Respiratory Exchange Ratio is Not Associated with Slowing in the Marathon

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ABSTRACT

Background: Previous research has shown that males slow more throughout the course of a marathon than females. Proposed reasons for differences in slowing include the fact that females oxidize proportionately more lipids and fewer carbohydrates during exercise when compared to males, and possible differences in thermoregulation. Respiratory exchange ratio (RER) can be used to estimate the ratio of fat to carbohydrates being metabolized.

Purpose: To compare the degree of slowing (time in the first vs. second half of a marathon) between men and women, and determine if steady-state RER or ambient temperature differences predict the rate of slowing in male and female novice marathon runners.

Methods: Chip times for 123 female and 44 male recreational marathon runners (21.0 ± 1.7yrs) were used to determine change in pace observed in the second half of the marathon compared to the first half. A two-mile time trial (2MI) was used to assess baseline fitness and pace for steady-state measurements. A submaximal 6-minute treadmill run at 75% of 2MI velocity was completed 1-3 weeks before the marathon. RER was collected using a metabolic cart (Medical Graphics Diagnostics, St. Paul, MN). Baseline measures and outcomes (RER and percent slowing) were analyzed using independent samples t-tests to detect differences between the groups (men vs. women and by year 2014, cool weather vs. 2015, warm weather). Univariate ANOVA tests were run to analyze the differences in percent slowing (%slowing) and RER by year and sex. Pearson's Product Moment Correlation Coefficient (r) was used to determine the strength of the relationship between RER and %slowing as well as the relationship between %slowing and percent body fat (%BF), weight, height, body surface area (BSA), and BSA to mass ratio (BSA/M).

Results: The mean %slowing for the total sample for 2014 and the total sample in 2015 was 14.1± 12.0% and 22.0 ± 16.5%, respectively ($p<0.05$). The mean %slowing for the combined group from 2014 and 2015 males and females was 20.6± 14.8% and 17.02 ± 14.8%, respectively ($p <0.05$). Females had a significantly lower RER during steady-state exercise in comparison with males (Female = 0.87 ± 0.05, Male = 0.89 ± 0.05, $p<0.05$). Sex and year were predictors of %slowing. There was no significant relationship between RER, temperature of marathon, weight, %BF, BSA, or BSA/M and %slowing in the total group, but RER and height were significantly related ($p<0.05$).

Conclusion: Consistent with previous research, males slow more than females from the first to second half of the marathon. However, RER was not associated with slowing during the marathon. Temperatures of the race did affect the rate of slowing, but men and women were not affected differently. This suggests that pace maintenance is not due to substrate metabolism.

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CHAPTER 1: INTRODUCTION

Marathon participation levels are at an all-time high, particularly amongst recreational athletes. Although finishing times continue to narrow between males and females, previous research has demonstrated that males slow more during the marathon, when compared to females (Deaner et al., 2015; March et al., 2011;Trubee et al., 2014). Although the mechanism is not yet known several possible mechanisms have been proposed, including: running ability, experience, weather, hyperthermia, pacing strategy, and substrate utilization.

It has been established that during the marathon, faster runners are able to pace themselves more effectively than slower runners and, when the adding the covariate of heat, better runners enhanced pacing abilities are magnified (March et al., 2011; Trubee et al., 2014). Though non-elite men and women differ in their pacing ability, when studying elite runners only, there is no sex difference in pacing ability even in warmer temperatures (Trubee et al., 2014). Vihma (2010) found that amongst marathon runners of varying ability, women of all ability levels were less affected by warmer weather than men. This could be due to females having a greater body surface area to mass ratio (BSA/M), allowing them to dissipate heat more effectively (Cheuvront & Haymes, 2001). Contrarily, it has been thought that female's larger percent body fat (%BF) could act as insulation and be less advantageous in warmer temperatures (Cheuvront & Haymes, 2001). Upton et al. (1983) found that for female distance runners, marathon time was positively correlated to body mass index ($r = 0.52$), and body fat ($r = 0.52$).

Hitting the wall (HTW) is described as marked slowing in a runner's pace due to fatigue around the 30-34 km mark of a marathon. Interestingly, women tend not to experience HTW as often as men (Stevinson and Biddle, 1998). Physiologically, HTW is when a runner's glycogen stores have been depleted (Stevinson and Biddle, 1998; Summers et al., 1983). Since previous work has demonstrated that women use more lipids in oxidative metabolism during prolonged exercise than males, this could be preventative of HTW (Carter et al., 2001; Friedlander et al., 1998; Horton et al., 1998; McKenzie et al., 2000; Tarnopolsky, 1990; Venables, 2004). Psychological mechanisms that could lead to men increased likelihood for HTW could be due to increased expectancy effect, adopting risky pace strategy, or competitive motivation (Allen & Dechow, 2013; Buman et al., 2008; Deaner et al., 2015; Stevinson & Biddle, 1998; Wilson et al., 1989).

Respiratory exchange ratio (RER) is used to study human metabolism by measuring the ratio of O_2 utilized and CO_2 expired to estimate substrate utilization (Brooks, 1984). Endurance exercise training is well described as being linked to lowering RER in humans, allowing increased fatty acid oxidation and decreased carbohydrate (CHO) oxidation, sparing glucose and muscle glycogen (Brooks, 1997). Because women have a lower RER for a given exercise intensity than men, it has been suggested that untrained or novice female runners, having a lower RER, would have an advantage over untrained men at avoiding fatigue due to glycogen depletion and, therefore, consequential slowing (Tarnopolsky, 2000).

The purpose of this study is to compare the degree of slowing (time in the first half compared to the second half of a marathon) between men and women and determine if steady state RER and BSA/M, an index that is thought to contribute to thermoregulation, are predictive of slowing in male and female college-age recreational marathon runners.

CHAPTER 2. REVIEW OF LITERATURE

Males slow more than females during the marathon

Marathon participation levels are at an all-time high, particularly amongst recreational athletes. Although finishing times continue to narrow between males and females, previous research has demonstrated that males slow more during the marathon than females (Deaner et al., 2015; March et al., 2011;Trubee et al., 2014). Although the mechanism is not yet known, females are better at maintaining their velocity from the beginning to end of a marathon.

March et al. (2011) conducted a study where the effect of sex, age, and run time on pacing ability during a marathon was examined. In this study, March, using 186 men and 133 women marathoners, demonstrated that pacing (defined at mean velocity of the last 9.7 km divided by the first 32.5 km as glycogen depletion during the marathon usually occurs at 3 hours or the 30 km mark) was better maintained by women, when compared to men, after controlling for finishing time and that age, sex, and race times were independent factors in pacing regardless of the other variables ($p<0.01$ for each) (March, et al., 2011).

Trubee et al. (2014) studied the affects of climate and running ability on pacing (defined as the mean velocity of the last 12.2 km divided by the mean velocity of the first 30 km for the same reason as March et al.) between the sexes. They found that non-elite female marathon runners were better at pacing in comparison to non-elite male marathon runners ($p<0.01$) and was even more pronounced in warmer climates than in cooler. Interestingly, this comparison cannot be extrapolated to elite marathon runners, as there is no difference in pacing ability between the sexes (Trubee et al., 2014).

Similarly, Deaner and colleagues (2015) demonstrated that male and female non-elite marathon runners demonstrated differences in pacing, specifically the runners' pace ability was compared after correcting for the 12% sex difference in maximal oxygen uptake. When comparing the first half to the second half of a participant's marathon time, Deaner et al. concluded that females were 1.46 times ($p=0.0001$) more likely to maintain their first half pace onto the second half of the race than men. The researchers also concluded that race experience was associated with less slowing from first to second half of the race, but the sex difference was not eliminated when controlling for experience (Deaner et al., 2015). Though others have demonstrated males slow more than females, the literature is lacking a definitive reason why. Collectively, these previous studies demonstrate that females have an advantage to be more effective at pacing during running, although the mechanism for these differences has yet to be elucidated.

Factors affecting slowing between males and females

Although the exact mechanism is not known as to what is causing the slowing difference between females and males, there have been several possible mechanisms proposed, including: running ability and experience, weather, hyperthermia, risky pacing strategy, and substrate utilization.

Running Ability and Experience

In general, it is recommended that long distance runners adapt an even pace velocity to achieve their fastest race performance (Foster et al., 1994; Maughan, Leiper, & Thompson, 1985; Noakes, 2001). Those who adopt an uneven pacing strategy experience a greater physiological demand, which results in poorer race performance in both faster and slower runners (Staab, Agnew, & Siconolfi, 1992) and it has been found that faster and more experienced runners are better at pacing than slower and less experienced runners. March et al. (2011) examined the affects of age, sex, and run time on marathon pacing and was able to replicate this finding, which was that the ability to maintain a more consistent pace was associated with faster finishing times, or that those that were faster runners were able to pace themselves more effectively and slower runners demonstrated marked decrease in run velocity (March et al., 2011). Similarly, when comparing pacing elite and non-elite runners with the added covariate of heat, Trubee et al. (2014) found that being a better runner resulted in better pacing abilities in hot and cold temperatures, where pacing was defined as the mean velocity of the last 12.2 km divided by the mean velocity of the first 30 km. Both male and female elite runners were significantly better pacers than their non-elite counter parts, with ability effect magnified in hotter temperatures ($p=0.0001$ vs. $p=0.010$ for men and $p=0.002$ vs. $p=0.018$ for women). The authors did not find a sex difference in pacing in the elite category in either weather temperatures ($p= 0.289$ for hot and $p=0.260$ for cool) suggesting that better runners seem to be able keep an even velocity in comparison to their slower counterparts (Trubee et al., 2014). Ely et al. (2008) demonstrated that slower runners go out faster for the initial 5 km, and then settle in for the rest of the race at a slower pace. Contrary to what Trubee et al. found, Ely et al. showed that instead of slower runners' pace being more affected by warmer temperatures, faster runners experienced pace change with increased temperature. The time difference between the initial 5 km and 35–40 km (pace differential) of the race winner increased as the weather warmed from -22 ±14 s to 7 ± 9 s and 24 ± 13 s (mean ± SE; $p< 0.05$) in cool (C), temperate (T), warm (W) conditions respectively, whereas the running velocity of the

100th place finisher was similar regardless of temperature (C = 199 ± 45 s, T = 166 ± 18 s, and W = 198 ± 40 s) (Ely et al., 2008).

It has been demonstrated that faster and more experienced runners have a greater ability to maintain their pace throughout a race independent of sex (March et al., 2011; Trubee et al., 2014). When it comes to running ability and pacing, at the elite level there is no difference in pace maintenance between the sexes, but previous research suggests that there is a sex difference in pacing ability in the non-elite category of runners (Deaner et al., 2015; March et al., 2011;Trubee et al., 2014).

Weather

Lind (1955) was the first to propose that there is an ideal zone of air temperatures that results in maintenance of internal thermal equilibrium and since then it has been demonstrated on multiple occasions that finishing time and ambient air temperature are correlated (Ely et al., 2008; Suping, et al., 1992; Vihma, 2010). Suping, Guanglin, Yanwen, and Ji (1992) studied the effect of temperature on the performance of the top ten runners from the 1981 to 1989 Beijing marathon. The researchers studied air temperature (*ta*), relative humidity (RH), wet bulb temperature (*tw*), wind velocity, and effective temperature (ET), defined as $ET= ta-0.4(ta-10)(1-RH/100)$, and found that temperature and average finishing times of the top ten finishers were significantly correlated ($r= 0.8910$). The authors found the number of people who ran fast marathons (under 2:20) was correlated with ET ($r =-0.95$), *ta* was more predictive for elites, and *tw* was most correlated with success of all participants ($r=0.73$) (Suping et al., 1992). These findings led to the question of if the air temperature had similar effects on runners outside of the elite category, which was addressed in a study by Ely et al. (2008). Ely and colleagues took results from three Japanese Women's championship marathons and analyzed the correlation between finishing place and air temperature using sixty-two years of race time data of the 1st, 25th, 50th, and 100th place finishers from each year. They found that warmer temperature was significantly related to slowing pace for the 25th place finisher and the winners of the marathons, but increasing temperature was not correlated with slowing in the 50th and 100th place finishers, indicating that the heat less affected slower runners (Ely et al., 2008).

In contrast, it has been said, the increase from 5 to 25°C affects slower runner more than faster runners (Vihma, 2010). Vihma studied the effect of weather parameters on marathon results in elite, intermediate, and slow male and female runners with finishing times between 2:11 – 5:00 hours and analyzed the relationship between weather parameters and the percentage of non-finishers. Finish time anomaly (FTA) was defined as the deviation of the annual finishing time from the linear trend of the finishing time and it was found that air temperature was the most correlated with FTA (r=0.66-0.73), with the slowest runners being the most effected, which is in contrast to Ely et al. (2008) that found that hotter temperatures effected faster runners more than slower runners. Vihma found that FTA was significantly correlated with solar shortwave radiation, air relative humidity, and that women of varying abilities were less affected by warmer weather than men. Vihma showed that the percentage of non-finishers was correlated with air temperature (r=0.72) and that that slower runners were more affected by poor weather conditions than faster runners, which was also demonstrated by Ely et al. (2007) (Vihma, 2010).

Body surface area is an important metric related to the effect weather has on a runner's performance. Muscle contractions that occur during physical activity result in metabolic activity that produces heat that can alter the body's internal temperature. In order to compensate for change in homeostasis, the heat from the muscles will be transferred to the skin via blood to be dissipated into the air. The rate of transfer of energy requires a gradient between inside and outside temperature; if there is a larger gradient, heat will dissipate faster (Wendt et al., 2007) and if a body has a greater surface area, there is more skin available for heat to dissipate from, resulting in greater ability to maintain exercise levels without experiencing hyperthermia. In contrast, when the external environment is colder than the body's internal temperature, arteries will vasoconstrict, sending less heat via the blood to the skin, resulting in less heat dissipation and it is beneficial for one to have less surface area from that to lose heat from (Roach, 2012). In a study conducted in all male, aerobically matched runners of East African and Caucasian descent were tested to see if surface area to mass ratio (BSA/M) affected 8 km race times in hot environments (Marino et al., 2004). The East African runners, having a larger BSA/M, were able to dissipate heat more affectively than their Caucasian counterparts (2.80 ± 0.23 and 2.58 ± 0.22 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively). The authors showed that the East African runners were faster in hotter temperatures (35°C) than Caucasians ($p<0.01$), but they did not see this difference in ability when it was cooler (15°C) (Marino et al., 2004).

On average, females have a smaller surface area and body mass when compared to males, but have a larger BSA/M (Cheuvront, and Haymes, 2001). Since heat production and dissipation are positively related to body mass and body surface area, respectively, it is thought that women should be able to regulate internal body temperature in hotter environments better than men (Cheuvront, and Haymes, 2001). Contrarily, it has also been thought that females larger percent body fat would act as insulation and be less advantageous in warmer temperatures (McLellan, 1998). Millard-Stafford et al. (1995) studied the thermoregulatory abilities of men and women running a hot weather 40 km race where they found women had a lower rectal temperature (T_{re}) than men despite having twice the percent body fat and similar VO_{2max}. Since females have a larger BSA/M than men, they may have a thermoregulatory advantage over men during hot and humid race temperatures that could be preventative of slowing.

Hyperthermia

Other areas of interest related to pace maintenance are vascular volume, plasma glucose concentration, and hyperthermia. Cade et al. (1992) studied 21 experienced runners to see if energy substrate depletion, hyperthermia, or both, contributed to pace slowing in the marathon. Runners drank either a glucose/electrolyte solution (GE), diluted GE solution, or water ad libitum throughout the race and found that pace in runners that drank water and diluted GE solution slowed to a greater extent than those who drank the full strength GE solution (37.2%, 27.9%, and 18.2% respectively). Ten of eleven runners that shifted to a walk/run/walk (WRW) pace during the last six miles of the race had a T_{re} of 39°C or higher and had an at least 10% decrease in plasma volume and five of the WRW runners having a significant reduction of plasma glucose in comparison to those who were able to run steadily. Out of the eleven with the WRW pace, five were from the water group, four in the diluted GE group, and two from the GE group (Cade et al., 2011). This data suggests that pace slowing resulted from hyperthermia associated with plasma volume depletion and hypoglycemia. Therefore, female’s larger BSA/M should make them less susceptible to hyperthermia than males and be less likely to experiences slowing due to hyperthermia related hypovolemia and hypoglycemia.

Hitting the wall

Hitting the wall (HTW) is another phenomenon that affects a runner’s ability to maintain their pace. HTW is described as marked slowing in a runners pace due to fatigue around the 30-34 km mark in a marathon (Stevinson & Biddle, 1998; Summers et al., 1983). Physiologically, HTW is described as when the body’s glycogen stores have been depleted and fat oxidation must be relied on for energy (Stevinson & Biddle, 1998). It has been reported that in a given marathon, 43-53% of runners report experiencing HTW (Buman et al. 2008; Stevinson & Biddle, 1998). There have been suggested psychological and physiological reasons for a runner to experience HTW, though a common theme in HTW research is that women tend to not experience HTW as often as men (Stevinson and Biddle, 1998).

Hitting the wall: Psychological Mechanism

Expectancy is a psychological phenomenon defined as how one expects to perform and how it affects the actual outcome of a task and has been studied in various manners within sport (Wilson et al., 1989). It is thought that if one expects to HTW before his or her race, then he or she may have a higher chance of doing so. Wilson et al. (1989) conducted a study that looked at the response of affective expectation of affective experience. Participant described experiences are more consistent with expectation when the intensity of the expectation is strong. The effect remained apparent even when the experience was contradictory to the expectation (Wilson et al. 1989). Buman et al. (2008)

conducted a study to explore the probability that a runner will HTW and describe the risk of HTW over the course of the marathon. They found that expectancy of HTW was the most robust predictor of HTW in their models, when controlled for sex and training volume. Twenty-eight percent of men and 20% of women has expectations of HTW, 45% of men and 37% of women experienced HTW, and of those participants who reported HTW, 19% of males and 13% of women indicated an expectation of HTW (Buman et al., 2008). Therefore, men may experience HTW more because the expectancy effect described by Wilson et al. (1989) is higher in their sex.

Another psychological reason for men to be more likely to HTW than women could be that they are generally more competitive (Deaner et al., 2015). Being more competitive could result in men starting out too fast or adopting a risky pace they cannot sustain (Allen & Dechow, 2013; Deaner et al., 2015; Stevinson & Biddle, 1998). Men are more likely to report that competition motivates them to run and when given the choice to enter a single-sex competitive road race or a single-sex noncompetitive road race, men are more likely to select the competitive race (Deaner et al., 2015).

Hitting the wall: Physiological Mechanism

As mentioned before, the physiological definition of HTW is when the body's glycogen stores have been depleted and needs to switch to fat oxidation for energy to continue exercise (Stevinson & Biddle, 1998). Metabolism during exercise is derived from a combination of carbohydrates (CHO) and lipids. CHO are found from plasma glucose and muscle glycogen whereas lipids are derived from plasma fatty acids (FA) and intramuscular triglycerides, which are stored at the level of the skeletal muscle as fat droplets (Coyle, 1995; Roepstorff et al., 2002). The amount of energy in the body stored as triglycerides is large, about 200-625 MJ in men and women of normal body fat percentage which allows for triglycerides to be hydrolyzed into glycerol and free fatty acids to be used by exercising muscles (Coyle, 1995). Although there is an abundance of stored energy in the form of fat, humans cannot oxidize fat at a high enough rate to provide energy at high intensity exercise, so they must switch to CHO oxidation to sustain activity. CHO are stored as glycogen within the skeletal muscle and liver, where approximately 8400 KJ of glycogen is stored in the muscles and 80 g of glycogen is stored in the liver (Coyle, 1995). This glycogen can be hydrolyzed back into glucose and be transported to working muscles for energy.

At rest and low-intensity exercise, plasma FA are the dominant substrate that is utilized for energy (<25% VO_{2max}). As exercise intensity increases (~65% VO_{2max}), there is a shift to muscle triglycerides and muscle glycogen, and at high intensities (>85% VO_{2max}) the body uses mostly muscle glycogen (Romijn et al., 1993)(Figure 1). Since glycogen is used at a higher rate during high intensity exercise, when un-replenished, people will deplete their stores and experience muscle fatigue during exercise (Coyle, 1995).

Some studies have shown that females use more lipids in oxidative metabolism during exercise than males (Friedlander et al., 1998; Horton et al., 1998; McKenzie et al., 2000; Tarnopolsky, 1990), which could be a factor in the male propensity to HTW and consequent slowing during the marathon. However, others have observed a similar relative utilization of CHO and lipids in females and males exercising at the same relative workload (Bergman & Brooks, 1999; Marliss et al., 2000; Romijn et al., 2000), therefore it remains unclear as to if there is a substrate metabolism ratio difference between the sexes.

Muscle fiber type is a factor that affects the ratio of CHO to lipid contribution to metabolism (Horton et al., 1998; Roepstorff et al., 2002). On average, women possess more type I muscle fibers and men possess more type II muscle fibers (Hunter, 2014). Type II muscle fibers allow for faster calcium kinetics, the generation of more power, faster shortening velocities, and faster fatiguing than type I fibers (Schiaffino & Reggiani 2011). The ability to oxidize more fats and less CHO at moderate to high intensity workouts in women can be partially attributed to muscle fiber type. The higher proportional area of type I skeletal muscle fibers in women leads to an inclination for lipid metabolism which includes greater mRNA levels of muscle lipoprotein lipase, membrane FA transport protein-1, FAT/CD36 protein levels, and citrate synthase, independent of training status and age and the presence of 17-estradiol (E2) allows women to metabolize lipids at the level of the skeletal muscle (Binnert et al. 2000; Kiens et al. 2004; Maher et al. 2010). Collectively, a higher proportion of type I muscle fibers allows women to avoid fatigue and recover force and power better than men due to substrate metabolism.

Venables et al. (2004) conducted a study with the aim of understanding substrate metabolism, specifically lipid oxidation at varying exercise intensities between men and women. The authors hypothesized that exercise intensity was the primary determinant of lipid oxidation level and sex, body composition, physical activity level, and training status are secondary contributors. Using indirect calorimetry, incremental exercise test, and scaling fat oxidation for fat free mass (FFM) to account for increased body fat percentage in women, the authors found that increasing exercise intensity from low to moderate to high, the rate of CHO oxidation increases, whereas lipid oxidation follows an inverted hyperbola pattern, where fat oxidation reached a peak rate at 48 ± 1% VO_{2max}, and decreased after any further increase in exercise intensity. Venables and colleagues were able to replicate other studies that concluded that women have a higher rate of fat oxidation at varying exercise intensities than men despite having lower VO_{2max} and activity levels. The authors reported that men had a lower cross over point, which is a concept that Brooks et al. (1998) introduced, referring to the time during exercise when a person goes from oxidizing predominantly lipids for energy at lower intensity, to using predominantly CHO for energy at increasing exercise intensities (Venables et al., 2004). Therefore, if men have a lower cross over point, it means that they switch over to reliance on CHO stores for energy sooner, or at a lower $\%VO_{2max}$ than women, which could lead to men depleting glycogen stores faster than women, resulting in fatigue and HTW.

A study conducted by Carter et al. (2001) looked at the change in substrate utilization between men and women after a seven-week endurance training intervention. This longitudinal study allowed for researchers to address the difference in substrate utilization during exercise without concern of the confounding variable, training status, between the sexes. The authors measured substrate utilization pre and post training intervention during a 90 minutes cycle ergometer at $60\%VO_{2max}$, where glucose and glycerol tracers were used to measure substrate appearance and disappearance. Carter and colleagues found that a training intervention resulted in a decrease in glucose flux in both men and women, which is beneficial to an endurance athlete because this decrease in CHO reliance spares muscle glycogen and plasma glucose, prolonging the onset of fatigue. Before and after a training intervention, the authors found that women demonstrated a lower ratio of CHO to fat metabolism and respiratory exchange ratio (RER) than men at the same relative intensity ($p<0.001$). The authors also found that women have a higher rate of glycerol appearance, pre and post training than men, ($p<0.001$) which suggests that women have a greater rate of lipolysis, which coincides with a lower RER, though a drawback to using RER and glycerol tracers is that the source of the lipid is unclear (Carter et al., 2001). Studies have suggested that the source of lipids may be from intramuscular triglycerides, peripheral adipocytes, or plasma FFA (Bergman & Brooks, 1999; Crampes et al., 1989; Despres et al., 1984; Hurley et al., 1986; Kiens et al., 1993; Phillips et al., 1996).

To address the question of where lipid oxidation is occurring, Roepstorff et al. (2002) conducted a study that looked at blood glucose, glycogen, plasma FA and myocellular triacylglyercols (MCTG) between exercising men and women. Muscle biopsies, stable isotope tracers, and net balances across the vastus lateralis muscle were taken during a 90-minute bicycle exercise test at 58% VO_{2max}. Males and females were matched on VO_{2max}, physical activity level, training history, and consumed the same diet for eight days prior to testing. The researchers found that during exercise at 58% VO_{2max}, RER was similar between men and women, and while the ratio of fats and CHO oxidized was similar, MCTG degradation was 12.4 ±3.2 mmol/kg dry wt in females and negligible in males. This use of MCTG accounted for 25.0 ± 6.0 and 5.0 ± 7.3% total oxidation in females and males, respectively ($p<0.05$) and oxidation of plasma FA and blood glucose were similar in males and females. The researchers were able to account for 99% of leg oxygen uptake in females, but were only able to account for 28% of oxygen uptake in males. Since RER was similar in males and females, this suggests that male must use an alternative lipid source, which Roepstorff et al. hypothesized that males may use very low-density lipoprotein-triacylglycerols (VLDL-TG), which is located between muscle fibers (Roepstorff et al., 2002).

Previous research has shown that males have a tendency to HTW more than women do while running. Hypotheses for the cause of this phenomenon have included psychological and physiological explanations. Wilson et al. (1989) proposed the expectancy effect, where men may expect to HTW more than females and therefore they do, and Buman et al. (2008) was able to confirm this, when expectancy to HTW wall was the best predictor of whether or not a runner would HTW during a marathon. Another psychological reason for men experiencing HTW more than women is that men are more competitive. This competitiveness could result in a risky pacing strategy that cannot be sustained leading to marked slowing as the race progresses. Another contributing mechanism to HTW is physiology, specifically substrate metabolism. It is clear that as exercise intensity increases, CHO utilization increases and lipid utilization decreases and with women have a higher proportional area of type I muscle fibers, which have the distinction of oxidizing more lipids than CHO, allows for women to spare muscle glycogen and be less prone to fatigue. Previous work suggests that on average women use proportionately more lipids than men during exercise, from fat sources that have been identified. This higher proportion of lipid utilization for a given exercise intensity and consequent muscle glycogen and blood glucose sparing could be predictive of the lower likelihood of HTW in females.

Respiratory Exchange Ratio

Direct calorimetry is used to measure the amount of energy, water, and carbon dioxide (CO_2) a substance gives off when burned in the presence of oxygen (O_2) (Edwards, Margaria, & Dill, 1934). Since measuring energy production directly in muscle cells was implausible, scientists developed indirect calorimetry to study human metabolism (Edwards, Margaria, & Dill, 1934), which allowed scientists to understand energy utilization by measuring O_2 utilized and CO_2 expired. This ratio of CO_2 and O_2 is called respiratory exchange ratio (RER). The term was coined when Krogh & Lindhard (1920) measured gas samples from the mouth during respiration, allowing for analysis of what type of substrate is being utilized for metabolism. For example, if RER is 0.7, then 100% of metabolism is coming from fat and if RER is 1.0 then 100% of metabolism is coming from CHO (Brooks, 1984), though humans can achieve an RER above one when there is additional CO_2 production measured from bicarbonate buffered acid (Naimark, Wasserman, & Mcllroy, 1964).

While RER is a reliable measurement of substrate utilization, there are a few outside factors that can determine a person's RER value like diet, training history, and exercise intensity that influence substrate utilization and therefore RER. To analyze how these factors affect exercising humans, Bergman and Brooks (1999) conducted a study where trained and untrained men where exercised at a range of intensities under fed or fasted states. The study allowed the researchers to look at the affect of training, diet, and exercise intensity on RER value. Endurance training has already been well described as being linked to lowering RER in humans, as exercise increases the activity of some mitochondrial enzymes, like citrate synthase, cytochrome C oxidase, and B-hydroxyacyl-

CoA dehydrogenase (Bergman & Brooks, 1999; Jeukendrup et al., 1997; Menshikova et al. 2005; Messonnier et al. 2005; Short et al. 2003; Tonkonogi et al. 2000). These changes drive fatty acid oxidation and lower RER allowing for athletes to use lipids more and CHO less, sparing glucose and muscle glycogen. Bergman and Brooks (1999) categorized subjects into trained (category 2 or 3 bicycle racers) or untrained (<2hours of regular physical activity per week) strata and then randomly assigned starting exercise intensity and nutritional state having each subject complete all exercise tests in both fed and fasted states. The authors found that the affect of training on RER was only apparent intensities corresponding to <40% VO_{2max}. When subjects were in the fasted state; they had a lower RER in comparison to the fed state in both trained and untrained participants. In comparison, food intake 3 hours before exercise increased RER values and CHO oxidation at intensities up to 59% VO_{2max}. The authors found that at high intensity (75% VO_{2max}) neither food nor training had a significant affect on RER, nor that power output was more of a determining factor (Bergman & Brooks, 1999). Previous research has found that RER is lower in trained men in comparison to untrained men at varying intensities (~70-78% VO_{2max}) (Coggan et al., 1990; Hagberg et al. 1988). Interestingly, Hurley et al. (1984) found that at some intensities (60, 70, and 75% VO_{2max}) trained men had lower RER than untrained, but not at others (65 and 80% VO_{2max}). Though there are varying results in previous work, well-controlled studies suggest that training influences RER at lower relative exercise intensities.

Since the marathon is often ran at approximately 65-76% VO_{2max} (Loftin et al., 2007; Trubee et al., 2014), it is important to look at research that analyzes RER at this intensity. Ramos-Jiménez et al. (2008) conducted a study that looked at RER in trained and untrained men at varying submaximal exercise intensities at a fixed workload: below, within, and above lactate threshold (LT) as an indicator of physical fitness. The trained subjects had significantly lower RER values, higher VO_2, and lower blood lactate levels than the untrained subjects for a given relative workload meaning that training resulted in lower RER values and therefore oxidized proportionately more lipids to CHO than untrained subjects (Ramos-Jiménez et al. 2008).

As exercise continues at a fixed level, like running a marathon, RER will remain constant or decrease (Pendergast, Leddy, & Venkatraman, 2000). Researchers have observed this pattern at 60-80% VO_{2max} exercise intensity during run times between 45 - 120 minutes where RER values ranged from 0.8-0.93 (Horvath et al. 2000; Muoio et al. 1994). Though the percentage of fat oxidized decreases with intensity, there is still fat oxidation occurring and contributing to energy needed to sustain running which is evident in these reported RER values. These values signify that metabolism has shifted towards lipid oxidation and away from CHO because of the potential of glycogen depletion. If glycogen is not replenished, fat oxidation will continue at a fixed rate until the athlete becomes fatigued. Brooks (1997) showed that well trained athletes improve their ability to utilized lipids during exercise therefore if someone has an increased ability to utilize fats and CHO feeds during sustained exercise, they may be able to avoid muscle glycogen depletion, fatigue, and pace slowing.

Since many marathon participants are not elite athletes, many likely haven’t made training adaptations resulting in a lower RER. However, since on average, women have a lower RER for a given exercise intensity than men it would be reasonable to hypothesize that untrained or novice women runners, having a lower RER, would have an advantage over untrained men at avoiding fatigue (Tarnopolsky, 2000).

Elite vs. Non-elite runners

It is important to describe the inherent differences between elite and non-elite athletes regarding fitness and anthropometric values. VO_{2max} has been established as a reliable indicator of cardiorespiratory endurance (Joyner & Coyle, 2008) and represents the ability of a body to oxygenate blood and the muscles ability to extract blood oxygen. Elite endurance athletes have higher VO_{2max} values than non-elites, where elite male athletes VO_{2max} values range from 70-85 ml $kg^{-1}min^{-1}$, and elite women being approximately 10-12% lower. Non-elite marathon runners have a significantly lower VO_{2max} than elites, with male and female VO_{2max} values around 60.6 and 51.6 ml $kg^{-1}min^{-1}$, respectively (Lorenz et al., 2013).

Endurance athletes have higher percentage of type I muscle fibers, which are more efficient and fatigue resistant. Having a higher proportion of type I muscle fibers allows runners to have a better running economy (RE), which is a measure of O_2 uptake for a given running velocity (Lorenz et al., 2013). The ability to consume a lower amount of O_2 for a given running intensity allows for a better RE. Between VO_{2max} and RE, a study of collegiate cross-country runners found that 92% of variance time could be accounted for during an 8000 m race (Lorenz et al., 2013).

When comparing novice, experienced, and elite women marathon runners, Christensen and Ruhling (1983) found that higher aerobic capacity and training history was associated with better marathon performance than body composition values. VO_{2max} values from highest to lowest were elite (59.1 ± 6.6 $mlkg^{-1}min^{-1}$), experienced (51.8 ± 3.2

ml $kg^{-1}min^{-1}$) and novice runners (45.8 ± 4.9 ml $kg^{-1}min^{-1}$). The females in this study were found to be lower in body weight and approximately the same in relative body fat as the average male, and lower in body weight and greater in relative body fat than male long distance runners (Christensen & Ruhling, 1983). Contrarily, other studies have found that body composition measures were associated with marathon time. Hagen et al. (1987) noted that marathon time was positively correlated to body mass index ($r = 0.52$), and body fat ($r = 0.52$) for female distance runners. The women in this study had varying race histories (2-15 finished marathons) and were separated into novice and experienced runner groups. The best predictor of marathon time in the novice group was VO_{2max} and the sum of 7 skin fold measurements, while in the experienced group the best predictors of marathon time were BMI, body weight, percent body fat, and VO_{2max}. In both groups of runners, training miles and pace had strong associations with marathon performance. In the novice runners, the training indices of distance run per day, training pace, total training distance run, and distance run per week gave the strongest correlation to marathon performance. For experienced runners, mean workout pace, total training distance, and total workout days were the strongest correlates to marathon performance (Hagen et al. 1987).

It is apparent that elite athletes have the physiological advantage over non-elite or novice marathon runners in regards to many aerobic and anthropometric measurements such as having a higher VO_{2max} and proportionate type I muscle fiber type. In a population that is not as genetically inclined to compete in endurance sport, it is important to study these physiologic values to see which are best predictors of performance in the average runner.

Summary

It has been established that women are better at maintaining their velocity throughout the course of a marathon (Deaner et al., 2015; March et al., 2011; Trubee et al., 2014). Physiological and psychological explanations for this have been suggested, including: running ability, body surface area to mass ratio, muscle fiber type, weather, hyperthermia, hypoglycemia, hypovolemia, the expectancy effect, and risk taking. A common theme of marathon slowing is the phenomenon of hitting the wall. Hitting the wall is associated with depletion of muscle glycogen stores and resulting fatigue and slowing (Stevinson & Biddle, 1998). It has been shown that during exercise women are better at oxidizing lipids for fuel instead of CHO than men, resulting in sparing muscle glycogen and plasma glucose which is evident by their lower RER values (Carter et al. 2001; Venables et al. 2004). It has been established that elite athletes have a lower RER than non-elite athlete as the untrained population does not have an aerobic endurance capacity similar to elite athletes (Bergman and Brooks, 1999; Coggan et al., 1990; Hagberg et al. 1988; Ramos-Jiménez et al. 2008). Since women have a lower RER for a given exercise intensity than men, excluding elite runners, it would be reasonable to hypothesize that untrained women would have an advantage over untrained men when it comes to avoiding fatigue due to glycogen depletion (Tarnopolsky, 2000). The purpose of this study is to compare the degree of slowing (time in the first half compared to the second half of a marathon) between men and women and determine if steady state RER is predictive of slowing in male and female college-age recreational marathon runners.

CHAPTER 3. METHODOLOGY

Subjects

The present study was conducted at the University of Minnesota Twin Cities during a Marathon Training class in the spring semesters of 2014 (n=85) and 2015 (n=82). Students were excluded from the study if they were physically unable or unwilling to meet the class requirements, which included receiving medical clearance to train for and complete a marathon, or if they did not participate in the associated research portion of the class. In total 167 (male= 44 and female= 123) subjects participated in all aspects of the present study with their completion of class requirements including four months of aerobic training and completion of a local marathon.

The University of Minnesota's Institutional Review Board (IRB) granted approval for this research. Prior to undergoing physiological and performance testing, signed informed consent was obtained from each participant and no subject was allowed to be tested without written informed consent. Subjects required a medical physical that was administered by subject's primary care physician to make sure participants were in good health and able to undergo the training required to finish the marathon.

Instrumentation

Subjects underwent anthropometric measurements including: height, weight, and body composition and aerobic testing at both pre-and post-training. Approximately three weeks prior initiation of the marathon-training protocol, and three weeks prior to the marathon, subjects were required to participate in a two-mile time trial (2MI) in which they completed 16 laps plus 18 meters on a 200-meter indoor track located in the University of Minnesota field house. Subjects were hand-timed with stopwatches by assigned lap counters that recorded 1-mile split time and 2-mile finish time.

At two separate time points the subjects were required to report to the laboratory for physiological testing: approximately two weeks prior initiation of the marathon-training protocol, and two weeks prior to the marathon. For this testing, subjects were required to arrive at the testing facility in the Laboratory of Physiological Hygiene at the University of Minnesota on the day of their test in the fasted state (3-4 hours) without consuming any caffeine, alcohol, or tobacco within 8 hours prior to the test. On testing days, height and weight were taken prior to testing. Subjects removed footwear, and height was measured to the nearest ¼ inch using an Accustat Genetech Stadiometer (San Francisco, CA). Weight was measured in pounds to the nearest tenth using a ProDoc Detecto (PD300) scale (Webb City, MO). During weighing, subject wore light, minimal clothing, such as a swimsuit or spandex shorts and a sports bra for women. Body Mass Index (BMI) was calculated from height and weight and is expressed using the equation BMI= weight (kg)/height (m^2) and BSA was calculated from height and weight and is expressed using the Dubois and Dubois (1918) equation: BSA (m^2)= 0.20247 x height (m) $^{0.725}$ x weight (kg) $^{0.425}$. Body composition was assessed using hydrostatic underwater weighing and VO_{2max} testing was performed on a motorized Woodway Pro XL 27 treadmill (Waukesha, WI) and breath-by-breath (BTB) gas samples were collected using Ultima CPX metabolic cart (Medical Graphics Diagnostics, St. Paul, MN). For metabolic testing, the gas sensor was calibrated using 21%O_2/79%N_2 and 5%CO_2 /12% O_2/83%N_2 and gas flow was calibrated using a three-liter syringe. Subjects were fitted with a facemask and pneumatechograph and heart rate was monitored using a heart rate monitor strap and wristwatch (Polar, Kempele, Finland). The VO_{2max} test included an initial one-minute warm up walk at 3.0 miles per hour, then subjects ran for 6-minutes at

75% of the subjects initial pretesting 2MI velocity. This stage time ensured that subjects were exercising at a steady-state workload. A graduated protocol was utilized, with velocity increasing each minute up to pretesting 2MI velocity at 1.0% incline, and then increasing in incline by 1.5% each minute until exhaustion was reached.

The marathon was run on a certified course and the subjects were timed by the official marathon electronic timing system. Subject's first half, second half, and full marathon chip times were gathered from online race results. Pace maintenance was calculated as the percentage change in pace in the second half the marathon relative to the first half (%slowing = (second half time – first half time) / first half time). Meteorological data was obtained at hour intervals throughout the race as reported for Eau Claire Wisconsin, USA by Weather Underground, Inc (Ann Arbor, MI) and averaged. The meteorological index used in this study was the effective temperature (ET). This index was calculated using outside air temperature (OAT) and relative humidity (RH) in the following equation: ET= OAT-0.4(OAT-10)(1-RH/100) (Suping et al., 1992). Marathon ET will be summarized as the mean hourly ET during the race.

Data Analysis

Collection and analysis of gas exchange data was completed using the Breezesuite software package (Medgraphics, St. Paul, MN). All statistical calculations were performed using SPSS, Version 22 (IBM Corp., Armonk, NY). Means and standard deviations were calculated for each measure using standard methods. Baseline measures and outcomes (RER and %slowing) were analyzed using independent samples t-tests to detect differences between the groups (men vs. women, 2014 vs. 2015). Univariate ANOVA tests were run to analyze the differences in %slowing and RER by year and sex.

Pearson's Product Moment Correlation Coefficient (r) was used to determine the strength of the relationship between RER and %slowing as well as the relationship between %slowing and %BF, weight, height, BSA, and BSA/M. All data is presented as means ± SD unless stated otherwise. Significance for all tests was set at $p \leq 0.05$, a priori.

CHAPTER 4. RESULTS

Participant Characteristics

Eighty-five subjects participated in 2014 and 82 subjects in 2015, totaling 167 subjects included in the study, of which 123 were female and 44 male. There was no difference in age according to sex, but men demonstrated higher values for height, weight, BSA, BSA/M and RER whereas women had significantly greater %BF, and longer finishing time (Table 1) ($p < 0.05$). There were no significant differences in age, height, weight, BSA, BSA/M, or RER between years (Table 2). Participants from the 2015 cohort had significantly higher %BF and finishing time, when compared to the 2014 cohort.

Average race OAT and RH was 8.9°C, 43% and 20.6°C, 53% for 2014 and 2015 respectively. Average race ET was 4.11°C for 2014 and 14.5°C for 2015.

Running performance

Males demonstrated greater steady state speed, VO_2, and VCO_2 (Table 3). At each time check, men were faster than women (first half split, 111 vs. 134 min; second half split 135 vs. min 157; and full time, 247 vs. 291 min).

Slowing

Participants in 2015 had a significantly higher %slowing than the participants of 2014 (Figure 2; Table 4). However, in each of the two years men slowed significantly more than women (Figure 2; Table 5). For the combined group from 2014 and 2015, males had a significantly higher %slowing than females (Figure 3). An ANOVA analysis found that there was a significant influence of sex ($p = 0.001$) and year the marathon took place ($p = 0.034$) with %slowing, but that there was no significant interaction between sex and year ($p = 0.756$), indicating that the temperature the marathon was run at did not influence rate of slowing differently between men and women.

Respiratory Exchange Ratio

There was no significant difference in RER between runners participating in 2014 and the runners participating in 2015 (Table 6). In 2014 and in 2015, males had a significantly higher RER, when compared to females (Figure 4; Table 6). The combined 2014 and 2015 data demonstrated that males had a significantly higher RER compared to females (Figure 5; Table 5). Analysis of variance comparison found that there was a significant interaction between sex and RER ($p = 0.007$). There was no significant impact of year with RER ($p = 0.941$).

Slowing and Body Composition

Neither %BF, weight, nor BSA/M were significantly related to %slowing (%BF $r=0.02$, weight $r=0.09$, $p>0.05$, BSA/M $\beta=0.22$, $p>0.05$). However, height was significantly related to % slowing ($r=0.18$, $p<0.05$) and BSA was trending towards significance ($r=0.13$, $p = 0.086$). In the females, height was significantly related to %slowing ($r=0.22$, $p=0.017$), but not in males. There was no relationship between RER and %slowing in the total sample of both years ($r = 0.058$, $p=0.460$), females ($r = 0.027$, $p = 0.77$) or males ($r = 0.064$, $p=0.68$).

CHAPTER 5. DISCUSSION

In the present study, we found that males slowed significantly more than females from the first half to the second half of the marathon, and males had significantly higher RER values when compared to females, but that there was no relationship between steady state RER and slowing in the marathon. We found that ambient weather conditions influenced the rate of slowing, but weather condition did not affect males and females differently.

Consistent with other studies, we were able to replicate that females were better at maintaining their pace when compared to males and that %slowing was influenced by sex (Deaner et al., 2015; March et al., 2011; Trubee et al., 2014). March et al. (2011) conducted a study examining the effect of sex, age, and run time on pacing ability during a marathon. This study of 186 men and 133 women marathoners, demonstrated that pacing was better maintained by women, when compared to men, after controlling for finishing time and that age, sex, and race times were independent factors in pacing regardless of the other variables (March et al., 2011). Similarly, Deaner and colleagues (2015) demonstrated that male and female non-elite marathon runners demonstrated differences in pacing. When comparing the first half to the second half of a participant's marathon time, Deaner et al. (2015) concluded that females were 1.46 times (p=0.0001) more likely to maintain their first half pace onto the second half of the race than men.

In the present study, we did not find that that warmer weather increased the sex difference in %slowing. Our initial hypothesis was that females might have a cooling advantage over males because, on average, females have a smaller surface area and body mass when compared to males, but have a larger BSA/M (Cheuvront & Haymes, 2001). Since heat production and dissipation are positively related to body mass and body surface area, respectively, we thought that females would able to regulate their internal body temperature in hotter environments better than men and therefore decrease %slowing (Cheuvront & Haymes, 2001). There was no relationship between %BF or and %slowing suggesting that %BF does not affect one's ability to regulate internal body temperature even though the females in our study had significantly higher %BF when compared to males. This agrees with Millard-Stafford et al. (1995), who studied the thermoregulatory abilities of men and women running a hot weather 40 km race. They found women had a lower rectal temperature than men despite having twice the percent body fat and similar VO_{2max}. Trubee et al. (2014) studied the effects of climate and running ability on pacing between the sexes and found that non-elite female marathon runners were better at pacing in comparison to non-elite male marathon runners ($p<0.01$) and that this effect was even more pronounced in warmer climates than in cooler. In the present study the difference in temperature was 10.4°C, while the difference in temperature in the study by Trubee et al was 23.9°C, which could explain the difference between their findings and the findings in the present study. Additionally, in the present study, we found no relationship between pacing and BSA/M, which is thought to influence thermoregulation. In contrast, temperature has been shown to influence pacing in elite runners in several studies. Suping et al. (1992) studied the effect of temperature on the performance of the top ten runners from the 1981 to 1989 Beijing marathon. The researchers studied air temperature, relative humidity, wet bulb temperature, wind velocity, and effective temperature and found that temperature and average finishing times of the top ten finishers were significantly correlated ($r= 0.8910$). Interestingly, when Ely and colleagues (2008) analyzed the correlation between finishing place of from three Japanese Women's championship marathons and air temperature using 62 years of race time data on the 1st, 25th, 50th, and 100th place finishers they found that warmer temperature was significantly related to slowing pace for the 25th place finisher and the winners of the marathons, but increasing temperature was not correlated with slowing in the 50th and 100th place finishers (Ely et al., 2008). Vihma (2010) studied the effect of weather parameters on marathon results in elite, intermediate, and slow male and female runners and analyzed the relationship between weather parameters and the percentage of non-finishers. Finish time anomaly (FTA) was defined as the deviation of the annual finishing time from the linear trend of the finishing time and it was found that air temperature was the most correlated with FTA (r=0.66-0.73). The author found that women of varying abilities were less affected by warmer weather than men.

We found that in both 2014 and 2015 and in the combined 2014 and 2015 data, males had a significantly higher RER, when compared to females (Figure 4; Figure 5). Other studies have shown that females use more lipids in oxidative metabolism during exercise than males (Friedlander et al., 1998; Horton et al., 1998; McKenzie et al., 2000; Tarnopolsky, 1990) however, some have observed a similar relative utilization of CHO and lipids in females and males exercising at the same relative workload (Berman et al., 1999; Marliss et al., 2000; Romijn et al., 2000). Venables et al. (2004) studied lipid oxidation at varying exercise intensities between men and women. The authors hypothesized that exercise intensity was the primary determinant of lipid oxidation level and sex, body composition, physical activity level, and training status are secondary contributors. Venables and colleagues (2004) were able to replicate other studies that concluded that women have a higher rate of fat oxidation at varying exercise intensities than men despite having lower VO_{2max} and activity levels. The authors reported that men had a lower cross over point, which is a concept that Brooks and Mercier (1994) introduced, referring to the time during exercise when a person goes from oxidizing predominantly lipids for energy at lower intensity, to using predominantly CHO for energy at increasing exercise intensities (Venables et al., 2004).

Since our RER data was collected after a standardized 20-week marathon-training program, we were able to account for training status as a potential confounding variable between males and females. A similar protocol carried out by Carter et al. (2001) looked at the change in substrate utilization between men and women after a seven-week endurance training intervention. The authors measured substrate utilization pre and post training intervention during a 90 minutes cycle ergometer at 60% VO_{2max}, where glucose and glycerol tracers were used to measure substrate appearance and disappearance. Carter and colleagues (2001) found that a training intervention resulted in a decrease in glucose flux in both men and women and that before and after a training intervention women demonstrated a lower ratio of CHO to fat metabolism and respiratory exchange ratio (RER) than men at the same relative intensity ($p<0.001$). The authors also found that women have a higher rate of glycerol appearance, pre and post training than men, ($p<0.001$) which suggests that women have a greater rate of lipolysis, which coincides with a lower RER (Carter et al., 2001).

We hypothesized that women's lower RER and increased ability to utilized lipids during exercise would allow them to be less likely experience muscle glycogen depletion, fatigue, and that these differences would be reflected in pace slowing. Despite finding that males slowed more and had a higher RER in the total sample, 2014, and 2015 when compared to females, there was no relationship between RER and %slowing in the total sample of both years, suggesting that a lower RER is not protective of HTW and consequential pace slowing. This evidence suggests that substrate utilization is not solely responsible for runners HTW. It is therefore possible that psychological mechanisms may play larger role in the sex differences in HTW, when compared to the proposed physiological factors. Buman et al. (2008) conducted a study to explore the probability that a runner will HTW and described the risk of HTW over the course of the marathon. The researchers found that expectancy of HTW was the most robust predictor of HTW in their models, when controlled for sex and training volume. In this previous work 28% of men and 20% of women had expectations of HTW, 45% of men and 37% of women experienced HTW, and of those participants who reported HTW, 19% of males and 13% of women indicated an expectation of HTW (Buman et al., 2008). Therefore, men may experience HTW more because the expectancy effect is higher in their sex (Wilson et al., 1989). Another psychological reason for men to be more likely to HTW than women could be that they are generally more competitive (Deaner et al., 2015). Being more competitive could result in men starting out too fast or adopting a risky pace that cannot be sustained (Allen & Dechow, 2013; Deaner et al., 2015; Stevinson & Biddle, 1998). Men are more likely to report that competition motivates them to run and when given the choice to enter a single-sex competitive road race or a single-sex non-competitive road race, men are more likely to select the competitive race (Deaner et al., 2015).

Study Limitations:

This study was not conducted without limitation. Though we were able study physiological characteristics related to pace slowing, we did not collect any data concerning the psychological contribution to pacing in runners. Another potential limitation to the study was that we did not collect RER measurements during the marathon; instead we collected RER values during a steady state run on a treadmill. Collecting data on RER in the laboratory setting may have it advantages, such as controlled temperature and participant diet, controlled surface, and a steady-state based on previously-determined subject intensity, all factors that could affect RER during a race. Core and skin temperatures were not measured on our participants, limiting our understanding of thermoregulation occurring during the marathon, however maximal core temperature has not been shown to be related to running time or fluid balance responses (Byrne et al., 2006).

CHAPTER 6. CONCLUSION

Though we were able to establish that in both years males slowed more from the first half of the marathon to the second half and had a higher RER when compared to women, there was no relationship between steady state RER and %slowing, nor was there an effect of temperature on the differences in slowing between men and women, suggesting that males may be more affected by the psychology of pacing rather than physiology.

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APPENDIX

Table 1. Participant Characteristics by Sex (mean ± standard deviation)

	Female	Male
N	123	44
Age	20.9 ± 1.8	21.0 ± 1.6
Height (m)	1.7 ± 0.07	1.8 ± 0.06*
Weight (kg)	62.8 ± 8.0	75.4 ± 9.3*
BSA	1.7 ± 0.12	1.9 ± 0.13*
BSA/M	1.02 ± 0.05	1.06 ± 0.17*
% BF	23.7 ± 4.7	14.3 ± 5.7*
Finishing time (min)	291.4 ± 40.8	247.0 ± 52.0*
RER	0.87 ± 0.05	0.89 ± 0.05*

Values are mean ± SD, BSA = Body Surface Area, % BF = Percent body fat, RER = respiratory exchange ratio, * = statistically significant difference between females and males.

Table 2. Participant Characteristics by Year (mean ± standard deviation)

	Total Sample	2014	2015
N	167	85	82
Age	21.0 ± 1.7	20.96 ± 1.71	20.96 ± 1.7
Height (m)	1.7 ± 0.09	1.7 ± 0.1	1.7 ± 0.07
Weight (kg)	66.1 ± 10.0	66.8 ± 9.6	65.3 ± 10.4
BSA	1.8 ± 0.16	1.8 ± 0.17	1.8 ± 0.15
BSA/M	1.03 ± 0.09	1.04 ± 0.54	1.02 ± 0.13
% BF	21.2 ± 6.5	19.9 ± 6.7	22.7 ± 6.0*
Full time (min)	279.7 ± 48.0	268.96 ± 47.48	290.9 ± 46.3*
RER	0.87 ± 0.5	0.88 ± 0.059	0.87 ± 0.04

Values are mean ± SD, BSA = Body Surface Area, % BF = Percent body fat, RER = respiratory exchange ratio, * = statistically significant difference between 2014 and 2015.

Table 3. Running Performance Variables of Participants (mean ± standard deviation)

	Speed (MPH)	VO_2 (ml/kg/min)	VO_2 (ml/min)	VCO_2 (ml/min)
Total Sample	5.7 ± 0.8	31.9 ± 4.8	2115.3 ± 479.02	1847.1 ±444.03
Females	5.4 ± 0.5	30.3 ± 3.5	1889.4 ± 249.4	1633.1 ± 216.6
Males	6.5 ± 0.9*	36.6 ± 5.0*	2746.7 ± 394.3*	2445.1 ± 362.1*

Values are mean ± SD, statistically significant $p < 0.05$, * = statistically significant different between females and males.

Table 4. Percent Slowing by Year and Sex (mean ± standard deviation)

	% Slowing	
	2014	p-value
Total Sample	14.08 ± 12.0	
Females	12.5 ± 9.9	
Males	17.2 ± 15.0**	
	2015	
Total Sample	22.02 ± 16.5*	0.001*
Females	20.8 ± 17.1	
Males	27.2 ± 12.4**	

Values are mean ± SD, statistically significant $p < 0.05$, * = statistically significant difference between total sample 2014 and total sample 2015, ** = statistically significant difference between females and males.

Table 5. Percent Slowing and Respiratory Exchange Ratio of Males and Females (mean ± standard deviation)

	Female	Male	p-value
% Slowing	17.02 ± 14.8	20.6 ± 14.8*	0.034
RER	0.87 ± 0.05	0.89 ± 0.05*	0.007

Values are mean ± SD, RER = respiratory exchange ratio, statistically significant $p<0.05$, * = statistically significant difference between females and males.

Table 6. Respiratory Exchange Ratio by Year and Sex (mean ± standard deviation)

	RER
2014	
Total Sample	0.88 ± 0.06
Females	0.87 ± 0.06
Males	0.89 ± 0.05*
2015	
Total Sample	0.87 ± 0.04
Females	0.86 ± 0.04
Males	0.89 ± 0.04*

Values are mean ± SD, RER = respiratory exchange ratio, statistically significant $p<0.05$, * = statistically significant different between females and males.

Figure Legends

Figure 1. The contribution of muscle glycogen, muscle triglyceride, plasma free fatty acid (FFA), and plasma glucose after 30 minutes of exercise at 25%, 65%, and 85% of maximal oxygen uptake. Reproduced from Figure 8 of Romijn et al. (1993).

Figure 2: Percent slowing for total year group, males, and females for each year cohort. Values are mean ± SE, statistically significant $p < 0.05$, * = statistically significant difference between total sample 2014 and total sample 2015, ** = statistically significant difference between females and males.

Figure 3: Percent slowing for males and females. Values are mean ± SE, statistically significant $p< 0.05$, * = statistically significant difference between females and males.

Figure 4: RER (respiratory exchange ratio) for total year group, males, and females for each year cohort. Values are mean ± SE, statistically significant $p < 0.05$, * = statistically significant difference between total sample 2014 and total sample 2015, ** = statistically significant difference between females and males.

Figure 5: RER (respiratory exchange ratio) for males and females. Values are mean ± SE, statistically significant $p< 0.05$, * = statistically significant difference between females and males.

Figure 1. Romijn et al. (1993).

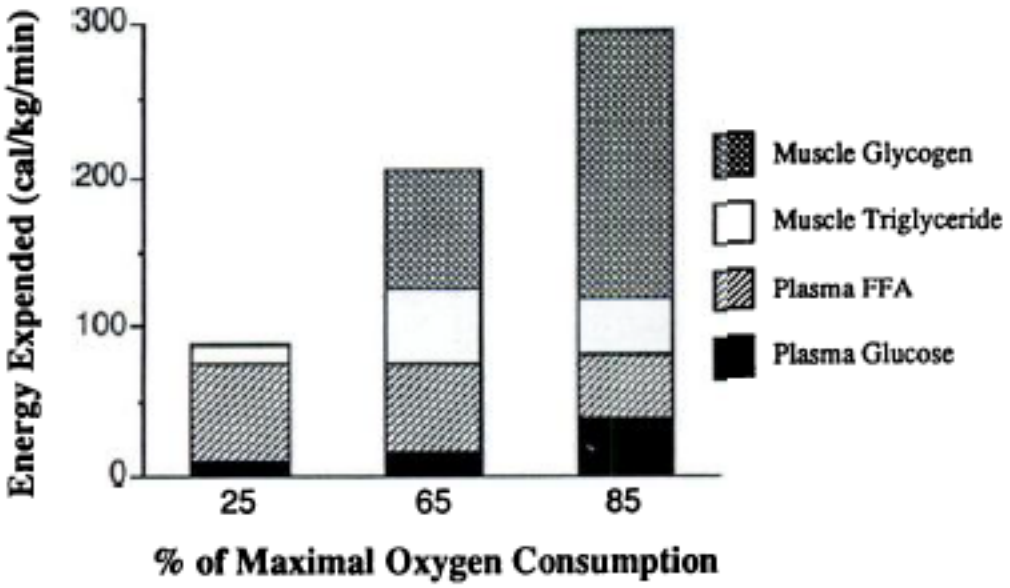

Figure 2. Percent slowing for total year group, males, and females for each year cohort

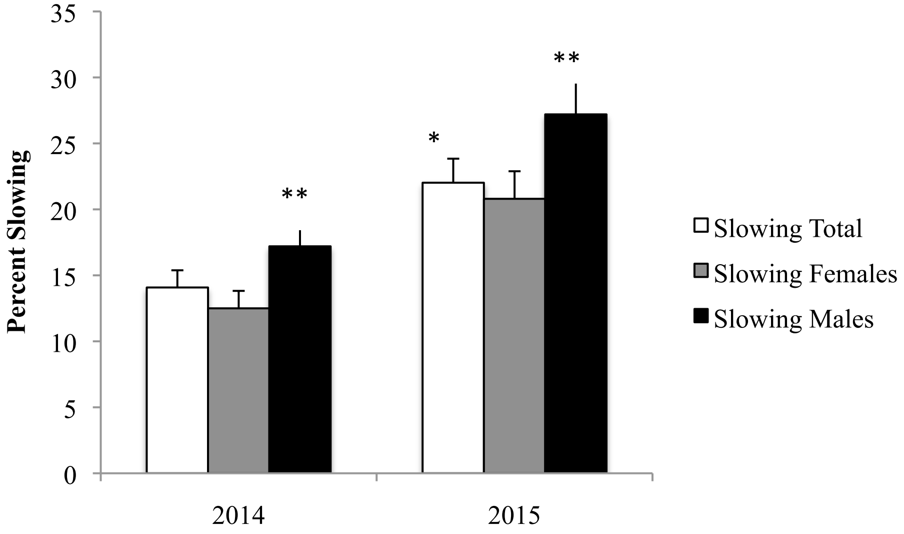

Figure 3: Percent slowing for males and females

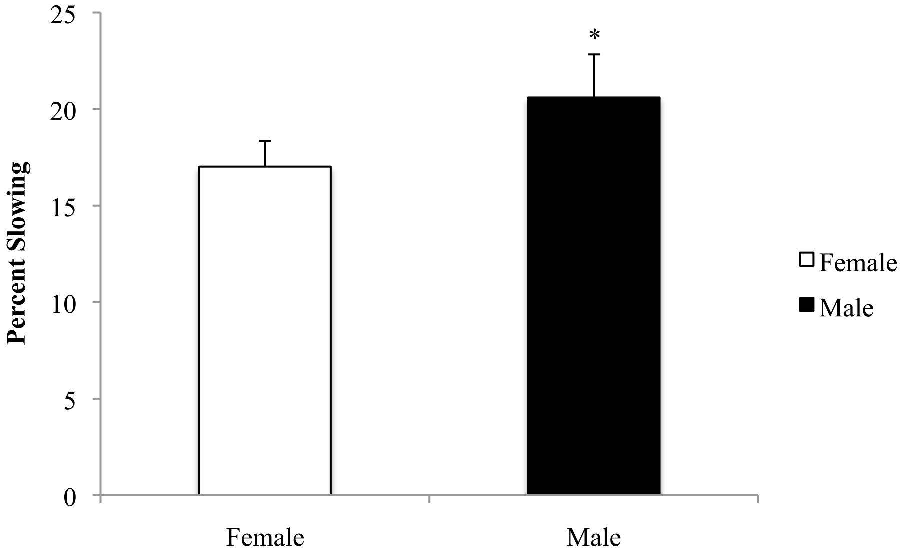

Figure 4. Respiratory Exchange Ratio for total year group, males, and females for each year cohort

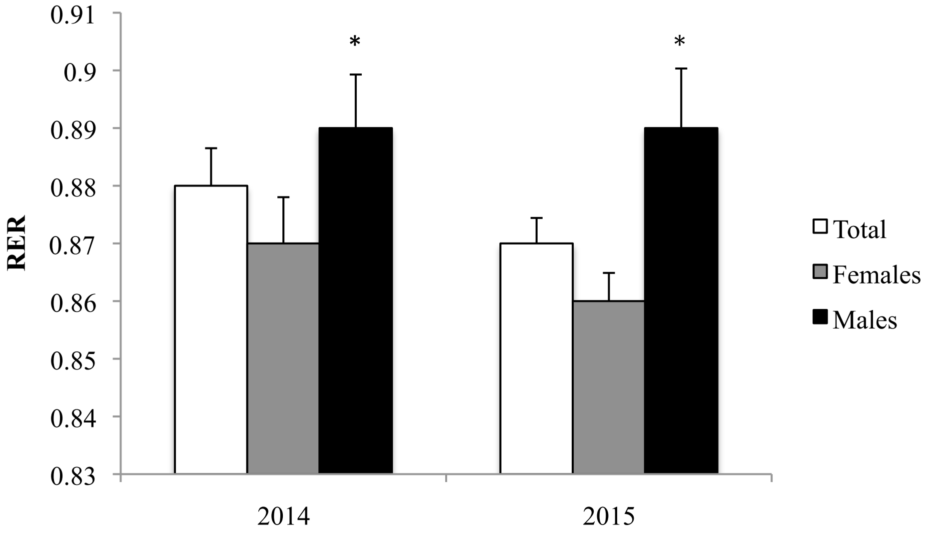

Figure 5. Respiratory Exchange Ratio for males and females