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The Relationship between Cardiac Load and Metabolic Changes throughout a Collegiate Cross-country Season

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78 Pages

Overtraining is a widespread epidemic in collegiate cross-cross country which causes excessive fatigue and limits improvement in critical physiological measures such as maximal oxygen uptake (VO2 max), ventilatory threshold (VT), and running economy (RE). Research has suggested that overtraining can be identified by monitoring daily and weekly cardiac load (CL) as well as changes in load over time measured by an acute to chronic cardio load ratio (A:C). Assessing the relationships between these foundational aerobic athlete variables and A:C will provide important information about fitness changes over the course of a competitive season as well as potential insight into the overtraining phenomenon. **PURPOSE:** To determine the metabolic changes in elite endurance athletes over a cross country season and identify a relationship with cardio load and A:C. **METHODS:** Volunteer participants ranging from 18-23 years of age were recruited from the Illinois State University cross country team for this study. Athletes recorded heart rate data daily from each training session and attended both a pre and post season laboratory testing session. In the lab, a discontinuous maximal graded exercise test was performed consisting of 3 submaximal bouts lasting 4 minutes each separated by 1 minute of rest. After the 3^{rd} stage and subsequent rest, a maximal ramp protocol was initiated by increasing the incline 1% each minute until volitional exhaustion. An analysis of the metabolic variables of interest was conducted in Microsoft Excel to determine change from pre to posttest as well as any interactions with cardiac load data. **RESULTS:** A:C tended to decrease throughout the season for most athletes with the team average gradually declining from 1.11 during the week of September 25th to 0.65 for October 30th. Top performers at the postseason championship races had the highest average A:Cs (Top male: 1.30; Top female 0.95), and worst performers for a given race tended to have the lowest relative CL in the preceding week. In the lab, there was high individual variability and few significant global changes. Average VO2 max for males increased from 66.3 mL.kg-1.min-1 during preseason testing to 67.3 mL.kg-1.min-1 for postseason (53.8 to 53.8 for females). Individual outlying VO2 max values tended to regress towards the mean, VT increased slightly for both sexes (Females: +5.1 %VO2; Males: +4.6 %VO2 max) with established long-distance runners consistently demonstrating the highest values, and RE improved moderately for all stages excluding 2 notable outliers. Top performers according to test duration typically had the best RE values for all stages (Female: 42.4, 79.3 & 86.7 %VO2 max for stages 1,2 & 3; Male: 66.1, 72.1, 83.5 %VO2 max). **CONCLUSION:** Data suggests that maintaining consistently high CL and A:Cs above 0.9 throughout the season may be optimal for improving race performance. Specifically, CL should not decrease significantly in the week leading up to a competition. Physiological testing confirms the importance of measuring VO2 max, VT, and RE, and monitoring changes in these values over the year could be predictive of performance or potential success at specific distances.

KEYWORDS: Cardio Load, Internal Workload, VO2 max, Ventilatory Threshold, Running Economy, Endurance Running

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CONTENTS

TABLES

FIGURES

CHAPTER I: DESCRIPTIVE ANALYSIS OF INTERNAL WORKLOAD AND PHYSIOLOGICAL CHANGES OF DIVISION I CROSS COUNTRY ATHLETES

Introduction

The structure of a successful endurance athlete training program is predicated on maintaining a delicate balance between work and rest. Too little physiological stress ignores the principle of progressive overload and limits fitness adaptations; too much causes the body to enter a state of overreaching. Overreaching for an extended period can lead to overtraining syndrome which promotes greater general fatigue, decreases motivation, heightens injury risk, and ultimately causes impaired performance (1). In order to optimize fitness benefits, a successful training plan must continually manage volume and intensity while providing adequate rest for the athlete to avoid overtraining. Unfortunately, this concept of overtraining is highly individualized and can be difficult to identify and nearly impossible to quantify.

One emerging line of research attempts to predict and prevent overtraining by utilizing heart rate data (2). By measuring the time spent in each heart rate zone during a given workout, it is possible to approximate the cardiac work done by the body during that session. Tracking this internal cardio load (CL) provides a quantifiable variable which gives insight into how hard the athlete is working on a given day. In this study CL is calculated based upon a proprietary algorithm from Polar Electro based out of Kempele, Finland which is integrated into the data retrieved from heart rate monitoring units. CL can be useful for creating training plans which manage intensity increases appropriately according to the principle of progressive overload.

Perhaps an even more useful application, however, arises from the changes in internal load over time. Research suggests that acute spikes in intensity relative to an individual athlete's normal effort are related to both increased injury risk and diminished fitness gains (3, 4, 5, 6, 7).

This concept is quantified by a metric known as the acute to chronic internal load ratio (A:C). A:C is calculated by dividing the sum of the CL scores for the current week by the average of the CL scores from the previous weeks. The most commonly used time frame for chronic load calculations is 4 weeks (8). A systematic review of 27 studies concludes that there is a significant decrease in injury risk when A:C is kept consistently between 0.8 and 1.3 (8).

The outcome variable of interest in this study was performance capacity over a cross-country race distance of 6-10 kilometers. In addition to raw race results, the 3 foremost predictors of endurance capabilities are maximal oxygen uptake (VO2 max), lactate threshold (LT), and running economy (RE) (9). VO2 max is a measure of the body's ability to take in and utilize oxygen, and it is often measured using a metabolic gas analyzer and an ergometer (9). When intensity is increased on the ergometer without a subsequent increase in VO2, a plateau is said to have been reached indicating that the subject has achieved maximal oxygen consumption (9). In the century since this concept of VO2 max was originally introduced by AV Hill, maximal oxygen uptake has been the primary measure of aerobic fitness in the body. Higher VO2 max relative to body size suggests the ability to continue utilizing aerobic metabolic pathways at higher intensities with higher energy demands. Therefore, elite runners have 50-100% higher VO2 max values than the general healthy population (10). Typical elite values range from 70-85 mL.kg-1.min-1 for males compared to 30-40 mL.kg-1.min-1 for average men (11). Female values tend to be approximately 10% lower due primarily to a higher relative percentage of body fat and lower hemoglobin levels (12).

Although VO2 max is useful for distinguishing between trained and untrained long-distance runners, it loses significant predictive power within an elite population. At the highest levels of competition, there is little variation in VO2 max, and efficiency becomes more significant for performance projection (9). Efficiency, referred to as running economy, is defined as the oxygen cost of running at a given speed and can vary by up to 30-40% between individuals running at the exact same pace (13). This large difference is a product of numerous physiological, metabolic, anatomical, neuromuscular, and biomechanical attributes which allow some runners to move more efficiently than others (9). Running economy is often expressed as a percentage of VO2 max and was assessed in this study at 3 typical training paces for collegiate athletes.

Another prominent predictor of performance in the literature is LT (9). The oxidative capacity of the skeletal muscles determines the point at which the rate of pyruvate production exceeds the capability of the mitochondria to oxidize pyruvate into lactic acid. Beyond this point, lactic acid accumulates at an accelerated rate and the constituent hydrogen ion causes rapid muscle fatigue. Lactic threshold is also a trainable metric and can increase from approximately 60% of VO2 max in untrained subjects to 75-90% VO2 max in elite endurance athletes (14, 15). Those that are able to delay the onset of blood lactate accumulation are able to resist local muscle fatigue longer and will ultimately perform better in an endurance event. Unfortunately, accurate measurement of lactate threshold requires finger-prick blood samples which can be uncomfortable for participants during a maximal exercise test. Therefore, this study opted to measure ventilatory threshold (VT) as a best approximation. VT occurs when the body utilizes the bicarbonate buffering system to remove lactic acid from the blood and produces excess non-metabolic CO2 (16) Although there are slight differences between LT and VT, the two metrics both describe anaerobic threshold, are highly correlated (r=.95), and will be assumed to have the same predictive power for race performance (17).

Together, these three variables were assessed along with raw race results in order to describe overall endurance performance capacity. If an athlete is training optimally, fitness should increase, and that improvement will be reflected in the physiology laboratory data. However, if the overtraining which we hope to quantify via A:C using heart rate monitoring occurs, then fitness gains will be limited. The purpose of this study was to examine the relationship between the internal load data and the described changes in VO2 max, RE, and VT throughout a cross-country season in Division I runners. As a secondary objective, this study will try to identify changes in these key physiological variables from pre to post season for an elite collegiate population. It is hypothesized that there will be significant increases in VO2 max, RE, and VT, and that the magnitude of these changes will be associated with A:C internal load data such that more time spent within the optimal 0.8-1.3 ratio predicts greater improvements.

Methods

Sample

A total of 14 college-age endurance athletes (6 men and 8 women) were recruited from the Illinois State University cross country team. Two individuals dropped out due to scheduling concerns prior to the preseason VO2 testing, and one additional participant was unable to complete postseason testing after suffering a stress injury. Of the 11 athletes that completed the study, all were college-age adults (18-23 years old) and expected to have elite or near-elite VO2 max values (Males: >60 mL.kg-1.min-1; Females: >50 mL.kg-1.min-1). The Institutional Review Board approved of all data collection procedures, and an informed consent was obtained from all participants prior to testing.

Procedures

Data collection was conducted in two parts: Cardiac load was measured daily during each training session by Polar heart rate monitoring technology, and pre/post season metabolic data was collected in the Illinois State University School of Kinesiology and Recreation's Exercise Physiology Laboratory at 2 time points 10-12 weeks apart during the fall 2022 semester.

Heart Rate Monitoring

During the first official week of the cross-country season, Polar H10 heart rate monitoring devices were given to all participants. After signing an informed consent form, participants were instructed on how to collect and share data. First, each participant was shown how to moisten the electrodes on the heart rate strap, attach the H10 monitor, and secure the strap with the peanut resting snugly in the center of the chest against the sternum. Using the Polar Beat application on their smartphones, participants then recorded the activity and uploaded it to Polar Flow where researchers could access the data. In order to minimize down time and obtain meaningful average heart values, athletes were instructed not to include static warmups or weight training sessions in the data collection recording. All running and other endurance activities (cycling, swimming, etc) were included. Cardiac load was recorded session by session as well as on a daily and weekly average. A:Cs were also calculated by dividing the current weekly CL by the chronic load average over the preceding 4 weeks.

Data Analytics

At the start of the study, a glitch with the HR monitors caused them to fail to record data out of Bluetooth range from the phone with the Polar app. 34 of the 714 recorded training sessions lost data before this error could be addressed, and these days were later filled with the season-average CL for the individual whose data was not recorded. Additionally, the participants in this study were not comfortable wearing the monitors during race days, and thus no CL data was recorded. Instead, race day data was estimated to be equal to an individual's maximum workout CL from throughout the season. The monitors were self-tested and race CL including warm up and cooldown was found to be not less than the maximum CL for any other workout. Although this method loses some amount of accuracy, athlete comfort was a priority in this descriptive study. Also, data points were necessary for the calculation of A:C and self-testing results suggest that this strategy is the best possible approximation.

Metabolic Testing

Maximal exercise testing was conducted on a Trackmaster 4000 treadmill, and metabolic data were collected via indirect calorimetry using the Vyntus Vyaire metabolic cart. Prior to each day of testing, the metabolic cart was calibrated according to the user manual including both air flow and gas analyzer verification. As the athletes arrived, height and weight measurements were recorded to the nearest 0.1 cm and 0.1 kg. Next participants were fitted with Hans Rudolph 7450 Series Masks and corresponding head strap apparatuses as well as Polar H10 Heart Rate Devices. They were then instructed to complete self-guided warm-ups reflective of normal race-day preparations and allowed to start the test.

The discontinuous VO2 max protocol selected for this study was comprised of 3 submaximal speeds (14, 16, and 18 km/hour for the men and 10, 12, and 14 km/hour for the women) lasting 4 minutes each separated by 1 minute resting periods. All 3 stages were performed at 1% grade. These speeds and incline were selected to simulate typical training paces for both sexes and allow for accurate assessment of running economy at familiar workloads. Immediately following the 3rd stage, the belt was paused for a final 1-minute rest before initiating a maximal ramp protocol. Here, the treadmill speed was increased to 20 km/hour for men (16 km/hour for women), a simulated 10 km race effort, at 1% grade. Each minute, the incline was raised by 1% while holding the speed constant until volitional exhaustion. VO2 max, HR max, and RE expressed as %VO2 max were recorded for all 3 stages. All data points were recorded throughout the test in 20 second intervals, and VO2 max was considered to be the single highest VO2 value achieved over the 20 second time period. RE for each stage was assessed by averaging the VO2 values achieved for the last minute of each stage (3 20-second intervals) after steady state had been achieved. VT was also calculated using the Vyntus software to identify the point of respiratory compensation at which the increase in VCO2 outpaced the increase in VO2. Verification criteria for a true maximal VO2 included an RER above 1.10 and a maximal HR within 10 bpm of age predicted max heart rate. A typical test for this population lasted approximately 18-20 minutes for both sexes, and all athletes achieved a true maximal effort except for one instance in post-season testing which will be addressed. After 10-12 weeks, as athletes completed their respective cross-country seasons, they reported to the lab for follow-up post-season measurements. The exact same procedure was repeated, and changes were recorded for each metabolic variable of interest.

Results

Descriptive characteristics of the participants are presented in Table 1. A total of 6 male and 8 female participants from a Division I university volunteered for the study. However, due to HR monitor discomfort, 4 males and 2 females elected to drop out of the HR monitoring portion of the study. One of these women later suffered an injury and could not complete the second round of laboratory testing. Data from these cases are available but have been omitted from discussion of the results.

Table 2, Table 3, and Table 4 display the acute CL, preceding 4 week chronic CL, and the 4 week A:Cs respectively throughout the season. Data collection began August 28th and continued until the week of November 6th, and weekly CL values can be seen in Table 2. Note, Subjects 5 and 11 suffered from various injuries throughout the season especially in the final weeks and recorded values near 0 which artificially lowered the team-wide weekly CL averages. Because chronic load calculation requires having 4 complete weeks of data, Table 3 values begin the week of September 25th. Similarly, the A:Cs presented in Table 4 are calculated by dividing values from Table 2 by values from Table 3 and therefore are only available from September 25th onward. Averages A:Cs were computed both for each individual and for the team during each week of the season.

Table 5 depicts the race results of all study participants in meets where a full team (>5 runners) competed. Note that the women's race distance is 6 kilometers and the men's is 8 kilometers. For the final race of the year, NCAA Midwest Regionals, which was contested on 11/03, the men ran 10 km so the final time was converted to 8 km by dividing the total race time by 10 and multiplying the calculated 1 kilometer average by 8. Because there is variability in course difficulty and weather conditions, place on team for participating athletes was also considered. Percentile rank for each race was calculated by dividing place on team by total number of Illinois State University athletes competing in that race to provide an additional outcome variable which is not dependent on course conditions.

Table 6 & 7 present pre and post season metabolic data respectively measured in the physiology lab sessions. For each stage of testing, RE is recorded both as an absolute VO2 value as well as a relative percentage of VO2 max. Duration is measured in seconds and considered from the start of the final ramp protocol to test termination. Finally, VT is expressed both at the absolute VO2 value at which respiratory compensation occurred, as determined by the Vyntus Vyaire software, as well as a percentage of each individual's VO2 max. Female, male, and overall averages are also given. Table 8 & 9 show the percentage and absolute change respectively between the pre and post season testing. In general, beneficial adaptations are represented by positive changes, but improved RE is indicated by a decrease in oxygen cost to run the given pace and therefore negative changes are desirable.

Figure 1 graphs the race time and position on team for each athlete over the course of the season. These graphs include all races contested by that participant and vary slightly depending on which athletes qualified for championship races. A linear average of race time is also included to demonstrate season-long trends. A negative slope indicates faster times and improved performance. Figure 2 compiles the A:C trends throughout the season for each subject. Once again, subjects 5 & 11 dealt with injuries especially at the end of the year, which is reflected in the outlying low values. Subject 12 ran his longest run of the season the week of November 6th and is the only male who raced the 10 km distance that final week of the season which likely contributes to his abnormally high A:C. Finally, Figure 3 is a combination graph with the line representing race time and the bar displaying cardio load from the week preceding each race. Lower CL indicates lower relative intensity that week and lower race time indicates better performance.

Discussion

This investigation explored the daily, weekly, and monthly CL placed on Division I cross country athletes as well as the physiological changes undergone throughout a competitive season.

Physiological Changes

The first laboratory testing session took place within the first 2 weeks of the cross-country season, and the second was conducted within 1 week of the end of the season for each athlete. Although there was some variability in the end date depending on which athletes qualified for conference and regional meets, the time between tests was approximately 3 months. In this timeframe, we expect to see improvement in key physiological variables. Specifically, athletes who improved over the season should show a higher VO2 max and VT and/or a lower RE at the prescribed paces. All tests met the secondary criteria of RER > 1.10 and HR within 10 bpm of age predicted max except for Subject 4's post season test. This subject only achieved a maximal RER of 1.08 but had a HR of 209 bpm and reported an RPE of 19 in the final stage. Given the few participants and predominantly descriptive nature of this study, her test was included in the analysis, but her data specifically should be interpreted with caution.

Overall, VO2 max did not improve appreciably between tests, but there was high variability between individuals. As seen in Table 8, the 2 women who lost significant VO2 max capacity from pre to post season were Subjects 5 and 7. One explanation is that these two athletes are also the only undergraduate participants in this study. Although no research could be found to support this conclusion, personal experience with the sport suggests that the transition from high school to collegiate running can be difficult especially in low mileage runners and often results in impaired performance during the first few NCAA seasons. Perhaps less experience with the collegiate running intensity made them more susceptible to overtraining and thus led to decreased VO2 max throughout the long season. If this were the case, the data may suggest the need to modify training according to age and experience level to avoid overtraining and underperforming at the end of the competitive season. Another possible explanation, however, is that these runners were simply regressing towards the mean considering that they had the highest initial VO2 max in the preseason. On the men's side, Subject 12, a senior, demonstrated a similar pattern. All athletes train on their own in the summer preseason but perform the same training throughout the season, so it logically follows that VO2 max scores might cluster around the mean for postseason testing. Without more subjects, it is impossible to discern concrete relationships, but trends for both age/experience based training and overtraining may be worth monitoring in future research.

VT was measured in the final stage at the point where VCO2 outpaced VO2 indicating a respiratory compensation threshold. In general, both men and women showed improvement over the course of the season, but there was a high degree of variability. Additionally, some VT values seen in Table 3 and Table 4 occurred at over 90% of measured VO2 max. According to classic literature such a result is unlikely as even the most elite runners tend not to have a VT in excess of 90% VO2 max (14). It is possible that the discontinuous nature of the test is not conducive to accurate VT measurement. The Vyntus software relies on slopes of ventilation, VO2, and VCO2 to calculate VT, and the repeated starting and stopping may have impacted its ability to recognize VT, and the runners themselves may have responded differently in a continuous test. In future studies, a manual plot of ventilation and VO2 and/or VCO2 may be beneficial to assess VT specifically in the final stages of this protocol. Nonetheless, the methodology was consistent across all trials and trends may still be cautiously observed from VT data. One point of interest is that the highest male and female VTs, Subjects 12 and 5 respectively, are both longer distance runners in track with primary events in the 5k and 10k. Conversely, Subjects 4, 6, and 11 are all predominantly 800m and 1500m runners. Higher VT allows a runner to maintain a pace closer to VO2 max for a longer period of time without accumulating lactate. Perhaps high VT could predict tolerance or success at longer distances. However, some of the unrealistic VT values achieved in this study suggest that more research with a better VT identification protocol is necessary to confirm any of the observed trends.

The running economy paces were selected to simulate common training paces. Stage 1 represents a typical recovery day run, and Stage 2 reflects a long tempo effort that athletes typically ran at the end of long runs or beginning of workouts. Finally, Stage 3 is intended to imitate a threshold tempo workout run at a pace slightly slower than VT which these runners targeted 1-2 times per week during in-season training. Over the 3-month trial period during which athletes became increasingly familiar with these paces, it should be expected that RE decreased for each stage from pre to post testing. However, this was not the case. Table 7 indicates that there was actually a slight increase or no significant change in RE on average across both sexes for all 3 measured paces. Given the observed relationship between RE and performance, this result is potentially concerning (13). However, as evidenced in Table 7, there is a high individual variation in RE for both sexes. Specifically, Subjects 4 and 9 both had significant negative changes in RE especially for the first pace in stage 1. It is possible that an inadequate warm-up or pre-test anxiety artificially elevated these values beyond their typical O2 cost at the Stage 1 paces. Removing these two outliers would show a trend towards improved RE for both sexes, but it is impossible to make any concrete conclusions without additional testing and more participants.

By considering duration of the final stage of the test as a performance variable, we can attempt to quantify which athletes improved the most from overall pre to post test. Although the design of this study and small group of participants limits statistical power, it does allow for in-depth individual analysis. Notably, the most improved male athlete, Subject 11, lasted 2 minutes longer on the second test compared to the first. This progress was likely brought about by a combination of a 2.6 mL.kg-1.min-1 increase in VO2 max and an 11.7 mL.kg-1.min-1 increase in VT despite little significant change in RE at any stage. The highest female improvement came from Subject 2 who managed to last 80 seconds longer on her posttest with an identical VO2 max gain of 2.6 mL.kg-1.min-1, but an RE improvement of at least -5% for all 3 stages and no significant change in VT. By contrast, Subjects 3 and 4 were the only 2 subjects whose performance worsened on the second test. In both cases, these women had slight decreases in both VO2 max and increases in RE across the board. These four performances are important to note because they reaffirm the credibility of the selected physiological variables as predictors of performance for the participants in this study. Improvement in any combination of VO2 max, VT, and RE are certainly related to elevated performance capacity and decreases appear to have an association with worsening performance.

The male subject with the greatest improvement in VO2 max, Subject 9, also had the lowest VO2 max for his sex at the start of the season. Similarly, Subjects 1 and 2 had 2 of the 3 lowest female VO2 max preseason scores and were the only 2 women to improve in VO2 max throughout the season. Many of the other athletes with higher initial VO2 max values as seen in Table 3 did not improve VO2 max at all despite 3 months of intense training. This trend supports existing research which suggests that VO2 max is trainable to a certain point but is not the primary predictor of performance at an elite level (13). Further evidence for the diminishing returns of VO2 max can be found in Table 6. In this study, the two women with the longest test duration, Subjects 3 and 6, did not have the highest VO2 max values. In fact, their VO2 max scores were only slightly above the female average. However, they did demonstrate the best running economy relative to VO2 max at all 3 stages. Table 7 upholds this trend for the female athletes. Once again, this result is consistent with literature suggesting that runners needed to attain a minimum threshold for elite VO2, but thereafter performance was more impacted by RE than VO2 max (13).

It should be noted that there are significant limitations to the pre-post test design of this study. First, day to day variation is always a concern and is difficult to account for with only 2 testing days. However, all participants are trained athletes and should be accustomed to standardizing preparation and producing consistent performances on a given day. The greater concern is a diminished motivation from pre to post test. At the beginning, athletes tend to be excited for the upcoming season, and the VO2 max protocol was their first chance to run fast and truly test themselves. Contrast this scenario with the post season test where the athletes had just finished a grueling 3-month long training block culminating in a highly competitive regional championship race. Amidst the celebrating of a successful season, participants were asked to delay their well-earned time off, and come into the lab for a strenuous exercise test. Despite the best efforts of the researchers, excitement and motivation were noticeably lower for certain athletes during the second test, and it is possible that posttest values suffered to some degree because of this. In future studies, it may be ideal to conduct post-test measurements before the final race rather than after, but such a design is difficult to coordinate with hectic training schedules and specific workout needs in the final weeks of the season.

Cardio Load

Cardio load was measured by HR monitor, and weekly load was calculated by summing the workout totals for each session in a given week starting on Sunday. After the first month, chronic load for each participant was determined to be the average of the most recent 4 weeks of activity and A:C was subsequently calculated by dividing the current week’s acute load by the chronic load over the preceding 4 weeks. Because the first full week of data collection took place on August 25th, 4-week chronic loads could only be assessed beginning the week of September 25th. Unfortunately, the nature of cross country is such that many of the athletes begin training in earnest over the summer, and therefore A:C data missed the critical initial buildup period despite beginning data collection within the first weeks of the Fall semester. Additionally, Figure 3 indicates that the highest team A:Cs occurred in the first recorded week of September 25th. In order to accurately capture the season-long cardio load changes and see A:Cs leading up to the 25th, data collection in an ideal study would have begun over the summer when the athletes first began training.

Figure 1 shows the finish times of athletes in this study for every race throughout the season. For conference-qualifying athletes of both sexes, there was a trend to perform well early in the season, struggle at the conference meet (10/28), and return to baseline finish times for the final race of the season. It is worth noting that the conference meet had particularly bad weather and times tended to be slow across the board, but both the mens and womens teams still underperformed relative to their competition. Despite 2 months of in-season training, the team as a whole did not improve race times from the beginning of the competitive season. Although there will certainly be some variability course to course and day to day, the 9/30 and 11/11 races were contested on the same course which provides a convenient reference for comparison. Again, there was no significant improvement between the two races for either sex.

Perhaps one contributing factor for this degree of maintenance can be found in the A:C data. These same athletes' average A:Cs started the year at 1.17 just before the first competition, but then gradually declined all the way to 0.81 the week leading up to the conference meet. According to the principle of progressive overload, continually increasing physiological stress is necessary for beneficial adaptations. A:Cs on this team consistently below 1.0 indicate that the athletes were actually decreasing in intensity rather than increasing. There are many possible explanations for this trend, including specific training needs. Typically, distance programs focus on longer duration aerobic efforts early and pace-specific speed work later, which may elicit lower cardio loads given the decreased duration. In this case, another physiological stress variable such as heart rate variability may be worthwhile to track to give an additional reference for relative intensity. Another possibility, however, is that that some athletes were “tapering” on race weeks by reducing volume on recovery days and intensity on workout days in order to feel fresher for competitions. In this second scenario, tapering athletes may have performed better on early races due to the lower pre-meet intensity, but struggled to improve for post-season meets due to the subsequent decrease in CL and A:C.

This tapering theory is supported by individual A:C data. As seen in Table 3, Subjects 3, 4, and 12 were the 3 athletes with the highest average A:C throughout the season. Figure 2 shows the weekly trends for these runners, and all 3 started high and typically maintained A:Cs close to or above 1.0 even on race weeks throughout the core of the season. Additionally, all 3 had similar, and perhaps optimal, race trends. Figure 1 shows race time performances for these 3 runners, and each of them tended to have their worst races in the middle of the season but set personal bests en route to becoming the top male and top 2 female performers on the team for the last meet of the season, NCAA Midwest Regional Championships. All other athletes in this study had consistently lower A:Cs throughout the season and none ran season’s best races at the most competitive final meets of the year. The direction of the relationship is difficult to determine, and there is likely some degree of reciprocal determinism in that the best athletes had resiliency to maintain high A:Cs and those who maintained high A:Cs became the best athletes. In either case, this result is consistent with the literature which proposes the optimal A:C range of 0.9-1.3. Additional research on consistent progressive overload, tapering, cross country A:C ranges, and peak performances in post-season races is certainly warranted given these results.

Another glimpse into the concept of tapering can be seen in Figure 3. The line graph depicts time for each race of the season for each athlete, and the bar shows CL for the preceding week from Sunday-Friday. When considering each athlete's best and worst races, one notable pattern emerges: lower CL does not equate to faster race times. In fact, in many cases too low CL appears to be related to the poor race performances. Subjects 4, 5, 6, 9, and 12 all ran their slowest times after weeks with their lowest respective CLs. This is counterintuitive because one would assume that lowering training intensity would increase feelings of freshness and thus improve race times. However, it appears that reducing training intensity prior to races has an association with slower times. Conversely, an athlete's highest CL never preceded their slowest race except for one outlying instance with Subject 2 on September 11^{th}. There are several possible explanations for this trend. Perhaps athletes perform best in an established routine, and altering training breaks their natural rhythm. Anecdotally, some coaches preach the idea of "priming the legs" by still running a relatively hard workout or fast strides the week of a race in order to avoid staleness. Future studies may seek to establish a more concrete correlation or physiological basis for "priming" and performance.

Although existing research on the topic is limited, a growing body of evidence supports the idea of limiting tapering. One article examining the tapering technique in elite weightlifters found that volatility in training load (measured by Session RPE or sRPE) prior to competition has a significant association with decreased performance. Rather, these authors recommend maintaining a relatively constant internal load especially in the 21 days leading up to an event rather than tapering (18). Several other studies suggest similar trends and have found that a consistently high (<.9) A:C is both beneficial for aerobic capacity and protective against injury in a wide variety of populations including distance running, Australian Rules Football, rugby, and soccer (5, 6, 7, 19, 20, 21).

Although there is insufficient data from this study to establish a causal relationship and there exists the threat of overall fatigue as a confounding variable forcing athletes to reduce training and race slower, this trend suggests the need for additional research. If a true correlation can be found between low pre-meet CL in endurance athletes and slower race times, it would suggest that "over-tapering," or reducing CL too sharply prior to a race may have negative outcomes for that competition. Additionally, the previously discussed A:C data indicates that tapering too often and consistently lowering A:Cs may diminish overall fitness gains throughout the season as a whole.

Practical Application

Cardio load data and the derived A:Cs indicate that this team during the 2022-23 season had decreasing intensity throughout the year. Additionally, the 3 athletes with the highest A:Cs had the best performances at the end of the season for the NCAA Regional Championship. The immediate application is that coaches should consider targeting higher A:Cs for athletes throughout the season. Daily cardio loads could be monitored and workouts adjusted to keep weekly A:Cs above the recommended 0.9 threshold. Although there were too few instances in this study of athletes above the proposed 1.3 optimal ceiling, presumably HR monitoring systems could also be used to reduce intensity and avoid overtraining when necessary. This may be especially important on race weeks. Results from this study suggest that reducing A:C too much may have negative implications both for the proceeding race as well as the rest of the season if athletes taper too much too often. Rather, they may consider maintaining relatively normal schedules and only slightly reducing intensity only for the most important races.

From a laboratory perspective, early physiological testing such as that conducted in this study could offer a wealth of information for teams especially because the lab provides a consistent environment to monitor changes. Due to the nature of the sport, weather and course conditions may make it impossible to demonstrate improvement in competition even after significant physiological adaptations. Lab testing can provide coaches with data to track development and identify potential for breakthroughs which may not come across in races. Additionally, it provides a unique physiological profile for each athlete. Coaches could compare pre and post season data from year to year to determine which training methods led to the most successful seasons both for the team as a whole and for individual athletes. Over time, a database would be established with the longitudinal data on a variety of runners who went through the cross-country program at this university. One potential application for such information is primary event selection. Specialization in a primary track event is often determined by a process of trial and error and can sometimes take multiple years to find the best event for an athlete. Data from this testing may help identify physiological profiles of athletes in this specific program that find success at certain distances. For example, the high VT athletes in this pilot study were established long-distance runners, and it could be highly beneficial to identify freshman runners with similar characteristics who may find success in the 10k. Training could be adjusted earlier, and runners would not have to waste years of eligibility racing shorter races for which they are not as physiologically suited.

Conclusion

The purpose of this study was to use HR monitoring to identify instances of overtraining leading to decreased performance capacity in both a competitive and laboratory setting. However, the HR data and calculated A:Cs appear to paint an entirely different picture. The majority of athletes in this study maintained a relatively consistent performance ability throughout the season. On average, there was no significant improvement in times between the first and last race nor in the physiological variables measured in the lab. One possible explanation for the stagnation is consistently low A:Cs. The team as a whole averaged an A:C of 0.88 throughout the season with a downward trend suggesting that intensity decreased as time went on. The only 3 regional qualifying athletes to set season's best times at regionals were also the 3 with the highest A:C at .95, .95 and 1.30. These values fall within the literature recommended range of 0.9-1.3.

From this descriptive pilot study, many avenues of future research can be identified. Tapering, event selection, age and/or experience-based training intensity modification, cross-country specific A:C ranges, and HRV to performance relationships could all be explored more in depth. Perhaps more immediately useful, however, are the potential direct applications for this specific Division I program. Although this 2022 season was relatively successful, we would typically like to see more improvement from athletes over the course of the competitive year in race times and perhaps in the physiological variables as well. A future research project with a true randomized controlled design could seek to establish HR monitoring and A:C calculations as a viable training tool. Workout paces, number of reps, and recovery day mileage could all be easily adjusted on an individual basis to maintain optimal A:C throughout the season and track whether CL-based training improves performance. This project at the very least suggests the possibility that consistency and optimal A:Cs could be associated with increased performance, and testing of this theory should be a priority.

Table 1
Descriptive Characteristics of the Cross-Country Athletes

Subject Number	**Sex**	**Weight (kg)**	**Height (cm)**	**Age (years)**	**BMI**	**Primary Event**
1	F	53	166.4	22	19.1	Hybrid
2	F	53	157.5	21	21.4	Long Distance
3	F	52	167.6	22	18.5	Long Distance
4	F	56	170.2	22	19.3	Middle Distance
5	F	53	160	19	20.7	Long Distance
6	F	63	175.3	22	20.5	Middle Distance
7	F	60	167.6	19	21.4	Middle Distance
8	F	60	170.2	20	20.7	Long Distance
9	M	67	182.9	23	20.0	Middle Distance
10	M	70	196.8	21	18.1	Hybrid
11	M	67	177.8	21	21.2	Middle Distance
12	M	61	165.1	21	22.4	Long Distance

Table 2

Weekly Cardio Load Throughout Season measured in Arbitrary Units (AU's)

Subject Number	**28-Aug**	**4-Sep**	**11-Sep**	**18-Sep**	**25-Sep**	**2-Oct**	**9-Oct**	**16-Oct**	**23-Oct**	**30-Oct**	**6-Nov**	**Average**
2	1198.0	1032.0	1304.0	655.0	1124.0	834.0	1204.0	1084.0	886.0	791.0	237.0	940.8
3	851.0	1080.0	1252.0	805.0	1069.0	942.0	947.0	998.0	828.0	774.0	757.0	936.6
4	795.4	950.0	1360.0	790.0	1181.0	920.0	963.0	942.0	719.0	556.0	900.0	916.0
5	630.0	437.9	850.3	693.3	810.6	1170.3	778.0	683.3	649.0	299.0	0.0	636.5
6	1012.3	757.0	1157.0	892.0	934.0	577.0	892.0	545.0	645.0	572.0	802.0	798.7
7	880.0	1064.0	1155.1	972.1	804.0	933.0	892.0	836.0	559.0	624.0	212.0	811.9
9	919.0	1040.0	1057.0	975.0	939.0	546.0	969.0	842.4	566.0	227.0	424.0	773.1
11	545.2	265.0	727.0	781.0	592.0	255.0	96.0	490.3	399.0	146.0	27.0	393.0
12	460.0	789.0	295.0	329.0	594.0	795.0	417.0	700.0	588.0	583.0	1187.0	612.5
Average	**810.1**	**823.9**	**1017.5**	**765.8**	**894.2**	**774.7**	**795.3**	**791.2**	**648.8**	**508.0**	**505.1**	**757.7**

Table 3

Previous 4 Weeks Average Cardio Load Throughout Season measured in AU's

	Week Starting on Sunday							
Subject Number	**25-Sep**	**2-Oct**	**9-Oct**	**16-Oct**	**23-Oct**	**30-Oct**	**6-Nov**	**Average**
2	1047	1029	979	954	1062	1002	991	1009
3	997	1052	1017	964	1013	976	934	993
4	974	1100	1092	993	1031	915	824	990
5	653	698	881	863	861	848	630	776
6	955	935	890	844	757	704	703	827
7	1018	1029	996	930	896	805	728	915
9	998	1003	879	857	824	731	651	849
11	580	591	589	431	358	310	283	449
12	468	521	522	553	646	644	591	564
Average	**854**	**884**	**872**	**821**	**827**	**771**	**704**	**819**

Table 4

Acute to Chronic Ratios Throughout the Season

	Subject Number									
Week Starting on Sunday	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**11**	**12**	**Average**
25-Sep	1.07	1.07	1.33	1.24	0.98	0.91	0.94	1.02	1.43	1.11
2-Oct	0.81	0.90	0.84	1.68	0.62	0.91	0.54	0.43	1.53	0.92
9-Oct	1.23	1.02	0.88	0.88	1.09	0.90	1.10	0.16	0.80	0.90
16-Oct	1.14	1.03	0.95	0.79	0.65	0.90	0.98	1.14	1.27	0.98
23-Oct	0.83	0.91	0.81	0.88	0.96	0.62	0.69	1.11	1.03	0.87
30-Oct	0.79	0.79	0.61	0.35	0.81	0.78	0.31	0.47	0.91	0.65
6-Nov	0.24	0.91	1.23	0.00	1.25	0.29	0.65	0.10	2.14	0.76
Average	**0.87**	**0.95**	**0.95**	**0.83**	**0.91**	**0.76**	**0.75**	**0.63**	**1.30**	**0.88**

Table 5

Race Results of Participating Athletes by Week and Sex

Race Date	**Time** (minutes)	Place on Team	Percentile
16-Sep	**22.89**	**4.75**	**59.38**
F	**22.89**	**4.75**	**59.38**
2	24.04	8.00	100.00
3	21.87	1.00	12.50
6	22.39	4.00	50.00
7	23.24	6.00	75.00
30-Sep	**23.26**	**5.43**	**59.80**
F	**22.53**	**5.80**	**58.00**
2	23.25	9.00	90.00
3	21.40	1.00	10.00
4	21.97	4.00	40.00
6	22.11	5.00	50.00
7	23.91	10.00	100.00
M	**25.09**	**4.50**	**64.29**
9	25.21	6.00	85.71
12	24.97	3.00	42.86
14-Oct	**22.95**	**5.25**	**40.38**
F	**22.33**	**5.33**	**41.03**
2	22.93	9.00	69.23
3	21.29	1.00	7.69
4	22.41	5.00	38.46
5	22.46	6.00	46.15
6	22.12	3.00	23.08
7	22.78	8.00	61.54
M	**24.80**	**5.00**	**38.46**
9	24.96	6.00	46.15
12	24.63	4.00	30.77
28-Oct	**23.77**	**5.17**	**64.58**
F	**22.62**	**4.75**	**59.38**
3	22.12	3.00	37.50
4	22.05	2.00	25.00
5	23.20	8.00	100.00
6	23.12	6.00	75.00
M	**26.07**	**6.00**	**75.00**
9	27.00	8.00	100.00
12	25.13	4.00	50.00
11-Nov	**22.38**	**2.50**	**35.71**
F	**21.68**	**3.00**	**42.86**
3	21.04	1.00	14.29
4	21.70	2.00	28.57
6	22.29	6.00	85.71
M	**24.50**	**1.00**	**14.29**
12	24.50	1.00	14.29

Table 6

Preseason Physiological Testing Results

Subject Number	Sex	Stage 1 Economy (mL.kg-1.min-1)	Stage 1 (%VO2 Max)	Stage 2 Economy (mL.kg-1.min-1)	Stage 2 (%VO2 Max)	Stage 3 Economy (mL.kg-1.min-1)	Stage 3 (%VO2 Max)	VO2 Max (mL.kg-1.min-1)	Duration (s)	VT (mL.kg-1.min-1)	VT/VO2 (%VO2 Max)
1	F	34.0	70.2	38.7	80.0	42.9	88.6	48.4	200.0	38.5	79.5
2	F	40.4	78.1	45.3	87.6	49.0	94.8	51.7	160.0	48.6	94.0
3	F	37.1	68.5	41.3	76.1	46.8	86.3	54.2	260.0	43.3	79.9
4	F	31.7	62.1	43.8	85.8	47.5	93.1	51.0	240.0	38.9	76.3
5	F	46.0	79.2	50.1	86.2	55.9	96.2	58.1	140.0	45.2	77.8
6	F	38.6	71.3	42.7	79.0	46.9	86.6	54.1	300.0	41.8	77.3
7	F	43.8	74.3	48.6	82.3	52.2	88.4	59.0	240.0	49.3	83.6
F Average		38.8	71.9	44.3	82.4	48.7	90.6	53.8	220.0	43.7	81.2
9	M	35.6	59.8	40.3	67.8	48.0	80.6	59.5	240.0	47.8	80.3
10	M	46.1	71.0	52.4	80.8	59.0	91.0	64.9	240.0	51.9	80.0
11	M	50.6	74.9	56.5	83.7	62.1	92.0	67.5	180.0	50.5	74.8
12	M	48.2	65.6	53.7	73.2	60.8	82.8	73.4	300.0	66.7	90.9
M Average		45.1	67.8	50.7	76.4	57.5	86.6	66.3	240.0	54.2	81.5
Overall Average		41.1	70.4	46.7	80.2	51.9	89.1	58.3	227.3	47.5	81.3

Table 7
Postseason Physiological Testing Results

Subject Number	Sex	Stage 1 Economy (mL.kg-1.min-1)	Stage 1 (%VO2 Max)	Stage 2 Economy (mL.kg-1.min-1)	Stage 2 (%VO2 Max)	Stage 3 Economy (mL.kg-1.min-1)	Stage 3 (%VO2 Max)	VO2 Max (mL.kg-1.min-1)	Duration (s)	VT (mL.kg-1.min-1)	VT/VO2 (%VO2 Max)
1	F	38.7	74.8	43.0	83.0	46.2	89.2	51.8	240.0	45.6	88.0
2	F	39.3	72.3	44.2	81.3	48.7	89.6	54.3	240.0	47.1	86.7
3	F	38.1	70.4	44.6	82.4	49.0	90.6	54.1	220.0	45.0	83.2
4	F	41.9	83.4	44.9	89.3	47.9	95.2	50.3	180.0	41.8	83.1
5	F	44.2	78.4	45.4	80.6	51.1	90.8	56.3	140.0	53.0	94.1
6	F	37.6	70.3	42.4	79.3	46.4	86.7	53.5	320.0	38.7	72.3
7	F	42.1	74.4	45.9	81.0	50.3	88.9	56.6	280.0	50.8	89.8
F Average		40.3	74.9	44.3	82.4	48.5	90.1	53.8	231.4	46.0	85.3
9	M	47.0	71.5	51.7	78.7	56.8	86.5	65.7	240.0	55.7	84.8
10	M	45.0	70.5	50.4	79.0	57.2	89.7	63.8	240.0	45.4	71.2
11	M	51.9	74.1	55.6	79.3	62.3	88.8	70.1	300.0	62.2	88.7
12	M	46.7	66.1	50.9	72.1	58.9	83.5	70.6	320.0	68.0	96.3
M Average		47.6	70.6	52.2	77.3	58.8	87.1	67.6	275.0	57.8	85.2
Overall Average		43.0	73.3	47.2	80.6	52.3	89.0	58.8	247.3	50.3	85.3

Table 8

Percent Change in Key Physiological Variables Between Preseason and Postseason Physiological Testing

Name	Sex	Stage 1 Economy (mL.kg-1.min-1)	Stage 1 (%VO2 Max)	Stage 2 Economy (mL.kg-1.min-1)	Stage 2 (%VO2 Max)	Stage 3 Economy (mL.kg-1.min-1)	Stage 3 (%VO2 Max)	VO2 Max (mL.kg-1.min-1)	Duration (s)	VT (mL.kg-1.min-1)	VT/VO2 (%VO2 Max)
1	F	14.0	6.5	11.0	3.7	7.7	0.6	7.0	20.0	18.4	10.7
2	F	-2.7	-7.4	-2.5	-7.2	-0.7	-5.5	5.0	50.0	-3.1	-7.7
3	F	2.5	2.7	8.1	8.3	4.8	5.0	-0.2	-15.4	3.9	4.1
4	F	32.5	34.3	2.7	4.1	0.8	2.2	-1.4	-25.0	7.5	9.0
5	F	-4.0	-0.9	-9.4	-6.5	-8.5	-5.6	-3.1	0.0	17.3	21.0
6	F	-2.5	-1.4	-0.7	0.4	-1.0	0.1	-1.1	6.7	-7.4	-6.4
7	F	-3.9	0.2	-5.6	-1.6	-3.5	0.6	-4.1	16.7	3.0	7.4
F Average		5.1	4.9	0.5	0.2	-0.1	-0.4	0.3	7.6	5.7	5.1
9	M	32.1	19.7	28.3	16.2	18.4	7.2	10.4	0.0	16.5	5.5
10	M	-2.4	-0.7	-3.8	-2.2	-3.0	-1.4	-1.7	0.0	-12.5	-11.0
11	M	2.7	-1.1	-1.7	-5.3	0.3	-3.5	3.9	66.7	23.2	18.6
12	M	-3.1	0.7	-5.2	-1.5	-3.1	0.8	-3.8	6.7	1.9	6.0
M Average		7.3	4.6	4.4	1.8	3.1	0.8	2.2	18.3	7.3	4.6
Overall Average		5.9	4.8	1.9	0.8	1.1	0.1	1.0	11.5	6.2	4.9

**Beneficial physiological adaptations in green; negative changes in red*

Table 9

Absolute Change in Key Physiological Variables Between Preseason and Postseason Physiological Testing

Name	Sex	Stage 1 Economy (mL.kg-1.min-1)	Stage 1 (%VO2 Max)	Stage 2 Economy (mL.kg-1.min-1)	Stage 2 (%VO2 Max)	Stage 3 Economy (mL.kg-1.min-1)	Stage 3 (%VO2 Max)	VO2 Max (mL.kg-1.min-1)	Duration (s)	VT (mL.kg-1.min-1)	VT/VO2 (%VO2 Max)
1	F	4.8	4.6	4.3	3.0	3.3	0.6	3.4	40.0	7.1	8.5
2	F	-1.1	-5.8	-1.1	-6.3	-0.4	-5.2	2.6	80.0	-1.5	-7.3
3	F	0.9	1.9	3.3	6.3	2.2	4.3	-0.1	-40.0	1.7	3.3
4	F	10.3	21.3	1.2	3.5	0.4	2.1	-0.7	-60.0	2.9	6.8
5	F	-1.8	-0.7	-4.7	-5.6	-4.8	-5.4	-1.8	0.0	7.8	16.3
6	F	-1.0	-1.0	-0.3	0.3	-0.5	0.1	-0.6	20.0	-3.1	-4.9
7	F	-1.7	0.1	-2.7	-1.3	-1.8	0.5	-2.4	40.0	1.5	6.2
F Average		1.5	2.9	0.0	0.0	-0.2	-0.4	0.1	11.4	2.3	4.1
9	M	11.4	11.8	11.4	11.0	8.8	5.8	6.2	0.0	7.9	4.4
10	M	-1.1	-0.5	-2.0	-1.7	-1.8	-1.3	-1.1	0.0	-6.5	-8.8
11	M	1.4	-0.8	-0.9	-4.4	0.2	-3.2	2.6	120.0	11.7	13.9
12	M	-1.5	0.5	-2.8	-1.1	-1.9	0.6	-2.8	20.0	1.3	5.4
M Average		2.6	2.7	1.4	0.9	1.3	0.5	1.2	35.0	3.6	3.7
Overall Average		1.9	2.8	0.5	0.3	0.3	-0.1	0.5	20.0	2.8	4.0

**Beneficial physiological adaptations in green; negative changes in red*

Figure 1A. Race Data Throughout the Season for Subject 2

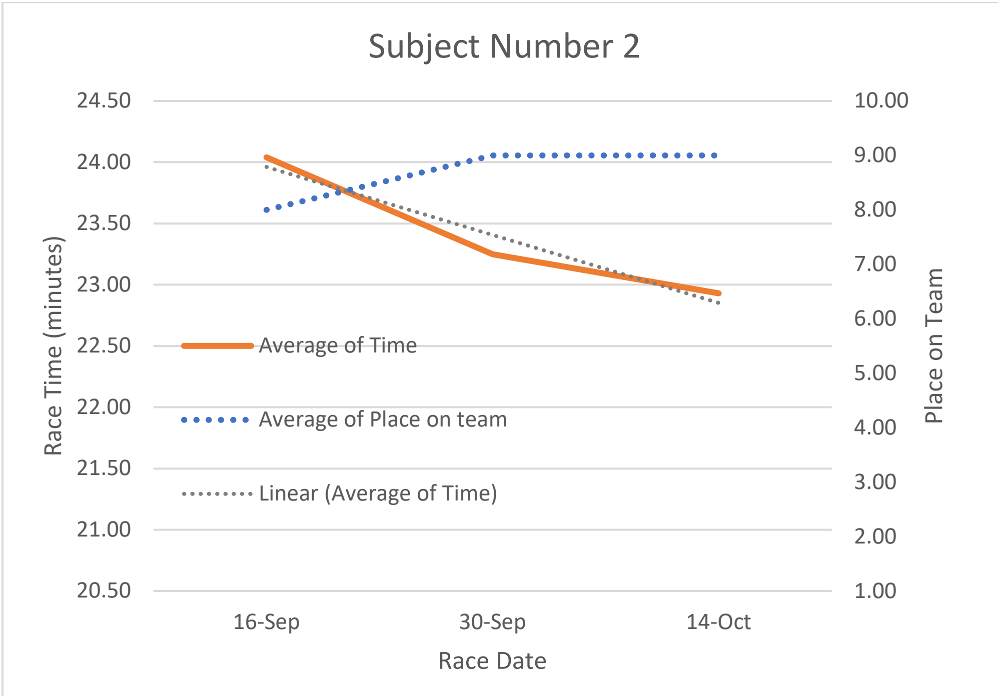

Figure 1B. Race Data Throughout the Season for Subject 3

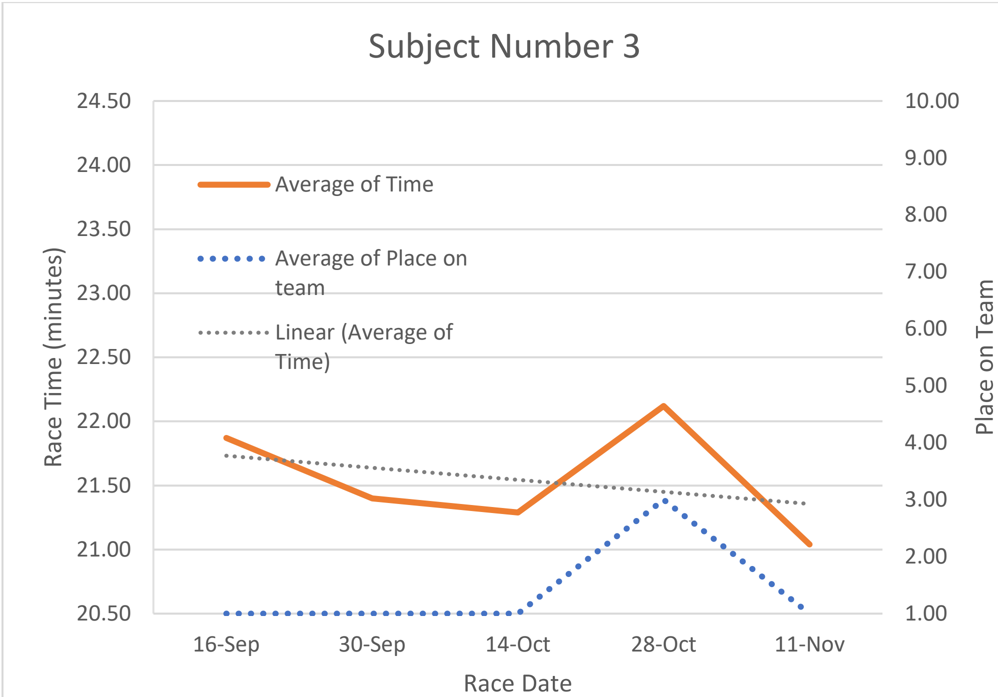

Figure 1C. Race Data Throughout the Season for Subject 4

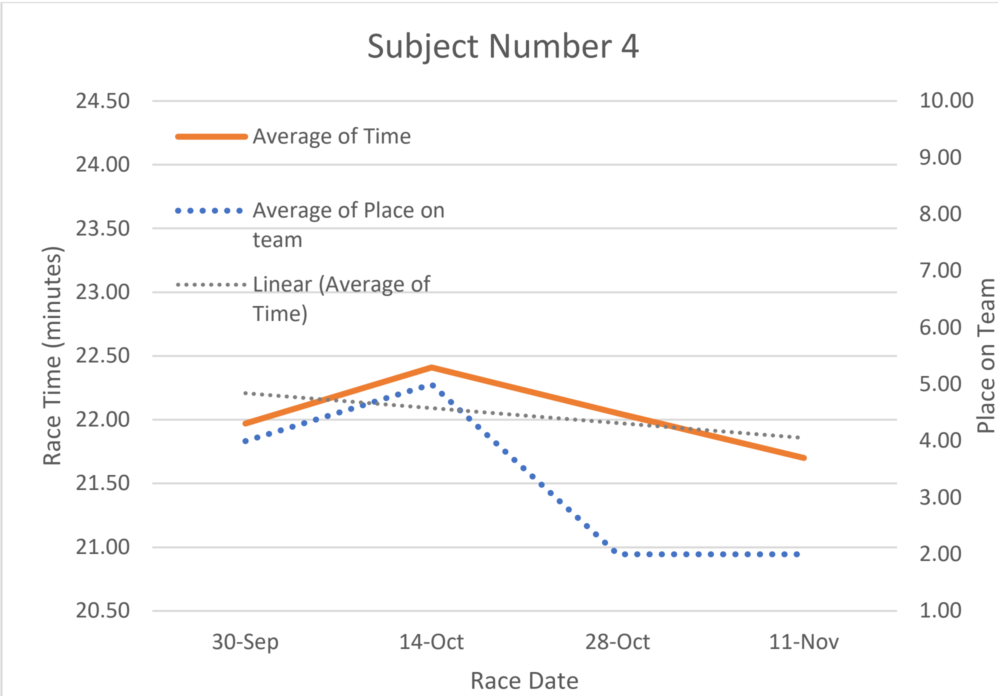

Figure 1D. Race Data Throughout the Season for Subject 5

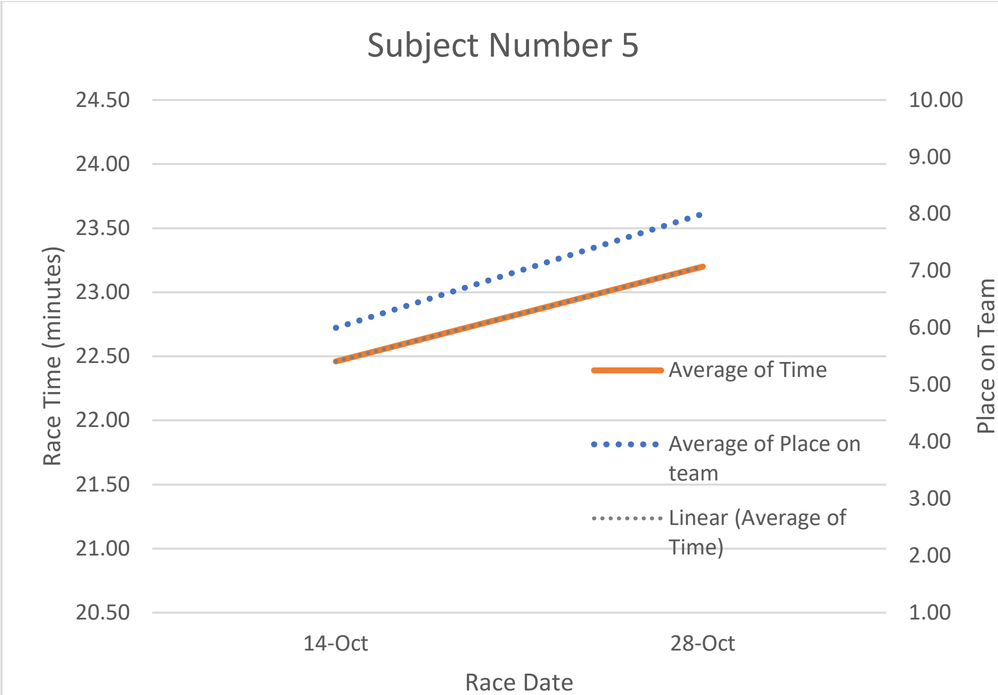

Figure 1E. Race Data Throughout the Season for Subject 6

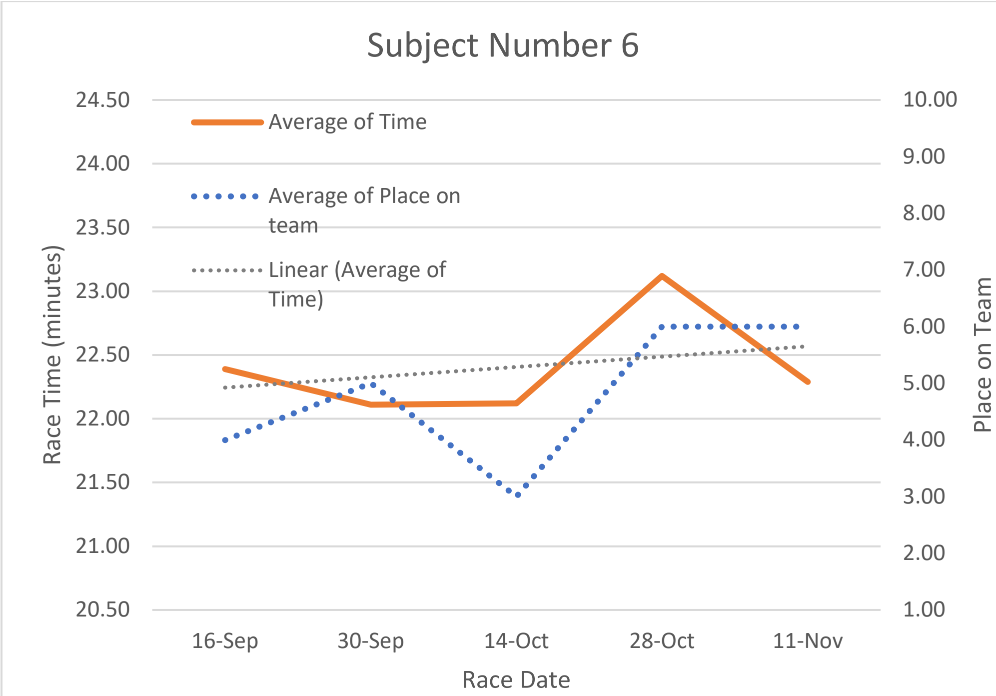

Figure 1F. Race Data Throughout the Season for Subject 7

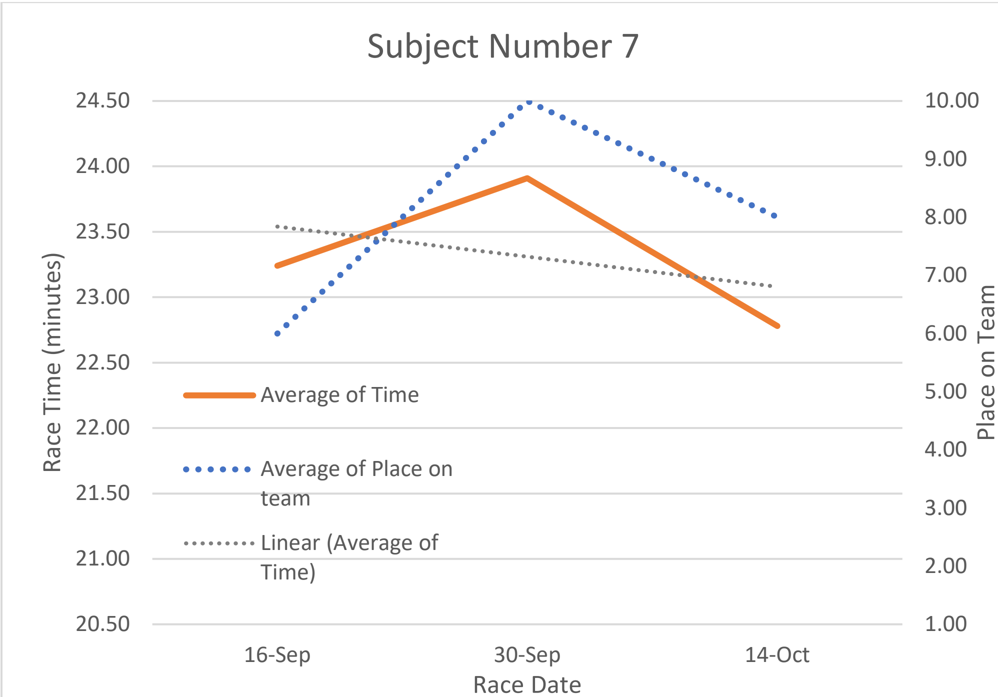

Figure 1G. Race Data Throughout the Season for Subject 9

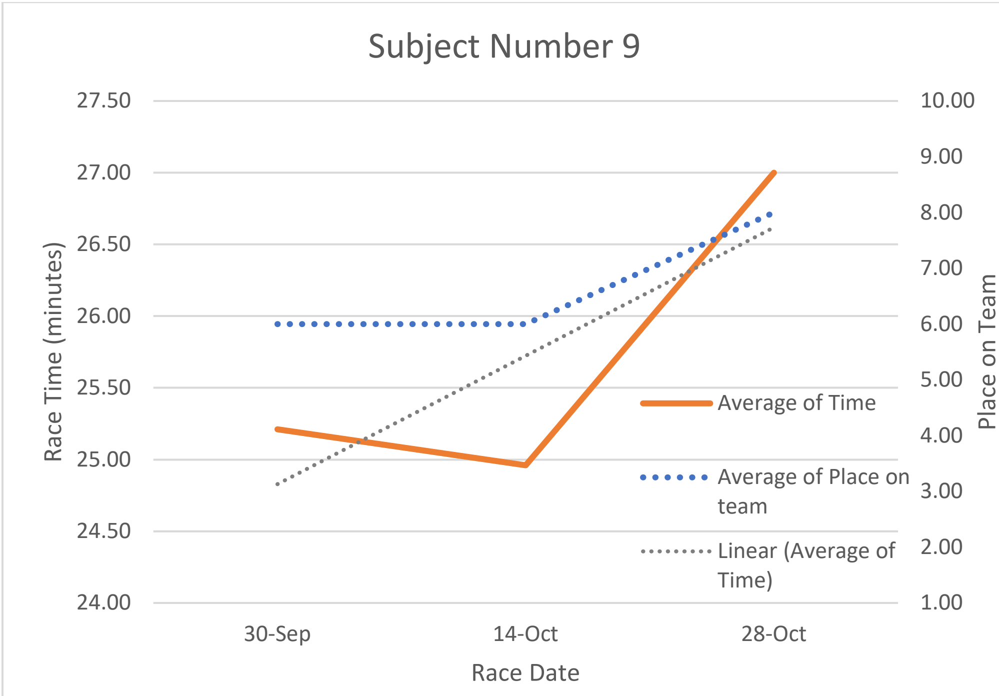

Figure 1H. Race Data Throughout the Season for Subject 12

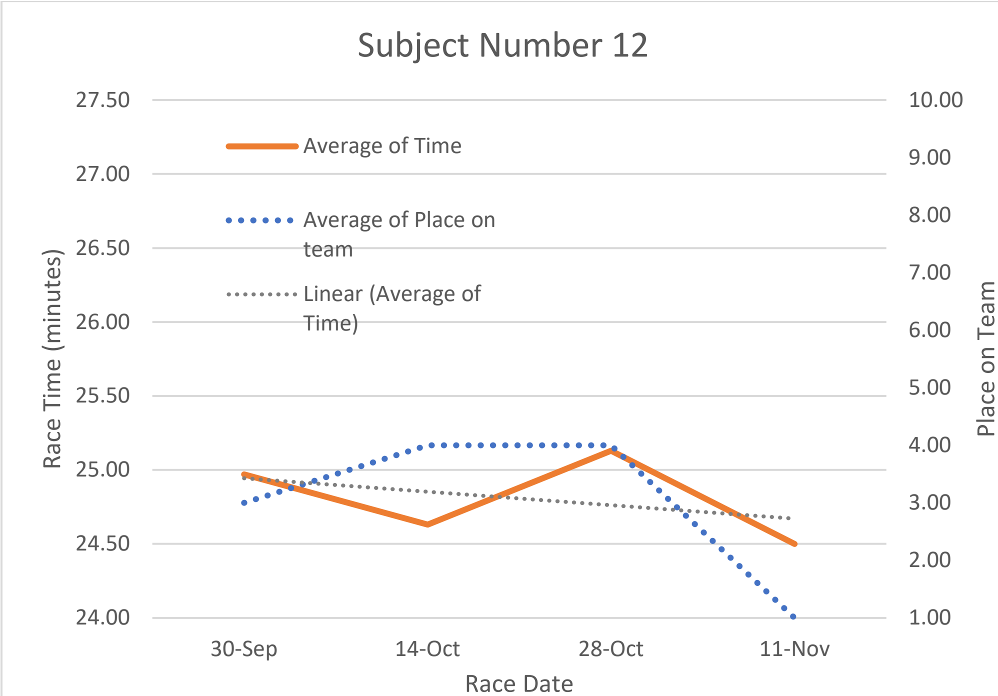

Figure 2. Acute to Chronic Ratio Trends Throughout the Season

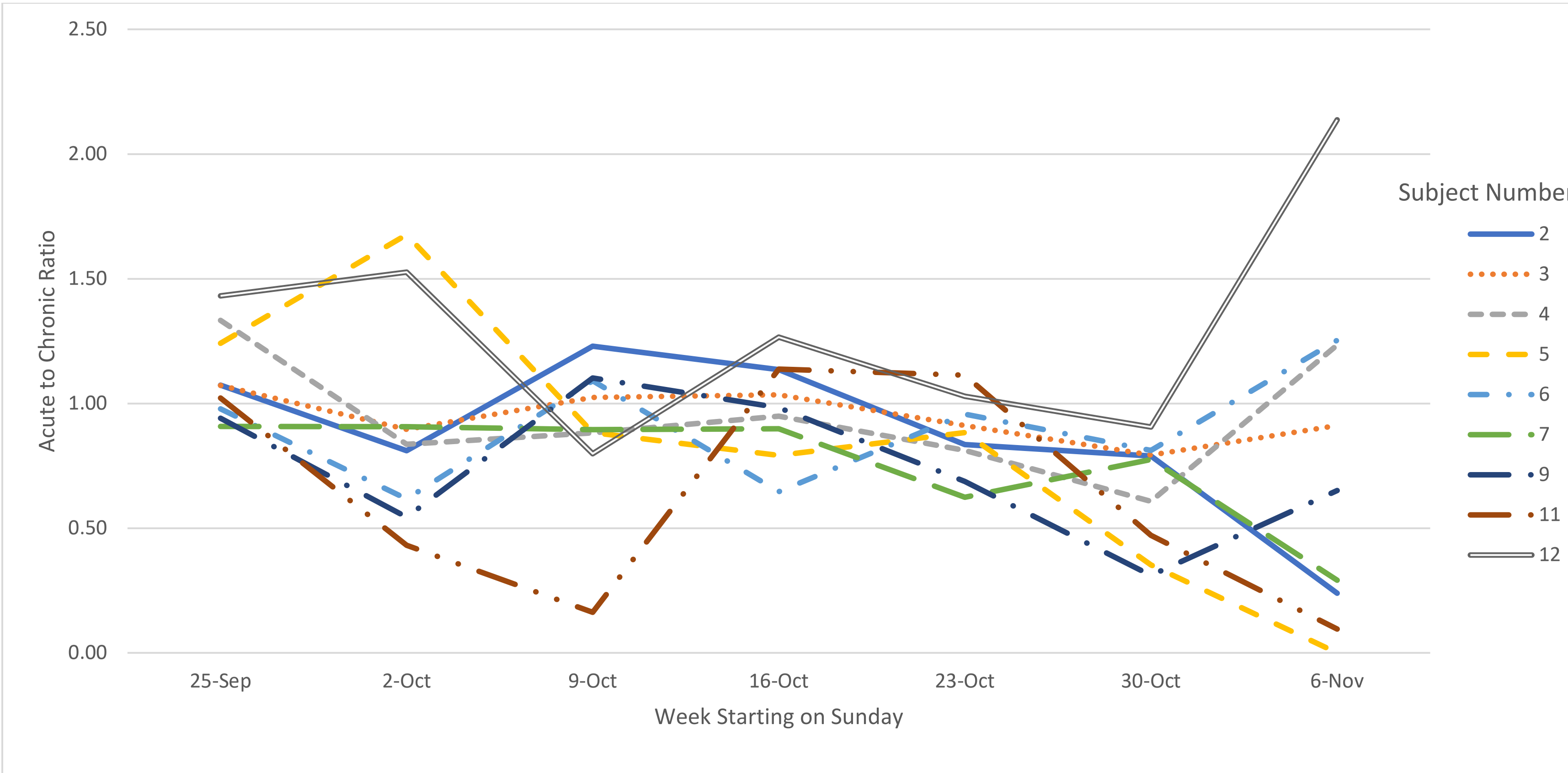

Figure 3A. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 2

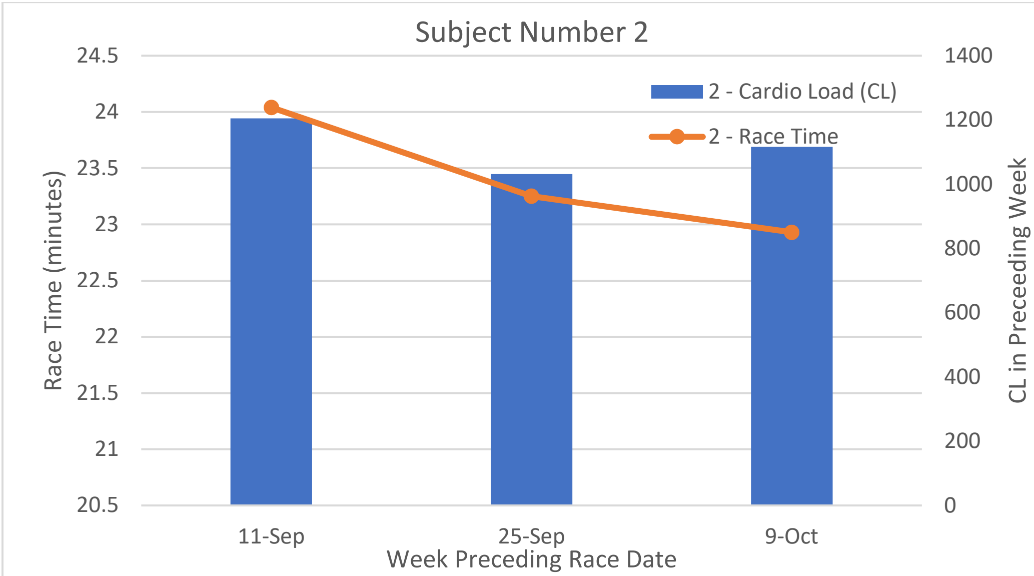

Figure 3B. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 3

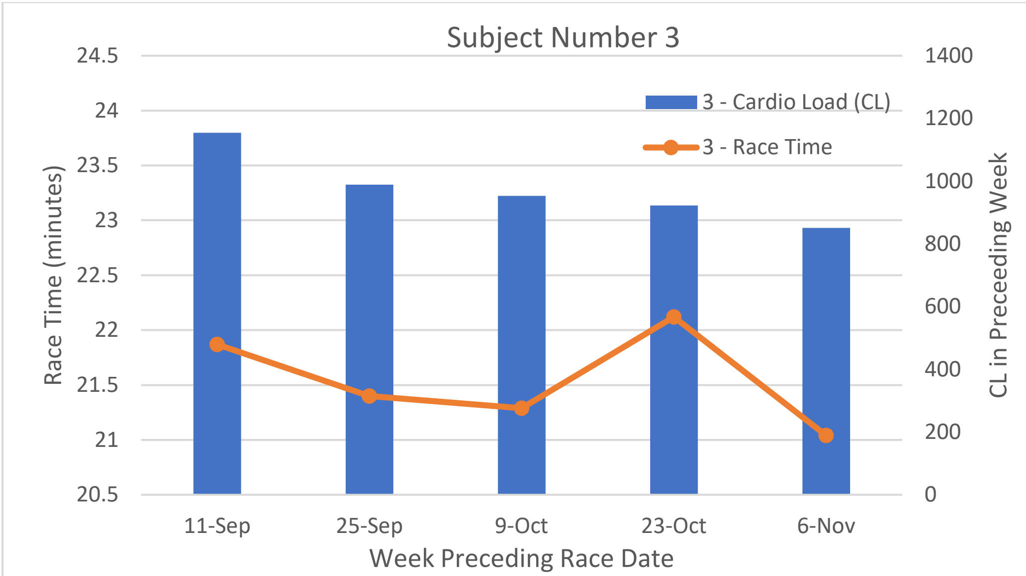

Figure 3C. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 4

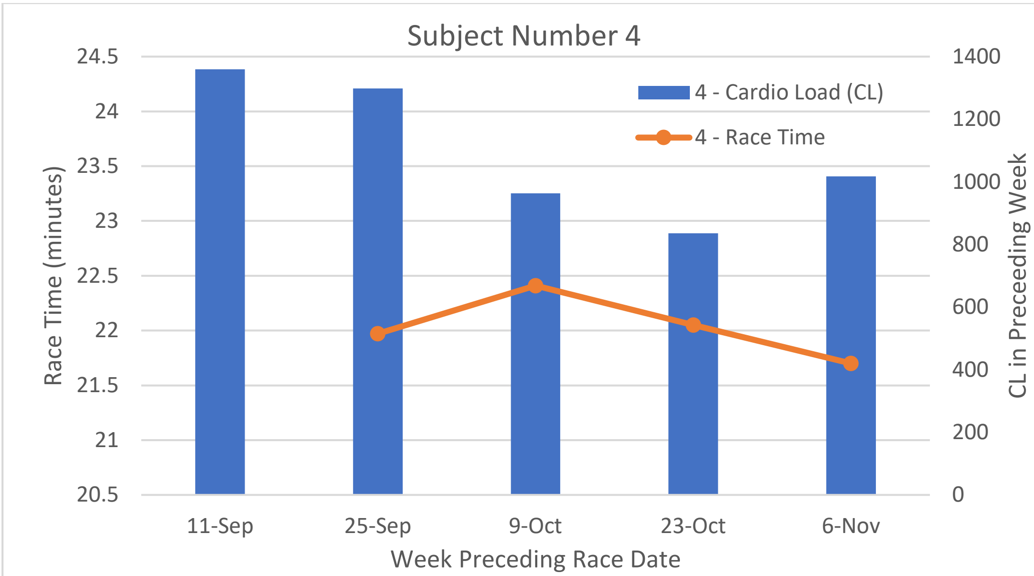

Figure 3D. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 5

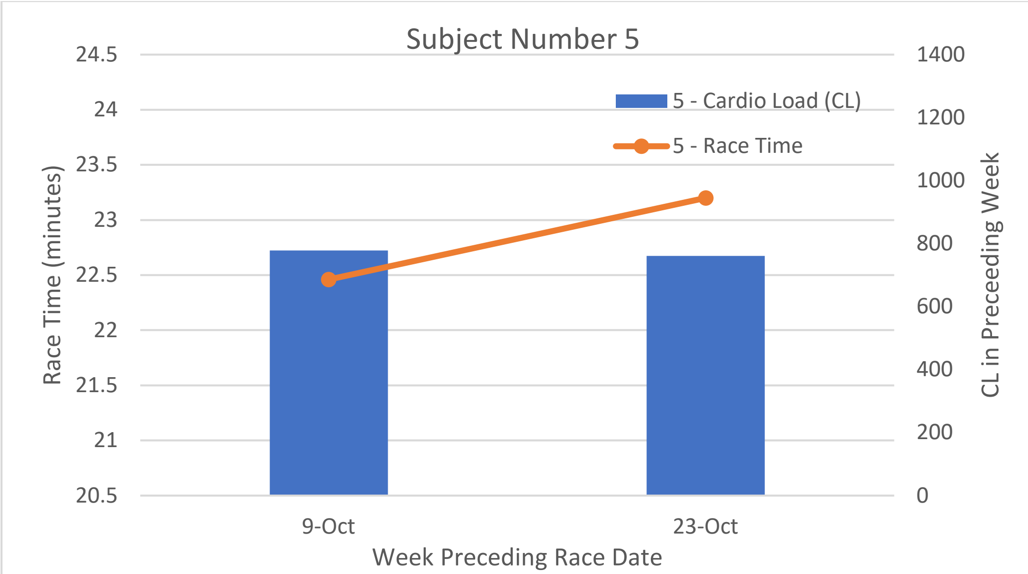

Figure 3E. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 6

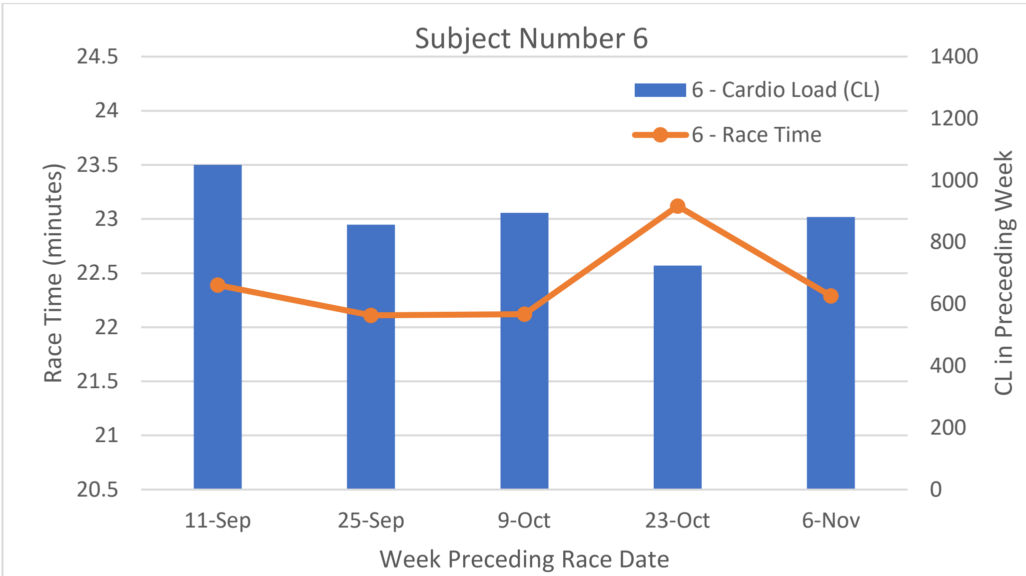

Figure 3F. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 7

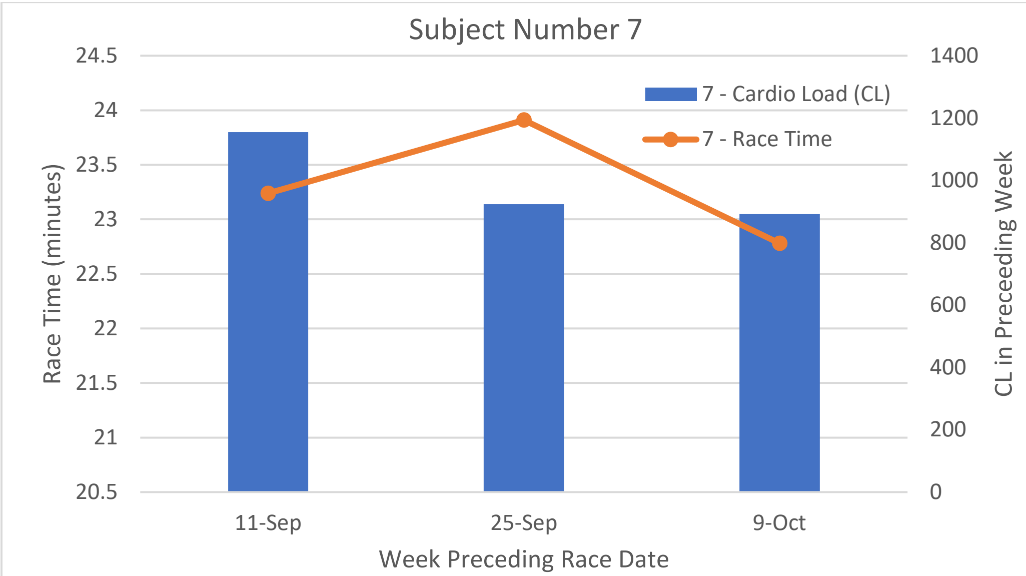

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Figure 3G. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 9

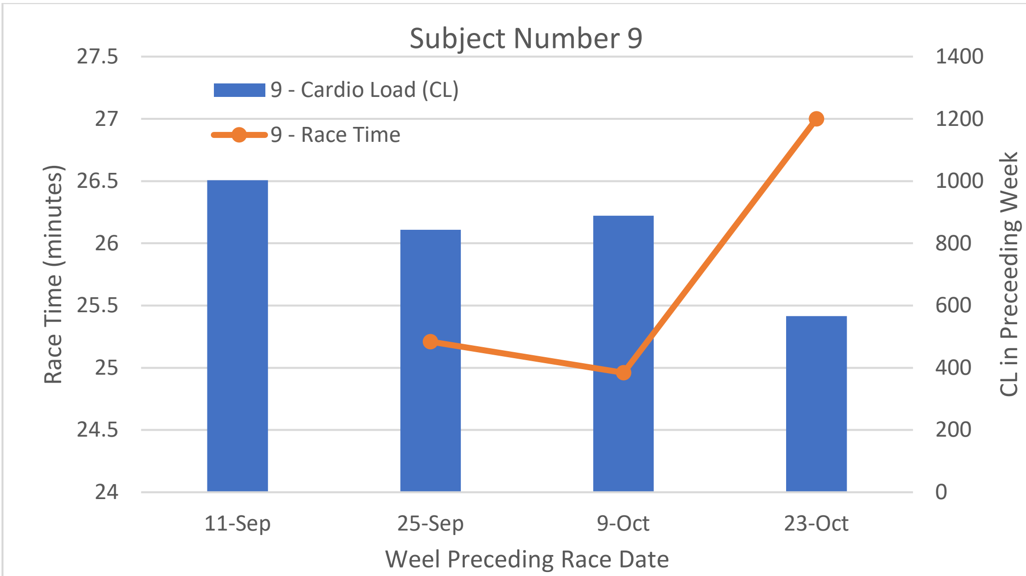
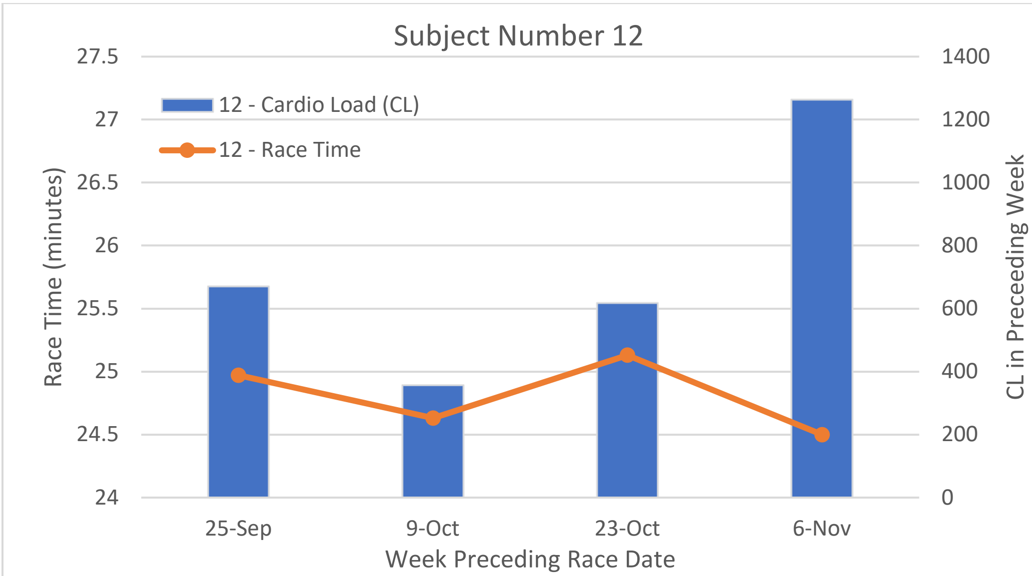


Figure 3H. Race Time vs. Preceding Week Cardio Load Throughout the Season for Subject 12



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CHAPTER II: EXTENDED LITERATURE REVIEW.

Internal Workload and Heart Rate Monitoring

The world of sports performance has experienced a revolution in recent decades as wearable monitoring technology has become more readily available. Whether recreational or elite, nearly all endurance athletes own one of the numerous forms of wrist or chest-based GPS or heart rate (HR) monitoring systems to gather workout data and ultimately improve performance. Although the exact metric differs by brand, all popular running technology companies provide feedback about duration and intensity in an attempt to describe workload for a given session. Many companies use an external workload which primarily considers total distance covered to summarize effort. However, one of the leading HR-monitoring companies, Polar Elctro (Kempele, Finland), calculates *internal* workload with a variable known as Cardio Load (CL). CL utilizes a proprietary algorithm which weights time spent in each HR zone to output a single number summarizing workout intensity each day. Because HR zones are based off of measured maximum HR, this internal workload method is highly individualized and has become one of the most popular techniques for assessing workload.

CL is especially important in endurance activities because progress in the sport hinges on maintaining an optimal work-rest balance. The principle of progressive overload dictates that load must be continually increased to experience improvement. However, too much intensity can lead to overtraining syndrome, which impairs performance (1). Research has shown that measures of internal workload, and CL in particular, provide important feedback to quantify intensity, improve performance, and reduce injury (2).

A 2017 study monitored the training load of 60 Australian Rules Football players (21.3 ± 2.9 years) throughout a 14-week preseason period (3). Although ARF is technically a skill-based sport, players typically cover between 12 and 15 kilometers over the course of a 2-hour game (4). Given the intense running requirement inherent in the sport, it is reasonable to consider ARF athletes under the endurance umbrella. Researchers calculated internal load with a metric known as session rating of perceived exertion (sRPE) which quantifies workload by multiplying a Foster's RPE value by the session duration in minutes. Although HR is not directly measured in this method, the RPE scale is based on HR data and literature has shown sRPE to be a reliable measure of internal load when compared to both CL and external load metrics (5). Researchers found significant associations between training load and aerobic fitness as measured by the results of a 2-kilometer time trial contested at 4 time points throughout the season. Time trial ability among the participants improved by 4.10 ± 2.20% over the course of the study, and the most significant improvements in aerobic capacity were associated with players whose training load averaged between 1,600 and 2,000 arbitrary units (AU) per week (effect size [ES] = 0.47–1.01). Training loads below 1600 AU seemingly were not high enough intensity to elicit desirable physiological adaptations, and training loads in excess of 2000 AU may have verged into overreaching and attenuated potential fitness gains (3). The results of this study reinforce the importance of maintaining an appropriate training stress balance and lend credibility to measurements of internal load.

Given the specific demands of AFR, it is unlikely that this range of 1600-2000 AU is a universal "sweet spot" for all athletes. Rather, there is likely a large individual and sport-specific variance. Another popular internal load metric gaining research traction is acute to chronic workload ratio (A:C). This value, derived from internal workload, divides the acute workload from the current week by the chronic load over the previous 4 weeks to measure the individual intensity of an athlete's sessions relative to their typical load (2). A study of Division I track and field sprinters from Florida State also found performance correlations with training load using A:C calculated from sRPE data on 7 elite sprinters during the 2018 outdoor season. Researchers found positive but non-significant correlations between average A:C and season best 200-meter sprint time ($r = 0.765$; $P = 0.235$) (6). The lack of significance is largely attributable to the small sample size, but the trend once again implies the potential impact of internal load monitoring.

In addition to the observed performance implications, sub-optimal training loads and A:Cs also have important injury implications. High loads and A:Cs can be predictive of overreaching and overtraining which leaves an athlete more susceptible to many types of injuries, but particularly overuse injuries. Following a 2014 study examining data from the NCAA Injury Surveillance Program found that an average of 12,612 track injuries occur each year across member schools in the NCAA (7). Overuse injuries are of particular concern because, according to recent NCAA data collected via a nationwide sample, runners suffered injuries at an alarming rate of 3.99 injuries per 1,000 athletic exposures. Among distance runners, 52.1% of all injuries sustained were classified as overuse and primarily affected the lower leg and foot/ankle region (8).

In recent years, numerous researchers have sought to better understand the connection between injury risk and A:C in sport. A 2020 systematic review analyzed 27 such studies including both internal and external A:Cs and found a trend toward an optimal ratio range of 0.80-1.30 for injury prevention (2).

A running-specific study from Amsterdam wanted to go a step further and model injury risk across A:C values in long-distance joggers. Researchers performed a prospective cohort study on a group of 435 recreational runners and collected data on external A:C measured by weekly distance and incidences of running-related injures (RRI) over an 18–65-week period.

They found that runners with an average A:C of >0.7 had a predicted probability of 9.6% (95% CrI: 7.5-12.4%) predicted probability of sustaining an RRI compared to 1.3 % (95% CrI: 07-1.7%) for runners with an A:C > 1.38. Modeling this relationship revealed an inversely proportional L-shaped curve which largely agrees with previous literature (9). The primary discrepancy, however, is that there was no upper threshold of A:C for which RRI risk increased. Many previous studies have suggested a ceiling of 1.3 above which performance is attenuated and injury risk spikes. The most likely explanation for this disagreement is that the Dutch study included only recreational runners, few of whom ever reached above an A:C of 1.3 and likely had a much lower absolute internal workload during these periods (9).

Physiological Testing

One of the primary challenges in this study was identifying an exercise test that accurately assessed VO2 max, ventilatory threshold (VT), and running economy (RE) for both men and women. The following section provides additional context for these physiological variables and outlines the selection and subsequent justification for the testing protocol.

Maximal oxygen uptake (VO2 max) is a measure of the body's ability to take in and utilize oxygen, and it is often measured using a metabolic gas analyzer and an ergometer. When intensity is increased on the ergometer without a subsequent increase in VO2, a plateau is said to have been reached indicating that the subject has achieved maximal oxygen consumption. Ever since this concept of VO2 max was introduced by AV Hill in 1923, maximal oxygen uptake has been the primary measure of aerobic fitness in the body. Despite the groundbreaking nature of his work, Hill's research also established a dangerous precedent that has been a common in current research: he only recruited male subjects (10). In the century since Hill's foundational paper, numerous researchers have established more specific protocols to elicit a true measure of the body's maximal capacity to utilize oxygen. Unfortunately, many such protocols were also developed using exclusively male data (11).

Women, especially endurance trained women, have many physiological differences which may impact outcomes of a VO2 test. Body size, lung capacity, hematocrit levels, fatigue indices, and normalization of VO2 to body weight have all been thoroughly studied and found to vary significantly between male and female runners (12). Biomechanical differences are also present. Some research has shown that sex-specific female anatomical differences, including a wider pelvis and smaller lower limb to total height ratio, tend to cause different neuromuscular activation patterns specifically at the gluteus maximus and vastus lateralis which may influence running economy (13). Other studies have found only marginal differences in activation patterns and no significant sex-specific differences in sagittal plane motion (14 & 15). These discrepancies in literature can likely be attributed to the prescribed pace, ability of the athletes, and incline of the treadmill on which they were tested, but an in-depth analysis of existing research is needed to clarify sex disparities in biomechanical running patterns.

This portion of the review will explore the current literature and topics surrounding VO2 max testing and optimal protocol selection specifically for elite female and male endurance athletes. First, barriers to female participation in sport and exercise research will be analyzed to place the issue within a cultural and historical context as well as to highlight the need for additional studies. By including foundational VO2 max studies as well as high quality randomized controlled or crossover design trials this review will then present an overview of the development of the most popular VO2 max protocols. Next, it will more thoroughly discuss the key physiological and biomechanical differences between sexes during running which necessitate testing considerations for female athletes specifically. Given the nature of the question, randomized trials are not feasible, so the evidence in this section will come from descriptive studies with a level V level of evidence. Finally, after synthesizing the established literature, this review will make suggestions regarding current VO2 testing protocols and identify avenues for future research. The main purpose of this study is to evaluate the reliability of established VO2 max testing protocols for female endurance athletes and identify an optimal method for both accuracy and feasibility that will be utilized in the current study.

Sufficient research on endurance trained women is difficult to locate. To begin with, female participation in long-distance running events was historically non-existent. In fact, the first women's marathon in the Olympics was not contested until 1984 due to a purported physiological inability to safely compete over extended distances (16). Since that time, females have shown remarkable improvement in endurance events, evidenced by the rapid progression of world record times post-1984 relative to men. So pronounced was the improvement, that certain popular lines of research predicted women to outpace men in ultra-marathon distances should it persist (17). Although record-setting paces have since plateaued, overall participation rates have continued to improve. According to a global survey encompassing millions of road racing results from 1986 to 2018, female participation in road races worldwide has eclipsed that of males over the past five years (18).

Despite an increase in women's sports participation, female athletes are still severely underrepresented in scientific research. In fact, a comprehensive 2014 probe into three prominent exercise and sport medicine journals revealed that, on average, only thirty-five of every 100 research participants over the preceding three years were female (19). While there is evidence of this sex disparity on a widespread clinical scale, it is certainly exacerbated within the world of exercise and sport medicine (20). Far too many studies fail to recruit an appropriate number of female participants due to a combination of volunteer bias as well as investigator bias. In either case, an underlying discrimination against women in sports likely influences the lack of involvement (21). More intentional recruitment effort from researchers will help to accurately categorize physiological differences between the sexes be properly understood.

Despite these challenges, many VO2 max protocols have been established and are widely used amongst female participants of all levels. According to a position statement from the American Heart Association, the Bruce protocol is the most widely used procedure for all genders at all levels (22). The Bruce protocol is a graded exercise test to volitional exhaustion consisting of successive 3-minute stages beginning at a walk on a gentle incline and progressing to a jog at steep inclines up to more than 20% in the later stages (23). Gaining traction throughout the 1950s with exclusively male subjects, the Bruce protocol was eventually validated for women in the 2000s, but only from a health and wellness or recreational standpoint. Because it consists primarily of walking stages with increasing incline, this modality suffices for a general population but may not be effective for athletes.

The goal of exercise testing should be to simulate a race environment as closely as possible, and recent studies have begun to ask whether the severe inclination achieved by elite athletes who endure to the later stages of the Bruce protocol is comparable to training situations. The idea of mirroring testing protocol to real-world activities is referred to as the specificity principle, and it is reinforced by recent research comparing running to cycling. Eleven highly trained distance runners and eleven elite cyclists completed maximal VO2 tests on both cycle and treadmill ergometers using a randomized crossover design. The runners achieved a 7% higher VO2peak on average on the treadmill compared to the cycle, but the cyclists experienced the opposite result with an 8% lower measured VO2 on the treadmill (24). This research confirms the importance of the specificity principle and implies that familiarity with the exercise mode, perhaps in combination with neuromuscular patterning and capillarization, has a substantial impact on measured VO2 max. As such, care must be taken to subject participants to a protocol that is comparable to the training that they regularly perform. Because distance running is predominantly performed on a level surface, it has been suggested that the extreme slope of the Bruce protocol is sufficiently different from flat running that it can nearly be considered an entirely different mode and should be avoided for elite athletes.

In addition to the Bruce protocol, there are numerous other VO2 measurement procedures which each carry a large body of supporting research. Although there are some interesting avenues of investigation, many studies suffer from the same limitations as the Bruce protocol, and it is beyond the scope of this review to address them all individually. Rather, procedures will be examined as a whole. The current stance on VO2 testing is that protocol does not make a statistically significant difference on maximal oxygen uptake. This position comes largely from a foundational 1976 paper by Pollock et. al. in which fifty-one volunteers were tested on four different popular treadmill protocols using a randomized crossover design (25). The protocols selected included the Bruce, Balke, Ellestad, and Astrand, which subjected participants to incremental increases in either speed, grade, or both, and no significant differences were found in VO2 max between any procedure (25). However, accuracy of VO2 measurement has increased significantly in the past fifty years, and, once again, the study included no female participants. Several other studies have since revisited this research on optimal VO2 protocol searching specifically for ideal stage and total test durations. Buchfurer found that VO2 values and incidence of plateau were greatest in tests lasting between 8 and 12 minutes, but he also failed to include any female participants (26). Not until 2007, was an adequate protocol validation study conducted on both sexes, but even then, no elite women were represented limiting the applicability to trained athletes (27). The most recent review, a meta-analysis published in 2016, acknowledged the lack of female participants and concluded that women, especially trained women, showed no decrease in VO2 max regardless of the length of the incremental stages or the total test duration after pooling results from previous research (28). Given this conclusion, elite endurance trained women are able to achieve a true max result in tests beyond the traditional 12-minute duration. This may be preferred for many athletes to minimize the jump in intensity between consecutive stages in an incremental test.

In order to determine an appropriate protocol for female athletes, it is important to consider the physiological differences between men and women. To begin with females in general tend to have a smaller body size which impacts the size of the heart and lungs. However, a large-scale descriptive study found that women have smaller lungs and airways even when compared to age and size matched men (29). Lower lung volume combined with greater resistive forces from narrower airways limits female minute ventilation which is a key determinant of VO2 max. Similarly, cardiac size, which is already reduced by tinier frames, is also smaller for females even after normalizing for lean body mass between sexes (30). Although endurance training results in significant hypertrophy in the left ventricle wall in both sexes, a cohort study of competitive British athletes found markedly lower ventricular thickness in females, who peaked at 11mm compared to males who peaked at 14mm as measured by echocardiography (31). Smaller heart size inhibits cardiac output which once again limits VO2 max for females compared to males. Given these limitations, optimal VO2 protocols in mixed-sex studies should consider adjusting the pace of the protocol according to the sex of the participant. By adjusting the absolute workload in this way, relative intensity remains the same for both sexes and should result in a test of approximately equal duration for participants of the same ability level.

Running biomechanics present another important difference between males and females. Research has shown that female runners tend to have minor anatomical differences such as a wider pelvis structure, but it is unclear how these anatomical differences impact running kinematics (32). One observational study examined 34 healthy endurance trained volunteers during walking and running trials at various speeds with inclinations of 0, 10, and 15%. Females consistently presented an elevated peak internal hip rotation, hip adduction, and level of gluteus maximus activation under all conditions. Additionally, electromyography readings at the sites of the gluteus medius and vastus lateralis showed significant discrepancy in activation patterns between genders. Females tend to have a greater relative gluteus maximus activation while running, and, more importantly, the rate of increase in vastus lateralis activity in response to increasing treadmill incline is significantly higher in women (13). Perhaps due to the previously identified wider pelvic anatomy, female runners must employ different neuromuscular pathways than males to achieve the same task (33). The hip rotation and adduction suggest excessive non-sagittal plane motion compared to men which could impact efficiency at the same relative intensity. Further, as the grade becomes steeper, women rely more heavily on the vastus lateralis and quadriceps in general than do men. Because maximal VO2 values are partially dependent on muscle size, disproportionately high quadriceps usage may skew results for females under inclined conditions (10). Thus, VO2 treadmill protocols that include an exaggerated graded component may elicit different responses between sexes. This result is consistent with the research arguing against the incline achieved in the traditional Bruce protocol. Given the current state of the literature, VO2 testing recommendations should consider limiting the graded component to below 10-15% in mixed-sex studies to minimize potential sex-specific kinematic changes which could impact VO2 outcomes.

The interconnected nature of running biomechanics introduces the possibility that these differences at the hip may manifest at the knee and ankle joints as well. A 2014 study by Phinyomark et. al. examined 483 endurance runners ranging from recreational to nationally competitive for kinematic sex differences at all joints of the lower extremity. In addition to the previously identified hip modifications, researchers found that females also tended to have slightly lower peak knee flexion angles at preferred running speed than males (34). Lower knee flexion implies a lower potential drive during swing phase and, ultimately, less power generation. However, this result contradicts previous studies from both Sinclair et. al. and Ferber et. al. which found no change in sagittal plane motion at any joint in a similar study. (14 & 15). Most likely, the conflicting results are due to the discrepancies in running speed. The large scale Phinyomark study allowed for preferred speeds between 8 and 12 kilometers per hour whereas the preceding research imposed speeds of 13 and 14.4 kilometers per hour in the Sinclair and Ferber studies respectively. It is impossible to draw definitive conclusions, but these results imply that female runners may moderate knee flexion at slower speeds and only increase flexion as needed to meet the sagittal motion demands of higher speeds. This mechanism may enhance overall efficiency for female athletes running at submaximal speeds and ultimately delay fatigability (33).

Biomechanical and neuromuscular efficiency, in this context, contribute significantly to overall running economy. RE is a measure of the oxygen cost of running at a given pace. A relatively large body of research exists supporting this theory of superior running economy in female athletes. Helgeud et. al. tested nine male and six female near-elite distance runners for efficiency as measured by oxygen cost of running at various percentages of a previously measured VO2 max for each individual. Researchers found that females runners had significantly lower oxygen cost of running at all relative intensities than did the males (35). It should be noted that many running economy studies, especially in elite female athletes such as Helgeud et. al., have access to only very limited subject pools. As such, there are many contradictory results which are unable to determine a significant difference between male and female running economy (33). Additionally, many researchers utilized different speeds, inclines, training statuses, and relative intensities making it impossible to draw definitive conclusions from the existing literature.

Because RE is a product of numerous physiological, metabolic, anatomical, and biomechanical attributes, it is difficult to pin down the exact cause of any potential female efficiency advantages. However, recent research claims that neuromuscular patterning may be the dominant factor. A 2021 study examined activation patterns for thirteen lower limb muscles on sixty male and sixty female endurance runners. Although the timings of the relative activity peaks were consistent between sexes, females demonstrated a narrower synergy window during the weight acceptance phase of the stride (36). This result suggests an overall shorter duration of neuromuscular activation to achieve the same stride as males. A more effective neuromuscular synergy could theoretically reduce fatigability and improve running economy in female endurance athletes. Certainly, more research with more consistent protocols is needed to understand running economy discrepancies between men and women. However, sufficient evidence exists to suggest the possibility of superior efficiency in female runners, and thus, any testing to quantify the endurance ability of female athletes should include a measurement of economy.

In conclusion, opportunities in both racing and research have been severely limited for female athletes historically but are constantly improving with intentional effort. Much research is still needed to fully understand the biomechanical and physiological sex-related discrepancies. Specifically, joint kinematics need to be measured using a consistent protocol with male and female athletes of a similar relative ability level in order to better quantify differences in biomechanical efficiencies, especially in the sagittal plane. Additionally, both physiological and biomechanical research with more elite participants is needed to substantiate the claim that female runners have superior running economy. Quantifying this difference could help accurately represent a female athlete's fitness profile compared to that of a male.

Based on the review of existing literature, several recommendations can be made regarding the optimal VO2 protocol for female endurance runners. First, despite the extraordinary progress of female endurance athletes over the past decades, physiological deficiencies relative to males including limited lung and heart capacity suggest the need to adjust the pace of treadmill protocols to achieve the same relative intensity between sexes. Additionally, the grade should not exceed approximately 10% at any point during the test. Not only does such extreme grade increase discomfort, but it is also not realistic for race-day conditions and may suffer from the specificity principle. Further, female vastus lateralis activation patterns are sufficiently different than males that increased elevation may elicit slightly different VO2 responses. Many lines of interdisciplinary research also suggest the possibility of superior running economy in females compared to males. As such, any measurement of endurance ability should include incremental stages of at least 3-5 minutes to allow time to reach steady state and calculate an estimate of economy at each intensity. Finally, the neuromuscular efficiency of female runners suggests that they may have a lower fatigability than male runners, and, especially at an elite level, both sexes can certainly handle long duration tests. Based on these key theories and recommendations, the optimal protocol for the population in this study should be an incremental (3-5 minutes per stage), pace-adjusted (same relative intensity expressed as a percentage of VO2 max), graded exercise test (below 10% incline). Future research should use large-scale randomized control trials to validate such a protocol for this population collecting data on VO2 max, running economy, and participant feedback on the smoothness of the testing process.

Given the current literature, the protocol selected for this project was modeled after an existing study that adhered to the recommended grade and duration parameters. Saunders et. al. tested 11 elite male distance runners (VO2 max = 70.3 ± 7.3 mL.kg-1.min-1) on two separate occasions 7 days apart. The chosen protocol consisted of 3 4-minute bouts of submaximal running at 14, 16, and 18 km/hour separated by 1 minute rest at 0% grade. Finally, a maximal ramp protocol was initiated beginning at 18 km/hour and every minute incrementally increasing first speed to 20 km/hour and then grade by 1% until exhaustion (37). The present research study elected to maintain a 1% grade throughout the test to better simulate the pace-specific effort and improve familiarity for the athletes in the study who typically performed all treadmill runs at 1% grade. Additionally, the maximal testing portion began at 20 km/hour for the men in order to limit test durations greater than 20-25 minutes. Finally, paces were adjusted to 10, 12, 14, and 16 km/hour for females according to IAAF conversion tables as well as participant feedback.

The Saunders study also incorporated a second test within one week after the first which was intended to measure test reliability. Researchers found an average typical error of 2.4% for VO2, 7.3% for VE, 27% for Lac, 1 and 4% for respiratory exchange ratio and HR (37). Given these findings, changes above 2.4% from preseason to postseason testing in the present study may be considered “real” and be indicative of physiological training adaptations rather than testing error.

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APPENDIX A: CONSENT FORM

SCHOOL OF KNR – EXERCISE PHYSIOLOGY LABORATORY

INFORMED CONSENT

Thank you for your interest in the services that are provided by the Exercise Physiology Laboratory. We feel that the information that can be provided to you as a result of these physical assessments will benefit you as you continue to make decisions regarding your health and wellbeing. While we are pleased to be able to provide you feedback regarding the physical fitness assessments that you have selected, we also like to be able to utilize that information measured to better understand fitness trends and activity of those individuals who utilize the Exercise Physiology Laboratory. Therefore, this form will serve two purposes; 1) allow you to provide your consent for us to perform the physical assessments that you are interested in, and 2) give your consent for us to be able to use the information measured for research purposes on the condition that your identity will remain anonymous. Read through both sections of the Informed Consent and sign where indicated. Additionally it should be noted that this form also serves as Parental Informed Consent and Informed Assent Agreement for participants that are under the age of 18 years of age.

Part 1 - Informed Consent for Physical Assessments

I fully recognize that there are dangers and risks to which I may be exposed by participating, voluntarily, in the following tests. I understand that Illinois State University does not require me to participate in this activity, but I want to do so, despite the possible dangers and risks and despite this Informed Consent form. I therefore agree to assume and take on myself all of the risks and responsibilities in any way associated with the following tests and further release, indemnify and agree to hold harmless the State of Illinois, Illinois State University and its governing board, officers, attorneys, employees, and agents from any and all claims, causes of action, judgments, fees, and accounts receivable that may arise from injury or harm to me, from my death or from damage to my property, whether in tort or in contract, including any past, present, or future claims or injuries that have arisen or may arise, in connection with the administering of the tests. This release shall be binding on my heirs, including my parents, spouse, children, successors, assigns, representatives, and attorneys. I have had the opportunity to answer all questions regarding the testing procedures.

Tests to be administered (select/check all of those that apply):

☐ 1.) Aerobic Exercise Performance

☐ 2.) Anaerobic Exercise Performance

☐ 3.) Body Composition

☐ 4.) Muscular Strength

☐ 5) Muscular Endurance

☐ 6) Lung Function

☐ 7) Flexibility

☐ 8) Student Fitness Program (includes all tests)

Address and Phone number:

______________________________ ______________________________
Name (please print)

____

______________________________ ______________________________
Signature

____

Parent's Name (if under 18)(please print)

Parent's Signature (if under 18)

Date

SCHOOL OF KNR – EXERCISE PHYSIOLOGY LABORATORY

Illinois State University

Part 2 - Informed Consent for Research Participation

Data Use for Research Purposes:

The ongoing analysis of information collected from individuals during physical fitness assessments is important for our further understanding of the role activity plays in the health and wellbeing of Americans. Your information will help us gain a better understanding of the type of response expected across a wide spectrum of ages, genders, and ethnicities.

What additional expectations are there for you for research purposes:

Nothing more, other than your consent. We are not asking you (or your child) to do anything additional than what you came to the Exercise Physiology Laboratory for in the first place. If you agree to allow your (or your child's) data to be used, we only need you (and your child) to sign this form, the attached informed consent form, and return both forms back to us.

Risks & Benefits:

Risks. There are minimal risks involved with your (or your child's) data being used in this research project. Your (or your child's) information will be completely anonymous and confidential. In other words, your name (or your child's) will not appear anywhere on the results produced from this research and only the Exercise Physiology Laboratory Director will have access to the data. Benefits. There are no direct benefits to you (or your child) in having your data included for research purposes. However, your information will help us to better understand physical fitness characteristics of individuals in our society. This is extremely important given the significant role the physical fitness plays in the relationship to various disease processes.

Voluntary Participation & Confidentiality:

Participation. Your participation (or your child's) in these physical assessments are completely voluntary and done so at your choosing/desire. If you decide not to have your (or your child's) data included for research purposes, do not sign/return the bottom of part 2 of this form and the data will be left out of potential future research studies. Confidentiality. Your (or your child's) information will be handled confidentially. Your (or your child's) name will not appear in any of the publications/presentations that result from your (or their) involvement with the Exercise Physiology Laboratory. Further, we will not show your (or your child's) data to anyone else. All data will be kept in a locked file within the Exercise Physiology Laboratory.

Who to contact if you have questions about the use of data for research purposes:

Dr. Dale D. Brown, School of Kinesiology and Recreation, Illinois State University, Normal, IL 61790-5120. Telephone (309) 438-7547.

Who to contact if you have questions about your rights in the study:

ISU Research Ethics & Compliance Office, Normal, IL 67901-5900. Telephone (309) 438-2529.

If you agree to allow your data (or your child's) to be included in the research study described above, please sign and date this form, and return the forms prior to your assessments.

Address and Phone number:

Name (please print)

Signature

Parent's Name (if under 18)(please print)

Parent's Signature (if under 18)

Date