THE EFFECTS OF AGE, SEX, HEAT STRESS, AND FINISH TIME ON PACING IN
THE MARATHON

Thesis
Submitted to
The School of Education and Allied Professions of the
UNIVERSITY OF DAYTON

In Partial Fulfillment of the Requirements for
The Degree of
Master of Science in Exercise Science

By
Nicholas William Trubee
Dayton, Ohio
May, 2011
THE EFFECTS OF AGE, SEX, HEAT STRESS, AND FINISH TIME ON PACING IN
THE MARATHON

Name: Trubee, Nicholas William

APPROVED BY:

_______________________________________
Paul M. Vanderburgh, Ph.D.
Committee Chair

_______________________________________
Wiebke S. Diestelkamp, Ph.D.
Committee Member

_______________________________________
Kurt J. Jackson, Ph.D.
Committee Member
TABLE OF CONTENTS

ABSTRACT ................................................................................................................... iv
INTRODUCTION ........................................................................................................... 1
METHOD ....................................................................................................................... 5
RESULTS ...................................................................................................................... 7
DISCUSSION ............................................................................................................... 10
CONCLUSION ............................................................................................................. 13
REFERENCES ........................................................................................................... 14
APPENDICES ........................................................................................................... 17
   A. Table 1 Subject Descriptive Statistics ......................................................... 17
   B. Table 2 Repeat Runners ............................................................................. 17
   C. Figure 1 Mean Running Velocity by 5 Kilometer and Sex ....................... 18
   D. Figure 2 Mean Running Velocity by 5 Kilometer and Finish Time Tertile . 18
   E. Figure 3 Mean Running Velocity by 5 Kilometer and Age Tertile .......... 19
   F. Figure 4 The Interaction Between Sex and Heat Stress on Pacing Index ..... 19
ABSTRACT

THE EFFECTS OF AGE, SEX, HEAT STRESS, AND FINISH TIME ON PACING IN THE MARATHON

Name: Trubee, Nicholas William
University of Dayton

Advisor: Dr. Paul M. Vanderburgh

Research has suggested that faster, women, and older runners are more likely to run at a consistent pace during marathon races. Therefore, the purpose of this study was to determine the simultaneous influences of age, sex, heat stress and finish time on marathon pacing. Pacing was defined as the mean velocity of the last 12.2 kilometers divided by the mean velocity of the first 30 kilometers. Subjects included 22,990 men and 13,233 women runners from the 2007 and 2009 Chicago marathons. The average ambient temperatures during the 2007 and 2009 marathons were 26.67 °C and 2.77 °C, respectively. Multiple regression analysis indicated that age, sex, heat stress, and overall finish time (p<0.01 for each) were simultaneous independent elements of pacing. Women were consistently better pacers than men in both marathons though the gender difference increased from cold to warm race temperatures. Coaches and runners can use these findings to improve the likelihood for more optimal pacing.
INTRODUCTION

The effect of temperature on athletic performance has been thoroughly investigated (2, 4, 5, 10, 14, 15, 17, 26, 28). Many of these studies examined the impact of environmental heat on variability in running velocity (13, 14, 15) and the increase in internal body temperature (2, 10, 17) during competition. As environmental and internal body temperature increased, the ability of endurance runners to maintain a high running velocity decreased, leading to either a decreased running speed as the race progressed (13, 14, 15) or caused participants to drop out completely (4, 28). Research has suggested that a steady or constant running velocity produced faster performances (1, 15, 22, 24). This constant running velocity was found to be most effective during longer distances, such as the marathon, in both cooler and warmer temperatures (15).

Pacing strategies have been defined in both cycling (16, 25) and running (15, 18, 22, 24) events. Mattern and colleagues (25) investigated how starting velocities effected overall finish time in a 20 kilometer cycling time trial. Thirteen United States Cycling Federation male cyclists were involved in three time trials. In the first trial, subjects were told to finish the 20 kilometer time trial as quickly as possible, using a self-selected pacing strategy. During the second and third trials, the cyclists rode at 15% below and 15% above their average power output from the self-selected trial for the first four minutes of the race, then finished the 20 kilometers as quickly as possible. Results
suggested that the fastest times were produced when the subjects adopted the slower start. This trend was also seen by Foster et. al. (16) when researching starting speeds during a 2 kilometer time trial event using 9 well trained volunteer cyclists. The fastest overall times were produced when the subjects started the race implementing a slower or even velocity compared to their average cycling velocity of the race. These findings coincide with Abbiss et. al. (1) who suggested that an even or constant pace was optimal for prolonged endurance events (> 2 minutes) including both running and cycling.

Gosztyla and colleagues (18) examined starting strategies of eleven moderately trained female distance runners. Each runner completed a preliminary 5 kilometer trial with the average velocity of the three 1.63 kilometer splits (1 mile) used as a reference starting velocity for three experimental trials. The three experimental trials consisted of each subject running a pace even to, 3% faster than, or 6% faster than their average 1.63 kilometer split time from the baseline test. This velocity was held for the first 1.63 kilometers, followed by a pace selected by each runner to finish the race as quickly as possible. The major finding of the study was that the fastest overall run times were produced from the 6% faster than average starting velocity trial. The slowest times recorded in the trial involved the even to average starting velocity.

Ely et. al. (15) researched pacing during prolonged events such as the marathon. In this investigation, 219 women, including the race winners, as well as the 25th, 50th and 100th place finishers were examined from 62 combined years of the Tokyo, Osaka, and Nagoya women’s championship marathons. Pacing was examined in 5 kilometer increments, where each runner’s average velocity was tracked for each 5 kilometer. The
race winners displayed a close to even pacing profile throughout the initial 40 kilometers. The pacing profiles of the 25th, 50th, and 100th place finishers showed a nonlinear decline in running velocity from their initial 5 kilometers. They also reported that an increase in race temperature was accompanied with a decrease in running velocity for both faster and slower runners. Conversely, races that were held in cooler weather conditions, faster runners were able to maintain a more even running velocity compared to their slower competitors.

Though temperature and differing pacing strategies have been shown to affect running speed and finish time, gender may also contribute to this phenomenon. In world record efforts, men have outperformed women in running distances ranging from 100 meters to 200 kilometers by 9-15% (6, 11, 23, 30). However, when men and women were matched according to age and performance of previous ultra-marathon races, those matched pairs produced near identical finish times in races held later (19, 30). Speechly et. al. (30) found when grouping males and females based on equal finish times from a previous marathon, women were able to perform at a higher percentage of their VO2 max than their male counterparts. Loftin and colleagues (23) also reported this trend in 20 middle aged male and female marathoners. This investigation expressed VO2 max allometrically to body mass^{-0.75} and found that over a 1-hour treadmill run, women ran at 76.3% of their VO2 max compared to 67.7% for men. Carter (9), Ruby (29) and Tarnopolsky (31) also stated that females tended to show a lower RER than males during submaximal endurance exercise. This indicated that women had a tendency to oxidize fat for energy, while sparing glycogen. Runners who are able to spare glycogen can delay
“hitting the wall,” a phenomenon where glycogen stores in the body are fully depleted, limiting performance (7, 12, 29, 31). Women also tend to have a larger surface area-to-mass ration than males (10) allowing them to dissipate a larger percentage of heat produced due to running. However, women tend to have larger amounts of subcutaneous fat and lower exercise capacities compared to men (21), as well as a tendency to sweat less during exercise in the heat (3, 20, 21).

March and colleagues (24) examined the effects of age, sex, and finish time on pacing in 319 marathoners. Their investigation coincided with previous research that faster marathoners tend to run at a more even pace compared to slower runners (1, 15, 22, 24) and that older runners were better pacers than their younger competitors. March’s main finding, however, was that when controlling for finish time and age, women were better pacers than men. To our knowledge, no empirical research has evaluated this gender effect on marathon pacing in cold versus hot environmental conditions.

Therefore, the purpose of this investigation was to simultaneously examine the effects of age, sex, heat stress and finish time on pacing in the marathon. It was hypothesized that the previously stated trends would persist in similar temperatures, pacing would decline as temperatures increased, and the pacing gender gap would increase from cold to hot race conditions.
METHODS

All data for this study were obtained from the Bank of America Chicago Marathon website (http://www.chicagomarathon.com/cms400min/chicago_marathon/) which included subject age, gender, 5 km split time, and overall finish time. This marathon was chosen for its large sample size, flat course, and large temperature difference between its 2007 and 2009 events. In fact, the average ambient temperatures during the 2007 and 2009 marathons were 26.67 °C and 2.77 °C respectively (http://weather.org/weatherorg_records_and_averages.htm)

Subjects

Sample one included 11,581 and 20,540 runners from the 2007 and 2009 marathons, respectively, not counting runners who ran both races, a necessary condition for multiple regression analysis. The descriptive data for these subjects are shown in Table 1. Sample two included a total of 2,051 runners who participated in both races and were compared using paired samples t-tests. The descriptive data for the repeat runners are shown in Table 2. The Institutional Review Board (IRB) granted approval for this study and approved the waiver of informed consent since these data are in the public domain. In order for a participant to be included in this study, all 5 kilometer split times and the overall finish time must have been recorded, and finish times were less than five hours. This time cut-off was selected because a five hour marathon correlated to an
average run velocity of 2.33 m s\(^{-1}\) (approximately 11:30 min mile\(^{-1}\), or 5.2 mph), a pace described by March and colleagues (24) to be a pace difficult to walk. This method ensured that all runners included in the study ran the majority of the race. Since the data were retrieving from an online public source, we could not ascertain running experience, training level, and weather acclimatization of participants.

**Procedures**

The course consisted of 42.2 kilometers (26.2 mi) with digital clocks set at every mile marker and 5 kilometer checkpoint. At each 5 kilometer checkpoint, runner’s shoe-worn chips crossed a digital receiver, documenting split times. The cooler temperature and flat landscape of the 2009 marathon was similar to the March (24) study in that the change in pacing due to hyperthermia was not likely. However, the warmer temperature in 2007 was similar to Ely (15) and Roberts (28) investigations, where pacing and running ability would likely impair overall run performance.

Pacing was defined as the mean velocity of the last 12.2 kilometers (7.6 mi) divided by the mean velocity of the first 30 kilometers (18.6 mi). March (24) used a similar pacing index where the mean velocity of the last 9.7 kilometers was divided by the first 32.5 kilometers. This method was used because glycogen depletion during the marathon often occurs at approximately 3 hours or 30 km for the average marathoner, leading to a noticeable decline in running velocity (8, 12, 31). By calculating the change in running velocity over time, we were able to focus on the change in pacing during the latter stage of the race.
Statistical Analysis

Stepwise multiple linear regression was used on the 32,121 non-repeat runners to evaluate the impact of age, gender, heat stress, and overall finish time on pacing. Key two-way interactions involving heat stress were assessed using the same population in order to account for the effect that an independent variable on pacing may depend on the level of another independent variable. Paired samples t-tests were also conducted in order to consider the effects of gender, heat stress and finish time on the 2051 repeat runners. An alpha level of 0.01 was selected because multiple tests of significance were applied.

RESULTS

Age, sex, finish time, and heat stress were each statistically significant \( p < 0.01 \) determinants of pacing with all four in the model. Figures 1-3 depict the effects of age, sex, finish time, and heat stress on pacing (age and finish time shown by tertiles) by 5 kilometer split times. As shown in Figure 1, the marked decrease in running velocity in men is greater than that of women. A large decrease in running velocity can also been seen in Figure 2, as those runners with slower finish times seem to be less able to sustain a higher running velocity than those with faster finish times. When considering age and running velocity, both younger and older runners seem to follow a similar trend as seen by Figure 3. The equation developed from the multiple regression analysis can be
beneficial when interpreting the degree of the effects. Thus, we calculated each term (coefficient x independent variable difference) for the following independent variable differences: male versus female, 25 versus 55 years of age, 3 hours versus 4.5 hours finish time, and hot versus cool running temperature. March (24) used this method to interpret the effects of the independent variables age, sex, and finish time on pacing. As an example, because 25 years of age versus 55 years of age signifies a 30 year difference in age, we multiplied 30 by the age coefficient of 0.000223 to produce an effect of 0.0067, or 0.67% on pacing. Described differently, the effect of being 30 years older rendered a 0.67% increase in pacing. Similarly, the effect of being female and faster translated to a 5.09% and 6.40% increase in pacing, respectively. The greatest effect on pacing was heat stress, which caused an independent decrease of 9.18% in pacing by the runners.

Including the key interactions in the model, all three were significant ($p < 0.05$): finish time x heat stress, age x heat stress, and sex x heat stress. An interaction among finish time and heat stress denoted that heat had an overall deleterious effect on pacing and can be seen in Figure 2. As runners get slower, via overall finish time, heat had a slightly greater effect on pacing. Faster runners between cool and warm temperatures differed in pacing by 10.53% whereas slower runners differed in pacing by 12.18%. The interaction between age and heat stress can be seen in Figure 3. This interaction signified that the age difference on pacing increased from cool to warm temperatures. However, this difference was quite small meaning the difference in pacing of older runner between cool and warm race temperatures was 12.12% whereas the difference in pacing of
younger runners between temperatures was 13.00%. The third interaction, sex x heat stress, indicated that women were consistently better pacers than men though the gender difference increased from cool to warm race temperatures. The difference in pacing between genders in cool race temperatures was 3.02% whereas the difference in pacing between genders in warm temperatures was 7.53%. This interaction can be seen graphically in Figure 4. Although all three of the interactions were significant ($p < 0.05$), the main finding from these interactions was that as heat increased, the gender difference on pacing increased. With the use of a large sample size, the other two interactions (age x heat stress and finish time x heat stress), although significant, showed a much smaller and less practical difference than the sex x heat stress interaction.

Paired sampled t-tests were conducted on the 2,051 runners who completed both marathons under the specified 5 hour cut-off time. Table 2 lists the descriptive data for these runners. There was a 13.65% difference between the mean pace indexes in 2007 and 2009, which was found to be statistically significant ($p < 0.01$), meaning that the cooler temperature during the 2009 race offered a more suitable stage for even pacing. A 13.36% difference between the mean finish times among the repeated measures was also found to be statistically significant ($p < 0.01$), indicating that the cooler temperature allowed those runners to run at a higher velocity in the later stages of the race. Sexes were then assessed separately using paired samples t-tests. The difference between the mean pace indexes as well as the difference between the mean finish times for the repeat female and repeat male runners were statistically significant ($p < 0.01$). Women decreased their pace index and increased their finish time from 2009 to 2007 on average
of 9.41% and 11.02%, respectively, while males decreased their pace index and increased their finish time on average of 15.19% and 14.36% respectively. This finding was similar to the heat stress x gender interaction in the regression analysis, showing as temperature increased the gender difference in pacing also increased. Sexes were also mutually examined for finish time and pace index. Repeat women runners were found to be significantly \((p < 0.01)\) superior pacers compared to their male counterparts in both hot and cold temperatures by 7.60% and 2.20% respectively. However, the repeat male runners were significantly \((p < 0.01)\) faster than repeat female runners in hot and cold temperatures by 3.75% and 6.87% respectively.

**DISCUSSION**

The principle finding of this study is women were consistently better pacers than men though the gender difference increased from cool to warm race temperatures. Female runners among all ages and finish times show a trend for better pacing than men in both the 2007 and 2009 marathon. This may be due to the suggestion that women are able to spare glycogen and oxidize fat for energy because of a lower RER at submaximal intensities (9, 29, 31, 32). While sparing glycogen, women may be able to fend off “hitting the wall” allowing them to run at a more even pace throughout the race. This even running velocity is assumed to be the most metabolically efficient strategy for completing endurance races (27).
The larger difference in pacing between males and females in warmer temperatures may also be due the finding that women generally have a larger surface area-to-mass ratio than males (10). Since heat production via exercise is proportional to body mass and heat loss is a function of body surface area, women runners should be able to dissipate a higher percentage of excess heat generated due to running. Males, then, would likely fatigue earlier (17) and display the markedly slower running velocities in late stages of the race.

As seen in Tables 1 and 2, finish time and pace exhibited significantly worse scores from cold to hot race conditions. Hyperthermia, caused by an increased ambient temperature and internal body temperature (2, 4, 5, 10, 17) can lead to declines in aerobic performance, causing participants to decrease their running velocity as the race progresses. Often, as temperatures increase, many runners are unable to finish the race. This was seen in the 2007 marathon when the race was cancelled 3 hours and 35 minutes into the race. Many runners finished after the race was cancelled, ignoring the decision by the race staff to terminate the race, while over ten thousand runners did not finish due to the rise in temperature. Roberts (28) concluded that the 2007 Chicago marathon should have been cancelled prior to the start of the race due to high temperatures the morning of the race. Although heat seems to be the likely cause for the drop in performance, others variables such as running experience, training level, and weather acclimation may have an additive effect to this phenomenon as well. Based on the archival nature of the data, we could not determine if these variables played a role in the decreased pace indexes and increased finish times.
As seen in the March (24) study and the current investigation, the negative coefficient for finish time in the regression equation suggests that a higher pace index (closer to 1 or above) is correlated with a faster run time. Taking into consideration the equation used to calculate pacing in this investigation, runners who demonstrated consistent finishing velocities (last 12.2 kilometers) compared to the running velocities of the first 30 kilometers were also associated with a faster run time. An additional similarity to March (24) in this investigation is that runners in cooler temperatures seemed to adopt a slower initial velocity compared to runners in the heat, regardless of age, sex, or finish time. This trend is quite prevalent in Figures 1-3. March (24) also found that being 30 years older on average translated to a 7.3% increase in pacing. In the current study, runners competing in similar temperatures were found to only have a 0.91% increase in pacing due to being 30 years older. The current investigation was comparable to the March (24) when assessing the difference in gender on pacing. The current study found that when running in cooler temperatures, women had a 4.14% increase in pacing, whereas the aforementioned study found a 4.06% increase in pacing by being female. Being faster in cooler temperatures also meant there was a 5.94% increase in pacing, whereas March (24) found that being faster lead to a 10.71% increase in pacing.

These marathons were selected for investigation because of their flat topography, negligible wind speeds, large entrant pool, significant difference in temperature, and limited maturation of repeat subjects. The decrease in running velocity in the heat is seen in Figures 1-3, negatively affecting age and sex similarly. The noticeable decline in
running speed is seen as early as the 15 kilometer mark and is more severe as the race progresses. There was however, a trend for an increase in pace among all groups in both temperatures from the 40 kilometer mark to the finish. This may have been caused by extra motivation to complete the task when runners are nearly finished with the race. A similar occurrence was studied by Ely and colleagues (15) where the term “end spurt” was used to explain the increase in pace in the latter stages of a race. Overall, these findings coincide with those from March (24), stating that older, women, and faster runners produced the best pace indexes. When considering environmental conditions, the difference in pacing between males and females increased as temperature increased.

**CONCLUSIONS**

The results from the current investigation match those of March (24). With the addition of heat stress, women remained superior pacers to males, while the effects of age and finish time were practically insignificant. This study is the first to examine age, sex, heat stress, and finish time simultaneously on pacing in the marathon. Suggested by previous research and the current investigation, a consistent running velocity has been shown to produce faster performances by marathoners. Women were consistently better pacers than men though the gender difference increased from cold to hot race temperatures.
REFERENCES


## APPENDICES

Table 1. Subject Descriptive Statistics (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Men Hot (n = 7,391)</th>
<th>Men Cool (n = 12,663)</th>
<th>Women Hot (n = 4,191)</th>
<th>Women Cool (n = 7,877)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>37.53 ± 9.48</td>
<td>37.35 ± 10.06</td>
<td>33.65 ± 8.36</td>
<td>33.60 ± 8.66</td>
</tr>
<tr>
<td>Pace Index</td>
<td>0.79 ± 0.09</td>
<td>0.91 ± 0.09</td>
<td>0.85 ± 0.08</td>
<td>0.94 ± 0.07</td>
</tr>
</tbody>
</table>

Table 2. Repeat Runners (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Men Cool</th>
<th>Hot</th>
<th>p</th>
<th>Women Cool</th>
<th>Hot</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finish Time</td>
<td>3:40:08</td>
<td>4:11:44</td>
<td>&lt; 0.000</td>
<td>3:55:15</td>
<td>4:21:11</td>
<td>&lt; 0.000</td>
</tr>
<tr>
<td>Pace Index</td>
<td>0.91</td>
<td>0.79</td>
<td>&lt; 0.000</td>
<td>0.93</td>
<td>0.85</td>
<td>&lt; 0.000</td>
</tr>
</tbody>
</table>
Figure 1. Mean Running Velocity by 5 Kilometer and Sex

![Graph showing mean running velocity by 5 kilometer and sex.]

Figure 2. Mean Running Velocity by 5 Kilometer and Finish Time Tertile (T1, T2, T3)

![Graph showing mean running velocity by 5 kilometer and finish time tertile.]

---

18
Figure 3. Mean Running Velocity by 5 Kilometer and Age Tertile (T1, T2, T3)

Figure 4. The Interaction Between Sex and Heat Stress on Pacing Index