THE PROCESS OF LEARNING PACING STRATEGY IN VARIOUS AGE GROUPS

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

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By Kacie O'Brien

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

The candidate has completed the oral defense of the thesis.

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ABSTRACT

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The effectiveness of pacing strategy as a competitive technique has been demonstrated several times. Additionally, it is evident that the development of a pacing strategy occurs over a series of time trials, indicating that there is a learning effect. Is the process of learning this strategy different in youth compared to adults? Ten elementary school students and ten college students with no previous systematic training in pacing participated in three 1-mile time trials on an indoor 200-meter track. The subjects were instructed to finish the trial as quickly as possible. Velocities (m/s) were calculated every 50-meters, and RPE was expressed every 200-meters. There were significant differences for total running time between the youth and college subjects ($p<.001$), however running time did not decrease significantly in either group. Variation of running speed (expressed as the within trial coefficient of variation) also decreased across trials for both groups ($p<.01$). There was not a significant difference in the rate of decrease in variability between the youth and college students ($p=.198$). Therefore, the pacing strategy between youth and adults is different, and both groups can normalize pacing strategy with repetition over a series of trials, but learning appears to occur at the same rate.

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INTRODUCTION

Adults are able to rapidly identify the appropriate speed necessary for common tasks such as running around the neighborhood block. Adults are also aware that the speed chosen for that task is not the same as the pace they would use if they decided to do something more challenging, such as run a marathon. There is a clear pattern of learning how to pace various tasks in adults, although the pacing pattern is fundamentally stable from a very early age.[1,2] However, if six-year-old children to run a similar long distance event, it would be expected that they would probably start with a fast sprint and soon be walking. Children typically display an oscillating pattern of easy and hard exertion. When do children learn a more appropriate distribution of exertion? How do the children learn to develop a pattern of pacing? Does this different pattern of learning pacing vary in people of different ages?

The significance of pacing strategy in athletic competition was initially investigated in 1993.[1,3] Although other competitive factors were studied extensively, the importance of pacing strategy was not well appreciated. The current interest in pacing began with an analysis of various pacing strategies in middle distance cycling time trials. Foster et al. (1993) determined the impact on time trial performance using widely varying starting speeds (slow-fast). The study indicated that there was a potentially "optimal" pacing pattern.[1]

The importance of pacing strategy was further supported in an analysis of racing technique during world-record performances. A series of record-setting races were evaluated for pacing strategy as a function of distance. The study concluded that middle and long distance events (>110 seconds) typically used a more even pace with a surge of speed at the end of the race.[3] In contrast, shorter distance events (<110 seconds) utilized a burst of speed in the initial part of the race with a progressive deceleration toward the end. Regardless of the distance of competition, the importance of pacing was clearly evident. Pacing is a key contributor to optimal performance, and there is a physiological process that factors into the strategy used during periods of exertion.

The ability to perceive exertion and adjust accordingly can be attributed to the feedback system.[4] Through the examination of the relationship between RPE and intensity, Ulmer in 1996 was able to elaborate on this concept of feedback. The combination of efferent and afferent messages as well as a pre-exercise template allows our bodies to regulate exertion appropriately. The power of this feedback system and the anticipation of task duration were combined in the concept of teleoanticipation, which is the unifying concept in the studies of pacing strategy.

Anticipation of the remaining duration in an event is a contributing factor to exertion perceived by our bodies. Power output and metabolic functions are directly related to the perceived task duration.[5] In a study that examined the effect of previous fatigue on the current RPE, Eston et al. demonstrated that physiological factors were not the only contributors to RPE. Instead, the study demonstrated that there was a scalar property that allows humans to control exertion based on the time remaining in the task.

Thus, a person is likely to perceive exertion relative to the remaining duration rather than the preceding fatigue.

In an attempt to appropriately distribute exertion for optimal performance, humans need to create an accurate starting point. In an anticipation of the expected fatigue towards the end of the exercise bout, we are likely to control our power output in a manner that takes several components into consideration.[6] According to the "Anticipatory feedback-RPE model," our physiological systems tend to compile information such as environmental conditions and expected disturbances in homeostasis in order to establish both an initial RPE and an acceptable rate of increase. This conceptual model prompted the evaluation of a progression in pacing patterns, both how the template develops and how many trials it takes to create this pacing strategy.

Accordingly, it appears that pacing strategy is an important component of exercise performance and needs to be mastered in order to reach peak competitiveness. Only recently has the question been asked, "How does the pacing template pattern develop?" In 2009, Foster et al. performed a series of time trials with different exercise modalities in order to observe the process of developing a pacing pattern. The results of this study indicated a majority of growth in pacing strategy occurred within the initial three trials.[7] Despite preliminary surges in power output and RPE at the beginning of each successive time trial, there was minimal differentiation at the end of the trials across each of the series of time trials, indicating the probability that the learning effect occurs early in the succession of trials.

The intertwining of RPE into pacing strategy is important to note, but it is unknown if children perceive exertion in the same methods as adults. Eston et al. (2009)

offered an evaluation of challenges with the use of RPE with children. They concluded that a more appropriate measure of perceived exertion in children is through the use of modified RPE scales such as the Eston-Parfitt (E-P) Scale that utilizes verbal and graphic indications of the stages of exertion on a curvilinear gradient.[8]

The evaluation of aerobic fitness in children is a challenging factor. In several physical education courses both the 1-mile run/walk test and the PACER test are used. More accurate estimates of maximal oxygen consumption can be obtained through the use of the PACER test.[9] This test requires students to run between two points (20-m distance) using a descending sendoff signaled by an auditory stimulus, until they can no longer finish in the allotted time. The obstacle with this form of testing is that the test of fitness is not self-paced; instead the programming of the PACER protocol controls the pacing. A potentially more real-world test of self-paced physical fitness is the 1-mile run/walk test.[10] This test not only measures physical fitness, but it also accounts body fat, anaerobic capacity, running skill and muscular strength. Additionally, the identification of pacing ability can be observed through the use of this test.

The information that is currently available regarding pacing does not evaluate the process of learning a pacing strategy in various age groups. Interest in a better understanding of the development of pacing templates prompts the focus of this study and the question of the how different age groups expend energy over a series of trials. It is hypothesized that there will be a decrease in pace variability with successive 1-mile time trials, which will indicate a more even pacing pattern.

METHODS

This study used two groups of 10 participants, both male and female, of two age groups. The first group was pre-pubertal children (eight boys and two girls) in the 3rd and 4th grade recruited from local elementary schools. This group of youth was selected from participants in a sports activities camp held at the University of Wisconsin-La Crosse. The second group of participants consisted of first and second-year college students (five men and five women) who had no systematic training in running or past participation in sports that might have required pacing (swimming, track or cycling).

The University of Wisconsin-La Crosse Institutional Review Board approved this study. Written informed consent was obtained from the college students. Because the children were minors, a written informed consent was obtained from a parent or legal guardian, with written assent from the child.

The participants performed a total of three 1-mile time trials. For the youth, the testing occurred on three consecutive days. The testing for the college students occurred with at least three days between each trial. The trials were performed on a 200-m indoor track with times recorded at 50-m increments from video recordings. Armbands and bibs were used to augment individual identification while evaluating the video data. Running velocity was calculated from the time required for 50-m segments.

Four cameras were located in the center of the track facing outwards with 90° between each camera angle, in order to capture the image of subjects as they passed each quarter (50 meters) of the track distance. There were posters with the RPE scale located on the inner edge of the track in order to record RPE every 200-m. The subjects were familiarized with the Eston-Parfitt RPE Scale prior to the time trials, and they indicated, with use of fingers, a value (1-10) as they passed the camera at the end of each lap.

As a motivational tool to encourage the quickest possible finish, the subjects were provided an incentive at each successive testing after the initial trial (gift cards to a grocery store for the college students and toys for the youth). This was in order to promote a competitive feel to the time trials, which would hopefully encourage the subjects to improve.

Repeated measures ANOVA was used to test the hypothesis of a decrease in variability (as measured by the within trial coefficient of variation in running speed) across the time trials. The total time between trials was also compared using repeated measures ANOVA.

RESULTS

At the time of data collection for youth, the number of subjects was n=11. However, one subject completed only two of the three trials, so analysis was performed using n=10. Similarly, at the time of the college student data collection, the original number of subjects was n=11. However, following the initial trial, one subject admitted to being ill during the run, and the data of this individual for T_1 was highly inconsistent with the following two trials (T_2,, T_3). Accordingly, this subject was eliminated and the college student group analyzed was also n=10.

With respect to total running time, there was not a significant main effect (8.92 ± 1.87, 8.70 ± 1.77 and 8.77 minutes ± 2.05, respectively for T_1, T_2 and T_3, p=.26). There was a significant main effect for group membership (p<.001) for youth verses college students. There was not a significant group by trials interaction (p>.43). Thus although the college students were faster than the youth, neither group improved time significantly across the three trials nor did the pattern of change vary between groups (Figure 1).

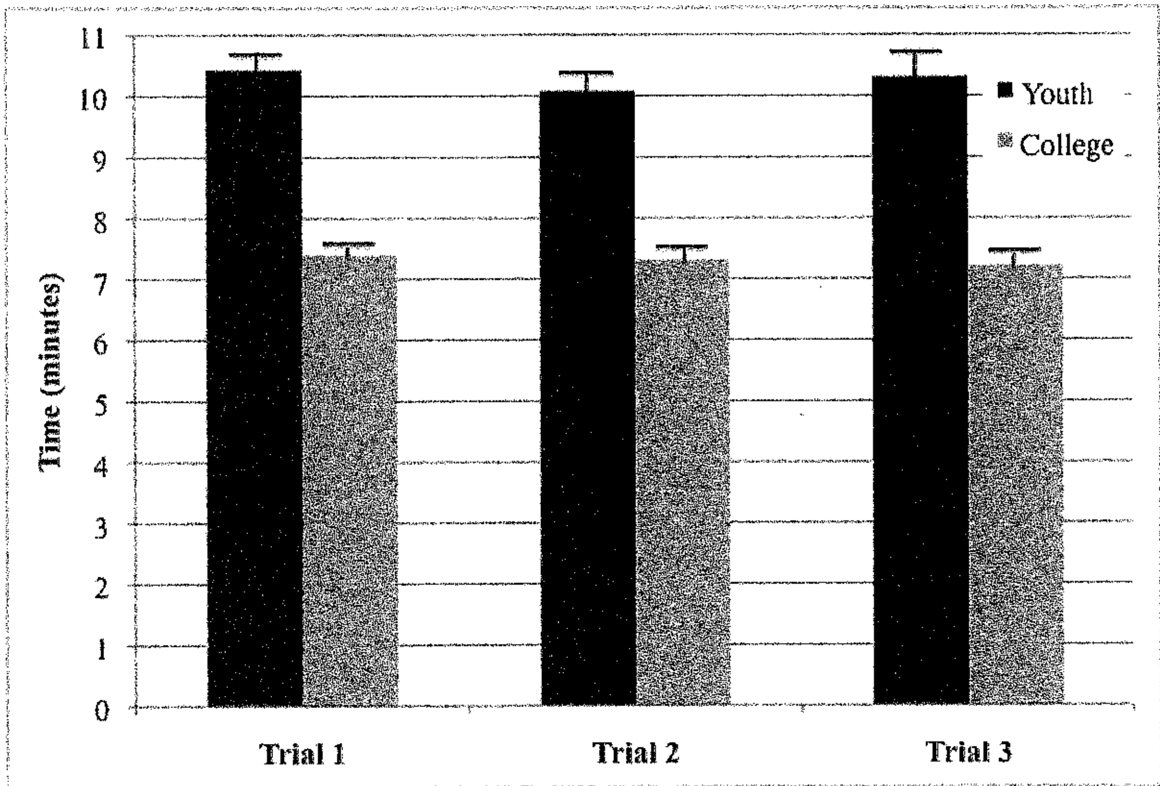


Figure 1. Total Time by Trials

Through a visual evaluation of mean running velocities, it was evident that the youth established a pattern of running at a slower mean velocity in comparison the college students (Figure 2).

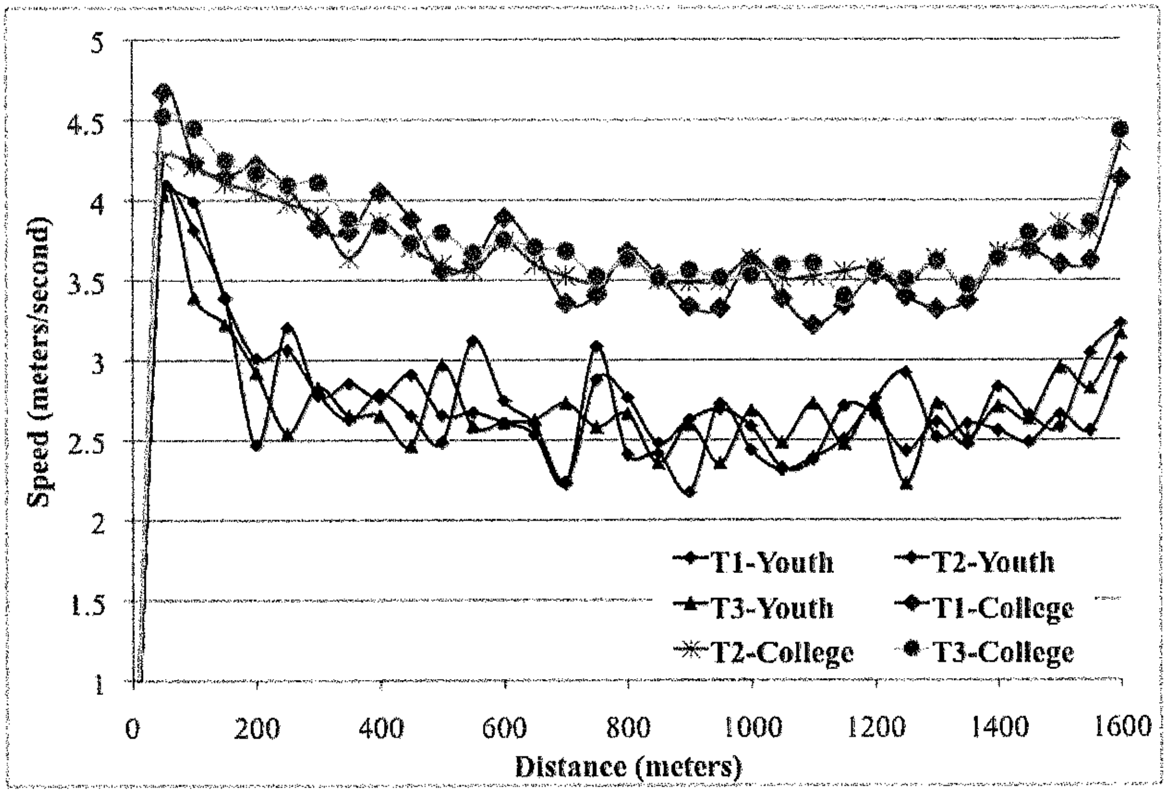


Figure 2. Mean Velocities for T_1–T_3

Expressed quantitatively, the coefficient of variation of running speed (T_1, T_2 and T_3) significantly decreased across trials ($p<.01$). There was also a significant difference in the coefficient of variation for the youth compared to the college students indicating that the college students had significantly less variation in running velocity throughout all trials ($p<.01$). However, the magnitude of decrease in variability over the series of trials was not significantly different between the youth and college students ($p=.198$). These effects are displayed in Figure 3.

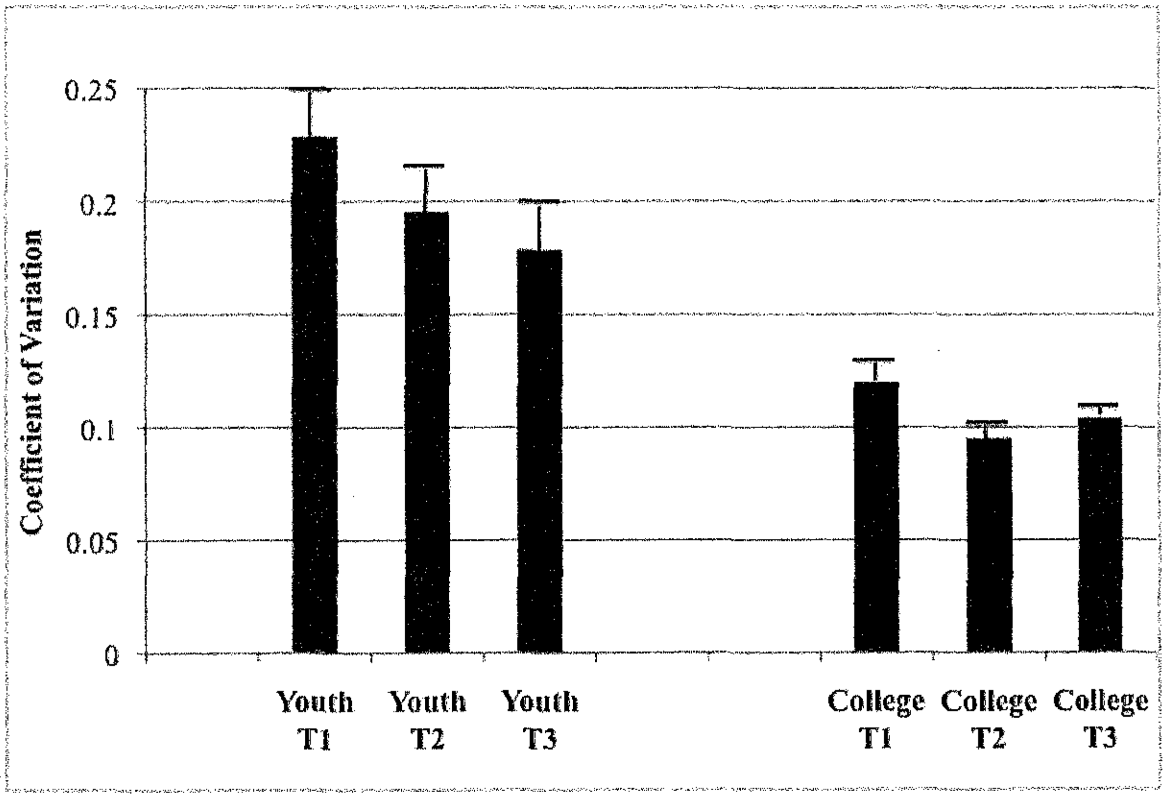


Figure 3. Coefficient of Variations for Each Trial

As with total time, the average running speed of subjects over the series of trials did not significantly change (p=.287). Similarly, there was not a significant group by trials interaction, and the speed of the groups did significantly change throughout repetition of trials (p=.187). As with total time, the youth and college students did have a significant difference in speed (p<.01).

The RPE progression varied between the youth and college subjects and is presented in Figures 4 and 5. The youth displayed a gradual increase in RPE similar to the college subjects. However, the effort expended was seemingly unpredictable, and this may indicate that children are unable to manage their RPE effectively. The average RPE value for youth at the end of the trial was 6.8 ± 1.00. The college subjects increased their RPE in a linear fashion and were consistent between trials. The average RPE value at the end of the trials was 8.9 ± .10.

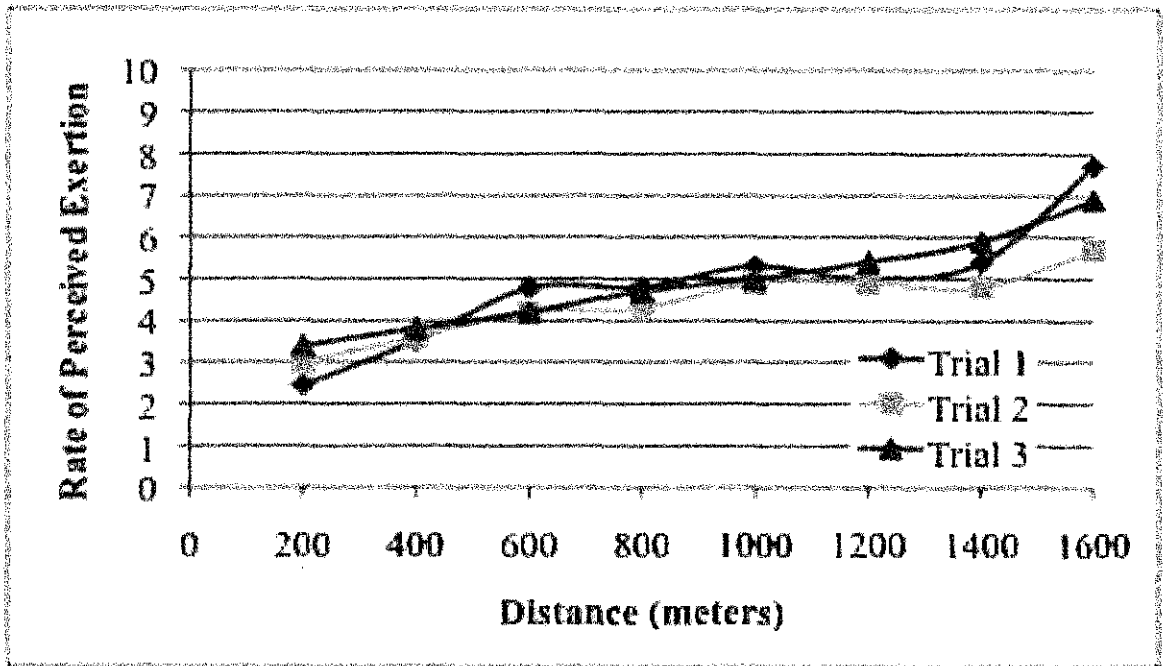


Figure 4. Rate of Perceived Exertion (Youth)

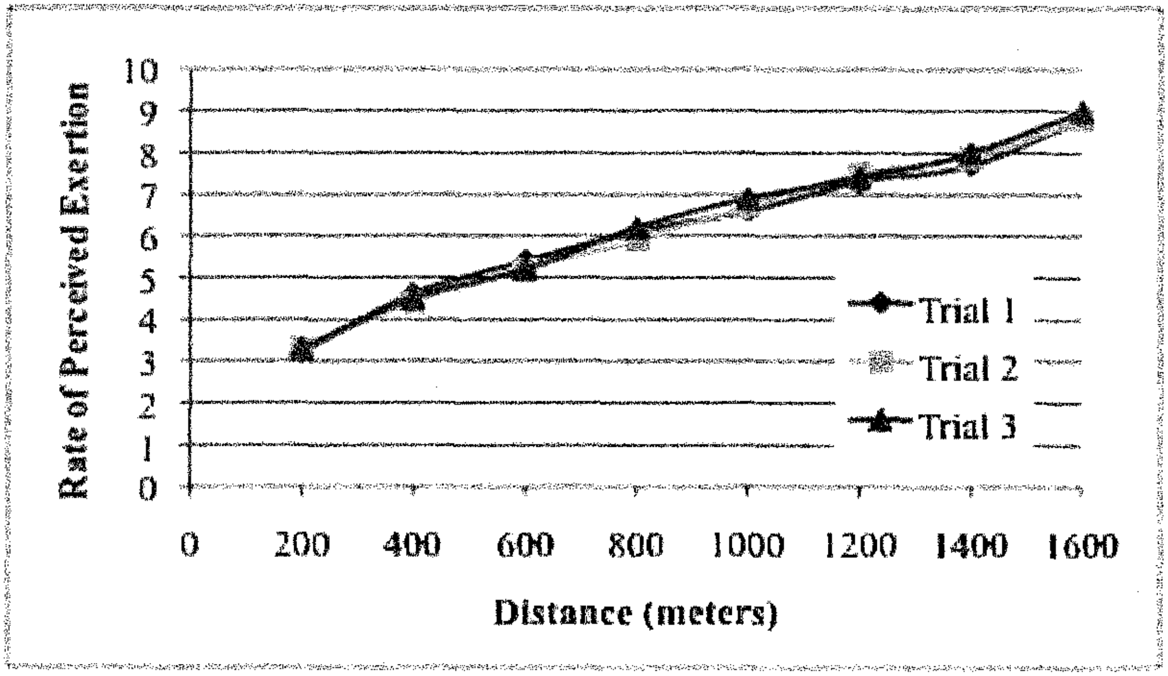


Figure 5. Rate of Perceived Exertion (College)

DISCUSSION

As hypothesized, there is a large variability of pacing strategy in a pre-puberty population in comparison to young adults. Young children tend to display oscillating patterns of pacing as they run for an extended period of time, indicating that they are unaware of an optimal pacing strategy. In contrast, college-age students, even those who have not been exposed to pacing strategy through sports such as running and swimming, displayed a more even pacing strategy, even in the initial one-mile time trial. Over the series of three trials, both the youth and college students decreased their variability significantly, indicating that a learning process was taking place.

The process of developing a pacing strategy was evaluated by Foster et al. in 2009, and it was established that a majority of learning occurs within the first three trials. The normalizing of a pacing strategy seen in rowing and cycling, as used in that study are consistent with the development of an optimal pacing strategy observed in both the youth and college students. It would be interesting to evaluate the learning and pacing over a few more trials in order to determine if their pacing strategies continued to improve.

There were some factors throughout these trials that may have acted to influence the results of these tests. Due to the logistics of recruiting children for these trials, it was necessary that the subjects ran on three consecutive days. Thus, fatigue could be a factor in the way that their pacing strategies developed, and it is possible that there would have been different results if the trials had been distributed over several days. Additionally, it may have been beneficial to collect results from additional trials to determine how long it took to achieve a stable level of performance.

The logistics of recruiting subjects to complete these trials also created a situation in which a group was running during the same period. The influence of a group on any individual's pacing strategy needs to be acknowledged. The concept of Constraints Triangle (Karl Newell, 1986) discusses the influence that environment has on the behavior of individuals. The method that the subjects chose to pace themselves with was partially determined by how the others in the group chose to run the mile. It is probable that subjects both competed against each other and paced together throughout the trials. Other studies that have evaluated pacing learning have utilized individual time trials, so the influence from other subjects was not a factor.[7]

In future evaluation of pacing strategy development in youth, it would be beneficial to extend the trial number in order to determine when a stable pattern emerged. In the initial trials there was a general correlation of improvement in total time with a decrease in variation of speed (21 of 40 increases in speed and decreases in variation were in this direction) (Figure 6).

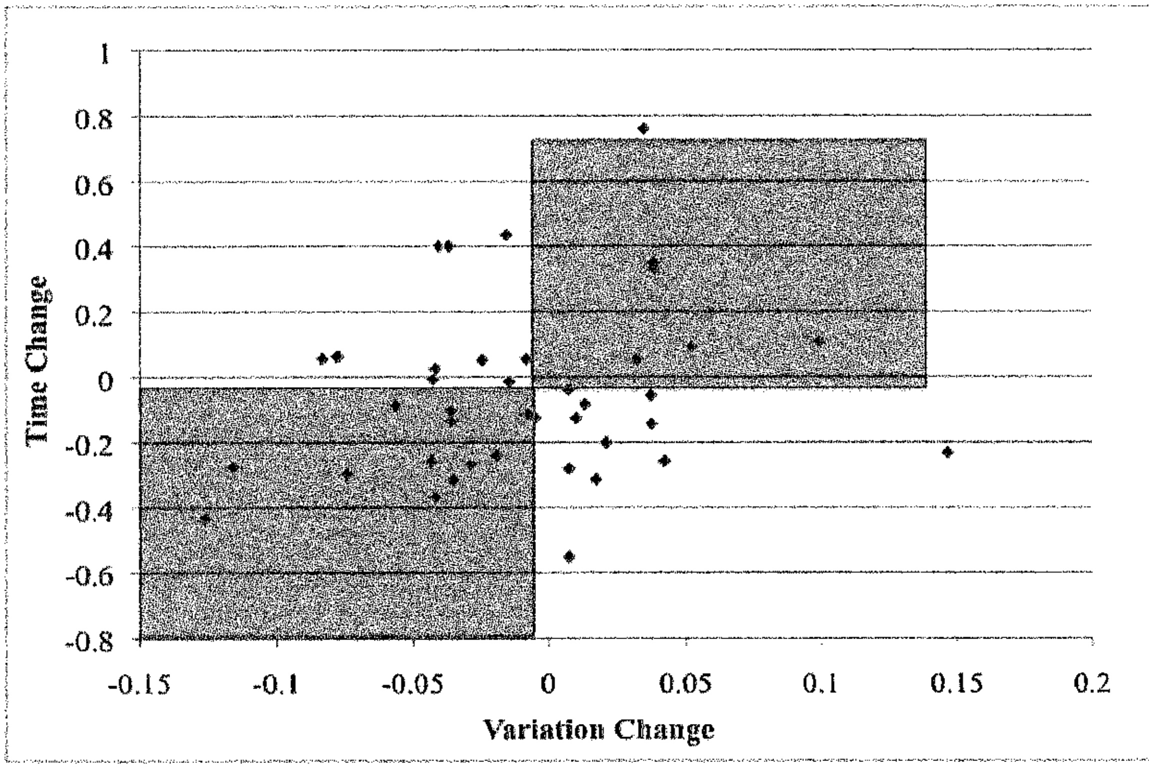


Figure 6. Time Change vs. Variation Change

The development of a pacing strategy appears to occur throughout all age groups. It may take children who have not reached puberty a longer period of time in order to reach an optimal pacing strategy because of the high initial variability in pacing patterns. In future research, it would be beneficial to evaluate the changes made in pacing strategy over a series of six trials to see if further learning occurs. It would also be interesting to note the effects of teaching the idea of pacing followed by successive trials.

In summary, children are more variable than young adults. Both of these populations decrease variability over successive trials. Although there is a decrease in variability, there is not a net performance improvement throughout the trials.

REFERENCES

1. Foster C, Snyder AC, Thompson NN, et al. Effect of pacing strategy on cycle time trial performance. Med Sci Sports Exerc 1993;25:383-88.

2. Galamback K, Foster C, Eber-Lee T. Pacing strategy in the six minute walk test: the effect of repeated trials. J Cardiopulm Rehabil Prev 2009;29:257.

3. Tucker R, Lambert MI, Noakes TD. An analysis of pacing strategies during men's world-record performances in track athletics. Int J Sports Physiol Perform 2006;1:233-45.

4. Ulmer HV. Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback. Experientia 1996;52:416-20.

5. Eston R, Faulkner J, St Clair Gibson A, et al. The effect of antecedent fatiguing activity on the relationship between perceived exertion and physiological activity during a constant load exercise task. Psychophysiology 2007;44:779-86.

6. Tucker R. The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. Br J Sports Med 2009;43:392-400.

7. Foster C, Hendrickson K, Peyer K, et al. Pattern of developing the performance template. Br J Sports Med 2009;43:765-69.

8. Eston R. What do we really know about children's ability to perceive exertion? Time to consider the bigger picture. Pediatr Exerc Sci 2009;21:377-83.

9. Mahar MT, Welk GJ, Rowe DA, et al. Development and validation of a regression model to estimate VO_2 peak from PACER 20-m shuttle run performance. J Phys Act Health 2007;3:34-46.

10. Rowland T, Kline G, Goff D, et al. One-mile run performance and cardiovascular fitness in children. Arch Pediatr Adolesc Med 1999;153;845-49.

APPENDIX A

INFORMED CONSENT

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

Principal Investigator: Kacie O'Brien
220 N. 14th St.
La Crosse, WI 54601
608-215-3635

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

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 do not understand something.

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

There will be approximately 10 people from two age groups that will participate in this study. The two age groups will include children between the ages of 9 and 10 and young adults. The study will last approximately four weeks, and your participation time will be about 30 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. There will be three 1-mile races that we will ask you to run. These races will occur on an indoor track. We want you to run the mile as fast as you can, but to go at your own pace. During the races we will videotape you to allow us to see changes in your running pace.

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 only be temporary. There is very low risk of serious injury or 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 other researchers understand the process of learning a pacing strategy.

Do you have to participate?

Participation in this study is voluntary. You may stop participating at any point without penalty.

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 Kacie O'Brien, (608-215-3635), or her advisor (Dr. Carl Foster, 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).

Informed Assent
(If participant is under the age of 18)

Child/Adolescent Understanding (if under the age of 18):
Have all your questions regarding how the research study might affect you been answered? Yes / No (Circle one)

If you are interested in 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 (if child is under the age of 18):
Have all your questions about how the research study is going to affect your child and/or yourself been answered? Yes / No (Circle one)

I believe that my child is willing to participate in this study.

Parent's/ Guardian's name:______________________

Parent's/ Guardian's signature:____________________ Date:__________

Informed Consent
(If participant is 18 years or older)

Participant understanding (if subject is 18 or older):
Have all of your questions about how this research study is going to affect you been answered? Yes / No (Circle one)

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

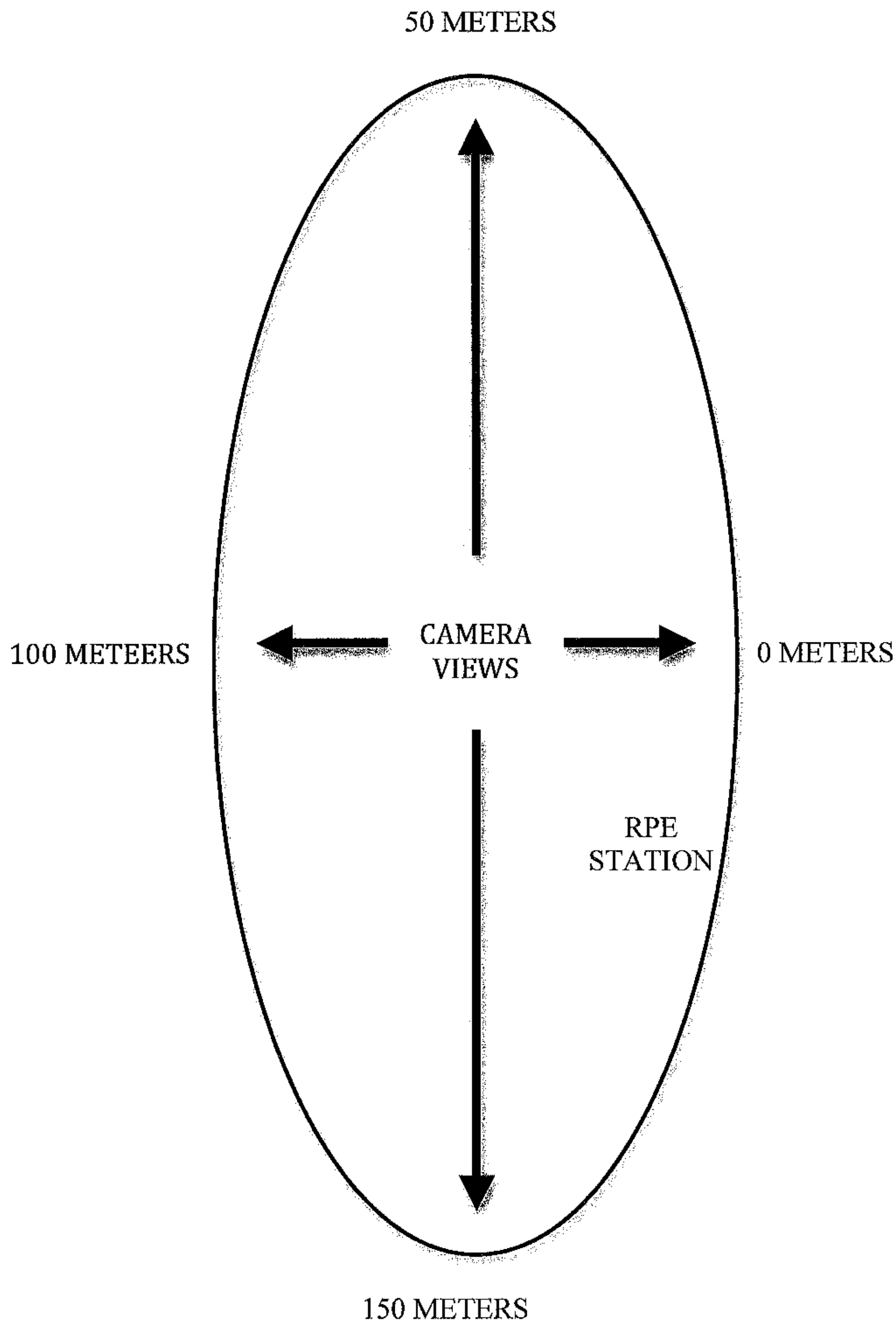
Participant's name:______________________________

Participant's signature:___________________________ Date:__________

Researcher's signature:___________________________ Date:__________

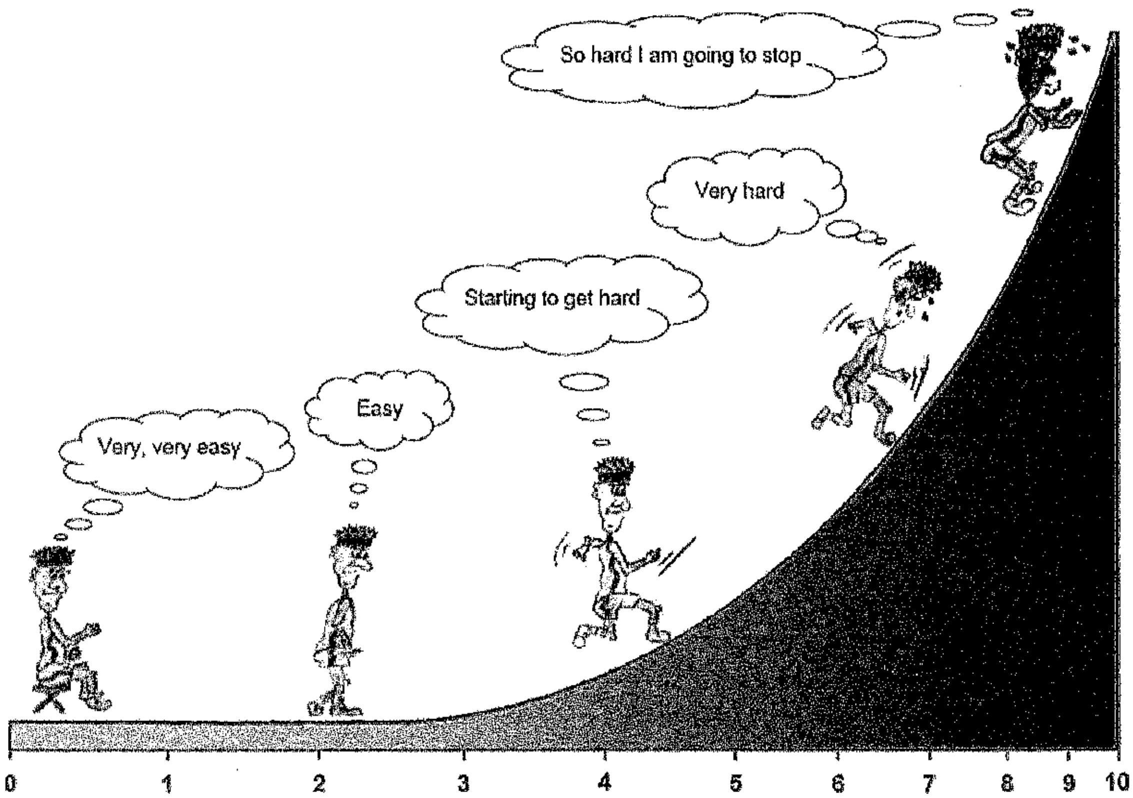
APPENDIX B

DIAGRAM OF TRACK DURING DATA COLLECTION


50 METERS
100 METEERS
CAMERA VIEWS
0 METERS
RPE STATION
150 METERS

APPENDIX C

ESTON-PARFITT RATE OF PERCEIVED EXERTION CHART



Eston, R. G., Lambrick, D. M., & Rowlands, A. V. (2009). The perceptual response to exercise of progressively increasing intensity in children aged 7-8 years: validation of a pictorial curvilinear ratings of perceived exertion scale. *Psychophysiology*, 46, 843–851

APPENDIX D

REVIEW OF THE LITERATURE

The purpose of this paper is to review the literature regarding the history and effectiveness of pacing, physiological and psychological components of pacing, development of a pacing template and special considerations for pacing in youth.

THE EFFECTIVENESS OF PACING STRATEGY

Prior to 1993, the effects of pacing strategy on competition had not been systematically evaluated as a technique to improve performance. Foster et al. in 1993 initiated the interest in utilizing pacing strategy as a competitive technique.[1] This consisted of an evaluation of varying initial speeds in a mid-distance cycling time trial. The subjects attempted five trials with different starting pacing strategies (ranging from slow to fast). As expected, there was a difference in overall performance when the pacing strategies were varied. More specifically, an even pace was optimal for this distance of a cycling time trial. The results from this study suggested that pacing technique should be further reviewed as a form of competitive strategy amongst athletes in different modalities and distances.

The concept of pacing strategy was further supported through a review of world record performances in track events.[2] Repeated results indicate that there is a pattern of pacing strategy seen throughout these elite-level performances. More specifically, in the long distance events (>110 seconds), the athletes utilized an even pacing strategy in order to conserve energy for the final surge. In contrast, the characteristics of the sprint races (<110 seconds) consisted of an all-out pacing strategy. It is evident that these strategies were well practiced and employed by these athletes in order to optimize their performance.

In addition, other modalities and durations of events have been reviewed in reference to the ideal pacing strategy. Consistently, there is a pivotal point in the distance spectrum in which the pacing strategy should be altered. Generally, an event of shorter duration is best completed through the use of the all-out pacing strategy at the initiation of the race. At a certain point it becomes more profitable to utilize an even pacing strategy for the longer distance events.[3.4] The ideal pacing strategy, however, is dependent on the individual and is composed of several variables.

THE PROCESS OF PACING

The physiological components of pacing have been continually analyzed and developed over several years. The foundation of pacing intertwines four key components that combine into a feedback system in order to structure our body's manifestation of pacing.[5] The feedback system utilized to control exertion is a combination of efferent messages from the brain and afferent messages from the muscles as well as the muscles and central nervous system. Additionally, a central programmer must exist which allows us to anticipate the endpoint of exercise task in the form of teleoanticipation. The anticipation of the duration of an event in combination with this feedback model provides the optimal foundation to create a pacing strategy.

For an extensive period, the peripheral theory was utilized in exercise physiology to explain the development of fatigue during exercise bouts. This theory suggests that the accumulation of metabolites in the peripheral system is the sole indication of fatigue during exertion.[6] In this model, the peripheral systems reach fatigue following the collection of metabolites in the skeletal muscle. According to this theory, it is at this point that there can be no further exertion and failure occurs. A review of this theory offers a strong contrasting argument for this model, suggesting that the central nervous system is the foundation for control of exertion in exercise bouts.[6,7]

Several challenging arguments to this catastrophe theory have led to the promotion of the current school of thought, the central governing model.[6,7] In this model, the central nervous system is responsible for the maintenance of homeostasis. It does this through controlling exertion by determining the number of motor units recruited to complete the task. The central nervous system is continually working to maintain homeostasis through this process, and when homeostasis can no longer exist, the body must terminate exercise.

There have been several additional studies that utilize the central governing model in the explanation of the results. It is suggested that RPE and fatigue are the contributors to this central governing model in order to protect the body from a disruption of homeostasis by encouraging a shutdown of exercise prior to any dangerous levels being reached.[8-10]

There are several possible indications of fatigue that can be seen in an exercise bout, most commonly either through an increase in perceived exertion or a decrease in the ability to perform at the same level. There is an increase in discomfort through the perception of fatigue that offers feedback in the form of physiological, biomechanical and other sensory messages.[7] This is communicated with the central nervous system through feedforward and feedback messages that help to control homeostasis.[7]

A few significant models exist to explain the process of fatigue in exercise.[11] The peripheral-fatigue model is no longer commonly supported. It suggests that fatigue is activated due to changes in the periphery such as an accumulation of lactate in the muscles. A more widely accepted theory in exercise physiology is the central-teleoanticipatory model that suggests a feedforward system protects the individual from changes in homeostasis.

The most commonly used model used to describe fatigue in exercise currently is the cognitive discussion model.[11] In this theory, a combination of perception of effort and prior experience determine guidelines for fatigue. The sensation of fatigue is due to an alteration in physical state that an individual can perceive such as an increase in breathing rate.[8] Additionally, there are cognitive functions including motivation and fear that can contribute to this sensation as well.[8,11]

The use of a perceived exertion scale (RPE) is a common tool in the field of exercise physiology as a subjective measure of overall exercise intensity.[12] It acts as an evaluation of a combination of afferent signals, psychological messages, and expected task duration and determines an overall perception of exercise intensity.[13] This method of perceiving exertion contributes to the maintenance of homeostasis as a protective agent.[8] Increasingly, RPE has been shown to be an important contributor to pacing strategy in a continuous feedforward loop.

Our bodies interpret exertion through a complex process. Afferent signals from our body's physiological systems such as ventilation, heart rate and metabolite accumulation allow us to have a conscious perception of exercise intensity.[14] This indication of physical strain combines with psychological signals to provide additional feedback to our brain.

A large component of psychological feedback is the concept of affect.[14] Affect refers to an emotion towards a particular event or idea.[15] In a recent study, runners perceived exertion to be much greater when their affect towards the situation drastically changed during an unexpected increase in duration.[14] The significant change in RPE didn't mirror the change in physiological measures (heart rate and VO_2). This indicates that psychological factors are taken into consideration when evaluating perceived exertion. Additionally it is suggested that, in regard to teleoanticipation and RPE, the perceived exertion may be controlled at an appropriate level due to dissociative thoughts that help to distract from the physical cues of fatigue.[16]

The anticipatory RPE feedback model proposes that the physiological and psychological factors of perceived exertion combine with the anticipation of duration (teleoanticipation) to create a feedforward mechanism based on a template.[5,13] It is suggested that a template exists from the onset of exercise in anticipation of the expected duration in order to scale exercise intensity appropriately.[13,17,18] In addition, this model uses previous experience and expectation of the remaining duration to develop the particular template for the exercise duration.[9,13]

This idea of an exercise template is further supported in an evaluation of RPE in a comparison of two subject groups in a study that compared low and high glycogen levels over an exercise bout.[18,19] RPE was plotted in relation to remaining duration in both the low and high glycogen groups. This showed that a linear relationship existed for both situations indicating that RPE can be used as an determinant for remaining duration. This template is ever changing, however, because it takes into account the afferent signals, physiological feedback, and expected duration in a continuous feedforward manner in order to regulate intensity.[13]

As previously discussed, the exercise duration is a key factor in the development of a template that considers several factors in an attempt to establish a pacing strategy for the remaining exercise bout.[10,13,17,18] The anticipation of remaining task duration rather than the proceeding exercise bout seems to have a significant effect on the perception of exertion.[14,17] This evaluation of RPE as a function of time has prompted the development of the scalar property of pacing.[10,17]

In an attempt to determine whether fatigue and RPE are a function of the task completed or the duration remaining, Eston et al. in 2007 evaluated the effects of antecedent fatiguing activity on RPE. In a comparison of RPE with and without proceeding fatigue, there was a similar pattern of exertion in both trials.[17] The characteristics of this study suggest that RPE is the result of a scalar property. This property is most likely due to an internal mechanism that regulates exertion in anticipation of remaining duration.

Additionally, a review of RPE during different durations of running races revealed a similar scalar property.[10] While the subjects of this study completed runs of varying durations (both a 7-mile run and a half marathon), the relative plotting of RPE in relation to time remained constant. This continues to support the scalar relationship of RPE and the anticipation of the remaining duration.

Perceived exertion plays an important role in the regulation of further performance during an exercise bout in the form of pacing strategy. The importance of the feedforward loop of communication between afferent messages, physiological perception and anticipated duration is again emphasized because of its innate ability to regulate further performance.[10] The constant feedback provided by RPE contributes to the parameters of the anticipated remaining exercise and signals the periphery through the use of efferent messages from the brain and central nervous system.[5,10] The use of this information provided by RPE is critical in the distribution of resources in order to guarantee that anaerobic sources are not depleted until the very end.[20] The ability to distribute resources in an adequate manner emphasizes the necessity to anticipate the end and scale accordingly.

DEVELOPING A PACING TEMPLATE

A well-trained athlete gains the experience necessary to employ pacing strategies through practice and competitive experience. However, it is interesting to note the process of establishing a pacing pattern in non-elite adults. There is consistent discussion in regard to the development of pacing strategy throughout a series of time trials.[21,22,23] However, there are conflicting views in terms of the results due to familiarization with task demand.

The feedforward mechanism considers the knowledge of an endpoint in addition to prior experience in order to optimize pacing strategy.[5,9] In a series of three 2000-meter time trials performed by male cyclists, adaptations to pacing strategy were observed after the initial time trial.[21] The subjects modified their strategy after the initial time trial that resulted in a reduction of power output in the initial 500 meters of the time trial followed by an increase in power output in the final 750 meters.

Contrasting results were obtained in an evaluation of the development of a performance template over a series of time trials.[23] Individuals who were physically fit but not trained in the specific modality completed a series of time trials. There appeared to be a reassurance in the ability to complete the task duration because of the familiarization that occurred over the period of trials. This was displayed through an increased power output in the initial stages of the successive time trials. A template of pacing strategy solidified itself through the series of time trials, with a majority of the adaptations in pacing seen in the initial three trials.

CONSIDERATION FOR YOUTH

Physical fitness in children is typically evaluated in physical education classes beginning in elementary school. There are two common forms of predicting physical fitness and maximal aerobic capacity in youth: the 20-m shuttle run (PACER) and the one-mile run/walk test.[24] These tests are both frequently used and have advantages and disadvantages. However, because the one-mile run/walk test is a self-paced assessment of VO_2, it is a more accurate predictor of pacing ability than the PACER test.[25]

A child's ability to perceive exertion is another factor that separates them from adults. There are several considerations when utilizing an RPE scale for youth.[26] Because children have a different repertoire of experience than adults they may perceive exertion differently due to a number of factors including the sensations of exercise, anticipated duration, type of test and the scale used. One method of accounting for a possible differentiation in RPE is through the use of a child-friendly scale such as the Eston-Parfitt (E-P) Scale that utilizes pictures and appropriate descriptions. This evaluation of RPE uses a curvilinear representation of exertion and has been described as valid form of RPE identification in youth.[27]

A final consideration to make when evaluating pacing in children is the development of motor skills (such as running a time trial) in contrast to adults. Several differences exist in the acquisition of new motor skills in children including a different method of information processing, different learning techniques and slower speeds of development.[28] Because of this, it is suggested that children require additional practice time with supplementary feedback in order to acquire a new skill. This may be important to evaluate as children attempt to develop a pacing template.

SUMMARY

In conclusion, there is a significant amount of evidence of the importance of pacing strategy in competition. There are significant physiological and psychological components that contribute to fatigue and RPE, therefore resulting in adaptations in pacing strategy. The development of a pacing template has yet to be evaluated in various populations.

REFERENCES

1. Foster C, Snyder AC, Thompson NN, et al. Effect of pacing strategy on cycle time trial performance. Med Sci Sports Exerc 1993;25:383-88.

2. Tucker R, Lambert MI, Noakes TD. An analysis of pacing strategies during men's world-record performances in track athletics. Int J Sports Physiol Perform 2006;1:233-45.

3. deKonig JJ, Bobbert MF, Foster, C. Determination of optimal pacing strategy in track cycling with an energy flow model. J Sci Med Sport 1999;2:266-77.

4. Bishop D, Bonetti D, Dawson, B. The influence of pacing strategy on VO2 and supramaximal kayak performance. Medicine and Science in Sports Medicine 2002;34:1041-47.

5. Ulmer HV. Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback. Experientia 1996;52:416-20.

6. Noakes TD, St Clair Gibson A. Logical limitations to the catastrophe models of fatigue during exercise in humans. Br J Sports Med 2004;38:648-49.

7. Noakes TD, St Clair Gibson A, Lambert EV. From catastrophe to complexity: a novel model of integrative central neural regulation of effort and fatigue during exercise in humans: summary and conclusions. Br J Sports Med 2005;39:120-24.

8. St Clair Gison A, Baden DA, Lambert MI, et al. The conscious perception of the sensation of fatigue. Sports Medicine 2003;33:167-76.

9. Micklewright D, Papadopoulou E, Swart J, et al. Previous experiences influences pacing during 20-km time trial cycling. Br J Sports Med 2009.

10. Faulkner J, Parfitt G, Eston R. The rating of perceived exertion during competitive running scales with time. Psychophysiology 2008;45:977-86.

11. St Clair Gibson A, Lambert EV, Lambert MI, et al. Exercise and fatigue-control mechanisms. Int J Sports Med 2001;2:1-14.

12. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14:377-81.

13. Tucker R. The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. Br J Sports Med 2009;43:392-400.

14. Baden DA, McLean TI, Tucker R, et al. Effect of anticipation during unknown or unexpected exercise duration on rating of perceived exertion, affect, and physiological function. Br J Sports Med 2005;39:742-46.

15. Crews DJ. Psychological state and running economy. Med Sci Sports Exerc 1992;24:475-82.

16. Baden DA, Warwick-Evans L, Lakomy J. Am I nearly there? The effect of anticipated running distance on perceived exertion and attentional focus. J Sport Exerc Psychol 2004;26:215-31.

17. Eston R, Faulkner J, St Clair Gibson A, et al. The effect of antecedent fatiguing activity on the relationship between perceived exertion and physiological activity during a constant load exercise task. Psychophysiology 2007;44:779-86.

18. Noakes TD, Snow RJ, Febbraio MA. Linear relationship between the perception of effort and the duration of constant load exercise that remains. J Appl Physiol 2004;96:1571-73.

19. Baldwin J, Snow RJ, Gibala MJ. Glycogen availability does not affect the TCA cycle of TAN pools during prolonged, fatiguing exercise. J Appl Physiol 2003;94:2181-87.

20. Foster C, deKonig JJ, Hettinga F, et al. Pattern of energy expenditure during simulated competition. Med Sci Sports Exerc 2003;35:826-31.

21. Corbett J, Barwood MJ, Parkhouse K. Effect of task familiarization on distribution of energy during a 2000-m cycling time trial. Br J Sports Med 2009;43:770-75.

22. Galamback K, Foster C, Eber-Lee T. Pacing strategy in the six minute walk test: the effect of repeated trials. J Cardiopulm Rehabil Prev 2009;29:257.

23. Foster C, Hendrickson K, Peyer K, et al. Pattern of developing the performance template. Br J Sports Med 2009;43:765-69.

24. Anderson GS. The 1600-m run and multistage 20-m shuttle run as predictive tests of aerobic capacity in children. Pediatr Exerc Sci 1992;4: 312-18.

25. Rowland T, Kline G, Goff D, et al. One-mile run performance and cardiovascular fitness in children. Arch Pediatr Adolesc Med 1999;153;845-49.

26. Eston R. What do we really know about children's ability to perceive exertion? Time to consider the bigger picture. Pediatr Exerc Sci 2009;21:377-83.

27. Eston RG, Lambrick DM, Rowlands AV. The perceptual response to exercise of progressively increasing intensity in children aged 7-8 years: validation of pictorial curvilinear ratings of perceived exertion scale. Psychophysiology 2009;46:843-51.

28. Sullivan KJ, Kantak SS, Burtner PA. Motor learning in children: feedback effects on skill acquisition. Phys Ther 2008;88:720-32.