# UNLV | UNIVERSITY LIBRARIES

# Variability of pacing in marathon distance running

Thomas A. Haney Jr.
*University of Nevada, Las Vegas*

## Repository Citation

VARIABILITY OF PACING IN MARATHON DISTANCE RUNNING


by


Thomas A. Haney Jr.


Bachelor of Science
University of Nevada, Las Vegas
2007


A thesis submitted in partial fulfillment
of the requirements for the


**Master of Science in Kinesiology**
**Department of Kinesiology and Nutrition Sciences**
**School of Allied Health Sciences**
**Division of Health Sciences**


**Graduate College**
**University of Nevada, Las Vegas**
**December 2010**

**UNLV**
UNIVERSITY OF NEVADA LAS VEGAS

<span style="color:red">THE GRADUATE COLLEGE</span>

We recommend the thesis prepared under our supervision by

**Thomas A. Haney Jr.**

entitled

**Variability of Pacing in Marathon Distance Running**

be accepted in partial fulfillment of the requirements for the degree of

**Master of Science in Kinesiology**
Department of Kinesiology and Nutrition Sciences

John Mercer, Committee Chair

Laura Kruskall, Committee Member

Gabriele Wulf, Committee Member

Jefferson Kinney, Graduate Faculty Representative

Ronald Smith, Ph. D., Vice President for Research and Graduate Studies
and Dean of the Graduate College

**December 2010**

ABSTRACT

**Variability of Pacing In Marathon Distance Running**

by

Thomas A. Haney Jr.

Dr. John A. Mercer, Examination Committee Chair
Professor of Kinesiology
University of Nevada, Las Vegas

The purposes of this study were to describe variability of pacing during a marathon and to determine if there is a relationship between variability of pacing and marathon performance. A total of 301 race profiles that contained personal global positioning system (GPS) from the Rock 'n' Roll Las Vegas (Race 1) and San Diego (Race 2) marathons were downloaded (http://connect.garmin.com) and analyzed. Each marathon finish time was placed into one of three finish time bins: Bin 1: 2.5 – 3.9 hrs, Bin 2: 4.0 – 4.6 hrs, Bin 3: 4.7 – 7.2. The coefficient of variation of velocity ($Vel_{cov}$) was calculated for each race profile and compared between races using an independent T-test. $Vel_{cov}$ was not different between races (Race 1: $16.6 \pm 6.3\%$, Race 2: $16.7 \pm 6.5\%$). $Vel_{cov}$ was lower in Bin 1 vs. Bin 2 ($p < 0.05$), lower in Bin 1 vs. Bin 3 ($p < 0.05$), and lower in Bin 2 vs. Bin 3 ($p < 0.05$) for both races. It was determined that $Vel_{cov}$ was different between marathon finish times such that $Vel_{cov}$ was greater for slower finish times for either race. It appears that slower marathon finishers had greater $Vel_{cov}$ compared to faster marathoner finishers. These results indicate it would be prudent to match training specificity with the event and runner ability.

iii

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

During endurance running events, there are many factors that can influence the pace of the runner. For example, the pace of a runner could change due to changes in terrain, elevation, environmental temperature, and fatigue. Likewise, a runner may strategize to maintain a constant or variable pace in response to race conditions or specific course elements.

Variability in pacing has been studied in respect to short- and middle-distance running (e.g., 3,000 m to 10 km) (Léger and Ferguson, 1974; Ariyoshi et al., 1979; Billat, 2001; Cottin et al., 2002; Sandals et al., 2006; Garcin et al., 2008; Jones et al., 2008). These studies have focused on the influence of pacing on metabolic and performance measures. For example, Cottin et al. (2002) demonstrated that fatigue did not increase variability in pacing compared to a constant-pace strategy.

Despite the research that has been done to examine the effects of variability of pacing during distance running and cycling, there is no research on the actual variability of pace during a marathon. There is some insight into variability of pacing since Billat (2001) reported that the coefficient of variation in velocity was 1%-5% during a 3000 m run. Also, Cottin et al. (2002) demonstrated a variable pace did not increase the time to completion for a short-distance run at a set intensity. Ely et al. (2008) further reported that elite runners completing a marathon had very little change in 5 K pace during a marathon – suggesting low variability of pace. However, there are no other published data on variability of pace during a marathon. Understanding variability of pacing may lead to better understand factors that influence marathon performance. Therefore, the

purpose of this study is to determine the variability of pacing during a marathon. A second purpose is to determine if there is a relationship between variability of pacing and marathon performance.

It is hypothesized that the variability of pace will be greater than what has been reported for shorter events (i.e., 1-5% for a 3000 m run, Billat, 2001). It is also expected that that variability of pace will be related to running performance such that slower runners will experience less variation in pace compared to mid-range finshers throughout the race. Faster runners attempting to maintain a pace throughout the race will also have less variability of pace compared to mid-range finishers.

CHAPTER 2

REVIEW OF RELATED LITERATURE

In this chapter a presentation on cycling and running studies focusing on the influence and/or description of pacing on endurance performance will be provided. These studies are necessary to review because they establish the basis for the examination of variability of marathon distance running. There exists a limited body of research on the influence of pacing during endurance running events on physiological parameters. However, there is a parallel line of research on the influence of pacing on physiological parameters during cycling events; therefore, this area of research is included for its applicability to pacing strategies on physiological parameters.

In the first section of this chapter studies focusing on pacing during cycling will be reviewed in order to better understand how pacing influences physiological and psychological parameters during endurance events in general. Examinations of cycling performance in response to random- vs. constant-intensity cycling will be used to show how pacing affects performance (Palmer et al., 1997) and physiological variables (Palmer et al., 1999). In the second section of the chapter classic examinations of variability of pacing during running, such as Léger and Ferguson (1974) and Ariyoshi et al. (1979), are presented to show the background research on how pacing affects oxygen consumption and feelings of perceived exertion. Contemporary research is finally presented to show the variability of pacing during middle-distance running (Billat, 2001) and how changes in velocity affect pacing and rate of oxygen consumption ($VO_2$) (Sandals et al., 2006). Finally, contemporary running studies are presented to show the role psychological

variables [rate of perceived exertion (RPE), estimated time limit (ETL)] plays in running pacing (Cottin et al., 2001; Garcin, Danel, & Billat, 2008).

<p style="text-align:center">Measures of Variability of Pacing</p>

There are several ways to describe variability of pacing. The main parameter discussed in the current paper is Coefficient of Variation (CoV). This parameter represents a normalized measure of dispersion of a probability distribution. It is calculated as the ratio of the standard deviation (σ) to the mean (μ) $c_v = \dfrac{\sigma}{\mu}$.

For example, Billat (2001) used CoV to quantify the variability in a runner's pace during distance running and established that a runner's pace was 1%–5% variable during a 3,000 m to 10 km race.

Another technique to describe variability of pacing is Standard Deviation (std dev). This is a widely used measure of the variability or dispersion in a data set. It is used to show how much variation there is from the "average score" and is calculated using this formula:

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2},$$

For example, Palmer et al. (1997) used std dev to report the deviation from the mean for Peak Power Output (PPO) of cycle time trial participants. The authors reported the PPO to be $58 \pm 12.2\%$ for a stochastic (randomly, self-selected effort) during a 150 minute paced cycle ergometer ride.

The range of a data set can also be used as a descriptor of variability. The range is the length of the smallest interval which contains all the data. It is calculated by subtracting the smallest observation (sample minimum) from the greatest (sample maximum) and

provides an indication of statistical dispersion. Ely et al. (2008) used the range of data to express the variability in pacing for competitive female marathon runners between the winners and 25th, 50th, and 100th percentiles. The authors reported the range of runner velocity to be significantly different between the winners and 25th, 50th, and 100th percentile runners, as well as significantly different between the 100th percentile runners and the 25th and 50th percentile runners.

In the present paper, coefficient of variation of velocity ($Vel_{cov}$) will be used to describe the variability of velocity during a marathon. The velocity data will be collected from a publicly available web site that contains individual velocity data sets during marathons. Data from two marathons, the Rock 'n' Roll Las Vegas Marathon and the Rock 'n' Roll San Diego marathon, will be used.

## Pacing During Cycling

In an examination of time-trial performance, Palmer et al. (1997) observed that a laboratory-based variable training protocol randomly performed twice within 7-14 days, and immediately prior to the time-trial evaluation, diminished overall time-trial performance compared to steady-state training. The variable training protocol was performed on a cycle ergometer. After a 10-15 minute warm-up, the workload was adjusted to 250 W and thereafter continuously increased by 20 W·min$^{-1}$ until the subject could no longer maintain the required power output. The authors stated that the increased bouts of energy output during the stochastic ride (35.8 to 82.3% of PPO) could have led to increased fatigue and fuel utilization (Palmer et al., 1997). During a subsequent study, Palmer et al. (1999) reported that variable-intensity cycling for 140 minutes showed no differences in mean HR, RPE and $VO_2$ compared to steady-state cycling for the same

5

time period.  However, blood lactate concentrations tended to be higher throughout the latter stages of the variable-intensity exercise compared with during the steady-state cycling.

In an attempt to quantify the differences between the physiological responses of well-trained cyclists to laboratory-based stochastic exercise, Palmer et al. (1997) evaluated the effects of prolonged, submaximal steady-state and stochastic cycling on subsequent cycling time-trial performance.  In this study, six highly trained male cyclists (mean ± std dev, age: 25± 8.0 years, body mass: 80.75 ± 9.0 kg, height: 1.84 ± 0.04 m, peak power output (PPO): 432 ± 38.6 W) participated in two random-order 150-minute paced rides on a cycle ergometer.  The trial was either constant load (58% of PPO) or variable in nature (58 +/- 12.2% of PPO).  The subjects warmed up at a self –selected intensity for 10-15 minutes and, for the variable protocol, the workload was adjusted to 250 W and thereafter continuously increased by 20 W·min$^{-1}$ until the subject could no longer maintain the required power output.  The constant load protocol subjects maintained 58% PPO throughout the trial.  These rides were immediately followed by a 20-km TT performance on an air-braked ergometer.  The subject's PPO was taken as the highest average power during any 60-second period of the exercise test.  During the maximal test and the subsequently described trials, HR was measured using a Polar Sports Tester HR monitor and during all experimental trials on the cycle ergometer, power output (W) and pedal cadence (rpm) were monitored continuously.

Based upon a review of the results, the authors concluded mean HR responses throughout the 150-min paced rides and during the subsequent TT were not significantly different between trials or with those recorded previously in the field during an actual

competition of approximately the same duration. However, despite equal power outputs and HR during the initial 150 minutes of exercise between the steady-state and stochastic conditions, there was a significant improvement in the time to complete the 20-km TT following the 150-min fixed intensity ride versus the variable ride (an average improvement of 1:36 ± 1:18 min:sec). The results of this study reinforce that of Foster et al. (1993), who concluded that even pacing in middle distance events produce the best outcome and any variation in pacing can have negative consequences.

Pacing During Running

Classical Running Studies

While trying to ascertain the optimal training protocol, evaluations must be made on the effect of different pacing strategies on $VO_2$ and RPE as well as peak lactate and exercise tolerance. While examining peak lactate and oxygen uptake, Léger and Ferguson (1974) aimed to examine whether pace changes similar to those experienced in competition could affect the relative contribution of aerobic and anaerobic processes to overall energy utilization during running. More specifically, the authors were interested in whether or not a fast start increased the energy contribution from aerobic metabolism during a race. In this study, eight middle- and long-distance runners (mean ± std dev, age: 25.6 ± 1.8 years, body mass: 66.2 ± 1.1 kg, height: 1.76 ± 0.02 m) participated in two running paces for the first three-quarters of a mile: 1) a fast-medium-very slow pace (F-M-S) and 2) a slow-medium-slow pace (S-M-S). Running conditions were done in random order on a motor-driven treadmill. Both conditions were completed with the following constraints: 1) The total time for the three-quarters of a mile run was equal for each condition; 2) The difference between a fast and a slow first quarter was based on the

normal pace variations occurring in competition; and 3) The intensity of the test was

supramaximal in an attempt to reach $VO_{2\,max}$ within the first minute. Both pace

conditions were ran at competition pace, therefore the "slow start" condition was still

able to elicit the athlete's $VO_{2\,max}$ within the first minute. After warm-up each subject ran

at their previously acquired competition speed with respect to the test condition of

competition performance. Distance run was determined by counting treadmill belt

revolutions and $VO_2$ was measured for each quarter of a mile and during the first 15

minutes of recovery with an open-circuit method.

The authors reported no significant difference between the two paces for $VO_2$ and HR

during the first quarter mile (possibly due to the warm-up protocol or the small difference

in speed between conditions). Total oxygen consumption (combination of four quarter-

mile segments) during the run and for 15-minute post-run recovery $VO_2$ and post-

exercise peak lactate values were also not different between pace conditions. However,

$VO_2$ during the second quarter mile was significantly higher for S-M-S compared to F-

M-S. The findings of the authors show that variations of speed similar to those

experienced in competition do not affect the distribution of aerobic and anaerobic energy

sources and a fast start does not seem to increase $VO_2$ at competition speed versus a slow

start. Further, a fast start does not decrease $VO_2$ during recovery.

Further exemplifying the findings of Léger and Ferguson (1974), Ariyoshi et al.

(1979) employed three different techniques of middle distance running pacing: 1)

fast/slow; 2) slow/fast; and 3) steady pace to test peak $VO_2$ and HR. In this study 10

middle-distance and long-distance male runners carried out the three patterns of running

on a treadmill according to a randomly ordered sequence, on each occasion covering

1400 m in 4 minutes. The authors observed no difference in the peak $VO_2$ between any of the employed pacing strategies. However, HR was greater during the first phase of technique 1 but became insignificant as the run progressed.

Taken together, these studies demonstrate that pacing strategies do not influence performance and physiological parameters, including $VO_2$ and HR. Therefore, it makes sense to determine how pacing varies during long distance events (e.g., marathon) in order to explore whether or not marathon performance can be improved by either increasing or decreasing variability of pace.

<div align="center">Contemporary Running Studies</div>

The following studies reviewed are focused on understanding how physiological and psychological parameters are influenced by pacing during running events. A limitation of the studies reviewed is that they are focused on distances shorter than a marathon. Nevertheless, the results are likely related to pacing during an endurance event such as a marathon.

When pace varies, there is a change in velocity. Acceleration is a term used to describe how velocity changes. In order to examine the influence of acceleration of pacing strategies on physiological parameters, Sandals et al. (2006) investigated the influence of an acceleration phase with and without a pacing strategy on the $VO_2$ attained during 800 m pace treadmill running to exhaustion. Eight male middle-distance volunteer runners (mean ± S.D. age: $25.8 \pm 3.3$ years, height: $1.78 \pm 0.10$ m, body mass: $67.8 \pm 4.7$ kg) with a personal best 800 m time of $112.0 \pm 3.3$ s participated in a speed-ramped progressive test to determine $VO_{2max}$ and three random 800 m pace runs to exhaustion. The three 800 m pace runs (based on time to exhaustion) included constant

speed ($C_{run}$), acceleration ($A_{run}$), and race simulation runs ($R_{run}$). Oxygen uptake was determined throughout each test using 15 s Douglas bag collections. Following the application of a 30 s rolling average, the highest $VO_2$ during the progressive test ($VO_{2max}$) and the highest $VO_2$ during the 800 m pace runs ($VO_{2peak}$) were compared.

The authors reported that the constant speed "square wave" run followed the findings described in Draper, Wood & Fallowfield (2003), showing that middle-distance runners achieve approximately 90% $VO_{2max}$ given a fast-start protocol. Trend analysis identified a significant linear trend (%$VO_{2max}$ attained/Time (s); p = 0.025) between the runs. The %$VO_{2max}$ attained was higher for the acceleration run than the constant speed run, and higher still for the race simulation run. Total time to exhaustion was reported as: $C_{run}$: 107.9 ± 20.7 s; $A_{run}$: 110.7 ± 15.3 s; and $R_{run}$: 111.2 ± 20.0 s (p = 0.612). These results demonstrate that, in middle-distance runners, pacing strategy influences the $VO_2$ attained, with a race simulation run elevating the $VO_2$ attained compared with other pacing strategies.

Intraevent variability of pace has not been fully examined during endurance events. However, Billat (2001) reported the range of coefficients of variation in velocity is 1%− 5% for middle- and long-distance (3,000 m to 10 km) running. Cottin et al. (2002) examined whether the effects of fatigue caused velocity variations during free-paced middle-distance runs. More specifically, the authors set out to determine whether: 1) velocity variability during a middle-distance all-out run increases with fatigue; 2) velocity variability alters the slow phase of the oxygen kinetic because of small spontaneous recoveries compared with the same distance run at constant velocity; 3) a maintained average velocity over a given distance is enhanced by a variable pace rather

than by a constant pace. The slow phase of oxygen kinetic is defined as the point at which work rates associated with increased blood lactate, i.e., above the lactate threshold (LT), causes $VO_2$ to increase slowly beyond 3 min. In contrast, at constant-load exercise of moderate intensity, oxygen uptake (VO2) increases monoexponentially, reaching a constant value within 3 min, i.e., steady state.

In this study, ten long-distance runners performed two series of all-out runs over the distance (previously determined) which they could cover maintaining a velocity equal to 90% of eliciting maximal oxygen consumption. In the first series (free-pace) the subjects were asked to run as fast as possible, without any predetermined velocity profile. In the second series, the same distance was covered at a constant velocity (equal to the average in the previous free-pace run). Short-term Fourier transformation (harmonic analysis) was used to analyze the velocity oscillations pertaining to the changes associated with fatigue. The authors reported that: 1) for all subjects, the mean energy spectrum did not change throughout the free-pace runs, suggesting that velocity variability did not increase with fatigue; 2) the kinetic of oxygen uptake (increase of $VO_2$ towards $VO_{2max}$) and its asymptote were not changed during the free-pace runs compared to the constant-velocity run; 3) performance was not significantly improved by free-pace average velocity [mean (sd) 4.22 ±0.47 m·s$^{-1}$ compared to 4.25 ± 0.52 m·s$^{-1}$, for constant and free-pace, respectively]. The data reported by the authors indicate that, during middle-distance running, fatigue does not increase variations in velocity and a free-pace strategy does not change performance or the oxygen kinetic.

In a related study, Garcin, Danel, & Billat (2008) examined the influence of free- versus constant-pace on RPE and a perceptually-based scale regarding subjective

estimation of exhaustion time [estimated time limit (ETL)] in order to assess how pacing strategies affect running performance. Ten athletes performed a graded test aimed to determine maximal oxygen uptake ($VO_{2max}$) and the velocity associated with $VO_{2max}$ ($Vvo_{2max}$). They also completed two running conditions: 1) a constant run to exhaustion at 90% $Vvo_{2max}$ to determine the time and distance to exhaustion at this relative velocity, and 2) a free-paced run over the distance to exhaustion set by the time to exhaustion at 90% $Vvo_{2max}$. Oxygen uptake and velocity during constant-pace and free-pace were recorded and averaged throughout the entire period of exercise and with the last lap being excluded in the analysis.

The authors observed no significant effect of free versus constant pace on RPE and ETL. Averaged oxygen uptake between free and constant pace runs was not found to be significantly different, whereas averaged $Vvo_{2max}$, % $Vvo_{2max}$ and time to exhaustion was significantly higher for free pace vs. constant pace runs only for the entire exercise. Consequently, compared to the constant pace run, the free pace run only allowed athletes to finish the run by a sprint which was effective in increasing performance, but not to perceive the free pacing run as being less strenuous than the constant pace one. These results further illuminate the findings of Palmer et al. (1999) and Billat (2001), in which it was observed that whole body metabolic and cardiovascular responses to 140 min of either steady-state or variable intensity exercise at the same average intensity are similar, despite differences in skeletal muscle carbohydrate metabolism and recruitment. Further, variations in velocity occurred during the run and velocity increased during the last lap, following the St. Clair Gibson and Noakes' theory. This theory asserts that during heavy exercise the runner adjusts their metabolic rate using a feedback control system based

upon prior, and continuous, subconscious calculations of the metabolic cost required to complete a given exercise task (St. Clair & Noakes, 2004). This allows the selection of an optimum pacing strategy that will allow completion of the task in the most efficient way while maintaining internal homoeostasis and a metabolic and physiological reserve capacity.

Research to date has not accounted for the spontaneous nature of velocity changes during distance running or the effects on pace strategies. To examine the effects of pacing during a marathon (42.2km) in regards to ambient temperature, Ely et. al (2008) evaluated the influence of air temperature on pacing of competitive female marathoners. In this study, the profiles of 219 runners of multiple abilities, the race winner, as well as the 25th, 50th, and 100th place finishers results were analyzed by comparing the time to complete each measured (true) 5 km race interval to the average 5 km time (true 5 km time – average 5 km time) for the initial 40km. The last 2.2 km segment was analyzed separately due to spontaneous increases in speed at the end of the race. This analysis consisted of comparing the 1-km race pace of the last 2.2 km (last 5.2% of the race) to the average 1-km race pace over the initial 40 km and to the average 1-km race pace from the true 35 to 40 km. To evaluate pacing in regards to ambient temperature over the initial 40 km, races were binned by 5° increments in ambient temperature into cool I, temperate (T), and warm (W) conditions (C = 5.1-10°C, T = 10.1-15°C, and W = 15.1-21°C) and also separated by ability (1st, 25th, 50th and, 100th). The same binning method was used to examine the interaction of weather on the end spurt.

Race winners exhibited a linear pacing profile (time vs. velocity, $r^2 = 0.15$) in that they ran close to an even velocity throughout the first 40 km and close to the current

course record. The 25th, 50th, and 100th place finishers showed a nonlinear pace profile over the first 40 km (cubic fit: $r^2$ = 0.98, 0.98, 0.96, respectively). That is, their initial 5 km was their fastest. The 50th and 100th place finishers then slowed to a pace which was maintained from 10 to 20 km while the 25th place finisher maintained pace from 10 to 25 km, after which all populations progressively decelerated until 40 km. Further, the 100th place finishers slowed even more from their average pace than the other groups during the latter phases of the race. The pacing profiles of the 25th, 50th and 100th place finishers was a consistent pattern, as only 5%, 4%, and 1% of the runners in the 25th, 50th, and 100th place groups, respectively, ran evenly throughout the race.

The impact of weather on pacing was dependent on finishing position. First place finishers in the cool temperature condition (5-10°C) started out relatively slow compared to their average running velocity and accelerated such that their time to run the 5 km distance between 35 and 40 km was faster than their average velocity over 40 km. In contrast, first place finishers in the warm condition (15-21°C) started out at a pace similar to their average running velocity and slowed ($P < 0.05$) during latter stages of the race. The running velocities over the first 5 km for the 25th, 50th, and 100th place finishers were all faster than their velocities between 35 and 40 km, regardless of the temperature condition and the difference between the two times increased as the temperature warmed.

End spurts were exhibited by the race winners, 25th and 50th place finishers. These runners increased their running velocity over the last 2.2 km compared to their velocity between 35 and 40 km ($P < 0.05$). The magnitude of acceleration differed between finishing groups as first place finishers were able to accelerate to their average velocity for the initial 40 km, whereas the 25th and 50th place finishers could not ($P < 0.05$). An

end spurt was not observed in the 100th place finishers. For the race winner, the end spurt was only present in the W condition when end spurt velocity was faster ($P < 0.05$) than the runners velocity between 35 and 40 km and statistically similar to their average running velocity over the initial 40-km. An end spurt in the 25th and 50th place finishers was only present in the W condition where running velocity was significantly increased over 35-40 km but slower ($P < 0.05$) than the average running velocity over the initial 40 km.

Based upon a review of the results, the authors concluded that the pacing of the race winners was distinctly different than that of competitive slower runners over the marathon distance, wherein winners ran an even pace over the 42.2-km distance. However, slower runners started out faster than their average pace for the initial 5 km before achieving a pace that could be maintained for 20 km (50th and 100th) or 25 km (25th) before decelerating for the remainder of the race until the end spurt. The consistency of this pacing pattern between finishing groups suggests that the winner and slower runners represent two unique populations with respect to pacing.

Influence of Elevation on Pacing

Variability in elevation is inevitable in distance running. For example, while navigating a marathon, or half-marathon, a course can involve gradual and even abrupt changes in elevation. It is hypothesized that, in an attempt to optimally manage energy resources in response to changes in elevation and running distance, runners match their speed and adopt compensatory strategies to achieve optimal performance. In order to quantify optimal pacing strategies for distance running it is necessary to investigate the metabolic costs in relation to speed and pace over changes in gradient.

To quantify the speed regulation during overground running with changes in elevation, Townshend, Worringham & Stewart (2009) investigated the speed changes and oxygen consumption of eight healthy male distance runners (age = 28.1 ± 9 yr, height = 178.9 ± 7.3 cm, weight = 70.2 ± 7.6 kg) over 3 laps of a 3175 m course circuit, including four sections: level section (765 m), uphill (820 m), level (770 m), and downhill (820 m). The uphill/downhill portion of the course used the same section of road completed in the opposite direction. For subsequent analysis, each section was divided into eight subsections- gradients for each subsection of uphill components were: 6.3%, 9.3%, 11.2%, 6.8%, 11.7%, 10.7%, 1.5%, and 7.8%. Gradients, distances and speed were measured using non-differential GPS and physiological data were recorded using a portable metabolic analyzer and activity monitor [single-lead ECG (HR) and triaxial accelerometer (body acceleration in the sagittal, frontal, and transverse planes)]. The metabolic analyzer provided information on $VO_2$, carbon dioxide production, and ventilation. Values were collected breath by breath and averaged during 15-s intervals, with maximal oxygen consumption defined as the highest value achieved in either the laboratory or the field test.

The authors observed that there exists definite adaptation to elevation variables. Participants ran 23% slower on uphills and 13.8% faster on downhills compared with level sections. Speeds on the level sections were significantly different for 78.4 ± 7.0 s following an uphill and 23.6 ± 2.2 s following a downhill. Speed changes were also shown to be primarily regulated by stride length, which was 20.5% shorter uphill and 16.2% longer downhill, whereas stride frequency was relatively stable throughout the experiment. Oxygen consumption averaged 100.4% of runner's individual ventilatory

thresholds on uphills, 78.9% on downhills, and 89.3% on level sections. Approximately 89% of group-level speed was predicted using a modified gradient factor; however, due to individual differences, individual regression values were slightly less than group values. The authors also reported large individual variations in pacing with respect to gradient. In general, runners who varied their pace more as a function of gradient showed smaller changes in oxygen consumption. Downhill running speed showed particularly wide individual variation. Further analysis concerning pacing strategies showed there was little, if any, relationship between pacing over the three laps and pacing over the varying gradients. This is important because those who adopted a conservative strategy with respect to laps (minimizing lap-to-lap energy expenditure fluctuations by keeping average speed consistent) did not necessarily do so over hills (minimizing uphill vs. downhill energy expenditure fluctuations by increasing speed differences on these sections).

This study has exemplified strategies that runners use to adapt to the gradient differences in distance running. Runners during this study tended to limit uphill running to a speed that resulted in oxygen consumption values in line with their ventilatory threshold; however, there was a large potential to improve time on downhill sections because runners were not limited by physiological cost. Despite the reduction in physiological demand, runners may be unable or unwilling to greatly increase speeds on these sections because of imposed biomechanical, kinematic and psychological constraints. Runners who varied their pace in relation to gradient also showed smaller changes in $VO_2$. This adaptation can potentially be the means to a more effective pacing strategy.

Summary

Endurance running performance involves many complex biological and biochemical parameters, including oxygen consumption, HR, lactate accumulation and substrate depletion.  Psychological factors (RPE and ETL) also contribute to the myriad of factors that the endurance athlete must train for to optimize their performance outcome.  When examining the influence of variability in pacing on physiological parameters, it has been observed that variations in pacing similar to competition does not decrease lactate formation or oxygen consumption during recovery (Léger and Ferguson, 1974; Ariyoshi et al., 1979). Further, HR, RPE and ETL are not significantly altered by variable-intensity exercise (Palmer et al., 1999; Garcin, Danel & Billat, 2007; Garcin et al., 2008); however, time to exhaustion was significantly greater for a fast-start strategy and $VO_2$ increases more rapidly toward its peak in the first 120s of exercise during the fast-start strategy (Jones et al., 2008).  Draper, Wood & Fallowfield (2003) also observed that a fast-start protocol elicited a greater attained $VO_2$ than a constant-pace protocol.  Fatigue has also been observed to not increase variations in velocity and a free-pace strategy has been shown not to alter performance or the oxygen kinetic (Cottin et al., 2002). Townshend, Worringham & Stewart (2009) also showed that runners who adopted a more conservative running strategy minimized lap-to-lap energy expenditure fluctuations by keeping average speed consistent but fluctuated their speed over hills to decrease energy expenditure.  The runners who varied their pace in relation to gradient also exhibited smaller changes in oxygen consumption, which further supports the theory proposed by St. Clair Gibson and Noakes (2004), which asserts self-selection of an optimum pacing strategy will allow completion of the task in the most efficient way

while maintaining internal homoeostasis and a metabolic and physiological reserve capacity. These adaptations to terrain and physiological demands can potentially be the means to a more effective pacing strategy. Further, given that the coefficients of variation in velocity during a distance event are reported to be 1%-5% (Billat, 2001), it is prudent to examine further techniques of pacing variability and the variability associated with marathon distance running. While examination of elite female marathon runners has shown the best runners maintain a more even pace throughout their races, the lack of research pertaining to non-elite marathon runners makes the need for such research even more important for its applicable performance contributions to distance running. Despite all of this research, there remains a gap in the literature in which no one has documented the variability of pacing during a marathon for a variety of finisher profiles.

CHAPTER 3

METHODS

Subjects

Secondary GPS data from marathon runners were used for this study. All data sets

represented GPS data from marathon events and were publicly available through a web

site maintained by Garmin (http://connect.garmin.com/). Each data set represented the

GPS data recorded by a runner using a Garmin GPS device with each runner voluntarily

uploading the data to the website so that anyone can access the data. Due to the

limitations of the website there was no subject-specific descriptive information available

(e.g., age, gender, height, weight, or ethnicity). The study was determined to be exempt

from requiring consent from human subjects since deidentified secondary data are being

used.

Data Set Description

Only complete GPS data records over the marathon race distance were used. A

complete data set included: 1) marathon location, 2) marathon date, 3) speed, 4)

elevation, 5) time, and 6) position data. 311 records for 2 races were initially utilized.

Data were exported from http://connect.garmin.com/ (.tcx – training center format) and

saved in a file directory corresponding to the applicable race.

Data Reduction

The sampling rate of the Garmin devices ranges between one sample every 1 -10 s

(i.e., 1 – 0.1 Hz) depending on the unit and whether or not the unit is moving in a straight

line or at all. Specifically, the Garmin Forerunner 310 and 405 will decrease the sample

rate if the unit is traveling in a straight line to 0.1 Hz or will increase sample rate to 1 Hz

if a change in direction is detected (personal communication: Garmin Technical Support).
Therefore, velocity data were resampled using a custom program (Matlab, Mathworks, version 6.1) to yield consistent sample rate for all subjects of 0.15 Hz (9 samples per minute).

Marathon finish time was determined by identifying the last time in the data set. Each marathon finish time was placed into one of three finish time bins: Bin 1: 2.5 – 3.9 hrs, Bin 2: 4.0 – 4.6 hrs,  Bin 3: 4.7 – 7.2 hrs.  These bins were defined in order to have an evenly distributed number of data sets per bin.

Variability of pacing was determined by calculating the Coefficient of Variation of velocity ($Vel_{cov}$).  The Speed data were used to calculate $Vel_{cov}$ using the formula:

$$Vel_{cov} = \frac{std\,dev\,(vel)}{mean\,(vel)}(100)$$

Where:

std dev (vel) = the standard deviation of velocity over the marathon.

mean (vel) = the average velocity over the marathon.

## Additional Data Processing

Prior to analyzing data, all GPS data sets were inspected graphically to determine whether or not the data were suitable for analysis.  Ultimately, 10 profiles were removed for reasons explained below.  In the end, 301 total race profiles were used for analysis.

1) Missing data from the file

Five (5) profiles from Race 1 and 1 file from Race 2 were removed because there were large gaps between data points within the data sets.  These gaps were likely the result of the GPS watch losing the signal to track the runner.

2) Erroneous negative spikes in velocity

Four (4) profiles (2 from each Race) had large spikes in negative velocity due to noise in the Garmin GPS unit. These spikes were evident on the velocity vs. time graph. Since it is not possible for a runner to exhibit negative velocity with the GPS unit these files were removed, resulting in a final number of 130 (Race 1) and 171 (Race 2).

3) End time drop-offs

While examining the data files it was clear that some runners failed to stop recording information on their device after they have crossed the finish line. This was evident by inspecting the velocity vs. time graph. After closer investigation of the file, these segments were removed at the point of last run velocity. This was identified by mapping the GPS coordinates of the runner profiles versus the GPS coordinates of the marathon finish line. The data were removed after this point. Two (2) files from Race 1 and 11 files from Race 2 were edited for this reason.

## Statistical Analysis

The main purpose of the study was to describe the variability of pacing during a marathon; therefore, a frequency distribution of $Vel_{cov}$ per race was generated. The $Vel_{cov}$ data were tested for normality using the Kolmogorov-Smirnov test. If the data were not normally distributed, non-parametric tests (Mann – Whitney, descriptive statistics; Kruskal – Wallis, inferential statistics) were conducted, in addition to parametric tests (below).

Descriptive statistics were calculated for $Vel_{cov}$ and marathon finish time for each race. These variables were compared between marathons using an independent T-test. The second purpose of the study was to determine if a relationship exists between

variability of pacing and marathon performance. An analysis of variance (ANOVA) was used to compare the dependent variable ($Vel_{cov}$) between the independent variable marathon bin finish times (3 bins). An ANOVA was run for each race. Post-hoc tests were computed if the omnibus F-ratio was found to be significant using LSD to compare $Vel_{cov}$ between bins.

CHAPTER 4

RESULTS

The main purpose of this study was to describe the variability of pacing during a

marathon.  The $Vel_{cov}$ was observed to be 16.6 ± 6.3% and 16.7 ± 6.5% for Race 1 and

Race 2 (Table 1).  The frequency distributions of $Vel_{cov}$ for each race are presented in

Figures 1 and 2.  The most frequent $Vel_{cov}$ for Race 1 was 12 percent and 15 percent for

Race 2.  59 of 130 $Vel_{cov}$ were above the mean for Race 1 and 72 of 171 above the mean

$Vel_{cov}$ for Race 2.  The range of $Vel_{cov}$ was 24.15% for Race 1 vs. 40.24% for Race 2.



Figure 1: Distribution of runners within Race 1 by $Vel_{cov}$.

**Race 2**

Figure 2: Distribution of runners within Race 2 by $Vel_{cov}$.

It was determined that $Vel_{cov}$ was not normally distributed for either Race 1 or Race 2 ($p < 0.01$). Non-parametric tests and parametric tests were conducted with both analyses yielding identical results. Therefore, results from the parametric tests only are reported.

The $Vel_{cov}$ was not different between Race 1 ($16.6 \pm 6.3\%$) and Race 2 ($16.7 \pm 6.5\%$) (Table 1; $t_{299} = -0.012$, $p = 0.990$). Additionally, marathon time was not different between Race 1 ($4.3 \pm 0.8$ hr) and Race 2 ($4.4 \pm 0.9$ hr) (Table 1; $t_{299} = -0.870$, $p = 0.385$).

| Race | N | Vel$_{cov}$ (%) | Finish Time (hrs) |
|---|---|---|---|
| 1 | 130 | 16.6 ± 6.3 | 4.3 ± 0.8 |
| 2 | 171 | 16.7 ± 6.5 | 4.4 ± 0.9 |

Table 1: Means and standard deviation for coefficient of variation of velocity (Vel$_{cov}$) and marathon times per race. Vel$_{cov}$ and marathon times were not different between races.

### Marathon Performance and Coefficient of Variation of Velocity

The Vel$_{cov}$ during Race 1 was influenced by bin finish time (Figure 3, $F_{2, 129} = 24.948$, $p < 0.001$). Using post-hoc tests, it was determined that Vel$_{cov}$ was lower in Bin 1 vs. Bin 2 ($p < 0.05$), lower in Bin 1 vs. Bin 3 ($p < 0.05$), and lower in Bin 2 vs. Bin 3 ($p < 0.05$) (Table 3). The Vel$_{cov}$ during Race 2 was influenced by marathon finish time across all time Bins ($F_{2, 170} = 62.557$, $p \leq 0.001$), with the Vel$_{cov}$ being lower in Bin 1 vs. Bin 2 ($p < 0.05$), lower in Bin 1 vs. Bin 3 ($p < 0.05$), and lower in Bin 2 vs. Bin 3 ($p < 0.05$) (Table 4).

| Finish Time Bin* | N | Race 1 Vel$_{cov}$ (%) | N | Race 2 Vel$_{cov}$ (%) |
|---|---|---|---|---|
| Bin 1 (2.5 – 3.9 hrs) | 45 | 13.1 ± 4.6 | 56 | 12.3 ± 3.5 |
| Bin 2 (3.9 – 4.6 hrs) | 42 | 15.9 ± 5.8 | 61 | 15.4 ± 5.2 |
| Bin 3 (4.6 – 7.2 hrs) | 43 | 21.1 ± 5.5 | 54 | 22.6 ± 6.0 |
| Total | 130 | 16.6 ± 6.2 | 171 | 16.6 ± 6.5 |

Table 3:  Means and standard deviation for coefficient of variation of velocity (Vel$_{cov}$) per Bin for Race 1 and Race 2.  N equals number of runners. The Vel$_{cov}$ was influenced by bin finish time (*$p \leq .001$).
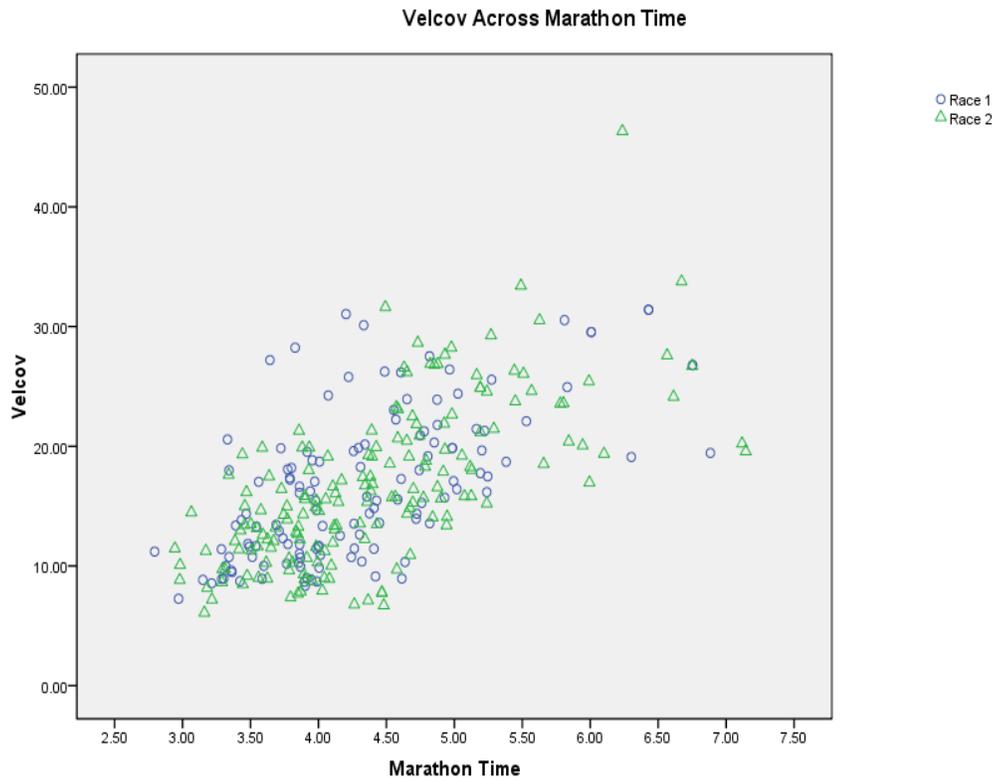
Figure 3:  Vel$_{cov}$ across marathon finish time. Vel$_{cov}$ increased as marathon time increased for Race 1 and Race 2.

CHAPTER 5

DISCUSSION

This study set out to describe the variability of marathon pace using coefficient of variation of velocity ($Vel_{cov}$). Using 301 GPS data sets from two different marathons, it was determined that the $Vel_{cov}$ was not different between these races with the overall mean being 16.6% ± 6.4% (Race 1:16.6 ± 6.3% ; Race 2: 16.7 ± 6.5%). A second goal of this study was to determine if there was a relationship between marathon finish time and $Vel_{cov}$. By placing each marathon finish time in a specific bin (i.e., 2.5 – 3.9 hrs., 4.0 – 4.6 hrs., 4.7 – 7.2 hrs.), it was determined that $Vel_{cov}$ was different between marathon finish times such that $Vel_{cov}$ was greater for slower finish times for either race. Therefore, the hypothesis that the relationship between $Vel_{cov}$ and marathon finish time is non-linear such that the runners with the fastest and slowest finishing times will have the least variability compared to runners with an average finishing time was not supported.

There are minimal published data on variability of pacing in endurance events of which to compare the data from the present study to. The few studies that have reported variability of pacing have either been of shorter distances (e.g., Billat, 2001) or of elite runners (e.g., Ely et al., 2008). For example, Billat (2001) reported that $Vel_{cov}$ of middle- and long-distance running to be in the range of 1%–5% for 3,000 m to 10 km for competitive runners. Additionally, Ely et al. (2008) reported that the fastest runners (winners) in a marathon maintained low variability in velocity throughout the race while slower runners slowed progressively. Although the authors did not report $Vel_{cov}$, inspection of the data indicates that the race winners had low variability of pacing (approximately less than 20 s difference between 5 K splits) as did the 100th place

29

finishers (range of about 3 minute difference between fastest and slowest 5 K splits).  The greater variability of pace observed in the present study (i.e., $Vel_{cov}$ = 16.6% ± 6.4%) compared to these studies is likely because the subjects in this study were not elite runners.  Considering all 301 data sets, the mean marathon finish time was 4.4 ± 0.84 hrs.  Along with this, $Vel_{cov}$ was calculated over a marathon vs. a shorter distance.  Nevertheless, given the result that $Vel_{cov}$ was influenced by marathon time (range: 2.8 – 7.1 hrs.), it does makes sense that the $Vel_{cov}$ will be higher among non-competitive marathon distance runners compared to elite marathoners with finishing times under 3 hours.

Vel$_{cov}$ can be influenced by several factors such as elevation changes, fatigue, and strategic approach to pacing, for example.  However, it can also be influenced by errors in the data set.  For example, it was observed that some data sets had large periods of time where data were missing.  In cases like that, data sets were removed from the analysis.  In other instances, it was difficult to determine whether or not a data set should be removed from analysis or edited in some way.  For example, there were data sets that contained velocity spikes that were beyond normal running speed but would be apparent only for a single data point.  Because of that, it was decided to process the data further and smooth the data set using a low-pass filter (cutoff frequency of 1/4$^{th}$ of the 0.15 Hz sample rate).  The purpose of using this filter was to remove any high frequency noise in velocity.  The smoothed data set was then used for the same statistical test as the original data and it was determined that the outcome of the analysis was the same regardless of which data set was used.  Therefore, the velocity spikes observed did not influence the interpretation that $Vel_{cov}$ was influenced by marathon finish time.

Another source of error in the GPS data sets was caused by whether or not the device was started or stopped at the beginning or ending of the race. Inspection of individual data sets revealed that some runners stopped the device at some point after the race had ended. This was evident by a dramatic and obvious drop in velocity at the end of the data set (Figure 2). In these cases, the GPS position coordinates (i.e., latitude and longitude) were used to confirm the discrepancy from the actual finish point of the race using www.mapmyrun.com. The end point of the data set was identified by the position coordinates and the data after the finish location were deleted. This was observed in 13 files and resulted in deleting approximately 0.05 mi worth of data. To determine if editing these files influenced the outcome of the analysis, the analysis was repeated by removing the data sets entirely. In this case, the mean $Vel_{cov}$ was $16.7 \pm 6.2\%$ for Race 1 and $16.8 \pm 6.7\%$ for Race 2 vs. $16.6 \pm 6.3\%$ and $16.7 \pm 6.5\%$, respectively. There was no difference in the statistical outcome if the files were or were not, used. Therefore, the files were retained for the analysis and subsequent discussion.

**End Time Drop-off**

Figure 2.Illustration of end time drop-off.  The points removed were identified by a sudden drop near the end of the record, followed by a section of very slow velocity.  This indicated the runner decreasing their velocity immediately following the finish line and then slowly moving through the finish corral.  The end point of the data set was identified by the GPS position coordinates and the data after the finish location were deleted (approximately 0.05 mi).

Changes in elevation may have an effect on $Vel_{cov}$ since runners tend to change their velocity while running up or downhill.  The influence of elevation changes on $Vel_{cov}$ was not inspected in this study.  However, it was determined that $Vel_{cov}$ was not different between races.  The elevation profiles for each race are illustrated in Figure 3.  From this illustration, it seems that the changes in elevation were not dramatic between or within a race.  Nevertheless, it is hypothesized that races with larger changes in elevation would

result in a greater $Vel_{cov}$ than what was observed in this study. Future research could be directed at determining how elevation changes could influence $Vel_{cov}$.



Figure 3. Elevation profiles for the Rock 'n' Roll Las Vegas and San Diego marathons. The graph represents elevation by percent of the GPS data recorded.

Relationship between Marathon Performance and $Vel_{cov}$

It was determined that $Vel_{cov}$ increased with marathon time during both races. This increase was seen across the bins during Race 1 (Bin1 to Bin 2 = 2.8% increase; Bin 2 to Bin 3 = 5.2% increase; Bin 1 to Bin 3 = 8.0% increase) with the greatest increase between Bin 2 and Bin 3. This increase was also observed across the bins during Race 2 (Bin 1 to Bin 2 = 3.1% increase; Bin 2 to Bin 3 = 7.2% increase; Bin 1 to Bin 3 = 10.3%

increase) with the greatest increase between Bin 2 and Bin 3. It makes sense that $Vel_{cov}$ is low for fast marathon times (e.g., Ely et al., 2008) since runners are trying to maintain as fast a velocity possible over the entire distance in an attempt to achieve a faster finishing time. In this case, large fluctuations in $Vel_{cov}$ over the course of the race would mean the runner is slowing down and this would, obviously, be detrimental to marathon performance. It also makes sense that $Vel_{cov}$ is greater for slower marathon times since the runner does not have the same physical capacity as the elite marathon runner to maintain a consistent pace. For example, $Vel_{cov}$ would be greater for a runner who would run for a period of time but then need to walk to recover from the exertion then a runner who would maintain the same pace over the same period of time. However, it is not clear why $Vel_{cov}$ continued to increase for very slow marathon times (4.7 – 7.2 hrs). Originally, it was thought that these runners would have low variability of pace since the capacity to run fast was reduced and therefore the capacity to change velocity was also reduced. However, that was not what was observed. It seems that greater variability in pace is detrimental to marathon performance.

Many factors contribute to the performance of a runner during a marathon. Physiological and psychological attributes during training and competition both play an integral role in the runner's event performance. The increase in $Vel_{cov}$ as marathon finish time increased is consistent with the findings of St. Clair Gibson & Noakes (2004) wherein the individual subconsciously selected a pacing strategy that allowed completion of the task efficiently while maintaining internal homoeostasis and a metabolic and physiological reserve capacity. This was evidenced by examining a simulated 100 km cycle time trial with repeated high intensity 1 and 4 km sprint bouts. While measuring

integrated electromyographic (IEMG) outputs of the vastus lateralis it was shown that

average power outputs decreased progressively during the consecutive 1 km sprints and

integrated EMG activity declined in parallel with these reductions in power output. These

changes occurred even though 20% or less of the available motor units in the lower limb

were recruited.  Heart rate was also observed to be near maximal during each of the

sprints, probably indicating that the subjects consciously attempted to produce a maximal

effort, even though the extent of their skeletal muscle recruitment declined progressively.

The authors concluded that these results indicate the central brain recruitment of a

progressively a lower number of motor units despite an increase in conscious demand

from the athlete.  That is, even though the athlete tried to work harder, less motor units

were recruited despite this increased demand.

St. Clair Gibson et al. (2003) identify the perception of fatigue to be instrumental in

the conscious decision to continue or cease activity.  In their review of brain structure

activity and homeostatic mechanisms, the authors reported that the development of the

sensation of fatigue is associated with changes in motor activity, motivation and emotion.

Changes in neural network activity in any areas of motor control may be responsible for

the generation of the sensation of fatigue.  Emotional states such as anger and fatigue

involve adjustments in homeostatic balance and peripheral physiological changes, such as

heart rate.  Functional imaging studies (Dougherty et al., 1999; Mayberg et al., 1999)

revealed increased or decreased activity in several brain areas when normal individuals

experience motions such as sadness, happiness, fear or anger. As motivation and drive are

affected by all these different emotional states, fatigue may originate in different brain

areas associated with emotional responses.  These factors act to create a "mental map" for

the individual to create parameters by which the body performs during exercise. When changes in the external environment occur the mind creates an additional map, based upon its emotions and feelings, a second map is created. The individual is, at some point, able to discern the differences between the models and choose to override the "set point" created by the first model in response to perceived fatigue.

Novices may have very little or no previous mastery experience upon which to base their beliefs about their abilities (self-efficacy), and therefore lack the skills necessary to form beliefs about being able to successfully perform a sport task (Law & Hall, 2009). Given these observations, it makes sense that the slower runners would exhibit a greater variability of pace as they may not have developed the same level of confidence in their own ability that faster, more experienced, runners have attained and may not assess their level of fatigue at the same level as faster runners. The faster runner is most likely able to assess their level of fatigue better than the slower runner and make the conscious decision to maintain their velocity, whereas the slower runner would succumb to their subconscious perceptions. The extent to which these factors affected the performance of the runners in this investigation is unclear. Therefore, future research is recommended to investigate the effects of self-efficacy and perception of fatigue on variability of pace during marathon distance races.

<div align="center">Practical Application</div>

Several applications to marathon performance and training can be gleamed from these results and are salient to the formation of marathon training programs. The runner's anticipated marathon completion time will have a significant impact on the variability of their pacing while training. The faster runners may have their training protocol tailored

to a less variable strategy, whereas the slower runners would employ a more variable strategy given that their variability of pace is higher than the faster runners. For example, typical strategies for marathon training emphasize low variability despite runner ability or anticipated finish time. Given that the results of this study indicate slower runners are more variable in their pace than faster runners, it is important to match training specificity with the event. Therefore, the training regimen of slower runners should reflect the increased variability during competition. Conversely, faster runners would attempt to achieve maximum speed with little variability. Runners wanting to decrease their finish time should work towards a less variable pace followed by increased speed. Future research is necessary to investigate the role of different pacing strategies on marathon performance.

## Conclusion

The main purpose of the study was to describe the variability of pacing during a marathon. A secondary purpose of this study was to determine if there is a relationship between variability of pacing during a marathon and marathon performance (i.e., finish time). Based upon the examination of $Vel_{cov}$ associated with marathon finish time segment, a relationship has been shown to exist between variability of pacing and marathon performance. The fastest runners exhibited the least variability while slower runners had greater variability in pacing. The results of this study have provided important knowledge into the pacing characteristics of the non-elite marathon runner. These findings are important to the future study of marathon pacing variability and development of ideal training protocols for runners of varying abilities.

APPENDIX 1

SUMMARY OF STATISTICS

Differences in Coefficient of Variation of Velocity between Races

(independent samples *t*-test)

**Group Statistics**

|  | Race | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| CoV | 1 | 130 | 16.6369 | 6.25523 | .54862 |
|  | 2 | 171 | 16.6462 | 6.54659 | .50063 |

**Independent Samples Test**

|  |  | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | |
|---|---|---|---|---|---|---|---|---|
|  |  | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| CoV | Equal variances assumed | .003 | .960 | -.012 | 299 | .990 | -.00928 | .74734 |

Differences in Marathon Times between Races

(independent samples *t*-test)

**Group Statistics**

|  | Race | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Time | 1 | 130 | 4.3261 | .82460 | .07232 |
|  | 2 | 171 | 4.4112 | .85323 | .06525 |

**Independent Samples Test**

|  |  | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | |
|---|---|---|---|---|---|---|---|---|
|  |  | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Time | Equal variances assumed | .295 | .587 | -.870 | 299 | .385 | -.08511 | .09786 |

# Differences in Coefficient of Variation of Velocity between Race Bins (ANOVA)

## Race 1

**Descriptives**

| CoV | | | | | 95% Confidence Interval for Mean | | | |
|---|---|---|---|---|---|---|---|---|
| | N | Mean | Std. Deviation | Std. Error | Lower Bound | Upper Bound | Minimum | Maximum |
| 1 | 45 | 13.1283 | 4.64792 | .69287 | 11.7319 | 14.5247 | 7.26 | 28.24 |
| 2 | 42 | 15.8594 | 5.83080 | .89971 | 14.0424 | 17.6764 | 8.33 | 31.04 |
| 3 | 43 | 21.0682 | 5.51906 | .84165 | 19.3697 | 22.7667 | 8.95 | 31.41 |
| Total | 130 | 16.6369 | 6.25523 | .54862 | 15.5515 | 17.7224 | 7.26 | 31.41 |

**Test of Homogeneity of Variances**

CoV

| Levene Statistic | df1 | df2 | Sig. |
|---|---|---|---|
| 1.440 | 2 | 127 | .241 |

**ANOVA**

CoV

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1423.709 | 2 | 711.854 | 24.948 | .000 |
| Within Groups | 3623.786 | 127 | 28.534 | | |
| Total | 5047.495 | 129 | | | |

**Multiple Comparisons**

CoV

LSD

| (I) Bin | (J) Bin | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | -2.73113* | 1.14606 | .019 | -4.9990 | -.4633 |
| | 3 | -7.93988* | 1.13915 | .000 | -10.1941 | -5.6857 |
| 2 | 1 | 2.73113* | 1.14606 | .019 | .4633 | 4.9990 |
| | 3 | -5.20876* | 1.15886 | .000 | -7.5019 | -2.9156 |
| 3 | 1 | 7.93988* | 1.13915 | .000 | 5.6857 | 10.1941 |
| | 2 | 5.20876* | 1.15886 | .000 | 2.9156 | 7.5019 |

*. The mean difference is significant at the 0.05 level.

# Race 2

**Descriptives**

CoV

| | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | | |
| 1 | 56 | 12.2506 | 3.48171 | .46526 | 11.3182 | 13.1831 | 6.08 | 21.29 |
| 2 | 61 | 15.3875 | 5.20000 | .66579 | 14.0557 | 16.7192 | 6.71 | 31.62 |
| 3 | 54 | 22.6265 | 5.96657 | .81195 | 20.9980 | 24.2551 | 13.40 | 46.32 |
| Total | 171 | 16.6462 | 6.54659 | .50063 | 15.6580 | 17.6345 | 6.08 | 46.32 |

**Test of Homogeneity of Variances**

CoV

| Levene Statistic | df1 | df2 | Sig. |
|---|---|---|---|
| 5.122 | 2 | 168 | .007 |

**ANOVA**

CoV

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 3109.903 | 2 | 1554.951 | 62.557 | .000 |
| Within Groups | 4175.928 | 168 | 24.857 | | |
| Total | 7285.830 | 170 | | | |

**Multiple Comparisons**

CoV

LSD

| (I) Bin | (J) Bin | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | -3.13681* | .92269 | .001 | -4.9584 | -1.3152 |
| | 3 | -10.37589* | .95088 | .000 | -12.2531 | -8.4987 |
| 2 | 1 | 3.13681* | .92269 | .001 | 1.3152 | 4.9584 |
| | 3 | -7.23909* | .93156 | .000 | -9.0782 | -5.4000 |
| 3 | 1 | 10.37589* | .95088 | .000 | 8.4987 | 12.2531 |
| | 2 | 7.23909* | .93156 | .000 | 5.4000 | 9.0782 |

*. The mean difference is significant at the 0.05 level.

APPENDIX 2

IRB APPROVAL

# UNLV
UNIVERSITY OF NEVADA LAS VEGAS

## Biomedical IRB – Exempt Review
## Approved as Exempt

DATE:       February 8, 2010

TO:         **Dr. John Mercer**, Kinesiology

FROM:       Office for the Protection of Research Subjects

RE:         Notification of IRB Action by Dr. Charles Rasmussen, Co-chair
            Protocol Title: **Variability of Pacing in Marathon Distance Running**
            OPRS# 1001-3334M

---

This memorandum is notification that the project referenced above has been reviewed by the UNLV Biomedical Institutional Review Board (IRB) as indicated in Federal regulatory statutes 45CFR46.

The protocol has been reviewed and deemed exempt from IRB review.  It is not in need of further review or approval by the IRB.

*Any* changes to the exempt protocol may cause this project to require a different level of IRB review. Should any changes need to be made, please submit a **Modification Form**.

If you have questions or require any assistance, please contact the Office for the Protection of Research Subjects at OPRSHumanSubjects@unlv.edu or call 895-2794.

Office for the Protection of Research Subjects
4505 Maryland Parkway • Box 451047 • Las Vegas, Nevada 89154-1047
(702) 895-2794 • FAX: (702) 895-0805

45

APPENDIX 3

MANUSCRIPT

VARIABILITY OF PACING IN MARATHON DISTANCE RUNNING

Thomas A. Haney Jr.
5643 Crowbush Cove Pl.
Las Vegas, NV 89122
(702) 335-9286
haneyt@unlv.nevada.edu


Department of Kinesiology and Nutrition Sciences
School of Allied Health Sciences
Division of Health Sciences

UNIVERSITY OF NEVADA, LAS VEGAS

VARIABILITY OF PACING IN MARATHON DISTANCE RUNNING

# ABSTRACT

The purposes of this study were to describe variability of pacing during a marathon and to determine if there is a relationship between variability of pacing and marathon performance. A total of 301 race profiles that contained personal global positioning system (GPS) from the Rock 'n' Roll Las Vegas (Race 1) and San Diego (Race 2) marathons were downloaded (http://connect.garmin.com) and analyzed. Each marathon finish time was placed into one of three finish time bins: Bin 1: 2.5 – 3.9 hrs, Bin 2: 4.0 – 4.6 hrs, Bin 3: 4.7 – 7.2. The coefficient of variation of velocity ($Vel_{cov}$) was calculated for each race profile and compared between races using an independent T-test. $Vel_{cov}$ was not different between races (Race 1: $16.6 \pm 6.3\%$, Race 2: $16.7 \pm 6.5\%$). $Vel_{cov}$ was lower in Bin 1 vs. Bin 2 ($p < 0.05$), lower in Bin 1 vs. Bin 3 ($p < 0.05$), and lower in Bin 2 vs. Bin 3 ($p < 0.05$) for both races. It was determined that $Vel_{cov}$ was different between marathon finish times such that $Vel_{cov}$ was greater for slower finish times for either race. It appears that slower marathon finishers had greater $Vel_{cov}$ compared to faster marathoner finishers. These results indicate it would be prudent to match training specificity with the event and runner ability.

Key Words: pace, velocity, performance, elevation

INTRODUCTION

During endurance running events, there are many factors that can influence the pace of the runner. For example, the pace of a runner could change due to changes in terrain, elevation, environmental temperature, and fatigue. Likewise, a runner may strategize to maintain a constant or variable pace in response to race conditions or specific course elements.

Variability in pacing has been studied in respect to short- and middle-distance running (e.g., 3,000 m to 10 km) (1,2,3,6,7,9,11). These studies have focused on the influence of pacing on metabolic and performance measures. For example, Cottin et al. (3) demonstrated that fatigue did not increase variability in pacing compared to a constant-pace strategy.

Despite the research that has been done to examine the effects of variability of pacing during distance running and cycling, there is no research on the actual variability of pace during a marathon. There is some insight into variability of pacing since Billat (2) reported that the coefficient of variation in velocity was 1%-5% during a 3000 m run. Also, Cottin et al. (3) demonstrated a variable pace did not increase the time to completion for a short-distance run at a set intensity. Ely et al. (5) further reported that elite runners completing a marathon had very little change in 5 K pace during a marathon – suggesting low variability of pace. However, there are no other published data on variability of pace during a marathon. Understanding variability of pacing may lead to better understand factors that influence marathon performance. Therefore, the purpose of this study is to determine the variability of pacing during a marathon. A second purpose

is to determine if there is a relationship between variability of pacing and marathon performance.

It is hypothesized that the variability of pace will be greater than what has been reported for shorter events [i.e., 1-5% for a 3000 m run, (2)]. It is also expected that that variability of pace will be related to running performance such that slower runners will experience less variation in pace compared to mid-range finshers throughout the race. Faster runners attempting to maintain a pace throughout the race will also have less variability of pace compared to mid-range finishers.

## METHODS

### Experimental Approach to the Problem

Only complete GPS data records over the marathon race distance were used. A complete data set included: 1) marathon location, 2) marathon date, 3) speed, 4) elevation, 5) time, and 6) position data. 311 records for 2 races were initially utilized. Data were exported from http://connect.garmin.com/ (.tcx – training center format) and saved in a file directory corresponding to the applicable race.

The sampling rate of the Garmin devices ranges between one sample every 1 -10 s (i.e., 1 – 0.1 Hz) depending on the unit and whether or not the unit is moving in a straight line or at all. Specifically, the Garmin Forerunner 310 and 405 will decrease the sample rate if the unit is traveling in a straight line to 0.1 Hz or will increase sample rate to 1 Hz if a change in direction is detected (personal communication: Garmin Technical Support). Therefore, velocity data were resampled using a custom program (Matlab, Mathworks, version 6.1) to yield consistent sample rate for all subjects of 0.15 Hz (9 samples per minute).

Marathon finish time was determined by identifying the last time in the data set. Each marathon finish time was placed into one of three finish time bins: Bin 1: 2.5 – 3.9 hrs, Bin 2: 4.0 – 4.6 hrs, Bin 3: 4.7 – 7.2 hrs. These bins were defined in order to have an evenly distributed number of data sets per bin.

Variability of pacing was determined by calculating the Coefficient of Variation of velocity ($Vel_{cov}$). The Speed data were used to calculate $Vel_{cov}$ using the formula:

$$Vel_{cov} = \frac{std\ dev\ (vel)}{mean\ (vel)}(100)$$

Where:

std dev (vel) = the standard deviation of velocity over the marathon.

mean (vel) = the average velocity over the marathon.

## Subjects

Secondary GPS data from marathon runners were used for this study. All data sets represented GPS data from marathon events and were publicly available through a web site maintained by Garmin (http://connect.garmin.com/). Each data set represented the GPS data recorded by a runner using a Garmin GPS device with each runner voluntarily uploading the data to the website so that anyone can access the data. Due to the limitations of the website there was no subject-specific descriptive information available (e.g., age, gender, height, weight, or ethnicity). The study was determined to be exempt from requiring consent from human subjects since deidentified secondary data are being used.

Procedures

Prior to analyzing data, all GPS data sets were inspected graphically to determine whether or not the data were suitable for analysis. Ultimately, 10 profiles were removed for reasons explained below. In the end, 301 total race profiles were used for analysis.

3) Missing data from the file

   Five (5) profiles from Race 1 and 1 file from Race 2 were removed because there were large gaps between data points within the data sets. These gaps were likely the result of the GPS watch losing the signal to track the runner.

4) Erroneous negative spikes in velocity

   Four (4) profiles (2 from each Race) had large spikes in negative velocity due to noise in the Garmin GPS unit. These spikes were evident on the velocity vs. time graph. Since it is not possible for a runner to exhibit negative velocity with the GPS unit these files were removed, resulting in a final number of 130 (Race 1) and 171 (Race 2).

3) End time drop-offs

While examining the data files it was clear that some runners failed to stop recording information on their device after they have crossed the finish line. This was evident by inspecting the velocity vs. time graph. After closer investigation of the file, these segments were removed at the point of last run velocity. This was identified by mapping the GPS coordinates of the runner profiles versus the GPS coordinates of the marathon finish line. The data were removed after this point. Two (2) files from Race 1 and 11 files from Race 2 were edited for this reason.

Statistical Analysis

The main purpose of the study was to describe the variability of pacing during a marathon; therefore, a frequency distribution of $Vel_{cov}$ per race was generated. The $Vel_{cov}$ data were tested for normality using the Kolmogorov-Smirnov test. If the data were not normally distributed, non-parametric tests (Mann – Whitney, descriptive statistics; Kruskal – Wallis, inferential statistics) were conducted, in addition to parametric tests (below).

Descriptive statistics were calculated for $Vel_{cov}$ and marathon finish time for each race. These variables were compared between marathons using an independent T-test. The second purpose of the study was to determine if a relationship exists between variability of pacing and marathon performance. An analysis of variance (ANOVA) was used to compare the dependent variable ($Vel_{cov}$) between the independent variable marathon bin finish times (3 bins). An ANOVA was run for each race. Post-hoc tests were computed if the omnibus F-ratio was found to be significant using LSD to compare $Vel_{cov}$ between bins.

RESULTS

The main purpose of this study was to describe the variability of pacing during a
marathon.  The $Vel_{cov}$ was observed to be $16.6 \pm 6.3\%$ and $16.7 \pm 6.5\%$ for Race 1 and
Race 2 (Table 1).  The frequency distributions of $Vel_{cov}$ for each race are presented in
Figures 1 and 2.  The most frequent $Vel_{cov}$ for Race 1 was 12 percent and 15 percent for
Race 2.  59 of 130 $Vel_{cov}$ were above the mean for Race 1 and 72 of 171 above the mean
$Vel_{cov}$ for Race 2.  The range of $Vel_{cov}$ was 24.15% for Race 1 vs. 40.24% for Race 2.
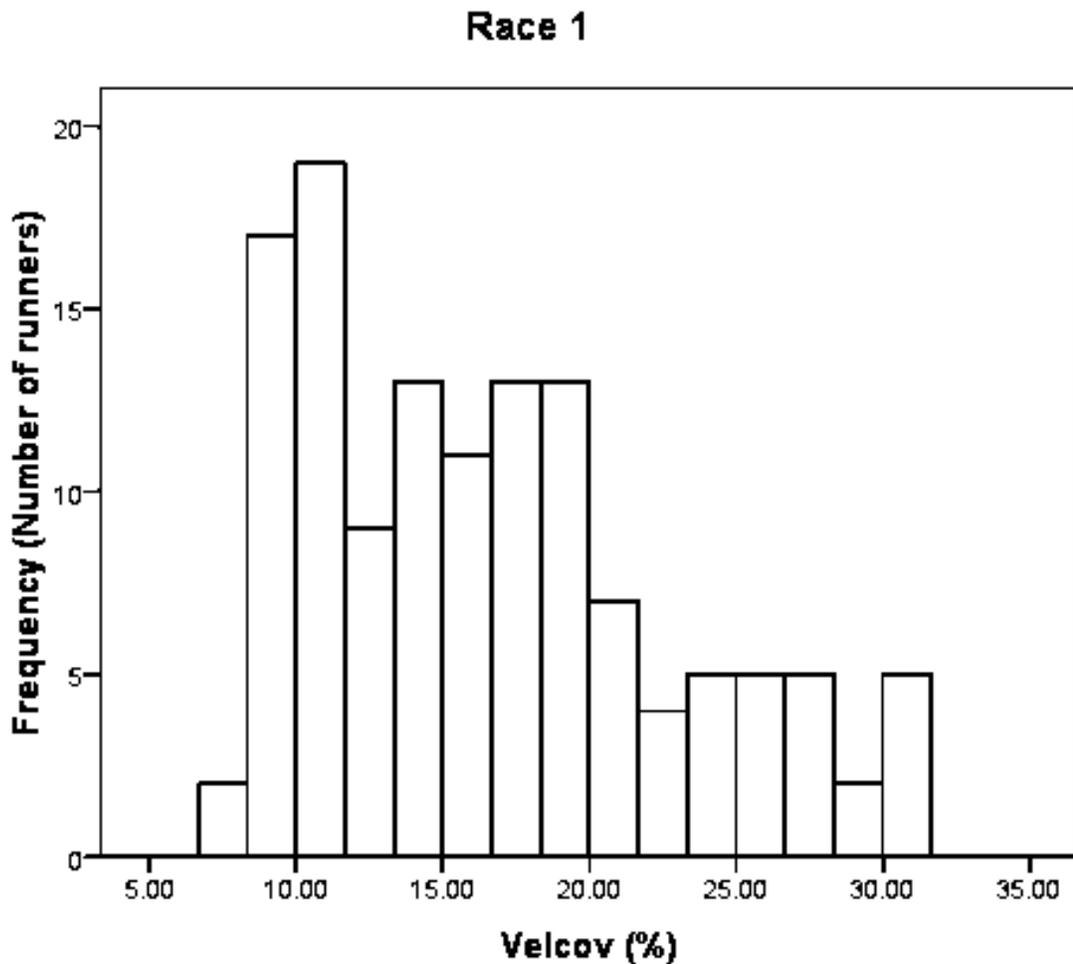
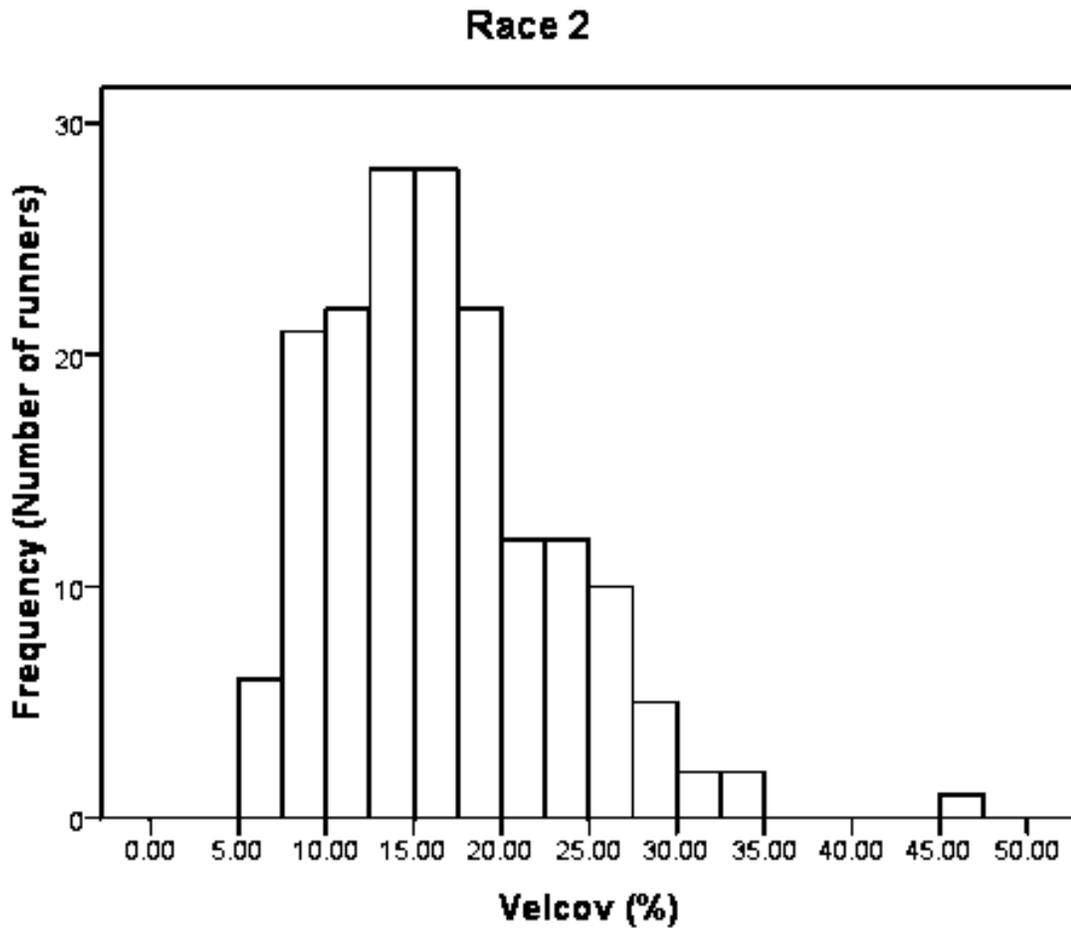Figure 1: Distribution of runners within Race 1 by $Vel_{cov}$.

Figure 2: Distribution of runners within Race 2 by $Vel_{cov}$.

It was determined that $Vel_{cov}$ was not normally distributed for either Race 1 or Race 2 ($p < 0.01$). Non-parametric tests and parametric tests were conducted with both analyses yielding identical results. Therefore, results from the parametric tests only are reported.

The $Vel_{cov}$ was not different between Race 1 ($16.6 \pm 6.3\%$) and Race 2 ($16.7 \pm 6.5\%$) (Table 1; $t_{299} = -0.012$, $p = 0.990$). Additionally, marathon time was not different between Race 1 ($4.3 \pm 0.8$ hr) and Race 2 ($4.4 \pm 0.9$ hr) (Table 1; $t_{299} = -0.870$, $p = 0.385$).

| Race | N | Vel$_{cov}$ (%) | Finish Time (hrs) |
|:---:|:---:|:---:|:---:|
| 1 | 130 | $16.6 \pm 6.3$ | $4.3 \pm 0.8$ |
| 2 | 171 | $16.7 \pm 6.5$ | $4.4 \pm 0.9$ |

Table 1:  Means and standard deviation for coefficient of variation of velocity (Vel$_{cov}$) and marathon times per race.  Vel$_{cov}$ and marathon times were not different between races.

### Marathon Performance and Coefficient of Variation of Velocity

The Vel$_{cov}$ during Race 1 was influenced by bin finish time (Figure 3, $F_{2, 129} = 24.948$, $p < 0.001$).  Using post-hoc tests, it was determined that Vel$_{cov}$ was lower in Bin 1 vs. Bin 2 ($p < 0.05$), lower in Bin 1 vs. Bin 3 ($p < 0.05$), and lower in Bin 2 vs. Bin 3 ($p < 0.05$) (Table 3).  The Vel$_{cov}$ during Race 2 was influenced by marathon finish time across all time Bins ($F_{2, 170} = 62.557$, $p \leq 0.001$), with the Vel$_{cov}$ being lower in Bin 1 vs. Bin 2 ($p < 0.05$), lower in Bin 1 vs. Bin 3 ($p < 0.05$), and lower in Bin 2 vs. Bin 3 ($p < 0.05$) (Table 4).

| Finish Time Bin* | N | Race 1 Vel$_{cov}$ (%) | N | Race 2 Vel$_{cov}$ (%) |
|---|---|---|---|---|
| Bin 1 (2.5 – 3.9 hrs) | 45 | 13.1 ± 4.6 | 56 | 12.3 ± 3.5 |
| Bin 2 (3.9 – 4.6 hrs) | 42 | 15.9 ± 5.8 | 61 | 15.4 ± 5.2 |
| Bin 3 (4.6 – 7.2 hrs) | 43 | 21.1 ± 5.5 | 54 | 22.6 ± 6.0 |
| Total | 130 | 16.6 ± 6.2 | 171 | 16.6 ± 6.5 |

Table 3:  Means and standard deviation for coefficient of variation of velocity (Vel$_{cov}$) per Bin for Race 1 and Race 2.  N equals number of runners. The Vel$_{cov}$ was influenced by bin finish time (*$p \leq .001$).
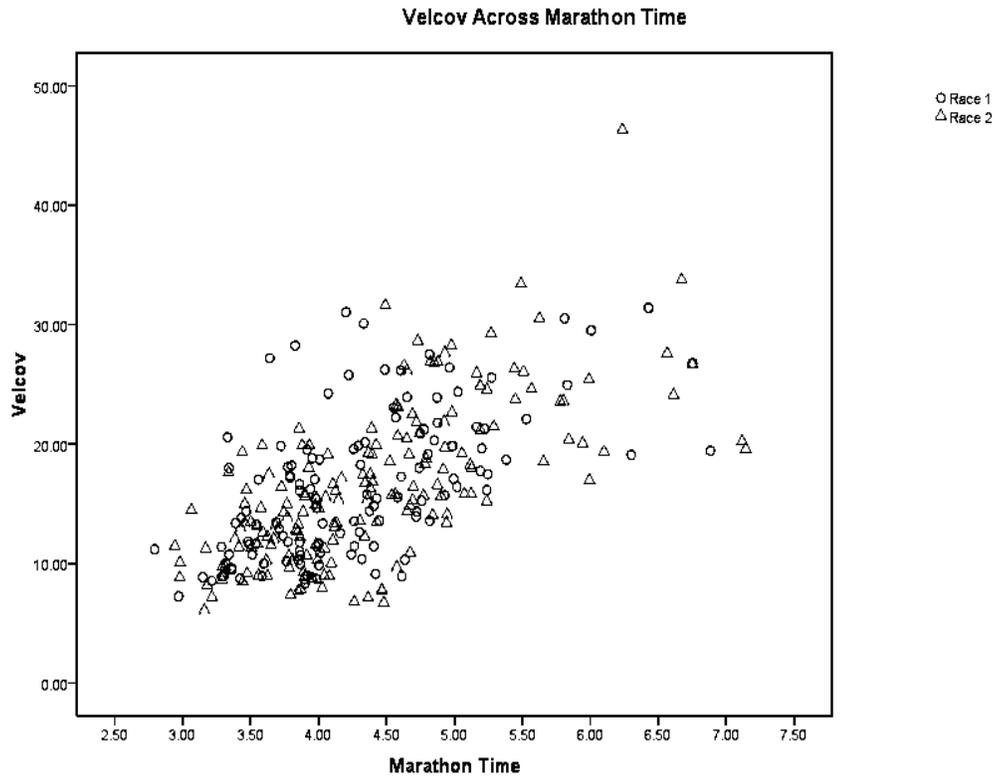
Figure 3: Vel$_{cov}$ across marathon finish time. Vel$_{cov}$ increased as marathon time increased for Race 1 and Race 2.

DISCUSSION

This study set out to describe the variability of marathon pace using coefficient of variation of velocity ($Vel_{cov}$). Using 301 GPS data sets from two different marathons, it was determined that the $Vel_{cov}$ was not different between these races with the overall mean being 16.6% ± 6.4% (Race 1: 16.6 ± 6.3% ; Race 2: 16.7 ± 6.5%). A second goal of this study was to determine if there was a relationship between marathon finish time and $Vel_{cov}$. By placing each marathon finish time in a specific bin (i.e., 2.5 – 3.9 hrs., 4.0 – 4.6 hrs., 4.7 – 7.2 hrs.), it was determined that $Vel_{cov}$ was different between marathon finish times such that $Vel_{cov}$ was greater for slower finish times for either race. Therefore, the hypothesis that the relationship between $Vel_{cov}$ and marathon finish time is non-linear such that the runners with the fastest and slowest finishing times will have the least variability compared to runners with an average finishing time was not supported.

There are minimal published data on variability of pacing in endurance events of which to compare the data from the present study to. The few studies that have reported variability of pacing have either been of shorter distances [e.g., Billat (2)] or of elite runners [e.g., Ely et al., (5)]. For example, Billat (2) reported that $Vel_{cov}$ of middle- and long-distance running to be in the range of 1%–5% for 3,000 m to 10 km for competitive runners. Additionally, Ely et al. (5) reported that the fastest runners (winners) in a marathon maintained low variability in velocity throughout the race while slower runners slowed progressively. Although the authors did not report $Vel_{cov}$, inspection of the data indicates that the race winners had low variability of pacing (approximately less than 20 s difference between 5 K splits) as did the 100th place finishers (range of about 3 minute difference between fastest and slowest 5 K splits). The greater variability of pace

observed in the present study (i.e., $Vel_{cov}$ = 16.6% ± 6.4%) compared to these studies is likely because the subjects in this study were not elite runners. Considering all 301 data sets, the mean marathon finish time was 4.4 ± 0.84 hrs. Along with this, $Vel_{cov}$ was calculated over a marathon vs. a shorter distance. Nevertheless, given the result that $Vel_{cov}$ was influenced by marathon time (range: 2.8 – 7.1 hrs.), it does makes sense that the $Vel_{cov}$ will be higher among non-competitive marathon distance runners compared to elite marathoners with finishing times under 3 hours.

$Vel_{cov}$ can be influenced by several factors such as elevation changes, fatigue, and strategic approach to pacing, for example. However, it can also be influenced by errors in the data set. For example, it was observed that some data sets had large periods of time where data were missing. In cases like that, data sets were removed from the analysis. In other instances, it was difficult to determine whether or not a data set should be removed from analysis or edited in some way. For example, there were data sets that contained velocity spikes that were beyond normal running speed but would be apparent only for a single data point. Because of that, it was decided to process the data further and smooth the data set using a low-pass filter (cutoff frequency of $1/4^{th}$ of the 0.15 Hz sample rate). The purpose of using this filter was to remove any high frequency noise in velocity. The smoothed data set was then used for the same statistical test as the original data and it was determined that the outcome of the analysis was the same regardless of which data set was used. Therefore, the velocity spikes observed did not influence the interpretation that $Vel_{cov}$ was influenced by marathon finish time.

Another source of error in the GPS data sets was caused by whether or not the device was started or stopped at the beginning or ending of the race. Inspection of individual

data sets revealed that some runners stopped the device at some point after the race had ended. This was evident by a dramatic and obvious drop in velocity at the end of the data set. In these cases, the GPS position coordinates (i.e., latitude and longitude) were used to confirm the discrepancy from the actual finish point of the race using www.mapmyrun.com. The end point of the data set was identified by the position coordinates and the data after the finish location were deleted. This was observed in 13 files and resulted in deleting approximately 0.05 mi worth of data. To determine if editing these files influenced the outcome of the analysis, the analysis was repeated by removing the data sets entirely. In this case, the mean $Vel_{cov}$ was $16.7 \pm 6.2\%$ for Race 1 and $16.8 \pm 6.7\%$ for Race 2 vs. $16.6 \pm 6.3\%$ and $16.7 \pm 6.5\%$, respectively. There was no difference in the statistical outcome if the files were or were not, used. Therefore, the files were retained for the analysis and subsequent discussion.

Changes in elevation may have an effect on $Vel_{cov}$ since runners tend to change their velocity while running up or downhill. The influence of elevation changes on $Vel_{cov}$ was not inspected in this study. However, it was determined that $Vel_{cov}$ was not different between races. The elevation profiles for each race are illustrated in Figure 3. From this illustration, it seems that the changes in elevation were not dramatic between or within a race. Nevertheless, it is hypothesized that races with larger changes in elevation would result in a greater $Vel_{cov}$ than what was observed in this study. Future research could be directed at determining how elevation changes could influence $Vel_{cov}$.
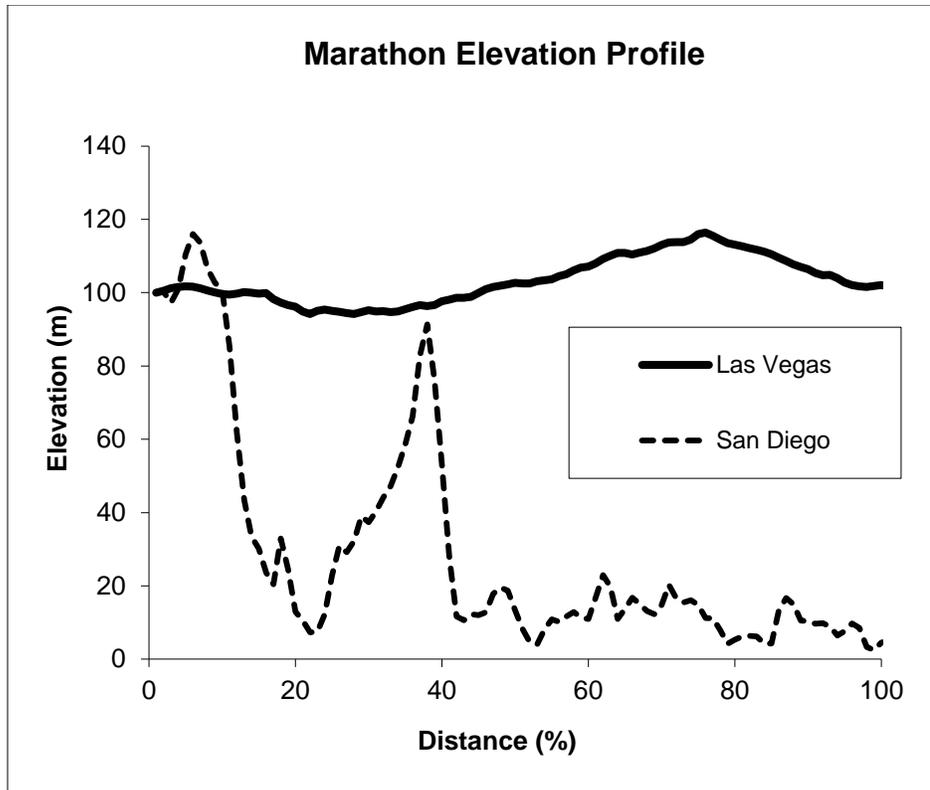
## Marathon Elevation Profile



Figure 3. Elevation profiles for the Rock 'n' Roll Las Vegas and San Diego marathons. The graph represents elevation by percent of the GPS data recorded.

### Relationship between Marathon Performance and $Vel_{cov}$

It was determined that $Vel_{cov}$ increased with marathon time during both races. This increase was seen across the bins during Race 1 (Bin1 to Bin 2 = 2.8% increase; Bin 2 to Bin 3 = 5.2% increase; Bin 1 to Bin 3 = 8.0% increase) with the greatest increase between Bin 2 and Bin 3. This increase was also observed across the bins during Race 2 (Bin 1 to Bin 2 = 3.1% increase; Bin 2 to Bin 3 = 7.2% increase; Bin 1 to Bin 3 = 10.3% increase) with the greatest increase between Bin 2 and Bin 3. It makes sense that $Vel_{cov}$ is low for fast marathon times [e.g., Ely et al. (5)] since runners are trying to maintain as fast a velocity possible over the entire distance in an attempt to achieve a faster finishing time. In this case, large fluctuations in $Vel_{cov}$ over the course of the race would mean the

63

runner is slowing down and this would, obviously, be detrimental to marathon performance. It also makes sense that $Vel_{cov}$ is greater for slower marathon times since the runner does not have the same physical capacity as the elite marathon runner to maintain a consistent pace. For example, $Vel_{cov}$ would be greater for a runner who would run for a period of time but then need to walk to recover from the exertion then a runner who would maintain the same pace over the same period of time. However, it is not clear why $Vel_{cov}$ continued to increase for very slow marathon times (4.7 – 7.2 hrs). Originally, it was thought that these runners would have low variability of pace since the capacity to run fast was reduced and therefore the capacity to change velocity was also reduced. However, that was not what was observed. It seems that greater variability in pace is detrimental to marathon performance.

Many factors contribute to the performance of a runner during a marathon. Physiological and psychological attributes during training and competition both play an integral role in the runner's event performance. The increase in $Vel_{cov}$ as marathon finish time increased is consistent with the findings of St. Clair Gibson & Noakes (13), wherein the individual subconsciously selected a pacing strategy that allowed completion of the task efficiently while maintaining internal homoeostasis and a metabolic and physiological reserve capacity. This was evidenced by examining a simulated 100 km cycle time trial with repeated high intensity 1 and 4 km sprint bouts. While measuring integrated electromyographic (IEMG) outputs of the vastus lateralis it was shown that average power outputs decreased progressively during the consecutive 1 km sprints and integrated EMG activity declined in parallel with these reductions in power output. These changes occurred even though 20% or less of the available motor units in the lower limb

were recruited.  Heart rate was also observed to be near maximal during each of the sprints, probably indicating that the subjects consciously attempted to produce a maximal effort, even though the extent of their skeletal muscle recruitment declined progressively. The authors concluded that these results indicate the central brain recruitment of a progressively a lower number of motor units despite an increase in conscious demand from the athlete.  That is, even though the athlete tried to work harder, less motor units were recruited despite this increased demand.

St. Clair Gibson et al. (12) identify the perception of fatigue to be instrumental in the conscious decision to continue or cease activity.  In their review of brain structure activity and homeostatic mechanisms, the authors reported that the development of the sensation of fatigue is associated with changes in motor activity, motivation and emotion. Changes in neural network activity in any areas of motor control may be responsible for the generation of the sensation of fatigue.  Emotional states such as anger and fatigue involve adjustments in homeostatic balance and peripheral physiological changes, such as heart rate.  Functional imaging studies (4,10) revealed increased or decreased activity in several brain areas when normal individuals experience motions such as sadness, happiness, fear or anger. As motivation and drive are affected by all these different emotional states, fatigue may originate in different brain areas associated with emotional responses.  These factors act to create a "mental map" for the individual to create parameters by which the body performs during exercise.  When changes in the external environment occur the mind creates an additional map, based upon its emotions and feelings, a second map is created.  The individual is, at some point, able to discern the

65

differences between the models and choose to override the "set point" created by the first model in response to perceived fatigue.

Novices may have very little or no previous mastery experience upon which to base their beliefs about their abilities (self-efficacy), and therefore lack the skills necessary to form beliefs about being able to successfully perform a sport task (8). Given these observations, it makes sense that the slower runners would exhibit a greater variability of pace as they may not have developed the same level of confidence in their own ability that faster, more experienced, runners have attained and may not assess their level of fatigue at the same level as faster runners. The faster runner is most likely able to assess their level of fatigue better than the slower runner and make the conscious decision to maintain their velocity, whereas the slower runner would succumb to their subconscious perceptions. The extent to which these factors affected the performance of the runners in this investigation is unclear. Therefore, future research is recommended to investigate the effects of self-efficacy and perception of fatigue on variability of pace during marathon distance races.

<center>PRACTICAL APPLICATION</center>

Several applications to marathon performance and training can be gleamed from these results and are salient to the formation of marathon training programs. The runner's anticipated marathon completion time will have a significant impact on the variability of their pacing while training. The faster runners may have their training protocol tailored to a less variable strategy, whereas the slower runners would employ a more variable strategy given that their variability of pace is higher than the faster runners. For example, typical strategies for marathon training emphasize low variability despite runner ability or

<center>66</center>

anticipated finish time. Given that the results of this study indicate slower runners are more variable in their pace than faster runners, it is important to match training specificity with the event. Therefore, the training regimen of slower runners should reflect the increased variability during competition. Conversely, faster runners would attempt to achieve maximum speed with little variability. Runners wanting to decrease their finish time should work towards a less variable pace followed by increased speed. Future research is necessary to investigate the role of different pacing strategies on marathon performance.

## REFERENCES

1. Ariyoshi, M., Yamaji, K., & Shephard, R. (1979). Influence of running pace upon performance: Effects upon treadmill endurance time and oxygen cost. *European Journal of Applied Physiology and Occupational Physiology, 41*(2), 83-91.

2. Billat, V., Slawinski, J., Danel, M., & Koralsztein, J. (2001). Effect of free versus constant pace on performance and oxygen kinetics in running. *Medicine and Science in Sports and Exercise, 33*(12), 2082-2088.

3. Cottin, F., Papelier, Y., Durbin, F., Koralsztein, J., & Billat, V. (2002). Effect of fatigue on spontaneous velocity variations in human middle-distance running: Use of short-term fourier transformation. *European Journal of Applied Physiology, 87*(1), 17-27.

4. Dougherty, D. D., Shin, L. M., Alpert, N. M., Pitman, R. K., Orr, S. P., Lasko, M., et al. (1999). Anger in healthy men: A PET study using script-driven imagery. *Biological Psychiatry, 46*(4), 466-472.

5. Ely, M., Martin, D., Cheuvront, S., & Montain, S. (2008). Effect of ambient temperature on marathon pacing is dependent on runner ability. *Medicine & Science in Sports & Exercise, 40*(9), 1675-1680.

6. Garcin, M., Danel, M., & Billat, V. (2008). Perceptual responses in free vs. constant pace exercise. *International Journal of Sports Medicine, 29*(6), 453.

7. Jones, M., Wilkerson, P., Vanhatalo, A., & Burnley, M. (2008). Influence of pacing strategy on O2 uptake and exercise tolerance. *Scandinavian Journal of Medicine and Science in Sports, 18*(5), 615-626.

8. Law, B., & Hall, C. (2009). Observational learning use and self-efficacy beliefs in adult sport novices. *Psychology of Sport and Exercise, 10*(2), 263-270.

9. Léger, L., & Ferguson, R. (1974). Effect of pacing on oxygen uptake and peak lactate for a mile run. *European Journal of Applied Physiology and Occupational Physiology, 32*(3), 251-257.

10. Mayberg, H. S., Liotti, M., Brannan, S. K., McGinnis, S., Mahurin, R. K., Jerabek, P. A., et al. (1999). Reciprocal limbic-cortical function and negative mood: Converging PET findings in depression and normal sadness. *American Journal of Psychiatry, 156*(5), 675-682.

11. Sandals, L., Wood, D., Draper, S., & James, D. (2006). Influence of pacing strategy on oxygen uptake during treadmill middle-distance running. *International Journal of Sports Medicine, 27*(1), 37-42.

12. St. Clair Gibson, A., Baden, D. A., Lambert, M. I., Lambert, E. V., Harley, Y. X. R., Hampson, D., et al. (2003). The conscious perception of the sensation of fatigue. *Sports Medicine, 33*(3), 167-176.

13. St. Clair Gibson, A., & Noakes, T. D. (2004). Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *British Journal of Sports Medicine, 38*(6), 797-806.

REFERENCES

Ariyoshi, M., Yamaji, K., & Shephard, R. (1979). Influence of running pace upon performance: Effects upon treadmill endurance time and oxygen cost. *European Journal of Applied Physiology and Occupational Physiology, 41*(2), 83-91.

Billat, V., Slawinski, J., Danel, M., & Koralsztein, J. (2001). Effect of free versus constant pace on performance and oxygen kinetics in running. *Medicine and Science in Sports and Exercise, 33*(12), 2082-2088.

Cottin, F., Papelier, Y., Durbin, F., Koralsztein, J., & Billat, V. (2002). Effect of fatigue on spontaneous velocity variations in human middle-distance running: Use of short-term fourier transformation. *European Journal of Applied Physiology, 87*(1), 17-27.

Dougherty, D. D., Shin, L. M., Alpert, N. M., Pitman, R. K., Orr, S. P., Lasko, M., et al. (1999). Anger in healthy men: A PET study using script-driven imagery. *Biological Psychiatry, 46*(4), 466-472.

Draper, S., Wood, D., & Fallowfield, J. (2003). The VO2 response to exhaustive square wave exercise: Influence of exercise intensity and mode. *European Journal of Applied Physiology, 90*(1-2), 92-99.

Ely, M., Martin, D., Cheuvront, S., & Montain, S. (2008). Effect of ambient temperature on marathon pacing is dependent on runner ability. *Medicine & Science in Sports & Exercise, 40*(9), 1675-1680.

Foster, C., Snyder, C., Thompson, N., Green, A., Foley, M., & Schrager, M. (1993). Effect of pacing strategy on cycle time trial performance. *Medicine & Science in Sports & Exercise, 25*(3), 383-388.

Garcin, M., Danel, M., & Billat, V. (2008). Perceptual responses in free vs. constant pace exercise. *International Journal of Sports Medicine, 29*(6), 453.

Jones, M., Wilkerson, P., Vanhatalo, A., & Burnley, M. (2008). Influence of pacing strategy on O2 uptake and exercise tolerance. *Scandinavian Journal of Medicine and Science in Sports, 18*(5), 615-626.

Law, B., & Hall, C. (2009). Observational learning use and self-efficacy beliefs in adult sport novices. *Psychology of Sport and Exercise, 10*(2), 263-270.

Léger, L., & Ferguson, R. (1974). Effect of pacing on oxygen uptake and peak lactate for a mile run. *European Journal of Applied Physiology and Occupational Physiology, 32*(3), 251-257.

Mayberg, H. S., Liotti, M., Brannan, S. K., McGinnis, S., Mahurin, R. K., Jerabek, P. A., et al. (1999). Reciprocal limbic-cortical function and negative mood: Converging PET findings in depression and normal sadness. *American Journal of Psychiatry, 156*(5), 675-682.

Palmer, G., Borghouts, L., Noakes, T., & Hawley, J. (1999). Metabolic and performance responses to constant-load vs. variable-intensity exercise in trained cyclists. *Journal of Applied Physiology, 87*, 1186.

Palmer, G., Noakes, T., & Hawley, J. (1997). Effects of steady-state versus stochastic exercise on subsequent cycling performance. *Medicine & Science in Sports & Exercise, 29*(5), 684-687.

Sandals, L., Wood, D., Draper, S., & James, D. (2006). Influence of pacing strategy on oxygen uptake during treadmill middle-distance running. *International Journal of Sports Medicine, 27*(1), 37-42.

St. Clair Gibson, A., Baden, D. A., Lambert, M. I., Lambert, E. V., Harley, Y. X. R., Hampson, D., et al. (2003). The conscious perception of the sensation of fatigue. *Sports Medicine, 33*(3), 167-176.

St. Clair Gibson, A., & Noakes, T. D. (2004). Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *British Journal of Sports Medicine, 38*(6), 797-806.

Townshend, A., Worringham, C., & Stewart, I. (2010). Spontaneous pacing during overground hill running. Medicine and Science in Sports and Exercise, 42(1), 160-169.

VITA

Graduate College
University of Nevada, Las Vegas

Thomas Haney Jr.

Degrees:
    Bachelor of Science, Kinesiological Sciences, 2007
    University of Nevada, Las Vegas

Thesis Title: Variability of Pacing in Marathon Distance Running

Thesis Examination Committee:
    Chairperson, John Mercer, Ph. D.
    Committee Member, Laura Kruskall, Ph. D.
    Committee Member, Gabriele Wulf, Ph. D.
    Graduate Faculty Representative, Jefferson Kinney, Ph. D.