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Quantifying fitness changes of a collegiate women's soccer program over the course of a competitive season: Utilizing physiological testing measurements and accelerometry

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Abstract

Objective: The goal of this research study is to objectively study a female collegiate soccer team throughout the course of their season. It was the purpose of this study to determine the efficacy of the implemented conditioning program by measuring and quantifying fitness changes through the use of sport-specific physiological tests. A secondary purpose was to utilize accelerometry to compare and quantify work conducted during a game to the respective subjects' measured fitness level. Research Methods and Procedures: This study took place during a competitive season of a collegiate women's soccer team. Twenty-five college-aged females were subjects. Four trials were conducted of each physiological test. The physiological tests chosen to be included in this study include critical velocity (CV) testing, indirect anaerobic capacity measurements and 8RM knee extension and flexion strength testing. On-field performance data was also collected in the form of touches on the ball and minutes played. This study also involved the use of four accelerometers during each competitive match. The ANOVA was run three times. First, comparing the physiological test results for each of the four trials, second comparing the physiological test results to the on-field performance data collected and finally comparing the accelerometry data to the respective subject's CV values. Results: During the 3.5 month study, significant differences were found in fitness levels based upon the CV test and anaerobic capacity results (p-value <0.05). Significant differences were also found between the four trials of 8RM knee extension and flexion testing (p-value <0.05). A moderately significant inverse correlation was found between anaerobic capacity and the CV outcomes (p-value <0.01). A strong correlation existed between the 8RM extension and flexion tests (p-value <0.01). Discussion: This data suggests that a decline in the fitness level, as measured by the CV tests, was observed throughout the competitive season. This data also suggests that as the aerobic capacity decreased the mean anaerobic capacity of the team increased, possibly due to the decrease of stress on the aerobic metabolic pathways during training. The data collected also has implications for furthering the scientific study of soccer using accelerometry.

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QUANTIFYING FITNESS CHANGES OF A COLLEGIATE WOMEN'S SOCCER PROGRAM OVER THE COURSE OF A COMPETITIVE SEASON: UTILIZING PHYSIOLOGICAL TESTING MEASUREMENTS AND ACCELEROMETRY.

BY

SARA L. SCHIFFBAUER

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ABSTRACT

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BY SARA SCHIFFBAUER

Objective: The goal of this research study is to objectively study a female collegiate soccer team throughout the course of their season. It was the purpose of this study to determine the efficacy of the implemented conditioning program by measuring and quantifying fitness changes through the use of sport-specific physiological tests. A secondary purpose was to utilize accelerometry to compare and quantify work conducted during a game to the respective subjects' measured fitness level. ***Research Methods and Procedures:*** This study took place during a competitive season of a collegiate women's soccer team. Twenty-five college-aged females were subjects. Four trials were conducted of each physiological test. The physiological tests chosen to be included in this study include critical velocity (CV) testing, indirect anaerobic capacity measurements and 8RM knee extension and flexion strength testing. On-field performance data was also collected in the form of touches on the ball and minutes played. This study also involved the use of four accelerometers during each competitive match. The ANOVA was run three times. First, comparing the physiological test results for each of the four trials, second comparing the physiological test results to the on-field performance data collected and finally comparing the accelerometry data to the respective subject's CV values. ***Results:*** During the 3.5 month study, significant differences were found in fitness levels based upon the CV test and anaerobic capacity results (p-value <0.05). Significant differences were also found between the four trials of 8RM knee extension and flexion testing (p-value <0.05). A moderately significant inverse correlation was found between anaerobic capacity and the CV outcomes (p-value <0.01). A strong correlation existed between the 8RM extension and flexion tests (p-value <0.01). ***Discussion:*** This data suggests that a decline in the fitness level, as measured by the CV tests, was observed throughout the competitive season. This data also suggests that as the aerobic capacity decreased the mean anaerobic capacity of the team increased, possibly due to the decrease of stress on the aerobic metabolic pathways during training. The data collected also has implications for furthering the scientific study of soccer using accelerometry.

INTRODUCTION

Soccer is a dynamic team field sport that requires hundreds of diverse movements during competition. A competitive soccer match requires the athlete to perform intermittent high intensity work with periods of lower intensity bouts. Within the research that has been performed, this idea of varying intensities is the basic premise for designing laboratory tests specific to soccer.[1,2,3,4] Even with the large spectrum of intensities during a soccer match, it is accepted that the average sprint distance is from 10-20m, for a span of 2-3 seconds. An individual can do anywhere from 19-62 of these sprints in the ninety minutes of competition.[1,2] Given the complex nature of soccer, the position of the athlete and team's style of play will affect the physiological requirements and therefore physiological responses of each individual athlete on the pitch. The average sprint distance as well as the duration and number of sprints in a game vary significantly. For example a forward will conduct more sprints for a shorter period of time than midfielders who will run fewer sprints but for a longer duration.[3]

Soccer requires the utilization of a number of different energy systems and the degree to which each one is utilized depends upon a number of factors such as the fitness level and position of the athlete as well as the stage of the match. Research of this kind allows one to develop an understanding of what is required of the athlete as far as fitness levels. Soccer requires the body to utilize a number of different energy systems during competition.

Energy systems reported to have considerable importance on the competitive performance of a soccer player are ATP production through the ATP-PC system, anaerobic glycolysis and the aerobic system.[2,4,5] Within a competitive game of soccer, at an elite level, the contribution of the ATP-PC system is very significant. This percentage has been reported at 55% during a three second sprint and may even increase as the game progresses and glycogen stores are depleted.[3,6] The ability of an individual to produce high power outputs has been directly related to the resynthesis of PCr.[2,7] With approximately 55% of energy production coming from ATP-PC during a three second sprint, it should be noted that other energy systems also contribute even in such short duration. With the contribution of all three energy systems in the production of ATP, PCr is not completely depleted from the muscle and can be used in later stages of the game but PCr cannot be completely resynthysized in repeated sprint team sports due to the short active recovery time during competition.[2] Due to this active recovery, a shorter time to exhaustion has been reported.[2,8]

Anaerobic glycolysis is simultaneously activated with PCr when the intensity is maximal or near maximal, not just when PCr stores in the muscle are depleted.[6,9] Anaerobic glycolysis contributes to an estimated 32% of ATP production during a three second sprint.[3,6] There is some variance with this percentage, as with each of the energy system contributions since the extent of each system's contribution depends upon the duration and intensity of the exercise.[2,3] Repeated sprint exercise, such as a competitive game of soccer, results in high muscle lactate concentrations. This high accumulation of H^+ molecules in the muscle cell is linked to muscular fatigue. Due to the active recovery between high intensity bouts, it is speculated that this may hasten the removal of lactate from active muscle and may even increase its utilization as a fuel source.[3] Soccer depletes glycogen stores by 85-90% and after the first half of a game there is a significant depletion which has been reported, which most likely contributes to second half fatigue.[3,7] As glycogen stores begin to decrease after subsequent sprints, especially late in the game, there is not a proportional decline in power output.[13,18]

The disproportional power output compared to the decreasing anaerobic glycolysis contribution have been speculated to be due to an increase in the rates of aerobic metabolism.[3,10] The aerobic contribution to a single three second sprint is minimal, estimated at 3% of the overall ATP production.[3,6] Yet as the sprints are repeated there is a decrease in anaerobic glycolysis but not a similar decline in power output. This is attributed to the fact that the contribution of the aerobic energy system increases with repeated sprints, especially in the latter stages of competition.

In general, the contributions of the physiological energy systems in intermittent exercise specific to soccer do not increase the demands placed on the aerobic energy system when compared to a continuous exercise that is done at an equivalent average speed. Studies have indicated the anaerobic energy system is more important during the intermittent exercise than it is during continuous exercise.[1] This is comparable to the findings in other investigations that have been collected about the physiology of soccer. These findings have important implications for identifying fitness requirements for the elite soccer player. Once the fitness requirements of an elite soccer player can be identified, the training of these athletes has the potential to improve substantially by focusing the training on the components of the player's physiology necessary for a soccer match.

Soccer requires efficiency and competence in several aspects of fitness. These aspects include aerobic and anaerobic power, muscle strength, flexibility and agility.[4] The aerobic and anaerobic aspects of soccer will be the focus of this section because most of the limited amount of research on soccer focuses on these aspects of soccer fitness.

Within a competitive soccer match, an individual's average exercise intensity is close to the lactate threshold at about 80-90% of their maximal heart rate.[3,11,12] The average minute ventilation is of a moderate overall aerobic demand at 60mL/kg/min[5] with other research finding similar values at 55-68mL/kg/min.[2] When testing women's VO_2max the results were close at 47.1-57.6mL/kg/min.[9] The slight difference in the VO_2max between women and their male counterparts may be in part attributed to varying styles of play as well as inherent genetics. Interestingly, the players who recorded a higher VO_2max value performed the highest number of sprints and took part more often in the decisive plays of the game than the players with the lower values for VO_2max.[2,13] However, these results have been found to vary from other research. Other findings have come to the conclusion that VO_2max may not always be a sensitive enough measure of soccer match performance. This conclusion has been attributed to the fact that the VO_2max does not take into account the individual's ability to perform soccer specific skills, despite the positive relationship that has been found between the standard of play and distance covered.[4]

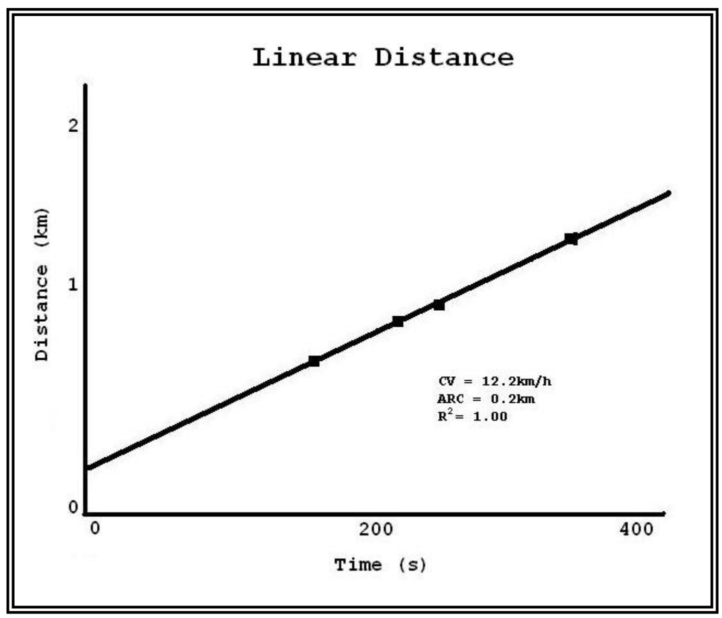
The average minute ventilation or VO_2max, has been reported to be higher in intermittent exercise than in steady state exercise at equal exercise intensity. This would be consistent with findings in the previous section that as the match continues the demand placed on the aerobic energy system increases.[4] The stroke volume of the individual is considered to be the most important factor in the limiting of aerobic endurance,[2] therefore training to increase the stroke volume may have a significant increase in the performance of the individual in later stages of match play. The shorter the recovery times between intense work bouts, the greater the decrement to performance. This would be important in determining the different fitness levels required for the varying positions of each athlete.

Along the lines of muscular strength, it is noted that strength training does not impair performance if conducted properly. Proper strength training specifically to soccer is done with few repetitions at high loads, with the focus being the fast mobilization of force in concentric actions. This style of training actually allows for better responses in aerobic endurance because of an improvement in running economy as well is improvements in sprinting and jumping.[4] From this it can be implied that plyometrics would be an important component of training for the soccer player.

The fitness requirements of soccer are multi-dimensional. Not only do these requirements include aerobic and anaerobic power and capacity they also include muscular strength and endurance, agility and the motor coordination of the athletes. However for the purposes of this study the focus was placed on measuring the aerobic and anaerobic capacity, muscular strength and body composition. Based upon previous literature it was concluded that a critical velocity (CV) test would be best to measure anaerobic and aerobic capacity and an 8RM knee extension and flexion test would be conducted to measure the muscular strength of the upper leg.

A critical velocity test is an estimate of the greatest exercise intensity that can be maintained for an indefinite period of time.[14] Critical velocity is the linear relationship between work conducted and time to exhaustion.(14,15) This relation can be mathematically represented by a line in slope-intercept form such as the model in Figure 1 where four tests of different time intervals were recorded and plotted.(15) The CV test is closely related to lactate threshold (14,15) and therefore may be a relevant test in measuring soccer fitness. A critical velocity test, if utilized, allows for the measurement of aerobic capacity and anaerobic capacity. It is comparable to a VO_2max test as a measure of aerobic capacity (14,15) and can be an indirect measure of anaerobic capacity related by the y-intercept. Anaerobic Capacity is the amount of work an individual can do without the contribution of energy through aerobic mechanisms [16] In theory the outcome of the CV test is indicative of how well trained the aerobic and anaerobic systems of the athlete are.

FIGURE 1. MATHEMATICAL MODEL OF CRITICAL VELOCITY.



Muscular strength can be defined as the force a muscle group can exert. It can be quantified by the maximum weight that can be lifted once and is usually used for structural exercises. However, to isolate specific muscles groups, assisted exercises are utilized but repetition maximum (RM) testing is not suited for such assisted exercises. Therefore, an 8 RM protocol was determined to be most appropriate for this study.

During this study another fitness measurement technique, accelerometry, was utilized. This measurement was conducted during competitive matches. Due to the advent of accelerometry use in non-laboratory settings, a more accurate measure of work output can be collected. An accelerometer is a piece of technology that can be used to quantitatively measure one's acceleration during movement in multiple planes. Following the use of the device the acceleration can be used to find a vector sum and determine the work output of the individual wearing the accelerometer. The use of such device could result in improvements made in the training of an athlete for such an event.

The use of these instruments outside of an exercise physiology laboratory and in a more natural environment has allowed exercise physiologists develop new and relevant research questions related to the training and event performance. [17,18,19,20] Accelerometric devices have been used for the analysis of various biomechanical events such gait, physical strain on muscles, activity levels and muscle power.[19]

Linear acceleration can be monitored via the use of a triaxial accelerometer. This accelerometer measures the change in velocity during movement away from the axis and records it as linear acceleration.[18] As mentioned, accelerometers have been used in the field of biomechanics in a variety of ways. According to a research study on children comparing the ability of heart rate, pedometry and accelerometry to predict VO_2, the best predictor of VO_2 was a triaxial accelerometric device.[19] According to this research, triaxial accelerometry also appears to be more accurate in predicting energy expenditure in adults who are engaged in a variety of activities.[19]

The purpose of this study was trifold. The first overall objective was to determine the efficacy of the conditioning program of a collegiate women's soccer team. The second objective was to measure and quantify fitness changes, both aerobic and anaerobic, throughout a competitive season and compare these changes with the conditioning program in place. The third objective was to utilize accelerometry to compare the accelerations conducted by each participating athlete during a given competitive match.

RESEARCH METHODS AND PROCEDURES

Subjects. The subjects of this study were recruited via informational meeting following the approval of the CHHS Human Subjects Review Committee of Eastern Michigan University. Subjects consisted of the 25 women's soccer program team members at Eastern Michigan University. All subjects were female and between 17 and 22 years of age at the time of participation in the study. For those under 18 years of age precautions were taken to receive legal guardian approval prior to participation. All 25 subjects participated in the physiological testing and on field data collection. Eleven of the 25 participants, chosen according to playing time, agreed to wear accelerometers during competitive matches.

Time Frame. A competitive collegiate soccer season begins with preseason in August, regular season play beginning in September and ends with post season play early in November. The total duration of this study was 3.5 months. Competitive matches typically took place on Fridays and Sundays with a day off from all training on Mondays following games. At four different times during the season, approximately three weeks apart, the critical velocity tests were performed. Each test was conducted on the same running track following the team's day off and before that day's training session. The CV tests were issued and took place in the middle of preseason, before the competitive season, mid-competitive season and following the competitive season.

Each 8RM knee extension test and 8RM knee flexion test were performed one week following CV testing and prior to that days training session. These measurements were conducted following preseason, early in the competitive season, mid-competitive season and following the competitive season. These tests were conducted on the same assisted weight machines each time.

Eleven subjects, not including the goalkeeper, had given prior consent separate from the general study to wear accelerometers during competitive matches. Each match day two midfielders, one defender and one forward were chosen to wear the accelerometers. These 11 subjects were rotated throughout the season so each participating subject wore the accelerometers during three different matches at the beginning, middle and end of the season. Prior to warm-up the accelerometers were fastened and to the players with the accelerometer box on the lumbar spine fasten with a heart rate monitor strap and athletic tape. Data collection also began prior to the warm-up. Data collected by the G-link model accelerometers (MicroStrain, VT) were stored to the device itself during wear. Agile Link software (MicroStrain, VT) was then used to download and control the data and Labview Express Software was used for the analysis of all accelerometry data. These files were saved to a computer and backed up using an external hard drive.

On field performance data was also collected during each competitive match. The on field performance data collection was kept for every participant and included minutes played, touches on the ball, assists, shots and goals broken down according to half and over time period. On field performance data was recorded following the season via game film. All data was recorded in a journal on site and transferred to a computer file where it was stored again on an external hard drive.

Physiological testing procedures. At the informational meeting subjects were given a packet that included a letter of recruitment, confidentiality statement, consent form, synopsis of the project and protocols for each of the physiological tests they would be participating in.

Critical velocity testing was conducted on a running track and two tests of two different time intervals were run during each of the four testing sessions. Subjects were lined up in the same order and staggered prior to each run. The two-minute test was conducted first. Subjects were instructed to run as far as they could in the allotted time. At two minutes subjects were instructed to stop immediately and mark, using athletic tape, their ending point. Subjects were then given ten minutes rest between trials. Following the ten-minute rest period, subjects were instructed to run the six-minute test in a similar manner as the two-minute test. Data collection was conducted following the completion of both tests.

One week following the CV and BC testing the 8RM extension and flexion strength testing was conducted. These tests were also conducted following the team's day off and prior to any training sessions. The subjects were instructed to complete a five-minute warm-up prior to beginning the testing. The 8RM knee extension was conducted first using the assisted seated knee extension machine. The subject was instructed to sit down in the machine with the back firm against the back pads, legs parallel to each other and ankles behind and in contact with the foot roller pad while grasping the handles. A weight was chosen according to the subject's past resistance training experience. Once the subject was properly aligned they were then instructed to raise the foot roller pad by fully extending the knees while keeping contact with the machine at the shoulders, back, buttocks and thighs. Following full extension the subject was instructed to flex at the knees slowly and controlled keeping the proper posture. This was repeated for a total of eight repetitions. If the subject was unable to perform eight repetitions the weight was decreased and following a one-minute rest period the subject was instructed to make a second attempt. If the subject performed more than eight repetitions the load was increased and following a one-minute rest period the subject was instructed to attempt the new load.

The 8RM knee flexion was conducted in a similar progression following the knee extension test. The flexion test was conducted on an assisted prone knee flexion machine. The subject was instructed to lay with hips and torso squarely placed against the pads with their ankles underneath the roller footpad. The subjects' knees were to fall slightly off the edge of the pad and then flex at the knee joint to pull the footpad to the buttocks keeping the hips and torso against the pad. The initial weight was found in the same manner as for the knee extension test and for the subsequent loads after that.

Statistical analyses. The outcomes of the physiological tests were recorded for all subjects able to complete the tests. The ANOVA was run on the physiological test outcomes for each of the four testing periods charting the changes in results. ANOVA was also used to compare several of the physiological test results against each other to find any existing correlations. The collected accelerometry was controlled using the Labview Express Software to compare one athlete's accelerations to another during a competitive match.

RESULTS

The 3.5-month study produced statistically significant results in measuring the changes in fitness throughout the course of the season. Table 1 gives the critical velocity averages, in meters per minute, with standard deviations for each of the four trials for the team, starter and non-starter categories. Also noted in Table 1 are the sample sizes for each category as there was variation in the sample sizes from trial to trial, due to injuries, illness or team status. Figure 3 is an illustration of each of the individual subjects' measured critical velocity (m/min) for each of the four trials. Figures 3 and 4 are illustrations of the results found in Table 1. Regardless of category, the general trend of the CV average outcomes was an increase from T1 to T2 followed by a steady decline from T2 to T3 and T4. In Figure 3 the second and third trial means are significantly different from T4 (p-value <0.05).

TABLE 1. MEANS AND STANDARD DEVIATIONS OF FOUR TRIALS OF CRITICAL VELOCITY TESTING.

	TRIAL 1	**TRIAL 2**	**TRIAL 3**	**TRIAL 4**
STARTERS MEANS	206.5	212.1	209.8	195.9
STDEV	21.4	12.3	9.8	9.9
n =	11	8	11	8
TEAM MEANS	199.7	209.4*	206.5*	193.4*
STDEV	21.6	13.0	10.0	10.8
n =	25	21	23	22
NON-STARER MEANS	194.5	207.7	203.9	190.9
STDEV	21.1	13.6	9.7	11.7
n =	15	13	12	14

*SIGNIFICANT VALUES

FIGURE 2. CRITICAL VELOCITY OUTCOMES: INDIVIDUAL OUTCOMES

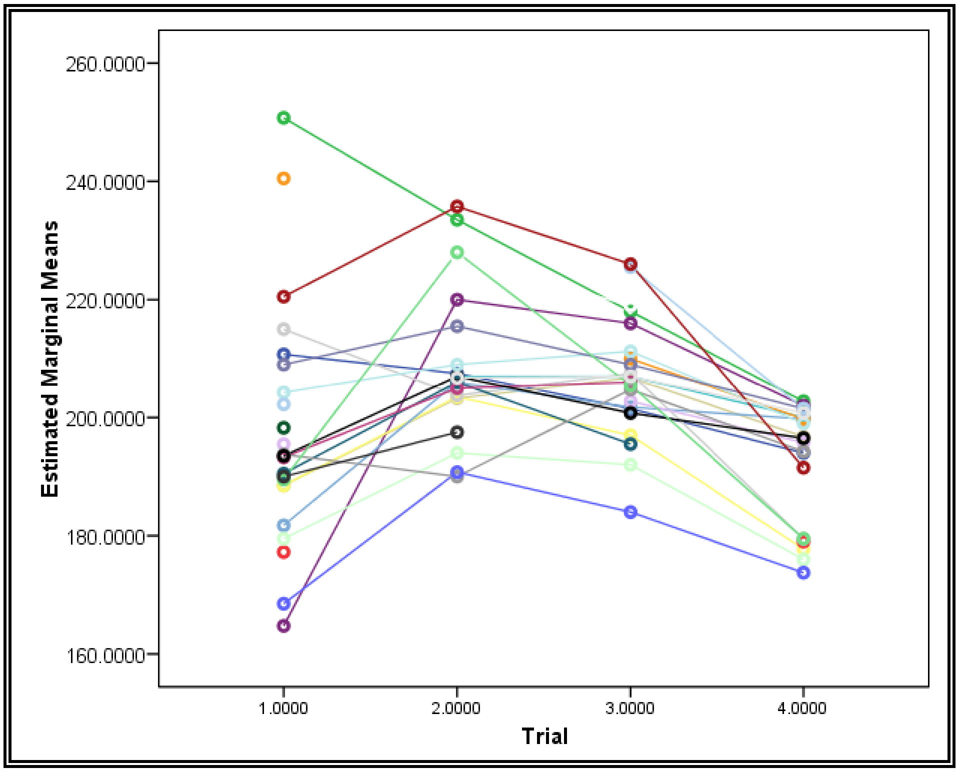


FIGURE 3. CRITICAL VELOCITY OUTCOMES: TEAM MEANS.

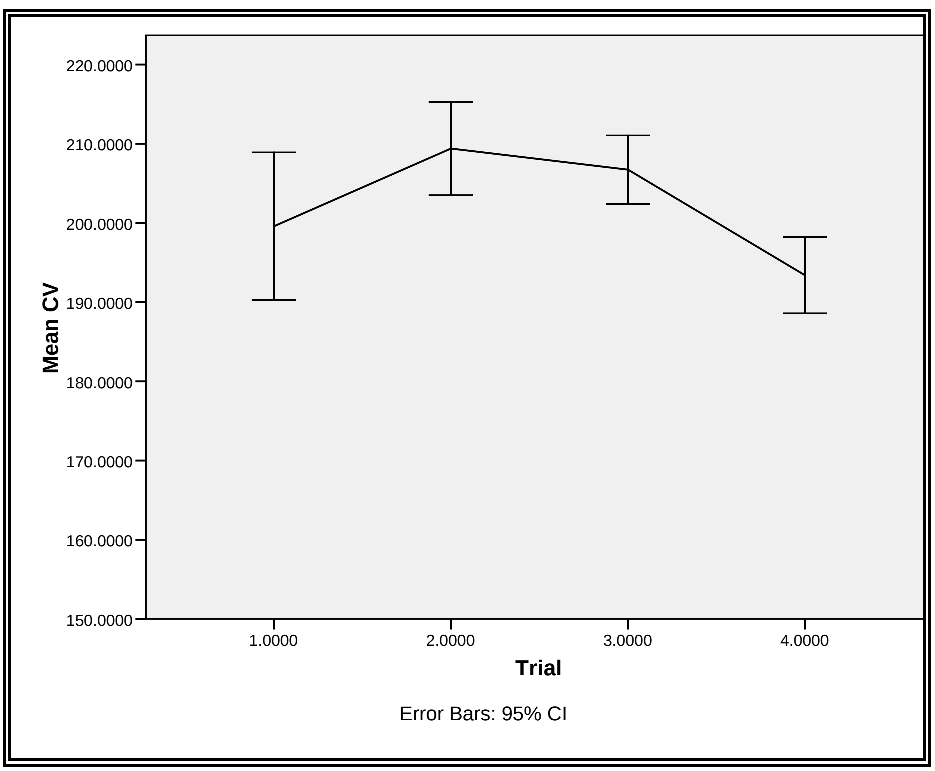
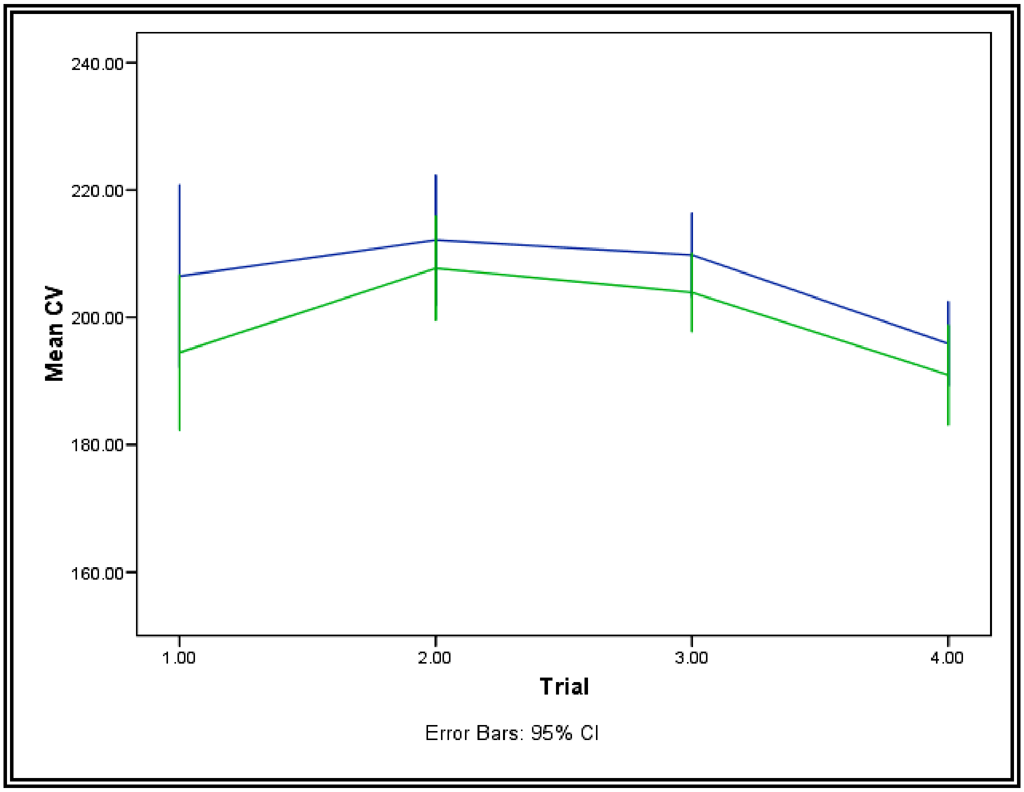
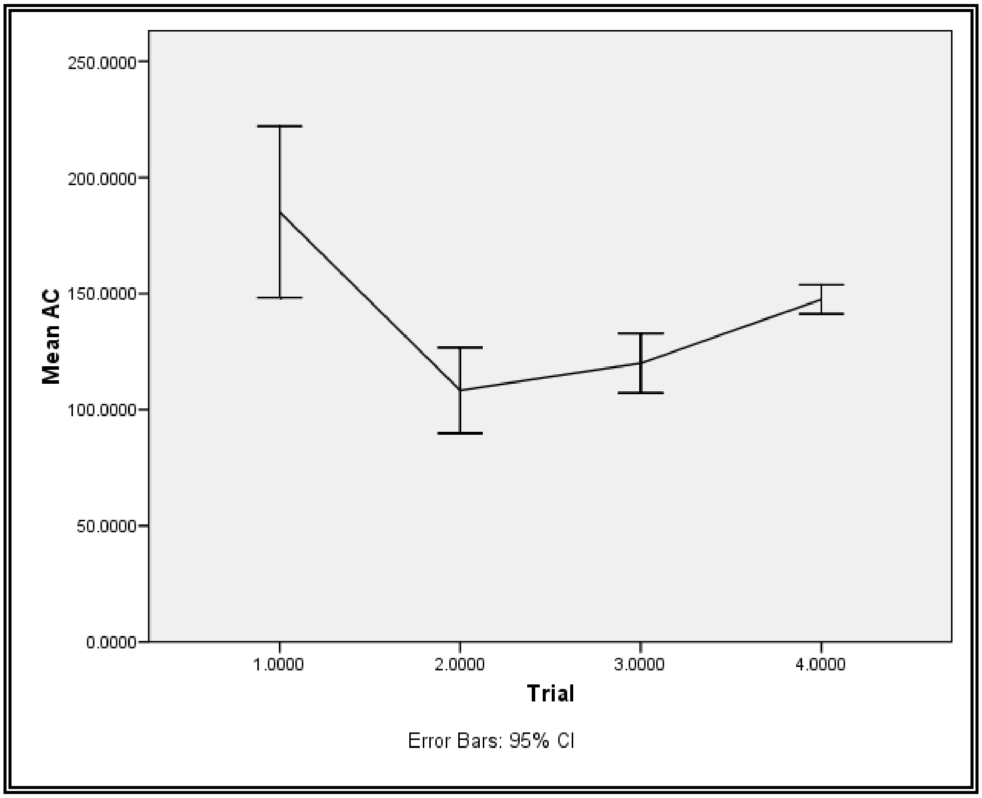


FIGURE 4. CRITICAL VELOCITY OUTCOMES: STARTER AND NON-STARTER MEANS.



Anaerobic capacity was found indirectly using the measured critical velocity for each subject and trial. Figure 5 illustrates the mean anaerobic capacity. The sample sizes for each trial shown are the same as those numbers for the team's CV means. The mean anaerobic capacity was the greatest at t1 and decreased sharply to t2. The team's mean anaerobic capacity then steadily increased from t2 to t3 and t4.

FIGURE 5. ANAEROBIC CAPACITY OUTCOMES



The resulting means and standard deviations of the 8RM extension and flexion strength tests are located in Table 2. These tests produced significant differences between trials (Figures 6 and 7 respectively). The mean outcomes of T3 and T4 were significantly greater than T1 (p-value <0.05) in the extension testing as shown by Figure 6. Significant differences were also found in the 8RM extension testing, as the team averaged a significantly higher volume during T4 than the initial trial (p-value <0.05) (Figure 7).

TABLE 2. 8RM EXTENSION AND FLEXION TESTING

	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
EXTENSION MEANS	706.7*	753.3	815.1*	876.2*
STDEV	152.7	147.6	140.8	144.2
n =	24	24	26	21
FLEXION MEANS	551.7*	608.3	646.4	674.3*
STDEV	82.5	104.2	95.0	110.5
n =	24	24	25	21

*SIGNIFICANT VALUES

FIGURE 6. 8RM EXTENSION TEST OUTCOMES.

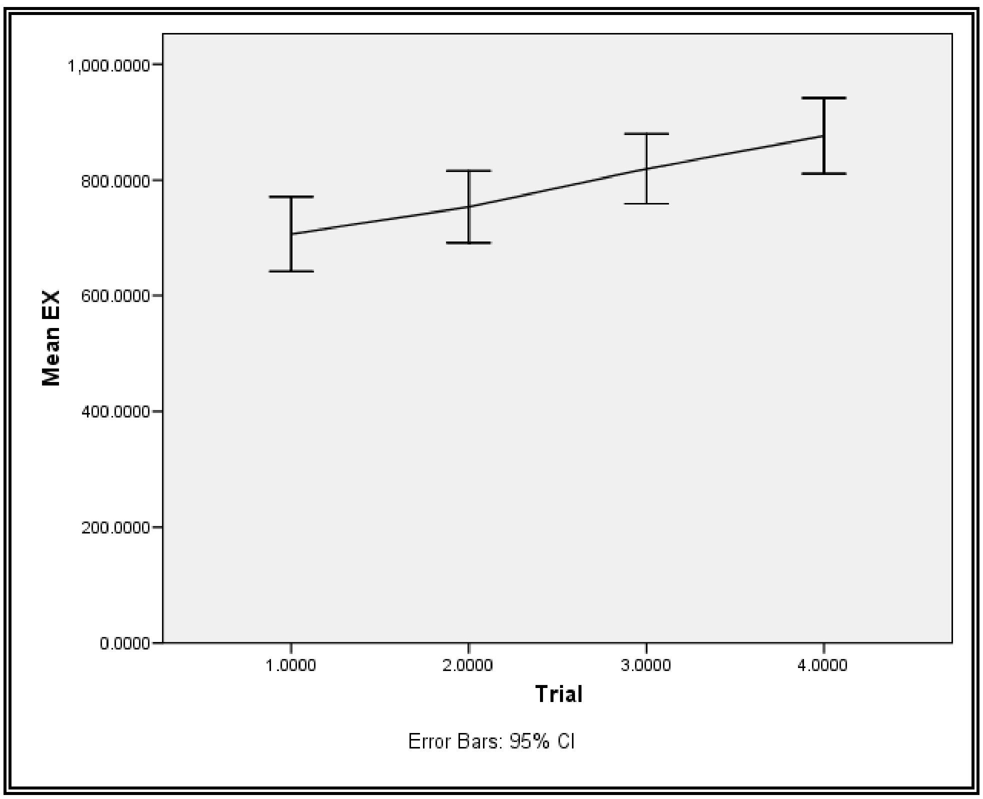
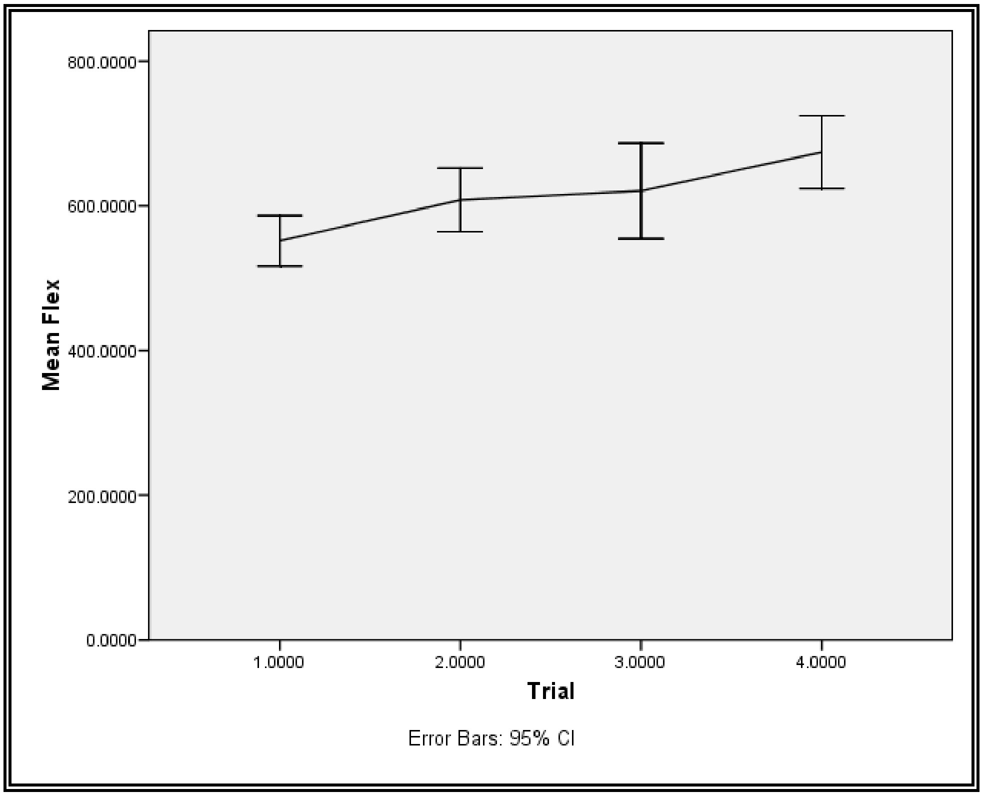


FIGURE 7. 8RM FLEXION TEST OUTCOMES.



The results of the study also produced significant correlations (Table 3 and 4). Table 3 presents the resulting fitness measurement correlations. A strong correlation was found between the CV outcomes and the 6-minute run outcomes (p-value <0.01). A weak correlation was found between the CV outcomes and the 2-minute run results (p-value <0.05). A weak correlation was also found to exist between the 2 and 6-minute runs (p-value <0.01). The critical velocities and anaerobic capacities were moderately inversely correlated (p-value <0.01). This was also true of anaerobic capacity and the 6-minute run (p-value <0.01). A weak to moderate positive correlation exists between the mean anaerobic capacities and the 2-minute run (p-value <0.01). A strong correlation was found between the 8RM flexion and extension tests (p-value <0.01). A weak inverse correlation was found between the 8RM extension test results and the 2-

minute runs, as well as the overall CV outcomes (p-value <0.05). The flexion strength testing was weakly inversely correlated with the two-minute run (p-value <0.01).

Correlations were also found to exist between the fitness measurement testing and the collected on-field performance data. The performance measurement correlations are presented in Table 4. The columns labeled PT, TOUCHES and TOTTOUCH represent playing time, touches on the ball per minute and total touches, respectively. A weak correlation existed between touches per minute and the CV outcomes (p-value <0.05). The same was true of touches per minute and total touches on the ball (p-value <0.05).

TABLE 3. FITNESS MEASUREMENT CORRELATIONS

Correlations

		CV	EX	Flex	two	six	AC
CV	Pearson Correlation	1	-.238*	-.140	.215*	.915**	-.625**
	Sig. (2-tailed)		.028	.198	.042	.000	.000
	N	90	85	86	90	90	90
EX	Pearson Correlation	*	1	.712**	-.248*	-.168	-.038
	Sig. (2-tailed)			.000	.021	.121	.729
	N		94	92	87	86	86
Flex	Pearson Correlation		**	1	-.286**	-.115	-.116
	Sig. (2-tailed)				.007	.287	.284
	N			94	88	87	87
two	Pearson Correlation	*	*	**	1	.330**	.486**
	Sig. (2-tailed)					.001	.000
	N				92	91	91
six	Pearson Correlation	**			**	1	-.664**
	Sig. (2-tailed)						.000
	N					91	91
AC	Pearson Correlation	**			**	**	1
	N						91

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

TABLE 4. PERFORMANCE MEASUREMENT CORRELATIONS.

Correlations

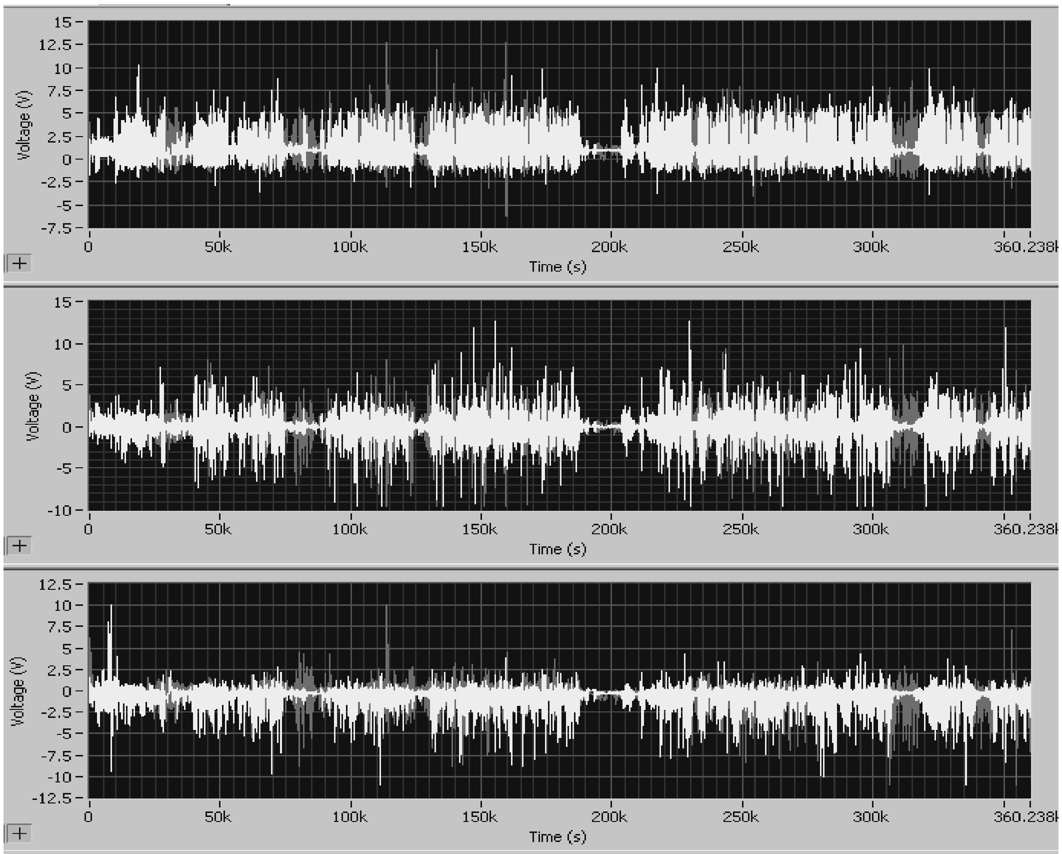
		CV	pt	touches	tottouch	AC
CV	Pearson Correlation	1	-.054	**.332***	.038	**-.625****
	Sig. (2-tailed)		.727	.028	.805	.000
pt	Pearson Correlation		1	.155	**.919****	.195
	Sig. (2-tailed)			.273	.000	.204
touches	Pearson Correlation	*		1	**.308***	-.040
	Sig. (2-tailed)				.026	.796
tottouch	Pearson Correlation		**	*	1	.227
	Sig. (2-tailed)					.139
AC	Pearson Correlation	**				1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 8A shows the individual axes of raw accelerometer data from two athletes and Figure 8B shows the total acceleration collected from two athletes. The data collected from Athlete 1, in grey, and Athlete 2, in white are overlaid to demonstrate differences. Athlete 1 exhibited greater peak accelerations (+12.65, -6.2 and p-p 18.9gs) compared to Athlete 2 (+10.26, -3.94 and p-p 14.20gs). In contrast to collected peak accelerations, root means squared (RMS) values indicated a greater average acceleration in Athlete 2 when compare to Athlete 1 (1.15 vs. 1.10gs respectively). These results indicate that during the same match, Athlete 1 exhibited greater maximal accelerations, while Athlete 2 exhibited greater average accelerations.

FIGURE 8. COLLECTED ACCELEROMETRY DATA: A COMPARISON OF TWO ATHLETES



DISCUSSION

Due to the dynamic nature of soccer, it is a difficult sport to study objectively. Therefore, little published research is available studying the relative energy system contributions during repeated sprint exercise, and even less with regard to soccer.[2,3,5,9] The more specific the group of athletes, such as female soccer players, the less research that exists for them. Possibly because of a lack of knowledge, today's training of the soccer player, tends to emphasis skill development, leading to deficiencies in fitness training.[21] The purpose of this study to determine how efficient the conditioning program of the Eastern Michigan University Women's Soccer Program during the 2007 competitive fall season by utilizing physiological testing measurements and on-field performance data collection. The secondary purpose of this study includes the measurement of fitness changes throughout the season and the utilization of accelerometry to quantify and compare the amount of work conducted during a competitive match with the athlete's fitness level.

The observed trend of the measured critical velocity and anaerobic capacity outcomes may be the best indicator of the fitness changes seen throughout the studies duration. The highest critical velocity mean was observed during the second trial in each of the three subject categories. Following the second trial a statistically significant decrease was observed up to the final trial. This may suggest that the installed conditioning program may have caused a peak in fitness that was induced too soon. The lack of a plateau in fitness may also suggest that the conditioning program during the competitive season did not stress the body systems enough to keep fitness at the elevated level. This is illustrated by the low critical velocity measurements in Trials 3 and 4. Starters and non-starters participated in the same conditioning program, therefore players who did not see minutes could have impacted the team's overall CV measures simply due to a lack of playing time. However this same trend occurred in all three sample groups, suggesting that the non-starters and starters, alike, saw decreases in fitness and that the team's decrease in fitness was not simply due to the fitness level of any one category of players.

A moderately significant inverse correlation existed between the CV outcomes and the anaerobic capacity incomes. Therefore the opposite trend was observed for the anaerobic capacity outcomes. As the season progressed, anaerobic capacity increased despite the lack of an implemented resistance training program. This may be attributed to the nature of muscle tissue and its response to different types of training. As a muscle becomes trained for aerobic exercise, mitochondrial and capillary density increases. Reduce the quantity of aerobic training on the muscle tissue and reductions are also seen in the mitochondria and capillary, therefore increasing the aerobic capacity of the muscle. This could explain the moderately strong inverse correlation between the CV outcomes and anaerobic capacity. This may also explain the average increase in load volumes from the initial trial to the final trial during the 8RM extension and flexion testing. As the conditioning program was less stressful on the aerobic system the subjects' muscles became well rested and therefore stronger.

The CV test was strongly correlated with the 6-minute run outcomes and weakly correlated with the 2-minute run outcomes, which may suggest that the outcomes of a CV test is a good indicator of aerobic fitness. The weak correlation between the 2 and 6-minute runs may indicate that each of these components of the CV test is indicative of two different fitness components. As mentioned the CV test and anaerobic capacity measurements were inversely correlated with each other. Along similar lines, the six-minute run and the anaerobic capacity measurements were also inversely correlated reinforcing the idea that the six-minute run may be a good test of aerobic capacity for soccer players. The weak correlation that was found to exist between the CV measurement outcomes and the touches per minute of playing time may begin to suggest that an individual with a higher critical velocity will be more involved in the run of play during a match.

The included accelerometry data is only a sample of the total collected accelerometer files. While it remains to be inconclusive the results demonstrated that one athlete can have higher peak accelerations while another athlete can have a higher acceleration mean. This noted difference between Athlete 1 and Athlete 2 could provide more research-based questions pertaining to the differences in physiological ability between athletes and how it corresponds to the different positions of the playing field. In the future collected on-field accelerometry could be compared to the collected physiological test measurements to track changes in fitness and compare the amount of work conducted during competitive play throughout the season.

There were a number of limitations on this particular project. One such limitation was the small sample sizes for the collection of accelerometry data. Only four accelerometers were available for use, therefore the sample size for each competitive match was limited to four subjects. Another such limitation would be the length of time between each round of tests. If more trials were to be conducted during the course of a season the results may be more specific as to when the fluctuations in fitness occur. The number of trials was limited for the purpose of keeping the interruption of regular season training activities to a minimum. Another limitation to be considered was the quality of home video game films from which the on-field performance measures were gathered.

Soccer is a multifaceted sport and requires much from the athletes in the areas of physiology, foot skills and agility, decision-making and psychology. There is much more research to be done within this realm. However, the findings from this project could have significant implications for future directions of research on the game of soccer. The results from the physiological testing of soccer players' allows both the athletes and the coaches to better understand strengths and weaknesses and train accordingly. This type of research may also allow coaches and managers to study the effectiveness of their training programs and adapt. It is hoped that these and any future research will provide a better foundation for the training of these athletes so that the game of soccer may continue to progress. An athlete has to meet the fitness demands of the sport without sacrificing the skills that make soccer unique and research in this area could make that task easier by allowing for a more inclusive perspective of how to train.

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