blood lactate concentration and the ratings of perceived exertion. This insinuates that when blood lactate concentration in the blood increases, the ratings of perceived exertion as felt by the participants also increases.

DISCUSSION

Mean gross mechanical efficiency

The effect of three types of pacing on the energy expenditure during a 20-km cycling time trial was investigated. The mean gross mechanical efficiency of 18.1±1 % determined in this study corresponded to previous data obtained for non-professional cyclists (Chavarren & Calbet, 1999; Moseley & Jeukendrup, 2001).

Total work done by cyclists

The total work done by all the cyclists was lowest for variable pace trial and highest for self pace trial, but there were no significant difference in the total work done among the three pacing trials. These results are in agreement of what was found in certain research studies that investigated shorter cycling distances (Hettinga, et al., 2006; Hettinga, et al., 2007) where they found also that even pace was found to be the preferred type of pacing. For a particular type pacing to be employed for a prolonged or endurance exercise, therefore, depends on the distance of the race. As shown in Figure 2, it was observed that the energy derived from the aerobic energy system pathway for even pace as greatest and least for variable pace. In contrast, it was observed that the energy derived through anaerobic metabolism for variable pace was greatest and least in even pace even though there was no significant difference in the total energy used by the cyclists for each pacing (Figure 3). Therefore, pacing did not necessarily favour a total economy of resources but rather influenced the way that energy was produced from the energy system pathways and it also helped to establish a suitable internal environment for the completion of physical activity.

Hazard Score index, RPE and blood lactate concentration

There is the tendency of the athletes to change pace (even in self pace time-trial) during competitive simulations which is partially related to how they feel at the moment (RPE) and to how much proportion of the event remains. The computation of a simple index by merging these two predictors produced the Hazard Score that represents the hazard of a competitively catastrophic collapse faced by the cyclist in a competition or a race, which seems to a good prediction of subsequent behaviour. It was found that the variable pace time trial caused the highest homeostatic disturbance, and least in self pace time trial as part of a conservatory nature or behaviour of the human organism. Interestingly, apart from the positive linear relationship between the rating of perceived exertion and blood lactate concentration, both measures were highest for variable pace as compared to the other pacing time trials.

CONCLUSIONS

In this study, the energy produced from anaerobic and aerobic metabolisms for various types of pacing for a 20-km cycling time trial were investigated. It can be deduced that even pace was aerobic energy system dependent, and variable pace was anaerobic energy system dependent. Hence, one of the questions that arises is whether a particular type of pacing favours a particular metabolic energy process (i.e. anaerobic or aerobic) and, if this is so, then there is a need to understand whether the human body system favours a particular energy system and optimizes performance accordingly. Furthermore, the hazard score index showed that the variable pace time-trial caused the greatest homeostatic disturbance as compared to the other pacing time-trials (self pace and even pace), and there was a correlation between blood lactate concentration and ratings of perceived exertion.

ACKNOWLEDGEMENTS

I would like say thanks Mr. Kevin Thomas and Dr. Mark Stone for their precious time in the lab for the collection of data, and also the research participants and club level cyclists who took part in this study. I would like to present my sincere gratitude to Professor Alan St Clair Gibson, Professor Kevin Thompson, Dr. Les Ansley, and Professor Maia Angelova for their helpful advice in the integration of findings from a physiological side of view and a mathematical side of view respectively. I would like to convey my enormous thanks to the School of Life Sciences, Northumbria University at Newcastle for my scholarship grant to pursue my research studies.

REFERENCES

1. Berger, R.L., & Casella. G. (2001). *Statistical Inference* (2nd ed.). Duxbury Press, p.374.
2. Borg G. (1970). Perceived Exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine*, *2*(2), pp.92-98.
3. Borg, G. (1998). *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: Human Kinetics.
4. Brooks, G.A. (2001). Lactate doesn't necessarily cause fatigue: why are we surprised? *J. Physiol.*, 536(1), pp.1
5. Chavarren, J., & Calbet, J. A. (1999). Cycling efficiency and pedalling frequency in road cyclists. *Eur. J. Appl. Occup. Physiol*, *80*, pp.555-563.
6. Cohen, J., Cohen, P., West, S.G., & Aiken, L.S. (2002). *Applied multiple regression/correlation analysis for the behavioral sciences*, 3rd ed. Psychology Press.
7. deKoning, J.J., Foster, C., Bakkum, A., Kloppenburg, S., Thiel, C., Joseph, T., Cohen, J., Porcari, J.P. (2011). Regulation of Pacing Strategy during Athletic Competition. *PLoS ONE, 6*(1).
8. Fasano, G., & Franceschini, A. (1987). A multidimensional version of the Kolmogorov–Smirnov test. *Monthly Notices of the Royal Astronomical Society*, *225*, pp.155-170.
9. Fitzgerald, M. (2009). *Racing Weight: How to Get Lean for Peak Performance*. VeloPress, Competitor Group, Inc., USA.
10. Flynn, M.G., Pizza, F.X., Boone, J.B., Andres, F.F., Michaud, T.A., & Rodriguez-Zayas. (1994). Indices of training stress during competitive running and swimming seasons. *Int. Journal of Sports Medicine*, *15*, pp. 21-26.
11. Hettinga, F.J., deKoning, J.J., Broersen, F.T., Van Geffen, P., & Foster, C. (2006). Pacing strategy and the occurrence of fatigue in 4000m cycling time trials. *Med. Sci. Sports Exerc.*, *38*, pp.1484-1491.
12. Hettinga, F.J., deKoning, J.J., Meijer, E., Teunissen, L., & Foster, C. (2007). The effect of pacing strategy on energy expenditure during a 1500 m cycling time trial. *Med. Sci. Sports Exerc.*, *39*, pp.2212-2218.
13. Lomax, R.G., & Hahs-Vaughn, D.L. (2012). *Statistical Concepts: A Second Course* (4th ed.). Routledge.
14. Lopes, R.H.C., Reid, I., & Hobson, P.R. (2007). The two-dimensional Kolmogorov-Smirnov test. *XI International Workshop on Advanced Computing and Analysis Techniques in Physics Research* (April 23–27, 2007) Amsterdam, the Netherlands.
15. Moseley, L., & Jeukendrup, A. (2001). The reliability of cycling efficiency. *Med Sci. Sports Exerc.*, *33*, pp. 621-627.
16. Palmer, G.S., Borghouts, L.B., Noakes, T.D., & Hawley, J.A. (1999). Metabolic and performance responses to constant –load vs. variable-intensity exercise in trained cyclists. *J. Appl. Physiol.*, *87*, pp. 1186-1196.
17. Robergs, R.A., Ghiasvand, F., & Parker, D. (2004). Biochemistry of exercise-induced metabolic acidosis. *Am. J. Physiol. Regul. Integr. Comp Physiol., 287*(3), pp. 502-16.
18. Sawilowsky, S. (2002). Fermat, Schubert, Einstein, and Behrens-Fisher: The probable difference between two Means when σ12 ≠ σ22. *Journal of Modern Applied Statistical Methods*, *1*(2), pp.461-472.
19. Ulmer, H-V. (1996). *Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback.* Experimentia, *52*, pp.416-20.
20. Yerkes, R.M., & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, pp.459-482.