AN ABSTRACT OF THE THESIS OF

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Running economy (RE) is the amount of oxygen utilized ($ml \cdot kg^{-1} min^{-1}$) when running a fixed speed, and it has been demonstrated to be an important factor determining race performance in distance runners. There is evidence that running economy and/or maximal oxygen consumption (VO_{2max}) improves over the course of a training season in distance runners. However, little research has examined RE in high-level team sports that require athletes to cover large distances over the course of a competition. PURPOSE: To examine RE and VO_{2max} values across a season in female NCAA Division I soccer athletes. METHODS: Fourteen female soccer players from a Pacific Athletic Conference team completed pre-season and post-season aerobic testing on a motorized treadmill; 14 weeks separated the testing sessions. Players performed a combined RE/VO_{2max} test that consisted of a 3-minute warm-up at 6mph, two continuous 6-minute bouts at 7 mph and 8 mph, during which RE was assessed, and a final, continuous segment that maintained the treadmill velocity at 8 mph and increased treadmill incline by 2% the next minute and 1% each successive minute until volitional exhaustion was reached. Minute-average data was collected from exhaled air using a ParvoMedics

TrueMax 2400 metabolic cart. RE was defined as the average of the oxygen uptake for the last three minutes of the 7 and 8 mph bouts. VO_{2peak} was determined with the highest one-minute average oxygen uptake value for each participant. RESULTS: Paired t-tests showed no significant differences between any of the RE or VO_{2peak} values from the pre-season and post-season test sessions. The mean subject height was 169.14 ± 3.37 cm. The mean body mass pre- and post-test was 63.83 ± 6.88 kg and 63.70 ± 6.60 kg, respectively. There was no difference between pre- and post-testing for RE at 7 mph or 8 mph, $p > 0.05$, (36.32 ± 1.40 $ml.kg^{-1}min^{-1}$ vs. 35.92 ± 1.23 $ml.kg^{-1}min^{-1}$ and 41.33 ± 1.27 $ml.kg^{-1}min^{-1}$ vs. 41.17 ± 1.75 $ml.kg^{-1}min^{-1}$). There was also no significant change in VO_{2peak}, $p > 0.05$, (46.19 ± 3.87 vs. 46.16 ± 4.54 $ml.kg^{-1}min^{-1}$). CONCLUSIONS: High-level soccer training and competition does not appear to elicit measurable changes in RE or VO_{2peak} over the course of a season.

VO_{2peak} and Running Economy in Female Collegiate Soccer Players Across a Competitive Season

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APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Johanna R. Olson, Author

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CONTRIBUTION OF AUTHORS

Dr. Wilcox was involved with the design and writing of this project. Dr. Peterson assisted in the interpretation of the data. Jay Penry assisted with data collection.

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VO_{2peak} and Running Economy in Female Collegiate Soccer Players Across a Competitive Season

INTRODUCTION

Since the inception of women's competitive soccer, it has increased in popularity at all levels of play, with an estimated 6.3 million females over the age of 7 years participating in the United States alone (35). Despite this increase in popularity, limited research has been conducted on the female soccer athlete (12, 16).

Over the years, soccer for males and females has become a much more dynamic sport in which superior technical, and individual and team tactical abilities can only be demonstrated consistently throughout a 90-minute game by players who have a high endurance capacity (46). This high-intensity intermittent team sport relies predominantly on the aerobic energy pathways during competition (17, 25, 46). Approximately 98% of the total work capacity used during a game comes from the aerobic pathways while the remaining 2% is anaerobic in nature (4). Aerobic fitness is a vital component among soccer players and has been positively correlated with distance covered over a match and other performance outcomes (7, 22).

Because a high level of physical fitness is an integral component of soccer, it is important to test aerobic capacities among players. Maximal oxygen carrying capacity (VO_{2max}), lactate threshold (LT) and running economy (RE) are three critical elements when determining aerobic endurance. Maximal oxygen capacity (VO_{2max}) is the greatest rate at which an individual can consume oxygen while performing muscular work (15, 41). VO_{2max} values among male soccer players range from 50-75 $ml \cdot kg^{-1} min^{-1}$ (2, 6, 11, 26, 32, 46). These values are higher than males from the general population yet lower than endurance athletes (2). Among female soccer players, VO_{2max} values lie between 47 $ml \cdot kg^{-1} min^{-1}$ and 57 $ml \cdot kg^{-1} min^{-1}$ (1, 2, 12). These values are also consistently above the general population yet below female distance runners, which range from 58.3 ml.kg-1min-1 to 78.6 ml.kg-1min-1 (15, 51).

Helgerud et al. (21) demonstrated increases in VO_{2max} among male soccer players after 8 weeks of high-intensity interval training, and Impellizzeri et al. (26) report that small-sided games of high intensity enhanced aerobic fitness and performance. It appears from these studies that total distance covered in a match and total distance covered at high-intensity are the most important performance indicators in soccer. VO_{2max} among male soccer players has also been positively correlated with rank among national teams in Hungary, Norway, and Iceland, however; in Denmark researchers found no correlation between VO_{2max} and rank (2, 3, 42, 53). Reilly et al. (41) concluded that there appears to be a VO_{2max} threshold below which soccer players cannot successfully compete at a top level. As it appears that a relatively high VO_{2max} value is necessary for competition in high-level soccer, and may not differentiate amongst them, it has been suggested that running economy also be tested to evaluate specific training effects (22).

Running economy can be defined as the steady-state oxygen consumption ($ml \cdot kg^{-1} min^{-1}$) at a standardized running velocity (1, 19, 20). When VO_{2max} values among highly trained distance runners are homogenous, running economy (RE) has been shown to play an important role in performance outcomes (12, 13, 14, 34). Because soccer is a high-intensity intermittent sport, in which mechanical skill and neuromuscular skill are important along with endurance capacity, improving RE may be more effective than attempting to increase VO_{2max} due to the nature of the sport (32). Hoff et al. (23) demonstrated that improving running economy through a strength-training program can increase aerobic performance. This is consistent with Paavolainen et al. (39), who found a significant change in 5 km performance among male athletes ($P < 0.05$) with improvements in RE and no change in VO_{2max} when a 9-week explosive strength-training program was implemented.

Improvements in RE could have the same positive effect on performance as increasing aerobic power because an athlete with good RE would show a lower relative intensity at a given speed than a less economical runner. This could lead to improved performance among runners and other endurance related sports (1, 13). Improvements in RE by 5% (25) and 5 $ml \cdot kg^{-1} min^{-1}$ in unpublished data reported by Stolen et al. (46) would theoretically result in an increase of 1000 to 1500 m, respectively, over the course of a game with no change in aerobic power among male soccer players.

Women's soccer has established itself as a popular and competitive sport at all levels of play over the past two decades yet research on the physiological and physical characteristics of women players is still limited. Davis and Brewer (16) report that characteristics of female soccer players seem to be similar to male players, but it is important to add to the scientific understanding of the physiological characteristics of this female athletic population in order to enhance the standard of the game.

The purpose of this study is to determine changes in RE and VO_{2max} that take place over a 14-week competitive season in female collegiate soccer athletes. By observing RE and VO_{2max} values among a team of Division I female soccer athletes, valuable information will be gained to assist coaches and athletes in improving aerobic capacities and therefore performance. It is hypothesized that VO_{2max} would remain stable or increase across the competitive season and that RE would improve due to the high-intensity intermittent play associated with soccer training.

METHODS

The methods and procedures of this investigation were approved by the Institutional Review Board at Oregon State University (Appendix A). Additionally, each participant granted written informed consent before participating in the investigation (Appendix B).

Participants

Volunteers were recruited from a Division I women's soccer team in the Pacific Athletic Conference (PAC-10). Eighteen women from the team volunteered for this study (18-22 y); fourteen were able to come back for post-season testing.

Study Procedures

A pre-season to post-season testing design was implemented. The dependent variables of interest in this study are pre-season and post-season VO_{2max} and running economy (RE) values.

Personal Information and Questionnaires

Each participant completed a health history questionnaire (Appendix C). This questionnaire was designed to collect personal information (name, age, history of cardiac events, medications) and emergency contact information. In order to ensure complete understanding of the questionnaire and study protocol, a research staff member was available to answer questions.

Running Economy (RE) and
Maximal Oxygen Consumption (VO_{2max}) Test

Pre-season Testing

All subjects were weighed with and without shoes and heart rate monitor on a calibrated scale in the Women's Building human performance lab at Oregon State University. All participants wore lightweight clothing of choice and running shoes for the test. In the RE test, body weights included weight of the clothing, shoes and heart rate monitor because it contributed to the running workload. The weight of the heart rate monitor and shoes were not included in body weight for the expression of VO_{2max}. All tests were conducted using a continuous running protocol on a Trackmaster TMX22 treadmill (Newton, KS). All participants were familiarized with the testing procedures prior to the onset of the test. The test consisted of a standardized three-minute warm-up at 6 miles per hour (mph) (161 $m \cdot min^{-1}$) on a level surface. Participants then ran for six minutes at 7 mph (188 $m \cdot min^{-1}$) followed directly by 6 minutes at 8 mph (215 $m \cdot min^{-1}$). The velocity of the treadmill at both steady state bouts was validated using a digital contact tachometer with an accuracy reading of ± 0.05% (Kernco Instruments Co. Inc., El Paso, TX). These two steady-state bouts were used to measure RE.

Upon completion of the steady state bouts, the velocity did not change and the elevation increased to 2% in the next minute and 1% each additional minute until the participant reached volitional exhaustion. This protocol was used because it has been shown that inclined treadmill tests recruit a larger muscle mass at a slower cadence, allowing individuals to reach their true VO_{2max} (4). Borg's rating of perceived exertion (RPE) scale was recorded in the last 15 seconds of each stage throughout the test.

Participants wore a breathing mask (Vmas; Hans Rudolph, Inc., Kansas City, MO) that covered both the nose and mouth that best fit their face sizes and shapes to provide an airtight seal. This low-resistance breathing apparatus allowed the participant to inhale room air and directed exhaled air to a metabolic cart. Metabolic gases were recorded in 15-second intervals and analyzed each minute using open-circuit spirometry (True One 2400 Metabolic Measurement System, PAR O Medics, Salt Lake City, UT). Flowmeter calibration was conducted at the beginning of each testing day using a 3-liter calibration syringe, series 5530 (Hans Rudolph, Inc. Kansas City, MO). Oxygen and carbon gas analyzers were calibrated prior to each test with known concentrations of standard gases. During testing, each participant wore a Polar heart rate monitor (Polar Electro, Inc., Lake Success, NY). Maximum heart rates were determined as the highest recorded one-minute value measured during the test.

Running economy values were determined by averaging the last three minutes of each steady-state bout. Criteria to get reliable measures of RE were a respiratory exchange ratio <1.00 and speeds utilizing ≤ 85% of VO_{2max} (44). Four criteria were used in order to determine if/when VO_{2max} was reached for each athlete: a plateau in the consumption of oxygen, defined as less than 2.1 ml.kg-1min-1 increase in O_2 consumption with increasing workloads (47), a respiratory exchange ratio of >1.10, failure of HR to increase with increasing workloads, and a rating of perceived exertion >17 on Borg's 6 to 20 point RPE scale (49). Three of the four criteria must be met in order for a true maximal value to be considered obtained. If a true maximal value was not obtained, the highest one-minute average was considered VO_{2peak}.

Post-season testing

Within one week of the end of the soccer season, the participants were invited to complete the study by testing in the above manner for a second time.

This experimental design allowed for standard in-season training to be maintained and to observe any physiological changes that took place due to the team's training.

Statistical Analysis

Statistics were calculated using SPSS 15.0 for windows. To compare pre-season to post-season test data, paired sample T-tests were used. Statistical analyses were run for both VO_{2peak} and RE (7 mph and 8 mph). The alpha level was set at 0.05 for all statistical analyses.

RESULTS

Eighteen participants completed the pre-season test, but due to injury and/or illness, only fourteen were able to return for post-season testing. Data from the 14 participants were analyzed and are presented here (Table 1). There was no significant change in body mass from pre-season to post-season testing ($p>0.05$).

Table 1: Physical Characteristics

Subject	Age	Height (cm)	Pre-season Body Mass (kg)	Post-season Body Mass (kg)
1*	21	167.64	70.00	67.70
2	22	162.56	56.82	57.73
3*	19	172.72	65.00	64.10
4*	19	170.18	61.82	64.32
5*	19	167.64	62.27	60.45
6*	22	170.18	59.10	57.27
7	20	170.18	59.10	58.64
8	21	166.37	55.91	57.73
9	20	170.18	82.27	81.82
10	20	164.47	59.55	59.10
11*	19	175.26	62.27	61.82
12	21	170.18	63.64	64.77
13	19	172.72	70.91	70.00
14*	18	167.64	65.00	66.36
Mean	20	169.14	63.83	63.70
± SD	1.24	3.37	6.88	6.60

*indicates self-reported injury during season

There was no significant change in VO_{2peak} ($p > 0.05$) from pre-season testing to post-season testing. Utilizing the criteria set by the American College of Sports Medicine (ACSM) guidelines for exercise testing and prescription (49) not all players reached true VO_{2max} values. In pre-season testing, five subjects reached three of the four criteria for VO_{2max} values and another 4 had values for RER >1.09 but <1.10, which places them very near VO_{2max}. The last five subjects did not reach criteria for VO_{2max} and therefore must be considered to have reached VO_{2peak} Eight subjects reached VO_{2max} during post-testing sessions (Table 2).

Table 2: VO_{2max}/VO_{2peak}

Subject	Pre ($ml \cdot kg^{-1} min^{-1}$)	Post ($ml \cdot kg^{-1} min^{-1}$)
1	*44.44	*42.62
2	*45.91	*42.52
3	*43.88	46.77
4	49.08	*44.47
5	*44.61	49.54
6	44.48	49.62
7	50.69	50.59
8	44.41	50.59
9	*40.35	*40.59
10	56.75	56.34
11	*44.86	*41.57
12	*45.03	*42.36
13	*46.31	44.20
14	*45.82	*44.47
Mean	46.19	46.16
SD ±	3.87	4.54

* did not meet ACSM criteria for VO_{2max}

A paired sample t-test also showed no significant differences between pre-season testing and post-season RE at 7 mph ($p > 0.05$) or 8 mph ($p > 0.05$). The criteria used to define sub-maximal effort during the RE tests were maintenance of RER <1.0 and VO_2 <85% VO_{2max} for each velocity. At 7 mph during pre-season testing, RER averaged 0.93 ± 0.03 and percent VO_{2peak} was 79.06% ± 6.24. The only participant to have a value >85% was the goalkeeper. Similar results occurred in post-season testing. At 7 mph, RER averaged 0.95 ± 0.03. Mean percent VO_{2peak} was 78.52% ± 7.17 and one subject exceeded 85% VO_{2peak} (Table 3). The pre-season test for RE at 8 mph resulted in a mean RER of 1.00 ± 0.04 and seven of the subjects exceeded the 1.0 RER value. The mean percent of VO_{2peak} was 89.96% ± 6.86. The only subjects that maintained <85% of maximal oxygen uptake were the two subjects with VO_{2peak} values greater than 50 $ml \cdot kg^{-1} min^{-1}$. The RE test at 8mph post-season resulted in an RER average of 1.01 ± 0.03 and 8 of the subjects exceeded RER values of 1.0. Mean percent VO_{2peak} was 90.14% ± 5.96. In post-season testing, the 3 subjects that maintained <85% VO_{2peak} values were those with a VO_{2peak} greater than 50.00 $ml \cdot kg^{-1} min^{-1}$ (Table 4).

Table 3: Running Economy at 7 mph

Subject	Pre ($ml \cdot kg^{-1} min^{-1}$)	Post ($ml \cdot kg^{-1} min^{-1}$)	Pre-season % VO_{2peak}	Post-season % VO_{2peak}
1	37.06	35.85	83.49	84.12
2	36.22	36.47	73.89	85.77
3	36.44	36.66	83.04	78.38
4	36.31	36.00	73.98	80.95
5	34.94	33.30	78.32	67.22
6	37.30	37.35	83.86	75.29
7	34.82	34.30	68.67	67.80
8	*39.28	37.89	88.39	74.91
9	33.84	34.03	83.87	83.84
10	37.21	37.27	65.57	66.15
11	35.05	*36.10	78.13	86.84
12	36.76	36.11	81.63	85.25
13	35.64	36.03	76.96	81.49
14	37.63	36.15	82.13	81.27
Mean	36.32	35.96	79.06	78.52
SD ±	1.40	1.29	6.24	7.17

* did not meet criteria for sub-maximal value (see Methods)

Table 4: Running Economy at 8 mph

Subject	Pre (ml·kg⁻ min⁻)	Post (ml.kg-min-)	Pre-season % VO_{2peak}	Post-season % VO_{2peak}
1	*42.57	*39.01	95.79	91.53
2	*39.45	*41.64	85.93	97.88
3	*41.33	*40.85	94.19	87.34
4	*42.32	*40.82	86.23	91.79
5	*40.43	*40.50	90.63	87.89
6	*42.58	*43.63	95.73	87.95
7	40.87	40.87	80.63	80.79
8	*43.36	42.94	97.57	84.90
9	*39.33	*40.18	97.45	98.99
10	41.53	44.67	73.18	79.29
11	*39.74	*37.77	88.59	90.86
12	*41.20	*41.30	91.49	97.50
13	*41.27	*41.23	89.12	93.28
14	*42.58	*40.96	92.93	92.11
Mean	41.33	41.17	89.96	90.14
SD ±	1.27	1.75	6.86	5.96

* did not meet criteria for sub-maximal value (see Methods)

DISCUSSION

To the knowledge of the authors, the present study is the first to measure running economy in conjunction with VO_{2max}/VO_{2peak} across a competitive season in female soccer athletes. Therefore the researchers found it important to look at aerobic measures across a soccer season.

Physical Characteristics

Height and weight were recorded during pre-season and post-season testing and both remained unchanged ($p>0.05$) across the 14 weeks. Body mass of this team was at the upper range for high-level female soccer players (59.5 to 63.2 kg) (12, 16, 27, 37, 45). Stable body mass over the season is consistent with findings reported by Clark et al. (12) when investigating energy intake of female Division I soccer athletes. The mean height of the athletes tested was 169 ± 3.4 cm. This is 2-3 cm taller than the mean of the height of women in the previously mentioned studies.

Aerobic Fitness

The researchers hypothesized that VO_{2max} would be maintained or improved across a season. This team did maintain maximal oxygen carrying capacity but there was no change across their competitive season. The soccer team also exhibited peak oxygen uptake values ($46.2\ ml \cdot kg^{-1} min^{-1}$) that approach other female soccer teams' maximum values, which range from $47.9\ ml \cdot kg^{-1} min^{-1}$ in Canadian university players to $57.6\ ml \cdot kg^{-1} min^{-1}$ in the Danish national squad (1, 12, 16, 27). The participants in this study tested prior to the competitive season and not before summer training.

Clark et al., (12) tested 9 Division I female soccer players across a competitive season and found a significant ($P<0.001$) increase in VO_{2peak} from 42.2 ± 4.9 ml·kg^{-1}min^{-1} to 50.00 ± 4.5 ml·kg^{-1}min^{-1}. Helgerud et al. (21) and Hoff et al. (23) also illustrate that improvements in aerobic capacity can occur in 8 weeks of aerobic training with or without the ball in highly trained male soccer players and that this improvement does indeed improve soccer performance.

It was hypothesized that RE would improve across the competitive season of female soccer players due to the high-intensity intermittent nature of the sport. This team however, showed no change in RE at 7 mph across a 14-week season. The 8 mph test cannot be used for a sub-maximal O_2 value because subjects did not meet criteria for a true sub-maximal test (see Methods).

It has been shown that RE can be improved with specific training in endurance runners and male soccer players in as little as 8 weeks (8, 24, 25,39, 44). Significant improvements in RE in male distance runners occur with employment of explosive strength training ($p < 0.05$) (39) and through plyometric training ($p=0.02$) (44) and in males and females through maximal strength training (47) with no concurrent changes in VO_{2max}. Female distance runners have also shown a trend toward improved RE across a collegiate Cross Country season (51). Intervention studies with male soccer players that utilized high-intensity interval training (4x4 minutes at 90-95% HR max) without the ball and small-sided games with the ball (90-95% HR max) demonstrate improvements in RE ranging between 2 and 14% (11, 21, 26). Soccer specific training, high-intensity interval work (90-

95%) and explosive strength work can elicit improvements in RE among male and female distance runners and soccer players.

The summer training program for the subjects was provided by the coaching staff and included a dynamic warm-up before each session consisting of form drills and build-up sprints. Three varieties of workouts were implemented throughout the summer and included: 20 to 40 yard speed workouts of maximum efforts, running workouts ranging from 110 yards to 4 minute intervals, and skills sessions with dribbling, juggling and kicking. According to Bangsbo (7), off-season training should have an equal focus on high-intensity aerobic training, anaerobic speed and speed endurance. It appears that anaerobic speed and speed endurance training were the focus (20-90s intervals) for this team's training. Summer training sessions were performed independently by each subject therefore it is unknown at what intensity workouts were completed.

A typical week of in-season training for this team, as reported to researchers by an assistant coach, is presented in Table 5.

Table 5: In-Season Training Protocol

Monday	Team day off
Tuesday	Running at 80-100% max H.R. combined with sprint work
Wednesday	Small sided games 2 v. 2 on field size of 35 feet x 35 feet to 6 v. 6 on 75% regulation field
Thursday	H.R. 60-80% max, walk through drills
Friday	90-minute game
Saturday	15-20 minute run at 60% H.R.max
Sunday	90-minute game

Heart rate data may not be the most accurate method for determining intensity during soccer practices due to the intermittent nature of the game (26), however, Esposito et al. (18) conducted a study utilizing amateur soccer players and concluded that average heart rate during soccer activities does provide an accurate representation of aerobic metabolic demands and was implemented successfully in many soccer-specific training interventions (11, 21, 23).

There are several aspects to aerobic fitness training that should be employed in soccer. Recovery training is often performed the day after a game to help a player avoid overtraining and return to a normal physical state. This type of training should be approximately 65% of a players HRmax, ranging from 40-80% (7). Low intensity endurance training should be performed between 65 and 90% HRmax with a mean of 80% and high intensity exercise should range from 80-100% HRmax with a mean of 90%. The overall purpose of this type of training according to Bangsbo (7) is to increase the work-rate during a match. Speed training and speed-endurance training are also important to success in soccer and should be performed regularly. During a season frequent sessions of aerobic high intensity work and speed training should be implemented and supplemented with regular match play.

The team studied used Nike Triax Elite heart rate monitor and database to record practices during in-season training. From the HR data, it appears that the team did not average intensities high enough to elicit the necessary aerobic fitness changes. The average result was also lower than the goal stated by the coach. Of the 12 days of practice where at least 10 subjects had HR data recorded, the highest average for a practice session was 72.92 ± 2.72% of HRmax.

Team Size and Injury

Another factor that could have influenced the RE and VO_{2peak} of this soccer team was its small number of athletes and incidence of injury. In the PAC-10 conference, the team tested had 18 players total, and 3 were unable to play due to season ending injuries. Though the incidence of injuries for other teams in the PAC-10 is unknown, their team membership ranged from 22 to 27 players (40). Among the 14 players that completed pre-season and post-season testing, seven reported injuries sustained during the season that kept them out of at least one week of practice. The coach confirmed these injuries. The coach also reported that one of the players had little competition time, which could affect aerobic fitness because an average of two 90-minute games were played per week.

Arnason et al. (2) studied 17 Icelandic teams and noted that the smaller teams had a lower ability to replace injured players. The absence of key players, or as in the case of the team studied, the continuous competition of key players while injured, could affect team standings more than in larger teams. Arnason et al. (2, 3) also reported that there was a trend between a high number of days lost to injury and lack of team success. The team studied in this project finished last in its conference and reported an abnormally high incidence of injuries for the season.

One of the researchers observed several practices during the second half of the season, and many of the players during each practice worked at lower intensities than average to “save” themselves for the game due to chronic pain/injury. Ostenberg and Roos (37) reported a higher incidence of injuries during the later part of games in the 123 female soccer players they studied. This was also seen by Arnason (2), and may have been a factor in this team because they did not have the capability to put in replacement players, therefore increasing the chance for injury among key players. This in turn affects fitness level and playing abilities due to time lost in practices and games (3).

Strengths and limitations

The utilization of laboratory testing to measure two aerobic components (VO_{2max} and RE) of female soccer players provides much needed data on the physiological aspects of this population. Most of the studies pertaining to aerobic capacity have been completed on males. RE is an important component of aerobic endurance and testing this in addition to the standard VO_{2max} allowed for greater understanding of aerobic changes that may have occurred across 14-weeks among female soccer athletes. Through the study design, it was illustrated that 8 mph was an intensity higher than this team's mean sub-maximal values. Also, because not all participants met the ACSM criteria for VO_{2max}, VO_{2peak} had to be employed. However, it is the belief of the researchers that all participants were motivated and completed each test to the best of their abilities.

A limitation of this study was the treadmill protocol that was utilized due to time constraints of test dates. Testing VO_{2max} prior to a separate RE test would allow for true sub-maximal values to be reached for each participant. Due to the continuous RE/VO_{2peak} test, the test lasted between 18 and 22 minutes which may have caused fatigue to set in limiting the number of participants who reached true max values.

Conclusion

The results of this study, which found no change from pre-season to post-season testing in VO_{2peak} and RE, may have been influenced by many factors. Exercising at intensities below that prescribed by the coach and below that indicated as necessary to maintain fitness in previous studies was one contributing factor. Other factors included the combination of a small team size and high rate of injuries. In the future, it would be beneficial to test athletes prior to summer training in addition to the pre-season and post-season tests employed in this study to assess fitness changes at three time periods. Testing more successful teams at the Division I level would also provide useful information to compare differences in aerobic fitness among teams. Intervention studies on female soccer players should be implemented to determine if improved RE and/or VO_{2max} improves performance among this population.

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APPENDIX

Appendix A IRB Protocol

1. Brief Description (1 paragraph)

A Division I women's soccer team will be tested at the onset of the fall athletic season and again post-season in order to observe changes in running economy (RE) and VO_2max that took place through training. The primary objectives are to determine if RE improves over time in a group of women athletes whose sports' success is vital to the ability of the athletes to run at high intensities for extended periods of time. We expect that RE will improve over the course of the season allowing the soccer players to compete at a higher intensity and improved performance

2. Background and Significance

Running Economy (RE), which can be defined as the aerobic cost of a given rate or distance of locomotion of sub-maximal running, is an important factor in running performance. (Franch, et al, 1998). RE is determined by measuring the steady-state consumption of oxygen and takes body mass into consideration (Saunders et al., 2004). Efficient utilization of available energy may illicit optimum performance. In elite runners, RE is a better predictor of performance than VO_{2max} (Saunders et al., 2004). Cross country runners and soccer players at the collegiate level train to improve endurance capacity and by measuring changes in RE over the course of the season in this female athlete population, this study aims to increase the understanding of the relationship between RE, VO_{2max} and female athletic performance. Therefore, our objective is to examine RE changes over the course of a season in order to assess improvement in RE, performance and VO_{2max} in women collegiate soccer athletes.

3. Methods and Procedures

RECRUITMENT

The Oregon State University women's soccer team will be invited to participate in this study with an anticipated participation rate of 20-25 women. The subjects will be thoroughly informed of the project and recruited from respective team meetings by the researcher. All athletes will be informed of the voluntary nature of the study and assured that their participation on the soccer team will be in no way compromised if she chooses not to participate or withdraws from the study. All volunteers will have successfully completed a recent health appraisal as per their respective institutions' guidelines (PAC-10 and NCAA DI). Written approval from the soccer coach is attached.

TESTING

The testing will consist of assessments performed at 0-months and 10-12 weeks later.

1. Assessments at 0-months, 10-12 weeks

Visit 1: approximately 1 hour

The participant will begin by warming up for approximately 3 minutes on a level treadmill at a pace of 6 miles per hour (MPH). The athletes will then run for 6 minutes at each of two speeds on the level treadmill, and then proceed to the maximal test portion of the protocol. The two speeds will be 7 and 8 MPH (8:34 and 7:30 min:sec/mile paces, respectively) for the soccer athletes. After completion of the second 6-min. running speed, the speed or inclination of the treadmill will increase every minute until the athlete reaches volitional exhaustion, which will likely occur in 4-8 minutes from this point in the test. The speed will increase first at 0.5 MPH increments per minute, until the participant indicates that she is experiencing a "hard" effort by her responses using the Borg Scale of Perceived Effort (see below). This rating will be elicited by holding the Borg Scale in front of her at the end of each minute interval, and she will point to the number that corresponds to her current sense of effort while running. When she rates the effort as "hard," the speed will be held constant for the remainder of the test, and the elevation will increase $1\% \cdot min^{-1}$ until she indicates by hand signals that she can no longer continue with the test (volitional exhaustion). At this point, the treadmill will be returned to its level position and the speed will decrease to a walking pace, and the athlete will walk for 4-5 minutes for a recovery cool-down.

Borg Scale of Perceive Effort

6 – 20% effort

7 - 30% effort – Very, very light (Rest)

8 - 40% effort

9 - 50% effort - Very light (gentle walking)

10 - 55% effort

11 - 60% effort – Fairly light

12 - 65% effort

13 - 70% effort – Somewhat hard (steady pace)

14 - 75% effort

15 -80% effort – Hard

16 - 85% effort

17 - 90% effort – Very hard

18 - 95% effort

19 – 100% effort- Very, very hard

20-Exhaustion

Athletes will be tested wearing work-out clothing (e.g., shorts and t-shirt) and running shoes. Prior to the treadmill test, the athlete will be weighed both with and without shoes. During the treadmill test, the athletes will breathe through a low-resistance breathing valve and mouthpiece that allows her to inhale room air and directs her exhaled air to a metabolic cart that will determine her oxygen consumption. She will also be wearing a heart-rate monitor that is held against her skin by an elastic chest strap.

4. Risk/Benefits Assessments

RISK:

Overall Risk/Running Economy and Maximal Oxygen Uptake: There is a very remote chance that one of the subjects may suffer a cardiac event during the maximal effort on the treadmill. This is considered a low risk, since all participants are highly trained soccer/endurance athletes who are accustomed to maximal efforts and who have all been cleared to participate in intercollegiate athletics by medical personnel.

BENEFITS:

The participants will receive detailed information will be provided with information relative to their running economy and maximal oxygen carrying capacity (VO_2 max). The participants are also making contributions to the understanding of running economy in women athletes in order to promote better fitness and increase performance.

CONCLUSION:

The risks to the participants are minimal and steps will be taken to minimize any risk during the study. By participating in this study, the participants will obtain valuable information regarding aerobic fitness, improvements over time, and running economy.

5. Participant Population

This study will involve women from the Oregon State University soccer team.

6. Subject Identification and Recruitment

This study will involve athletes, aged 18-25 years, who are currently training at the Division I level. All measures will be taken to maintain confidentiality of the participants' identity.

7. Compensation

Upon completion of all testing, participants will receive a shirt and water bottle from Brooks® Sports, Inc. (Bothell, WA) with an approximate retail value of $40.00.

8. Informed consent process

Please refer to the attached informed consent documents. A verbal description of the study provided by the primary researcher will allow potential participants to learn about the study and ask questions. The participants will be given ample opportunity to review the consent document and ask the research assistant any questions prior to signing the document.

9. Anonymity or Confidentiality

The names of the individuals will be available to the researchers only. Any and all references to subjects in any written or oral communications will not include the names or any other easily identifiable traits, etc. of the subjects. Codes will be assigned to each subject's data to insure confidentiality at all stages of testing and data analysis. All information will be stored and locked in Langton Hall 121A.

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Appendix B Informed Consent Document

INFORMED CONSENT DOCUMENT

Project Title: **Changes in running economy and VO_2max over a competitive season in collegiate female soccer athletes**
Principal Investigator: **Anthony Wilcox, Nutrition and Exercise Sciences**
Co-Investigator(s): **Johanna Olson, master's student**

WHAT IS THE PURPOSE OF THIS STUDY?

You are being invited to participate in this study in order to help researchers better understand how Running Economy (your oxygen consumption when running at moderate paces) and Maximal Oxygen Consumption change with training. We are studying this because we want to gain a better understanding of Running Economy among female athletes that rely on endurance to perform successfully.

WHAT IS THE PURPOSE OF THIS FORM?

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a member of the OSU Women's Soccer team and are cleared for competition for the fall of 2007.

WHAT WILL HAPPEN DURING THIS STUDY AND HOW LONG WILL IT TAKE?

The study will consist of assessments performed at the beginning and at the end of your fall season, approximately 10-12 weeks apart (Pre-Season and Post-Season, respectively).

Visit 1 Pre-Season: 1hour
After signing the informed consent document, you will complete a brief health history questionnaire. You will then be weighed both with and without shoes.

Treadmill (in the Oregon State University Human Performance Lab, Women's Building room 19)
You will then participate in a running economy (RE)/maximal oxygen carrying capacity test (VO_2max) on the treadmill. You will start the test with a 3-minute warm-up of running at 6 miles per hour (MPH). You will then run for 6 minutes at

7 MPH (8:34 min:sec/mile pace) and 6 minutes at 8 MPH (7:30 min:sec/mile pace) on a level treadmill.

After you complete the second 6-minute segment, the speed or inclination of the treadmill will increase every minute until you are too tired to continue and you signal that you want to stop, this will likely take 4-8 minutes from this point in the test. During the test you will be wearing a heart-rate monitor and a face mask that holds a breathing valve through which you can inhale room air and which directs your exhaled air to the metabolic cart, where your oxygen consumption will be determined.

Visit 2 Post-Season: 1 hour
Within one week of the completion of your fall competitive season, you will again report to the Women's Building Human Performance Lab for the same test that you performed on Visit 1.

If you agree to take part in this study, your involvement will last for

Descriptior	**Timing**	**Length per visit**	**Total Time**
Occurs at beginning of study, and/or completion of the season			
Visit 1	August 13th or 14th.	1.0 hour	1.0 hour
Visit 2	Within one week of season en	1.0 hour	1.0 hour
Total Time			2.0 hours

WHAT ARE THE RISKS OF THIS STUDY?

The possible risks and/or discomforts associated with the procedures described in this study include:

Running Economy/Maximal Oxygen Uptake:

1. You can expect to experience short-term fatigue when completing the maximal treadmill test. This fatigue is similar to that felt after running a half-mile race.

2. There is a very remote chance that you may suffer a heart attack during the maximal effort on the treadmill. This is considered a low risk for you, since you are a highly trained soccer athlete who is accustomed to maximal efforts and who has been cleared by medical personnel to participate in intercollegiate athletics. The researcher who will be administering the treadmill test is an American Red Cross-trained instructor in first aid and CPR.

WHAT ARE THE BENEFITS OF THIS STUDY?

You will receive personal information regarding your VO_2max and Running Economy, which relate to endurance capacity. You will also be making contributions to the understanding of running economy and performance among female athletes.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not be charged for any tests that are being performed for the purposes of this study.

WILL I BE PAID FOR PARTICIPATING?

Upon completion of the study you will be provided with a t-shirt and water bottle from Brooks® Sports, Inc. (Bothell, WA) with an approximate retail value of $40.00.

WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. To help protect your confidentiality, we will code all data using participant numbers. All data will be secured (locked) in Langton Hall 121A. If results of this project are published, your identity will not be made public.

DO I HAVE A CHOICE TO BE IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study, even during the treadmill test, and still keep the benefits and rights you had before volunteering.

You will not be treated differently if you decide not to participate or if you stop taking part in the study, and your participation on the Oregon State University Soccer team will not be compromised in any way. Your standing on the team will not change regardless of participation in this study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

New Information

If we obtain new information during the course of this study that might affect your willingness to continue to participate, you will be promptly informed. Under certain circumstances, your participation in this research study may be ended without your consent. This might happen because of illness, or your fitness, health, or medication use that disqualifies you for continued participation. Any data that is collected prior to your withdrawal may be included in study results.

WHAT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact:

Name	Phone number	Email address
Anthony Wilcox, Prinicipal Investigator	541-737-6799	anthony.wilcox@oregonstate.edu
Johanna Olson, Student Investigator	541-737-6791	olsonjoh@onid.orst.edu

If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-4933 or by email at IRB@oregonstate.edu.

POTENTIAL FOR FOLLOW-UP STUDIES

There is a chance you may be contacted in the future to participate in an additional study related to this project, which will require the researchers to retain your contact information after this study has been completed. If you would prefer not to be contacted, please let the researchers know, at any time. **If you are contacted, you can choose whether or not to participate.**

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed):

____

____

(Signature of Participant) (Date)

Appendix C Health History Questionnaire

Health History Questionnaire

Full Name: ________________________________ **Date:** ___/___/___

Age: ______ **Date of Birth:** ___/___/___ **I.D. #:** _________

The purpose of this questionnaire is to obtain information regarding your health prior to conducting physiological testing. Please answer all questions to the best of your knowledge. Circle the correct answers.

1. Do you have high blood pressure? YES NO
2. Do you have high blood cholesterol? YES NO
3. Do you currently smoke? YES NO
4. Are you a former smoker? YES NO
   If so, when did you quit? _______________
5. Have you ever had a heart attack? YES NO
6. Have you ever had chest pain (angina)? YES NO
7. Have any of your blood relatives had heart disease, heart surgery, or angina? YES NO
   If so, what is the relation? __________What did they have?____________
8. Are you diabetic? YES NO
   If so, list medications taken.____
9. Do you have any respiratory problems (Example: asthma, emphysema)? YES NO
   If so, list them. ____
10. Do you have any orthopedic problems (Example: arthritis, low back pain)? YES NO
    If so, list them. ____
11. Have you had any recent illness, hospitalization, or surgical procedures? YES NO
    If so, list them and when?____________________________________
12. Are you currently taking any medications? YES NO
    If so, list them. ____
13. Do you have any allergies? YES NO
    If so, list them. ____
14. Do you have any other conditions or problems that may affect your ability to exercise? YES NO

If so, list them. ____

Please provide us with emergency contact information.

Name: __________________________ Home Phone: __________________

Relation: ________________________ Work Phone: __________________

Appendix D Review of Literature

Soccer is one of the most widely played team sports in the world and is characterized by superior technical, tactical and physical skills. The Football Association formalized the game we know today in 1863 (43). The goal of soccer, or association football, is to drive a ball into the opponent's goal by kicking, heading or using any other part of the body except for the arms and hands. Soccer traditionally consists of eleven players per team with two 45-minute halves separated by a 15-minute break at half-time. Among skills necessary for success in soccer are kicking, jumping, heading and throwing the ball. Running is also an integral component of the game. Players run forward, backward and while dribbling a ball with their feet at varying intensities throughout a game. Players spend most of the time running without a ball in order to gain position on the field for scoring or defending.

The first men's Olympic soccer competition was held in 1908, while women were banned from the game in 1921 on grounds that "the game of football is quite unsuitable for females and ought not to be encouraged" (49). This ban was not lifted until 1971 and it was another 30 years before a world cup tournament was held for women, and 1996 was the first Olympic year for women's soccer. (49).

Because of the intermittent nature of this team sport, Hoff et al. (25) report that endurance shares importance with muscular strength and power for soccer performance. However, many efforts to improve soccer performance in the past focus on technique and tactics at the expense of fitness and applied physiology

(53). Despite this training tactic, elite level soccer players need to be able to maintain a high level of intensity throughout the 90-minute game. As Pate and Kriska (41) state, cardiorespiratory endurance is primarily an indicator of the exercise intensity that can be sustained for an extended period of time. Exercise physiologists often associate the limits of endurance performance with the body's ability to transport and consume oxygen (10, 36). When soccer players have a high level of aerobic fitness, maintenance of a high level of intensity and a faster recovery from high-intensity exercise occurs which can result in enhanced performance (5, 26). In soccer, if one team were to have a mean VO_{2max} that was 10% higher than their opponents, it would result in an effect of nearly an extra player on the field for the more physically fit team (3).

This review focuses on the aerobic component of soccer and its importance for success among high-level soccer players. Of particular interests are maximal oxygen carrying capacity (VO_{2max}) and running economy (RE) values. First, maximal oxygen carrying capacity (VO_{2max}) and running economy (RE) will be defined. Second, longitudinal changes that have been observed among endurance athletes concerning VO_{2max} and RE will be discussed. Finally, possible reasons for these changes will be reviewed.

Any activity that lasts for greater than 30 seconds depends on oxygen consumption and use. As activities increase from rest all the way to maximal workloads, the rate of consumption of a given volume of oxygen increases. The greatest rate at which an individual can consume oxygen at sea level while performing work is considered his/her maximal oxygen carrying capacity, or

VO_{2max} (Pate and Kriska, 1984). VO_{2max} values are described in relative terms as ml of $O_2 \cdot kg^{-1} min^{-1}$ when workloads involve weight-bearing modes, such as running. An individual's VO_{2max} is thought to determine the physical work capacity of an individual and is also a necessary component for recovery from sprints and other high intensity bouts of work (10). Highly trained distance runners have large VO_{2max} values ranging from a mean value of 58.3 $ml \cdot kg^{-1} min^{-1}$ to 78.6 in a female collegiate cross country team and a female Olympic gold medalist in the marathon, respectively (15, 50) Values for elite male endurance athletes have been found above 80 ml/kg/min range (15).

Among soccer players, VO_{2max} values generally lie somewhere between the general population and endurance athletes with ranges from 47 ml/kg/min to 57 ml/kg/min among female soccer players (1, 2, 12) while Arnason et al. (2, 3) reported values ranging from 56.8 to 67.6 ml/kg/min among elite male soccer players. VO_{2max} has traditionally been the factor used when identifying talented endurance athletes. Soccer is not simply an endurance event as it also requires superior technical and individual tactical skills. However, in order for these skills to be performed consistently throughout a 90-minute game, soccer players need strength, coordination and a high endurance capacity (46).

It is physiologically impossible to maintain levels above the anaerobic threshold for a 90-minute period of time due to accumulation of blood lactate. Because of this, soccer is heavily dependent on aerobic metabolism, filled with bouts of high and low intensity, leading to the accumulation and removal of lactate (46). The high intensity exercise is vital to success in soccer and athletes need to be able to perform repeated bouts of sprinting in order to compete well. Aziz et al. (6) reported after studying 40 members of the Singapore National male hockey and soccer teams that there were no significant correlations between both the absolute (l/min) and relative (ml/kg/min) VO_{2max} and a single sprint time ($r=0.08$ and $r=-0.21$; $p>0.05$). However, there was a significant but moderate ($r=-0.346$ and $r= -0.323$; $p<0.05$) correlation between total sprint time and VO_{2max}, indicating the importance of a well-trained aerobic system among athletes of team sports. If short bursts of maximal sprints are repeated without full recovery, contribution from energy systems changes resulting in greater utilization of the aerobic pathways. Helgerud et al. (21) demonstrated that by improving aerobic endurance (VO_{2max} and RE), male soccer athletes were able to maintain a higher percent intensity throughout the second-half of the games. These athletes spent significantly more minutes in the 85-90%, 90-95%, and >95% zones than the control group after training ($p<0.05$). Arnason et al. (3) compared individual male player values between elite and first division from Iceland and found significant differences in peak O_2 uptake (63.2 ± 4.5 vs 61.7 ± 5.1 mL/kg/min, $p=0.02$, $N = 226$), amounting to a 2.4% difference between groups.

McMillan et al. (32) conducted a study with professional British youth male soccer players with regard to maximal oxygen uptake. In this study, VO_{2max} increased significantly (58.6 to 60.3 ml/kg/min) from the start of pre-season to the beginning weeks of competition. This improvement in VO_{2max} resulted in significantly lower lactate levels at each velocity tested ($p<0.001$) allowing for higher intensity work to be performed.

Cardiac output is traditionally accepted as the limiting factor in VO_{2max} (11, 21) and interval training at an intensity of 90-95% heart rate maximum has demonstrated a way to increase in cardiac output (21). Helgerud et al. (21) conducted an eight-week intervention study in male soccer players under which the interval-training group performed 4 x 4 minute intervals at 95% HRmax two times per week. The average increase in VO_{2max} over this eight-week period was 5 $ml \cdot kg^{-1} min^{-1}$. This change resulted in a significant ($p<0.05$) increase in distance covered, number of sprints per game and number of involvements with the ball for the interval-trained group. Wilcox and Bulbulian (51) reported a significant ($p<0.05$) change in maximal oxygen uptake among a women's cross-country team over the course of a competitive season in which mean VO_{2max} increased from 53.8 to 58.3 $ml \cdot kg^{-1} min^{-1}$. Maximal oxygen carrying capacity can be improved through training in endurance athletes and soccer players as shown in the previously mentioned studies.

Standardized testing procedures of VO_{2max} for soccer players should occur on a motorized treadmill and meet three of the four following criteria: a plateau of less than 2.1 $ml \cdot kg^{-1} min^{-1}$ in VO_2 with increasing workloads, a respiratory exchange ratio (RER) above 1.10, a rating of perceived exertion (RPE) of >17 on the 6 to 20 scale, and a failure of HR to increase with further increases in exercise intensity (9, 26, 46, 48, 50). Obtaining VO_{2max} information on a treadmill provides valuable information for coaches and athletes that is difficult to obtain on the field. When this laboratory information is obtained, the information can then be utilized during practices and games by use of HR monitors. Esposito et al. (18) validated the relationship between heart rate (HR) and VO_2, allowing for studies to use HR monitors during intervention training strategies to ensure appropriate intensity levels.

VO_{2max} values are important to discriminate between elite and non-elite endurance athletes however it does not appear to determine success within a homogonous group of athletes (13). Conley and Krahenbuhl (13) found that VO_{2max} and performance in a 10-kilometer race were not significantly different from zero in 12 highly trained, experienced male runners. When this low correlation was found among groups of endurance athletes, researchers began investigating running economy (14, 15, 19). Running economy (RE) can be defined as the relationship between oxygen consumption (VO_2) and velocity (v) of running (15, 19, 30). It is the steady state consumption of oxygen at sub-maximal speeds. These sub-maximal speeds ensure that VO_2 is indicative of aerobic energy expenditure per unit of time and that there is not an anaerobic component to the values reported (31, 44). The ability to describe the VO_2 related to a certain running velocity provides useful data for comparing individuals, or an individual with himself or herself under a variety of conditions (14). RE needs to be examined in addition to VO_{2max} in order to gain a greater understanding of aerobic needs for success in the sport of soccer.

Running economy has many contributing factors . Two anthropometric variables that are commonly studied when testing influences on biomechanical effectiveness are body height (h) and mass (m_b) (1, 31, 34). Lucia et al. (30) studied the exceptional RE in the best Eritrean (eastern African) distance runners and found that their anthropometric variables including body mass index (BMI), maximal calf circumference and skin fold measurements were lower than Spaniards ($p<0.05$) whose RE and performance was not as good but whose VO_{2max} values were equal to or higher than the Eritrean runners. Maldonado et al. (31) extrapolates that by reducing excessive body fat, one could potentially improve running economy.

Training has also been found to improve RE. Franch et al. (20) reported that after only 6 weeks of intensified training in thirty-six trained male runners, two of the three training groups showed statistically significant improvements in RE with -6.6 +/-2.3 ($P<0.05$) $ml \cdot kg^{-1}km^{-1}$ and -7.3 +/-1.8 $ml \cdot kg^{-1}km^{-1}$ ($p<0.01$). Explosive strength training, plyometrics and maximal strength training have also shown significant improvements in RE among male and female runners in as little as 8 weeks (23, 39, 47). A similar study conducted by Nummela et al. (36) suggests that RE is affected by the ability of the neuromuscular system to produce power above VO_{2max}. Osteras et al. (38) conducted a study with highly trained male cross-country skiers to examine relationship between strength training and endurance performance. Results from this study show that a relatively small change in 1 repetition max (RM) resulted in a significant increase in time to exhaustion among the experimental group. Economy of double poling also increased significantly from pre- to post-test among the experimental group ($p<0.01$) Contradicting reports by Lake and Cavanagh (28) showed that after 6 weeks of training in relatively untrained subjects, $VO_{2submax}$ values increased significantly ($p<0.05$) by 1.4 $ml \cdot kg^{-1}min^{-1}$.

In unpublished data reported by Stolen et al. (46) a difference of approximately 5 $mL \cdot kg^{-1} min^{-1}$ in RE was observed between senior and cadet soccer players during a running treadmill test at 9 $km \cdot hour^{-1}$. This difference in RE theoretically yields a difference in distance covered of about 1500 m per player with no change in VO_{2max}. Despite Lake and Cavanagh's (28) results, improvements in RE can be seen in 6 to 8 weeks. As shown by Franch et al.'s (20) results, an improvement of $5 ml \cdot kg^{-1} min^{-1}$ is plausible. Helgerud et al. reported in a study that high intensity aerobic training improved RE by 6.7% among male soccer players along with soccer performance. A 20% ($p<0.01$) increase in distance covered in a game with the endurance trained group, a 100% ($p< 0.001$) increase in the number of sprints per player and a 24.1% ($p<0.05$) increase in the number of involvements with the ball per game. The endurance trained group also spent 19 more minutes in the high-intensity zone based on heart rate (>90% f_{cmax}) (21). Impellizzeri et al. (2005) also conducted an aerobic training study on male soccer players utilizing specific and generic groups. The generic group consisted of two days per week of 4 running repeats of 4 minutes at 90-95% HRmax followed by 3 minutes active recovery (60-70% HRmax). In this study there was a close to significance ($p<0.07$) change in running economy at lactate threshold. The previous studies illustrate through specific training types of different modalities, RE can be improved, with improved performance as a result.

When testing an individual to determine running economy, speeds utilizing ≤ 85% of VO_{2max} must be used to get reliable measures (44). If the intensity rises above the ventilatory threshold, steady state conditions are not likely achieved

(19). Durations of each sub-maximal velocity should last between 4 and 10 minutes (13, 15, 51). When performing a RE test, it is also important that the respiratory exchange ratio (RER) remain below 1.00 (13).

The overall aim of aerobic training in soccer is to minimize the decrease in technical performance and lapses in concentration due to fatigue and increase the work-rate during a match. Bangsbo (7) reports that there are three specific aims of aerobic training. The first aim is to improve the capacity of the cardiovascular system to transport oxygen, allowing a player to work at a higher intensity for longer periods of time. A second aim is to improve the capacity of specific muscles used in soccer to utilize oxygen and spare glycogen by an increase in fat oxidation. The final aim reported by Bangsbo (7) is to improve recovery ability after high-intensity bouts of exercise. Researchers have been observing VO_{2max} among soccer players in an attempt to understand and develop effective training programs. Most of these intervention and observational studies have been conducted on male players. Running economy may be another factor that is important for soccer players but has not yet been observed directly in male or female players.

Appendix E Pre-Season Testing With all Participants

Subject	Age	Height (cm)	Body Mass (kg)	RE 7 mph	RE 8 mph	VO_{2peak}
1	21	167.64	70.00	37.06	*42.57	**45.91
2	22	162.56	56.82	36.22	*39.45	**43.88
3	19	172.72	65.00	36.44	*41.33	**44.44
4	19	170.18	61.82	36.31	*42.32	49.08
5	19	167.64	62.27	34.94	*40.43	**44.61
6	22	170.18	59.10	37.30	*42.58	44.48
7	20	170.18	59.10	34.82	40.87	50.69
8	21	166.37	55.91	39.28	*43.36	44.41
9	20	170.18	82.27	*33.84	*39.33	**40.35
10	20	164.47	59.55	37.21	*41.53	56.75
11	19	175.26	62.27	35.05	*39.74	**44.86
12	21	170.18	63.64	36.76	*41.20	**45.03
13	19	172.72	70.91	35.64	*41.27	**46.31
14	18	167.64	65.00	37.63	*42.58	**45.82
15	19	175.26	70.00	34.52	*39.46	41.35
16	21	167.64	60.00	36.52	*43.24	48.17
17	18	165.1	65.00	32.51	37.94	46.47
18	18	168.00	65.9	38.08	*44.35	**47.18
Mean	19.80	169.11	64.01	36.12	41.31	46.10
± SD	1.3	3.48	6.27	1.64	1.69	3.62

* did not meet criteria for sub-maximal value (see Methods)

** did not meet ACSM criteria for VO_{2max} (see Methods)