

The Effects of Drafting Distances on Heart Rate Responses, Oxygen Consumption, and
Perceived Exertion for a Group of Female Cross-Country Runners

by

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Abstract

The purpose of this experimental study was to determine the physiological and psychological effect of drafting during running. Five female college-aged subjects exercised at submaximal effort during three trials: running alone to simulate a lead runner, running 1.0 meters behind another person, and running 2.5 meters behind another person. Heart rate, oxygen consumption and perceived exertion were recorded during each trial and the data collected was analyzed using a repeated measures ANOVA. The results showed that oxygen consumption and perceived exertion were significantly lower while running 2.5 meters behind another person when compared to running alone. Heart rate was significantly lower when drafting 1.0 meters behind another runner.

Preface and Acknowledgements

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CHAPTER I

INTRODUCTION

Background

Many studies have concluded that drafting is beneficial for athletes in various sports; however, there is little information on the effect of drafting on one's run performance. The advantages of drafting include a reduction in an athlete's energy expenditure, decreased feelings of exertion, and improved performance.

A reduction in an athlete's oxygen consumption while drafting has been reported in a variety of sports: in-line skating (Millet, Geslan, Ferrier, Candau, & Varray, 2003), triathlons (Hauswirth, Lehanaff, Dreano, & Savonen, 1999; Hauswirth, Vallier, Lehennaff, Brisswalter, Smith, Millet & Dreano, 2001) and up to a 62% reduction in cycling (Hagberg, 1990). The less oxygen an athlete needs at a given speed allows the athlete to conserve energy, meaning an athlete will be able to use drafting as an energy-saving strategy in competition.

Drafting has been reported to have an effect on other physiological factors including heart rate, blood lactate concentration, and perceived exertion. Heart rate has been shown to decrease significantly due to drafting in sports such as: cross-country skiing (Bilodeau, Roy, & Boulay, 1994; Bilodeau, Roy, & Boulay, 1995) and the triathlon (Hauswirth et al., 1999 and Hauswirth et al., 2001). Drafting can also reduce the lactate concentration in the blood post-exercise (Hauswirth, et al 1999). Lactic acid correlates with muscle fatigue, and signifies that drafting allows an athlete to compete at greater durations before tiring. Additionally, drafting can decrease feelings of exertion (Corvalán-Grössling, 1995). As a result of these benefits, many studies have concluded

that drafting can have a significant effect on overall performance. Drafting improved the performance of short-track speed skaters by 2% (Rundell, 1996). Although intermittent drafting has been shown to improve performance, continuous drafting can amplify the advantages (Hauswirth et al., 2001).

The benefits of drafting have been well-documented, though it is important to note how variances in speed and distance affect an athlete while drafting. While speeds may differ from sport to sport, Hagberg (1990) and Millet et al. (2003) concur that the advantages of drafting increase as speed increases. Also, Arnett (2002) determined that as wind velocity increased, the effect of drafting increased in runners. Additionally, Millet, et al. determined that during in-line skating, drafting closely behind another athlete produces physiological responses greater than those produced while drafting from further behind. The effect of drafting distances has not been studied for runners.

Problem Statement

Since drafting distances has not yet been studied in runners, the purpose of this study is to look at the effect the distance between the lead and draft runner has on the physiological and psychological responses of the draft runner. Also, there has been no study to solely examine the effects of drafting for female runners. Therefore, this study examined the relationship between drafting distance and heart rate responses, oxygen consumption and perceived exertion for female distance runners, supporting the conclusions made by Corvalán-Grössling (1995) and Arnett (2002).

The independent variable for this study was running position (factor 1 with 3 levels). The different levels of factor 1 were three running positions: no drafting, drafting 1 m behind a lead runner, and drafting 2.5 m behind a lead runner. The dependent

variables included: exercise heart rate (HR), the rating of perceived exertion (RPE), oxygen consumption (VO_2), and running economy.

Hypotheses

Based on the conclusions of previous studies, it was hypothesized for this study that:

1. The physiological and psychological variables (VO_2 , HR, and RPE) would significantly differ between the two running positions (leading and drafting). The variables would be significantly reduced during the drafting position.
2. The physiological and psychological variables (VO_2 , HR, and RPE) would significantly differ between the two distances (1 m and 2.5 m). The effect of drafting on the variables would be greater when the individual is drafting closely behind the lead runner (1 m).
3. For purpose of statistical analysis, the null hypotheses for this study were: There would be no significant difference between the dependent variables for the two running positions; and there would be no significant difference between the dependent variables for the three drafting distances.

Operational Definitions

Air Resistance – The force opposing an individual caused by air and wind

Carbon Dioxide Production (VCO_2) – The volume of carbon dioxide expired by the body (expressed in ml/kg/min).

Drafting – When an athlete is positioned directly behind or slightly to the side of another athlete in order to benefit from less air resistance.

Maximal Exercise – The highest rate at which an individual can exercise.

Maximal Oxygen Consumption (VO_{2max}) – The maximal volume of oxygen the body can consume and utilize per minute. Maximal oxygen consumption can be measured as an absolute rate (expressed in ml/kg/min) or as a relative rate (expressed in L/min).

Oxygen Consumption (VO_2) – The volume of oxygen consumed by the body. Oxygen consumption can be measured as an absolute rate (expressed in ml/kg/min) or as a relative rate (expressed in L/min).

Physical Activity Readiness Questionnaire (PAR-Q) – A questionnaire that is used to screen individuals in order to determine who should contact their physician before participating in moderate exercise.

Rating of Perceived Exertion (RPE) – A scale used to determine which exertion level an individual believes they are working at.

Respiratory Exchange Ratio (RER) – The non-protein ratio of oxygen consumption to carbon dioxide production (expressed as VO_2/VCO_2). This ratio can be used to determine the type of food the body is utilizing as fuel.

Running Economy – The volume of oxygen consumed by an individual when running at a given speed. Running economy can be measured as an absolute rate (expressed in L of O_2 /kg/km) or a relative rate (expressed as L of O_2 /km).

Steady State Exercise – Refers to when one's oxygen consumption plateaus or levels off at a given speed, intensity or workload.

Assumptions

In order for this study to proceed, certain assumptions were accepted. It was assumed that: (a) all subjects maintained consistent dieting, exercise and resting patterns,

or (b) the subjects reported to the researcher any changes in these patterns that could affect the outcome of the study, and (c) all participants refrained from exercise the day of testing. During pre-testing, it was assumed that (d) all participants were honest when reporting their health information on the Physical Activity Readiness Questionnaire (PAR-Q) (Appendix B).

Additionally, during exercise testing it was assumed that (e) the MedGraphics metabolic cart and all other equipment were valid and reliable and (f) the Breeze software accurately recorded and reported the data. It is also assumed that (g) the subjects gave maximal effort during the graded maximal exercise test, that (h) six minutes would allow each subject to reach steady state, and (i) the subject would be able to fully recovery in the eight minutes of rest time allotted between each trial. It is also assumed that (j) the ACSM metabolic equation to predict $\text{VO}_{2\text{ max}}$ scores based on the time completed in using the Bruce protocol, is an accurate measurement of an individual's maximal aerobic capacity. For purposes of statistical analysis, it is assumed that (k) the subject reached steady state at the third minute of exercise and (l) maintained that steady state for the last three minutes of each trial.

Limitations

Limitations to this study include (a) the laboratory setting, (b) the treadmill console which may have decreased the wind that reached the subject during the trials, (c) wind was simulated by an industrial fan, and (d) the "lead" runner was simulated using an individual that stood in front of the subject. Also, during testing (e) the metabolic cart was not valid for the maximal graded exercise testing. The time of year and competition schedule limited the (f) small sample size (n=5).

The type of testing, and the accessibility of researchers, machines, and monitors renders this study conducive to the laboratory setting. Although one may argue that the study would be more applicable if conducted in the field. Meyer, Welter, Scharhag & Kindermann (2003) reported that one's VO_2 recorded on a treadmill does not significantly differ from the same person's VO_2 recorded in the field. Therefore, the oxygen consumption results found in this laboratory study should be applicable to the "real world."

Delimitations

Limitations were set in order to successfully test the effects of drafting on run performance for female distance runners. Each subject must be (a) female, (b) a current member of the SUNY Cortland Track and Field team and (c) must participate in distance events at the collegiate level. Other delimitations of this study include that (d) all subjects must maintain consistent dieting, exercise, and resting patterns for the duration of the testing period and (e) must wear the same running shoes and tight-fitting apparel for the entirety of the study. In addition (f) each subject must attend both testing sessions with a minimum of 48 hours and a maximum of one week rest in-between sessions.

Significance of the Study

Having a good understanding of which running position elicits the best results will be beneficial to athletes and coaches alike. The advantages of drafting could be utilized during practice or competition as a strategy to better one's performance. Hopefully, this study will support previous research that determined that drafting can directly improve run performance by reducing energy cost during a race and ultimately better one's race time (Pfitzinger, 2004). An understanding of drafting would add to the

understanding about training and would positively affect coach's training decisions. For example, during training runners could periodically change positions during intervals, so as to equally benefit all participants. Furthermore, this study will add to the information regarding drafting during running by looking at the effects of drafting on female runners at different drafting distances and thus provide a comprehensive knowledge of drafting. It is important to research the effects of drafting in different positions because this distance could be varied during training or competition to produce certain desired results.

CHAPTER II

LITERATURE REVIEW

Introduction

Studies have shown that drafting can significantly decrease oxygen consumption (Hagberg, 1990; Millet et al., 2003; Hausswirth et al., 1999; Corvalán-Grössling, 1995; Arnett, 2002), heart rate (Bilodeau et al., 1994; Bilodeau et al., 1995; Rundell, 1996; Hausswirth et al., 2001), blood lactate concentration (Rundell, 1996; Hausswirth et al., 1999), and perceived exertion (Corvalán-Grössling, 1995; Arnett, 2002). Lower oxygen consumption, heart rate and blood lactate concentration can have a positive effect on performance. Therefore, the reduction in these physiological variables implies that there is a place for drafting in competition and training in sports.

The purpose of this chapter is to summarize the physiological and psychological effects of drafting (VO_2 , HR, and RPE) in a variety of sports. This chapter will also explain how drafting can be used as an energy-saving technique. Finally, the chapter will establish that the relationship between drafting distances and running performance is an area of research that needs further study.

Effects of Drafting during Cycling

In 1990, Hagberg conducted a study to determine the physiological effects of drafting on cycling performance. Five different drafting scenarios (drafting behind a cyclist, a line of 2 cyclists, a line of 4 cyclists, a group of 8 cyclists, and a car) at three different cycling speeds (20, 23, and 25 mph) were compared for 28 male cyclists. Oxygen consumption was significantly lower while drafting compared to cycling alone for all three speeds, with a reduction of 18%, 27% and 27% respectively. Yet, when

drafting among a group of 8 cyclists, with two riders in the front row and three riders in the second and third rows, oxygen consumption was reduced by 39%. Moreover, when positioned behind a car and riding at 25 mph, cyclists experienced a 62% reduction in oxygen consumption. These results indicate that drafting clearly plays a major role in reducing oxygen consumption in a cycling performance. The results imply that the benefits of drafting are the same when drafting behind one rider or a line of riders. Yet, the wider the object a cyclist can draft behind, as shown with the large group of cyclists and the car, the higher the reduction in oxygen consumption (Hagberg, 1990). It is accepted that the larger object with more surface area blocks more wind. It is implied that the more wind blocked by an object, the less resistance an athlete will encounter.

Effects of Drafting during Cross-Country Skiing

In addition to oxygen consumption, both heart rate and blood lactate concentration have been significantly reduced while drafting. Bilodeau et al. (1994) conducted a study using 6 male cross-country skiers and found a change in the subjects' heart rate as a result of drafting. Each skier completed a 2 km course, at a speed of $5.6 \text{ m} \cdot \text{s}^{-1}$ (12.5 mph), which would be used as a control and labeled the Lead Skier. This was compared to the same 2 km course completed in a position 2 m behind another skier, and called the Draft Skier. Heart rate was measured and recorded every 5 seconds during each condition (Lead and Draft Skier) and compared for each subject (Lead versus Draft). The body size of the skiers was also measured to determine if a size difference between the two skiers affected heart rate change. Lactate concentration in the blood was also analyzed before and 5 minutes after the trial. Heart rate was significantly lower when drafting behind another skier than when skiing alone. In accordance with Hagberg

(1990), there was an additional reduction in heart rate when skiing behind a larger skier as compared to a smaller skier. There was no change in blood lactate concentration between the two trials.

A similar study was conducted a year later using eight male and two female cross-country skiers. Again, each skier participated in two 2 km trials with 30 minutes rest in-between trials, one trial as the Lead Skier and one trial as the Draft Skier. The speeds of the trials were slower than the previous study with males skiing at an average $4.75 \text{ m}\cdot\text{s}^{-1}$ (10.6 mph) and females at a speed of $4.45 \text{ m}\cdot\text{s}^{-1}$ (10.0 mph). Again, heart rate was recorded every five seconds of the two conditions. For both male and female skiers, heart rate was lower during the “drafting” condition compared to the “lead” skier position (Bilodeau et al., 1995). Heart rate was also significantly lower for the skiers drafting behind a lead skier that had a larger body shape. Yet again, these results suggest that drafting can benefit cross-country skiers, and the size of the lead athlete can magnify the effects.

Effects of Drafting during Skating

A similar reduction in heart rate was reported in speed skaters and in-line skaters. Rundell (1996) observed that heart rate and blood lactate concentration decreased for a group of 18 short-track speed skaters while drafting. Each speed skater participated in two 4-minute trials at a speed of $8.8 \text{ m}\cdot\text{s}^{-1}$ (19.7 mph) as the lead and draft skater. Additionally, six speed skaters participated in a 333 m sprint at $9.2 \text{ m}\cdot\text{s}^{-1}$ (20.6 mph) immediately following the two trials, where sprint heart rate and blood lactate concentration were measured. Blood lactate concentration was lower when sprinting after the “drafting” trial compared to after the trial when leading. Although there was no

change in heart rate, post-drafting sprint performance significantly improved for these subjects.

A 2003 study was conducted to examine the relationship between drafting and in-line skating and to determine if drafting produced different results at two velocities and two drafting distances. Eight male in-line skaters completed six 6-minute trials at two drafting velocities, moderate and high, and three running positions, lead skater, drafting “close” and drafting “far” behind another runner. Oxygen consumption was significantly reduced for skaters during the moderate velocity in both drafting positions, with a greater reduction in the “close” drafting position. There was a 9.6% reduction in energy expenditure when drafting at a distance of .74 – .87 m, and 2.7% reduction when drafting at 1.19 – 1.36 m (Millet et al., 2003).

Effects of Drafting during the Triathlon

Research also indicates that one will experience benefits in a performance immediately following the use of a drafting technique; for instance, an athlete competing in several successive events. Hauswirth et al. (1999) states that drafting can significantly affect one’s performance during the cycling leg and the subsequent running leg of a triathlon. In this study, eight triathletes completed two tests; during the first trial, the subjects rode alone and during the second trial, the subjects rode while drafting behind another cyclist (at identical speeds) during the cycling section of the triathlon. Oxygen consumption, minute ventilation, heart rate, and lactate concentration were significantly reduced during the cycling section in which the athlete drafted, and speed significantly increased during the subsequent running section of the triathlon. These results suggest that drafting is not only beneficial during cycling, but can also improve

the following running performance and overall triathlon time. As explained by Millet and Vleck (2000), the energy cost of the running portion of the triathlon is 1.6 – 11.6% higher than ordinary running since the running segment is preceded by two events. Therefore, drafting can be seen as an energy-saving technique because energy can be conserved during the cycling segment and utilized during the running segment. This technique can be employed in the triathlon to increase speed and improve performance. Yet this technique may only be beneficial to elite athletes, because amateur athletes are not allowed to draft in competition (Bentley, D.J., Millet, G.P., Vleck, V.E., & McNaughton, L.R., 2002).

Hausswirth et al. (2001) also examined the effects of continuous and alternating drafting during the cycling section of a sprint triathlon. Ten male triathletes participated in two triathlons, wherein each athlete performed one of the two drafting methods, continuously drafting and alternating drafting/leading with another cyclist. Oxygen consumption, minute ventilation, and blood lactate concentration were recorded during each triathlon. The results indicate that both heart rate and oxygen consumption were significantly lower for continuously drafting as compared to alternating drafting. Moreover, the speed of the subsequent run after continuously drafting was increased by 4.2%. These conclusions imply that the more an athlete can draft during the cycling portion of a triathlon, the greater the benefits he/she will gain in the subsequent run and the best overall performance he/she will attain.

In accordance with the aforementioned research, Hue (2003) evaluated physiological variables taken between the cycling and running portions of a triathlon event for eight triathletes. Hue's hypothesis was that physiological variables after

drafting while cycling can be used to predict performance in the subsequent running portion and be used to forecast a triathlete's overall performance. More specifically, the study indicated that lactate threshold (measured after the subjects completed the drafted cycling portion) and the distance the subjects were able to cover during the subsequent running portion were two variables that predicted overall triathlon performance. This study is important because it implies that the effects of drafting (statistically significant or not) lower an athlete's physiological variables and have a positive effect on overall performance.

Effects of Drafting during Running

Consistent with previous studies in other sports, oxygen consumption and carbon dioxide production and perceived exertion were significantly lower for runners while drafting behind another athlete. Corvalán-Grössling (1995) conducted a study using nine well-trained male master distance runners to examine the effect drafting had on runners. Each subject participated in three running conditions (no drafting, drafting 1m behind the lead runner, and drafting 1m behind the shoulder of the lead runner) for a total of 1200 m each, at a speed of $4.7 \text{ m}\cdot\text{s}^{-1}$ (10.5 mph). The variables at the two drafting positions were each averaged and compared to the lead running position. Oxygen consumption, carbon dioxide production and perceived exertion were all significantly lower when drafting behind another runner. Yet there was not a significant difference between the two drafting conditions. These results suggest that both drafting positions can effectively reduce oxygen consumption and carbon dioxide production at identical rates. The rating of perceived exertion (RPE) was significantly lower while drafting at an angle compared to the other two conditions, which implies that the subjects believe that running at a

certain speed is easiest when drafting at an angle behind another runner. This position was also “preferred” by the subjects (Corvalán-Grössling, 1995).

In accordance with Corvalán-Grössling, a 2002 study by Arnett examined the effects of drafting when running directly into two varied wind velocities: $3.64 \text{ m}\cdot\text{s}^{-1}$ (8.1 mph) and $4.7 \text{ m}\cdot\text{s}^{-1}$ (10.5 mph) compared drafting with no wind. Arnett conducted a study using three male and three female subjects. Each subject ran two trials at each speed, one trial alone and the second trial behind a lead runner. Heart rate, oxygen consumption, blood lactate and RPE were collected after each six-minute trial. Perceived exertion was significantly lower when drafting behind another runner at a wind velocity of $4.7 \text{ m}\cdot\text{s}^{-1}$. The results also indicate that oxygen consumption was significantly reduced by 2.9% when drafting at a wind velocity of $4.7 \text{ m}\cdot\text{s}^{-1}$. Despite lower oxygen consumption, heart rate and blood lactate concentration were not significantly different during the trials. This study is important because it shows that a higher wind velocity, like drafting behind a larger object, has a greater impact on decreasing oxygen consumption. Yet, the disparity in how drafting affects the physiological variables shows a need for further research.

Indications

Improving Running Economy. Researchers Kyröläinen, Belli and Komi (2001) report in their essay, “Biomechanical factors affecting running economy,” that air-resistance is a physiological and environmental factor that can affect running economy. Since drafting behind a person or object will reduce the amount of air-resistance, Pfitzinger (2000) recommends drafting behind another runner or a group of runners in order to improve running economy and to become more efficient. Pfitzinger’s ideas were

further supported by the research of Corvalán-Grössling (1995) and Arnett (2002) in which subjects consumed less oxygen at a given trial while drafting compared to running alone. At a certain speed, a runner with adequate running economy will use less oxygen compared to a runner with poor running economy (Saunders, Pyne, Telford, & Hawley, 2004). Therefore, examining how much oxygen is consumed during drafting and leading trials is an indicator of running economy.

Improving Performance. Energy expenditure was reduced by 7 % while drafting 1 m behind another runner at a speed of $21.6 \text{ km} \cdot \text{hr}^{-1}$ (13.4 mph) as compared to running alone. According to McArdle, Katch, and Katch (2006), drafting at this speed can reduce time 1 s for every 400 m completed. This can improve the mile and 5000 km time by 4 and 12.5 seconds respectively. These results suggest drafting behind another competitor can improve race time and overall performance.

Summary

For runners, the benefits of drafting have been documented, although no recent research supporting these findings has been published. Likewise, there has been no research directly examining the differences in physiological responses when drafting at a variety of distances. Previous research regarding the effect of drafting has also been limited by the experimental design.

CHAPTER III

METHODS

The purpose of the chapter was to (a) describe the sample selection of the study and (b) present the information given to these subjects. Additionally, the chapter will (c) summarize the methods for data collection during rest, submaximal and maximal exercise and (d) explain the statistical approach used to analyze the collected data. This chapter will then (e) clarify techniques for calibration and (f) reliability of equipment. Finally, (g) the methods to keeping the collected data anonymous and trustworthy will be explained.

Research Assistants

Two research assistants helped during the study. Both assistants were enrolled at SUNY Cortland, in a graduate level Exercise Science program. The assistants were present for both a pilot study to determine the protocol and procedures and during the present study where they were responsible for assisting in the maximal exercise. One of the research assistants was responsible for standing in front of the runners to represent the lead runner during the drafting trials. The research assistants wore the same tight-fitting clothes and shoes for the entirety of the study.

Subjects

Protection of Human Subjects. All personal and health information, collected data, and signed informed consent documents remained anonymous for the entirety of the study. Each subject was assigned a number and identified by that number for the entirety of the study. The participants were not informed of their results until all testing procedures and statistical analyses were completed. All data was stored in a locked file

for the entirety of the study and all personal information was destroyed after the completion of the study.

Sample Selection. Subjects for this study consisted of five healthy female students at the State University of New York (SUNY) College at Cortland. All subjects were members of the SUNY Cortland track and field team and recruited through e-mail to participate in this study. All subjects specialized in distance events and had competed at the collegiate level for at least one year. Prior to testing, the members of the track and field team were approached and informed of the purpose of the study. Personal information (name and e-mail address) was collected for all who were interested in volunteering. An e-mail was sent to explain the purpose of the study, to confirm those who were still interested and to schedule testing times. Each subject committed to two testing days, where the second day of testing occurred exactly two days later.

Clothing. Shirts, shorts, socks, and personal shoes were the normal attire. All clothes were close-fitting.

Instruments

The ambient conditions were recorded before all tests using a Skymaster SM-28 (Great Falls, VA) to obtain barometric pressure, humidity, temperature, and wind speed in the laboratory. Physical measurements were recorded using a tape measure to measure height and a Life Source Pro Fit Precision Scale (Milpitas, CA) to measure body mass. All exercise sessions were performed on a Quinton Q65 series 90 treadmill (Bothell, WA). Physiological measurements were recorded using the Medgraphics Ultima CPX pulmonary function equipment and metabolic cart with gas exchange/spirometry equipment including Medgraphics pneumotach and PreVent mask. Breeze Suite 6.2

software for Windows (St. Paul, MN) was used for all procedures to measure oxygen consumption and carbon dioxide production. Heart rate was measured with a Polar S610 heart rate monitor and transmitter (Lake Success, NY) and TECA Electrode Conductivity Gel (Pleasantville, NY). All instruments and machines were calibrated before each testing session per manufacturer's directions.

All procedures took place in the same testing facility. Each participant arrived on the scheduled day dressed and prepared for exercise. The responsibilities as subjects, all testing protocols and any possible risks and benefits of the tests were explained to each participant before they signed the informed consent document (Appendix A). Each participant then filled out their health information in the Par-Q (Appendix B) to determine their health status. Based on the provided information, all five subjects were cleared for exercise. Each subject then answered questions about their health and running history in a general questionnaire (Appendix C).

Each subject's height, weight, body fat percentage, waist and hip circumferences were measured and recorded prior to exercise. The subject was then fitted with a Polar heart rate monitor and transmitter. The subject was also fitted with a pneumotach and mask and was instructed to sit in a chair in order to obtain resting measurements.

Data Collection during Exercise

Maximal Testing Protocol. Each subject participated in a graded maximal exercise test the first day in order to obtain her maximal oxygen consumption (VO_{2max}). The purpose of this test was to measure maximal aerobic capacity and can be used as a predictor of endurance performance (Brooks, Fahey & Baldwin, 2005; Meyer, Welter, Scharhag, & Kindermann, 2003). Each participant was tested individually.

Each subject was given the option to warm-up on the treadmill and all declined. Each subject was tested using the conventional Bruce graded maximal testing protocol, where speed (starting at 1.7 mph) and grade (starting at 10%) was increased every three minutes (see Appendix D), until volitional exhaustion (symbolized by grabbing the treadmill's handrail). Exercise VO_2 , HR, and RER were measured every 30 seconds of the test using Breeze software program. The subject was asked to evaluate their exertion level every three minutes during the testing using the Borg Rating of Perceived Exertion (RPE) scale (see Appendix E). At the end of the protocol, subjects cooled down on the treadmill at 1.7 mph with a 0% grade. After eight minutes, subjects felt sufficiently cooled-down and the treadmill was stopped and the subject was relieved of the mask and heart rate monitor. All information was recorded on a data collection sheet (see Appendix F).

Submaximal Testing Protocol. All subjects returned 48 hours later to complete the drafting trials. Height, weight, body fat percentage, and waist and hip circumferences were recorded for each subject. Each subject was fitted with a Polar heart rate monitor and preVent mask and asked to sit in a chair in order to obtain resting measurements. An industrial size column fan was set at a wind velocity of $3.2 \text{ m}\cdot\text{s}^{-1}$ (7.2 mph). The speed of the treadmill was set to represent 65% of their VO_2 .

The VO_2 , RER and HR values were recorded every 30 seconds of the test using the Breeze Software program. The subject actively recovered at 2.0 mph for two minutes. The subject then passively recovered in a chair for six minutes or until their heart rate returned to the resting value before starting the subsequent trial. Protocol for all six submaximal tests remained identical. At the completion of all trials, the subject

was relieved of the mask and heart rate monitors. All information was collected on the data collection sheet (Appendix G).

Calculations

The maximal volume of oxygen consumption during the Bruce Protocol was estimated, using the generalized cubic regression equation, $VO_2 \text{ max (ml/kg/min)} = 14.8 - 1.379$ (time exercised in minutes) + 0.451 (time²) - 0.012 (time³). A percentage of the $VO_2 \text{ max}$ was determined by multiplying that estimated VO_2 by .65 to determine 65% of the $VO_2 \text{ max}$ to be used on the second day of testing.

Experimental Design

The independent variable for this study was running position (factor 1 with 3 levels). The different levels of factor 1 were the three running positions: no drafting, drafting 1.0 m behind the lead runner, and drafting 2.5 m behind the lead runner. The dependent variables included: steady state oxygen consumption (VO_2), steady state heart rate (HR), and the overall rating of perceived exertion (RPE).

Statistical Analysis

The means of the physiological variables (VO_2 , HR, and RPE) during steady state were calculated for each position. The physiological variables were compared, for each subject, between positions and drafting distances. All data was analyzed using SPSS 12.0.2 for Windows using a one-way within-subjects analysis of variance (ANOVA). Due to the small sample size (n=5), the level of significance was set at $p < 0.1$ for all statistical tests.

CHAPTER IV

RESULTS AND DISCUSSION

Results

Subject profile. Using SPSS for Windows, the physical characteristics were compared using (Version 12) (see Table 1). All subjects were found to have similar weight, height, body fat percentage, waist-to-hip ratio and BSA. All subjects were female members of SUNY Cortland's Track and Field Team. The number of subjects in the present study was similar to subjects in previous laboratory research. Corvalán-Grössling (1995) used nine subjects and Arnett (2002) used three male and three female subjects.

Ambient conditions in the laboratory. On the first day of testing, the average barometric pressure was 981.7mmHg, the ambient temperature was 25.9°C and the humidity was 16.0%. On the second day of testing, the average barometric pressure was 978.3mmHg, the ambient temperature was 24.5°C and the humidity was 20.8%.

Maximal testing. Heart rate and RPE were collected every three minutes during the conventional Bruce protocol to determine VO₂ max of each subject. VO₂ max was determined using the formula $VO_2 \text{ max (ml/kg/min)} = 14.8 - 1.379 (\text{time exercised in minutes}) + 0.451 (\text{time}^2) - 0.012 (\text{time}^3)$ (see Table 2).

Submaximal testing. Resting oxygen consumption, heart rate and perceived exertion measurements were taken for each subject prior to each of the submaximal drafting trials. Oxygen consumption, heart rate and perceived exertion measurements were taken every thirty seconds of the 6 minute trials. The measurements from the last three minutes were averaged for each trial and considered steady state measurements (see Table 2).

Table 1

Physical Characteristics of Subjects*

Characteristic	Mean	Range (Minimum – Maximum)
Age (yrs)	19.8 ± 1.3	19 – 22
Height (cm)	158.3 ± .45	158 – 159
Weight (kg)	50.55 ± 2.54	47.06 – 53.75
Body Fat (%)	19.55 ± .03	16.5 – 22.9
Waist/Hip Ratio	.77 ± .03	.73 – .82
BSA (m ²)	1.50 ± .03	1.46 – 1.53
Miles Per Week	54 ± 4.18	50 – 60
Experience (Years)	6.2 ± 3.8	2 – 11
Best 1600m Time	5:43 ± 0:12	5:27 – 5:54
Best 5000m Time	20:00 ± 0:24	19:25 – 20:28
VO _{2max} (mL/kg/min)	48.14 ± 1.62	46.73 – 49.98

* n = 5; Means are ± SE

Table 2

Mean Measurements \pm Standard Deviation Collected at Three Running Positions

Characteristics	No Drafting	Drafting 1.0 m	Drafting 2.5 m
Heart Rate (bpm)	133.65 \pm 14.31	132.10 \pm 13.38	132.47 \pm 12.67
RPE	8.03 \pm 1.44	7.43 \pm .84	7.2 \pm .74
VO ₂ (mL/kg/min)	24.76 \pm 3.67	24.55 \pm 3.47	23.11 \pm 3.83
Economy (L/min)	7.47 \pm .12	7.40 \pm .11	7.17 \pm .16

Note: n = 5*; Means are \pm SE

Due to small sample size, Pillai's Trace was used. According to the Mauchly's test of Sphericity, the data entered into the ANOVA was not significant ($p > 0.05$ for all three variables). Epsilon for Sphericity was met for heart rate, but not for RPE and VO₂; researcher referred to Huynh-Feldt correction factor.

The Effects of Drafting Distance on Heart Rate

Using SPSS for Windows, it was found that there was not a significant effect of drafting positions on heart rate ($F_{(2,8)} = 1.373, p = .307$). The Least Significant Difference (LSD) post-hoc analysis revealed a significant difference in heart rate response between the non-drafting position and drafting 1.0 m behind another runner ($p = .041$). Heart rate was significantly lower when drafting 1.0 m behind another runner ($M = 132.1 \pm 13.38$ BPM) than when running alone ($M = 133.65 \pm 14.31$ BPM). Heart rate was not significantly different when running 2.5 m behind another runner ($M = 132.47 \pm 12.67$) than running alone ($M = 133.65 \pm 14.31$ BPM). There was not a significant difference in heart rate between the two drafting distances.

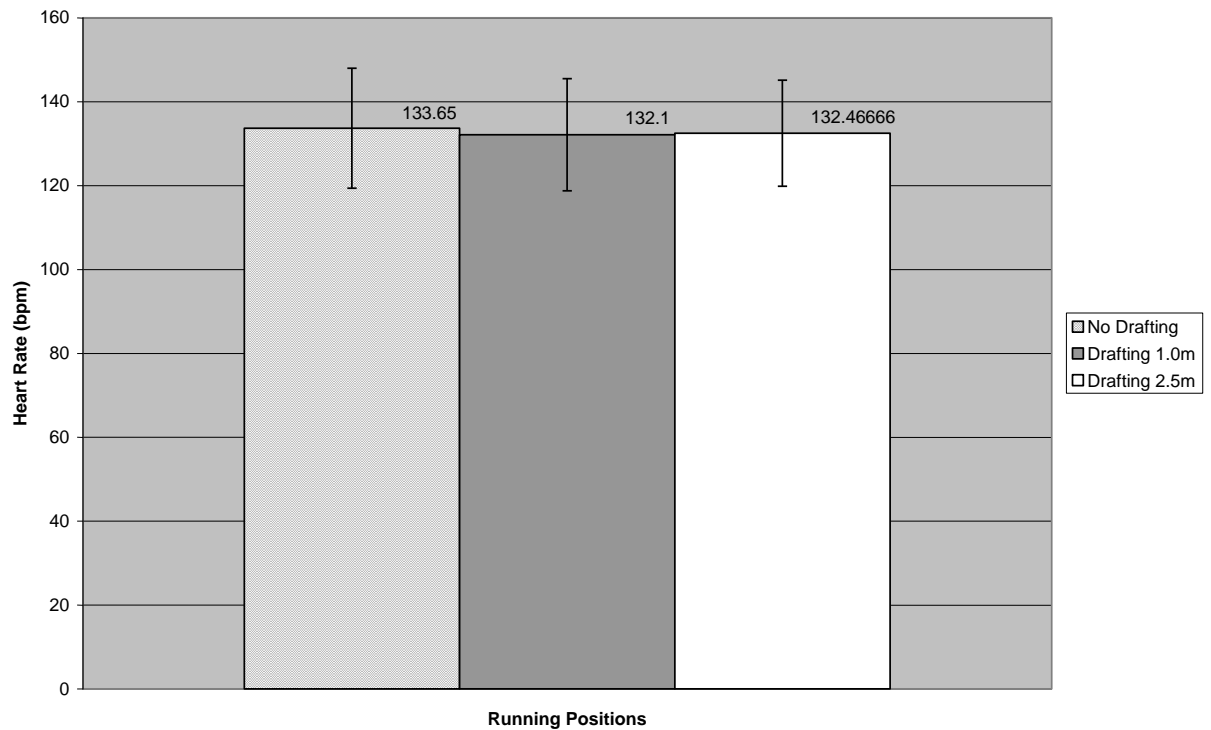


Figure 1. Graph of mean HR for different drafting conditions (error bars display the standard deviation).

The Effects of Drafting Distance on Oxygen Consumption

There was a significant effect of drafting positions on VO_2 ($F_{(1.449,5.796)} = 4.526$, $p = .078$). The LSD post-hoc analysis revealed a significant difference for oxygen consumption between the non-drafting position and drafting behind 2.5 m position ($p = .076$). Oxygen consumption was significantly lower when drafting 2.5 m behind a runner ($M = 23.04 \pm 3.83$ mL/kg/min) than when running alone ($M = 24.76 \pm 3.67$ mL/kg/min). Oxygen consumption while running 1.0 m behind another runner ($M = 24.55 \pm 3.47$ mL/kg/min) was not significantly different than running alone ($M = 24.76 \pm 3.67$ mL/kg.min). There was not a significant difference between the two drafting trials.

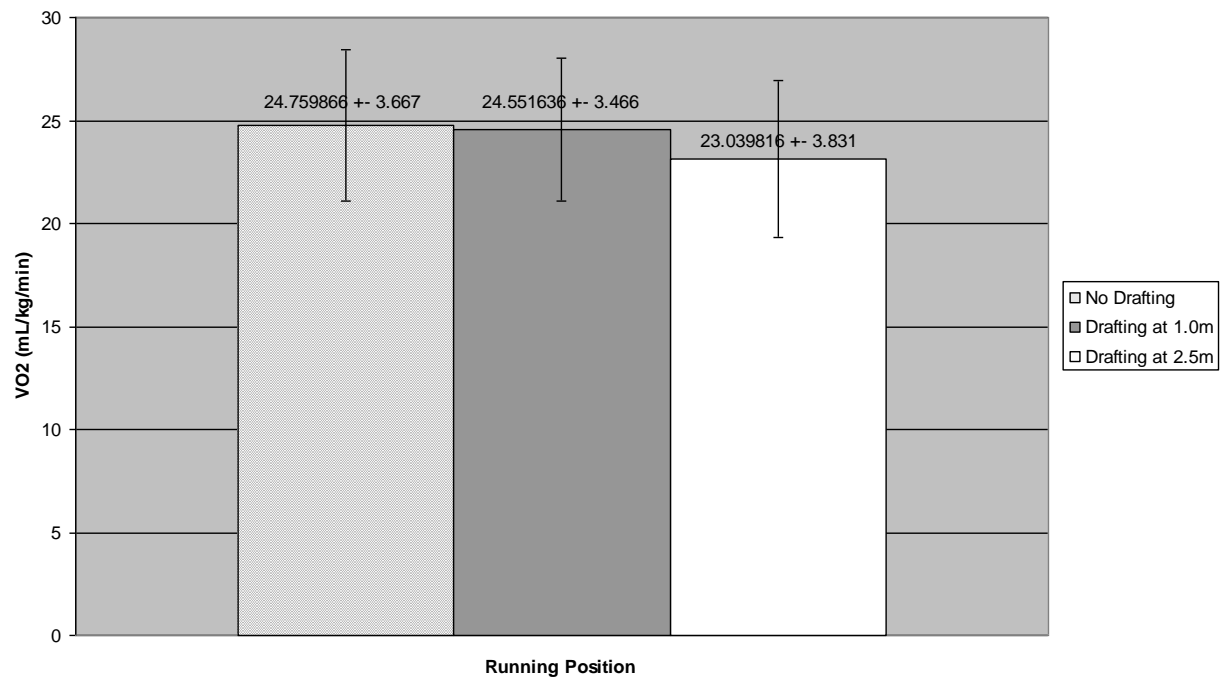


Figure 2. Graph of mean VO₂ for different drafting conditions (error bars display standard deviation)

The Effects of Drafting Distance on RPE

There was a significant effect of drafting positions on RPE values ($F_{(1,157,4.627)} = 4.526, p = .089$). The LSD post-hoc analysis revealed a significant difference in RPE between the non-drafting position and drafting behind 2.5 m position ($p = .082$). A significant difference between drafting 1.0 m and 2.5 m behind the lead runner ($p = .052$) was also found for RPE using the Least Significant Difference post-hoc test. RPE was significantly lower while drafting 2.5 m behind another ($M = 7.20 \pm .74$) than when drafting 1.0 m behind another runner ($M = 7.43 \pm .84$) and when running alone ($M = 8.03 \pm 1.44$). RPE when running 1.0 m behind another runner ($M = 7.43 \pm .84$) was not significantly different than running alone ($M = 8.03 \pm 1.44$).

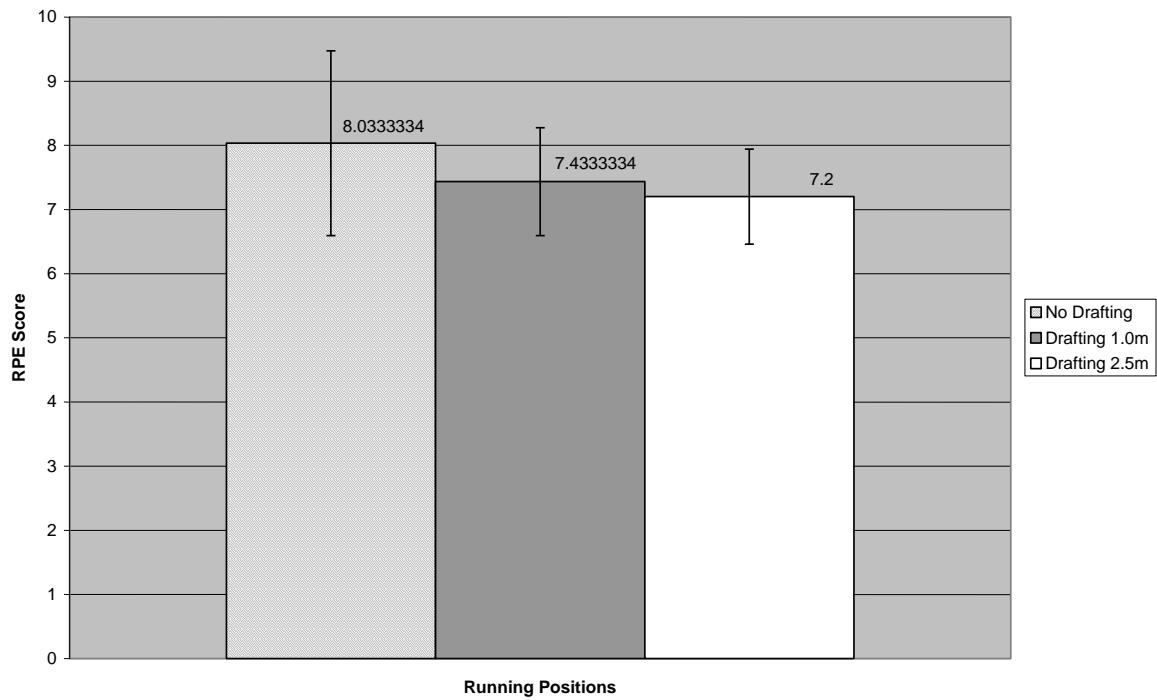


Figure 3. Graph of mean RPE for different conditions (error bars display standard deviation)

Discussion

Heart Rate. In the present study, heart rate was significantly lower when drafting 1.0 m behind a lead runner compared to running alone. Yet it would be expected that running 2.5 m behind another runner would yield significantly lower results, which it did not. In fact, the average heart rate when running 2.5 m behind was slightly higher than running 1.0 m behind a lead, 132.47 BPM compared to 132.1 BPM, respectively. This is an interesting finding yet it adds to the research of heart rate of runners while drafting. Heart rate has not been shown to be significantly lower during a drafting position by either Corvalán-Grössling (1995) or Arnett (2002). The results are inconclusive due to the fact that heart rate was lower during the drafting positions when compared to running

alone, yet only when drafting 1.0 m behind the lead showed significant results and were lower than the second drafting position. According to Bilodeau (1995), heart rate was significantly lower when athletes drafted behind a lead athlete with a larger body shape. Although this could suggest that the heart beat less when drafting, further research is needed.

Oxygen consumption. The present study's findings on lower oxygen consumption when drafting agree with Corvalán-Grössling (1995) and Arnett (2002). Although, in the present study, oxygen consumption is significantly lower when drafting 2.5 m behind another runner, yet is not significantly lower when 1.0 m behind another runner. It is likely that this was a result of more wind being blocked by the lead runner as the person acting as the lead runner stood closer to the fan. This shows the same effect as the early study by Hagberg (1990) when cyclists had the lowest oxygen consumption when drafting behind a large object, a car. This result confirms findings from researchers Kyröläinen, Belli and Komi (2001) in that wind-resistance can have an effect on running economy. The greater the air-resistance, as can be seen when drafting 2.5 m behind a runner, the less oxygen consumed and in turn the more efficient a runner is at a certain speed.

RPE. In accordance to previous research and similar to oxygen consumption, perceived exertion was found to be significantly lower when drafting 2.5 m behind another runner than when running alone or running 1.0 m behind another runner. Although RPE values were lower in both drafting positions, only the second drafting trial was significantly lower than the lead runner. This result adds a psychological effect to the research, as it indicates that the subjects in the present study felt they exerted less force

when drafting further behind a lead runner. Similar results were found in research by Corvalán-Grössling (1995) and Arnett (2002).

Summary

The main conclusion of this study is that drafting behind another runner lowers oxygen consumption and perceived exertion when 2.5 m behind another runner. This supports the notion that drafting behind a runner during competition can lessen the oxygen consumed, as well as lessen the feeling of exertion at that speed compared to other runners not drafting. The findings in this study concur with previous research, although it is the recommendation of the researcher that more studies are needed to determine if drafting improves performance of runners.

Additionally, it should be noted that ACSM's guidelines for physical activity define intense physical exertion as 65% or greater (2000). Therefore, this percent seemed to make sense as an intense pace that would exert the subjects without bringing them to fatigue during the 6-minute trials. Yet, the average volume of oxygen consumed during the tests ranged from 23.11- 24.76 mL/kg/min. This value is only half of the average $\text{VO}_{2\text{max}}$ value of 48.14 mL/kg/min. Therefore, the subjects were only running at 50%, rather than the 65% of their maximum effort. This discrepancy in the calculations may have affected the results of the testing. The subjects were running at a significantly slower and easier pace than anticipated.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the physiological and psychological effects of drafting during running in three different running scenarios (running alone as the lead runner, running 1.0 m behind another runner, running 2.5 m behind another runner). Previous research has been inconclusive about the effects of drafting. Although laboratory research has found that heart rate and oxygen consumption was significantly lower while drafting, there has been no published research to support these findings. The findings in the present study were intended to determine if drafting was effective in female track and field athletes.

Five healthy female athletes from a collegiate track and field team volunteered to participate in this study. Data collection consisted of a two-day testing period. The first day of testing included a submaximal graded VO_2 max test using the conventional Bruce protocol. The second day of testing included three six-minute running trials at different running positions (lead runner, 1.0 m behind a lead runner, 2.5 m behind a lead runner). Oxygen consumption, heart rate and perceived exertion were collected during each trial. SPSS for Windows was used to analyze the data; due to the small sample size, $n=5$, a p value of 0.1 was considered significant. Heart rate was significantly lower when drafting 1.0 m behind another runner ($M = 132.1$ BPM) than when running alone ($M = 133.65$ BPM). Oxygen consumption was significantly lower when drafting 2.5 m behind a runner ($M = 23.04$ mL/kg/min) than when running alone ($M = 24.76$ mL/kg/min). Perceived exertion was significantly lower while drafting 2.5 m behind another ($M = 7.20$

$\pm .74$) than when drafting 1.0 m behind another runner ($M = 7.43 \pm .84$) and when running alone ($M = 8.03 \pm 1.44$). Results of oxygen consumption and perceived exertion concur with Corvalán-Grössling (1995) and Arnett (2002) that less oxygen is consumed and RPE is lower when drafting 2.5 m behind another runner. Heart rate was not shown to be significantly lower during a drafting position by either Corvalán-Grössling (1995) or Arnett (2002).

Conclusions

The following conclusions were made based on the results of the statistical analysis:

1. The physiological and psychological variables (VO_2 , HR, and RPE) were not significantly different between the two running positions (leading and drafting), not supporting the researchers hypothesis. However, running economy was significantly different between the two positions. Also, VO_2 and RPE were significantly lower when running 2.5 m behind a lead runner compared to when running alone, which supported the researcher's hypothesis. Heart rate was significantly lower when running 1.0 m behind compared to running alone.
2. The physiological and psychological variables (VO_2 , HR, and RPE) were not significantly different between the two distances (1.0 m and 2.5 m); not supporting the researcher's hypothesis.
3. The null hypothesis was supported for oxygen consumption, heart rate, and RPE, as no significant difference was determined between the two running positions.

Recommendations for Future Research

Based on these conclusions, it is recommended for future research that:

1. Future studies could more accurately mimic a running event or race within the laboratory or could be done in the field. Due to the inability to find a treadmill that can safely hold two runners single-file, the runners in this study had to draft behind a “lead runner” that was represented by a person standing between them and the fan. This may not have accurately represented drafting behind another runner. Also, the treadmill in this study had a large console that blocked wind during all three positions. It is highly recommended to use portable devices to measure oxygen consumption and heart rate during the trials to more accurately represent a running scenario.
2. Future studies could also increase and vary the subjects used in the research. This can be done by increasing the subject pool to include gender, different body types and sizes, and trained and untrained runners. A gender effect can be determined if studying both male and female runners. Also, similar to Bilodeau et al. (1994), a larger drafting effect may be seen when drafting behind a larger runner.
3. Future research could continue researching different wind and running speeds, and expand the research to include more running scenarios. This could be done in the field or using more than one fan to produce greater wind speeds. Similar to the research by Hagberg (1990), different running scenarios could be set up using more lead runners, large groups or a car.

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Appendix A

Informed Consent

Subject # _____

The research that you have been asked to participate in is being conducted by Stephanie Bailey of the Exercise Science and Sports Studies Department at SUNY Cortland. We request your informed consent to be a participant in the project described below. Please feel free to ask about the project, its procedures, or objectives.

Information and Procedures of This Research Study:

The purpose of this study is to investigate the effects of drafting on running performance. The study consists of two days of testing. On the first day, your maximal oxygen consumption (VO_{2max}) will be measured by connecting you to mask, mouth piece and hose which are hooked to an oxygen analyzer. You will then run on the treadmill until you reach exhaustion. You may experience some discomfort during this test. You will return two days later and complete 3 six minute trials on the treadmill. Your running pace for the trials will be 65% of your VO_{2max} . On both days, your height, weight, body fat percentage and resting heart rate will be measured and recorded.

Before agreeing to participate you should know that:

A. Freedom to Withdraw

You are free to withdraw consent at any time without penalty. Even if you begin the testing protocol and realize for any reason that you do not want to continue, you are free to withdraw from the study.

B. Protection of Participants Responses

All data collected is strictly anonymous. Only the presiding faculty member, research assistants and investigator named above will have access to your personal information and data. You will use an issued identification number throughout the course of the study. Only this number will be connected with your data. Your name will not be connected to your data. All collected information will be kept in a locked cabinet in the principle investigator's office and any identifying information will be destroyed at the end of the study. Your coach will not be aware of who does or does not participate in this study, nor will your coach have access to any of the collected data. At the end of the data collection process, you will be allowed access to your VO_{2max} scores and will have the choice to inform your coach or not.

C. Length of Participation

The study should take approximately an hour and a half on each test day. The actual VO_{2max} test conducted on the first day will not take any longer than 25 minutes. On the second day you will run on the treadmill for six minutes for three trials. There will be an eight minute walk in between each trial for a total of forty-two minutes on the treadmill.

D. Risks Expected

With any physical activity you run the risk of physical injury. There is a possibility that you could trip and fall of the treadmill. You may experience pain and discomfort during the VO_{2max} tests and the 3 trials.

E. Benefits Expected

From participating in this study you should expect to come to a greater understanding of the way in which research is conducted. You will also be informed of your VO_{2max} score, a valuable and reliable estimate of your aerobic capacity. At the completion of the test, you will be made aware of the results and if drafting has an effect on running performance. Your participation should greatly enhance your understanding of research design and how scientists answer theoretical and practical research questions.

F. Contact Information

For questions concerning the purpose or results of this study, please contact Stephanie Bailey, Principle Investigator, SUNY Cortland at (607) 342-4447. Office: A-14 Studio West. E-mail:SBailey8581@yahoo.com

For questions about research or research subjects' rights, contact Amy Henderson-Harr, IRB Designee, Office of Sponsored Programs, SUNY Cortland, at (607) 753-2511.



I _____ have read the description of the project for which this consent is requested, understand my rights, and hereby consent to participate in this study.

Print Name

Signature of Participant

Date

Signature of Witness

Date

05/06-S28

Cortland

State University of New York College at Cortland

Institutional Review Board
607.753.2511

March 27, 2006

Stephanie Bailey
Exercise Science and Sport Studies
Studio West

RE: 05/06-S28

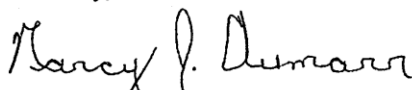
Dear Ms. Bailey:

Thank you for your email dated March 26, 2006, requesting a modification to the above referenced project titled, *The Effects of Drafting on Run Performance*.

Your request to modify your project using the research methods as described in your letter has been approved. Additionally, according to IRB policies, you must contact the IRB immediately should the following occur: 1) if there are any modifications in your research plan which affects the method of using human participants; and 2) should any participants experience problems that may arise in connection with the study.

The IRB wishes you every success in your continued research. Please do not hesitate to contact me or Amy Henderson-Harr should you need any further assistance.

Sincerely,



Nancy J. Aumann
IRB Chair

Appendix C

The Physical Activity Readiness Questionnaire

Being physically active is very safe for most people. Some people, however, should check with their doctors before they increase their current level of activity. The PAR-Q has been designed to identify the small number of adults for whom physical activity may be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Answer yes or no to the following questions:

-
1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
 2. Do you feel pain in your chest when you do physical activity?
 3. In the past month, have you had chest pain when you were not doing physical activity?
 4. Do you lose your balance because of dizziness or do you ever lose consciousness?
 5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
 6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
 7. Do you know of any other reason why you should not do physical activity?

If you answered yes:

If you answered yes to one or more questions, are older than age 40 and have been inactive or are concerned about your health, consult a physician before taking a fitness test or substantially increasing your physical activity. You should ask for a medical clearance along with information about specific exercise limitations you may have.

In most cases, you will still be able to do any type of activity you want as long as you adhere to some guidelines.

If you answered no:

If you answered no to all the PAR-Q questions, you can be reasonably sure that you can exercise safely and have low risk of having any medical complications from exercise. It is still important to start slowly and increase gradually. It may also be helpful to have a fitness assessment with a personal trainer or coach in order to determine where to begin.

Appendix D

General Questionnaire

Subject # _____

Name: _____

Age: _____

Date: _____

Time: _____

Mileage Per Week: _____

Years Experience: _____

Best 1 Mile Time: _____

Best 5 K Time: _____



Yes

No

Do you smoke?

Are you taking any prescription medications?

If yes, please list: _____

Do you wear a pacemaker?

Are you injured?

If yes, have you been cleared by a physician?

Do you consider yourself healthy?

Is there a family history of cardiac, pulmonary, or metabolic disease, stroke or sudden death?

Have you had an recent illness, hospitalization, new diagnoses or surgical procedures?

If yes, please explain: _____

Do you experience any pain/discomfort during regular exercise (i.e. chest pain, dizziness, shortness of breath, or heart murmur)?

If yes, please explain: _____

Appendix E

The conventional Bruce Treadmill VO₂ max Test Protocol

Stage	Time (min)	Speed (mph)	Grade (%)
1	0:00 – 3:00	1.7	10
2	3:00 – 6:00	2.5	12
3	6:00 – 9:00	3.4	14
4	9:00 – 12:00	4.2	16
5	12:00 – 15:00	5.0	18
6	15:00 – 18:00	5.5	20
7	18:00 – 21:00	6.0	22
Recovery	0:00 – 2:00	2.5	12

According to American College of Sports Medicine (2000).

Appendix F

Rating of Perceived Exertion (Borg Scale)

Category Scale	Description
6	
7	Very, Very Light
8	
9	Very Light
10	
11	Fairly Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, Very Hard
20	

According to Borg, G.A. (1998)

Appendix G

Data Collection: Day One

Subject # _____

Date: _____

Time: _____

Environmental Conditions

Wind Speed: _____ km/hr Temperature: _____ oC

Barometric Pressure: _____ mmHg Humidity: _____ %

Resting Measurements

Height: _____ cm Weight: _____ kg

Waist Circumference: _____ cm Hip Circumference: _____ cm

Percent Body Fat: _____ % Body Surface Area: _____ m²

.....

Graded Exercise Testing

Protocol: _____

VO₂ max: _____ mL/kg/min

<i>Stage</i> (Speed/Grade)	Time (min)	HR (bpm)	VO ₂ (mL/kg/min)	VO ₂ (ml/kg)	VE (L/min)	RER	RPE
Rest	0						
1.7 @ 10%	3						
2.5 @ 12%	6						
3.4 @ 14%	9						
4.2 @ 16%	12						
5.0 @ 18%	15						
5.5 @ 20%	18						
Recovery							

Stopped test at: _____ min

Appendix H

Data Collection: Day Two

Subject # _____

Date: _____

Time: _____

Environmental Conditions

Wind Speed: _____ km/hr Temperature: _____ °C

Barometric Pressure: _____ mmHg Humidity: _____ %

Resting Measurements

Height: _____ cm Weight: _____ kg

Waist Circumference: _____ cm Hip Circumference: _____ cm

Percent Body Fat: _____ % Body Surface Area: _____ m²



Exercise Testing

Position: _____

Drafting Distance: _____ m

Treadmill Speed	Time (min)	HR (bpm)	VO ₂ (mL/kg/min)	VO ₂ (ml/kg)	VE (L/min)	RER	RPE
Rest	0						
	1						
	2						
	3						
	4						
	5						
	6						
Recovery	2						
2.0	4						
2.0	6						
2.0	8						

Position: _____

Drafting Distance: _____m

<i>Treadmill</i>	Time (min)	HR (bpm)	VO ₂ (mL/kg/min)	VO ₂ (ml/kg)	VE (L/min)	RER	RPE
Speed							
Rest	0						
	1						
	2						
	3						
	4						
	5						
	6						
Recovery	2						
2.0	4						
2.0	6						
2.0	8						

Position: _____

Drafting Distance: _____m

<i>Treadmill</i>	Time (min)	HR (bpm)	VO ₂ (mL/kg/min)	VO ₂ (ml/kg)	VE (L/min)	RER	RPE
Speed							
Rest	0						
	1						
	2						
	3						
	4						
	5						
	6						
Recovery	2						
2.0	4						
2.0	6						
2.0	8						

