Predictors of High-Intensity Running Capacity in Collegiate Women During a Soccer Game

WILLIAM P. MCCORMACK, JEFFREY R. STOUT, ADAM J. WELLS, ADAM M. GONZALEZ, GERALD T. MANGINE, MAREN S. FRAGALA, AND JAY R. HOFFMAN

Department of Educational and Human Sciences, Institute of Exercise Physiology and Wellness, University of Central Florida, Orlando, Florida

ABSTRACT
McCormack, WP, Stout, JR, Wells, AJ, Gonzalez, AM, Mangine, GT, Fragala, MS, and Hoffman, JR. Predictors of high-intensity running capacity in collegiate women during a soccer game. J Strength Cond Res 28(4): 964–970, 2014—The purpose of this investigation was to determine which physiological assessments best predicted high-intensity running (HIR) performance during a women’s collegiate soccer game. A secondary purpose was to examine the relationships among physiological performance measures including muscle architecture on soccer performance (distance covered, HIR, and sprints during the game) during a competitive collegiate women’s soccer game. Ten National Collegiate Athletic Association (NCAA) Division I women soccer players performed physiological assessments within a 2-week period before a competitive regulation soccer game performed during the spring season. Testing consisted of height, body mass, ultrasound measurement of dominant (DOMleg), and nondominant leg (NDOMleg) vastus lateralis for muscle thickness (MT) and pennation angle (PA), \( \dot{V}_{\text{O}_{2}} \)max, running economy, and Wingate anaerobic test (WAnT) for peak power (PP), mean power (MP), and fatigue rate (FR). During the game, distance run, HIR, and sprints were measured using a 10-Hz global positioning system. Stepwise regression revealed that \( \dot{V}_{\text{O}_{2}} \)max, dominant leg thickness, and dominant leg PA were the strongest predictors of HIR distance during the game \( (R = 0.989, \text{SEE} = 115.5\, \text{m}, p = 0.001) \). \( \dot{V}_{\text{O}_{2}} \)max was significantly correlated with total distance run \( (r = 0.831; p = 0.003) \), HIR \( (r = 0.755; p = 0.012) \), WAnTPP \( (r = -0.737; p = 0.015) \), WAnTPP-kg\(^{-1} \) \( (r = -0.706; p = 0.022) \), and WAnTFR \( (r = -0.713; p = 0.021) \). DOMlegMT was significantly correlated with WAnTFR \( (r = 0.893; p = 0.001) \). DOMlegPA was significantly correlated with WAnTFR \( (r = 0.740; p = 0.023) \). The NDOMlegPA was significantly correlated to peak running velocity \( (r = 0.781; p = 0.013) \) and WAnT MP-kg\(^{-1} \) \( (r = 0.801; p = 0.01) \). Results of this study indicate that \( \dot{V}_{\text{O}_{2}} \)max and muscle architecture are important characteristics of NCAA Division I women soccer players and may predict HIR distance during a competitive contest.

KEY WORDS women’s soccer, muscle architecture, ultrasound, global positioning system

INTRODUCTION
Soccer has been described as the most popular sport in the world (27,28). The game requires a large amount of aerobic activity interspersed with explosive bouts of sprinting. At the elite level, women can cover a distance between 9 and 11 km during a game (17,24,29) and perform between 70 and 190 high-intensity runs per game (2,17,24). The activity profile of women’s soccer has been described in previous studies (17,25) with activity levels described as standing/walking, jogging/light running, moderate running, high-intensity running (HIR), and sprinting.

To be successful, soccer players must possess the aerobic and anaerobic capacity to meet the distance and speed requirements of the game (20,30). Aerobic capacity can be measured in a laboratory setting with a metabolic cart or on the field with a test such as the Yo-Yo Intermittent Recovery Test (Yo-YoIR), which has been shown to have a significant correlation with aerobic capacity (17). Several studies have described the maximal aerobic capacity of elite female soccer players between 48.4 and 54.0 ml-kg\(^{-1}\)-min\(^{-1} \) (9,14,17,18).

Researchers and training staffs have used various tests to measure lower-body power including unilateral and bilateral vertical and horizontal jump tests, short sprints, and Wingate Anaerobic Tests (WAnTs) (20,21,26). These measurements allow coaches to assess the success of their training programs and the conditioning level of their players. Athletes with greater lower-body power may have an advantage in soccer by being able to rapidly accelerate to get into a position to attack or defend in various game situations (21). Several studies have examined the relationship of lower-body power in women’s soccer (measured by jump or cycle load tests) with short-sprint performance (20), Yo-YoIR test results (26), and sprint performance after a game (18), whereas others have examined changes in power performance during a competitive...
season (21). To the authors’ knowledge, no one has examined the relationship between power and HIR in women’s soccer.

High-intensity running measured during a game seems to be an important predictor of physical performance in women soccer players (17,24). Accordingly, HIR has been defined as a player running faster than 14 km h⁻¹ (27), 15 km h⁻¹ (27,17.24), and more recently suggested by Dwij and Gabbett (11) as greater than 12 km h⁻¹. It has been reported that HIR increases as the level of competition increases (international vs. domestic), and the same player will perform more HIR against better competition (2,24,25).

Krüstrup et al. (17) reported that performance in elite women soccer players varied with the physical capacity of each athlete. Thus, the more aerobically fit women were (higher Vo₂max) the more distance of HIR they were able to cover when compared with less aerobically fit players. Krüstrup et al. (17) further reported that the amount of HIR during a women’s soccer game has been shown to be significantly correlated with Vo₂max (r = 0.809), Yo-YoIR test distance covered (r = 0.762), intermittent treadmill test performance (r = 0.818), and running speed at 2 mmol L⁻¹ of blood lactate (r = 0.834). High-intensity running may therefore be a measure that coaches can use to differentiate between good and average players or the conditioning status of their players.

Ultrasonography has been used as a noninvasive measure to determine muscle architecture, including muscle thickness (MT), fascicle length, and pennation angle (PA) (1,7,8,15). These measures have been used to differentiate between sprinters and distance runners (1). Ultrasonography has also been used to differentiate between soccer players and swimmers (15). There has also been work examining the architectural changes from chronic (7) and acute exercise (8). Significant positive correlations have been reported between MT and power output during a cycle ergometer test (8) and between MT, fascicle length, and PA in sprinters, distance runners, soccer players, and swimmers (1,15). These measures may help coaching and training staffs examine the effects of training programs and measure architectural changes across a competitive season.

The purpose of this investigation was to determine which physiological assessments best predicted HIR performance during a women’s collegiate soccer game. A secondary purpose was to examine the relationships among physiological performance measures including muscle architecture on soccer performance (distance covered, HIR, and sprints during the game) during a competitive collegiate women’s soccer game.

**METHODS**

**Experimental Approach to the Problem**

The players were tested on 2 separate visits to the University’s Human Performance Lab (HPL), with all testing conducted at the same time of day, with a minimum of 48 hours between visits. Players were asked to report to the HPL well rested. The first visit consisted of anthropometric measures (height and body mass), ultrasound (US) measurement of the dominant (DOM) and non-dominant (NDOM) vastus lateralis (VL), running economy (RE), and maximal aerobic capacity (Vo₂max) tests. Body mass (±0.1 kg) and height (±0.1 cm) were measured using a Health-O-Meter Professional scale (Patient Weighing Scale, Model 500 KL; Pelstar, Alsip, IL, USA). Visit 2 testing consisted of the Wingate anaerobic test (WAnT). Two weeks after completion of testing, an intrasquad game was played at which time performance data were collected.

**Subjects**

Ten National Collegiate Athletic Association (NCAA) Division I women soccer players (19.5 ± 1.0 years; 165.2 ± 5.5 cm; 62.1 ± 6.4 kg; age range = 18–22 years) were tested at the HPL and tracked during the intrasquad game. The players were informed of all procedures before testing. All performance assessments were part of the regular assessment protocol that was designed to provide feedback to the coaching staff regarding player fitness. All assessments were approved by the University’s Institutional Review Board.

**Procedures**

**Ultrasound Measurements.** Vastus lateralis MT, and PA were determined with US (GE LOGIQ P5; Madison, WI, USA). Longitudinal measurements were made at the midpoint of the thigh between the greater trochanter and the lateral border of the patella with the leg flexed 10–15° at the knee. The same laboratory technician performed all US measurements throughout the testing period. The intraclass correlation coefficients ± SEM for MT and PA were 0.99 ± 0.03 and 0.95 ± 0.91, respectively, for the laboratory technician.

**Physiological Measurements.** Running economy measures were made at a speed of 12.0 km h⁻¹ for all players. This speed was selected after discussion of their normal endurance training pace. A 5-minute warm-up was conducted on a treadmill (TrackMaster, Newton, KS, USA) at a self-selected speed before beginning the RE trial. Expired gases were analyzed (TrueOne; ParvoMedics, Sandy, UT, USA) during the 4-minute RE trial, and the average Vo₂ over the final minute was used as the RE measure. At the conclusion of the RE trial, the treadmill speed was increased in 2-minute increments to reach the players estimated 1-mile running speed. This speed was determined in pre-testing questions of all players. Once this speed was reached, subsequent stages were 1 minute in duration with an 1% increase in elevation at the end of each minute with speed remaining constant. The criteria used to determine if a valid Vo₂max test was performed included a plateauing of Vo₂ with increasing intensity, respiratory exchange ratio of greater than 1.10, and reaching estimated maximum HR (220 – age). Vo₂max values are reported as ml·kg⁻¹·min⁻¹.
was used for all testing. Peak power \(W_anT\) was defined as the highest mechanical power during the test. Mean power was defined as the average mechanical power during the 30-second test. \(W_anT\) FR was determined by dividing the lowest power output by the highest power output. The \(W_anT\) has been proven to be a reliable test for anaerobic power with test-retest coefficients between 0.89 and 0.97 (4,6).

**Game Data Collection.** After all testing, which coincided with the end of the team’s spring training period (time during the off-season program [~4 weeks] where contact time between the soccer coaches and players are permitted), the team conducted an intrasquad game. The game was conducted with the same rules and regulations as any regular season competitive contest including the use of referees. The coaching staff selected the players for each side to try and equalize the competition. The regular season starters were split between the 2 teams. The teams went through their normal warm-up routine as if they were preparing for a regular season game. Each half was 45 minutes in duration with a 15-minute halftime. Ten players were fitted with a 10-Hz global positioning system (GPS) receiver/transmitter (Minimax 4.0, Catapult Systems, Victoria, Australia). Five players from each side were outfitted with the GPS for the game. The players were forwards \(n = 4\), midfielders \(n = 5\), or an outside defender \(n = 1\). The data downloaded from the GPS receivers/transmitters included total distance covered \(m\); total HIR distance \(m\), which was defined as the distance covered running at a speed greater than 13 \(km\cdot h^{-1}\); and the number of sprints \((speed > 22 \text{ \(km\cdot h^{-1}\)}}\). Catapult Sprint software was used to download all data. Before the game and after the team warm-up, all players performed 2 maximum effort 54-m (end line to the midfield line) sprints. The peak velocity \((m\cdot s^{-1})\) reached during either sprint was recorded as the player’s peak running velocity (PKRUNVEL). Varley et al. (31) reported that the 10-Hz GPS units have proven to be valid and reliable for quantifying acceleration, deceleration, and constant velocity running in team sports.

**Statistical Analyses**

A stepwise regression was conducted to determine the physiological factors that best

### Table 1. Physiological and game performance measures.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
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<tbody>
<tr>
<td>Height (cm)</td>
<td>165.18 ± 5.47</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.08 ± 6.40</td>
</tr>
<tr>
<td>Game distance (m)</td>
<td>8,953.9 ± 1,035.4</td>
</tr>
<tr>
<td>Game HIR (m)</td>
<td>1,585.6 ± 594.6</td>
</tr>
<tr>
<td>Sprints per player during game</td>
<td>4.70 ± 4.24</td>
</tr>
<tr>
<td>DomLeg MT (cm)†</td>
<td>1.62 ± 0.26</td>
</tr>
<tr>
<td>DomLeg PA (°)</td>
<td>11.69 ± 2.46</td>
</tr>
<tr>
<td>NonDomLeg MT (cm)†</td>
<td>1.51 ± 0.15</td>
</tr>
<tr>
<td>NonDomLeg PA (°)</td>
<td>9.77 ± 2.29</td>
</tr>
<tr>
<td>(V_\text{O}_2) max (ml·kg(^{-1})·min(^{-1}))</td>
<td>48.00 ± 3.80</td>
</tr>
<tr>
<td>(RE) (ml·kg(^{-1})·min(^{-1}))</td>
<td>39.78 ± 1.81</td>
</tr>
<tr>
<td>(W_anT) peak power (W)</td>
<td>1,034.0 ± 223</td>
</tr>
<tr>
<td>(W_anT) peak power·kg(^{-1}) (W·kg(^{-1}))</td>
<td>16.66 ± 3.10</td>
</tr>
<tr>
<td>(W_anT) mean power (W)</td>
<td>476.7 ± 65.2</td>
</tr>
<tr>
<td>(W_anT) mean power·kg(^{-1}) (W·kg(^{-1}))</td>
<td>7.70 ± 0.68</td>
</tr>
<tr>
<td>(W_anT) total work (J)</td>
<td>14,116 ± 2,062</td>
</tr>
<tr>
<td>(W_anT) FR (%)</td>
<td>83.8 ± 14.1</td>
</tr>
</tbody>
</table>

*\(W_anT\) = wingate anaerobic test; HIR = high-intensity running; DomLeg = dominant leg; MT = muscle thickness; PA = pennation angle; NonDomLeg = nondominant leg; RE = running economy; FR = fatigue rate.
†Muscle thickness measurements were of the vastus lateralis.
\(^2\)\(V_\text{O}_2\) measured at 3.35 m·s\(^{-1}\).

**Wingate Anaerobic Test Measurements.** The \(W_anT\) was performed on an electronically braked cycle ergometer (Lode; Excalibur Sport, Groningen, Netherlands). Seat height and handlebar position were adjusted for each player before commencing the test. A 5-minute warm-up was conducted on the cycle ergometer at a self-selected cadence and resistance before beginning the test. Before the onset of the test, the player pedaled at 60 rpm at a resistance of 50 W, and a countdown from 5 seconds was given before the beginning of the test. Verbal encouragement to give maximum effort was given by the laboratory staff. A torque factor of 0.85 N·m·kg\(^{-1}\) was used for all testing. Peak power \((W_anTPP)\) (W), mean power \((W_anTMP)\) (W), total work \((W_anTTW)\) (J), and fatigue rate \((W_anTFR)\) (%) were recorded. Peak power was defined as the highest mechanical power during the test. Mean power was defined as the average mechanical power during the 30-second test. \(W_anT\) FR was determined by dividing the lowest power output by the highest power output. The \(W_anT\) has been proven to be a reliable test for anaerobic power with test-retest coefficients between 0.89 and 0.97 (4,6).

### Table 2. Pearson product-moment correlations between physiological and game performance measures.

<table>
<thead>
<tr>
<th></th>
<th>Peak running velocity</th>
<th>Sprints per player during game</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game distance run</td>
<td>0.831</td>
<td>0.319</td>
</tr>
<tr>
<td>*p 0.003</td>
<td>0.410</td>
<td>0.369</td>
</tr>
<tr>
<td>Game HIR</td>
<td>0.755</td>
<td>0.726</td>
</tr>
<tr>
<td>*p 0.012</td>
<td>0.606</td>
<td>0.017</td>
</tr>
<tr>
<td>Sprints per player during game</td>
<td>0.417</td>
<td>1.000</td>
</tr>
<tr>
<td>*p 0.231</td>
<td>0.022</td>
<td></td>
</tr>
</tbody>
</table>

*HIR = high-intensity running.
predict HIR distance over the duration of a collegiate soccer game. Pearson product-moment correlations were also used to examine bivariate correlations between the physiological measures and game data. All data are reported as mean ± SD. Statistical significance was set at \( p \leq 0.05 \). Data were analyzed using SPSS v20 software (SPSS Inc., Chicago, IL, USA).

RESULTS

The mean ± SD of the physiological and game performance measures are presented in Table 1. The \( VO_{2\max} \) values of these players are consistent with those seen in other elite level women soccer players (17,18,23). Results of the stepwise regression using all the physiological and power measures revealed that \( VO_{2\max} \), DOMlegMT, and DOMlegPA were the best predictors of HIR distance during the game \( (R = 0.989, \text{SEE} = 115.5 \text{ m}, p = 0.001) \). The \( VO_{2\max} \) alone had an \( R \) value of 0.888 \( (\text{SEE} = 295.4 \text{ m}, p = 0.003) \) for this group of players for predicting HIR distance over the game duration.

Selected bivariate correlations between physiological measures and game performance are presented in Table 2. The total distance run during the game and the total distance of HIR were significantly correlated to \( VO_{2\max} \) \( (r = 0.831; p = 0.003 \) and \( r = 0.755; p = 0.012 \), respectively) (Figure 1). Number of sprints per person during the game was also significantly correlated with PKRUNVEL \( (r = 0.707; p = 0.022) \). There were no other significant correlations between game performance measures and physiological measures.

| Table 3. Pearson product-moment correlations between muscle architecture and power measures.* |
|---------------------------------|---------|--------|----------|----------|----------|
| DOMlegMT | 0.989 | 0.618 | 0.361 | 0.370 | 0.318 | 0.893 |
| \( r \) | 0.001 | 0.060 | 0.305 | 0.292 | 0.371 | 0.001 |
| DOMlegPA | 1.000 | 0.536 | 0.068 | 0.164 | 0.413 | 0.740 |
| \( r \) | 0.137 | 0.861 | 0.673 | 0.269 | 0.023 |
| NDOMlegPA | 0.444 | 0.781 | 0.069 | 0.221 | 0.801 | 0.081 |
| \( r \) | 0.232 | 0.013 | 0.860 | 0.957 | 0.010 | 0.836 |
| \( VO_{2\max} \) | -0.086 | 0.125 | -0.737 | -0.706 | -0.009 | -0.713 |
| \( r \) | -0.826 | 0.730 | 0.015 | 0.022 | 0.979 | 0.021 |
| RE | -0.447 | -0.102 | -0.539 | -0.664 | 0.227 | -0.603 |
| \( r \) | 0.228 | 0.779 | -0.108 | -0.036 | 0.528 | -0.065 |
| Peak run velocity | 0.536 | 1.000 | 0.151 | 0.104 | 0.663 | 0.230 |
| \( r \) | 0.137 | 0.678 | 0.776 | 0.037 | 0.523 |

*DOMleg = dominant leg; WAnTPP = wingate anaerobic test peak power; WAnTPP kg\(^{-1}\) = wingate anaerobic test peak power per kg; WAnTMP kg\(^{-1}\) = wingate anaerobic test mean power per kg; WAnTFR = wingate anaerobic test fatigue rate; MT = muscle thickness; PA = pennation angle; NDOMleg = nondominant leg; RE = running economy.
Predicting High-Intensity Running in Soccer

and other physiological or power measures. There was a trend toward a relationship between PKRUNVEL and game HIR ($r = 0.614; p = 0.06$).

Bivariate correlations between muscle architecture and power are presented in Table 3. DOMlegMT was significantly correlated with WAnTFR ($r = 0.893; p = 0.001$). DOMlegPA was significantly correlated with WAnTFR ($r = 0.740; p = 0.023$). The NDOMlegPA was significantly correlated to PKRUNVEL ($r = 0.781; p = 0.013$) and WAnTMP-kg$^{-1}$ ($r = 0.801; p = 0.01$). There were no other significant correlations between the US measures and game and power measures. There was a trend toward a relationship between DOMlegMT and PKRUNVEL ($r = 0.618; p = 0.06$).

There were several significant correlations between $V_{O_2}$max, PKRUNVEL, and WAnT measures. Inverse correlations were noted between $V_{O_2}$max and both WAnTPP ($r = -0.737; p = 0.015$) and WAnTPP-kg$^{-1}$ ($r = -0.706; p = 0.022$). An inverse relationship was also noted between WAnTPP-kg$^{-1}$ and RE ($r = -0.664; p = 0.036$). WAnTMP-kg$^{-1}$ was significantly correlated with PKRUNVEL ($r = 0.663; p = 0.037$). WAnTFR was significantly correlated with $V_{O_2}$max ($r = -0.713; p = 0.021$). There was a trend toward a relationship between RE and WAnTFR ($r = -0.603; p = 0.065$).

**DISCUSSION**

The main finding in this study was that $V_{O_2}$max, dominant leg MT, and dominant leg PA were the strongest predictors for the total distance of HIR completed during a 90-minute competitive collegiate women’s soccer game. These findings suggest that aerobic fitness and muscle architecture may be important predictors of soccer performance. To our knowledge, this is the first investigation examining muscle architecture as a potential predictor for performance in collegiate women soccer players during a competitive game.

High-intensity running has been reported to be related to many physiological variables, including $V_{O_2}$max, incremental treadmill performance, intermittent recovery tests, and blood lactate levels (17). This study showed HIR to be positively correlated ($r = 0.755; p = 0.012$) with $V_{O_2}$max. This is in agreement with Krstrup et al. (17) who reported a similar relationship between HIR and $V_{O_2}$max ($r = 0.809$) in elite Danish women soccer players. It has been reported that the distance covered in a game for female soccer players is between 9 and 11 km (17,24), which is comprised of repeated high-intensity runs and seems to require a high level of aerobic fitness. Our data support previous studies, which suggest a strong relationship between $V_{O_2}$max and the ability to maintain sprint performance during repeated sprinting in soccer (3,10).

The muscle architecture results reported in this population contrast with those reported by Kanehisa et al. (15). The VL MT values of the dominant leg in this study were 1.62 ± 0.26 cm (range between 1.26 and 1.99 cm) compared with the right leg (assumed to be dominant leg) of 2.20 ± 0.08 cm (range between 1.70 cm–2.80 cm) reported by Kanehisa et al. (15). In addition, the VL PA of the dominant leg in this study was 11.69 ± 2.46° (range between 8.13 and 15.18°) vs. the right leg measures of Kanehisa et al. of 15.90 ± 0.63° (range between 12.50 and 22.90°). Although differences in measurement technique, including protocol and measurement site (19), and individual technician experience and techniques (5,12) may account for some of these differences, Kanehisa et al. (15) reported their results from female Japanese Olympic soccer players. It is likely that differences between level of play (collegiate players in this study compared with elite Olympic caliber) and age/experience (19.5 ± 1.0 years in this study vs. 23.7 ± 0.8 years in the study by Kanehisa et al.) may partially explain some of the differences seen in muscle architecture between the studies. Although the correlation was not significant, the trend in the relationship between DOMlegMT and PKRUNVEL ($r = 0.618; p = 0.060$) suggests that MT tended to be related to the players ability to sprint. This is supported by the previous work of Abe et al. (1) who reported that sprinters have a larger MT than endurance athletes. These results suggest that female soccer players with larger lower limb muscle mass seem to have an advantage for sprint speed than athletes with less mass in the VL.

The significant correlation observed between PKRUNVEL and WAnTMP-kg$^{-1}$ ($r = 0.663; p = 0.037$) suggests that the ability to sustain power output for 30 seconds is a good predictor of running speed in female soccer players. A trend was also observed between PKRUNVEL and HIR ($r = 0.614; p = 0.060$), suggesting that the fastest soccer players tended to perform more high-intensity runs during the contest. This is supported by our findings that PKRUNVEL was significantly correlated with sprints per game ($r = 0.707; p = 0.022$). These 2 relationships along with the relationship between PKRUNVEL and WAnTMP-kg$^{-1}$ support the idea that although soccer has been classified as an intermittent athletic sport (17,24), there is a need to perform high-intensity activity, such as repeated sprints (25,26), during preparation for a competitive season. The trend towards another significant linear relationship between PKRUNVEL and WAnTMP-kg$^{-1}$ ($r = -0.606; p = 0.063$) and WAnTPP-kg$^{-1}$ ($r = -0.607; p = 0.063$) is difficult to explain and may be spurious.

The $V_{O_2}$max was negatively correlated with WAnTFR, WAnTPP-kg$^{-1}$, and WAnTFR. These significant negative correlations seem to support the supposition by Mc Lester et al. (22), that increased $V_{O_2}$ through endurance training instead of exercising for strength and power may compromise power performance. It also supports previous research that questioned the use of the WAnT for evaluating soccer athletes (16). The inverse relationship between aerobic capacity and WAnTFR is consistent with previous studies that have demonstrated the limited role that high levels of aerobic capacity have on recovery during high-intensity exercise (6,13). Beneke et al. (6) showed that the aerobic contribution during a WAnT was approximately 20% and...
suggested that if aerobic contribution increases in an aerobically trained individual, it would follow that their FR would be lower than someone who is contributing a higher percentage of power output from their anaerobic metabolic pathways. Hoffman (13) has also suggested that aerobic capacity may have a role in enhancing recovery from anaerobic events. However, this contribution becomes less important as aerobic capacity improves. This may also explain the significant relationship between DOMegMT and WAnTFR ($r = 0.893, p = 0.001$). An individual with a thicker VL, as shown by Abe et al. (1) comparing sprinters and distance runners, will possibly be able to generate more force or power, but may fatigue at a higher rate than those people that are more aerobically fit and have a smaller muscle mass. It is incumbent on soccer coaches and training staffs to balance the need for a high level of aerobic fitness to meet the distance and recovery demands of the game yet maintain explosive power to produce repeated high speed sprints.

A limitation of this study was the small number of players and the pooling of data across 3 positions, with 4 forwards; 5 midfielders; and 1 outside defender analyzed as 1 group. Research has shown that there can be a difference in game characteristics between field position with midfielders covering more distance than other positions and attackers performing more sprints than other positions (25). The outside defender included with this group had the freedom to cover the entire length of the field and in game data had similar statistics as the midfielders. Ingebritsen et al. (14), however, have shown no statistical difference between playing positions and $V_o_{2max}$ values.

In conclusion, the results of this study support the important role that both aerobic capacity and muscle architecture have in predicting HIR distance during a competitive soccer game in NCAA Division I women soccer players. Although these results should not be extrapolated to male collegiate soccer players, it does provide the impetus for further study on whether there are gender differences in the relationship between aerobic capacity, muscle architecture, and HIR distance.

**Practical Applications**

The findings in this study have direct implications for coaching staffs and strength and conditioning personnel. Training programs for female soccer players should focus on enhancing both aerobic and anaerobic capacity. This could include interval type training that has been shown to improve both aerobic and anaerobic capacity (32). These conditioning programs can also enhance the metabolic buffering capacity of the player who will contribute to a quicker recovery from a bout of HIR.

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