Less total body fat and lower extremity fat are associated with more high-intensity running during games in female university soccer players.

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Abstract

Less total body fat and lower extremity fat are associated with more high-intensity running during games in female university soccer players.

The purpose of this study was to investigate the relationship between body composition and in-game physical performance measures in female collegiate soccer players. Body composition measures including total mass, fat mass, and lean tissue mass, both for the lower extremities and for total body were acquired in 10 players using dual energy x-ray absorptiometry. In-game physical performance measures were collected using global positioning system (GPS) devices and included total distance covered and distance covered in 6 different speed zones. Data from fourteen regular season games were analyzed over the 1st half, 2nd half, and entire game. The level of significance was set at $p<0.05$. Players covered less distance in the 2nd half compared to the 1st half of the game (3356.5±1211.7m vs. 4544.7±495.2m, $p=0.004$). A repeated measures ANOVA revealed decreases in distance covered jogging, at low-intensity running, and at moderate-intensity running during the 2nd half compared to the 1st half of the game ($p<0.001$). Lower measures of total body fat mass, total body fat percentage and lower extremities fat mass were correlated to covering more distance at moderate-intensity and high-intensity running during the 2nd half and as well as the whole game (r values from -.644 to -.745, p values from <0.01 to 0.04). Our results suggest that body composition can influence the distance covered at moderate- and high-intensity running speed during competitive games. Training strategies that help reduce excess fat mass and incorporate high-intensity training bouts may be beneficial for female soccer players and contribute to overall team success.

Key words: Performance, football, body composition, GPS

Contribution of Authors

Data collection – Body composition measures: Dr. Maryse Fortin
Data collection – In-game physical performance measures: Stephanie Di Lemme
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Introduction

Soccer is the most popular sport in the world, played and watched by millions of people. (5) Measuring or evaluating in-game physical performance of individual soccer players is challenging. Individual player statistics mainly rely on goals scored, however very few goals are scored on average each game. Also, only a few players from each team score goals. On average, 2 to 3 goals are scored per game during the FIFA World Cup since 1962. (78) Some studies have evaluated and ranked individual player performance according to birthplace and salary. However, birthplace and salary do not directly provide information on the player's performance during games and can be influenced by regional bias and market changes. (24, 45) In addition, high-level soccer players need to possess a high number of skills and physical attributes in different domains, which makes the evaluation of individual player performance even more challenging. (84) Currently, no model or on field test for example is validated or used regularly by high-level soccer academies for individual talent identification. (84)

Individual physical performance tests do not consistently differentiate players that perform better during games or that compete at different levels. (103, 114) College-level players in the National Collegiate Athletic Association (NCAA) present similar results on a 30-meter sprint than professional players competing in European championships, suggesting that a maximal running test does not differentiate professional soccer players from college-level players. (11) Also, in a professional soccer team, starters do not present higher aerobic capacity test results than non-starters. (101) Aerobic capacity does not differentiate starting players that compete for most of the game from players that are substitutes and spend significantly less time on the field. Players that have a greater aerobic capacity usually cover larger total distances during soccer games. (59, 60, 65) Although aerobic capacity may indicate a player's level of fitness, the test result cannot predict a player's in-game performance or level of competition. (98, 103) Other factors considerably impact individual in-game performance such a technique, team tactics, coaching environment, psychological factors, and injuries. (5, 47) Tests therefore have a limited ability to predict in-game performance of soccer players. (103) In-game measures are more accurate than individual physical tests because in-game measures directly assess the player's individual performance during competition. Conversely, an aerobic capacity test or a maximal sprint test does not directly transfer to in-game situations.

Coaches often evaluate players based on their contribution to the team's success rather than by objectively measuring what the player is accomplishing during the game. (84) A more robust and objective evaluation of in-game performance can assist team coaches in selecting the best players for the team or determining who are the best players on the team. (51) Recent advances in global positioning system (GPS) devices and miniature heart rate (HR) sensors allow to easily monitor individual player movement as well as physiological responses during games. (36) The use of GPS devices helped determine that players cover less total distance and cover less distance at high-intensity running in the second half than during the first half of the game.(34, 73, 113) Fatigue may help explain the reduced physical performance throughout a soccer game, however the reason for this decrease in individual physical performance in the second half is still unknown. (73) Coaches and sports scientists can use GPS and HR measures to objectively measure in-game physical performance of soccer players.

An aspect that has been examined a lot with regards to influencing soccer athletes' performance is body composition. (98) Various methods of body composition assessment are available, however researchers must consider specific methods of body composition assessment in athletic populations.(71, 91) Although muscle mass has a considerable impact on athletic performance, many studies only focus on assessing total body mass and total body fat percentage. (69) In addition, regional body composition is rarely assessed. Body composition differs significantly between different regions of the body and also between athletes of different sports, therefore should be evaluated. (69) Researchers and coaches often hypothesize that an increase in percent body fat would impair performance and that an increase in muscle mass would improve performance. (88) Although in some studies fat mass was negatively correlated to performance of cardiovascular endurance tests, sprint tests, and vertical jump tests, other studies did not support such findings. (20, 98, 102) Physical tests results have been examined in relation to body composition in soccer players. (20, 98) As physical tests can provide a score in a particular fitness domain, physical tests do not directly transfer to in-game performance. (103) The contribution of body composition to individual physical performance during games has not yet been established in soccer players, since studies have only examined relationships between specific physical tests and body composition. (98) Therefore, the purpose of this study is to examine the relationship between in-game physical performance measures and regional body composition measures in women college soccer players.

Review of the current literature

Talent identification in soccer

Soccer players individual in-game performance depends on many different factors. Top-level players need to possess reasonable fitness levels and technical skills, as well as a complex understanding of the game. (5, 84) Soccer coaches and sports scientists seek to identify key determinants that can distinguish players with better success potential as compared to other average competitive players. (80, 86) Talent detection is more difficult in team sports such as soccer compared to individual sports such as running, cycling or rowing, where predictors of performance are more clearly defined. (82, 83) Moreover, identifying young talented soccer players at an early age yields many advantages. Early talent detection may allow a more long-term development of players and greater individual potential achievement. (84) Numerous soccer academies around the world attempt to select young soccer players and train them over several years with the objective of having them compete at national and international levels. The huge economical and human resource investment for this process calls for efficient methods for talent selection and development. (61) In the attempt to perform an objective evaluation of the young soccer players' potential, anthropometrical measures and physical test results are of interest. (51) In addition, analyzing performance of players during games can provide accurate measurements of what players are exactly doing on the field. Wearable monitors tracking player movement and individual physiological responses during games may provide a non-invasive and safe way to analyze performance at any age, and at any level of competition. (36) Asking players to wear monitors that track individual in-game performance seems more feasible than having each player perform physical tests. In addition, some physical tests require maximal effort, which can cause discomfort and may be inappropriate in younger populations. Research on performance predictors can complement subjective observations and intuitions from experienced coaches regarding the most talented players.(86)

Challenges of measuring performance in soccer players

Measuring performance in soccer players is difficult. Very few statistics are recorded in soccer, in comparison with other team sports such as basketball or American football. In soccer, individual player statistics collected include number of goals scored, however very few goals are scored on average each game. (23) The number of goals scored provide limited information regarding the performance of the 11 players on the field for each team. Another statistic that is recorded in soccer is team possession, which corresponds to the proportion on the 90-minute game during which one team held the ball. Team possession provides information on collective team performance rather than individual player performance. Measures of individual performance are necessary in order to determine which players perform best during games. Many studies investigated physical tests results in elite soccer players in the attempt of determining what the physical profile of a successful player would look like. (60)

Physical performance tests

The Yo-Yo Intermittent Recovery Test Level 1

The Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) provides information regarding individual physical capacity to perform repeated intense exercise. (10) The Yo-Yo IR1 has been used to differentiate elite soccer players competing at different levels. (73) The Yo-Yo IR1 can also identify players that have the ability to achieve more high-intensity running distance during a competitive soccer game. (59, 60) The Yo-Yo IR1 test differs from the multi-stage fitness test . The Yo-Yo IR1 incorporates a recovery period whereas the multi-stage fitness test does not. (103) In the Yo-Yo IR1, players must repetitively run back-and-forth across a 20-meter distance. Between each running bout, players have a 10-second recovery period during which they have to slowly jog for 10 meters (2x5 meters, back-and-forth). A first auditory sound indicates when the player must begin running from the start line. A second auditory signal indicates when the player must have completed the 20-meter distance and reached the second line, and also indicates the start of the 10-second recovery period. The sequence of auditory signals is repeated over the duration of the test. The audio recording progressively decreases the time elapsed between the two auditory signals, forcing the players to increase their running speed. When a player fails twice to reach the finish line before the second auditory signal, the test ends. The total distance covered is calculated by counting the number of shuttles performed and multiplying it by 20 meters. The total distance covered is recorded as the Yo-Yo IR1 result. (8) During the Yo-Yo IR1, both aerobic and anaerobic energy systems are highly solicited. The Yo-Yo IR1 is appropriate to examine the physical capacity of intermittent-sports athletes. (8, 10) The test is valid and reliable, can be conducted on multiple players at a time, and requires limited equipment. (59) The Yo-Yo IR1 test result is a valid indication of soccer-specific aerobic fitness that mimics the activity patterns of players during a competitive soccer game. (10) Research suggests that the Yo-Yo IR1 test differentiates professional soccer players competing at different levels. (73) One study investigated the difference in Yo-Yo IR1 scores between top-class professional players competing in the Italian League or the European Champions League and moderate-level professional players competing in the top Danish league. Top-class players performed significantly better on the Yo-Yo IR1 (2.26 + 0.08 km) than moderate-level players (2.04 + 0.06 km). Another study investigated the relationship between Yo-Yo IR1 results and in-game performance in a Division I women's professional team in Denmark. (60) Players that covered more distance during the Yo-Yo IR1 also covered greater total distance during games ($r = 0.56$, $P < 0.05$). In the same study, the Yo-Yo IR1 was also a predictor of players' ability to perform high-intensity running during the game. Female players that had a better Yo-Yo IR1 score covered more high-intensity running distance (≥15 km/h) during the game ($r = 0.76$, $P < 0.05$). (60) The Yo-Yo IR1 is also a good predictor of in-game performance in male professional soccer players. Strong positive correlations between Yo-Yo IR1 results and high-intensity running distance (≥18 km/h) were found in male professional soccer players ($r = 0.71$, $P \leq 0.05$). (59) The Yo-Yo IR1 is an intermittent test and therefore is suggested as a more specific test than aerobic capacity. (10) However, numerous studies have assessed aerobic capacity in elite soccer players and have suggested a relationship between aerobic capacity and in-game performance of soccer players. (60, 65)

Aerobic capacity

Aerobic capacity or $VO_{2\ max}$ in elite female soccer players is reported approximately between 50 and 58 ml/kg/min. (29) In elite male soccer players, aerobic capacity is reported between 60 and 65 ml/kg/min. (49, 95) Aerobic capacity is an important factor affecting players' in-game performance. (95) In a National Collegiate Athletic Association (NCAA) Division I women soccer team, players with higher aerobic capacities performed more high-intensity running during games, and also covered more total distance throughout games. (60, 65) A positive relationship between aerobic capacity and high-intensity running during games was also observed in a women professional team in Europe ($r=0.81$, $P < 0.05$). However, the study only analyzed one competitive game. (60) In a study conducted with 37 elite men players, aerobic capacity and high-intensity running during games were not correlated. However, in the same study, a relationship was found between aerobic capacity and total distance covered in a match ($r=0.52$, $p<0.05$). (59)

As described in the above section, a relationship between players' aerobic capacity or Yo-Yo IR1 test results and in-game performance measures has been suggested, however other studies did not observe such relationships. Conflicting results suggest that other factors may require consideration in the evaluation of in-game performance. Although soccer players need great endurance in order to compete during the 90-minute game, players must also be able to perform anaerobic efforts throughout the game.

Anaerobic energy utilization in competitive soccer

Soccer is primarily an aerobic sport, however players are required to complete frequent bouts of anaerobic activity during a competitive game. (101) Players' activity is largely anaerobic during the most crucial moments of the game when directly contributing to winning the ball, keeping team possession of the ball, contributing to a goal, or preventing the opponent from scoring a goal. (84) Anaerobic activity in the form of sprints is frequently performed and occurs over short distances, usually from a flying start. Players initiate sprints from walking or striding, and other times from moderate to high running speeds. (103) Sprints are rarely initiated from a stationary start. During a game, players sprint over distances of 10 to 30 meters for average durations of less than 6 seconds. (103) In addition to sprinting, a number of physically demanding efforts such as high-intensity running, rapid changes in direction, jumping, tackling, protecting the ball, and kicking are required. (8) The ability to accelerate and quickly attain a high running speed is an important quality for high-level soccer players. (66)

Heart-rate responses during soccer games

Although soccer is mainly aerobic, players perform anaerobic bouts of activity on average every 30 seconds. (84) The mean work rate during a soccer game is about 70–75% of maximum oxygen uptake and close to the anaerobic threshold. (11) During preseason games, the average heart rate of men professional soccer players from Spain's first division was 165 beats per minute, corresponding to 85% of individual maximal heart rate. (64) Similar results were obtained in second division men professional players in Portugal. The players competed with mean heart rates corresponding to 87% of maximal heart rate during a 90-minute game. In the same study, team average peak heart rates were 99.7% of maximal heart rate. (6) Peak heart rate corresponds to the highest cardiac frequency recorded throughout the game for each player. In women professional soccer players, average heart rate during a competitive game was 167 beats per minute, corresponding to 87% of maximal heart rate. The women's team average peak heart rate was 186 beats per minute, corresponding to 97% of maximal heart rate. (60) High-level players must possess the ability to perform and recover from high-intensity intermittent exercise throughout the 90-minute game.

Muscle strength

Muscular strength as well as power of the lower limbs and trunk are important for high-level soccer players. (8, 40) Players perform rapid turns, accelerations, and tackles, in addition to passing and kicking the ball. (8) Although soccer is primarily a lower-body dominant sport, upper body strength is also important. Players with greater trunk and upper body strength may better protect the ball, battle for the ball more efficiently, and gain possession of the ball more often. Upper body strength is also an advantage to throw the ball back into play. (95) Muscle strength has been suggested as a differentiating characteristic between age categories and levels of play. Players on the Swedish national team and in the Swedish first division have higher torque values for knee flexors and extensors than players from fourth division clubs. (76) Isokinetic strength is also significantly higher in Japanese national team players compared to university players. (82) However, measures of isokinetic strength are questionable in soccer as players perform multi-joint concentric and eccentric muscular actions. (103) Symmetrical muscle mass and muscle strength between both lower limbs is important for injury prevention. Appropriate strength ratio of knee flexors and extensors is also an important factor for injury prevention. (83, 99) Professional soccer players with similar muscle strength between knee flexors and extensors are less likely to sustain lower body injuries. (44)

In the past, soccer players were assumed to have one leg stronger than the other. While the non-dominant leg is planted on the ground and stabilizes the pelvis and rest of the body, the dominant leg requires more strength and power to strike the ball. (63) Since kicking is mainly performed with the dominant foot, scientists thought that players would develop asymmetrical lower body musculature, especially over many years of competition. (31) Despite lower limb dominance and the asymmetrical nature of kicking a soccer ball, researchers identified symmetry of the lower limbs in elite soccer players. (31) Assessment of bone mineral content, lean mass and fat mass using dual-energy x-ray absorptiometry (DXA) suggested symmetry between the dominant and non-dominant limbs. In the same study, muscle strength and range of motion were also symmetrical between both lower limbs. (31) Kicking is not the primary movement performed by soccer players, explaining why soccer players display lower limb symmetry. Players perform a number of ball touches that include dribbling, passing, striking, crossing, or heading the ball, that often involve asymmetrical movement patterns. However, each player only touches the ball 35 to 45 times during a game, depending on team success. (80) The number of ball touches performed by the player is very low compared to the average 10 kilometers that players cover during a game. (101) Since running is a symmetrical movement pattern that requires an equal involvement of both lower limbs, the predominant running movement counteracts the asymmetrical activity pattern of kicking the ball. Players walk, jog and sprint for nearly the entire duration of the game, suggesting why stronger unilateral muscle development does not occur in the dominant limb. (31)

Limitations of physical performance tests

Laboratory or field tests cannot evaluate all technical, tactical and physical aspects of a soccer game and predict individual performance during games. (103) Some tests can provide insight on the player's ability to cover a large total distance and to perform great high-intensity running distances during a competitive game. However, field tests or physical tests do not help identify players who will perform best on the field, and do not differentiate players from different levels of performance. One study investigated the difference in aerobic capacity among starters and non-starters of a first division team in Denmark. Starters and non-starters from the first team did not show any difference in $VO_{2\ max}$. (101) Similarly, aerobic capacity did not differentiate starting from non-starting players in a male NCAA Division I team. (98) In elite and professional teams, high levels of performance are required from all team members. (98) Starters and non-starters usually follow identical training programs, perhaps explaining why both groups possess similar aerobic capacities. The only difference in training load is that starters play a greater number of minutes in competitive games compared to non-starters. The difference in playing time may not be enough to cause significant differences in aerobic capacity. In addition, in many elite teams, non-starters complete additional training to maintain training loads that are similar to the starters on the team. For example, players that competed for less than 30 minutes during a game may have to do an additional training session on the next day, while the other players that competed over 30 minutes during the game do active or passive recovery.

Another example that presents the limitations of a physical test measure such as aerobic capacity to predict performance is the example of the MAC Hermann trophy. In the NCAA, the MAC Hermann trophy is awarded annually to the best male and female soccer player in the United States. A few years ago, an exceptional athlete received the award two years in a row (2012 and 2013), being only 1 in 5 athletes to receive this award twice. Researchers analyzed the aerobic capacity of the top college-level player in comparison with his teammates over 2 full competitive seasons. (92) The top college-level player in the nation and recipient of the trophy showed a significantly lower relative aerobic capacity as compared to his teammates. (92)

Similar 30-meters sprint times were found between men college-level players and players competing in European professional leagues. Players competing at significantly distinct levels showed relatively similar results in sprint times, indicating that running speed cannot solely be used to differentiate players from different levels of performance. Coaches need to consider other measures for proper player selection. (11, 98) At an elite level, all players are expected to have the ability to accelerate and reach fast running speeds over a short distance, hence why running speed cannot predict greater player success on the field. In addition, soccer does not consist of straight forward motions that begin from a static start. (103) Changes in direction, dribbling of the ball, and decision-making constantly occur in game situations while the player is running. (98) Sprint test performance does not directly translate to in-game sprinting performance. Measures obtained during tests such as sprint time do not predict in-game performance in soccer players and cannot be used in isolation to identify talent. (98)

Relationship between different measures of performance

Coaches often implement training programs in order to improve individual fitness in soccer players. Training programs that aim to increase running speed often include plyometric and power exercises, in addition to sprint training. (116) One study aimed to better understand the relationship between jump training and sprint performance. The researchers examined the relationship between various jumping kinematics and 10- and 25-meters sprint performance in NCAA Division I women soccer players. Eight different jumps, including varied unilateral and bilateral jumps were performed. No relationship was found between bilateral jump kinematics and 10- and 25-m sprint time, step length, or step frequency. A correlation was found between unilateral vertical jump tasks and 25-meter sprint performance. (116) The results suggest that unilateral jumping is more closely related to sprint performance because sprinting requires unilateral force production. Unilateral plyometric exercises seem more appropriate than bilateral plyometric exercises in order to improve sprint performance. (66)

A single physiological measure or test result may not be sensitive enough to differentiate top-elite players from average elite players, or to differentiate players that should be starters from non-starters. (86) A team composed of players of higher fitness levels would perhaps have a definite advantage over opponents that have a lower physical fitness. (5) Nonetheless, at the elite level, aerobic capacity, muscle strength, jump height or 30-meter sprint times are not predictors of individual player performance. Although data from laboratory and field tests are useful in providing information on players' physical profile and soccer-specific fitness, test results can never be used to predict the overall performance during games. (103) The dynamic nature of soccer requires players to excel in many different domains. (84) In addition, most elite players have been exposed to similar training programs for many years, which makes it difficult to predict how individual player performance will differ during games. Other factors such as player technique, team tactics, psychological factors, or injuries all impact individual performance during games and may be overlooked by laboratory and field tests. (5) Since predicting individual in-game performance is so challenging, directly measuring what players are doing during competitive games may provide more useful information regarding individual performance. Sports scientists need to find new measures that can help identify which players are achieving more on the field and further contributing to team success.

Wearable technology to assess in-game physical performance

The physical demands of soccer can be better understood by analyzing the movement patterns of individual players during games. The use of wearable technology allows to objectively measure individual physical performance of players throughout a soccer game. (11, 17) Recent advancements in technology have led to the development of miniaturized heart rate sensors and movement trackers specifically designed for physical activity monitoring. Sensors and trackers allow easier collection of performance data and increased potential for athlete monitoring. (36) In fact, most of what we know regarding soccer performance is due to increasing use of wearable monitors by elite soccer teams during training and games.

Quantification of internal and external training load

Soccer players can wear individual monitors that collect data throughout a training session or a game. The data from each athlete that is then transmitted to an external device, and information regarding internal and external load can be analyzed. (36) Internal load parameters can be measured with variables such as heart rate, heart rate recovery (HRR) and heart rate variability (HRV). (1, 50) The external load can be measured with variables such as distance, velocity, acceleration, as well as duration and frequency of physical activity. (50) Heart rate sensors as well as GPS-enabled devices provide a valid and reliable estimate of physical workload. (12, 28, 67, 81) The use of monitoring devices is advantageous as it allows to collect scientific data in a simple and non-invasive way.

Rating of perceived exertion

Rating of perceived exertion (RPE) is a subjective variable that can also be used to quantify internal training load. (54) RPE is easy to record, does not require expensive equipment, and is highly sensitive for evaluating general fatigue in response to exercise. Session-RPE is identified as a reliable and valid measure of internal training load. (54) Session-RPE is a subjective rating provided by the player in regards to the exertion that he or she felt during the training session or the game. To ensure a rating is representative of the entire training session, athletes identify the session-RPE 30 minutes after completion of the session by referring to a numerical value on the Foster's Modified Borg Scale, ranging from 0 (no effort) to 10 (maximal effort). (27) Session-RPE correlates significantly with heart-rate-based methods that are used to quantify internal training load in endurance runners (43) Correlations between session-RPE and heart-rate-based methods have also been found in basketball athletes where both aerobic and anaerobic systems are utilized. (28) Session-RPE can be considered a good indicator of global internal load during soccer training and competition. (54) The RPE method is useful and practical for coaches and athletic trainers to monitor internal load, as well as to design periodization strategies. (54) Up to now, no wearable monitors collect and assess subjective factors such as RPE. (36)

Training load has been quantified using heart rate, heart rate variability, hormonal levels, total distance, distance measured at different movement speeds (walking, jogging, sprinting), and rate of perceived exertion. (36) In addition to training load data obtained with wearable monitors, athlete's subjective responses should be considered. Subjective markers have been shown to be superior to objective markers to quantify training load and training response in athletes. (36, 93)

Training load and injury risk

When athletes perform higher workloads than they are prepared for, they are more likely to sustain an injury. (15) Monitoring individual training loads can benefit athletes' health and minimize risks of injury. (15, 36, 48) Researchers recently suggested that specific variations in training load significantly increase the likelihood of non-contact injuries in athletes. (15, 21) Australian rules football players that increase or decrease their workload over 3 subsequent days compared with the previous 21 days have a greater risk of injury occurrence than players that maintain a constant 3- to 21-day workload ratio. (21) Specifically, increases or decreases in moderate speed running distance (18-24 km/h) led to an risk of non-contact injuries occurring during games (R^2=0.79) and in the immediate 2 or 5 days following games (R^2=0.76-0.82). In Australian rules football athletes, workload ratios calculated in terms of moderate speed running distance should remain as constant possible in order to minimize risks of injuries. (21)

Comparisons between loads sustained over a short or acute period of time and loads sustained over a long or chronic period of time allows to calculate the acute-to-chronic workload ratio. Acute-to-chronic workload ratio can be calculated using different variables, depending on the athlete, the sport, the most common injury mechanisms, as well as the training and games schedule. (21) Variables such as total distance, collisions, accelerations, decelerations, and session rate of perceived exertion may be used when monitoring workload (15, 43) In soccer athletes, variables such as total distance covered and high-intensity running distance could be considered in the acute chronic workload model. (15)

Injuries and team success

Team success is significantly influenced by injury occurrence. (5, 39) A study demonstrated that lower injury incidence was associated with higher team ranking, (r=0.929, p=0.003), a greater number of games won (r=0.883, p=0.008), and a higher number of goals scored (r=0.893, p=0.007). (39) Another study also found a significant relationship between a team's final league standing at the end of the season and the number of injuries sustained by players in the team. Teams that sustained a lower number of injuries throughout a season had better final league rankings. (5) Maintaining injury risks as low as possible benefits both the individual's and the team's performance. Therefore, monitoring training loads as well as in-game loads can help a team be more successful.

In-game measures influence training strategies

Wearable devices that are equipped with heart rate monitors and global positioning system (GPS) technology are a simple and objective method to quantify both internal and external loads in soccer athletes, and can help modify training strategies. (55) The frequency of sampling of wearable devices affects the precision of the data collected. High sampling frequencies are required when collecting data of individuals performing physical activity because parameters vary rapidly. (36) Changes of direction and changes of speed occur very often during a soccer game, causing variations in players' movement and heart rate. Global positioning system units with a frequency of 10 hertz are valid and reliable for the quantification of acceleration, deceleration, and constant velocity running in team sports. (22, 108) Analyzing in-game measures helps develop efficient training programs. (33) Training strategies often aim to closely replicate the demands and the conditions of competition. An in-depth analysis of competitive soccer games is therefore necessary in order to plan effective training programs. In-game measures have shown that elite men and women soccer players cover total distances between 9 and 11 kilometers during a 90-minute game (17, 60, 72, 73, 101). In addition, elite soccer players perform 70 to 190 high-intensity runs per game. (3, 60, 72). The information collected during training or games is important for coaches, trainers, and medical staff members, allowing the implementation of effective training programs while monitoring workload. (35)

High-intensity running in soccer

High-intensity running (HIR) has a considerable impact on soccer match performance. (84) High-intensity running is the total distance covered by players during a game at a determined running speed. High-speed running is the distance covered above 18 km/h in men soccer players, and the distance covered above 15 km/h in women soccer players. (3, 59, 72, 73) However, certain studies use different values to define high-intensity running, making comparisons between studies more difficult. (38, 60) High-intensity running only accounts for 11% of the total distance covered by professional players during a game. However, actions performed at high-intensity running represent the most crucial or important moments of the game, directly contributing to winning possession of the ball, scoring or conceding goals. (34, 84) The ability to cover large distances at high-intensity running is an important quality for high-level soccer players. (66) Variables that directly affect the amount of high-intensity running such as number of high-intensity actions, running speed, and distance covered can be precisely measured with GPS-enabled devices worn by players during games.

Decreased in-game physical performance in the second half

In elite and professional soccer, players cover less distance during the second half compared to the first half of the game. Decreases in distance covered in the second half compared to the first half of the game were identified in men professional soccer players. (11, 89) In-game measures also suggest that total high-intensity running distance is shorter in the second half compared to the first half of the game. The decrease in distance covered at high-intensity running speed in the second half has been observed in women college soccer players (113), Premier league players (34), as well as in Italian league and European Champions League players (73).

The reason explaining the decrease in distance covered and the decrease in high-intensity running in the second half of the game is unknown. The decrease in high-intensity running in the latter part of the game may be due to fatigue or to other factors. (73) Some players may be more efficient in their energy utilization and may be able to maintain a high performance during the second half of the game. Some players may possess characteristics that help them maintain a relatively stable workload throughout the 90-minute game. Measuring individual body composition could potentially help understand which factors are related to better energy conservation and superior in-game performance. In soccer, a hypothesis may be that a player that weighs less or that has a lower relative fat mass can run for a longer distance and run at a faster speed during the game. (98)

Different in-game physical performance according to level of play

Researchers have attempted to distinguish players of different competition levels based on in-game measures. (11) One study demonstrated that elite domestic players cover a greater total distance during the game compared to international players. (89) The suggestion that international players cover less total distance than elite domestic players is counterintuitive, as we would expect high-level players to cover more distance throughout a game. One in-game measure that may help distinguish players of better competition levels is high-intensity running. (65) Top-class women soccer players part of a national team perform 28% more high-intensity running (>18 km/h) than high-level women soccer players that compete in leagues within their country. In addition, women soccer players competing at the international level also perform 24% more sprints (>25 km/h) throughout the game. (72) Similar results were found in men professional players. (73) Men top-class players competing a the international level perform 58% more sprinting (>30 km/h) compared to moderate-level professional players competing in divisions within their nation. (73) The results of the study suggest that better players that compete at a higher level may perform more high-intensity running as well as more sprinting. Despite the presented results, men elite domestic players and international players were shown to have similar measures of total distance covered and distance covered at high-intensity running (>14.4 km/h) during games. (16) Maximal running speed and mean recovery time also appear similar between elite domestic and international players. (16) Maximizing high-intensity running performance and maintaining a stable performance throughout the game may contribute to team success. A team that maintains high-intensity running during the last few minutes of the game may have an advantage over the opposing team. The relationship between in-game measures and level-of-competition is not yet fully understood, and results are conflicting. Additional factors influencing in-game performance of players need to be considered.

In-game performance and heart rate

One study examined the relationship between in-game physical performance and physiological responses such as heart rate. Specifically, the study assessed the distance covered in different speed zones compared to the time spent in different heart rate zones during a soccer game. (60) A general hypothesis in soccer performance is that players that work harder on the field cover more distance and run faster, and therefore would present elevated heart rates compared to other players that do not work as hard. Interestingly, the authors suggested that players' in-game performance measures and physiological responses did not correlate. (60) In the study, players covered relatively short distances at high-intensity running and sprinting. However, the elite women team's average heart rate was of 165 beats per minute, corresponding to approximately 85% of age-predicted maximal heart rate. The mismatch between in-game running performance and in-game heart rate responses suggests that other variables influence individual in-game performance. (60)

We have described the relationship between fitness tests results and in-game measures. However, fitness tests are not sufficient to predict a player's in-game performance. (103) Other factors such as anthropometric variables may help explain variations in individual performance. (84) Body mass, muscle mass or fat mass can provide information regarding players' ability to perform more high-intensity running and sprinting during games. Top-class players follow strict daily training programs, and their training is closely monitored by coaches. In contrast, lower level players may complete self-directed physical training on their own time. As a result of the intensive training and physiological adaptations, top-class players may have a different body composition than high-level players. Anthropometric measures might help explain why some players have the ability to cover greater total distance, greater distance at high-intensity running, and a higher number of sprints throughout the game. Body composition may also provide information regarding the decrease in performance observed during the second half compared to the first half of the game.

Body composition in soccer players

Soccer is a high-intensity, intermittent field-based team sport where low body mass, high muscle mass, and low body fat are beneficial to performance (34, 75). High proportions of body fat may lead to reduced movement efficiency in soccer players. (37) In an elite female soccer team, body fat percentage was of 16% as determined by hydrostatic weighing. (25) In an elite male soccer team, body fat percentage was of 10 to 11% as determined by dual-energy x-ray absorptiometry (DXA). (68) Men elite soccer players have lower proportions of body fat than sedentary populations, but higher proportions of body fat than endurance runners. (95) The variation in body fat percentages of players on an elite soccer team ranges from 7 to 19%. (30, 88, 89, 115). Body composition varies significantly between soccer players of different positions. (68) A soccer team's average body fat percentage must be cautiously interpreted due to difference in players' positions in the team. The large variation of body fat percentages reported in soccer players is also due to the different methods of body composition assessment used in each study that vary in precision. (49)

Methods of body composition assessment

The use of a standard equations to estimate body composition despite inter-individual variations can lead to considerable error in body composition assessment. (85) Many body composition estimation techniques use a two-compartment model. The techniques assume that the body is divided into the fat mass (FM) and the fat-free mass (FFM). The fat mass is relatively homogenous. However, the fat-free mass consists of a mix of water, mineral, protein and other constituents. (112) Equations used to estimate body composition are based on the assumption that the density of the fat-free mass is the same for all individuals. However, hydration, bone mineralization, protein, and potassium fractions of the fat-free mass may be different, leading to individual variations in density of the fat-free mass. (57, 71) Furthermore, the density of the fat-free mass may be considerably different in athletic populations where individuals present more advanced muscular development compared to sedentary individuals. (57, 71) Assumptions regarding the constant density of the fat-free mass across individuals can lead to error in the calculation of the fat mass. In addition, equations used to estimate body composition assume the density of the fat-free mass to be equal throughout the whole body. (85) However, the fat-free mass density varies between body regions and is a direct reflection of the load that is placed on that area of the body. (85) Increases in bone mass density occur specifically in areas of increased loading and mechanical strain. (106) Soccer players have higher bone density in the lower limbs as well as in the lumbar spine. (19, 106) Equations assuming an equal density of the fat-free mass throughout the body and a constant fat-free density across individuals can lead to considerable error in the assessment of body composition. (71, 91) A study suggested that skinfold-based equations did not accurately track body composition changes in elite judo athletes compared to reference measurements obtained with dual-energy x-ray absorptiometry (DXA). (96) Similarly, a body composition equation significantly overestimated body fat percentages compared to DXA results in weight trainers. (71) In the study, the Siri equation assumed a constant density of the fat mass and a constant density of the fat-free mass throughout the whole body of all individuals. (71) Assessment methods that account for inter-individual variability in fat-free mass density as well as intra-variability fat-free mass density are necessary in order to accurately evaluate body composition in athletic populations. (96)

Dual-energy x-ray absorptiometry (DXA)

Dual-energy x-ray absorptiometry (DXA) is the most valid and reliable method to assess body composition in athletes. (13) DXA was first used as a reference method to measure bone density. More recently, research has suggested that DXA is the "gold standard" to determine a three-compartment model of body composition and should be used for an accurate measurement of whole body composition in athletes. (57, 91, 107) DXA uses a three-compartment model of body composition that estimates bone mass, lean tissue mass, and fat mass in the body. (57, 69) The sum of bone mass and lean tissue mass is equal to the fat-free mass. The sum of fat-free mass and fat mass yields the total body mass. Therefore, total body mass is the sum of total bone mass, total lean mass, and total fat mass. (57) Dual-energy X-ray absorptiometry does not assume a constant density of fat-free mass within each individual and for all individuals, but rather measures regional body density in each individual. (26, 57, 85) DXA is more valid and reliable than bioelectrical impedance analysis and skinfolds-based methods to assess body composition in highly trained team sport athletes. (13) DXA is accurate, precise, has good reproducibility, is rapid to administer, and is relatively inexpensive. (18, 56, 105) In addition, DXA imposes very low risk to participants. A whole-body DXA scans exposes the participant to radiations of 0.04 to 0.86 millirem, depending on the instrument and on the size of the individual. DXA radiation exposure is comparable to a 1 to 10% chest radiograph (x-ray). (62)

DXA has the advantage of accurately estimating bone mass, lean mass, and fat mass in distinct body regions. (18, 62) DXA allows estimation of regional body composition and is advantageous over other body assessment methods such as skinfold-based equations, bioelectrical impedance, hydrodensitometry, and air displacement plesmography that only estimate total body composition. (62) Regional body composition assessment has many interesting applications in athletic populations, such as evaluating the effectiveness of training programs as well as rehabilitation programs following an injury. (18)

Fluctuations in body composition throughout a soccer season

A study investigated the changes in regional body composition in upper limbs, lower limbs and trunk in professional soccer players throughout the year. The study used DXA to estimated regional body composition of soccer players, and suggested that body composition varies throughout different phases of the season. (68) An annual soccer season can be separated into three simple phases which consist of pre-season, in-season and off-season. Pre-season training focuses on rebuilding fitness parameters following the detraining that typically occurs during the off-season. During the in-season phase, training focuses on technical and tactical development and the maintenance of the physical fitness developed during preseason. (83) Elite soccer players experience changes in body composition through pre-season, in-season and off-season. Fat mass increases and fat-free mass decreases over the off-season because of reduced training that typically occurs. During pre-season, body fat decreases and fat-free mass increases. (20, 32, 68, 87). During pre-season, the significant loss in body fat and the gains in lean mass are a result of the high levels of aerobic, anaerobic, and strength training performed during this period. Soccer games place high demands on the aerobic energy system and causes large energy expenditure. During pre-season and in-season games, the body uses fat stores as energy, leading to a decrease in fat mass. (52, 82)

The sudden increase in training load during the preseason compared to the off-season may lead to acute overtraining syndrome and a subsequent increased risk of injuries. (15, 21, 58) Immediately before pre-season, many players attempt to rapidly increase their fitness levels and return to the level of fitness they possessed at the end of the previous competitive season. To avoid the harmful effects of overtraining, players should perform maintenance training during the off-season in order to avoid the abrupt increase in training load at the start of preseason. (20, 58)

Body composition and performance

A few studies have investigated the relationship between physical tests performance and body composition in soccer players. (20, 98) However, the relationship between in-game performance and body composition in soccer players is still unknown. (98) In a study that investigated variations in fitness levels among soccer players throughout a 12-month period, significant increases in body fat percentage during the off-season were associated with an increase in 15-meter sprint times. (20) In the study, body fat percentage was evaluated using bioelectrical impedance. Meanwhile, from pre-season to mid-season, decreases in body fat percentages were associated with an improvement in 15-meter sprint times. (20) In another study investigating body composition and test performance in men NCAA Division I soccer players, higher body mass, fat mass, and percent body fat were correlated with a decrease in sprint performance. (98) In addition, body fat percentages showed a negative correlation with vertical jump height as well as with aerobic capacity. (98) Excess body fat acts as dead weight during activity and can significantly reduce energy efficiency in horizontal and vertical movements in relation to gravity. (49, 88) The results of the studies suggest that body composition may affect a player's ability to run at higher speeds and cover longer distances during a competitive soccer game.

Players competing at higher levels have more relative lean mass than players competing at lower levels. A study suggested that players from a first team competing in the English Premier League have higher proportions of lean mass than players part of the under twenty-one years old (U21) and under eighteen years old (U18) reserve teams of the same soccer club. (69) The study used DXA to assess whole body and regional body composition of players competing at different levels but training within the same academy. Players part of the first team displayed lower total body fat percentages than players in both reserve teams. However, the results were not explained by a lower body fat percentage in the first team players, but rather by a higher lean mass in the first team players. The first team and reserve team players were differentiated by lean mass rather than by body fat percentage. (69) The study suggested that training interventions in soccer players should aim to promote increases in lean mass, as opposed to promoting decreases in fat mass. Reserve team players that increase their lean mass will have a body composition closer to the physical attributes of a first team player in a professional European league. (69)

While some studies show that a high proportion of fat-free mass compared to fat mass may beneficial to sprint or jump tests, other studies do not support such findings. (20, 98, 102) A general hypothesis is that an athlete with more lean mass will jump higher than an athlete with less lean mass. The hypothesis relies on the assumptions that lean tissue should provide more strength and power in order to move the body against gravity. (98) However, two studies have identified a negative correlation between athlete's lean body mass and vertical jump height, suggesting that leaner athletes do not necessarily have a better jump performance. In the studies, athletes with greater lean mass did not jump higher than athletes with lesser lean mass. (98, 102) In the studies, athletes' total body composition was assessed, however regional body composition was not. Fat and fat-free mass distribution, types of muscle fibers in the lean mass, as well as metabolic, physiological, and psychological factors may impact athletes results on physical tests, and impact performance during competition. (98) Assessment of total body composition may overlook important factors that can be related to test performance as well as in-game performance in soccer players. In addition, an athlete's result on one test does not give a good indication of his or her overall physical performance during competition. (86) Test results can never be used to predict the overall performance of soccer players during games. (103) Soccer in-game performance such as individual running speed and running distance may be influenced by measures of regional body composition.

Lastly, the relationship between distance covered at high-intensity running during a soccer game and muscle characteristics has been examined in one study. (65) In the study, dominant leg thickness, dominant leg vastus lateralis pennation angle, and aerobic capacity were the strongest predictors of high-intensity running distance during the game ($R = 0.989$, SEE = 115.5 m, $p = 0.001$). (65) The pennation angle is the angle between a muscle fascicle's orientation and the tendon axis. Pennation angle is an important muscle characteristic that affects force production and limb strength. (46) This is the only study to our knowledge that examined the relationship between lower-limb muscle characteristics and in-game performance. Muscle characteristics may influence the player's ability to cover longer distances at high-intensity running during games. (65) Assessment of regional lean mass in soccer players may help understand which factors influence in-game performance.

Predictors of soccer in-game performance have not yet been determined. A player that runs faster, jumps higher, or has better kicking accuracy may perform better on specific physical tests, however might not show superior performance during competitive games, and therefore may not be selected for higher competition levels. Directly measuring individual in-game performance allows to objectively measure what a player is doing on the field. (7) More research is necessary in order to understand which factors are associated with superior in-game physical performance. The relationship between body composition and in-game physical performance has not been established in soccer players. (98) A few studies have examined the relationship between soccer players' physical tests results and anthropometric measures. However, fitness tests do not transfer to being a better player on the field. (69) In addition, most studies only focused on measures of fat mass, however fat-free mass and muscle mass are important factors affecting athletic performance. (69) Most studies also used predictive equations, skinfolds measurements, and bioelectrical impedance in order to estimate body composition in athletes. The techniques used introduce considerable error in the assessment of body composition in athletic populations and only provide total rather than regional body composition assessment. (71, 91, 97) To our knowledge, no study investigated the relationship between in-game physical performance and body composition in soccer players. We propose a research project that will examine the relationship between measures of in-game performance and regional body composition variables in high-level soccer players.

Manuscript

Less total body fat and lower extremity fat are associated with more high-intensity running during games in female university soccer players.

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Running head: Body Composition Correlates to In-game Physical Performance

ABSTRACT

The purpose of this study was to investigate the relationship between body composition and in-game physical performance measures in female collegiate soccer players. Body composition measures including total mass, fat mass, and lean tissue mass, both for the lower extremities and for total body were acquired in 10 players using dual energy x-ray absorptiometry. In-game physical performance measures were collected using global positioning system (GPS) devices and included total distance covered and distance covered in 6 different speed zones. Data from fourteen regular season games were analyzed over the 1st half, 2nd half, and entire game. The level of significance was set at $p<0.05$. Players covered less distance in the 2nd half compared to the 1st half of the game (3356.5±1211.7m vs. 4544.7±495.2m, $p=0.004$). A repeated measures ANOVA revealed decreases in distance covered jogging, at low-intensity running, and at moderate-intensity running during the 2nd half compared to the 1st half of the game ($p<0.001$). Lower measures of total body fat mass, total body fat percentage and lower extremities fat mass were correlated to covering more distance at moderate-intensity and high-intensity running during the 2nd half and as well as the whole game (r values from -.644 to -.745, p values from <0.01 to 0.04). Our results suggest that body composition can influence the distance covered at moderate- and high-intensity running speed during competitive games. Training strategies that help reduce excess fat mass and incorporate high-intensity training bouts may be beneficial for female soccer players and contribute to overall team success.

Key words: Performance, football, body composition, GPS

INTRODUCTION

While soccer is a sport that appears to be largely aerobic, players are required to complete frequent bouts of anaerobic activity during a competitive game.(101) Recently, sports scientists gained a much better understanding of the activity profile of soccer players and the physical demands of competitive soccer games. Technological enhancements such as miniaturized tracking devices facilitated the monitoring of in-game physical performance, which can be measured in total distance covered as well as distance covered at different speeds, such as walking, jogging and sprinting, among others. In-game physical performance measures suggest that elite men and women soccer players cover total distances between 9 and 11 kilometers during the course of a 90-minute game.(17, 60, 72, 73, 101) Moreover, players cover more distance during the 1st half compared to the 2nd half of the game (11, 89), and more distance at high-intensity running during the 1st half when compared to the 2nd half of the game (distance covered >18 km/h in men and >15 km/h in women).(34, 73, 113) Additionally, men and women professional players competing at higher levels seem to cover greater distances at high-intensity running than other professional players competing at lower levels.(72, 73) Though a decrease in physical performance during the 2nd half of the game has been reported in men and women competing at the college, elite, and professional levels (34, 73, 113), the cause for such a decline in performance in the latter part of the game is still unknown.(9, 73) A common hypothesis is that fatigue may contribute to the decline in individual performance, yet this has never been directly measured.(9, 73) The relationship between in-game physical performance (distance covered sprinting for example) and fatigue has not yet been established.(9, 73)

Previous research suggests that body composition can affect soccer players' performance on physical tests. Players with more fat mass tend to score poorly on aerobic capacity tests, sprints tests, and vertical jump tests compared to players with less fat mass.(41, 98) Seasonal variations in body composition over a 12-month period were reported in soccer athletes, with lowest percentage body fat observed at the end of the competitive season and highest percentage body fat at the start of pre-season.(20,77) Body fat also negatively affects vertical jump height in soccer players.(98) Although body fat seems to negatively influence physical tests results, the relationship between lean body tissue and performance has not yet been established. A common hypothesis is that players with more lean mass will run faster and jump higher than players with less lean mass. Despite this belief, studies have shown that athletes with more lean mass do not score better on sprint tests or vertical jump tests compared to athletes with less lean mass.(98, 102) The influence of body composition on test performance warrants further attention.(20, 98, 102) Furthermore, while body composition is now considered a fundamental component of a complete elite athlete assessment, most studies use skinfolds prediction equations or bioelectrical impedance analysis (BIA) to evaluate body composition.(20, 77, 94) Although practical and inexpensive, such methods introduce considerable error when assessing body composition in athletic populations.(71, 96) Dual energy x-ray absorptiometry (DXA) precisely estimates regional as well as whole body composition following a three-compartment model (e.g. bone mass, lean tissue mass, and fat mass), and is a valid and reliable method to assess body composition in athletes.(57, 91, 107), DXA can also assess body composition of specific regions of interest such as the lower extremities for example, a key feature when studying a lower-body-dominant sport such as soccer.(14, 19, 106)

Physical tests such as sprint, vertical jump, and aerobic capacity tests provide information on the player's physiological profile and soccer-related fitness, yet are unable to differentiate players that will perform better during games or that will compete at higher levels.(92, 98, 101) Similar sprint test results were noted between players in the National Collegiate Athletic Association (NCAA) and professional players competing in the European championships,(11) as well as between the starting line up and substitutes of a professional soccer team.(101) Furthermore, a recent study compared the physiological profile of the most outstanding male college soccer player in the NCAA to the physiological profile of his teammates, revealing that the specific player had a significantly lower aerobic capacity than his teammates.(92) Evidence suggests that physical tests such as $VO_{2\ max}$ or sprint tests do not correlate to higher levels of performance or higher levels of competition.(92, 98, 103) Players that run faster, jump higher, or have a higher aerobic capacity may perform better on specific physical tests, however may not show superior performance during games.(92, 98, 103) Physical tests only assess players' ability to accomplish one specific task and do not account for factors related to competitive games.(5) Body composition seems to influence physical tests results in soccer players, however the relationship between body composition and in-game physical performance has not yet been investigated.(98) Objective assessments of in-game physical performance may yield more specific measures that physical tests scores.(7) To the best of our knowledge, we are not aware of any study that examined body composition measures in relation to in-game performance of soccer players.

The purpose of this study was to examine the relationship between body composition and in-game physical performance in women college soccer players. We investigated the relationship between total mass, fat mass, and lean mass and the total distance covered as well as the distance covered at different speeds during games over the course a competitive season. We hypothesized that (i) players with less percentage body fat would cover more total distance during the game and cover more distance at high-intensity running, (ii) players with less total percentage body fat would cover more distance in the second half of the game, and (iii) players with greater lower extremities lean mass would cover more distance at high-intensity running.

METHODS

Experimental Approach to the Problem

Each player's body composition was measured at the beginning of the season using DXA (Lunar Prodigy Advance, GE). We collected the following body composition measurements for total body and for the region of the lower extremities: total mass, fat mass (in kg and in percentage) and lean tissue mass (in kg and in percentage). The lower extremity boundary in DXA scans is defined by a line bisecting the hip joint from the iliac crest to the pubis. All DXA scans were conducted by the same certified medical imaging technologist.

In-game physical performance measures were collected during 14 regular season games. We recorded the total distance covered as well as the distance covered standing and walking (0–6.0 km/h), jogging (6.1–8.0 km/h), low-intensity running (8.1–12.0 km/h), moderate-intensity running (12.1–15.5 km/h), high-intensity running (15.6–20.0 km/h), and sprinting (>20.0 km/h).(111) These speed zones were based on reports of female soccer players competing in the National Collegiate Association (NCAA) and motion-analysis research on high-level and professional women soccer players.(38, 109, 110) We completed data reduction for 14 season games. We only kept physical performance measures collected during the first half and the second half of the game. We analyzed in-game physical performance measures of players that started and were on the field for the entire duration of the game and therefore did not have to account for substitutions.

Subjects

Ten female university-level soccer players (age 20.3±1.6 years, height 164.98±6.87 cm, weight 64.22±8.79 kg) participated in the study. We obtained Human Research Ethics Committee approval of this protocol (Cert# 30010037). We explained the purpose, risks, and benefits of the study to all players. Players who wished to participate completed the informed consent. Goalkeepers were not included in the study because of the significant difference in distance covered during the game compared to outfield players.

Procedures

Body composition

All players wore loose fitting clothing and were asked to remove any metal to avoid interference with the DXA scan. Age, height, weight, and ethnicity were entered in the computer software prior to imaging. Participants were instructed to lie down supine in the center of the scanner with their arms slightly away from the body, thumbs pointing upwards, legs slightly apart and toes pointing upwards. The DXA scan lasted approximately 15 minutes.

In-game physical performance assessment

Before the start of each game, we provided each player with a global positioning system (GPS) device (10 Hz, Polar Team System, Polar Electro, OY, Finland). Players were familiar with the devices since they had trained and competed with them during the previous season. Players used the strap to secure the device below their chest according to the manufacturer's instructions. At the end of the game, we retrieved the devices from each player and in-game performance data were directly downloaded on a computer. Since physical activity measures are collected as soon as the participant begins wearing the GPS monitor, we then removed all activity data that occurred before the start of the game and during warm-up (see figure 1). We also removed all activity outside of playing time (i.e.: halftime, cool-down).

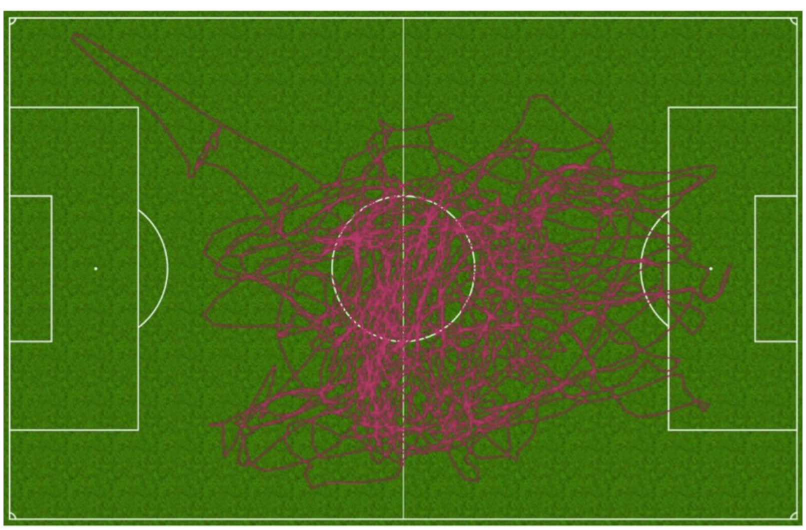

Figure 1. An example of in-game physical performance data collected with GPS device (raw data). The line represents the total distance covered by one participant during the 2nd half of one game.

Statistical analyses

We used a paired t-test to compare the total distance covered during the 1st half and the 2nd half of the game. We performed a repeated measures ANOVA and a Tukey post hoc test to compare the distance covered in each speed zone during the 1st half and the 2nd half of the game. We used Pearson product-moment correlations to assess the relationship between each in-game performance variable and each body composition variable. We categorized correlations as small (≥0.3), moderate (≥0.5), large (≥0.7) and very large (≥0.9).(53) The level of significance was set at $p<0.05$ and all analyses were conducted using SPSS version 24.

RESULTS

In-game physical performance

We present the distance covered in each speed zone, and the total distance covered in the 1st half, 2nd half, and entire game in table 1. Players covered on average 7901.2±1577.9 m during a game, and covered significantly less distance in the 2nd half (3356.5±1211.7 m) compared to the 1st half (4544.7±495.2 m, $p=0.004$). Players covered more distance at moderate-intensity running in the 1st half (696.9±53.6 m) compared to the 2nd half of the game (464.0±86.5 m, $p<0.001$). Significantly more distance was also covered jogging and at low-intensity running during the 1st half (jogging 623.7±28.8 m; low-intensity running 1453.4±88.1 m) compared to the 2nd half of the game (jogging 424.1±48.3 m; low-intensity running 988.0±131.6 m, $p<0.001$).

Speed zone	1st half (m)	2nd half (m)	Game (m)
Standing/walking	1403.39 (200.58)	1335.69 (494.22)	2739.09 (624.66)
Jogging	623.65 (90.94) *	424.07 (152.87)	1047.72 (189.84)
Low-intensity running	1453.46 (278.43)*	987.95 (416.29)	2441.41 (614.23)
Moderate-intensity running	696.94 (169.42) *	463.99 (273.55)	1160.93 (423.61)
High-intensity running	294.04 (113.02)	236.27 (128.42)	530.31 (236.34)
Sprinting	73.20 (41.48)	67.51 (37.72)	140.70 (76.89)
Total distance covered	4544.69 (495.27) *	3356.53 (1211.64)	7901.22 (1577.93)

Data are presented as means (SD). *: Significantly greater compared to the second half.

Table 1. Distance covered in 6 different speed zones including total distance covered on average per game.

Relationship between body composition and in-game physical performance

Players' body composition measures are presented in table 2. Correlations between body composition measures and in-game performance measures are presented in table 3. Fat mass, percentage body fat, lower extremities fat mass, and lower extremities total mass were significantly correlated to the distance covered at moderate- and high- intensity running.

Variable	Mean (SD)
Age	20.3 (1.6)
Height (cm)	164.98 (6.87)
Total body mass (kg)	64.22 (8.79)
Trunk mass (kg)	30.00 (4.44)
Lower extremities mass (kg)	23.04 (3.46)
Arms mass (kg)	6.92 (0.99)
Total lean tissue mass (kg)	44.23 (4.09)
Trunk lean tissue mass (kg)	11.48 (7.15)
Lower extremities lean tissue mass (kg)	15.17 (1.90)
Arms lean tissue mass (kg)	3.50 (0.92)
Total fat mass (kg)	17.39 (5.39)
Trunk fat mass (kg)	7.73 (3.26)
Lower extremities fat mass (kg)	6.87 (1.73)
Arms fat mass (kg)	1.99 (0.57)
Total body fat (%)	26.58 (5.11)
Trunk fat mass (%)	25.64 (7.39)
Lower extremities fat mass (%)	29.50 (3.72)
Arms fat mass (%)	29.67 (4.93)

Data are presented as means (SD).

Table 2. Demographic characteristics and body composition measures of the 10 participants.

	Distance covered during first half		Distance covered during second half		Distance covered over entire game	
	Moderate-intensity running	High-intensity running	Moderate-intensity running	High-intensity running	Moderate-intensity running	High-intensity running
Total body mass	-0.543, p=0.11	-0.583, p=0.08	-0.564, p=0.09	-0.610, p=0.06	-0.582, p=0.08	-0.610, p=0.06
Total body fat mass	-0.545, p=0.10	-0.578, p=0.08	**-0.674, p=0.03**	**-0.701, p=0.02**	**-0.653, p=0.04**	**-0.658, p=0.04**
Total body fat %	-0.536, p=0.11	-0.549, p=0.10	**-0.704, p=0.02**	**-0.718, p=0.02**	**-0.670, p=0.03**	**-0.654, p=0.04**
Total body lean mass	-0.409, p=0.24	-0.457, p=0.89	-0.297, p=0.41	-0.355, p=0.32	-0.356, p=0.31	-0.412, p=0.24
Lower extremities total mass	-0.612, p=0.06	**-0.679, p=0.03**	-0.608, p=0.06	**-0.676, p=0.03**	**-0.638, p<0.01**	**-0.692, p=0.03**
Lower extremities fat mass	-0.531, p=0.11	-0.629, p=0.05	**-0.669, p=0.03**	**-0.745, p=0.01**	**-0.644, p=0.04**	**-0.706, p=0.02**
Lower extremities fat %	-0.368, p=0.30	-0.460, p=0.18	-0.601, p=0.07	**-0.666, p=0.04**	0.536, p=0.11	-0.582, p=0.08
Lower extremities lean mass	-0.604, p=0.07	**-0.644, p<0.01**	-0.490, p=0.15	-0.539, p=0.11	-0.558, p=0.09	-0.601, p=0.07

p <0.05

Table 3. Pearson product-moment correlations between body composition and in-game physical performance in female college soccer player

Total fat mass and percent body fat relationship with in-game performance

Players with less total fat mass covered significantly more distance at moderate-intensity (r=-0.674, p=0.03) and high-intensity running (r=-0.701, p=0.02) during the 2nd half of the game. Players with less total fat mass also covered significantly more distance at moderate-intensity (r=-0.653, p=0.04) and high-intensity running (r=-0.658, p=0.04) over the entire game. Players with less total percentage body fat also covered more distance at moderate-intensity running (r=-0.704, p=0.02) and high-intensity running (r=-0.718, p=0.02) during the 2nd half of the game. Over the course of the game, players with lower total percentage body fat covered significantly more distance at moderate-intensity (r=-0.670, p=0.03) and high-intensity running (r=-0.654, p=0.04).

Lower extremities fat mass relationship with in-game performance

Players with less fat mass in the lower extremities covered significantly more distance at moderate-intensity (r=-0.669, p=0.03) and high-intensity running (r=-0.745, p=0.01) during the 2nd half. Players with less fat mass in the lower extremities also covered significantly more distance at moderate-intensity (r=-0.644, p=0.04) and high-intensity running (r=-0.706, p=0.02) over the entire game compared to players with more fat mass in the lower extremities.

Lower extremities total mass relationship with in game performance

Lastly, players with less total mass in the lower extremities covered significantly more distance at high-intensity during the 1st half of the game (r=-0.679, p=0.03) and more distance at moderate-intensity during the 2nd half of the game (r=-0.669, p=0.03). Over the course of the 90-minute game, players with more total mass in the lower extremities covered more distance at moderate-intensity (r=-0.638, p<0.01) and high-intensity (r=-0.692, p=0.03) running.

Players' lower extremities lean mass was negatively correlated to the distance covered at high-intensity running during the 1st half of the game (r=-0.644, p<0.01). No other significant relationships were found between lean mass and measures of in-game physical performance.

DISCUSSION

The purpose of this study was to examine the relationship between body composition and in-game measures of physical performance. We investigated the relationship between total body and lower extremities body composition and distance covered in different speed zones in a female university soccer team. The average total distance covered by players per game in our study (7901.2±1577.9 m) was slightly higher compared to a previous study (7481.96±958.57 m).(113) In contrast to Wells et al. who included in-game physical performance measures of players who competed over 55 minutes during a game, our study included in-game physical performance measures of players competing over 90 minutes, or the entire duration of the game.(113) The difference in total playing time in our study compared to Wells et al. might explain why our players covered a slightly greater distance on average per game. Our findings suggest that players covered more total distance in the 1st half than in the 2nd half of the game, and greater distance at moderate-intensity running in the 1st half compared to the 2nd half of the game. The decline in total distance covered during the 2nd half corroborates with previous reports in professional soccer players.(11, 72, 89, 113) In addition, the decrease in distance covered at moderate-speed running (12.1-15.5 km/h) during the 2nd half of the game is consistent with a previous report investigating in-game physical performance in women college soccer players.(109, 113)

The decline in in-game physical performance during the second half of the game may be due to fatigue.(9, 73) Our results and previous studies have noted a decrease in distance covered in the second half, however, no study directly investigated the cause for the decrease in physical performance during the 2nd half.(9, 73) Players with greater fat mass may use their energy less efficiently in horizontal movements such as running, which may lead to the decrease in physical performance throughout the game.(49, 88) The ability to cover large distances at high-intensity running is an important quality for elite soccer players.(66) Recent reports suggest that soccer players perform bouts of high-intensity running and sprinting during the most crucial moments of the game such as when winning the ball, keeping possession of the ball, contributing to a goal, or when preventing the opponent from scoring a goal.(42, 84, 90) Body composition may affect in-game physical performance during decisive situations and overall throughout the course of the game. Soccer players with more total body mass and fat mass perform poorly on sprint tests and aerobic capacity tests compared to players with less total mass and less body fat.(49, 88, 98) Although specific physical tests do not directly transfer to in-game situations, slower sprint times and lower aerobic capacity may contribute to less high-intensity running over the course of a 90-minute game.(69)

Our study presents significant relationships between body composition and in-game physical performance. The body composition measures reported in this soccer team are slightly higher compared to other reports on female university players competing in the NCAA.(70, 100) Players with less total body fat (kg and %) and less lower extremities fat (kg) covered more distance at moderate-intensity and high-intensity running during the 2nd half of the game, as well as during the entire game. Another way we could interpret our results is that players with more body fat and more lower extremities fat covered less distance at moderate- and high- intensity running during the 2nd half as well as during the course of the game. However, coaches may rather increase the distance players cover at high-intensity running as it has been suggested to positively affect individual player performance. Top-class women soccer players part of a national team achieve 28% more high-intensity running (>18 km/h) than high-level women soccer players that compete in domestic leagues within their country.(72) Similar results were found in men professional players, suggesting that high-intensity running may differentiate high-level players from different competition levels.(73) Maximizing high-intensity running and maintaining a stable performance throughout the first and second halves of the game may yield an advantage over the opposing team. Coaches may want to increase their players' high-intensity running distance during games as a way to contribute to team success. Our findings suggest that precise measurements of total body composition as well as lower extremities composition are important in soccer players. Very few studies have assessed factors that influence in-game physical performance. One study suggests that high-intensity running distance during games is correlated to players' aerobic capacity, vastus lateralis thickness, and vastus lateralis (dominant leg) pennation angle ($R = 0.989$, SEE = 115.5 m, $p = 0.001$).(65) Muscle architecture may be an important predictor of in-game physical performance in female college soccer players.(65) Body composition measurements may in addition provide valuable information regarding in-game physical performance of soccer players.

We acknowledge that players' in-game physical performance as measured by total distance covered and distance covered at different speeds may be affected by external factors. Reports suggest that the quality or strength of the opponent, the location of the game, as well as the match status may influence in-game physical performance.(4, 79) Players may also cover greater distance and perform more high-intensity running when playing against higher ranked opponents.(4, 79) In addition, players perform more high-intensity running distance when they are winning compared to when they are losing during the game.(4) Assessment of in-game physical performance, as conducted in the present study, should be carried over multiple games or over an entire season in order to account for variations due to match location, match status, and opponent. Measuring in-game physical performance over several games could provide coaches with valuable information regarding individual and team success.

We did not find any significant relationships between total body or lower extremities lean mass and in-game physical performance. While DXA provides precise estimation of total and regional lean mass distribution, it does not assess muscle quality and muscle fiber type. Specific muscle characteristics may influence aerobic and anaerobic capacities. Endurance athletes possess a greater proportion of slow-twitch fibers compared to athletes competing in sports that require speed, agility, and power.(104) Competitive soccer games require large aerobic endurance as well as the ability to complete short intense bouts of anaerobic activity. To our knowledge, only one study measured muscle characteristics of the vastus lateralis in soccer players.(2) The relationship between muscle characteristics and in-game physical performance has not yet been established. Muscle fiber type may affect athletes' ability to perform short-term intense bouts of running and to perform long distance running, which may explain why we did not find a relationship between lean mass and in-game performance.

Soccer players that compete at the highest levels must be talented in many different aspects and master numerous skills. In addition to physiological abilities, elite players require advanced technical and cognitive skills, and may possess distinct physiological attributes.(114) Sports psychology research has suggested that young soccer players that score better on measures of hope for success, task orientation, self-optimization, and self-efficacy, among other psychological measures, are more likely to be recruited by highly competitive training academies during their adolescent years.(74) To date, no study investigated psychological factors in relation to in-game physical performance during soccer matches.

To our knowledge, this is the first study to assess the relationship between body composition and direct measurements of in-game physical performance in soccer players. In the present study, we used DXA to precisely estimate total mass, fat mass and lean tissue mass of the whole body and of the lower extremities. Since we limited our analyses to starters that played for the entire duration of the game, our sample size did not allow for comparison analyses between player positions. Total distance covered and distance covered at moderate- and high-intensity running can vary according to the player's position.(33, 34) Future research should examine the association between total and regional body composition and in-game physical performance among defenders, midfielders and attackers. Future investigations should also evaluate how muscle characteristics as well as psychological measures affect in-game physical performance.

PRACTICAL APPLICATIONS

Accurate body composition assessments of soccer players at the start of the season provide valuable information to coaches. Body composition affects the distance players cover at moderate- and high-intensity running during season games. Soccer players' body composition varies over the course of a year, and significant increases in total body mass and fat mass have been reported during the off-season.(32, 68) Our study further supports the importance of off-season training to maintain optimal body composition and physiological fitness. Players that follow adequate off-season and pre-season training may show greater in-game physical performance over the course of the season. Following the principle of specificity, soccer training should incorporate anaerobic bouts that mimic the high-intensity efforts that players must sustain during the 90-minute game. Training strategies that help reduce excess body weight and fat mass may also help players use their energy more efficiently and maintain a stable performance during the 2^{nd} half of the game. Maximizing total distance covered and distance covered at moderate- and high- intensity running during the 2^{nd} half of the game may yield an advantage over opponents and contribute to team success.

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References

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