UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

EFFECT OF RUNNING EXPERIENCE ON PACING STRATEGY

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

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EFFECT OF RUNNING EXPERIENCE ON PACING STRATEGY

By Samantha Bischel

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

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ABSTRACT

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The purpose was to learn how people develop a pacing template during running and test the hypothesis that there is less variability in running velocity as subjects become more familiar with all-out time trials. 12 fit subjects (3f, 9m) with minimal experience in competitive running completed six 3km running trials. Subjects completed the trials in the fastest time possible, with incentives being offered to improve time. RPE was measured every 200 meters and velocity every 100m. Blood lactate was measured pre and post trial. HR was recorded throughout each trial. Time improved from trial to trial. Mean starting velocity increased from trial to trial but mean finishing velocity was the same. There was not a significant decrease in the coefficient of variation of velocity across trials. The slower starting velocities in the initial trials agree with the anticipatory regulation of exercise response. The subjects started out slower and as the trial neared the end they were able to speed up because they felt as though they would not harm themselves. In subsequent trials, they started faster, based on the experience in the preceding trial. As the starting velocities got faster, ending velocities remained essentially constant. We had hypothesized that with experience the subjects would develop a more even pacing pattern. However, the data did not support our hypothesis.

ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude and appreciation to my family, who has been there for me in everything I have done throughout my life. They have been a huge influence on my life and I would like to thank them for having such a positive impact in my life.

I would like to thank Dr. Carl Foster for his time and efforts throughout this thesis. It was wonderful to work with such a knowledgeable and influential person. Thank you for everything, I could not have done this without all of your help.

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INTRODUCTION

Nearly everyone knows or is familiar with Aesop's fable "The Tortoise and the Hare". As the story goes, there is a hare that was continuously bragging about how fast he can run and he would laugh at the tortoise, which was so slow. One day the tortoise finally challenged the hare to a race and the hare laughed and quickly agreed. On the day of the race the hare was very confident and quickly flew past the tortoise. As the race went on the hare stopped to play and take a nap while the tortoise slow, but steadily kept moving. When the hare reached the finish line, he saw that the tortoise was already there waiting for his arrival. Did the hare lose because he was overconfident or did the tortoise pace himself just right? There are many ways to interpret this tale just like there are many ways people can interpret the correct pacing strategy in athletic performance.

Robinson et al. (8) performed the first systematic study of the effects of pace variations on performance. They had three well-trained men run the same distance with three different pacing patterns; a fast start, an even start, and a slow start. They found that there was a higher VO_2 requirement, higher post-exercise blood lactate levels, and greater subjective effort with the fast start strategy. Robinson et al. suggested that the best way to run a middle distance event was to wait until as close to the end as possible before putting forth the most effort. The next systematic study of pacing pattern was not until 1993 when Foster et al. (4) studied the effect of 5 pacing strategies on performance in 2km time trials (TT) on a bicycle. The participants were asked to complete the first kilometer of each trial in a predetermined percentage of a control time based on practice trials, ranging from very slow to nearly as fast as the subject could ride for one kilometer. For the final kilometer, the subject finished in the fastest time possible, with the intent of minimizing the total time for the trial. Results of this study showed that trial time difference between the slow start and the fast start was 7.2 seconds, and the trial time difference between the even start and the fast start was 4.2 seconds. Although the even start had the fastest total time for the 2km TT, it was stated that for a shorter race a fast start is more optimal than an even or slow start. Since this 1993 study, there have been many studies regarding pacing strategy.

In 1996, Ulmer looked at the concept of teleoanticipation (10). Feedforward and afferent feedback systems were looked at by taking two duration activities, one long (swimming) and one short (running), and assigning athletes to perform to a specific RPE value. Ulmer found that in the short duration activity, the assigned RPE values peaked in velocity during the initial seconds and was followed by a steady decrease for the rest of the bout. During the long duration activity, assigned RPE values peaked initially, and was followed by a rapid decline and a long plateau. These results showed that exertion is set at first by a feedforward system and then altered by an afferent feedback system once the exercise has begun (10).

Swart et al. also looked at the concept of teleoanticipation (9). There was two parts involved in this study, part one involved a self-paced 40km TT. One TT was performed each week, for four consecutive weeks. All subjects were asked their RPE values at 5km intervals. A fifth trial was added in order to create uncertainty about distance and subjects were asked to report RPE at random intervals. The second part of this study involved four trials; 5, 10, 40, and 100km. The results provided further evidence that exercise is controlled by a feedforward system and this occurs in a teleoanticipatory fashion (9). It was also pointed out in this study that the more familiar a subject is with an exercise bout, they will approach the task with a more aggressive strategy (9).

Baden et al. looked at two groups of well-trained runners. One group was instructed to run for 10 minutes at 75% maximum oxygen uptake and the other group, the control group, was instructed to run for 20 minutes (1). As the 10 minute group approached the end of their run, they were told to run an additional 10 minutes. What they found was that the RPE values were significantly higher in the eleventh minute of the 10 minute group, than the eleventh minute in the control group (1). This study highlights the importance of anticipation of the duration of an event. It also points out that RPE is not entirely related to physiological strains (1).

Given that pacing pattern can be determinative of performance, it is also of interest how a pacing template is developed (5). Foster et al. (5) performed a study with 4 parts; A) six 3km cycle TT, B) Three 2km rowing TT, C) Four 2km rowing TT with a training period in between trails 2 and 3, and D) Three 10km cycle TT. All of these TT were self-paced. At the beginning of the TT the subjects were told to finish as quickly as possible. During the TT, feedback was given and RPE was recorded. Results showed that in the beginning trials the power output was reduced during the first portion of the trials, and the power output during the end portions of the trail were consistent. Later trials showed a more aggressive early pace, which gave evidence that a stable performance template was achieved by the third or forth trial. In summary, there appears to be a learning effect during the performance of successive high-intensity TT.

The Rating of Perceived Exertion (RPE) is a very common tool used when it comes to exercise testing. RPE is a representation of how hard you feel your body is working (2). One version of the scale ranges in numbers from 6-20, with 6 being "no exertion at all" and 20 being "maximal exertion". This scale increases linearly with physiological measures, such as, heart rate, and VO_2. More recently, a Category-Ratio Scale has been developed. This scale is numbered 0-10, with 10 being "very, very strong" for the heaviest exercise or physical work as perceived by the subject (2). On the opposite end of the scale is "very, very weak", which is set at .5 (2). When using this scale people are permitted to use decimals and also go beyond 10 (2). In one psychological study a close correlation between ratings according to this new scale and both blood and muscle lactate concentrations were obtained (6).

By studying pacing strategies a greater understanding can be gained in regards to how athletes should use their energy to achieve their best performance during athletic competition. O'Brien (7) performed a study looking at variations in pacing strategies within various age groups. It was observed that the college-aged subjects began developing a less variable pacing pattern over the three TT that were performed. This demonstrates that as people participate in successive TT, they become more comfortable with the task, therefore they are able to perform harder and with less variability.

This study was designed to observe how people develop a pacing template during running. We hypothesized that there would be less variability in running velocity as subjects become more familiar with the trial runs.

METHODS

Subjects

The subjects provided written informed consent and the study protocol was approved by the University of Wisconsin- La Crosse Institutional Review Board for the Protection of Human Subjects prior to beginning the study. There were 12 subjects who participated in this study, 9 men and 3 women. The subjects ranged in age from 20-30 years. Subjects had little to no specific training in any pacing technique. See Table 1 for subject descriptive characteristic, although all were very physically active.

Table 1. Descriptive Characteristics

Mean Characteristics ± SD	Men (n=9)	Women (n=3)
Age (years)	21.1 ± 1.9	25.0 ± 5.0
Height (cm)	181.9 ± 5.1	165.9 ± 5.8
Weight (kg)	81.0 ± 6.2	69.7 ± 8.6
$V0_{2max}$ (ml/kg)	56.7 ± 4.1	43.7 ± .8
Max HR (bpm)	186.8 ± 9.0	187.7 ± 8.3

Protocol

Subjects completed six trials of a 3km run, with at least 72 hours between runs in order to ensure that fatigue was not an issue. Subjects were allowed to do other forms of exercise in between the trials, but asked not to perform any maximal effort activities the day before or day of the trials. All trials were performed on an indoor 200m running track. A camera was used to record the duration of each subjects' six trials. A RPE Scale was placed on the inside of the track ~20m from the start/finish point. Ratings of Perceived Exertion were recorded every 200 meters. Each subject performed a standard warm-up before each trial, which consisted of three laps jogging followed by one lap walking. Immediately following the warm-up, blood lactate was measured in capillary blood from a fingertip. Blood lactate was also measured immediately (~1 minute) after each trial was completed. Start times were staggered, with at least ten seconds between each subjects starting time, with the intent of preventing head-to-head competition. Radiotelemetric heart rate monitors were worn to record heart rate during each trial. The subjects performed the first trial and were asked to complete it in the fastest time possible. After the first trial was completed, the subjects were informed of a monetary incentive ($5 gift card) they would receive if they kept improving their performance. This was to ensure their maximal effort was given.

Each subject also completed a maximal graded exercise test (GXT) in the laboratory. The maximal GXT involved 2-minute stages, beginning at 2 mph and 1% grade. RPE and heart rate was recorded at the end of every stage.

RESULTS

Table 2. Mean Responses During 3km Time Trials. Values are Mean ± SD

Trial	1	2	3	4	5	6
Time (min)	14.8 ± 2.4	14.6 ± 2.5	14.4 ± 2.4	14.0 ± 2.2	13.9 ± 2.3	13.8 ± 2.2
Max HR (bpm)	197.8 ±13.6	199.8 ±14.3	197.9 ± 10.1	200.6 ± 11.3	195.6 ± 7.3	201.6 ± 11.7
HLa Rest (mmol*l-1)	3.9 ± 1.8	2.9 ± 1.2	3.1 ± 1.1	4.2 ± 1.3	3.3 ±1.3	3.6 ±1.2
HLa Ex (mmol*l-1)	13.4 ± 3.0	11.7 ± 4.0	12.4 ± 3.8	14.2 ± 2.9	14.9 ±4.5	14.1 ± 3.3
Max RPE	9.5	9.5	9.8	9.9	9.8	9.9
CV velocity (m/s)	0.0417 ± 0.02	0.0415 ± 0.02	0.0369 ± 0.01	0.0428 ± 0.02	0.0582 ± 0.02	0.0596 ± 0.02

With each trial, mean time continued to improve. As trials went on, there appeared to be a plateau beginning to develop with the fourth, fifth, and sixth trials (Figure 1). This time improvement suggests that the subjects were trying their best on the trials; they were becoming more familiar and more comfortable with their abilities, indicating that the anticipatory mechanism was coming into play with each trial. Starting mean running velocity also improved with each trial. The first trial had the slowest starting mean velocity and with each following trial starting velocity increased (Figure 2). While mean velocity improved at the beginning of each trial, ending mean velocity remained constant. In Figure 3 the trials are separated in order to see the mean velocities of each trial along with the velocity of each subject throughout each trial. The subjects began the study much more even paced for the earlier trials. In the later trials velocity variability increased, especially at the end of the trial runs. Delta velocity was calculated and we found in the first two trials that most of the subjects remained consistent with delta velocity until the last 500 meters of the trial runs. As the trials went on, delta velocity increased earlier on in the race. Figure 4 shows the delta velocity of each subject for each of the six trial runs, with the mean delta velocity in bold. The coefficient of variation (CV) running velocity was calculated and is shown in Figure 5. The trials in this study are compared to a study by O'Brien, which involved three trials of a 1-mile run (7). The subjects included in the study ranged from children to college-aged students. The coefficient of variation in the O'Brien study got smaller with the trials as compared to this study where CV got larger (Figure 5). During each trial RPE was recorded every 200 meters. We asked that each subject ran the trials in their fastest time possible, so they should have finished each run with an RPE of approximately 10. In Figure 6, the RPE recordings for each subject for each trial can be seen. The mean RPE at the end of each trial was at or very close to a 10, indicating that the subjects were running their best for that day. Heart rate was recorded for each trial. Figure 7 shows that mean heart rates for each trial were slightly above the mean max values taken from the V02max tests that were done in the lab. Pre and post blood lactates can been seen in Figure 8. Post trial was much higher than the pre exercise blood lactate levels. The post exercise blood lactate concentrations are in the range often observed following competition. The increase in heart rate during the trials and the increase in blood lactate levels suggest that there was a competitive level effort made by subjects.

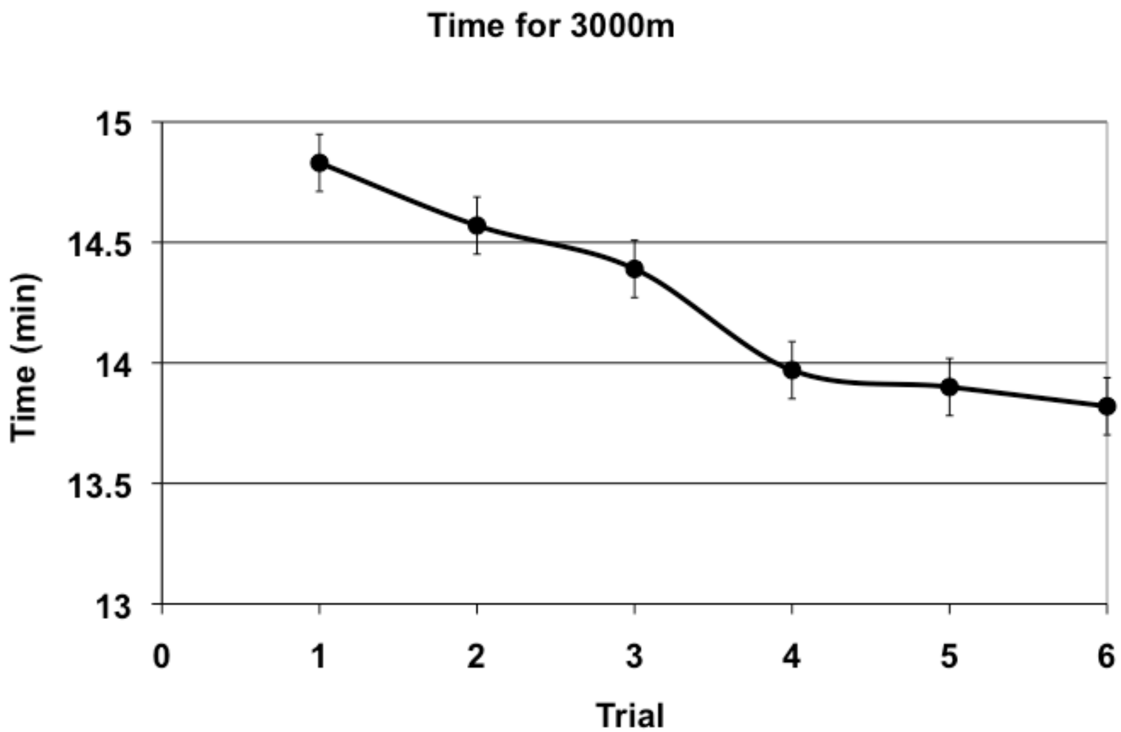

Figure 1. As trials went on, mean times improved, each time faster than the trial preceding it. A slight plateau can be seen developing in trials four, five, and six.

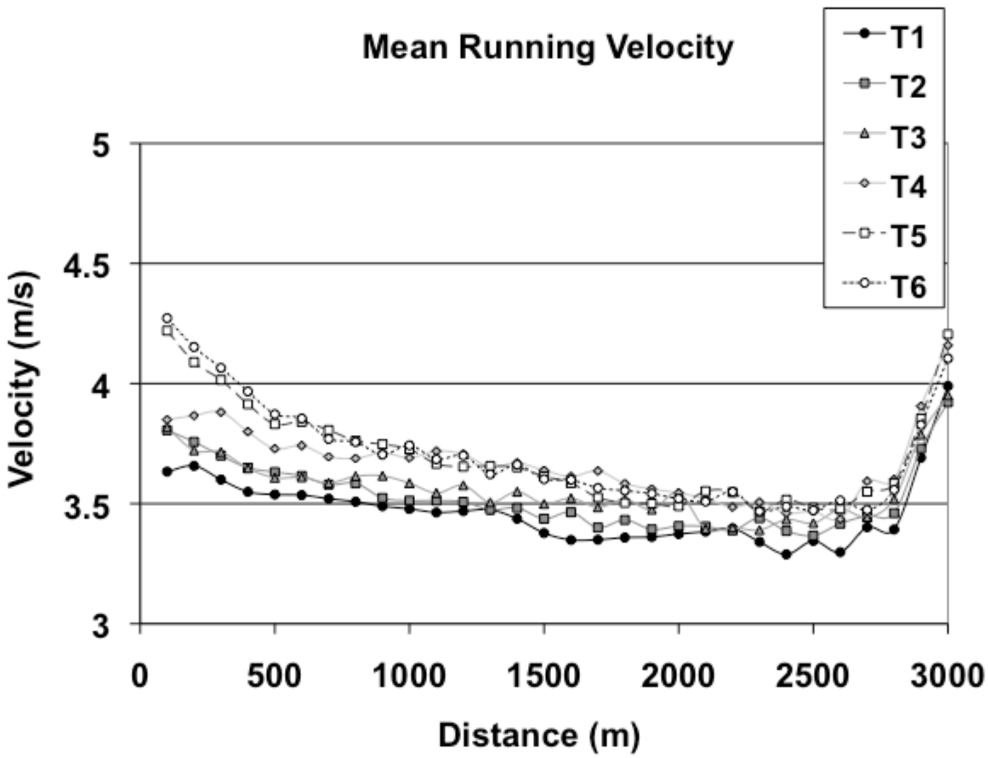

Figure 2. Mean running velocity was calculated for each trial. There was an improvement in starting mean velocity, while ending mean velocity remained constant.

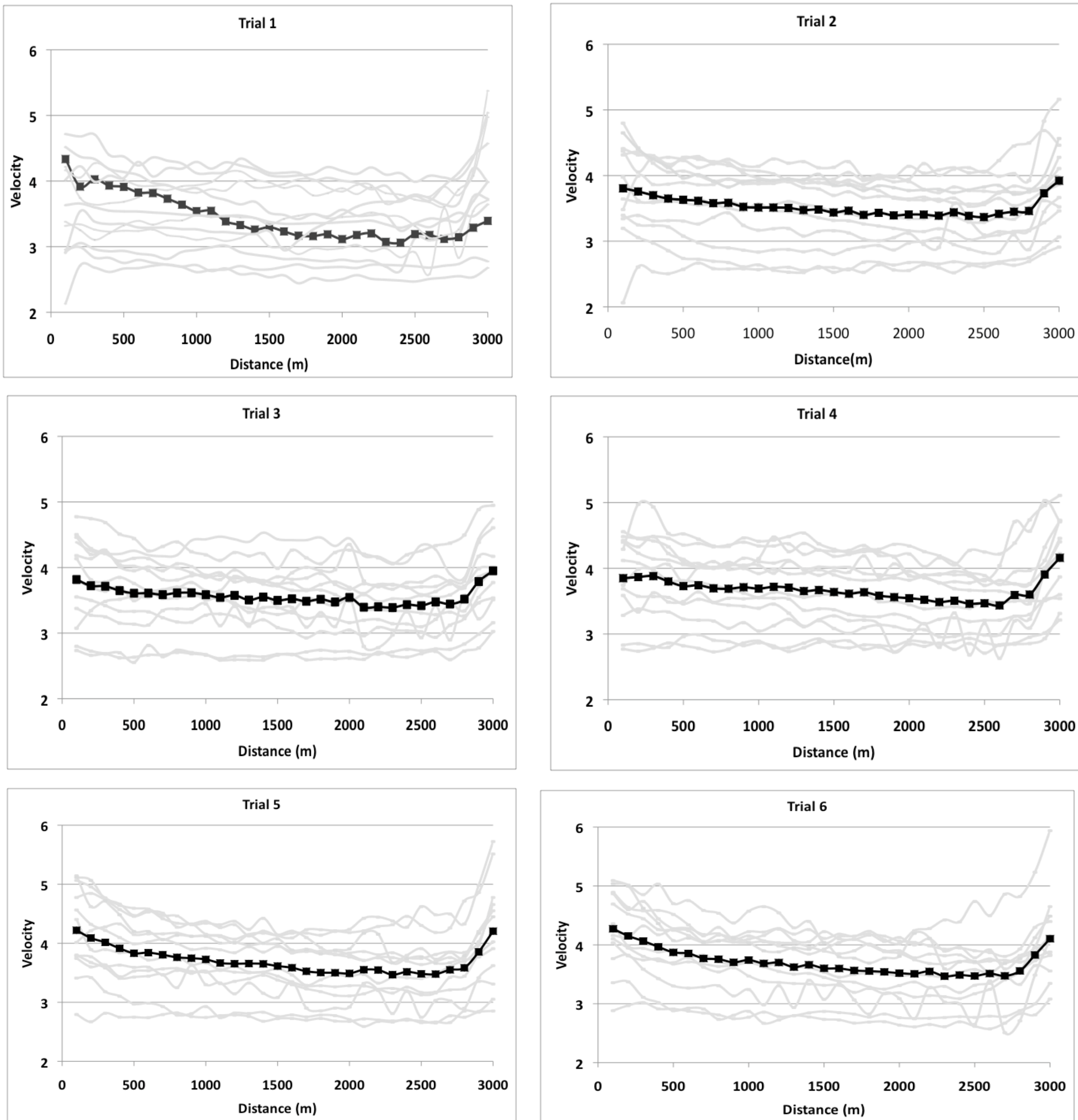

Figure 3. The velocities from all six trials are shown in the above graphs. Subjects started the study with a more even pace and as the trials went on velocity became more variable.

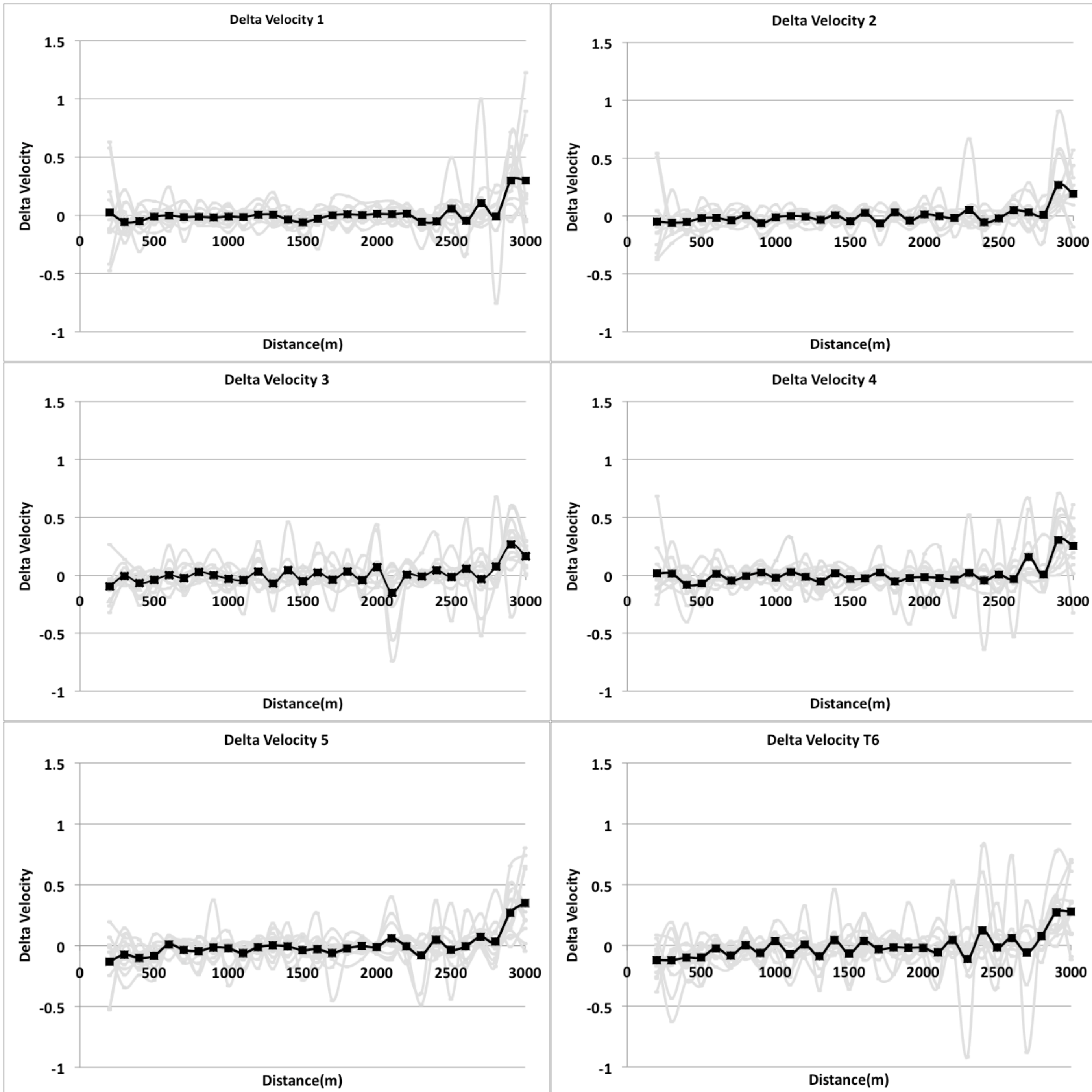

Figure 4. Delta velocity was calculated for each subject on all six trials. Subjects remained fairly constant during early trials, having a burst at the end. As the trials went on subjects became more variable in delta velocity.

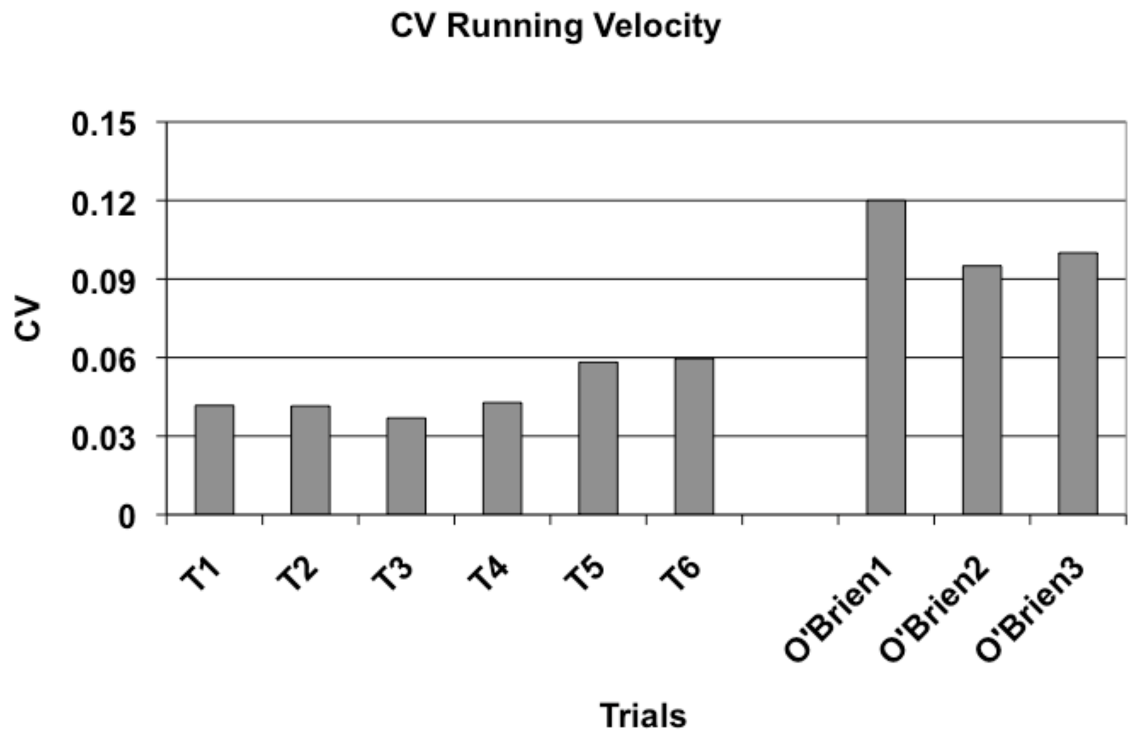

Figure 5. Contradictory to our hypothesis, in T1-T6 coefficient of variation grew as trials went on. In the O'Brien study coefficient of variation improved after the first trial.

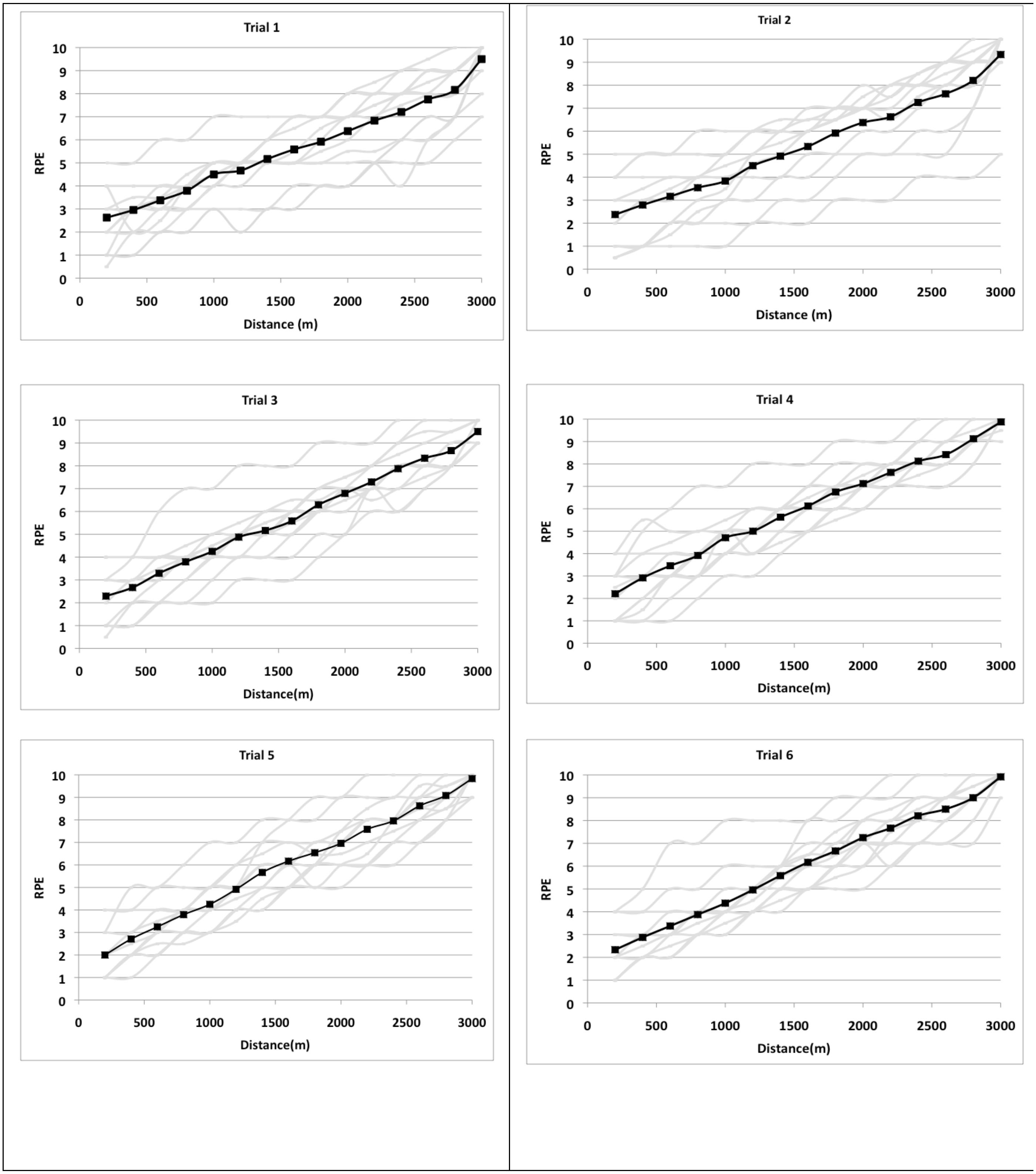

Figure 6. RPE was recorded every 200 meters. Mean RPE in bold shows that by the end of each trial the subjects were running their hardest.

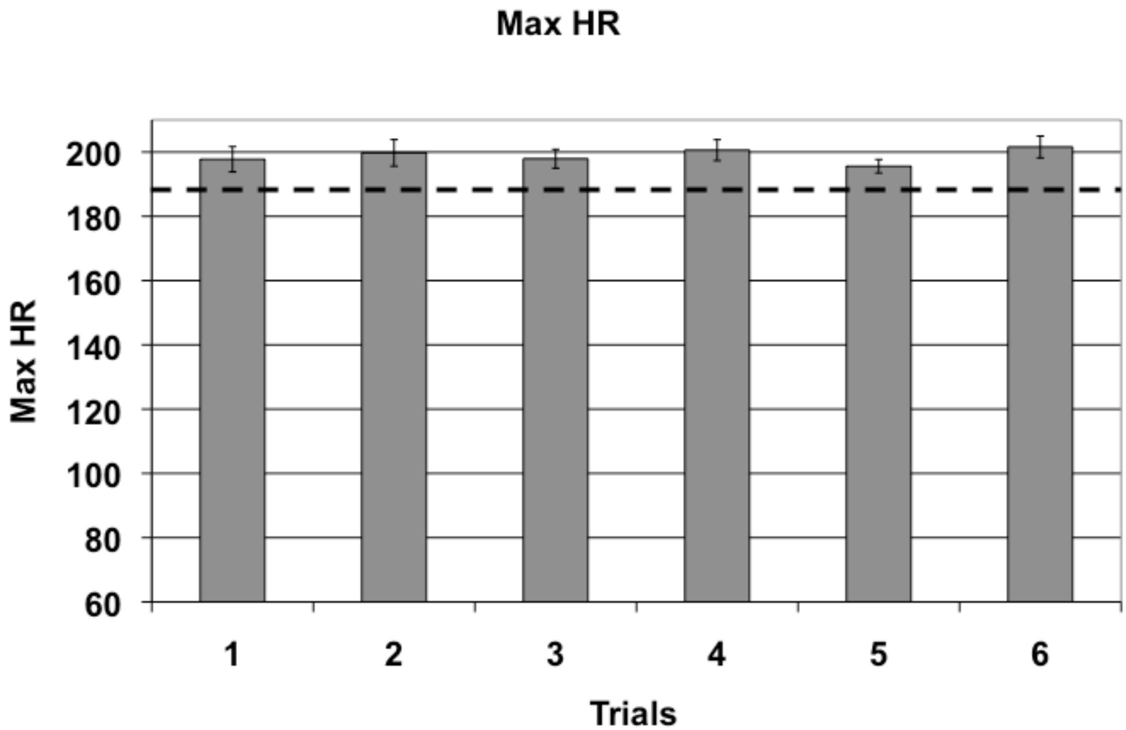

Figure 7. Mean maximal heart rates recorded during each trial were slightly above the mean max heart rate that was achieved during V02max testing.

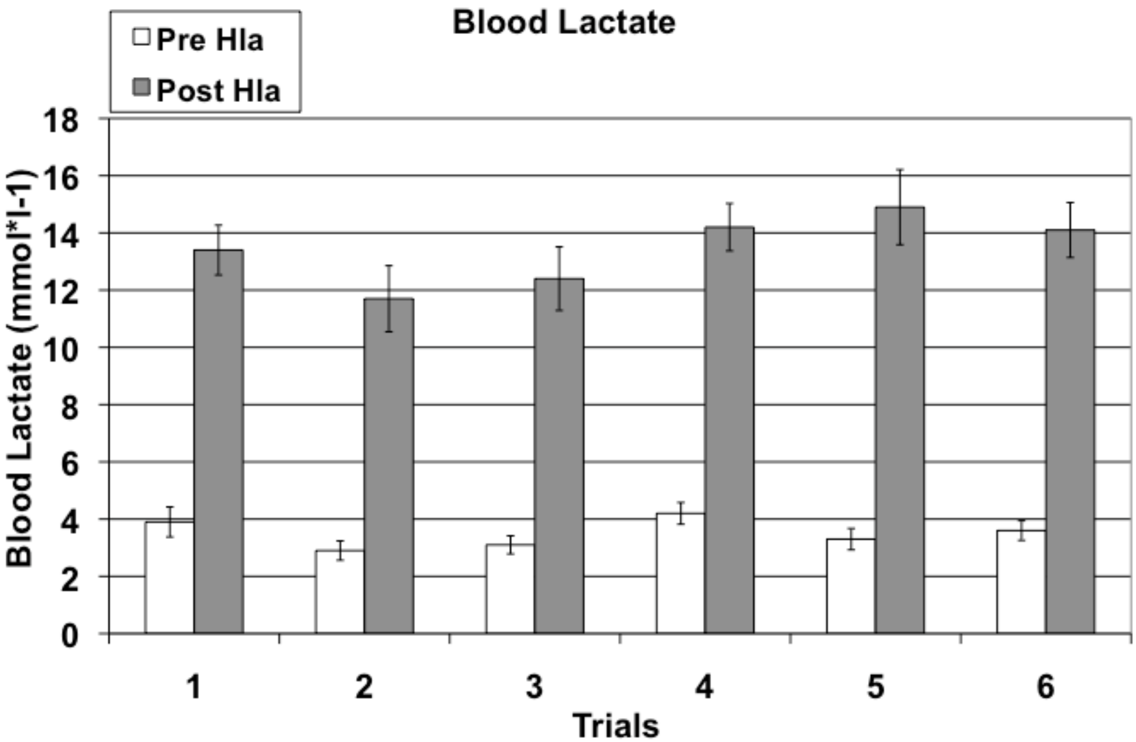

Figure 8. Pre and post blood lactate shows the post lactate was at significantly higher levels than pre blood lactates.

DISCUSSION

The findings of this study agree with the findings of Foster et al., that there is a learning effect during the performance of successive time trials. We found that the first trials performed started off more tentatively. People usually start slower to make sure they can perform the task within their body's limitations, this agrees with Ulmer's concept of teleoanticipation (10). As the trials go on, people realize that they are able to push themselves harder and still safely complete the trial, leading to an increase in starting velocity. We found in this study that subjects got more variable in their velocity as the trials went on; this disagrees with both our hypothesis and the O'Brien study. Instead of developing a more even pacing pattern, the subjects seemed to play with their velocity toward the end of the later trials. This may demonstrate that a high level of familiarity was developed and subjects felt comfortable enough to try out different velocities. This familiarity agrees with the studies of Foster et al. and Swart et al. Both stated that the more familiar someone is with an exercise bout, the more aggressively they will take on the task. If more trials could be performed, we may have been able to eventually see a more even pacing pattern develop. Further studies will have to be done to see a change in pacing.

We found from this study that there was evidence of a teleoanticipatory response that goes along with athletic events. In the beginning trials the subjects began running at a slower velocity and as the trials went on their starting velocities became faster, with ending velocity remaining pretty constant (Figure 2). According to Ulmer, the teleoanticipation response is a conscious perception of effort that influences the athlete's behavior to ensure homeostasis is maintained during exercise (10). The fact that subjects became more variable in their pacing strategy may suggest that they became more confident in the ability to complete the trial, so they began to play with speed. Mean total time for each trial improved each week and started to slightly plateau towards the last trials (Figure 1). This variation in pacing did not agree with our hypothesis, so our major finding was that the teleoanticipation response was demonstrated throughout the six trials.

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APPENDIX A

INFORMED CONSENT

Informed Consent

Protocol Title: The Process of Learning Pacing Strategy in Various Age Groups

Principal Investigator: Carl Foster, Ph.D.
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608 785 8681

Why have you been asked to take part in this research?

This study is evaluating how people in varying age groups learn to use their energy during an exercise task. You have been invited to participate in this study because you are the right age that we are interested in studying. Participating in this study is voluntary, and you may quit this study at any time. Please do not hesitate to ask questions about this consent form or the procedures if you do not understand something.

How many people will be in this study and how long will it last?

There will be approximately 100 people from three age groups that will participate in this study. The three age groups will include children between the ages of 9 and 10, adolescents between the ages of 15 and 17 and young adults. The study will last approximately six weeks for each individual subject, and your participation will be about 30-60 minutes each week.

What will happen if you agree to be part of this study?

If you agree to be part of this study, you will exercise on several different occasions. At the beginning and end of the study, your physical fitness level may be evaluated. During this test, you will walk/run on a treadmill until you are tired. You will wear a scuba diver's mouthpiece to measure how much you are breathing, and a heart rate monitor to measure your heart rate.

Additionally, there will be several races (ranging in distance from 1-6 miles), that we will ask you to run. These races will occur on an indoor track. We want you to run them as fast as you can, but to go at your own pace. During the races we may videotape you to allow us to see changes in your running pace and have you wear a heart rate monitor so that we can measure your heart beat.

Before and after the races, we may take a very small blood sample from your finger tip to allow us to measure some things in your blood (lactate, glucose). During all tests, we may ask you to rate your momentary effort from a Rating of Perceived Exertion chart.

What are the possible risks and discomforts from this study?

Similar to any form of exercise, you will get tired and your muscles may get sore. However, these effects will be only temporary. There is a very low risk of serious complications in healthy individuals.

How will you benefit from participating in this study?

There is a possibility that you will know more about your physical fitness level. Additionally, you will help the researchers understand the process of learning a pacing strategy and how humans cope with fatiguing tasks.

What are the costs of participating?

There are no costs for you to participate in this study.

What are your rights and confidentiality during this study?

All of the data will be kept confidential through the use of number codes. If this study is published or presented for scientists and teachers, your data will not be personally identifiable. None of the videotapes will be publically released.

Questions regarding the requirements of this study will be answered by Carl Foster, Ph.D. (608 785 8687), a Professor in the Department of Exercise and Sport Science at the University of Wisconsin-La Crosse. 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).

Subjects Understanding

Have all your questions regarding how the research study might affect you been answered? Yes/No (circle one)

If you consent to participating in this study, please sign your name. You will not be penalized or treated differently for not participating in this study.

Participant's name:____

Participant's signature:_____________________________________ Date__________

Parent's/Guardian's Understanding:

Have all our questions about how the research study is going to affect your child and/or yourself been answered? Yes/No (circle one)

Parent's/Guardian's name__________________________________

Parent's/Guardian's signature_______________________________ Date__________

Researcher's signature_____________________________________ Date__________

NASA Code for Physical Activity

Use the number (0 to 7) that best describes your general activity level for the previous month

Do not participate regularly in programmed recreation sport or heavy physical activity

0 Avoid walking or exertion, for example, always use elevator, drive whenever possible instead of walking

1 Walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration

Participate regularly in recreation or work requiring modest physical activity, such as golf, horseback riding, calisthenics, gymnastics, table tennis, bowling, weightlifting, yard work

2 10 to 60 minutes per week

3 Over 60 minutes per week

Participate regularly in heavy physical exercise such as running or jogging, swimming, cycling, rowing, skipping rope, running in place or engaging in vigorous aerobic activity exercise such as tennis, basketball, or handball

4 Run less than 1 mile (1.6 kilometers) per week or spend less than 30 minutes per week in comparable physical activity

5 Run 1 to 5 miles (1.6 to 8 kilometers) per week or spend 30 to 60 minutes per week in comparable physical activity

6 Run 5 to 10 miles (8 to 16 kilometers) per week or spend 1 hour to 3 hours per week in comparable physical activity

7 Run over 10 miles (16 kilometers) per week or spend over 3 hours per week in comparable physical activity

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

There have been many studies done regarding pacing, yet the idea of an "optimal" pacing strategy remains somewhat of a mystery. Pacing can be described as a strategy employed to avoid catastrophic failure in any peripheral physiological system (34). There are many ways in which people can interpret what the correct pacing strategy is in athletic performance, but which is the "optimal" strategy is still up for debate.

A variety of pacing strategies have been observed during different exercise tasks and under differing exercise conditions (16, 35,1). These include negative, "all-out", positive, even, parabolic-shaped and variable pacing strategies (1). Abbiss and Laursen describe negative pacing as an increase in speed observed over the duration of the event. This is strategy is most often seen in middle distance events. "All-out" pacing is mostly seen during shorter distanced events and it is when the athlete starts out at a sprinting pace and continues that way for the entire race duration. A positive pacing strategy is one where an athlete's speed gradually declines throughout the duration of the event (1) and this is seen in middle distance events. An even pacing strategy, where an athlete remains at a more constant pace for the duration of the event, is used mostly in prolonged (> 2 min.) events. Parabolic-shaped pacing is where athletes gradually reduce speed during an event and then increase speed toward the later portion, this results in a U or J-shape on a graph. This pacing strategy can be seen in long duration events. Finally, variable pacing strategy refers to the fluctuations in exercise intensity or power output observed during exercise (1,3, 26, 4). This varying strategy can be due to many factors such as, race duration (17), course geography (38), and environmental conditions, such as wind (11, 29) and environmental temperature (41,40).

So, there are many different strategies out there when it comes to pacing and the duration of the event will most likely influence how an athlete chooses to pace themselves during an event.

In 1958, Robinson et al. performed the first systematic study of the effects of pace variations on performance (32,16). In this study they had three well-trained men run the same distance with three different pacing patterns; a fast start, an even start, and a slow start. Robinson et al. found that there was a higher O_2 uptake requirement, higher post-exercise blood lactate levels, and greater subjective effort with the fast start strategy. So, in conclusion of Robinson et al. determined that the best way to run a middle distance event was to wait until as close to the end as possible before putting forth the most effort. Then, in 1993, Foster et al. studied the effect of 5 pacing strategies on performance in a 2 km time trial (TT) on a bicycle attached to a windload simulator (16). The participants were asked to complete the first kilometer of each trial in a predetermined percentage, ranging from very slow to nearly as fast as the subject could ride for one kilometer of their best previous time. During the first kilometer there was a range of times that were usually seen in competition. For the final kilometer, the athlete finished in the fastest time possible, with the intent of minimizing the total time for the trial. Results of this study showed that time difference between the slow start and the fast start was 7.2 seconds, which can be a huge amount in an athletic competition. It also showed that the difference between the even start and the fast start was 4.2 seconds. So, for a shorter race such as this, a fast start is much more optimal than an even or slow start (16). Another study done to try and determine an optimal pace strategy in track cycling was done in 1999 by de Koning et al. In this study the aerobic power contribution and the anaerobic capacity was kept constant in all simulations, but the mechanisms and the strategy in which the anaerobic power output was used were systematically changed. Time to constant anaerobic power (TC), which is the time that the cyclist changed from an "all-out" strategy to a more constant power distribution, was used as the variable to change the strategy of using anaerobic capacity. The remaining anaerobic energy at TC was calculated in the simulations and averaged that amount over the remaining part of the race. The results showed the fastest time in the 4000 m pursuit for different anaerobic kinetics and values of the time at which the model switched from the initial "all-out" starting strategy to a more constant anaerobic power output strategy after 12 seconds (TC=12s). This study shows that even small changes in pacing strategy can have substantial effects in racing results.

The previous studies that have been discussed were involving athletic events that were considered to be short in duration. Since there has been little research done involving longer duration endurance events Gosztyla et al. did a study to determine if there is an "optimal" pacing strategy for 5-km running races. It was hypothesized that a more moderate pace at the start of the race would optimize performance (19). This study involved eleven women distance runners, with nine of them being current or former NCAA Division 1 cross country runners. The subjects went through body composition analysis, $V0_2$ max testing, lactate threshold (LT) testing, and also 2 baseline 5-km time trials (TT). The first 1.63 km (1 mile) of each TT was controlled and based upon the subject's average 1.63 km pace from their best baseline trial. The experimental TTs were then run either even to (EVEN), 3% faster than (3%), or 6% faster than (6%) the best baseline TT 1.63 km pace. For the rest of the race the subjects were allowed to pick their own pace in order to complete the race as fast as possible. Gosztyla et al. allowed the subjects to have a warm-up before each TT and in order to control the paces of the self-selected trials the subjects communicated with the treadmill technician to increase or decrease the speed. The results show that the 6% trial was the fastest for 8 of the 11 subjects, with the other 3 subjects' fastest times resulting from the 3% trial, making the EVEN trial the slowest for all subjects. It is also noted that the both the 6% and the 3% TTs decreased in speed from the first 1.63 km to the second and third 1.63 km, while the EVEN TT remained at a constant speed for both the first and second 1.63 km and increased speed for the final 1.63 km. This study showed that based on the average finishing times, the EVEN trial was the slowest, therefore the time lost in a slower start could not be compensated for in the second and third 1.63 km of the TT (19). Based on these findings, in order to optimize 5 km performance, it is recommended that moderately trained runners should start the first 1.63 km (1 mile) of a 5 km race at paces 3-6% faster than current average race pace (19). The results of this study differ from the results of the previously discussed studies due to the duration of the event that the subjects participated in.

Another area of interest when it comes to pacing is the development of a learning template. This was studied by Foster et al. in 2009. This study involved 4 parts; A) six 3 km cycle TT, B) Three 2 km rowing TT, C) Four 2 km rowing TT with a training period in between trails 2 and 3, and D) Three 10 km cycle TT. With all of these TT were self-paced. At the beginning of the time trails the subjects were just told to finish as quickly as possible. During the trials feedback was given and rating of perceived exertion was recorded. Foster et al. found that in the beginning trials the initial power output was reduced during the first portion of the trials, and the power output during the end portions of the trail were consistent. Later trials showed a more aggressive early pace, which gave evidence that a stable performance template was achieved by the third or forth trial. So, in summary, Foster et al. saw for the current series of four studies that there is a learning effect during the performance of successive high-intensity time trials.

When it comes to pacing, an athlete is required to control multiple variables, with one of these variables being fatigue. Fatigue has been described as a decrease in force production and power output, or as the inability to maintain force despite the presence of an increased perception of action (22.23). The human body helps to regulate exertion in order to maintain homeostasis within the body. Many studies have been done to examine the effects of this process during athletic performance. Alan St. Clair Gibson et al. looked at mechanisms to develop a hypothetical model of how the brain creates and maintains a pacing strategy enabling an athlete to complete an exercise bout in the shortest possible time, while avoiding catastrophic failure of any physiological system. In a process described as 'teleoanticipation' (35,43), knowledge of the endpoint in an athletic event is used by the brain as the anchor for creating the particular algorithm for a particular exercise bout and moderating power output during the exercise bout. In the teleoanticipatory process (35,43) the brain algorithm for a particular event with a known endpoint would initiate a particular pacing strategy at the start of the event, based on prior knowledge of previous similar events performed by the athlete (35,30). The other factors taken into account by the brain-pacing algorithm at the start of the event would be factors such as current environmental conditions, current health status and metabolic fuel reserves (35,31). The algorithmic process would then send out efferent commands to create appropriate power output, and metabolic rates in the different organs and physiological systems of the body (35). Once the athletic event begins, afferent input supplying information from thermoreceptors, cardiovascular pressure receptors, and mechanoreceptors would inform the teleoanticipation pacing center in the brain about motion, force output, muscle metabolic rate and core temperature changes associated with the chosen power output (35,31,2,21,25,33,40). So, if the algorithm notices that a pace is to fast to allow the athlete to reach the endpoint without premature fatigue, further efferent commands would be modified to reduce power output and vice versa. Hampson et al. also studied the concept of teleoanticipation. According to Hampson et al. a 'central programmer' would function as an input/output black box to coordinate afferent and efferent pathways such that exercise intensity does not exceed the limits of the body (43). Hampson et al. declares that if we can refine teleoanticipatory strategies, maybe we can coach elite athletes to pace themselves appropriately during athletic events.

Swart et al. also did a study to examine the RPE and performance during repetitive maximal effort of 40 km time trials as well as after an intervention that aimed to decrease certainty about the remaining distance of the exercise bout, also, examining the RPE during exercise bouts of markedly different duration (39). This study was done in two different parts, the subjects for the first part were 12 well-trained, competitive cyclists. The second part involved 6 well-trained, recreational-level cyclists. All subjects reported to the lab for preliminary testing and subsequently at intervals to complete the experimental trials (39). On the subjects' first visit they underwent anthropometric assessment and preliminary testing for measurement of VO_{2max}, along with height and body mass. The subjects were asked to not eat or drink anything for at least 2 hours before each of the performance tests and each subject was asked to do a 90 minute low-intensity “recovery ride” 24 hours before the experimental trials. Also, subjects were asked not to consume any caffeine/any other stimulant the day of the performance tests and they were questioned to confirm that they had followed all the rules. The preliminary tests were performed on an electronically braked cycle ergometer (Computrainer pro 3D; RacerMate, Seattle, USA), which allowed subjects to cycle on their own bicycles (39). During the progressive exercise test the subjects were familiarized with both the Borg 15-point RPE scale (used for part 1) or the Borg category ratio scale (used for part 2) and a standard ser of instructions was given for the subsequent trials (39). VO_{2peak} was tested starting at a work rate of 2.50 W/kg body mass. The load was increased at a rate of 20 Watts every 60 seconds until the subject could not keep a cadence greater than 70 rpm (39). During part 1 of the cycle trials each cyclist completed a self-paced maximal 40 km time trial (TT) on a simulated flat 40 km course weekly for four consecutive weeks (TT1, TT2, TT3, TT4). Subjects were allowed to consume water freely (39,12) throughout each test and were asked to produce the fastest possible time (39). Subjects were asked to report RPE score at 5 km intervals (39). No feedback was given to the subjects during these trials. The subjects then performed a fifth 40 km TT (UTT) during which all feedback, including completed distance, was withheld until the final kilometer, at which point they were informed they had 1 km left to complete (39). During this trial, subjects were asked to report their RPE at 5 km intervals (39). To cause some confusion and uncertainty about the remaining distance, they were asked to report their RPE randomly at 18, 27, 33, and 38 km. After 39 km subjects were informed they still had 1 km to complete (39). Part 2 involved a 40 km familiarization trial and four more trials at 3-7 day intervals following the familiarization trial. These trials were 5, 10, 40, and 100 km in duration and were completed in random order, and subjects were informed of the distance before each trial. During the trials subjects were allowed to ingest a commercially available sports drink (8% carbohydrate content) at a rate of 600 ml/h, divided into 150 ml every 15 minutes, as this has been shown to prevent the development of hypoglycemia during prolonged exercise bouts (39,27). RPE scores were recorded at the start of the trial and at 10% distance intervals using the Borg category ratio scale (39,8). Results for part 1 showed that RPE increased significantly over time in the first four trials, with RPE much greater at 20, 25, 35 and 40 km in TT4 in comparison with TT1. During UTT, mean RPE scores were lower than during TT4 (39). RPE scores at 25, 30 and 35 km for the UTT were significantly lower than during TT4 (39). In part 1 power output during TT4 was significantly higher than during TT1 from 20 km to the end of the trial, and during the UTT power decreased after 30 km and was significantly lower at 35 km and 40 km than in TT4. In part 2 RPE increased significantly over time in all four trials (39). The RPE at 20% of the 5 km trial was significantly higher than the 100 km trial and it remained higher until 80% of the trial (39). The RPE was significantly higher in the 5 km trial at the start compared with the 40 km trial and it remained higher until 30% of the trial and again from 60% until 80% of the trial (39). Trials of shorter distances had a significantly higher average power output compared with the longer trial durations (39). The results of this study indicate that during maximal exercise bouts of varying duration, increases in perceived exertion are proportional to the relative distance completed (39). However, contrary to other findings, Swart et al. found that the rate of increase in perceived exertion is not always constant, but changes in relation to certainty about the endpoint of an exercise bout. When subjects were initially uncertain about an exercise bout, they chose a perceived exertion strategy that maintained a larger metabolic reserve, which was then accessed near the end of the bout (39). This strategy was associated with a non-linear growth in RPE over time and a conservative approach, rather than a linear strategy (39). With increased familiarity with the required exercise task, the RPE strategy became more aggressive, linear and presumably with less metabolic and cardiorespiratory reserve (39). When knowledge of the endpoint was obscured by blinding subjects to the completed distance and confusing them by asking for RPE scores at random, subjects reverted to a more conservative RPE strategy and once again maintained a greater metabolic reserve (39). To sum it up, Swart et al. provided further evidence that exercise is controlled in a feed-forward and adaptive teleoanticipatory fashion (39). In addition, it was provided that increasing familiarity with the exercise bout and certainty about its endpoint are associated with a more aggressive strategy that produces a superior exercise performance (39).

Faulkner et al. performed a study that assessed the relationship of RPE with heart rate and pacing strategy during competitive running races of differing distance and course elevation. This studying included 9 volunteers, 5 men and 4 women, who were free from acute and chronic injuries. All of the subjects were registered to compete in the 2007 Great West Run (GWR), a half marathon road race in Exeter (South-West England) (14). All participants had no prior experience of perceptual scaling with the Borg 6-20 RPE scale (14,9). Each participant performed three bouts of exercise, initially starting with a laboratory based graded exercise test (GXT) to volitional exhaustion to determine maximal functional capacity. Participants then completed a 7-mile run (7-MR) and the

GWR, approximately one and two weeks after the completion of the GXT, respectively (14). The GXT was performed on a motorized running treadmill (Woodway, USA), two weeks before the GWR. On-line respiratory gas analysis occurred every 10 seconds throughout the exercise test via a breath-by-breath automatic gas calibrator system (Cortex Metalyzer II, Biophysik, Leipzig, Germany) (14). The treadmill was set at a 1% grade during the test. The test commenced by gradually increasing the treadmill belt speed required for the first stage (14). The test was continuous and incremental in style, commencing at approximately 10 and 12 km/hour (6.25 and 7.5 mph, respectively) for male and female participants, respectively, and increasing by 1 km/hour (0.63 mph) every 3 minutes until the attainment of a maximal functional capacity (14, 24). During the remaining 30 seconds of each increment of the GXT, the participant stated their RPE using the Borg 6-20 RPE scale. The test ended when the participant reported volitional exhaustion, was unable to maintain the required running speed, attained a plateau in their oxygen consumption, a heart rate within +/- 10 bpm of the age-predicted maximum or an RER equal to or exceeding 1.15 (14,10). The 7-MR was completed one week after the GXT, and one week prior to the GWR. Before the race the subjects received all pieces of equipment; heart rate monitor and watch, RPE record sheet, and permanent marker pen. The subjects were informed by the investigator of the 7-MR route and how they would be recording data during the race. The RPE record sheet, which included the Borg 6-20 RPE scale and an area to report perceptual feelings were attached to the participants' non-dominate wrist. Markers were placed along the route to ensure the participants stayed on course. Participants were told to complete the run in the shortest time possible, and were informed that money would be rewarded to the male and female participants who finished first and second. Subjects recorded their RPE by ‘noting’ the mile number they had just finished next to the respective feeling of exertion at that moment in time. Participants also activated the split mile timer on their heart rate watch at each mile marker, this ensured that the time to finish the previous mile and the heart rate values were stored. Heart rate was continuously recorded every 5 seconds (14). An investigator associated with this study was located at each mile marker to ensure participants recorded their data (14). Prior to the start of the GWR, participants were given the needed equipment and were informed of the location of the mile markers. Each participant also wore a Radio Frequency Identification timing chip, supplied by the organizers of the GWR, to measure the exact time it took each participant to complete the GWR (14). Otherwise, the methodology of the GWR was identical to the 7-MR (14). In order to compare the two runs, the duration it took each individual to complete the races was converted to minutes. Results showed that completion of the 7-MR was much faster than the GWR, which was expected because of the difference in distance. The rate of change in RPE was significantly greater during the 7-MR than the GWR. This is attributable to the shorter distance of the 7-MR and the subsequent completion of the race in a faster time (~57 minutes) (14). However, when the RPE was plotted as a percentage of the time to complete the races, the rate of increase in RPE was similar for both the 7-MR and GWR, despite differences in the course elevation and pacing strategies. These findings provide strong support for the original observations by Noakes and Eston et al. who reported scalar linear properties of perceived exertion during exercise with carbohydrate-depleted and carbohydrate-replete participants, and under fatigued and non-fatigued conditions, respectively (14,28,13). This study suggests that RPE was set as a function of either how much of the exercise bout had been performed, or how much of the bout remained. The finding of a scalar time property may suggest that the brain regulates perceived exertion and physical performance in an anticipatory manner based on an "awareness" of metabolic fuel reserves and biomechanical performance as the start of the exercise bout (14). Faulkner et al. has provided evidence in this study that the ratings of perceived exertion have scalar linear time-based properties when utilized during competitive running races. The study demonstrated that despite significant differences in the course elevation, heart rate response, running velocity and pacing strategy adopted during the 7-MR and GWR, participants perceptual response may be dissociated from such underlying physiological or physical mechanisms when expressed as a proportion of the race completed (14).

Baden et al. performed a study investigating how the anticipation of exercise duration influenced RPE, affect, and running economy, as measured by changes in $V0_2$ during the exercise bout, and, in particular, how these variables were affected when the actual exercise duration was different from that anticipated before the onset of the exercise bout. There were sixteen subjects (eight male, eight female) recruited for this study. The subjects were told that they would be participating in 3 trials in which running on a treadmill would last 30 minutes maximum. The subject's age, height, mass, body fat %, and $V0_2$ max were all calculated during a familiarization session. This session also allowed for the subjects to get use to running on a treadmill if they were not already accustomed to it. There were to be three different scales used during the testing and the subjects were also able to become familiar with those during this session. Within one week of the initial familiarization session, the subjects performed three trials in random order on a treadmill. In all three trials the subjects ran at 75% of their treadmill speed (which was found during the first session). In trial one, subjects were told they would be running for 20 minutes and then completed a 20-minute run (20 MIN). In the second trial, subjects were told they would run for 10 minutes, but at 9 minutes they were told they would be running 10 more minutes, for a total of 20 minutes (10 MIN). Exercise intensity was maintained for the entire 20 minutes of the 10 MIN trial. The subjects in the third trial were not told how long they would be running for and were stopped at 20 minutes (unknown trial, UN). During each of the trials RPE, affect, attentional focus (% associative thoughts), $V0_2$, stride frequency, and heart rate were measured at 3,5,8,9,10,11,14,17,19 and 20 minutes. The results of this study in regards to RPE was that it increased linearly with increasing exercise duration in all three trials, but RPE increased much more between 10 and 11 minutes in the 10 MIN trial than in the 20 MIN trial until 17 minutes. RPE was also higher in the 10 MIN trial than in the UN trial from 11 minutes to 14 minutes. Affect scale scores decreased over the course of all three trials, but the score dropped much more between 10 and 11 minutes in the 10 MIN trial compared to the 20 MIN and UN trials. There were no significant differences when it came to associative thoughts, although there was a higher change when the 10 MIN trial was told they had 10 more minutes to go. $V0_2$ was significantly lower in the UN trial than in the 10 MIN and the 20 MIN trials. Both heart rate and stride frequency did not differ significantly between trials. In conclusion, the results of this study found that unknown exercise duration and an unexpected increase in exercise duration influenced RPE, affect, and $V0_2$ (5). RPE appeared to be influenced by affect, and was not merely the result of a direct interpretation of the physiological changes occurring in different metabolic systems, as RPE increased significantly after an unexpected increase in running duration in the absence of changes in exercise intensity, $V0_2$, or heart rate in this trial (5). Tucker also studied this concept and came up with a model that shows what happens when an athlete is misinformed about exercise duration. The top half of the model shows what happens when actual duration is shorter than the athlete is expecting, and the bottom half shows what happens when the actual duration is longer than expected (42). In both cases Tucker found that the result is underperformance. What these studies have shown us is that the concept of afferent feedforward and efferent feedback is a major contributor when it comes to how athletes pace themselves during athletic events.

Most scientists and practitioners in the health sciences agree that it is important to understand subjective symptoms and how they relate to objective findings (8). Therefore, we must develop methods to quantify these subjective symptoms (8). These methods should be equally applicable to most people regardless of gender, age, circumstances, and national origin (8). According to Borg, perceived exertion is the single best indicator of the degree of strain on the body. The overall perceived exertion rating includes a variety of information, including the signals elicited from the peripheral working muscles and joints, from the central cardiovascular and respiratory functions, and from the central nervous system (8). "Ratio-scaling methods" (8,36,37) were first developed to measure perceptual intensities. These methods were created to have the same metric qualities as were used in physiology and physics. One popular ratio-scaling method is "magnitude estimation" (8,37). Subjects are presented stimuli of different intensities with this method and they are to assign numbers to them. The numbers the subjects assign are depending on how intensely the stimuli is perceived. According to Borg, one major drawback with the ratio-scaling methods is that they do not provide any direct "levels" for interindividual comparisons. In other words, it is hard to compare the subjects with each other because they are only asked to make relative comparisons. To overcome the difficulties associated with the ratio-scaling methods, a scale for ratings of perceived exertion was developed by Borg (8, 6). The first was a 21-grade scale with verbal anchors. It represents one kind of category scale, often used in many applied situations when a simple but direct estimation of the subjective intensity is needed, but when the metric properties of the scale are of less importance (8). There is a high correlation coefficient between ratings of perceived exertion and heart rates that indicate the differential value of the scale. The perceived exertion determined by the ratio-scaling methods grew with an exponent of about 1.6, it was concluded by Borg (8,6) that an integration of central factors, such as heart rate, and peripheral factors would better explain the psychophysical variation than any single physiological variable (8). Borg then constructed a new category scale to increase linearly with the exercise intensity for work on a cycle ergometer (8,7). Borg's rationale for this was because oxygen consumption and heart rate increased linearly with workload, it would be a convenient means of constructing a scale. This scale ranges from 6-20 and correlates well with heart rate (60-200 bpm). This is the scale that most of us know and either have used or will use in the future.

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