Adaptations to Segmental Body Composition and Anthropometric Measurements in Division 1 Athletes from a Season of Competition

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INTRODUCTION: There is limited information on the general presentation of limb-specific body composition, in collegiate athletes. Additionally anthropometric measurements, from a 3-dimensional body scanner (3DBS) have seen limited use in an athletic population. The purpose of this study is to investigate segmental lean mass (sLM) and anthropometric measurements (AM) in the extremities of Division 1 athletes, and how these measurements change over a competitive season. **METHODS:** Dual-energy x-ray absorptiometry (DEXA) and 3DBS assessments were conducted on 188 athletes, 108 males (Age(years): 19.98 ± 1.47; Height(cm): 186.07 ± 7.43; Weight(kg): 102.00 ± 24.69) and 80 females (Age(years): 19.60 ± 1.55; Height(cm): 166.51 ± 8.22; Weight(kg): 64.48 ± 8.22) . SLM assessed with DEXA as well as limb surface area, limb volume, and circumferential measurements from the calf, thigh, forearm, and biceps were assessed with the 3DBS. Paired samples t-tests were used to assess changes in dependent variables over a season, one-way ANOVAs where used to assess inter-sport differences, 2-way mixed measures ANOVAs were used to assess intra-sport differences among male and female cross-country athletes, and Pearson's correlation coefficients were used to compare dependent variables from the DEXA to dependent variables from the 3DBS. Statistical significance was set a priori at $\alpha=0.05$. **RESULTS:** Overall the whole cohort saw an increase in all sLM variables ($p < 0.001 – 0.012$), and saw changes in all AM, besides right calf circumference, right arm surface area, and right arm volume. Inter-sport analysis showed a difference in all dependent variables between sports in the male cohort ($p < 0.001$) and in the female cohort ($p < 0.001 – 0.012$). Correlations between raw sLM and AM values were all strong to very strong ($r = 0.764 – 0.951$; $p < 0.001$). **CONCLUSION:** These results show that athletes from this cohort generally experienced increases in sLM and AM, adaptations to these measurements were different between sports, and strong correlations show there could be a use for the 3DBS in athletics. More research is needed to validate this study's findings, since there are few studies which assessed limb specific measurements, and the first study which assessed anthropometric measurements in populations assessed.

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Preface

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1.0 Introduction

Inter-limb differences, imbalances, or asymmetry, in areas such as body composition, strength and movement patterns, have been discussed as a potential factor for increasing injury risk and limiting the potential for performance optimization.[2,5,6,36,56,102] Asymmetries have the potential to cause athletes to alter motor control behaviors that cause tasks to be performed in a dysfunctional manner, which can lead to the accumulation of fatigue or microtrauma, increasing injury risk.[36] Additionally, physical constraints placed on the body due to asymmetries can cause the athlete to compensate and adapt postures during performance, which can lead to compromised joint or muscle health.[36] With the potential for limited performance and increased injury risk, little is known about how the segmental body composition of athletes adapt to their sport over a season. While the asymmetries in body composition and strength that stem from sports have investigated in sports such as tennis[76,77], softball[17,29], and soccer[16,26,42,59], there is little research on how these asymmetries within body composition change over a season. Furthermore, with body composition parameters, such as whole-body lean mass (LM) and segmental lean mass (sLM) within the extremities, having been identified as significant predictors of maximal lift capacity and performance in various load carrying tasks in the military,[3,4,39] further research is needed to investigate how the body composition of athletes adapts to the demands of the sport over a season. With further research into asymmetrical adaptations in segmental body composition, indicators of decreased performance or injury risk can be identified. Athletes who present with these indicators can be prescribed additional training interventions to optimize performance and mitigate injury risk.

1.1 Musculoskeletal Asymmetry in Sport

When completing an action humans will tend to prefer the use of one side of their body. This concept is called lateral preference or laterality.[11,88] With the tendency for humans to favor one side, the side that is typically used more is typically referred to as the dominant side. As the dominant limb is used more than the non-dominant limb, strength and body composition asymmetries then become progressively more pronounced when comparing both extremities. When limb dominance is looked at in terms of sport participation, the degree of asymmetry is directly related to the sport being played.[58] Since each sport requires specific demands of the body, that are unique to the sport, the demands tend to not be the same for each limb.[58] These specific demands magnify the effects of limb dominance, which leads to sporting asymmetry.[58] This concept of sporting asymmetry has also been referred to as morphological asymmetry, but it is not specific to sport participation.[56] Morphological asymmetry is considered to be the structural difference between the right and left sides of the body and is attributed to asymmetrical movements without the necessary compensation to minimize the differences bilaterally.[56] The study that looks at morphological asymmetries found that these asymmetrical adaptations tend to be exacerbated if the sport has a high limb preference, such as baseball, which coincides with how sporting asymmetries exacerbate. [56,58]

Sporting asymmetry has been examined in athletes who swim, run cross country, and play baseball.[93,96,97] Musculoskeletal adaptations were not studied in any of these populations; instead, they looked at the effect that swimming adaptations has on clinical measures, Achilles tendon adaptation asymmetries in cross country runners, and glenohumeral range of motion and scapular positioning adaptations in baseball players.[93,96,97] In tennis, sporting asymmetries have been investigated with a focus on musculoskeletal adaptations. The majority of these tennis specific motions generate high musculoskeletal loads are in the upper dominant limb of the athlete.[22,23] The adaptations from these high loads are seen in the bones and muscles of the dominant limb.[84] The dominant upper extremity of tennis athletes tends to present with an increased diameter of the ulna, radius, and humerus.[19,21] On top of the increased bone diameter, there was increased hypertrophy, circumferences, and segmental volumes in both the forearm and upper arm of the dominant extremity when compared to the non-dominant side.[47,77,83]

1.1.1 The Effect of Musculoskeletal Asymmetry on Injury Risk and Performance Optimization

Asymmetrical adaptations to strength and LM from sport participation are thought to help maintain the physical integrity of the athlete because they reflect the loads placed on the body from physical tasks that are required from the sport being played.[38] On the other hand, it has been found that there is a correlation between injury and bilateral musculoskeletal asymmetries. Tennis players with a previous history of wrist injury presented with a difference in arm circumference, while the athletes that had a prior elbow injury presented with asymmetrical bilateral proportions in distal to proximal ratios between the forearm and arm.[76] The tennis athletes that had a previous shoulder injury showed a difference in elbow circumference along with asymmetrical bilateral proportions in distal to proximal ratios between the forearm and elbow.[76] Even though asymmetrical adaptations are thought to be from limb dominance and exacerbated by sport participation, previous injury has been shown to be another factor in bilateral asymmetries.[76] This is due to the fact that adaptations have been shown to be specific to the site of injury.[76] While these adaptations are thought to be a necessary adaptation to protect the athlete, they should also necessitate concern for the safety of the athlete.[29]

Research done by Trivers et al.[101] found that sprinting performance is also affected by bilateral asymmetries. They concluded that more symmetrical track athletes tend to have a quicker time when running the 100m sprint.[101] The asymmetries investigated are anthropometric measurements (AM), for example knee and ankle width are the measurements that were found to have a significant effect on performance.[101] These asymmetries are attributed to 5% of the variation in sprinting performance.[6]

Asymmetries in strength has been used as a tool for injury risk and return to play after injury. A threshold of bilateral strength asymmetry of less than 10% has been used an objective measure with good results in return to play studies.[6,50,73] This threshold of 10% has been used to evaluate professional soccer players for knee flexor and extensor strength asymmetries.[42] A study by Izovska et al.[42], found that around 60% of the players who were injured throughout one season had a strength asymmetry of over the 10% threshold in pre-season testing. The lower extremity injuries that were sustained by these players were frequently to parts of the knee, especially rupture of the ACL.[42] When using asymmetries for injury risk not only should the magnitude of asymmetry in strength or body composition be considered, but the asymmetries in movement patterns should also be evaluated.[94] This is because it is theorized that variations in both can lead to a higher degree of injury risk.[94]

Asymmetry in sport specific movement patterns has been investigated in soccer athletes. Within soccer, the athletes must use both legs to kick the ball, but they tend to kick more often with a preferred limb.[29] Additionally, the numerous repetitive unilateral movements from practice and games causes various asymmetrical musculoskeletal adaptations.[26] When comparing both lower limbs of soccer athletes, the dominant limb has been shown to generate more power when kicking a ball.[59] This is thought to be the result of unilateral kicking and increased movement repetition with the favored extremity.[59] These statements about soccer training were investigated by Barbieri et al.[2], whose findings showed that there are significant differences in ball velocity and accuracy. During kicks where the soccer ball was stationary and moving, there was a 10%-11% difference in kicking velocity and a 28%-40% difference in kicking accuracy when comparing each limb bilaterally, p=0.001 and p=0.003, respectively.[2]

Bilateral asymmetries in LM have been found to be indicators of injury risk,[42] and it can be a limitation to optimizing performance.[6] It has been shown that asymmetries in thigh and shank LM account for 20% of variance in jumping force production in a counter movement jump.[5] This variance increases to 25% whenever there are additional LM asymmetries in the pelvis.[5] With LM being a significant predictor of performance within various military lifting and carrying tasks,[3,4,39] further predicates the thought that bilateral differences in LM may play a role in force and power asymmetries, which may act as a potential hinderance to performance optimization.[6]

1.1.2 Body Composition Asymmetries in Sport

Sport specific training has been shown to lead to imbalanced performance adaptations within the limbs, which can cause asymmetrical musculoskeletal adaptations that lead to increased injury risk.[56] Therefore, it can be postulated that the same asymmetrical performance adaptations that are associated with sport specific training can lead to decreased performance in non-sport specific tasks. This is based on the rationale that these sporting adaptations lead to asymmetrical musculoskeletal adaptations in strength, power, and body composition.

Sporting asymmetry has been investigated in the body composition of softball athletes. Czeck et al.[17] found no significant difference in body composition between positions, besides the fact that pitchers tend to have more fat mass (FM) than all the athletes that play other positions. Yet all players showed body composition asymmetries, specifically when comparing the upper extremities bilaterally.[17] They found differences in LM, bone mineral density, and bone mineral content, with the values all being greater in the throwing limb across all positions.[17,29] This adaptation to overhead throwing affects the mass in the throwing arm, which leads to the throwing arm being heavier than the nonthrowing arm.[29] This may protect the limb while throwing a softball but not much is known on how this asymmetry in body composition affects other tasks, such as playing other sports or activities of daily living.

Sporting asymmetries have been seen in fencing as early as 10-13 years old in the upper extremity and 14-17 years old in the lower extremity.[102] The reason for the asymmetry is attributed to the unique unilateral load required for sport specialization.[102] Yet, the reason for the age difference is not explicitly stated in the article, but this could be attributed to the fact that both lower extremities are constantly used while ambulating. Conversely, most tasks that require the use of upper extremity do not place equal forces on both limbs or the task only requires one extremity. With athletes requiring frequent sport specific training, which often consists of repetitive motions, the sport being played has a profound effect on musculoskeletal adaptations to the athlete.

A study done by Mala et al[56] looked at body composition asymmetries in elite soccer players. This study found that starting in the under-17 division and continuing to adults, there is a presence of lower extremity bilateral asymmetries in LM. On the other hand, when looking at youth players, who were classified as the under-12 and under-16 groups, there was no morphological asymmetry seen in the lower extremity. The difference seen between groups is attributed to the higher volume of training sessions and higher specificity of the movements done by the athletes in the under-17 division.[56] This suggests that more attention should be given to soccer athletes starting at the age of 17 due to the fact that the morphological asymmetries that they experience are associated with increased risk factors for injury.[16,65] For example, a musculoskeletal asymmetry that can increase injury risk would be differences in segmental muscle mass proportions.[56] This type of musculoskeletal asymmetry could stem from strength asymmetries, which have been shown to raise injury risk. As proof, it has been found that soccer players with lower extremity strength asymmetries have a muscle injury frequency of 16.5% while symmetrical players have an injury frequency of 4.1%.[16]

1.2 Dual-Energy X-ray Absorptiometry

Dual-energy x-ray absorptiometry (DEXA) was originally designed for measuring bone density, but now it is able to be used for assessing body composition, such as LM and FM.[17,53,80] DEXA is the most typical method for assessing body composition, due to it being considered to be the "gold standard".[80] To assess body composition, DEXA uses an x-ray beam that has two main energy peaks that passes through the subject, and the absorption of the 2 photon energies in the tissues is measured letting the machine differentiate between bone, fat mass, and le lean an mass.[17,49,61,70,72,80,82] Using this 3-compartment model, it can assess whole body composition along with regional body composition, with the regions being arms, legs, trunk, pelvis, android, and gynoid.[17,79] The process of collecting this data takes less than 10 minuites to perform a scan and requires little cooperation from the participant being scanned.[79,80] The scan is noninvasive, but it does subject the participant to radiation exposure.[53,79,80] This radiation exposure has been cited at <5 mrem, which is significantly less than a computed tomography scan.[70,80]

The values for bone mineral density and body composition, such as LM and fat mass, from the DEXA tend to have good precision and it has low inter-operator variability.[53,79] For measuring bone density, which is the primary function of the DEXA, the precision is excellent with a coefficient of variation being 1%. Additionally, it has good reliability with precision errors being 1.5% for LM and just below 1.5% for FM.[12,48,78,95]

When comparing DEXA to air displacement plethysmography in resistance trained individuals, there are strong and significant correlations between both methods when assessing FM and LM.[63] Even though these correlations are strong, air displacement plethysmography tended to slightly underestimate FM.[63] It also should be noted that between these two methods for assessing body composition, there was no difference seen in LM.[63] Compared to air displacement plethysmography, bioelectrical impedance showed more variation in measurements of FM, when compared to measurements from DEXA in the same, resistance trained population. Correlations between bioelectrical impedance and DEXA are moderate to strong with no difference seen in LM, but there is a greater discrepancy between the FM values from each of the methods due to an overestimation by bioelectrical impedance.[63] For FM, there are strong and significant correlations overall and for men, but only moderate correlations were seen in women.[63]

1.3 Anthropometric Measurements

Anthropometrics is a branch of ergonomics that focuses on the measurements of human physical characteristics.[69] These measurements typically focus on the size and shape of structures from the human body.[69] One of the most common uses of anthropometrics is the use of hip to waist ratios in a cardiovascular risk assessment.[43,68] Recently, anthropometrics has been used in research to estimate body fat percentage, body surface area, predict performance, and injury risk.[24,28,54,55,57,64,85,87,104]

1.3.1 3-Dimensional Body Scanner (3DBS)

Unlike the DEXA, which is a well-established research tool, 3DBS are a relatively novel technology that is becoming a common research tool.[68] 3DBS were designed to produce measurements for garment construction.[18,64,67] These scanners are used to capture a plethora of AM with a brief scan that typically lasts less than one minute.[13,37,52,99] The measurements from a 3D body scanner consist of a variety of limb lengths, volumes, and circumferences.[37,98,99] Furthermore, this quick scan is able to generate a high-quality 3D avatar of the subject's body surface.[37,68] To perform a scan with reliable data and an accurate avatar, the subject needs to be in minimal form fitting clothing because these scanners rely on visible and infrared light.[37,68] The machine utilizes controlled visual and infrared light, which is projected in a specific pattern through one or more cameras onto the subject.[37] Deformations in this pattern are then measured by one or more cameras to produce "point clouds" of optical data which are used for the generation of measurements and avatar construction.[37]

The measurements from 3DBS have been validated, are considered to be accurate, and are shown to be less affected by error when compared to manual measurements.[8,41,89,98] Furthermore, the circumferential measurements provided are consistent and correlate well with tape measurements.[8,98] Volumetric measurements, such as segmental limb volumes and body composition estimates have been shown to have agreement with the gold standards for these measurements, such as DEXA.[98,99] Even though the general consensus is that the machines are accurate and reliable, it should be noted that scans of women with Anorexia Nervosa will tend to present with increased or overestimated body mass index.[99] This was significantly different from the healthy female control subjects, where the scans were able to accurately estimate body mass index.[99]

With 3D body scanning being a relatively novel technology in the field of sports medicine, use of this technology is limited, and the full potential of this technology is not yet known. Various other medical uses have been discussed such as use for prosthetics, implant development, reconstructive surgery, and posture analysis.[45,68] Additionally, in a cardiovascular risk assessment waist to hip ratios can be measured with a 3DBS to minimize the interobserver variation, compared to tape measurements.[43,51,68]

1.3.2 Use in Athletics

In athletic populations, the 3DBS has been used to assess AM and assess body surface area in various sport specific positions. AM have been assessed in powerlifters. Even though the AM were not taken with a 3DBS, they still have relevance since it was found that particular measurements correlate with strength and power.[14,103] This study found that stronger male powerlifters have larger neck size, thigh girth, and arm girth when compared to the weaker athletes.[24] Within female powerlifters, the stronger athletes have increased arm girth and chest girth measurements. Similar trends were found within male rugby players. Correlations were found between the circumferences of the athletes' chest, mid-thigh, calf, and the flexed arm of the athletes, and their one rep max for bench press and back squat.[104] These studies show that there is potential for 3D body scanners to be used as a tool to predict performance in a timelier manner than manual tape measurements.[33]

3D body scanning has been scarcely used in the field of sports medicine to evaluate high level athletes. In Australia, the AM of elite rowers were compared to the general population. This study by Schranz et al.[85] found that heavyweight rowers were generally much larger than the general population, but the lightweight rowers were similar, if not smaller than the general population. Additionally, when looking at junior rowers, it was found that height, mass, leg length, body volume, and body surface area were the best predictors of performance.[86] A study by Schueler, Fichtner, and Uederschaer[87] used a 3DBS to detect minimal differences positions that are necessary for gymnastics, figure skating, and ski jumping. The goal of this study was to determine the optimal position for these sport specific tasks by analyzing elite gymnastics, figure skating, and ski jumping athletes.[87] The gymnasts were assessed in various upright and tucked positions to compare moments of inertia.[87] Figure skaters were also assessed for the moments of inertia, but they were in a closed flight position with legs crossed and arms crossed across the chest.[87] Both figure skaters and gymnasts were compared with other athletes from that sport to assess for the smallest moment of inertia. Ski jumpers were assessed in their in-run positions, or the position they are in as they go down the ramp. These ski jumpers' in-run positions were compared to each other since the goal of the position is to reduce air resistance.[87]

1.3.3 Use in The Military

Most of the research using 3DBS in the field of sports medicine is within military populations. Their potential use in the military stems from the importance that is placed on body composition as a health and fitness screening tool.[27] The purpose of using body composition, before the War in Vietnam, was to identify potential recruits that are underweight and cannot perform the tasks required from them.[15] After the Vietnam era, the body composition standards shifted to be focused on screening out individuals who are overweight, due to the fact that these potential recruits are more likely to have future health issues, such as type 2 diabetes, and decreased physical performance.[27] This focus on body composition is the underlying rational for using anthropometry, low physical fitness, and a high or low body mass index as screening tools to assess injury risk.[35,40,44,64] In recent decades, the military has used circumferential based measurements to estimate body fat due to the validity of the results while keeping the costs associated with acquiring measurements low, unlike other costly body composition assessment methods, such as DEXA.[28] Although these are typically done using a tape measure, the use of 3D body scanning could serve to reduce inter-operator variability of these measurements.[33]

There has been limited research within the military using 3DBS. In a study by Looney et al.[55] the researchers investigated United States Army soldiers to validate the best equation for calculating body surface area from the existing 15 methods using the US Army Anthropometric Survey database. By assessing the 3D body scans and traditional AM of 5603 soldiers, they were able to show that the most valid equations are from Du Boise and Du Boise[7] and Yu et al.[105]. Furthermore, they were able to conclude that upper limb measurements, such as arm span, help increase the accuracy of body surface area estimates.[55] They also provide two formulas, one for each sex, that were able to estimate body surface area the most accuracy for the subject sample that they used.[55] Recently, another study was done to improve the predictive formula for body surface area by Looney et. al.[54] This study used the Size Stream SS20 and was able to develop a new formula that was able to closely estimate body surface based only on height and weight. When comparing this new formula against the previous one, the new formula had values that correlated with the 3D body scanner and was more accurate than the previous equation.[54]

Another study, Sager et al.[81], looked at the relationship between 3D body scan measurements, traditional AM, and bioelectrical impedance validate methods of calculating body composition. One hundred and four men from the Swiss Army were investigated in this study. They found that 3D body scans and manual measurements of height, weight, and waist circumference correlated when calculating body mass index.[81] Additionally, they found that there are similar errors associated with body scanning and manual measurements when comparing calculated fat and LM to bioelectrical impedance.[81] This comparison was done using the same measurements between both anthropometric measuring methods. When using all the measurements available from a 3D body scanner, they were able to achieve their most accurate predictions with r^2 value of up to 0.99.[81] This further shows the accuracy of 3DBS when compared to manual measurements of height, weight, and waist circumference, which are also done at a significantly quicker rate than the traditional method.

In female warfighters, McClung et al.[62] described the circumferential measurements from elite female warfighters in comparison to the average military female. In this population, they found that the median circumferences of the neck, shoulder, bicep, forearm, wrist, calf, and ankle were all larger than their average female military member counterparts. Waist and butt circumferences were similar to the average female warfighter, while the thigh circumference in elite female warfighters was about 2% smaller.[62]

A study by Morse et al.[64] looked at the measurements from the scans that were originally measured for uniform fitting at Fort Jackson. Machine learning models were utilized to relate the scans of the recruits to injuries that caused the recruits to drop from basic training. The machine learning program was able to identify head circumference, torso length, leg length, and ankle circumference as predictors for recruits at risk for discharge. This machine learning model was able to accurately identify recruits who were discharged from basic training with a true positive rate of 69% and a false positive rate of 35%.[64] This shows that there is potential for artificial intelligence models to be developed that can predict injury at a more accurate rate. Further development would be able to help officers better assess the readiness of their soldiers and determine if they need more training or moved to a different military occupation.[34,64] Additionally, with more research and greater use of 3D body scanners in athletics, this model may be applicable to athletes in the same manor.

1.4 Methodological Considerations

1.4.1 3-Dimentional Body Scanner

1.4.1.1 Body Composition

The Size Stream has the potential to be used for body composition assessment. Although it would calculate body composition as a 2-compartment model, body volume and body fat percentage can be calculated in a comparable way to air displacement plethysmography.[1,99] This method of calculating body composition has potential for the development of more accurate prediction models. These prediction models can minimize error by using additional circumferences and body segmental ratios to minimize error due to increased body fat, different body shapes, and abnormal body composition phenotypes.[32] Even though there is still potential to improve accuracy, good correlations are seen between 3D body scanning and air displacement plethysmography when calculating total body volume.[9] It should be noted that these estimates are not equivalent to air displacement plethysmography.[99]

When comparing the SS20 scanner to DEXA, strong correlations were found when predicting LM and FM for the whole body and regionally.[9,66] Additionally Size Stream calculations passed the Bland Altman test for agreement in body fat percentage, when compared to DEXA and no significant differences were found between the sexes.[1]

1.4.1.2 Reliability of Measurements

A study by Parker et al.[67] was able to find that 44 of the measurements from the Size Stream SS20 3D body scanner was reliable in 99.73% of measurements. All the circumference measurements used in this study were a part of this group. The measurements that will be used consist of; Bicep Circumference (Right), Bicep Circumference (Left), Forearm Circumference (Right), Forearm Circumference (Left), Thigh Circumference (Right), Thigh Circumference (Left), Calf Circumference (Right), and Calf Circumference (Left).

In terms of body surface area, Looney et al.[54] found that the Size Stream SS20 has high reliability when assessing total body and regional surface area (ICC > 0.962) when compared to the formula used to estimate body surface area by the United States Marines and the ANSUR II formula (right leg: ICC=0.986, left leg: ICC=0.988, right arm: ICC=0.962, left arm: ICC=0.970) . It is also important to understand that there are no universally accepted standards for the precision and accuracy for estimating body surface area. A study by Tinsley et al.[99] investigated the reliability and precision of volumetric measurements done by the Size Stream SS20. The precision of segmental volumetric measurements is relatively high with an ICC ranging from 0.952-0.988 (right leg: ICC=0.983, left leg: ICC=0.988, right arm: ICC=0.952, left arm: ICC=0.957). In terms of validity, the Size Stream SS20 tend to underestimate regional body volume and it did not show equivalence with DEXA derived volumes.[99]

1.4.2 Segmental Body Composition and Anthropometric Data for Cross-Country Athletes

Cross-Country country is the only sport where segmental body composition and anthropometric data are available for both men and women.

1.5 Research Problem

In terms of body composition changes in Division 1 athletes over a season, there is little research that considers bilateral asymmetries. The majority of existing literature has focused on softball, soccer, tennis, and fencing athletes, but most of these studies did not look at changes over a season and the few that compared before and after a season did not assess for bilateral asymmetries.[17,29,56,76,83,102] Additionally, none of these studies used AM from a 3D body scanner. In terms of anthropometrics, there has been limited research in the field of sports medicine with an athletic population. Therefore, it is not known how asymmetries in body composition will present in highly trained athletes.

1.6 Study Purpose

The purpose of this study is to investigate changes to AM and segmental lean mass in the extremities of Division 1 athletes over a competitive season. Additionally, this study is to investigate the magnitude of asymmetry seen in segmental lean mass and AM, using a relatively novel technology, the 3D body scanner. To do this, the DEXA will be used as a comparison since it has been deemed the "gold standard" for body composition.[80] This comparison will additionally serve as a validation of the measurements that are produced by the 3D body scanner.

1.7 Specific Aims / Hypotheses

1.7.1 Specific Aim 1: To examine adaptations in the segmental body composition of Division 1 athletes over a season.

Hypothesis 1: It is hypothesized that segmental lean mass of the upper and lower extremities will change when comparing before and after a season of competition.

1.7.2 Specific Aim 2: To examine the change in upper and lower limb anthropometric measurements in Division 1 athletes from before and after a season.

Hypothesis 2: It is hypothesized that anthropometric measurements will change from before to after a season of competition.

1.7.3 Specific Aim 3: To examine the relationship between DEXA segmental mass values and anthropometric measurements in Division 1 athletes' pre-season and post-season.

Hypothesis 3: It is hypothesized that arm volume, surface area, and circumferential measurements from the forearm and bicep will correlate with DEXA lean mass values for the upper extremity, and leg volume, surface area, and circumferential measurements from the thigh and calf will correlate with DEXA lean mass values for the lower extremity.

1.7.4 **Specific Aim 4:** To examine segmental body composition and anthropometric measurements presented by Division 1 athletes that participate in different sports.

Hypothesis 4: It is hypothesized that segmental body composition and anthropometric measurements presented by the subjects will be sport specific.

1.7.5 **Specific Aim 5:** To examine the degree of asymmetry in lean mass and anthropometric measurements presented by Division 1 athletes that participate in different sports.

Hypothesis 5: It is hypothesized that the asymmetries in lean mass and anthropometric measurements presented by the subjects will increase over the course of a season and each sport's athletes will present with different adaptations.

1.8 Study Significance

This study will describe how the body composition of Division 1 athletes changes over a season. If the asymmetries in lean mass increase during the season, clinicians, such as athletic trainers, and strength and conditioning coaches can adapt their rehabilitation and training strategies to help combat these asymmetries. With the use of a 3-D Body Scanner, there is potential to relate the values from the DEXA to circumferential or other AM. If a correlation between the two measurements is established, clinicians may be able to identify asymmetries by using tape measurements. This would provide a set of measurements that relate to body composition, which could be implemented with little to no cost to the clinician.

If the use of the 3DBSF becomes well used in athletic populations, this study would serve as a reference for determining which measurements are appropriate for evaluating bilateral body composition asymmetries. These measurements could also be used in a military population. With the increased use of 3D body scanning in the military, determining which measurements correlate with body composition asymmetries could be essential to developing a screening tool for identifying new recruits that are at a higher injury risk or those who need additional training interventions. Nevertheless, more research would need to be done in body composition asymmetries to determine the exact asymmetries that increase the risk of injury.

2.0 Methods

2.1 Experimental Design

This study followed a observational study design. The purpose of this study was to observe changes in bilateral body composition and anthropometric adaptations over a season within Division 1 athletes. Subject testing for this study took place over two sepperate, one day sessions. One of these days being before the 2021-2022 season and the other testing day is held following the completion of the season. The study protocol consists of an anthropometric 3DBS followed by a DEXA full body scan. Identification of changes bilateral asymetires can show the effect that sport seasons have on asymetrical muscular adaptations. These bilateral asymeties can lead to decreased performance and an increase in injury risk.[3,58,60,94] Additionally, measures from the 3DBS will be validated against the measurements given from the DEXA.

2.1.1 Dependent Variables

The dependent variables for this study are the measurements from the 3DBS and DEXA, as well as the degree of asymmetry between the upper and lower extremities. The variables from the 3DBS are right bicep circumference (rBC), left bicep circumference (lBC), right forearm circumference (rFC), left forearm circumference (lFC), right thigh circumference (rTC), left thigh circumference (lTC), right calf circumference (rCC), and left calf circumference (lCC), which are collected in centimeters. Right arm surface area (raSA), left arm surface area (laSA), right leg surface area (rlSA), and left leg surface area (llSA) is measured in centimeters squared, and right arm volume (raV), left arm volume (laV), right leg volume (rlV), and left leg volume (llV) is measured in centimeters cubed, from each extremity will also be used. These measurements are defined by Size Stream and are as follows. Bicep circumference is defined as the largest circumference of the upper arm taken along the axial cross section of the arm.[90] Forearm circumference is defined as the largest contour circumference of the lower arm, taken orthogonally to the lower arm axis.[90] Thigh circumference is defined as the contour circumference of the leg measured two inches below the crotch landmark.[90] Calf circumference is defined as the maximum contour horizontal circumference of the leg above the ankle and below the knee.[90] The variables from the DEXA scan are sLM in grams from each of the subjects' upper and lower extremities; right arm lean mass (raLM), left arm lean mass (laLM), right leg lean mass (rlLM), and left leg lean mass (llLM). The degree of asymmetry will be calculated from the DEXA and 3DBS measurement values using an equation, which is described in the data reduction section.

2.1.2 Independent Variable

The independent variables for the study are the sex of the athlete, the sport in which the athlete participates, and the time of season when the athlete is tested. The sports being compared in this study are gymnastics, football, cross country, women's basketball, and women's lacrosse. Testing was done before the 2021 season and six months following their pretest, with the exception of football who were tested during the spring season of 2022.

2.2 Subjects

2.2.1 Subject Recruitment

Subjects were recruited through the parent study called the Bone and Body Composition Adaptations to Training Study and in co-operation with The University of Pittsburgh Athletic Department. Through this process, 300 athletes are invited to participate in this study. Of the 300 athletes who were invited, 188 athletes who participated in testing during the first year of this study will be used in this study. Athletes from five sports participated in this study, consisting of 29 Cross-Country athletes (12 male and 17 female), 19 female gymnasts, 11 women's basketball athletes, 33 women's lacrosse athletes, and 96 football athletes. Demographics for the athletes are included in Table 1a. Demographics for athletes when stratified by sport are included for the male and female athletes in Table 1b and Table 1c, respectively. This study took place at the Neuromuscular Research Laboratory / Warrior Human Performance Research Center at The University of Pittsburgh.

2.2.1.1 Table 1a: Subject Demographics

Subjects Age, Height, and Weight

	Age		Height (cm)		Weight (Kg)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Males	19.98	1.47	186.07	7.43	102.00	24.69
Females	19.60	1.55	166.51	8.22	64.48	15.59

2.2.1.2 Table 1b: Male Subject Demographics

Male Subjects Age, Height, and Weight

	Age		Height (cm)		Weight (Kg)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Cross-Country	19.42	1.68	179.45	6.80	69.05	4.78
Football	20.05	1.43	186.90	7.12	106.12	23.01

2.2.1.3 Table 1a: Female Subject Demographics

Female Subjects Age, Height, and Weight

	Age		Height (cm)		Weight (Kg)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Cross-Country	19.00	0.94	164.29	3.66	55.76	4.17
Gymnastics	19.42	1.43	162.43	6.07	60.79	6.54
Basketball	20.27	1.42	178.97	6.90	79.29	17.10
Lacrosse	19.79	1.82	165.86	7.63	66.15	11.86

2.2.2 Subject Consent

Due to the fact that all of the data for this study stems from the Bone and Body Composition Adaptations to Training study, subject consent was obtained through this study. Following an information session where the participants can ask any questions, they then signed the consent form that has been approved by the Intuitional Review Board from The University of Pittsburgh.

2.2.3 Power Analysis

Data for 188 participants was available for use in this study. The participants in this study were participants in a larger study, the Bone and Body Composition Adaptation to Training study. All participants with valid scans during the first year of testing were included in this analysis. A study by Dobrosielski et al[20] used similar sport sample sizes in a study that assessed body composition values of female NCAA Division 1 athletes. In this study the sample size for cross-country is 18, gymnastics is 23, basketball is 28, and lacrosse is 48.[20]

2.2.4 Inclusion Criteria

To be included in this study, the participants are all athletes from the University of Pittsburgh that have participated as subjects in the Bone and Body Composition Adaptations to Training study. The subjects are Division 1 athletes on one of the following teams: gymnastics, football, cross country, women's basketball, and women's lacrosse.

2.2.5 Exclusion Criteria

If the participant is pregnant, they will be excluded from this study. This is due to the radiation given off by the DEXA.

2.3 Instrumentation

2.3.1 Scale

A Health-o-Meter digital scale (Model 349KLX, Health-o-Meter, McCook, IL) was used to obtain the weights of the participants. Weight was recorded from this scale in kilograms and pounds.

2.3.2 Stadiometer

A Seca stadiometer (216 Accu-Hite, Seca, Austin, TX) was used to measure the heights of all subjects in this study. This stadiometer was mounted to a wall. The measurements were recorded in centimeters and inches.

2.3.3 3-Dimentional Body Scanner

A SizeStream 3D body scanner (SS20 Scanner, SizeStream, Cary, NC) was used to obtain limb surface area, volume, and circumferences, such as bicep circumference, forearm circumference, thigh circumference, and calf circumference, in centimeters. The Size Stream SS20 uses visible and infra-red light to generate a model of the surface of the body.[37]

The Size Stream SS20 Scanner has been found to provide measurements with an accuracy of up to 5mm.[18] This variability is allowed since this product is designed for the clothing industry, but only 49% of the measurements taken are at a confidence level of 99.37%.[67] All of the circumference measurements used in this study have a confidence level of at least 99.37%.

2.3.4 Dual-Energy X-ray Absorptiometry (DEXA)

A full body scan using the Lunar iDXA (General Electric Healthcare, Chicago, IL) was used to obtain body composition data, such as total mass, FM, and LM. The DEXA was also chosen since it is a "gold standard" for body composition research.[80] The GE Lunar uses a fan beam x-ray field to scan where a detector is used to measure the transmission of x-rays from a highly collimated source.[31,70,78] When compared with other models from General Electric, the Lunar iDXA is reported to have better precision from body composition measurements.[79] This machine has shown high precision for bone mineral density with a CV of 0.6%, the CV for LM is 0.7%, and 0.9% for FM.[79] For regional precision all measurements, excluding arm FM, was within 2.0% (full body: FM CV – 1.0% LM CV – 0.5%, arms: FM CV – 2.8% LM CV – 1.6%, legs: FM CV – 1.6% LM CV – 1.3%, trunk: FM CV – 2.0% LM CV – 2.0%).[79] For a full body scan, the radiation dose has been measured at 0.96 μSv and 1.92 μSv for a whole-body scan, thin and standard mode and thick mode respectively.[31,79]

2.4 Testing Procedures

2.4.1 Pre-Testing

Before testing there was an information session held. This session outlined the aims and objectives of the Bone and Body Composition Adaptations to Training study, which is where the data for this study is derived from. Following this session, the participants then consented to participation, by signing the consent form. Then the female participants were administered a pregnancy test. If the participant was pregnant, they were not allowed to participate because of the radiation that is administered from the DEXA scan.

2.4.2 Height and Weight

After consent, the subjects were then taken to a scale. After emptying their pockets and taking their shoes off they were instructed to step onto the scale. The weight of the subject was recorded in pounds and kilograms to the nearest tenth.

While the subject still has their shoes off, they were directed to the stadiometer. They were instructed to stand straight and look forward with their back against the wall. Once the participant is in position, their height was taken and recorded in inches and centimeters to the nearest tenth.

2.4.3 3-Dimentional Body Surface Scan

Before the day of testing began, the 3DBS was calibrated using the included calibration board. Calibration was done according to the manufacturer's instructions.[91] After the participants' height and weight were recorded, they were informed on how the 3DBS works and the correct procedures to ensure a valid scan. Body scans were done in less than a minute.[1] To ensure reliability, participants were given a swim cap and asked to complete the scans in form fitting compression shorts, and females were asked to wear a sports bra to ensure a proper scan.[34] All jewelry, including watches, was taken off and if the participants are wearing mid-calf or high socks, they were instructed to pull the socks all of the way up. This is to minimize the errors that can occur due to the socks not being tightly fitted around the lower leg and ankle. The subjects were then shown the correct position for the scan. This was explained to the participant as in the manufactures operating manual.[91]

The curtain was then closed, so the subject can change into compression clothes. After the participant is in position, the 10 second scan was started. Following the scan, the subject was asked to wait in the scanner while the scan was verified as valid. Once a valid scan is collected, the participant was allowed to change out of their compression clothes, concluding the 3D body scan.

2.4.4 Full Body Dual-Energy X-ray Absorptiometry Scan

Before the subject arrived, the DEXA was calibrated. This was done by using the calibration phantom that came with the Lunar iDXA. The calibration setup was run on the machine per the manufacturer's user manual.[30] All scans done by the Lunar iDXA were analyzed with enCORE Software v15.

The subject was first asked to remove all metal from their body. Additionally, before testing the participants were told not to wear clothes with any metal, such as zippers, buttons, etc....

They were then positioned supine with their body aligned on the guidelines provided on the machine. The subject's spine should be in align with the line that splits the scan region and their head should be at the top of the scan region. If the subject has long hair, they were asked to put it up and away from the shoulders. This was so the hair will be outside of the scan region and not interfere with the data from the DEXA scan. The participant's arms were then placed by their side with their palms facing medially. Their hands should not be in contact with the lateral thigh. After the subject was in position, they were then instructed to raise their feet off the table. The tester then places Velcro strap around the subject's lower legs so that their feet were about six inches apart. With the patient in position and feet secured by a strap, they were then instructed to remain as still as possible but breathe normally. Then the scan began, which took about 7-8 minutes. After the scan, a visual inspection of the scan was done to ensure that the scan was complete, and no data will be skewed.

2.5 Data Reduction

2.5.1 Lean Mass Data Reduction

Data from the DEXA will be excluded if the value was estimated. Estimation happens when an extremity is out of, or not fully in the scan region. This is shown by an "e" listed by the value in enCORE Software v15. Additionally, if an extremity is outside of the scan region and the value is not estimated, the LM data from that extremity will be excluded from the analysis.

2.5.2 Change in Variables Over a Season

To assess the correlation between changes in sLM and changes in AM, change was calculated using a percent change based on the pre-season testing value. The equation used to calculate this is as follows: % Change = (Pre – Post) / Pre. For this equation, a negative value indicates an increase over the season, while a positive value indicates a decrease over the season

2.5.3 Limb Asymmetry

Limb Asymmetry will be calculated using all DEXA and 3D body scanner measurements. Each dependent variable, including regional body composition values for LM and anthropometric (circumference, surface area, and volume) measurements, will be assessed using the equation: Symmetry Index (SI) = 100*((|Right – Left|) / (0.5 *(Right + Left))). All values from this equation are representative of an absolute percentage difference based off the average of the two extremities.

2.6 Statistical Analysis

Descriptive statistics (mean, standard deviation, median, interquartile range, proportion, as appropriate) will be calculated for all variables.

Specific Aims 1 and 2: Changes in dependent variables over the course of the season will be analyzed using paired t-tests or Wilcoxon signed ranks tests, as appropriate. Effect sizes will be calculated. Statistical analysis will be repeated after stratification by sex and sport. Two-way mixed measures analysis of variance (ANOVA) will be utilized to analyze the effect of time, sex, and the interaction between time and sex on the dependent variables, for cross country athletes. If data does not meet assumptions for ANOVA, non-parametric tests will be conducted.

Specific Aim 3: The relationship between DEXA segmental mass values and AM will be analyzed using Pearson or Spearman correlation coefficients, as appropriate. Separate analysis will be conducted for data collected before and after the season. The relationship between changes in DEXA segmental mass values and changes in AM will be analyzed using Pearson or Spearman correlation coefficients, as appropriate.

Specific Aim 4: Segmental lean mass and AM will be described separately by sex and sport. Group differences will be analyzed using one-way ANOVA or the Kruskal-Wallis test, as appropriate. Separate analysis will be conducted by sex and for data collected before and after the season.

Specific Aim 5: Asymmetries will be calculated and described separately by sex and sport. Group differences will be analyzed using one-way ANOVA or the Kruskal-Wallis test, as appropriate. Separate analysis will be conducted by sex and for data collected before and after the season. Two-way mixed measures ANOVA will be utilized to analyze the effect of time, sport, and the interaction between time and sport on the dependent variables. Two-way mixed measures ANOVA will be utilized to analyze the effect of time, sex, and the interaction between time and sex on the dependent variables, for cross country athletes. Two-way mixed measures ANOVA will also be utilized to analyze the effect of time, sport, and the interaction between time and sport on the dependent variables If data does not meet assumptions for ANOVA, non-parametric tests will be conducted.

Statistical analysis will be conducted using IBM SPSS Statistics (IBM Corp.; Armonk, NY). Statistical significance will be set *a priori* at alpha = 0.05, two-sided.

3.0 Results

3.1 Segmental Lean Mass Adaptations Over a Season

A paired-samples t-test was conducted to compare sLM before a season of competition or training and six months following the pre-season testing session in Division I cross-country, gymnastics, women's basketball, women's lacrosse, and football athletes. There was a significant difference in all sLM variables assessed before the season (raLM: Mean = 4445.51g ± 1748.03g; laLM: Mean = 3743.81g ± 1367.28g; rlLM: Mean = 11545.35g ± 3777.04g; llLM: Mean = 11360.45g ± 3661.80g) and after the season (raLM: Mean = 4519.58g ± 1806.35g, p = <0.001; laLM: Mean = 3827.24g ± 1428.03g, p = <0.001; rlLM: Mean = 11639.56g ± 3723.33g, p = 0.012; llLM: Mean = 11460.47g ± 3682.05g, p = 0.011). These results indicate that sLM was higher after six months of competition or training, when compared to before the season (Table 2).

3.1.1.1 Table 2: Changes in Segmental Lean Mass Over a Season

Changes in Segmental Lean Mass Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Right Arm Lean Mass (g)	146	4445.51	1748.03	4572.00	4519.58	1806.35	4614.00	<0.001*	-0.330
Left Arm Lean Mass (g)	120	3743.81	1367.28	3220.00	3827.24	1428.03	3316.50	<0.001*	-0.453
Right Leg Lean Mass (g)	153	11545.35	3777.04	11210.00	11639.56	3723.33	11413.00	0.012*	-0.206
Left Leg Lean Mass (g)	150	11360.45	3661.80	11129.50	11460.47	3682.05	11449.50	0.011*	-0.209

3.1.2 Segmental Lean Mass Adaptations Stratified by Sex and Sport

Paired-Samples T-Tests were also conducted after stratification by sex and sport. Within the male cross-country athletes, a significant increase was seen in laLM evaluated before the season (Mean = 3480.83g ± 339.86g) and following a season of competition (Mean = 3498.82g ± 329.24g, p = 0.010) (Table 3). In female cross-country athletes, there was a significant increase in laLM and raLM from before a season (raLM: Mean = 2131.67g ± 286.10g; laLM: Mean = 2105.89g ± 287.40g) to after a season of competition (raLM: Mean = 2296.11g ± 308.92g, p = 0.002; laLM: Mean = 2279.56g ± 298.91g, p = 0.001). These calculations show that laLM in male cross-country athletes, as well as laLM and raLM in female cross-country athletes were higher following a season of competition (Table 4).

In female gymnasts, significant decreases in sLM were seen over a season in raLM (Pre-Season: Mean = 2790.60g ± 363.24g; Post-Season: Mean = 2704.73g ± 346.21g, p = 0.017) and llLM (Pre-Season: Mean = 7501.87g ± 881.40g; Post-Season: Mean = 7250.87g ± 838.22g, p = 0.006) (Table 5). Conversely, female lacrosse athletes showed significant increases in leg LM when assessed before the season (rlLM: Mean = 7871.00g ± 1092.79g; llLM: Mean = 7827.77g ± 1091.19g) and after the season (rlLM: Mean = 8232.39g ± 1122.35g, p = <0.001; llLM: Mean = 8127.48g ± 1106.72g, p = <0.001) (Table 6). No significant changes in sLM were seen in female basketball athletes (Table 7).

Within the male football athlete sample of this study, significant changes were seen in raLM and laLM, as well as llLM which were assessed before a season of training (raLM: Mean = 5976.83g ± 895.75g; laLM: Mean = 5289.78g ± 637.51g; llLM: Mean = 14392.42g ± 2370.17g) and six months later, before the competitive season (raLM: Mean = 6106.23g ± 932.44g, p = <0.001; laLM: Mean = 5447.93g ± 704.73g, p = <0.001; llLM: Mean = 14527.79g ± 2347.43g, p

= 0.035). These results indicate that raLM, laLM, and llLM was higher following a six-month period of training, when compared to baseline testing (Table 8).

3.1.2.1 Table 3: Changes in the Segmental Lean Mass of Male Cross-Country Athletes Over a Season

Changes in the Segmental Lean Mass of Male Cross-Country Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Right Arm Lean Mass (g)	12	3521.75	401.64	3450.50	3605.58	353.24	3621.50	0.197	-0.397
Left Arm Lean Mass (g)	12	3480.83	339.86	3373.50	3598.83	329.24	3571.50	0.010*	-0.897
Right Leg Lean Mass (g)	12	10031.00	691.54	9905.50	10050.42	857.12	9811.50	0.826	-0.065
Left Leg Lean Mass (g)	12	9954.92	778.70	9944.00	9883.75	844.47	9838.00	0.488	0.207

3.1.2.2 Table 4: Changes in the Segmental Lean Mass of Female Cross-Country Athletes Over a Season

Changes in the Segmental Lean Mass of Female Cross-Country Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Right Arm Lean Mass (g)	9	2131.67	286.10	2046.00	2296.11	308.92	2252.00	0.002*	-1.509
Left Arm Lean Mass (g)	9	2105.89	287.40	2108.00	2279.56	298.91	2278.00	0.001*	-1.670
Right Leg Lean Mass (g)	9	7019.33	513.41	7008.00	7092.22	426.58	7112.00	0.479	-0.248
Left Leg Lean Mass (g)	9	7009.00	529.76	7115.00	7071.33	388.93	7063.00	0.572	-0.196

3.1.2.3 Table 5: Changes in the Segmental Lean Mass of Female Gymnasts Over a Season

Changes in the Segmental Lean Mass of Female Gymnasts Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Right Arm Lean Mass (g)	15	2790.60	363.24	2816.00	2704.73	346.21	2776.00	0.017*	0.698
Left Arm Lean Mass (g)	15	2696.07	364.43	2767.00	2657.33	369.73	2703.00	0.194	0.352
Right Leg Lean Mass (g)	15	7452.00	802.36	7609.00	7301.40	869.19	7365.00	0.101	0.453
Left Leg Lean Mass (g)	15	7501.87	881.40	7629.00	7250.87	838.22	7322.00	0.006*	0.840

3.1.2.4 Table 6: Changes in the Segmental Lean Mass of Female Lacrosse Athletes Over a Season

Changes in the Segmental Lean Mass of Female Basketball Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Right Arm Lean Mass (g)	6	3488.50	290.87	3613.00	3397.17	376.61	3569.00	0.204	0.596
Left Arm Lean Mass (g)	7	3512.29	696.04	3467.00	3508.71	615.66	3482.00	0.938	0.031
Right Leg Lean Mass (g)	7	10493.71	1453.81	10204.00	10320.14	1526.58	10155.00	0.381	0.357
Left Leg Lean Mass (g)	7	10359.14	1358.18	10076.00	10285.14	1474.00	9898.00	0.707	0.149

3.1.2.5 Table 7: Changes in the Segmental Lean Mass of Female Basketball Athletes Over a Season

Changes in the Segmental Lean Mass of Female Lacrosse Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Right Arm Lean Mass (g)	29	2639.52	355.12	2559.00	2655.34	337.16	2605.00	0.428	-0.149
Left Arm Lean Mass (g)	31	2586.35	373.77	2595.00	2598.10	323.75	2634.00	0.479	-0.129
Right Leg Lean Mass (g)	31	7871.00	1092.79	7679.00	8232.39	1122.35	8178.00	<0.001*	-1.239
Left Leg Lean Mass (g)	31	7827.77	1091.19	7824.00	8127.48	1106.72	8196.00	<0.001*	-1.019

3.1.2.6 Table 8: Changes in the Segmental Lean Mass of Male Football Athletes Over a Season

Changes in the Segmental Lean Mass of Male Football Athletes Over a Season

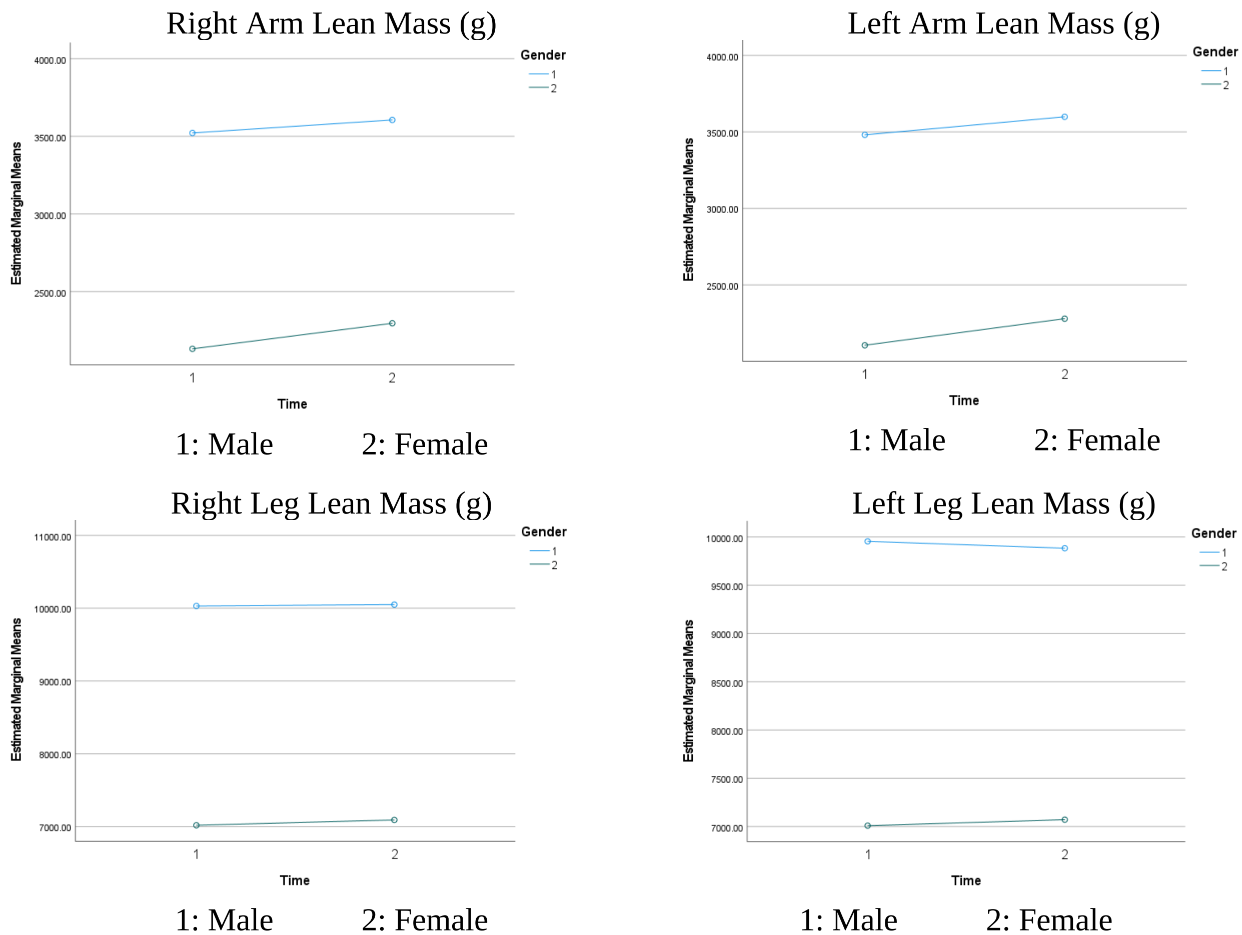
		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Right Arm Lean Mass (g)	75	5976.83	895.75	5953.00	6106.23	932.44	6127.00	<0.001*	-0.492
Left Arm Lean Mass (g)	46	5289.78	637.51	5034.00	5447.93	704.73	5258.50	<0.001*	-0.673
Right Leg Lean Mass (g)	79	14603.23	2468.69	14292.00	14676.61	2363.94	14554.00	0.211	-0.142
Left Leg Lean Mass (g)	76	14392.42	2370.17	13823.50	14527.79	2347.43	14097.00	0.035*	-0.246

3.1.3 Comparison Between Male and Female Cross-Country Athletes

A 2-way mixed measures ANOVA was used to analyze the effect of time, sex, and the interaction between time and sex on sLM variables. The 2-way interaction between time and sex was not significant for all sLM variables, so the main effects of time and group were analyzed. For raLM and laLM, there was a significant main effect of time (raLM: $p = 0.005$, partial $\eta^2 = 0.351$; laLM: $p = <0.001$, partial $\eta^2 = 0.613$), as well as a significant main effect of group (raLM: $p = <0.001$, partial $\eta^2 = 0.814$; laLM: $p = <0.001$, partial $\eta^2 = 0.835$). raLM was significantly higher in men (Men: Mean = 3563.67g, SE = 96.80g, Women: Mean = 2213.89g, SE = 111.77g). raLM was also higher after a season of competition (Pre-season: Mean = 2826.71g, SE = 78.84; Post-season: Mean = 2950.85g, SE = 73.93). laLM was also significantly higher in men (Men: Mean = 3539.83g, SE = 90.08, Women: Mean = 2192.72g, SE = 104.01) and following a season of competition (Pre-season: Mean = 2793.36g, SE = 70.29; Post-season: Mean = 2939.19g, SE = 79.85).

There was no significant main effect of time for rlLM and llLM, but there was a significant main effect of sex (rlLM: $p = <0.001$, partial $\eta^2 = 0.851$; llLM: $p = <0.001$, partial $\eta^2 = 0.834$). For rlLM, males had significantly more mass when compared to their female counterparts (Men: Mean = 10040.71g, SE = 187.72, Women: Mean = 7055.78g, SE = 216.76). Males also showed to have more llLM than female cross-country runners (Men: Mean = 9919.33g, SE = 192.60, Women: Mean = 7040.17g, SE = 222.40) (Figure 1) (Table 9).

3.1.3.1 Figure 1: Profile Plots for Inter-Sport Analysis of Segmental Lean Mass in Cross-Country Athletes



3.1.3.2 Table 9: Descriptive Statistics from Inter-Sport Analysis of Segmental Lean Mass in Cross-Country Athletes

	Sex	N	Pre			Post		
			Mean	SD	Median	Mean	SD	Median
Right Arm Lean Mass (g)	M	12	3521.75	401.64	3450.50	3605.58	353.24	3621.50
	F	9	2131.67	286.10	2046.00	2296.11	308.92	2252.00
Left Arm Lean Mass (g)	M	12	3480.83	339.86	3373.50	3598.83	329.24	3571.50
	F	9	2105.89	287.40	2108.00	2279.56	298.91	2278.00
Right Leg Lean Mass (g)	M	12	10031.00	691.54	9905.50	10050.42	857.12	9811.50
	F	9	7019.33	513.41	7008.00	7092.22	426.58	7112.00
Left Leg Lean Mass (g)	M	12	9954.92	778.70	9944.00	9883.75	844.47	9838.00
	F	9	7009.00	529.76	7115.00	7071.33	388.93	7063.00

3.2 Anthropometric Measurement Adaptations Over a Season

A paired-samples t-test was conducted to compare AM before a season of competition or training and six months following the pre-season testing session in Division I cross-country, gymnastics, women's basketball, women's lacrosse, and football athletes. There was a significant difference seen in all anthropometric variables assessed for, except rCC, raSA, and raV, when assessed before a season (lCC: Mean = 36.97 cm ± 3.45 cm; lTC: Mean = 58.55 cm ± 7.51 cm; rTC: Mean = 59.06 cm ± 7.57 cm; lFC: Mean = 26.30 cm ± 3.64 cm; rFC: Mean = 25.80 cm ± 4.13 cm; lBC: Mean = 29.63 cm ± 4.30 cm; rBC: Mean = 29.45 cm ± 4.74 cm; llSA: Mean = 4329.85 cm^2 ± 613.18 cm^2; rlSA: Mean = 4492.23 cm^2 ± 662.53 cm^2; laSA: Mean = 1599.58 cm^2 ± 318.97 cm^2; llV: Mean = 9626.36 cm^3 ± 2494.91 cm^3; rlV: Mean = 9781.04 cm^3 ± 2525.92 cm^3; laV: Mean = 3691.13 cm^3 ± 1030.21 cm^3) and after a season (lCC: Mean = 37.35 cm ± 3.31 cm, $p = 0.006$; lTC: Mean = 59.59 cm ± 7.84 cm, $p < 0.001$; rTC: Mean = 60.01 cm ± 7.88 cm, $p < 0.001$; lFC: Mean = 26.91 cm ± 3.43 cm, $p = 0.013$; rFC: Mean = 26.36 cm ± 3.38 cm, $p = 0.002$; lBC: Mean = 30.33 cm ± 4.46 cm, $p < 0.001$; rBC: Mean = 30.08 cm ± 4.18 cm, $p = 0.001$; llSA: Mean = 4363.90 cm^2 ± 578.63 cm^2, $p = 0.009$; rlSA: Mean = 4516.38 cm^2 ± 612.78 cm^2, $p = 0.021$; laSA: Mean = 1641.09 cm^2 ± 271.14 cm^2, $p = 0.039$; llV: Mean = 9791.08 cm^3 ± 2450.64 cm^3, $p = 0.003$; rlV: Mean = 9920.60 cm^3 ± 2472.34 cm^3, $p = 0.015$; laV: Mean = 3852.06 cm^3 ± 1105.46 cm^3, $p = 0.008$). These results show that all variables, except for rCC, rTC, lTC, raSA, raV, and llSA, had greater measurements after the season when compared to pre-season. There was no difference in rCC, raSA, and raV. For rTC, lTC, and llSA, the means from pre-season to post-season testing shows that there is an increase, but the median values show a decrease. Since these are not in agreement with each other, the median is used to indicate the direction of change (Table 10).

3.2.1.1 Table 10: Changes in Anthropometric Measurements Over a Season

Changes in Anthropometric Measurements Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Left Calf Circumference (cm)	69	36.97	3.45	36.30	37.35	3.31	36.90	0.006*	-0.342
Right Calf Circumference (cm)	69	37.41	3.43	36.40	37.54	3.23	37.00	0.258	-0.137
Left Thigh Circumference (cm)	69	58.55	7.51	57.10	59.59	7.84	56.60	<0.001*[x]	-0.471
Right Thigh Circumference (cm)	69	59.06	7.57	57.40	60.01	7.88	57.00	<0.001*[x]	-0.453
Left Forearm Circumference (cm)	69	26.30	3.64	25.30	26.91	3.43	26.50	0.013*	-0.308
Right Forearm Circumference (cm)	69	25.80	4.13	24.60	26.36	3.38	25.50	0.002*	-0.389
Left Bicep Circumference (cm)	69	29.63	4.30	28.40	30.33	4.46	29.00	<0.001*	-0.498
Right Bicep Circumference (cm)	69	29.45	4.74	27.80	30.08	4.18	28.90	<0.001*	-0.419
Left Leg Surface Area (cm^2)	69	4329.85	613.18	4191.10	4363.90	578.63	4162.70	0.009*^[x]	-0.200
Right Leg Surface Area (cm^2)	69	4492.23	662.53	4325.30	4516.38	612.78	4379.90	0.021*^	-0.170
Left Arm Surface Area (cm^2)	69	1599.58	318.97	1545.70	1641.09	271.14	1574.50	0.039*	-0.254
Right Arm Surface Area (cm^2)	69	1562.66	282.43	1495.30	1580.46	269.22	1496.90	0.056	-0.234
Left Leg Volume (cm^3)	69	9626.36	2494.91	8832.50	9791.08	2450.64	9096.20	0.003*^	-0.209
Right Leg Volume (cm^3)	69	9781.04	2525.92	9060.10	9920.60	2472.34	9153.10	0.015*^	-0.193
Left Arm Volume (cm^3)	69	3691.13	1030.21	3509.40	3852.06	1105.46	3572.40	0.008*	-0.331
Right Arm Volume (cm^3)	69	3731.88	1155.77	3479.10	3776.83	1274.17	3365.80	0.440	-0.093

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

[x] Mean and median do not change in the same direction, therefore change was assessed based off of the median

3.2.2 Anthropometric Measurement Adaptations Stratified by Sex and Sport

Paired-Samples T-Tests were also conducted after stratification by sex and sport. Male cross-country athletes showed significant differences in lTC (Pre: Mean = 53.28 cm ± 1.86 cm; Post: Mean = 54.08 cm ± 2.02 cm, p = 0.018) and rTC (Pre: Mean = 53.41 cm ± 2.14 cm; Post: Mean = 54.28 cm ± 2.24 cm, p = 0.026) (Table 11).

Female cross-country athletes showed significant increases in lCC (Pre-Season: Mean = 34.39 cm ± 1.19 cm; Post-Season: Mean = 35.18 cm ± 1.64 cm, p = 0.003), rCC (Pre-Season: Mean = 34.86 cm ± 1.18 cm; Post-Season: Mean = 35.32 cm ± 1.56 cm, p = 0.037), lTC (Pre-Season: Mean = 52.98 cm ± 1.60 cm; Post-Season: Mean = 54.79 cm ± 1.47 cm, p < 0.001), rTC

(Pre-Season: Mean = 53.81 cm ± 1.41 cm; Post-Season: Mean = 55.76 cm ± 1.36 cm, $p < 0.001$), rFC (Pre-Season: Mean = 22.14 cm ± 1.93 cm; Post-Season: Mean = 23.26 cm ± 1.35 cm, p = 0.014), lBC (Pre-Season: Mean = 26.07 cm ± 1.83 cm; Post-Season: Mean = 27.42 cm ± 1.81 cm, p = 0.001), rBC (Pre-Season: Mean = 25.54 cm ± 1.81 cm; Post-Season: Mean = 27.06 cm ± 1.66 cm, p = 0.003), rlSA (Pre-Season: Mean = 3974.41 cm^2 ± 205.16 cm^2; Post-Season: Mean = 4042.16 cm^2 ± 211.43 cm^2, p = 0.004), laSA (Pre-Season: Mean = 1213.04 cm^2 ± 385.72 cm^2; Post-Season: Mean = 1395.30 cm^2 ± 90.51 cm^2, p = 0.020), rlV (Pre-Season: Mean = 7892.06 cm^3 ± 632.82 cm^3; Post-Season: Mean = 8330.01 cm^3 ± 676.27 cm^3, p = 0.001), and llV (Pre-Season: Mean = 7718.82 cm^3 ± 632.82 cm^3; Post-Season: Mean = 8174.83 cm^3 ± 683.80 cm^3, $p < 0.001$) (Table 12).

Within the gymnast sample, the analysis shows a significant increase in lCC, lFC, rFC, lBC, rBC, llSA, and laSA when comparing pre-season testing (lCC: Mean = 35.64 cm ± 1.79 cm; lFC: Mean = 24.79 cm ± 1.29 cm; rFC: Mean = 24.16 cm ± 1.20 cm; lBC: Mean = 28.85 cm ± 1.90 cm; rBC: Mean = 27.95 cm ± 1.71 cm; llSA: Mean = 3867.65 cm^2 ± 312.67 cm^2; laSA: Mean = 1454.81 cm^2 ± 150.21 cm^2) to post-season testing (lCC: Mean = 36.35 cm ± 1.71 cm, p = 0.031; lFC: Mean = 27.27 cm ± 1.34 cm, $p < 0.001$; rFC: Mean = 25.47 cm ± 1.28 cm, $p < 0.001$; lBC: Mean = 30.07 cm ± 1.61 cm, p = 0.002; rBC: Mean = 29.19 cm ± 1.62 cm, p = 0.002; llSA: Mean = 3945.18 cm^2 ± 239.18 cm^2, p = 0.024; laSA: Mean = 1555.87 cm^2 ± 113.31 cm^2, p = 0.004;) (Table 13).

Female basketball athletes experienced significant differences in lCC, rCC, lTC, lFC, rFC, lBC, rBC, llSA, rlSA, laSA, and llV. The results indicate that from pre-season (lCC: Mean = 38.16 cm ± 2.65 cm; rCC: Mean = 38.46 cm ± 2.35 cm; lTC: Mean = 62.13 cm ± 3.85 cm; lFC: Mean = 26.03 cm ± 1.50 cm; rFC: Mean = 25.63 cm ± 1.75 cm; lBC: Mean = 29.16 cm ± 2.46 cm; rBC:

Mean = 28.67 cm ± 2.32 cm; llSA: Mean = 4820.04 cm^2 ± 307.35 cm^2; rlSA: Mean = 5037.59 cm^2 ± 306.06 cm^2; LaSA: Mean = 1822.83 cm^2 ± 204.39 cm^2; llV: Mean = 11541.64 cm^3 ± 1585.13 cm^3) to post-season (lCC: Mean = 40.41 cm ± 2.79 cm, $p < 0.001$; rCC: Mean = 39.41 cm ± 2.59 cm, $p = 0.006$; lTC: Mean = 63.76 cm ± 4.73 cm, $p = 0.035$; lFC: Mean = 28.91 cm ± 1.70 cm, $p < 0.001$; rFC: Mean = 28.04 cm ± 1.37 cm, $p < 0.001$; lBC: Mean = 31.83 cm ± 1.99 cm, $p = 0.001$; rBC: Mean = 31.47 cm ± 2.14 cm, $p < 0.001$; llSA: Mean = 5059.79 cm^2 ± 335.65 cm^2, $p = 0.001$; rlSA: Mean = 5162.49 cm^2 ± 321.67 cm^2, $p = 0.023$; laSA: Mean = 1868.37 cm^2 ± 194.27 cm^2, $p = 0.045$; llV: Mean = 12497.49 cm^3 ± 1820.17 cm^3, $p = 0.013$), there was an increase in all variables that experienced a significant change (Table 14).

Female lacrosse athletes experienced changes in lTC, rTC, rFC, and rlSA between the pre-season testing session (lTC: Mean = 58.30 cm ± 3.60 cm; rTC: Mean = 58.92 cm ± 3.32 cm; rFC: Mean = 24.01 cm ± 1.42 cm; rlSA: Mean = 4261.52 cm^2 ± 325.53 cm^2) and the post-season testing session (lTC: Mean = 58.84 cm ± 3.81 cm, $p = 0.041$; rTC: Mean = 59.64 cm ± 3.77 cm, $p = 0.011$; rFC: Mean = 24.40 cm ± 1.33 cm, $p = 0.020$; rlSA: Mean = 4319.98 cm^2 ± 335.05 cm^2, $p = 0.011$). These calculations have shown that the rFC, lTC, and rTC, as well as lTC and rlSA all increased between the two testing timepoints (Table 15).

When comparing the anthropometric variables assessed from pre-season to post-season, male football athletes experienced significant increases in laV (Pre-Season: Mean = 5277.63 cm^3 ± 712.00 cm^3; Post-Season: Mean = 5902.35 cm^3 ± 640.94 cm^3, $p = 0.005$) and raV (Pre-Season: Mean = 5809.08 cm^3 ± 858.21 cm^3; Post-Season: Mean = 6246.97 cm^3 ± 811.85 cm^3, $p = 0.010$). The male football athletes also experienced significant decreases in lCC (Pre-Season: Mean = 42.65 cm ± 3.84 cm; Post-Season: Mean = 41.78 cm ± 4.07 cm, $p = 0.030$), rCC (Pre-Season: = 42.91 cm ± 4.25 cm; Post-Season: Mean = 41.97 cm ± 4.56 cm, $p = 0.007$), rFC (Pre-Season: Mean

= 34.09 cm ± 2.79 cm; Post-Season: Mean = 32.58 cm ± 2.60 cm, p = 0.001), rBC (Pre-Season: Mean = 38.73 cm ± 3.90 cm; Post-Season: Mean = 37.73 cm ± 3.78 cm, p = 0.002), and rlSA (Pre-Season: Mean = 5559.70 cm^2 ± 612.32 cm^2; Post-Season: Mean = 5388.27 cm^2 ± 630.52 cm^2, p = 0.010) (Table 16).

3.2.2.1 Table 11: Changes in the Anthropometric Measurements of Male Cross-Country Athletes Over a Season

Changes in the Anthropometric Measurements of Male Cross-Country Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Left Calf Circumference (cm)	12	36.07	1.40	35.95	36.25	1.39	36.25	0.239	-0.360
Right Calf Circumference (cm)	12	36.67	1.24	36.40	36.57	1.33	36.90	0.688	0.119
Left Thigh Circumference (cm)	12	53.28	1.86	53.25	54.08	2.02	54.45	0.018*	-0.800
Right Thigh Circumference (cm)	12	53.41	2.14	53.25	54.28	2.24	55.00	0.026*	-0.740
Left Forearm Circumference (cm)	12	25.91	1.11	25.95	26.07	1.29	25.90	0.384	-0.262
Right Forearm Circumference (cm)	12	25.38	1.25	25.65	25.82	1.33	25.95	0.282	-0.327
Left Bicep Circumference (cm)	12	27.49	1.36	27.25	27.80	1.61	27.90	0.180	-0.413
Right Bicep Circumference (cm)	12	27.54	1.53	26.95	28.17	1.62	28.40	0.150	-0.446
Left Leg Surface Area (cm^2)	12	4244.43	287.22	4263.00	4298.42	294.84	4356.70	0.091	-0.535
Right Leg Surface Area (cm^2)	12	4431.12	310.09	4505.30	4455.24	329.47	4529.40	0.486	-0.208
Left Arm Surface Area (cm^2)	12	1612.87	111.48	1623.10	1586.01	113.83	1562.10	0.228	0.369
Right Arm Surface Area (cm^2)	12	1531.98	92.17	1503.45	1543.42	74.02	1539.60	0.562	-0.173
Left Leg Volume (cm^3)	12	8676.42	908.85	8572.70	8814.24	870.02	8781.80	0.239	-0.359
Right Leg Volume (cm^3)	12	8822.48	942.83	8714.15	8934.15	970.81	9020.60	0.405	-0.250
Left Arm Volume (cm^3)	12	3714.75	627.27	3682.55	3573.67	655.35	3420.20	0.082	0.553
Right Arm Volume (cm^3)	12	3695.56	565.31	3616.50	3538.34	454.56	3414.35	0.081	0.555

* Statistically Significant; p < 0.05

^ p-value is from non-parametric test

3.2.2.2 Table 12: Changes in the Anthropometric Measurements of Female Cross-Country Athletes Over a Season

Changes in the Anthropometric Measurements of Female Cross-Country Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Left Calf Circumference (cm)	9	34.39	1.19	34.40	35.18	1.64	35.40	0.003*	-1.366
Right Calf Circumference (cm)	9	34.86	1.18	35.00	35.32	1.56	36.10	0.037*	-0.831
Left Thigh Circumference (cm)	9	52.98	1.60	53.30	54.79	1.47	55.40	<0.001*	-1.987
Right Thigh Circumference (cm)	9	53.81	1.41	54.30	55.76	1.36	56.00	<0.001*	-1.942
Left Forearm Circumference (cm)	9	23.61	3.31	22.90	23.78	1.63	24.10	0.867	-0.058
Right Forearm Circumference (cm)	9	22.14	1.93	22.00	23.26	1.35	23.00	0.014*	-1.045
Left Bicep Circumference (cm)	9	26.07	1.83	26.10	27.42	1.81	28.00	<0.001*	-1.688
Right Bicep Circumference (cm)	9	25.54	1.81	25.70	27.06	1.66	27.50	0.003*	-1.407
Left Leg Surface Area (cm^2)	9	3860.48	212.11	3940.50	3902.36	200.31	3991.70	0.245	-0.419
Right Leg Surface Area (cm^2)	9	3974.41	205.16	4053.60	4042.16	211.43	4141.80	0.004*	-1.324
Left Arm Surface Area (cm^2)	9	1213.04	385.72	1298.60	1395.30	90.51	1397.20	0.020*^	-0.493
Right Arm Surface Area (cm^2)	9	1294.76	117.63	1291.80	1339.48	99.18	1356.90	0.076	-0.679
Left Leg Volume (cm^3)	9	7718.82	632.82	7989.30	8174.83	683.80	8385.80	<0.001*	-1.893
Right Leg Volume (cm^3)	9	7892.06	633.89	8207.20	8330.01	676.27	8563.90	<0.001*	-1.782
Left Arm Volume (cm^3)	9	2586.41	925.92	2517.90	2979.52	364.21	3026.10	0.155	-0.523
Right Arm Volume (cm^3)	9	2964.33	716.50	2522.70	2876.91	480.59	2908.70	0.718	0.125

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.2.2.3 Table 13: Changes in the Anthropometric Measurements of Female Gymnasts Over a Season

Changes in the Anthropometric Measurements of Female Gymnasts Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Left Calf Circumference (cm)	12	35.64	1.79	35.60	36.35	1.71	36.10	0.031*	-0.712
Right Calf Circumference (cm)	12	36.13	1.74	36.25	36.48	1.67	36.60	0.268	-0.337
Left Thigh Circumference (cm)	12	54.98	3.70	57.00	55.86	3.43	56.30	0.186	-0.408
Right Thigh Circumference (cm)	12	55.43	3.83	57.30	55.91	3.47	55.70	0.475	-0.214
Left Forearm Circumference (cm)	12	24.79	1.29	24.90	27.27	1.34	27.75	<0.001*	-1.676
Right Forearm Circumference (cm)	12	24.16	1.20	24.45	25.47	1.28	25.35	<0.001*	-1.782
Left Bicep Circumference (cm)	12	28.85	1.90	28.60	30.07	1.61	29.70	0.002*	-1.145
Right Bicep Circumference (cm)	12	27.95	1.71	27.70	29.19	1.62	28.85	0.002*	-1.167
Left Leg Surface Area (cm^2)	12	3867.65	312.67	3951.50	3945.18	239.18	4006.55	0.024*	-0.756
Right Leg Surface Area (cm^2)	12	3991.15	342.92	4055.75	4051.63	276.03	4059.10	0.082	-0.553
Left Arm Surface Area (cm^2)	12	1454.81	150.21	1454.75	1555.87	113.31	1541.10	0.004*	-1.064
Right Arm Surface Area (cm^2)	12	1408.61	150.84	1374.30	1428.18	126.70	1445.30	0.490	-0.206
Left Leg Volume (cm^3)	12	7977.62	1019.56	8192.35	8165.88	849.59	8314.85	0.198	-0.395
Right Leg Volume (cm^3)	12	8117.34	1116.73	8337.45	8291.73	958.54	8442.25	0.210	-0.385
Left Arm Volume (cm^3)	12	3347.65	379.48	3261.80	3456.53	307.46	3412.85	0.305	-0.311
Right Arm Volume (cm^3)	12	3194.92	534.23	3113.05	3092.13	355.30	3093.65	0.425	0.239

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.2.2.4 Table 14: Changes in the Anthropometric Measurements of Female Basketball Athletes Over a Season

Changes in the Anthropometric Measurements of Female Basketball Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Left Calf Circumference (cm)	7	38.16	2.65	39.40	40.41	2.79	41.50	<0.001*	-4.711
Right Calf Circumference (cm)	7	38.46	2.35	39.90	39.41	2.59	40.70	0.006*	-1.582
Left Thigh Circumference (cm)	7	62.13	3.58	64.20	63.76	4.73	66.00	0.035*	-1.023
Right Thigh Circumference (cm)	7	63.00	4.03	65.60	64.26	4.95	66.20	0.094	-0.752
Left Forearm Circumference (cm)	7	26.03	1.50	25.30	28.91	1.70	28.70	<0.001*	-3.429
Right Forearm Circumference (cm)	7	25.63	1.75	25.30	28.04	1.37	27.50	<0.001*	-3.432
Left Bicep Circumference (cm)	7	29.16	2.46	28.90	31.83	1.99	31.70	0.001*	-2.102
Right Bicep Circumference (cm)	7	28.67	2.32	27.60	31.47	2.14	30.80	<0.001*	-5.715
Left Leg Surface Area (cm^2)	7	4820.04	307.35	4920.90	5059.79	335.65	5188.30	<0.001*	-2.321
Right Leg Surface Area (cm^2)	7	5037.59	306.60	5150.60	5162.49	321.67	5343.80	0.023*	-1.145
Left Arm Surface Area (cm^2)	7	1822.83	204.39	1826.50	1868.37	194.27	1873.50	0.045*	-0.952
Right Arm Surface Area (cm^2)	7	1757.80	186.91	1736.70	1816.87	193.18	1721.70	0.085	-0.777
Left Leg Volume (cm^3)	7	11541.64	1585.13	12118.60	12497.49	1820.17	13438.60	0.013*	-1.330
Right Leg Volume (cm^3)	7	11791.69	1627.36	12438.00	12386.07	1854.13	13476.90	0.084	-0.783
Left Arm Volume (cm^3)	7	4130.99	862.87	4098.30	4211.30	762.74	3776.20	0.532	-0.250
Right Arm Volume (cm^3)	7	4077.56	854.70	3943.40	4064.59	829.70	3967.80	0.919	0.040

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.2.2.5 Table 15: Changes in the Anthropometric Measurements of Female Lacrosse Athletes Over a Season

Changes in the Anthropometric Measurements of Female Lacrosse Athletes Over a Season

		Pre-Season			Post-Season				
	N	Mean	SD	Median	Mean	SD	Median	p	Effect Size
Left Calf Circumference (cm)	18	35.81	2.03	36.30	35.95	2.03	36.35	0.442	-0.185
Right Calf Circumference (cm)	18	36.26	2.13	36.40	36.57	1.95	37.10	0.124	-0.381
Left Thigh Circumference (cm)	18	58.30	3.60	59.00	58.84	3.81	59.40	0.041*	-0.520
Right Thigh Circumference (cm)	18	58.92	3.32	59.45	59.64	3.77	60.45	0.011*	-0.672
Left Forearm Circumference (cm)	18	24.70	1.48	24.30	24.44	1.63	24.10	0.291	0.257
Right Forearm Circumference (cm)	18	24.01	1.42	24.00	24.40	1.33	24.60	0.020*	-0.607
Left Bicep Circumference (cm)	18	28.62	2.35	28.15	28.26	2.55	28.30	0.149	0.356
Right Bicep Circumference (cm)	18	28.31	2.10	28.05	28.24	2.26	28.10	0.798	0.061
Left Leg Surface Area (cm^2)	18	4126.34	289.89	4129.20	4154.65	318.08	4143.05	0.254	-0.278
Right Leg Surface Area (cm^2)	18	4261.52	325.53	4237.15	4319.98	335.05	4279.20	0.011*	-0.672
Left Arm Surface Area (cm^2)	18	1507.04	128.13	1490.35	1491.37	153.24	1475.70	0.425	0.192
Right Arm Surface Area (cm^2)	18	1441.00	126.29	1435.20	1460.89	148.58	1469.85	0.241	-0.286
Left Leg Volume (cm^3)	18	9039.55	1127.85	9067.80	9168.56	1235.03	9255.95	0.137	-0.368
Right Leg Volume (cm^3)	18	9200.04	1177.58	9101.45	9384.27	1245.10	9552.40	0.052	-0.492
Left Arm Volume (cm^3)	18	3316.16	588.36	3128.10	3344.94	652.74	3185.10	0.656	-0.107
Right Arm Volume (cm^3)	18	3094.01	480.44	3035.35	3220.80	655.71	3243.15	0.249	-0.282

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.2.2.6 Table 16: Changes in the Anthropometric Measurements of Male Football Athletes Over a Season

Changes in the Anthropometric Measurements of Male Football Athletes Over a Season

	N	Pre-Season			Post-Season			p	Effect Size
		Mean	SD	Median	Mean	SD	Median		
Left Calf Circumference (cm)	11	42.65	3.84	43.50	41.78	4.07	41.40	0.030*	0.760
Right Calf Circumference (cm)	11	42.91	4.25	43.40	41.97	4.56	41.90	0.007*	1.021
Left Thigh Circumference (cm)	11	70.91	8.89	73.30	72.16	10.00	72.80	0.387	-0.272
Right Thigh Circumference (cm)	11	71.23	9.27	76.20	72.12	10.63	73.80	0.488	-0.217
Left Forearm Circumference (cm)	11	33.34	2.09	33.60	32.78	2.53	32.40	0.403	0.264
Right Forearm Circumference (cm)	11	34.09	2.79	35.10	32.58	2.60	32.00	0.001*	1.323
Left Bicep Circumference (cm)	11	37.66	3.67	37.50	38.18	4.59	39.30	0.309	-0.323
Right Bicep Circumference (cm)	11	38.73	3.90	39.80	37.73	3.78	38.30	0.002*	1.270
Left Leg Surface Area (cm^2)	11	5332.36	557.89	5526.80	5169.33	554.80	5301.40	0.063	0.629
Right Leg Surface Area (cm^2)	11	5559.70	612.32	5845.20	5388.27	630.52	5732.70	0.010*	0.958
Left Arm Surface Area (cm^2)	11	2068.60	170.95	1994.60	2095.62	178.68	2038.70	0.402	-0.264
Right Arm Surface Area (cm^2)	11	2058.30	176.53	2121.10	2029.36	181.96	2089.20	0.211	0.403
Left Leg Volume (cm^3)	11	13763.39	2578.89	14672.20	13248.48	2935.57	12395.30	0.280	0.344
Right Leg Volume (cm^3)	11	13858.43	2721.75	14841.30	13383.77	3139.94	12819.10	0.272	0.351
Left Arm Volume (cm^3)	11	5277.63	712.00	5146.90	5902.35	640.94	5888.70	0.005*	-1.082
Right Arm Volume (cm^3)	11	5809.08	858.21	5964.60	6246.97	811.85	6441.30	0.010*	-0.961

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.2.3 Comparison Between Male and Female Cross-Country Athletes

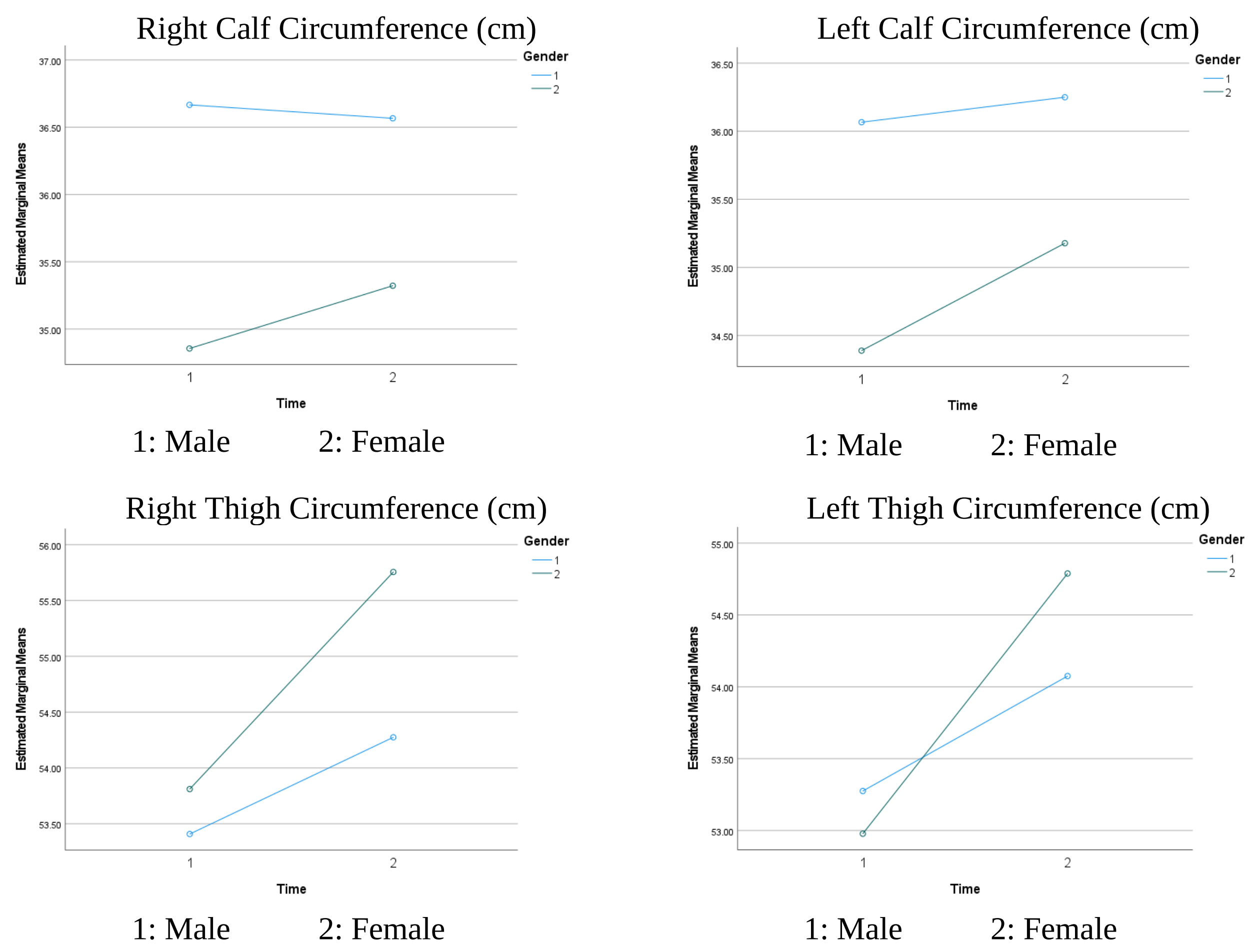
A 2-way mixed measures ANOVA was used to analyze the effect of time, sex, and the interaction between time and sex on anthropometric variables. The 2-way interaction between time and sex was significant for lCC ($p = 0.020$, partial $\eta^2 = 0.254$), rTC($p = 0.039$, partial $\eta^2 = 0.205$), lTC($p = 0.028$, partial $\eta^2 = 0.230$), lBC ($p = 0.006$, partial $\eta^2 = 0.333$), llV ($p = 0.042$, partial $\eta^2 = 0.200$), and laV ($p = 0.032$, partial $\eta^2 = 0.219$). Simple main effects were assessed for each variable for males (lCC: $p = 0.239$, $\eta^2 = 0.124$; rTC: $p = 0.026$, $\eta^2 = 0.374$; lTC: $p = 0.018$, $\eta^2 = 0.411$; lBC: $p = 0.180$, $\eta^2 = 0.157$; llV: $p = 0.239$, $\eta^2 = 0.124$; laV: $p = 0.082$, $\eta^2 = 0.250$) and females (lCC: $p = 0.003$, $\eta^2 = 0.677$; rTC: $p < 0.001$, $\eta^2 = 0.809$; lTC: $p < 0.001$, $\eta^2 = 0.816$; lBC: $p < 0.001$, $\eta^2 = 0.762$; llV: $p < 0.001$, $\eta^2 = 0.801$; laV: $p = 0.115$, $\eta^2 = 0.235$).

There was a significant main effect of time for rFC ($p = 0.010$, partial $\eta^2 = 0.302$), rBC ($p = 0.001$, partial $\eta^2 = 0.433$), rlSA ($p = 0.039$, partial $\eta^2 = 0.205$), rlV ($p = 0.004$, partial $\eta^2 = 0.367$), and llV ($p < 0.001$, partial $\eta^2 = 0.466$). These results show that there is an increase in these AM from pre-season (rFC: Mean = 23.76 cm, SE = 0.35; rBC: Mean = 26.54 cm, SE = 0.36; rlSA: Mean = 4202.76 cm^2, SE = 59.73; llSA: Mean = 4052.56 cm^2, SE = 56.94; rlV: Mean = 8357.27 cm^3, SE = 182.32) to post-season (rFC: Mean = 24.54 cm, SE = 0.29; rBC: Mean = 27.61 cm, SE = 0.36; rlSA: Mean = 4248.70 cm^2, SE = 63.01; llSA: Mean = 4100.38 cm^2, SE = 57.16; rlV: Mean = 8632.08 cm^3, SE = 189.43).

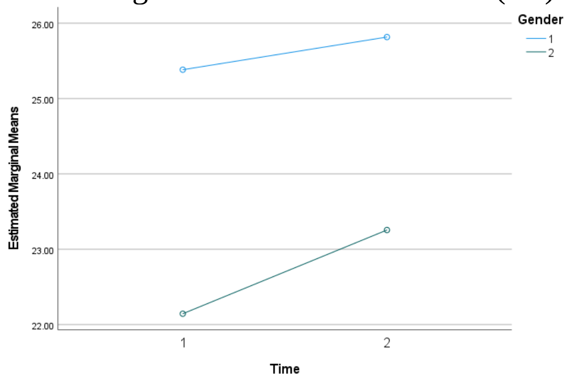
In terms of main effect of group, there were significant effects for rCC ($p = 0.014$, partial $\eta^2 = 0.281$), rFC ($p < 0.001$, partial $\eta^2 = 0.565$), lFC ($p = 0.006$, partial $\eta^2 = 0.340$), rBC ($p = 0.031$, partial $\eta^2 = 0.221$), rlSA ($p = 0.002$, partial $\eta^2 = 0.405$), llSA ($p = 0.002$, partial $\eta^2 = 0.390$), raSA ($p < 0.001$, partial $\eta^2 = 0.624$), laSA ($p < 0.001$, partial $\eta^2 = 0.483$), rlV ($p = 0.048$, partial $\eta^2 = 0.191$), and raV ($p = 0.005$, partial $\eta^2 = 0.348$). These results show that across these variables with a significant effect of sex, male cross-country athletes (rCC: Mean = 36.62 cm, SE = 0.37; rFC: Mean = 25.60 cm, SE = 0.38; lFC: Mean = 25.99 cm, SE = 0.48; rBC: Mean = 27.85 cm, SE = 0.44; rlSA: Mean = 4442.18 cm^2, SE = 79.22; llSA: Mean = 4271.43 cm^2, SE = 73.28; raSA: Mean = 1537.70 cm^2, SE = 25.72; laSA: Mean = 1599.44 cm^2, SE = 45.85; rlV: Mean = 8878.32 cm^3, SE = 237.32; raV: Mean = 3616.95 cm^3, SE = 153.10) displayed larger measurements than female cross-country athletes (rCC: Mean = 35.09 cm, SE = 0.42; rFC: Mean = 22.70 cm, SE = 0.44; lFC: Mean = 23.69 cm, SE = 0.55; rBC: Mean = 26.30 cm, SE = 0.51; rlSA: Mean = 4008.28 cm^2, SE = 91.48; llSA: Mean = 3881.42 cm^2, SE = 84.62; raSA: Mean = 1317.12 cm^2, SE = 29.70; laSA:

Mean = 1304.17 cm^2, SE = 52.94; rlV: Mean = 8111.03 cm^3, SE = 274.03; raV: Mean = 2920.62 cm^3, SE = 165.24) (Figure 2) (Table 17).

3.2.3.1 Figure 2: Profile Plots for Inter-Sport Analysis of Anthropometric Measurements in Cross-Country Athletes

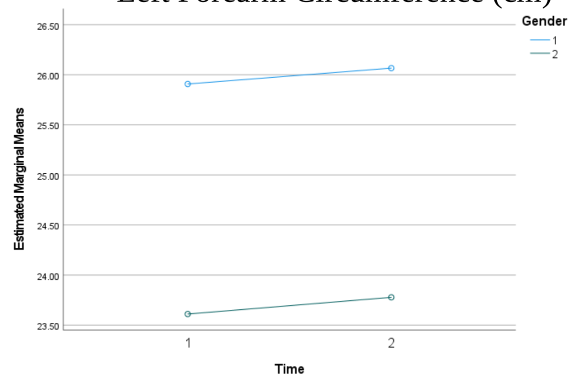


Right Forearm Circumference (cm)



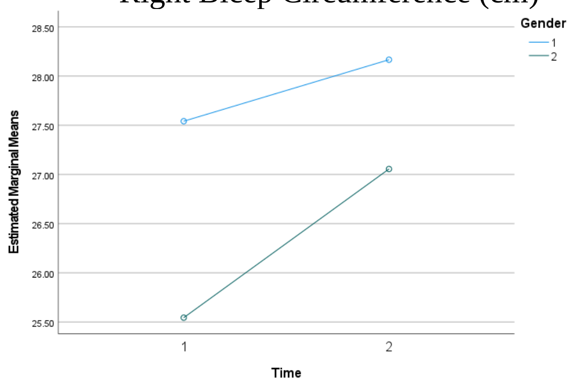
1: Male 2: Female

Left Forearm Circumference (cm)



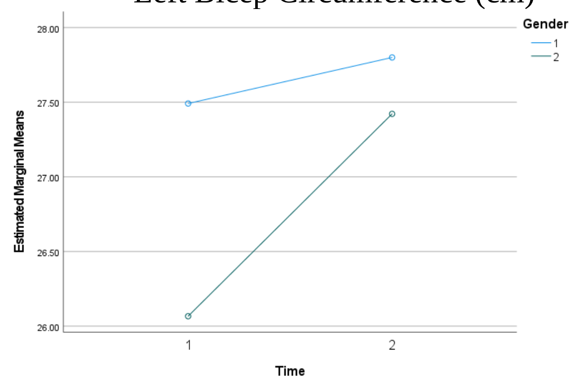
1: Male 2: Female

Right Bicep Circumference (cm)



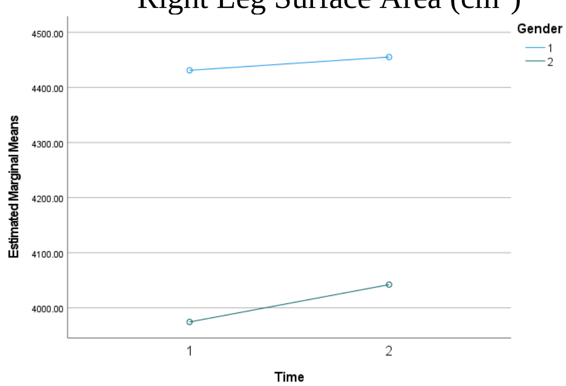
1: Male 2: Female

Left Bicep Circumference (cm)



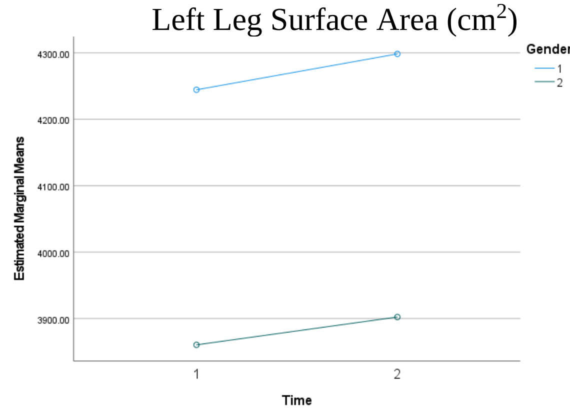
1: Male 2: Female

Right Leg Surface Area (cm^2)



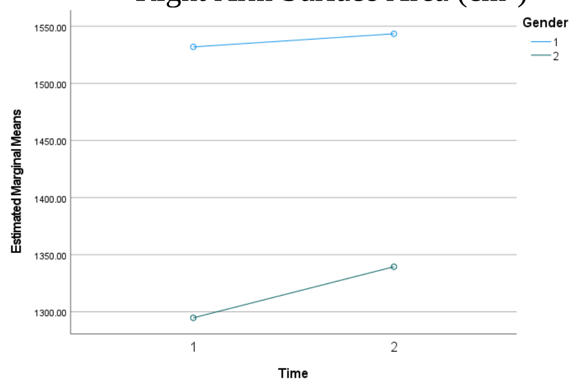
1: Male 2: Female

Left Leg Surface Area (cm^2)



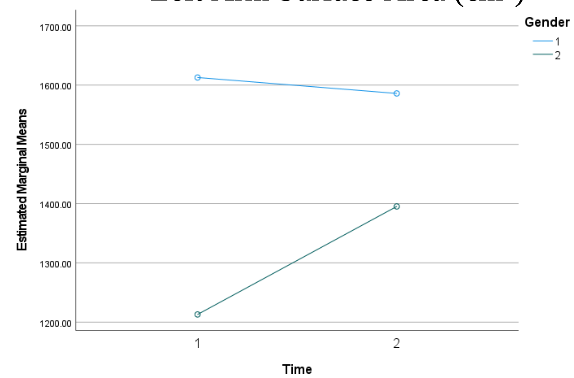
1: Male 2: Female

Right Arm Surface Area (cm^2)



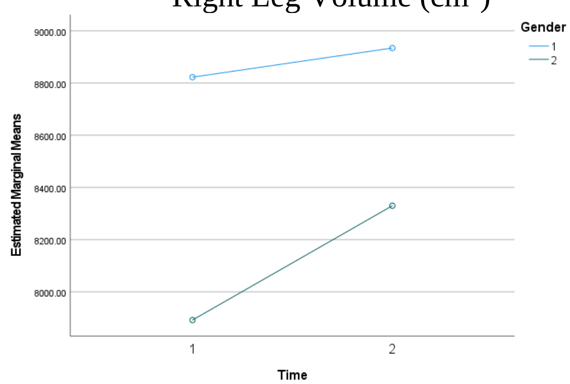
1: Male 2: Female

Left Arm Surface Area (cm^2)



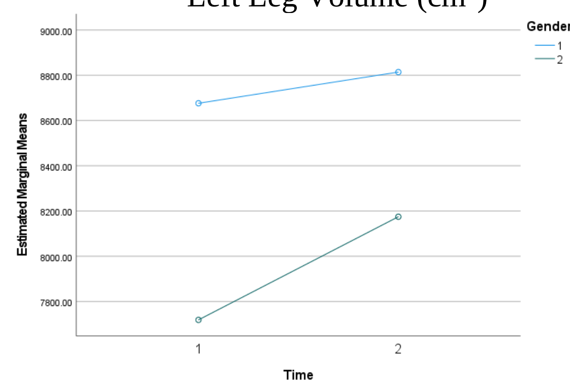
1: Male 2: Female

Right Leg Volume (cm^3)



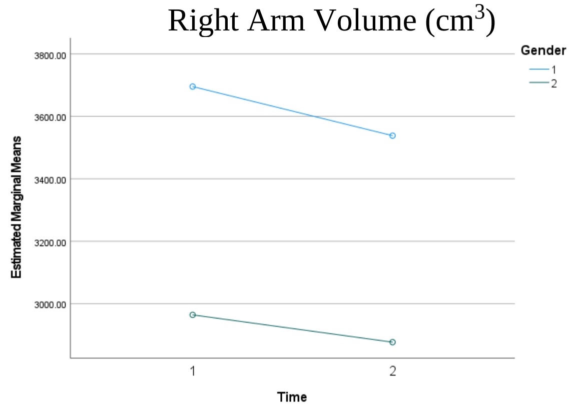
1: Male 2: Female

Left Leg Volume (cm^3)



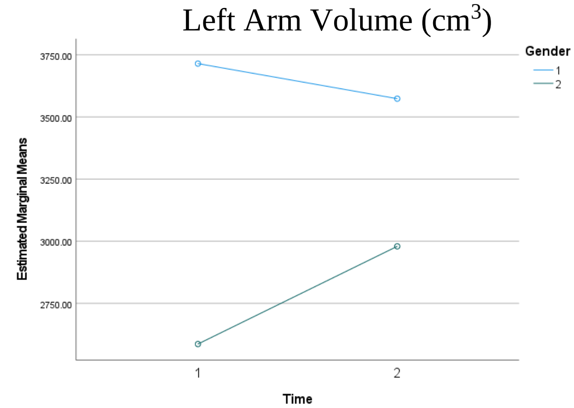
1: Male 2: Female

Right Arm Volume (cm^3)



1: Male 2: Female

Left Arm Volume (cm^3)



1: Male 2: Female

3.2.3.2 Table 17: Descriptive Statistics from Inter-Sport Analysis of Anthropometric Measurements in Cross-Country Athletes

	Sex	N	Pre-Season			Post-Season		
			Mean	SD	Median	Mean	SD	Median
Right Calf Circumference (cm)	M	12	36.67	1.24	36.40	36.57	1.33	36.90
	F	9	34.86	1.18	35.00	35.32	1.56	36.10
Left Calf Circumference (cm)	M	12	36.07	1.40	35.95	36.25	1.39	36.25
	F	9	34.39	1.19	34.40	35.18	1.64	35.40
Right Thigh Circumference (cm)	M	12	53.41	2.14	53.25	54.28	2.24	55.00
	F	9	53.81	1.41	54.30	55.76	1.36	56.00
Left Thigh Circumference (cm)	M	12	53.28	1.86	53.25	54.08	2.02	54.45
	F	9	52.98	1.60	53.30	54.79	1.47	55.40
Right Forearm Circumference (cm)	M	12	25.38	1.25	25.65	25.82	1.33	25.95
	F	9	22.14	1.93	22.00	23.26	1.35	23.00
Left Forearm Circumference (cm)	M	12	25.91	1.11	25.95	26.07	1.29	25.90
	F	9	23.61	3.31	22.90	23.78	1.63	24.10
Right Bicep Circumference (cm)	M	12	27.54	1.53	26.95	28.17	1.62	28.40
	F	9	25.54	1.81	25.70	27.06	1.66	27.50
Left Bicep Circumference (cm)	M	12	27.49	1.36	27.25	27.80	1.61	27.90
	F	9	26.07	1.83	26.10	27.42	1.81	28.00
Right Leg Surface Area (cm^2)	M	12	4431.12	310.09	4505.30	4455.24	329.47	4529.40
	F	9	3974.41	205.16	4053.60	4042.16	211.43	4141.80
Left Leg Surface Area (cm^2)	M	12	4244.43	287.22	4263.00	4298.42	294.84	4356.70
	F	9	3860.48	212.11	3940.50	3902.36	200.31	3991.70
Right Arm Surface Area (cm^2)	M	12	1531.98	92.17	1503.45	1543.42	74.02	1539.60
	F	9	1294.76	117.63	1291.80	1339.48	99.18	1356.90
Left Arm Surface Area (cm^2)	M	12	1612.87	111.48	1623.10	1586.01	113.83	1562.10
	F	9	1213.04	385.72	1298.60	1395.30	90.51	1397.20
Right Leg Volume (cm^3)	M	12	8822.48	942.83	8714.15	8934.15	970.81	9020.60
	F	9	7892.06	633.89	8207.20	8330.01	676.27	8563.90
Left Leg Volume (cm^3)	M	12	8676.42	908.85	8572.70	8814.24	870.02	8781.80
	F	9	7718.82	632.82	7989.30	8174.83	683.80	8385.80
Right Arm Volume (cm^3)	M	12	3695.56	565.31	3616.50	3538.34	454.56	3414.35
	F	9	2964.33	716.50	2522.70	2876.91	480.59	2908.70
Left Leg Volume (cm^3)	M	12	3714.75	627.27	3682.55	3573.67	655.35	3420.20
	F	9	2586.41	925.92	2517.90	2979.52	364.21	3026.10

3.3 Correlations Between Segmental Lean Mass and Anthropometric Measurements

A Pearson correlation coefficient was used to analyze the association between sLM and AM, from before and after a season of competition or training in Division I athletes. When pre-season values were analyzed, all sLM values correlated with AM ($r(86\text{-}93) \geq 0.764$, $p < 0.001$) (Table 18). Strong correlations were also found for sLM and AM taken during post-season ($r(90\text{-}94) \geq 0.810$, $p < 0.001$) (Table 19).

3.3.1.1 Table 18: Pre-Season Lean Mass and Anthropometric Measurement Correlations

Segmental Body Composition	Anthropometric Variables	N	Pearson r	p
Right Arm Lean Mass	Right Forearm Circumference	91	0.951	<.001*
	Right Bicep Circumference	91	.879	<.001*
	Right Arm Surface Area	91	.884	<.001*
	Right Arm Volume	91	.914	<.001*
Left Arm Lean Mass	Left Forearm Circumference	86	.863	<.001*
	Left Bicep Circumference	86	.764	<.001*
	Left Arm Surface Area	86	.835	<.001*
	Left Arm Volume	86	.824	<.001*
Right Leg Lean Mass	Right Calf Circumference	93	.880	<.001*
	Right Thigh Circumference	93	.845	<.001*
	Right Leg Surface Area	93	.944	<.001*
	Right Leg Volume	93	.920	<.001*
Left Leg Lean Mass	Left Calf Circumference	92	.872	<.001*
	Left Thigh Circumference	92	.843	<.001*
	Left Leg Surface Area	92	.938	<.001*
	Left Leg Volume	92	.918	<.001*

3.3.1.2 Table 19: Post-Season Lean Mass and Anthropometric Measurement Correlations

Segmental Body Composition	Anthropometric Variable	N	Pearson r	P
Right Arm Lean Mass	Right Forearm Circumference	92	.939	<.001*
	Right Bicep Circumference	92	.891	<.001*
	Right Arm Surface Area	92	.933	<.001*
	Right Arm Volume	92	.931	<.001*
Left Arm Lean Mass	Left Forearm Circumference	90	.872	<.001*
	Left Bicep Circumference	90	.810	<.001*
	Left Arm Surface Area	90	.915	<.001*
	Left Arm Volume	90	.916	<.001*
Right Leg Lean Mass	Right Calf Circumference	94	.825	<.001*
	Right Thigh Circumference	94	.817	<.001*
	Right Leg Surface Area	94	.932	<.001*
	Right Leg Volume	94	.903	<.001*
Left Leg Lean Mass	Left Calf Circumference	94	.811	<.001*
	Left Thigh Circumference	94	.820	<.001*
	Left Leg Surface Area	94	.925	<.001*
	Left Leg Volume	94	.902	<.001*

3.3.2 Correlations Between Changes in Segmental Body Composition and Anthropometric Measurements

A Pearson correlation coefficient was also used to analyze the association between the changes from pre-season to post-season in sLM and AM. There were weak correlations between raLM and raSA (r(67) = 0.354, p = 0.003) as well as raV (r(67) = 0.264, p = 0.031). There were more weak correlations between rlLM and rCC (r(69) = 0.287, p = 0.017) as well as rTC (r(69) = 0.334, p = 0.005) (Table 20).

3.3.2.1 Table 20: Pre-Season to Post-Season Changes in Segmental Lean Mass and Anthropometric Measurements; Correlations

Segmental Body Composition	Anthropometric Variables	N	Pearson R	P
Right Arm Lean Mass	Right Forearm Circumference	67	0.118	0.341
	Right Bicep Circumference	67	0.228	0.064
	Right Arm Surface Area	67	0.354	0.003*
	Right Arm Volume	67	0.264	0.031*
Left Arm Lean Mass	Left Forearm Circumference	64	-0.109	0.393
	Left Bicep Circumference	64	0.106	0.403
	Left Arm Surface Area	64	0.122	0.335
	Left Arm Volume	64	0.104	0.413
Right Leg Lean Mass	Right Calf Circumference	69	0.287	0.017*
	Right Thigh Circumference	69	0.334	0.005*
	Right Leg Surface Area	69	0.125	0.304
	Right Leg Volume	69	0.124	0.310
Left Leg Lean Mass	Left Calf Circumference	69	0.070	0.566
	Left Thigh Circumference	69	0.196	0.107
	Left Leg Surface Area	69	-0.055	0.652
	Left Leg Volume	69	0.107	0.381

*- Statistically Significant

3.4 Sport Specific Adaptations

To assess sport specific adaptations, one-way ANOVAs were used to assess inter-sport differences for all dependent variables assessed before and after the season.

3.4.1 Pre-Season Segmental Lean Mass

For male athletes, there was a significant difference in all pre-season sLM variables that were assessed between cross-country and football athletes (raLM: $F(1, 104) = 86.16$, $p < 0.001$, η^2

= 0.453; laLM: $F(1, 67) = 92.17$, $p < 0.001$, $\eta^2 = 0.579$; rlLM: $F(1, 106) = 40.99$, $p < 0.001$, $\eta^2 = 0.279$; llLM: $F(1, 103) = 41.65$, $p < 0.001$, $\eta^2 = 0.288$) (Table 21).

For female athletes, there was also a significant difference in all pre-season sLM variables (raLM: $F(3, 74) = 31.49$, $p < 0.001$, $\eta^2 = 0.561$; laLM: $F(3, 76) = 27.90$, $p < 0.001$, $\eta^2 = 0.524$; rlLM: $F(3, 76) = 25.619$, $p < 0.001$, $\eta^2 = 0.503$; llLM: $F(3, 76) = 26.33$, $p < 0.001$, $\eta^2 = 0.510$). To find the differences between sports, post hoc pairwise comparisons were performed using the Bonferroni adjustment. Cross-country athletes, when compared to gymnasts showed significantly less raLM (Cross-country: Mean = 2076.59g ± 247.75; Gymnasts: Mean = 2787.58g ± 323.84, $p < 0.001$) and laLM (Cross-country: Mean = 2037.06g ± 279.45; Gymnasts: Mean = 2689.26g ± 330.59, $p < 0.001$). There was a difference in all sLM variables when comparing the cross-country athletes (raLM: Mean = 2076.59g ± 247.75; laLM: Mean = 2037.06g ± 279.45; rlLM: Mean = 7000.65g ± 521.91; llLM: Mean = 6973.35g ± 559.56), with less sLM, to the basketball athletes (raLM: Mean = 3494.67g ± 605.45, $p < 0.001$; laLM: Mean = 3501.55g ± 743.62, $p < 0.001$; rlLM: Mean = 10560.36g ± 2036.01, $p < 0.001$; llLM: Mean = 10488.00g ± 1801.51, $p < 0.001$). There were also differences in all sLM variables when comparing cross-country athletes and lacrosse athletes (raLM: Mean = 2674.06g ± 348.45, $p < 0.001$; laLM: Mean = 2602.67g ± 367.67, $p < 0.001$; rlLM: Mean = 7941.09g ± 1096.09, $p = 0.035$; llLM: Mean = 7893.18g ± 1089.16, $p = 0.031$), with cross-country athletes having less sLM. Differences were also seen in all sLM variables when comparing basketball athletes and gymnasts (raLM: Mean = 2787.58g ± 323.84, $p < 0.001$; laLM: Mean = 2689.26g ± 330.59, $p < 0.001$; rlLM: Mean = 7461.26g ± 722.22, $p < 0.001$; llLM: Mean = 7531.32g ± 803.87, $p < 0.001$), with gymnasts having less sLM. There are also differences in all variables when comparing basketball athletes and lacrosse athletes, where basketball athletes were larger across all sLM variables ($p < 0.001$) (Table 22) (Table 23).

3.4.1.1 Table 21: Pre-Season Male Athlete Segmental Lean Mass ANOVA

Pre-Season Male Athlete Segmental Lean Mass ANOVA

	Cross Country				Football				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median		
Right Arm Lean Mass (g)	12	3521.75	401.64	3450.50	94	5934.32	885.92	5872.50	<0.001*^	0.453
Left Arm Lean Mass (g)	12	3480.83	339.86	3373.50	57	5284.79	629.33	5041.00	<0.001*^	0.579
Right Leg Lean Mass (g)	12	10031.00	691.54	9905.50	96	14562.58	2430.44	14073.00	<0.001*^	0.279
Left Leg Lean Mass (g)	12	9954.92	778.70	9944.00	93	14351.20	2334.28	13832.00	<0.001*^	0.288

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.4.1.2 Table 22: Pre-Season Female Athlete Segmental Lean Mass ANOVA

Pre-Season Female Athlete Segmental Lean Mass ANOVA

	Cross Country				Gymnastics				Basketball				Lacrosse				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median		
Right Arm Lean Mass (g)	17	2076.59	247.75	2029.00	19	2787.58	323.84	2793.00	9	3494.67	605.45	3539.00	33	2674.06	348.45	2692.00	<0.001*^	0.561
Left Arm Lean Mass (g)	17	2037.06	279.45	1991.00	19	2689.26	330.59	2751.00	11	3501.55	743.62	3467.00	33	2602.67	368.67	2598.00	<0.001*^	0.524
Right Leg Lean Mass (g)	17	7000.65	521.91	7016.00	19	7461.26	722.22	7609.00	11	10560.36	2036.01	10204.00	33	7941.09	1096.12	7998.00	<0.001*^	0.503
Left Leg Lean Mass (g)	17	6973.35	559.56	7003.00	19	7531.32	803.87	7629.00	11	10488.00	1801.51	10076.00	33	7893.18	1089.16	7833.00	<0.001*^	0.510

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.4.1.3 Table 23: Post HOC Comparisons; Bonferroni Adjustment

Pre-Season Female Athlete Segmental Lean Mass: Post HOC Compairsons; Bonferroni Adjustment

	Cross County vs Gymnastics	Cross County vs Basketball	Cross County vs Lacrosse	Gymnastics vs Basketball	Gymnastics vs Lacrosse	Basketball vs Lacrosse
Right Arm Lean Mass	<0.001*	<0.001*	<0.001*	<0.001*	1.000	<0.001*
Left Arm Lean Mass	<0.001*	<0.001*	<0.001	<0.001*	1.000	<0.001*
Right Leg Lean Mass	1.000	<0.001*	0.035*	<0.001*	0.825	<0.001*
Left Leg Lean Mass	0.735	<0.001*	0.031*	<0.001*	1.000	<0.001*

3.4.2 Post-Season Segmental Lean Mass

For the male athletes in the study there was a significant difference seen across all sLM variables between cross-country and football athletes (raLM: $F(1, 85) = 83.68$, $p < 0.001$, $\eta^2 = 0.496$; laLM: $F(1, 58) = 80.69$, $p < 0.001$, $\eta^2 = 0.582$; rlLM: $F(1, 89) = 44.70$, $p < 0.001$, $\eta^2 = 0.334$; llLM: $F(1, 88) = 46.59$, $p < 0.001$, $\eta^2 = 0.346$) (Table 24).

For the female athletes there were also significant differences seen across all sLM values (raLM: $F(3, 56) = 16.55$, $p < 0.001$, $\eta^2 = 0.574$; laLM: $F(3, 58) = 15.52$, $p < 0.001$, $\eta^2 = 0.445$; rlLM: $F(3, 58) = 16.28$, $p < 0.001$, $\eta^2 = 0.457$; llLM: $F(3, 58) = 18.92$, $p < 0.001$, $\eta^2 = 0.467$). Using post hoc pairwise comparisons were performed using the Bonferroni adjustment, inter-sport differences were analyzed. Significant differences across all variables were seen when comparing basketball athletes (raLM: Mean = 3605.29g ± 649.15; laLM: Mean = 3508.71g ± 615.66; rlLM: Mean = 10320.14g ± 1526.58; llLM: Mean = 10285.14g ± 1474.00), which had the most sLM, to each other sport, cross-country (raLM: Mean = 2296.11g ± 308.92, $p < 0.001$; laLM: Mean = 2279.56g ± 298.91, $p < 0.001$; rlLM: Mean = 7092.22g ± 426.58, $p < 0.001$; llLM: Mean =

7071.33g ± 388.93, p < 0.001), gymnastics (raLM: Mean = 2704.73g ± 346.21, p < 0.001; laLM: Mean = 2657.33g ± 369.73, p < 0.001; rlLM: Mean = 7301.40g ± 869.19, p < 0.001; llLM: Mean = 7250.87g ± 838.22, p < 0.001), and lacrosse(raLM: Mean = 2655.34g ± 337.16, p < 0.001; laLM: Mean = 2598.10g ± 323.75, p < 0.001; rlLM: Mean = 8232.39g ± 1122.35, p < 0.001; llLM: Mean = 8127.48g ± 1106.72, p < 0.001). Differences were also seen in rlLM when comparing lacrosse athletes to cross-country athletes (p = 0.034) and gymnasts (p = 0.039) (Table 25) (Table 26).

3.4.2.1 Table 24: Post-Season Male Lean Mass ANOVA

Post-Season Male Segmental Lean Mass ANOVA

	Cross Country				Football				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median		
Right Arm Lean Mass (g)	12	3605.58	353.24	3621.50	75	6106.23	932.44	6127.00	<0.001*^	0.496
Left Arm Lean Mass (g)	12	3598.83	329.24	3571.50	48	5469.69	698.92	5291.00	<0.001*^	0.582
Right Leg Lean Mass (g)	12	10050.42	857.12	9811.50	79	14676.61	2363.94	14554.00	<0.001*^	0.334
Left Leg Lean Mass (g)	12	9883.75	844.47	9838.00	78	14600.91	2361.07	14246.00	<0.001*^	0.346

* Statistically Significant; p < 0.05

^ p-value is from non-parametric test

3.4.2.2 Table 25: Post-Season Female Lean Mass ANOVA

Post-Season Female Segmental Lean Mass ANOVA

	Cross Country				Gymnastics				Basketball				Lacrosse				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median		
Right Arm Lean Mass (g)	9	2296.11	308.92	2252.00	15	2704.73	346.21	2776.00	7	3605.29	649.15	3621.00	29	2655.34	337.16	2605.00	<0.001*	0.470
Left Arm Lean Mass (g)	9	2279.56	298.91	2278.00	15	2657.33	369.73	2703.00	7	3508.71	615.66	3482.00	31	2598.10	323.75	2634.00	<0.001*	0.445
Right Leg Lean Mass (g)	9	7092.22	426.58	7112.00	15	7301.40	869.19	7365.00	7	10320.14	1526.58	10155.00	31	8232.39	1122.35	8178.00	<0.001*^	0.457
Left Leg Lean Mass (g)	9	7071.33	388.93	7063.00	15	7250.87	838.22	7322.00	7	10285.14	1474.00	9898.00	31	8127.48	1106.72	8196.00	<0.001*^	0.467

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.4.2.3 Table 26: Post HOC Comparisons; Bonferroni Adjustment

Post-Season Female Segmental Lean Mass: Post HOC Comparisons; Bonferroni Adjustment

	Cross County vs Gymnastics	Cross County vs Basketball	Cross County vs Lacrosse	Gymnastics vs Basketball	Gymnastics vs Lacrosse	Basketball vs Lacrosse
Right Arm Lean Mass	0.083	<.001*	0.100	<.001*	1.000	<.001*
Left Arm Lean Mass	0.116	<.001*	0.166	<.001*	1.000	<.001*
Right Leg Lean Mass	1.000	<.001*	0.034*	<.001*	0.039*	<.001*
Left Leg Lean Mass	1.000	<.001*	0.051	<.001*	0.051	<.001*

3.4.3 Pre-Season Anthropometric Measurements

A significant difference was seen in all AM taken before the season between male cross-country and football athletes ($F(1, 25) = 22.52 – 113.98$, $p < 0.001$, $\eta^2 = 0.474 – 0.820$) (Table 27).

Within the female athletes, significant differences were also seen across all variables ($F(3, 63) = 6.02 – 27.25$, p = <0.001 – 0.012, $\eta^2 = 0.223 – 0.569$). Inter-sport differences were analyzed for female athletes using post hoc pairwise comparisons, specifically the Bonferroni adjustment. For lCC, there are differences between basketball athletes (Mean = 38.17cm ± 3.84), and cross-country athletes (Mean = 34.28cm ± 1.86, p < 0.001), gymnasts (Mean = 35.68cm ± 1.69, p = 0.21), and lacrosse athletes (Mean = 35.90cm ± 2.01, p = 0.048). Differences in rCC were seen when comparing basketball athletes (Mean = 38.45cm ± 3.71) to cross-country athletes (Mean = 34.79cm ± 1.68, p < 0.001) and gymnasts (Mean = 36.07 ± 1.66, p = 0.036). When comparing lTC between the sports, basketball athletes (Mean = 62.78 ± 5.40) showed a significant difference from cross-country athletes (Mean = 52.59 ± 2.19, p < 0.001), gymnasts (Mean = 55.46 ± 4.08, p < 0.001), and lacrosse athletes (Mean = 58.32 ± 3.50, p = 0.017). Lacrosse athletes were also significantly larger than cross-country athletes (p < 0.001). Differences were seen when comparing the rTC of basketball athletes (Mean = 63.71 ± 6.24) to cross-country athletes (Mean

= 53.31 ± 2.25, $p < 0.001$), gymnasts (Mean = 55.77 ± 3.97, $p < 0.001$), and lacrosse athletes (Mean = 58.89 ± 3.23, $p = 0.011$). Also, cross-country athletes had a significantly lower rTC than lacrosse athletes ($p < 0.001$). Cross-country athletes (Mean = 22.78 ± 2.55) had presented with a lower lFC from gymnasts (Mean = 24.77 ± 1.13, $p = 0.007$), basketball athletes (Mean = 26.29 ± 1.85, $p < 0.001$), and lacrosse athletes (Mean = 24.69 ± 1.44, $p = 0.012$). In rFC differences were seen when comparing cross-county athletes (Mean = 21.91 ± 1.49), to gymnasts (Mean = 24.37 ± 1.10, $p < 0.001$), basketball athletes (Mean = 25.87 ± 2.07, $p < 0.001$), and lacrosse athletes (Mean = 24.03 ± 1.39, $p < 0.001$). There are also differences between gymnasts and basketball athletes ($p = 0.049$), as well as between basketball and lacrosse athletes ($p = 0.009$), with basketball having the highest rFC. Comparing the bicep circumferences of cross-country athletes to gymnasts, basketball athletes, and lacrosse athletes, significant differences were seen for lBC (Cross-Country: Mean = 25.24 ± 1.86; Gymnastics: Mean = 29.09 ± 2.13, $p < 0.001$; Basketball: Mean = 30.04 ± 3.50, $p < 0.001$; Lacrosse: Mean = 28.56 ± 2.30, $p < 0.001$) and rBC (Cross-Country: Mean = 25.03 ± 1.76; Gymnastics: Mean = 28.22 ± 1.97, $p < 0.001$; Basketball: Mean = 29.52 ± 3.43, $p < 0.001$; Lacrosse: Mean = 28.27 ± 2.05, $p < 0.001$). Differences in llSA were seen when comparing basketball athletes, who had the highest llSA, (Mean = 4825.75cm^2 ± 469.54) to all other athlete groups in this study (Cross-Country: Mean = 3854.91cm^2 ± 193.91, $p < 0.001$; Gymnastics: Mean = 3898.15cm^2 ± 284.26, $p < 0.001$; Lacrosse: Mean = 4136.14cm^2 ± 284.94, $p < 0.001$). Differences are also seen when comparing cross-country and lacrosse athletes ($p = 0.043$), with cross-country having a higher llSA. Differences in rlSA were found when comparing basketball athletes (Mean = 5046.58cm^2 ± 525.85) to the other athlete groups (Cross-Country: Mean = 3995.33cm^2 ± 200.95, $p < 0.001$; Gymnastics: Mean = 4015.42cm^2 ± 310.78, $p < 0.001$; Lacrosse: Mean = 4272.80cm^2 ± 319.52, $p < 0.001$). Differences are seen in laSA when comparing cross-country athletes (Mean = 1275.31cm^2 ± 297.71) to all other athlete groups (Basketball: Mean = 1814.03cm^2 ± 272.31, $p < 0.001$; Gymnastics: Mean = 1464.16cm^2 ± 128.76, $p < 0.049$; Lacrosse: Mean = 1501.63cm^2 ± 126.74, $p = 0.012$). Differences are also seen when comparing basketball athletes, with the highest laSA to gymnasts ($p < 0.001$) and lacrosse athletes ($p = 0.001$). Between basketball athletes (Mean = 1759.02cm^2 ± 267.52) and the other groups (Cross-Country: Mean = 1300.84cm^2 ± 104.46, $p < 0.001$; Gymnastics: Mean = 1408.47cm^2 ± 133.49, $p < 0.001$; Lacrosse: Mean = 1442.09cm^2 ± 122.82, $p < 0.001$), differences were seen in raSA, as well as between cross-country and lacrosse athletes ($p = 0.048$). For llV, rlV, and raV, differences were found when comparing basketball athletes (llV: Mean = 11710.86cm^3 ± 2265.72; rlV: Mean = 12012.34cm^3 ± 2467.66; raV: Mean = 4160.95cm^3 ± 1088.36) to cross-country athletes (llV: Mean = 7736.42cm^3 ± 676.22, $p < 0.001$; rlV: Mean = 7925.05cm^3 ± 668.59, $p < 0.001$; raV: Mean = 2827.77cm^3 ± 569.18, $p < 0.001$), gymnasts (llV: Mean = 8115.18cm^3 ± 1079.64, $p < 0.001$; rlV: Mean = 8223.45cm^3 ± 1129.21, $p < 0.001$; raV: Mean = 3149.71cm^3 ± 470.28, $p < 0.001$), and lacrosse athletes (llV: Mean = 9075.25cm^3 ± 1107.06, $p < 0.001$; rlV: Mean = 9233.34cm^3 ± 1153.57, $p < 0.001$; raV: Mean = 3109.99cm^3 ± 472.07, $p < 0.001$), and when comparing cross-country to lacrosse athletes differences were found in leg volume, (llV: $p = 0.048$, rlV: $p = 0.032$). For laV, differences were found when comparing cross-country athletes, with the smallest laV measurements, (Mean = 2687.82cm^3 ± 749.86) to all other groups (Gymnastics: Mean = 3355.76cm^3 ± 371.62, $p = 0.021$; Basketball: Mean = 4263.08cm^3 ± 1027.12, $p < 0.001$; Lacrosse: Mean = 333.52cm^3 ± 576.76, $p = 0.031$). Differences were also seen when comparing basketball athletes to gymnasts ($p = 0.004$) and lacrosse athletes ($p < 0.001$) (Table 28) (Table 29).

3.4.3.1 Table 27: Pre-Season Male Athlete Anthropometric Measurement ANOVA

Pre-Season Male Athlete Anthropometric Measurement ANOVA

	Cross Country				Football				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median		
Left Calf Circumference (cm)	12	36.07	1.40	35.95	15	42.78	3.40	43.10	<.001*^	0.621
Right Calf Circumference (cm)	12	36.67	1.24	36.40	15	43.23	3.86	43.40	<.001*^	0.560
Left Thigh Circumference (cm)	12	53.28	1.86	53.25	15	70.94	8.85	73.30	<.001*^	0.647
Right Thigh Circumference (cm)	12	53.41	2.14	53.25	15	72.36	10.24	76.20	<.001*^	0.612
Left Forearm Circumference (cm)	12	25.91	1.11	25.95	15	33.40	2.28	33.60	<.001*^	0.813
Right Forearm Circumference (cm)	12	25.38	1.25	25.65	15	33.95	2.54	34.70	<.001*^	0.820
Left Bicep Circumference (cm)	12	27.49	1.36	27.25	15	38.28	4.95	37.50	<.001*^	0.681
Right Bicep Circumference (cm)	12	27.54	1.53	26.95	15	39.93	6.40	39.80	<.001*^	0.631
Left Leg Surface Area (cm^2)	12	4244.43	287.22	4263.00	15	5360.55	523.99	5526.80	<.001*^	0.636
Right Leg Surface Area (cm^2)	12	4431.12	310.09	4505.30	15	5628.82	616.15	5845.20	<.001*^	0.600
Left Arm Surface Area (cm^2)	12	1612.87	111.48	1623.10	15	2157.12	276.63	2125.00	<.001*	0.620
Right Arm Surface Area (cm^2)	12	1531.98	92.17	1503.45	15	2022.17	210.19	2095.90	<.001*^	0.692
Left Leg Volume (cm^3)	12	8676.42	908.85	8572.70	15	13908.94	2514.26	14672.20	<.001*^	0.652
Right Leg Volume (cm^3)	12	8822.48	942.83	8714.15	15	14179.33	2825.39	14841.30	<.001*^	0.612
Left Arm Volume (cm^3)	12	3714.75	627.27	3682.55	15	5647.40	1290.44	5530.60	<.001*	0.474
Right Arm Volume (cm^3)	12	3695.56	565.31	3616.50	15	5850.28	883.05	5964.60	<.001*	0.682

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.4.3.2 Table 28: Pre-Season Female Athlete Anthropometric Measurement ANOVA

Pre-Season Female Athlete Anthropometric Measurement ANOVA

	Cross Country				Gymnastics				Basketball				Lacrosse				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median		
Left Calf Circumference (cm)	17	34.28	1.86	34.40	20	35.68	1.69	35.70	11	38.17	3.48	39.40	19	35.90	2.01	36.30	0.008*^	0.251
Right Calf Circumference (cm)	17	34.79	1.68	35.00	20	36.07	1.66	36.20	11	38.45	3.71	39.90	19	36.35	2.11	36.60	0.012*^	0.223
Left Thigh Circumference (cm)	17	52.59	2.19	52.50	20	55.46	4.08	55.55	11	62.78	5.40	64.20	19	58.32	3.50	59.00	<.001*^	0.462
Right Thigh Circumference (cm)	17	53.31	2.25	54.00	20	55.77	3.97	55.80	11	63.71	6.24	65.60	19	58.89	3.23	59.20	<.001*^	0.461
Left Forearm Circumference (cm)	17	22.78	2.55	22.20	20	24.77	1.13	24.75	11	26.29	1.85	25.80	19	24.69	1.44	24.40	<.001*	0.305
Right Forearm Circumference (cm)	17	21.91	1.49	21.80	20	24.37	1.10	24.55	11	25.87	2.07	25.30	19	24.03	1.39	24.00	<.001*	0.458
Left Bicep Circumference (cm)	17	25.24	1.86	25.00	20	29.09	2.13	28.60	11	30.04	3.50	30.50	19	28.56	2.30	28.00	<.001*	0.362
Right Bicep Circumference (cm)	17	25.03	1.76	25.50	20	28.22	1.97	27.70	11	29.52	3.43	29.40	19	28.27	2.05	27.80	<.001*^	0.348
Left Leg Surface Area (cm^2)	17	3854.91	193.91	3905.90	20	3898.15	284.26	3980.80	11	4825.75	469.54	4920.90	19	4136.14	284.94	4144.00	<.001*^	0.569
Right Leg Surface Area (cm^2)	17	3995.33	200.95	4053.60	20	4015.42	310.78	4056.35	11	5046.58	525.85	5150.60	19	4271.80	319.52	4273.20	<.001*^	0.565
Left Arm Surface Area (cm^2)	17	1275.31	297.71	1319.60	20	1464.16	128.76	1454.75	11	1814.03	272.31	1826.50	19	1501.63	126.74	1459.30	<.001*	0.414
Right Arm Surface Area (cm^2)	17	1300.84	104.46	1292.60	20	1408.47	133.49	1374.30	11	1759.02	267.52	1736.70	19	1442.09	122.82	1461.70	<.001*^	0.494
Left Leg Volume (cm^3)	17	7736.42	676.22	7870.10	20	8115.18	1079.64	8271.70	11	11710.86	2265.72	12118.60	19	9075.25	1107.06	9109.70	<.001*^	0.544
Right Leg Volume (cm^3)	17	7925.05	668.59	8207.20	20	8223.45	1129.21	8353.10	11	12012.34	2467.66	12438.00	19	9233.34	1153.57	9101.70	<.001*^	0.532
Left Arm Volume (cm^3)	17	2687.82	749.86	2692.20	20	3355.76	371.62	3311.95	11	4263.08	1027.12	4098.30	19	3333.52	576.76	3136.00	0.001*^	0.371
Right Arm Volume (cm^3)	17	2827.77	569.18	2602.70	20	3149.71	470.28	3071.60	11	4160.95	1088.36	3943.40	19	3109.99	472.07	3095.00	0.009*^	0.334

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.4.3.3 Table 29: Post HOC Comparisons; Bonferroni Adjustment

Pre-Season Female Athlete Anthropometric Measurement: Post HOC Comparisons; Bonferroni Adjustment

	Cross County vs Gymnastics	Cross County vs Basketball	Cross County vs Lacrosse	Gymnastics vs Basketball	Gymnastics vs Lacrosse	Basketball vs Lacrosse
Left Calf Circumference	0.352	<.001*	0.184	0.021*	1.000	0.048*
Right Calf Circumference	0.538	<.001*	0.249	0.036*	1.000	0.093
Left Thigh Circumference	0.151	<.001*	<.001*	<.001*	0.128	0.017*
Right Thigh Circumference	0.358	<.001*	<.001*	<.001*	0.089	0.011*
Left Forearm Circumference	0.007*	<.001*	0.012*	0.159	1.000	0.125
Right Forearm Circumference	<.001*	<.001*	<.001*	0.049*	1.000	0.009*
Left Bicep Circumference	<.001*	<.001*	<.001*	1.000	1.000	0.643
Right Bicep Circumference	<.001*	<.001*	<.001*	0.768	1.000	0.888
Left Leg Surface Area	1.000	<.001*	0.043*	<.001*	0.103	<.001*
Right Leg Surface Area	1.000	<.001*	0.097	<.001*	0.120	<.001*
Left Arm Surface Area	0.049*	<.001*	0.012*	<.001*	1.000	0.001*
Right Arm Surface Area	0.231	<.001*	0.048*	<.001*	1.000	<.001*
Left Leg Volume	1.000	<.001*	0.048*	<.001*	1.000	<.001*
Right Leg Volume	1.000	<.001*	0.032*	<.001*	0.141	<.001*
Left Arm Volume	0.021*	<.001*	0.031*	0.004*	1.000	0.003*
Right Arm Volume	0.769	<.001*	1.000	<.001*	1.000	<.001*

3.4.4 Post-Season Anthropometric Measurements

When comparing across sports for the post-season anthropometric variables, differences are seen across all variables between male cross-country and football athletes ($F(1, 33) = 21.67 – 128.61$, $p < 0.001$, $\eta^2 = 0.396 – 0.808$). For the female athletes, significant differences were also seen across all anthropometric variables ($F(3, 55) = 5.63 – 25.97$, $p = <0.001 – 0.005$, $\eta^2 = 0.235 – 0.527$) (Table 30)

Post hoc pairwise comparisons were performed using the Bonferroni adjustment to analyze inter-sport differences in female athletes. For lCC and rCC basketball athletes (lCC: Mean =

40.41cm ± 2.79; rCC: Mean = 39.41cm ± 2.59) were found to have differences from cross-country (lCC: Mean = 35.18cm ± 1.64, $p < 0.001$; rCC: Mean = 35.32cm ± 1.56, $p = 0.001$), gymnastics (lCC: Mean = 36.35cm ± 1.71, $p < 0.001$; rCC: Mean = 36.48cm ± 1.67, $p = 0.020$), and lacrosse athletes (lCC: Mean = 36.33cm ± 2.19, $p < 0.001$; rCC: Mean = 36.84cm ± 2.11, $p = 0.021$). Differences in thigh circumference were also seen between basketball athletes (lTC: Mean = 63.76cm ± 4.73; rTC: Mean = 64.26cm ± 4.95) and cross-country (lTC: Mean = 54.79cm ± 1.47, $p < 0.001$; rTC: Mean = 55.76cm ± 1.36, $p < 0.001$), gymnastics (lTC: Mean = 55.86cm ± 3.43, $p < 0.001$; rTC: Mean = 55.91cm ± 3.47, $p < 0.001$), and lacrosse athletes (lTC: Mean = 59.33cm ± 3.63, $p = 0.023$; rTC: Mean = 60.07cm ± 3.70, $p = 0.043$). Differences were also seen when comparing lacrosse athletes to cross-country athletes (lTC: $p = 0.007$; rTC: $p = 0.014$) and gymnasts (lTC: $p = 0.031$; rTC: $p = 0.007$). When looking at lFC, differences are seen between cross-country athletes (Mean = 23.78cm ± 1.63) and gymnasts (Mean = 27.27cm ± 1.34, $p < 0.001$), as well as basketball athletes (Mean = 28.91cm ± 1.70, $p < 0.001$). There were also differences seen when comparing lacrosse athletes (Mean = 24.53cm ± 1.55) to gymnasts ($p < 0.001$) and basketball athletes ($p < 0.001$). For rFC, there were similar differences when comparing cross-country (Mean = 23.26cm ± 1.35) athletes with gymnasts (Mean = 25.47cm ± 1.28, $p = 0.002$) and basketball athletes (Mean = 28.04cm ± 1.37, $p < 0.001$). Differences were also seen when comparing basketball athletes to gymnasts ($p < 0.001$) and lacrosse athletes (Mean = 24.54cm ± 1.31, $p < 0.001$). In both bicep circumferences, differences were seen when comparing basketball athletes (lBC: Mean = 31.83cm ± 1.99; rBC: Mean = 31.47cm ± 2.14) to cross-country (lBC: Mean = 27.42cm ± 1.81, $p = 0.001$; rBC: Mean = 27.06cm ± 1.66, $p < 0.001$) and lacrosse athletes (lBC: Mean = 28.75cm ± 2.50, $p = 0.009$; rBC: Mean = 28.59cm ± 2.26, $p = 0.009$).

When looking at the other AM, consisting of surface area and volumetric measurements, differences were seen when comparing basketball athletes (llSA: Mean = 5059.79cm^2 ± 335.65; rlSA: Mean = 5162.49cm^2 ± 321.67; laSA: Mean = 1868.37cm^2 ± 194.27; raSA: Mean = 1816.87cm^2 ± 193.18; llV: Mean = 12497.49cm^3 ± 1820.17; rlV: Mean = 12386.07cm^3 ± 1854.13; laV: Mean = 4211.30cm^3 ± 762.74; RaV: Mean = 4064.59cm^3 ± 829.70) to cross-country athletes (llSA: Mean = 3902.36cm^2 ± 200.31, $p < 0.001$; rlSA: Mean = 4042.16cm^2 ±211.46, $p < 0.001$; laSA: Mean = 1395.30cm^2 ± 90.51, $p < 0.001$; raSA: Mean = 1339.48cm^2 ± 99.18, $p < 0.001$; llV: Mean = 8174.83cm^3 ± 683.80, $p < 0.001$; rlV: Mean = 8330.01cm^3 ± 676.27, $p < 0.001$; laV: Mean = 2979.52cm^3 ± 364.21, $p < 0.001$; raV: Mean = 2876.91cm^3 ± , $p = 0.001$), gymnasts (llSA: Mean = 3945.18cm^2 ± 239.18, $p < 0.001$; rlSA: Mean = 4051.63cm^2 ± 276.03, $p < 0.001$; laSA: Mean = 1555.87cm^2 ± 113.31, $p < 0.001$; raSA: Mean = 1428.18cm^2 ± 126.70, $p < 0.001$; llV: Mean = 8165.88cm^3 ± 849.59, $p < 0.001$; rlV: Mean = 8291.73cm^3 ± 958.54, $p < 0.001$; laV: Mean = 3456.53cm^3 ± 307.46, $p = 0.036$; raV: Mean = 3092.13cm^3 ± 355.30, $p = 0.007$) and lacrosse athletes (llSA: Mean = 4143.57cm^2 ± 325.73, $p < 0.001$; rlSA: Mean = 4301.44cm^2 ± 349.08, $p < 0.001$; laSA: Mean = 1484.70cm^2 ± 148.80, $p < 0.001$; raSA: Mean = 1458.62cm^2 ± 145.13, $p < 0.001$; llV: Mean = 9267.76cm^3 ± 1239.29, $p < 0.001$; rlV: Mean = 9447.67cm^3 ± 1258.38, $p < 0.001$; laV: Mean = 3322.11cm^3 ± 614.69, $p = 0.002$; raV: Mean = 3240.64cm^3 ± 640.87, $p = 0.010$). In rlV, gymnasts had lower measurements than lacrosse athletes ($p = 0.044$) (Table 31) (Table 32)

3.4.4.1 Table 30: Post-Season Male Athlete Anthropometric Measurement ANOVA

Post-Season Male Athlete Anthropometric Measurement ANOVA

	Cross Country				Football				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median		
Left Calf Circumference (cm)	12	36.25	1.39	36.25	23	41.19	3.40	40.50	<.001*^	0.410
Right Calf Circumference (cm)	12	36.57	1.33	36.90	23	41.67	3.66	41.80	<.001*^	0.396
Left Thigh Circumference (cm)	12	54.08	2.02	54.45	23	69.49	7.60	67.20	<.001*^	0.588
Right Thigh Circumference (cm)	12	54.28	2.24	55.00	23	70.27	7.68	69.30	<.001*^	0.599
Left Forearm Circumference (cm)	12	26.07	1.29	25.90	23	32.57	2.25	32.30	<.001*	0.721
Right Forearm Circumference (cm)	12	25.82	1.33	25.95	23	32.76	2.29	32.70	<.001*	0.739
Left Bicep Circumference (cm)	12	27.80	1.61	27.90	23	37.76	3.63	37.40	<.001*^	0.711
Right Bicep Circumference (cm)	12	28.17	1.62	28.40	23	37.68	3.04	38.30	<.001*^	0.755
Left Leg Surface Area (cm^2)	12	4298.42	294.84	4356.70	23	5184.75	419.92	5137.00	<.001*	0.562
Right Leg Surface Area (cm^2)	12	4455.24	329.47	4529.40	23	5426.79	472.96	5405.80	<.001*	0.549
Left Arm Surface Area (cm^2)	12	1586.01	113.83	1562.10	23	2124.43	142.07	2118.90	<.001*	0.796
Right Arm Surface Area (cm^2)	12	1543.42	74.02	1539.60	23	2035.79	140.77	2020.20	<.001*	0.794
Left Leg Volume (cm^3)	12	8814.24	870.02	8781.80	23	13045.53	2202.22	12395.30	<.001*^	0.551
Right Leg Volume (cm^3)	12	8934.15	970.81	9020.60	23	13371.63	2319.48	12885.40	<.001*^	0.547
Left Arm Volume (cm^3)	12	3573.67	655.35	3420.20	23	5928.30	578.61	5888.70	<.001*	0.783
Right Arm Volume (cm^3)	12	3538.34	454.56	3414.35	23	6125.05	682.20	6159.50	<.001*	0.808

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.4.4.2 Table 31: Post-Season Female Athlete Anthropometric Measurement ANOVA

Post-Season Female Athlete Anthropometric Measurement ANOVA

	Cross Country				Gymnastics				Basketball				Lacrosse				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median		
Left Calf Circumference (cm)	9	35.18	1.64	35.40	12	36.35	1.71	36.10	7	40.41	2.79	41.50	31	36.33	2.19	36.40	<.001*	0.355
Right Calf Circumference (cm)	9	35.32	1.56	36.10	12	36.48	1.67	36.60	7	39.41	2.59	40.70	31	36.84	2.11	37.30	0.002*	0.235
Left Thigh Circumference (cm)	9	54.79	1.47	55.40	12	55.86	3.43	56.30	7	63.76	4.73	66.00	31	59.33	3.63	59.50	<.001*^	0.385
Right Thigh Circumference (cm)	9	55.76	1.36	56.00	12	55.91	3.47	55.70	7	64.26	4.95	66.20	31	60.07	3.70	60.30	<.001*^	0.384
Left Forearm Circumference (cm)	9	23.78	1.63	24.10	12	27.27	1.34	27.75	7	28.91	1.70	28.70	31	24.53	1.55	24.50	<.001*	0.572
Right Forearm Circumference (cm)	9	23.26	1.35	23.00	12	25.47	1.28	25.35	7	28.04	1.37	27.50	31	24.54	1.31	24.70	<.001*	0.515
Left Bicep Circumference (cm)	9	27.42	1.81	28.00	12	30.07	1.61	29.70	7	31.83	1.99	31.70	31	28.75	2.50	28.50	<.001*	0.257
Right Bicep Circumference (cm)	9	27.06	1.66	27.50	12	29.19	1.62	28.85	7	31.47	2.14	30.80	31	28.59	2.26	28.50	<.001*	0.257
Left Leg Surface Area (cm^2)	9	3902.36	200.31	3991.70	12	3945.18	239.18	4006.55	7	5059.79	335.65	5188.30	31	4143.57	325.73	4144.60	<.001*	0.586
Right Leg Surface Area (cm^2)	9	4042.16	211.43	4141.80	12	4051.63	276.03	4059.10	7	5162.49	321.67	5343.80	31	4301.44	349.08	4322.60	<.001*	0.544
Left Arm Surface Area (cm^2)	9	1395.30	90.51	1397.20	12	1555.87	113.31	1541.10	7	1868.37	194.27	1873.50	31	1484.70	148.80	1468.10	<.001*	0.486
Right Arm Surface Area (cm^2)	9	1339.48	99.18	1356.90	12	1428.18	126.70	1445.30	7	1816.87	193.18	1721.70	31	1458.62	145.13	1476.50	<.001*	0.478
Left Leg Volume (cm^3)	9	8174.83	683.80	8385.80	12	8165.88	849.59	8314.85	7	12497.49	1820.17	13438.60	31	9267.76	1239.29	9396.80	<.001*^	0.559
Right Leg Volume (cm^3)	9	8330.01	676.27	8563.90	12	8291.73	958.54	8442.25	7	12386.07	1854.13	13476.90	31	9447.67	1258.38	9589.80	<.001*^	0.517
Left Arm Volume (cm^3)	9	2979.52	364.21	3026.10	12	3456.53	307.46	3412.85	7	4211.30	762.74	3776.20	31	3322.11	614.69	3255.20	0.005*^	0.275
Right Arm Volume (cm^3)	9	2876.91	480.59	2908.70	12	3092.13	355.30	3093.65	7	4064.59	829.70	3967.80	31	3240.64	640.87	3165.70	0.002*	0.239

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric

3.4.4.3 Table 32: Post HOC Comparisons; Bonferroni Adjustment

Post-Season Female Athlete Anthropometric Measurement: Post HOC Comparisons; Bonferroni Adjustment

	Cross County vs Gymnastics	Cross County vs Basketball	Cross County vs Lacrosse	Gymnastics vs Basketball	Gymnastics vs Lacrosse	Basketball vs Lacrosse
Left Calf Circumference	1.000	<.001*	0.922	<.001*	1.000	<.001*
Right Calf Circumference	1.000	0.001*	0.312	0.02*	1.000	0.021*
Left Thigh Circumference	1.000	<.001*	0.007*	<.001*	0.031*	0.023*
Right Thigh Circumference	1.000	<.001*	0.014*	<.001*	0.007*	0.043*
Left Forearm Circumference	<.001*	<.001*	1.000	0.172	<.001*	<.001*
Right Forearm Circumference	0.002*	<.001*	0.075	<.001*	0.261	<.001*
Left Bicep Circumference	0.051	0.001*	0.689	0.584	0.507	0.009*
Right Bicep Circumference	0.132	<.001*	0.322	0.140	1.000	0.009*
Left Leg Surface Area	1.000	<.001*	0.214	<.001*	0.321	<.001*
Right Leg Surface Area	1.000	<.001*	0.206	<.001*	0.141	<.001*
Left Arm Surface Area	0.076	<.001*	0.602	<.001*	0.865	<.001*
Right Arm Surface Area	0.976	<.001*	0.186	<.001*	1.000	<.001*
Left Leg Volume	1.000	<.001*	0.110	<.001*	0.051	<.001*
Right Leg Volume	1.000	<.001*	0.113	<.001*	0.044*	<.001*
Left Arm Volume	0.338	<.001*	0.652	0.036*	1.000	0.002*
Right Arm Volume	1.000	0.001*	0.685	0.007*	1.000	0.010*

3.5 Sport Specific Asymmetry

To assess the inter-sport differences in asymmetry between right and left variables before and after a season, a one-way ANOVA was used.

3.5.1 Pre-Season Symmetry Index Variables

In the male athlete sample used in this study, there are no differences seen in SI values when comparing between cross-country and football athletes (Table 33). In the female athlete sample, leg surface area SI was the only variable that achieved statistical significance ($F(3, 63) = 3.62$, $p = 0.018$, $\eta^2 = 0.147$). There were no inter-sport differences seen in female athletes when using post hoc pairwise comparisons were performed using the Bonferroni adjustment (Table 34) (Table 35)

3.5.1.1 Table 33: Pre-Season Male Athlete Symmetry Index ANOVA

Pre-Season Male Athlete Symmetry Index ANOVA

	Cross Country				Football				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median		
Arm Lean Mass	12	5.66	4.47	4.86	55	4.10	3.03	3.84	0.145	0.032
Leg Lean Mass	12	2.19	1.57	1.80	93	2.57	1.77	2.45	0.481	0.005
Calf Circircumference	12	1.76	1.21	1.97	15	1.61	1.31	1.12	0.766	0.004
Thigh Circumference	12	0.89	0.92	0.55	15	2.44	5.07	0.95	0.306	0.042
Forearm Circumference	12	3.75	3.95	2.88	15	5.25	5.67	3.95	0.446	0.023
Bicep Circumference	12	2.38	2.41	1.41	15	4.44	3.46	4.29	0.093	0.109
Leg Surface Area	12	4.29	0.92	4.31	15	4.76	2.81	4.79	0.580	0.012
Arm Sureface Area	12	5.37	4.58	3.06	15	8.84	16.17	4.83	0.480	0.020
Leg Volume	12	1.85	1.27	1.42	15	3.01	2.76	1.88	0.164^	0.067
Arm Volume	12	7.58	6.60	6.55	15	13.80	10.50	11.75	0.086	0.113

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.5.1.2 Table 34: Pre-Season Female Athlete Symmetry Index ANOVA

Pre-Season Female Athlete Symmetry Index ANOVA

	Cross Country				Gymnastics				Basketball				Lacrosse				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median		
Arm Lean Mass	17	4.14	3.32	3.40	19	4.88	3.22	5.04	9	6.26	4.21	5.77	33	4.24	3.13	3.57	0.387	0.040
Leg Lean Mass	17	2.16	1.07	2.19	19	3.36	2.20	2.89	11	3.08	1.65	2.70	33	2.42	1.95	1.99	0.143^	0.064
Calf Circumference	17	1.61	1.47	0.91	20	1.44	1.06	1.11	11	1.53	1.54	0.98	19	1.90	1.15	1.85	0.712	0.021
Thigh Circumference	17	1.47	1.06	0.96	20	1.20	1.00	1.20	11	2.02	1.33	1.91	19	1.40	1.08	1.08	0.270	0.060
Forearm Circumference	17	4.94	7.34	3.05	20	2.05	1.63	1.60	11	1.81	1.81	1.50	19	3.28	2.48	2.07	0.129	0.085
Bicep Circumference	17	2.60	1.52	1.91	20	3.11	2.10	2.65	11	2.31	1.41	2.02	19	2.50	2.03	1.53	0.628	0.027
Leg Surface Area	17	3.97	0.98	3.79	20	2.93	1.30	2.89	11	4.41	1.70	4.68	19	3.19	1.62	2.98	0.018*^	0.147
Arm Surface Area	17	11.44	33.00	2.28	20	4.21	2.60	4.55	11	4.05	3.16	2.91	19	5.41	4.70	4.02	0.619^	0.033
Leg Volume	17	2.44	1.87	2.04	20	1.74	1.18	1.45	11	3.29	1.65	2.96	19	2.59	1.86	2.52	0.097	0.095
Arm Volume	17	15.48	39.00	3.58	20	7.63	4.76	7.45	11	6.29	3.87	3.85	19	8.52	6.59	7.05	0.550^	0.030

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.5.1.3 Table 35: Post HOC Comparisons; Bonferroni Adjustment

Pre-Season Female Athlete Symmetry Index: Post HOC Comparisons; Bonferroni Adjustment

	Cross County vs Gymnastics	Cross County vs Basketball	Cross County vs Lacrosse	Gymnastics vs Basketball	Gymnastics vs Lacrosse	Basketball vs Lacrosse
Arm Lean Mass	1.000	0.762	1.000	1.000	1.000	0.668
Leg Lean Mass	0.321	1.000	1.000	1.000	0.486	1.000
Calf Circircumference	1.000	1.000	1.000	1.000	1.000	1.000
Thigh Circumference	1.000	1.000	1.000	0.310	1.000	0.855
Forearm Circumference	0.219	0.314	1.000	1.000	1.000	1.000
Bicep Circumference	1.000	1.000	1.000	1.000	1.000	1.000
Leg Surface Area	0.167	1.000	0.593	0.380	1.000	0.144
Arm Surface Area	1.000	1.000	1.000	1.000	1.000	1.000
Leg Volume	1.000	1.000	1.000	0.092	0.697	1.000
Arm Volume	1.000	1.000	1.000	1.000	1.000	1.000

3.5.2 Post-Season Symmetry Index Variables

Thigh circumference SI was the only dependent variable in the male subset of participants that was able to achieve statistical significance ($F(1, 33) = 16.33$, $p = 0.002$, $\eta^2 = 0.196$). In the female athlete sample, calf circumference SI ($F(3, 55) = 4.07$, $p = 0.039$, $\eta^2 = 0.169$), leg surface area SI ($F(3, 55) = 7.54$, $p = 0.007$, $\eta^2 = 0.197$), and arm surface area SI ($F(3, 55) = 99.23$, $p < 0.001$, $\eta^2 = 0.301$) (Table 36).

Using post hoc pairwise comparisons, specifically the Bonferroni adjustment, inter-sport differences are analyzed. Calf circumference SI was different between gymnasts (Mean = 1.03 ± 0.84) and basketball athletes (Mean = 2.49 ± 1.85, $p = 0.030$). Differences were also seen in forearm circumference SI and arm surface area SI when comparing gymnasts (Forearm Circumference SI: Mean = 6.59 ± 5.11; Arm Surface Area SI: Mean = 9.19 ± 4.23) to cross-country

(Forearm Circumference SI: Mean = 2.68 ± 2.12, p = 0.008; Arm Surface Area SI: Mean = 4.13 ± 2.18, p = 0.013) and lacrosse athletes (Forearm Circumference SI: Mean = 2.36 ± 1.86, p < 0.001; Arm Surface Area SI: Mean = 3.38 ± 3.64, p < 0.001). Differences in leg surface area were only seen between basketball (Mean = 2.03 ± 1.34) and lacrosse athletes (Mean = 3.72 ± 1.18, p = 0.018) (Table 37) (Table 38)

3.5.2.1 Table 36: Post-Season Male Athlete SI ANOVA

Post-Season Male Athlete Symmerty Index ANOVA

	Cross Country				Football				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median		
Arm Lean Mass	12	3.56	1.80	3.63	45	3.77	2.80	3.06	0.799	0.001
Leg Lean Mass	12	2.92	1.69	3.10	78	2.39	1.73	2.14	0.333	0.011
Calf Circircumference	12	1.65	1.24	1.43	23	2.07	1.42	1.86	0.393	0.022
Thigh Circumference	12	0.93	0.92	0.67	23	2.37	1.62	2.75	0.002*^	0.196
Forearm Circumference	12	3.23	1.88	2.96	23	2.84	2.07	2.35	0.592	0.009
Bicep Circumference	12	2.60	1.80	2.27	23	2.95	2.63	2.17	0.685	0.005
Leg Surface Area	12	3.54	1.63	3.57	23	4.51	2.66	4.33	0.262	0.038
Arm Surface Area	12	4.36	3.38	3.09	23	5.15	2.04	5.72	0.467^	0.022
Leg Volume	12	2.37	1.95	2.21	23	3.78	2.86	3.61	0.136	0.066
Arm Volume	12	9.29	5.08	9.74	23	5.99	6.20	3.53	0.123	0.070

* Statistically Significant; p < 0.05

^ p-value is from non-parametric test

3.5.2.2 Table 37: Post-Season Female Athlete Symmetry Index ANOVA

Post-Season Female Athlete Symmetry Index ANOVA

	Cross Country				Gymnastics				Basketball				Lacrosse				p	η^2
	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median		
Arm Lean Mass	9	3.73	1.89	3.48	15	3.27	2.06	2.73	7	5.36	4.46	4.24	29	3.77	2.62	3.67	0.687^	0.050
Leg Lean Mass	9	2.77	1.33	2.76	15	2.29	1.67	2.58	7	2.77	2.60	2.34	31	2.67	2.09	2.32	0.911	0.009
Calf Circircumference	9	1.25	0.66	0.87	12	1.03	0.84	0.79	7	2.49	1.85	1.63	31	1.86	0.97	1.83	0.039*^	0.169
Thigh Circumference	9	1.75	1.04	2.09	12	1.26	1.75	0.54	7	1.30	1.00	1.43	31	1.28	1.03	1.28	0.759	0.021
Forearm Circumference	9	2.68	2.12	2.33	12	6.95	5.11	7.74	7	3.41	2.08	3.99	31	2.36	1.86	2.28	0.054^	0.294
Bicep Circumference	9	1.56	0.87	1.42	12	3.53	2.94	3.05	7	3.92	2.29	2.88	31	2.42	2.08	2.33	0.088	0.111
Leg Surface Area	9	3.51	1.45	3.09	12	2.62	1.44	2.46	7	2.03	1.34	2.61	31	3.72	1.18	3.58	0.007*	0.197
Arm Surface Area	9	4.14	2.18	3.72	12	9.19	4.23	9.42	7	4.80	3.16	4.44	31	3.38	3.64	2.29	<0.001*	0.301
Leg Volume	9	1.96	1.27	2.10	12	1.71	1.76	0.91	7	1.72	1.41	1.54	31	2.34	1.63	2.21	0.600	0.033
Arm Volume	9	6.17	3.29	5.50	12	11.35	8.64	10.11	7	10.16	6.27	7.61	31	8.04	6.97	6.47	0.318	0.061

* Statistically Significant; $p < 0.05$

^ p-value is from non-parametric test

3.5.2.3 Table 38: Post HOC Comparisons; Bonferroni Adjustment

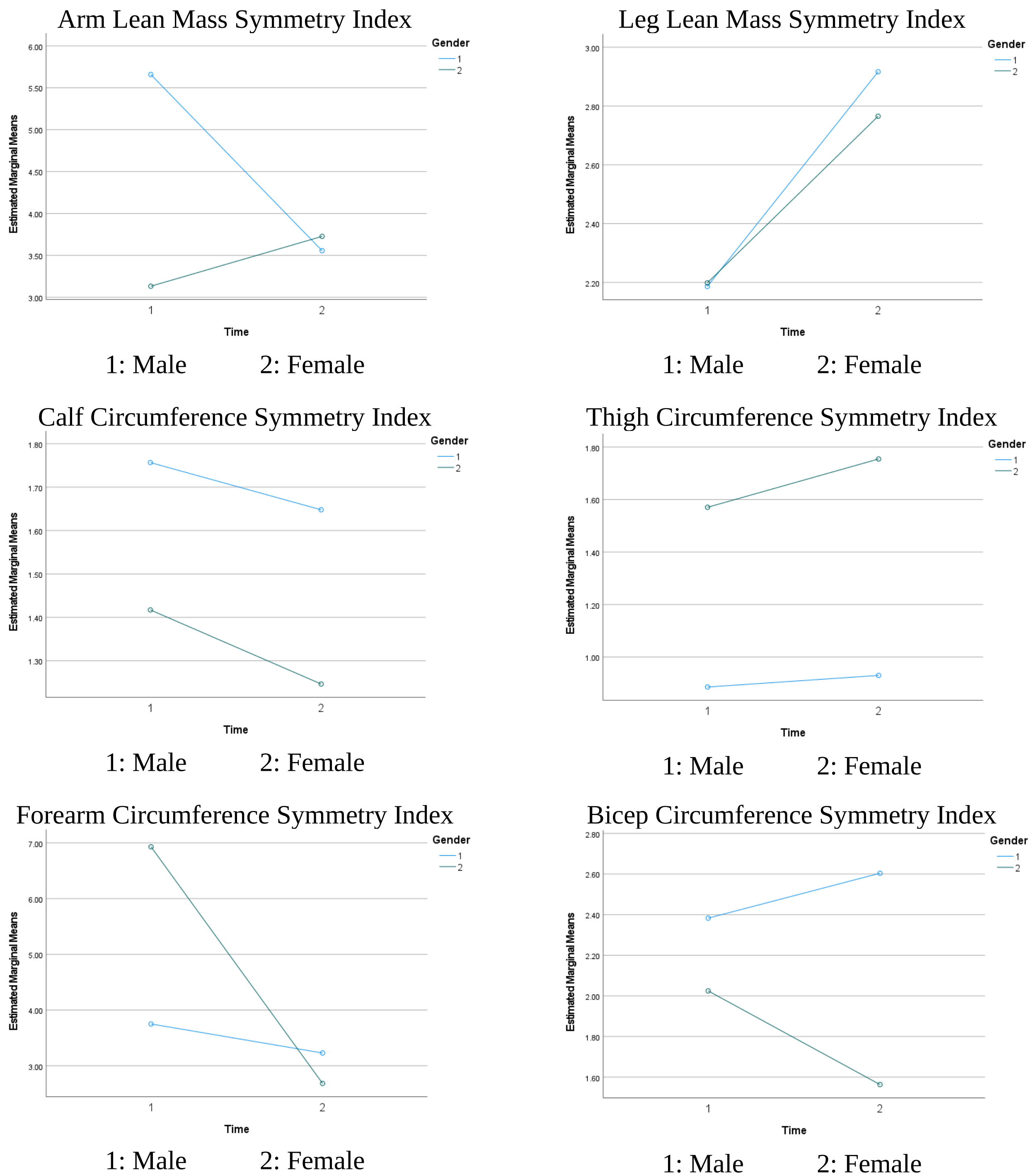
Post-Season Female Athlete Symmetry Index: Post HOC Comparisons; Bonferroni Adjustment

	Cross County vs Gymnastics	Cross County vs Basketball	Cross County vs Lacrosse	Gymnastics vs Basketball	Gymnastics vs Lacrosse	Basketball vs Lacrosse
Arm Lean Mass	1.000	1.000	1.000	0.561	1.000	0.977
Leg Lean Mass	1.000	1.000	1.000	1.000	1.000	1.000
Calf Circircumference	1.000	0.133	0.777	0.030*	0.147	0.928
Thigh Circumference	1.000	1.000	1.000	1.000	1.000	1.000
Forearm Circumference	0.008*	1.000	1.000	0.073	<0.001*	1.000
Bicep Circumference	0.276	0.219	1.000	1.000	0.833	0.629
Leg Surface Area	0.731	0.163	1.000	1.000	0.092	0.018*
Arm Surface Area	0.013*	1.000	1.000	0.072	<0.001*	1.000
Leg Volume	1.000	1.000	1.000	1.000	1.000	1.000
Arm Volume	0.558	1.000	1.000	1.000	0.978	1.000

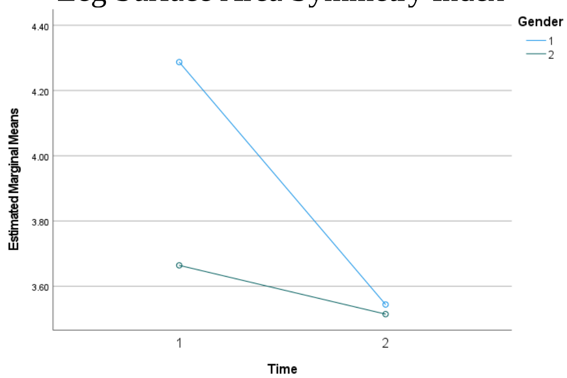
3.5.3 Differences in Symmetry Index Between Male and Female Cross-Country Athletes

When comparing cross-country athletes across time and sex, there were no significant interaction effects, main effects of time, nor main effects of sex (Figure 3) (Table 39)

3.5.3.1 Figure 3: Profile Plots for Inter-Sport Analysis of Symmetry Index in Cross-Country Athletes

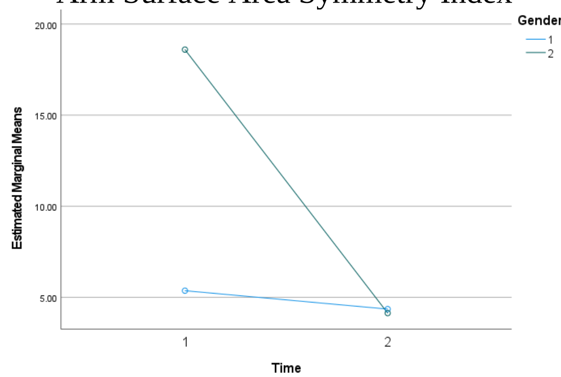


Leg Surface Area Symmetry Index



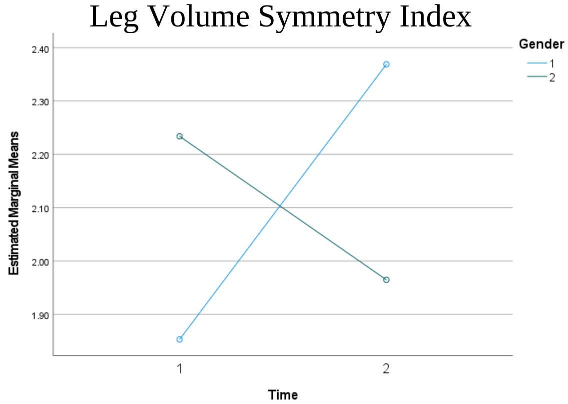
1: Male 2: Female

Arm Surface Area Symmetry Index



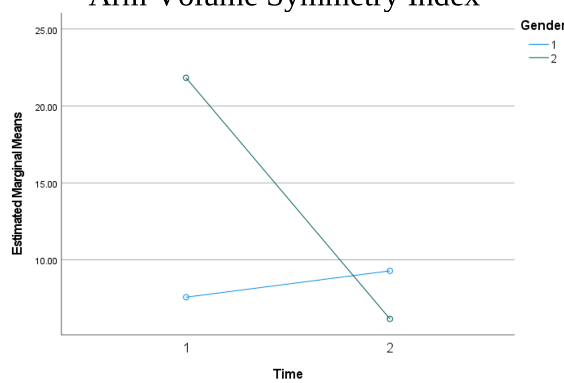
1: Male 2: Female

Leg Volume Symmetry Index



1: Male 2: Female

Arm Volume Symmetry Index



1: Male 2: Female

3.5.3.2 Table 39: Descriptive Statistics from Inter-Sport Analysis of Symmetry Index in Cross-Country Athletes

	Sex	N	Pre-Season			Post-Season		
			Mean	SD	Median	Mean	SD	Median
Arm Lean Mass Symmetry Index	M	12	5.66	4.47	4.86	3.56	1.80	3.63
	F	9	3.13	2.45	2.85	3.73	1.89	3.48
Leg Lean Mass Symmetry Index	M	12	2.19	1.57	1.80	2.92	1.69	3.10
	F	9	2.20	1.14	2.47	2.77	1.33	2.76
Calf Circumference Symmetry Index	M	12	1.76	1.21	1.97	1.65	1.24	1.43
	F	9	1.42	1.40	0.88	1.25	0.66	0.87
Thigh Circumference Symmetry Index	M	12	0.89	0.92	0.55	0.93	0.92	0.67
	F	9	1.57	1.13	0.77	1.75	1.04	2.09
Forearm Circumference Symmetry Index	M	12	3.75	3.95	2.88	3.23	1.88	2.96
	F	9	6.93	9.76	3.05	2.68	2.12	2.33
Bicep Circumference Symmetry Index	M	12	2.38	2.41	1.41	2.60	1.80	2.27
	F	9	2.02	1.53	1.54	1.56	0.87	1.42
Leg SA Symmetry Index	M	12	4.29	0.92	4.31	3.54	1.63	3.57
	F	9	3.66	1.02	3.33	3.51	1.45	3.09
Arm SA Symmetry Index	M	12	5.37	4.58	3.06	4.36	3.38	3.09
	F	9	18.60	45.25	3.76	4.14	2.18	3.72
Leg Vol Symmetry Index	M	12	1.85	1.27	1.42	2.37	1.95	2.21
	F	9	2.23	1.79	2.00	1.96	1.27	2.10
Arm Vol Symmetry Index	M	12	7.58	6.60	6.55	9.29	5.08	9.74
	F	9	21.83	53.30	3.05	6.17	3.29	5.50

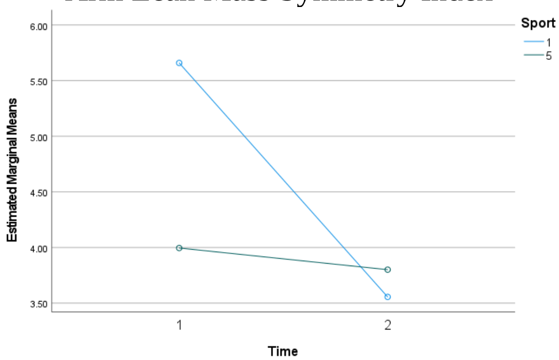
3.5.4 Inter-Sport Differences in Symmetry Index

Within the male athlete sample, there was no significant interactions effect between time and group for all variables. There was also no significant main effect of group for all variables. In terms of the main effect of time, there was one significant effect for the calculated SI from arm lean mass ($p = 0.048$, partial $\eta 2 = 0.072$). When comparing pre-season values (Mean = 4.83, SE = 0.57) to post-season values (Mean = 3.68, SE = 0.44), there is a decrease in SI values over a season, showing that, in terms of arm LM, athletes became more symmetrical over the course of a season. (Figure 4) (Table 40).

In the female athlete sample, transformations were needed to analyze the data. The only variable which did not meet the assumptions for an ANOVA was the SI for calf circumference. The square root was used since the natural log and reciprocal could not be used. The 2-way interaction between time and sport was significant for the SI of forearm circumference ($p < 0.001$, partial $\eta^2 = 0.342$), leg surface area ($p < 0.001$, partial $\eta^2 = 0.407$), and arm surface area ($p < 0.001$, partial $\eta^2 = 0.371$). Simple main effects were assessed for the female athletes in each sport for forearm circumference (Cross-Country: $p = 0.211$, $\eta^2 = 0.213$; Gymnastics: $p = 0.007$, $\eta^2 = 0.497$; Basketball: $p = 0.282$, $\eta^2 = 0.189$; Lacrosse: $p = 0.090$, $\eta^2 = 0.159$), leg surface area (Cross-Country: $p = 0.768$, $\eta^2 = 0.011$; Gymnastics: $p = 0.172$, $\eta^2 = 0.162$; Basketball: $p = 0.001$, $\eta^2 = 0.846$; Lacrosse: $p = 0.045$, $\eta^2 = 0.216$), and arm surface area (Cross-Country: $p = 0.647$, $\eta^2 = 0.032$; Gymnastics: $p < 0.001$, $\eta^2 = 0.696$; Basketball: $p = 0.779$, $\eta^2 = 0.014$; Lacrosse: $p = 0.140$, $\eta^2 = 0.124$). There were no significant main effects of group across all variables. There was a significant main effect of time for the SI of arm volume ($p = 0.033$, partial $\eta^2 = 0.106$). The data from pre-season (Mean = 6.31, SE = 0.93) and from post-season (Mean = 9.04, SE = 1.16) show that the athletes had a higher degree of asymmetry at post-season testing when compared to pre-season (Figure 5) (Table 41).

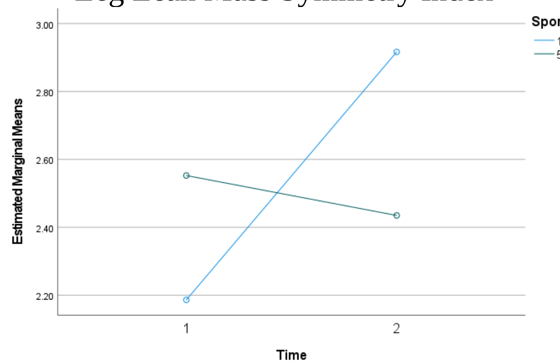
3.5.4.1 Figure 4: Profile Plots for Inter-Sport Analysis of Symmetry Index in Male Athletes

Arm Lean Mass Symmetry Index



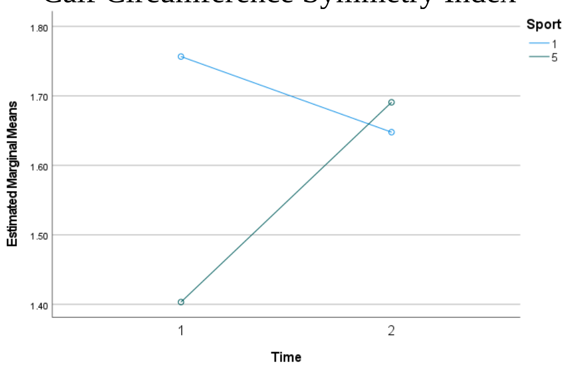
1: Cross-Country 5: Football

Leg Lean Mass Symmetry Index



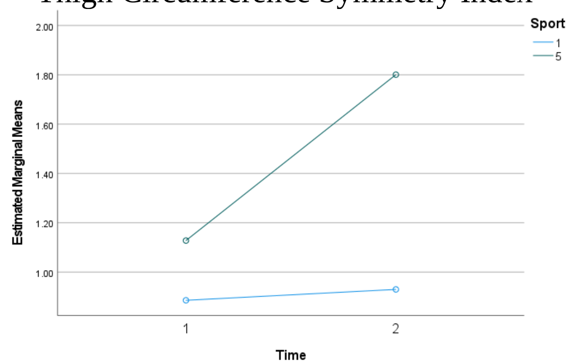
1: Cross-Country 5: Football

Calf Circumference Symmetry Index



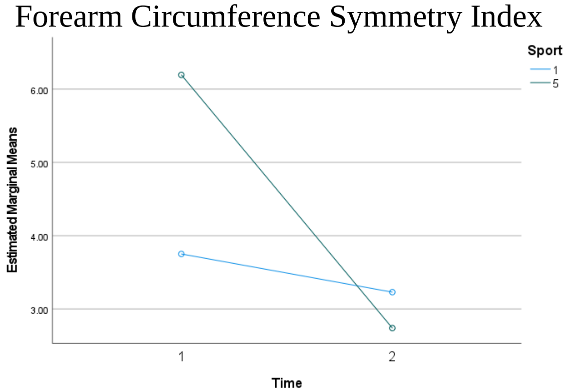
1: Cross-Country 5: Football

Thigh Circumference Symmetry Index



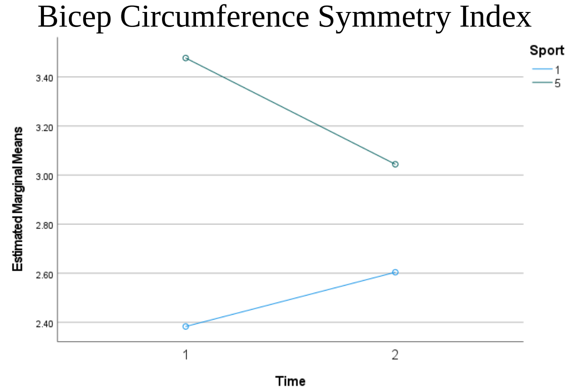
1: Cross-Country 5: Football

Forearm Circumference Symmetry Index



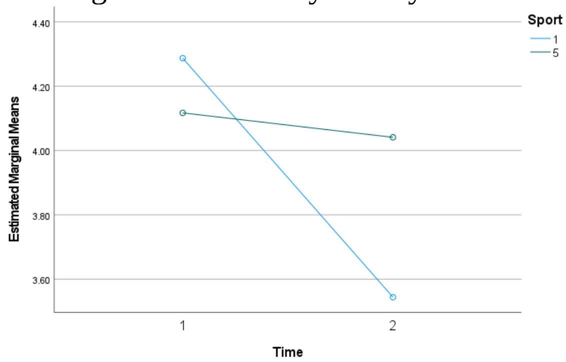
1: Cross-Country 5: Football

Bicep Circumference Symmetry Index



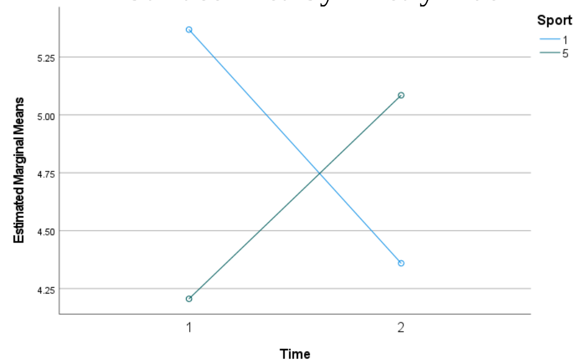
1: Cross-Country 5: Football

Leg Surface Area Symmetry Index



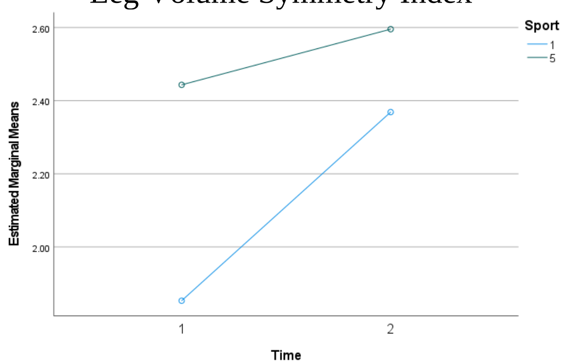
1: Cross-Country 5: Football

Arm Surface Area Symmetry Index



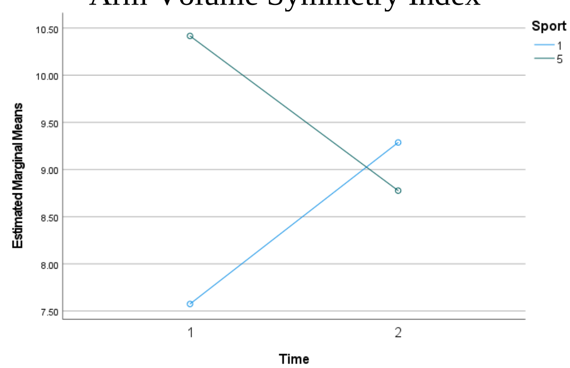
1: Cross-Country 5: Football

Leg Volume Symmetry Index



1: Cross-Country 5: Football

Arm Volume Symmetry Index



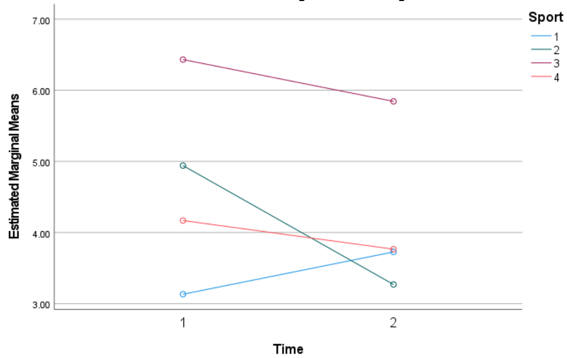
1: Cross-Country 5: Football

3.5.4.2 Table 40: Descriptive Statistics from Inter-Sport Analysis of Symmetry Index in Male Athletes

	Sport	N	Pre-Season			Post-Season		
			Mean	SD	Median	Mean	SD	Median
Arm Lean Mass Symmetry Index	Cross-Country	12	5.66	4.47	4.86	3.56	1.80	3.63
	Football	43	4.00	3.15	3.66	3.80	2.86	2.99
Leg Lean Mass Symmetry Index	Cross-Country	12	2.19	1.57	1.80	2.92	1.69	3.10
	Football	76	2.55	1.82	2.38	2.41	1.74	2.15
Calf Circumference Symmetry Index	Cross-Country	12	1.76	1.21	1.97	1.65	1.24	1.43
	Football	11	1.40	1.24	1.08	1.69	1.09	1.52
Thigh Circumference Symmetry Index	Cross-Country	12	0.89	0.92	0.55	0.93	0.92	0.67
	Football	11	1.13	1.00	0.95	1.80	1.53	1.72
Forearm Circumference Symmetry Index	Cross-Country	12	3.75	3.95	2.88	3.23	1.88	2.96
	Football	11	6.19	6.31	3.95	2.74	1.70	2.51
Bicep Circumference Symmetry Index	Cross-Country	12	2.38	2.41	1.41	2.60	1.80	2.27
	Football	11	3.48	2.53	2.78	3.04	2.50	2.31
Leg Surface Area Symmetry Index	Cross-Country	12	4.29	0.92	4.31	3.54	1.63	3.57
	Football	11	4.12	1.70	4.30	4.04	2.80	3.29
Arm Surface Area Symmetry Index	Cross-Country	12	5.37	4.58	3.06	4.36	3.38	3.09
	Football	11	4.21	2.85	3.47	5.08	2.27	5.73
Leg Volume Symmetry Index	Cross-Country	12	1.85	1.27	1.42	2.37	1.95	2.21
	Football	11	2.44	2.20	1.82	2.60	2.70	1.99
Arm Volume Symmetry Index	Cross-Country	12	7.58	6.60	6.55	9.29	5.08	9.74
	Football	11	10.42	6.12	10.39	8.78	7.87	8.02

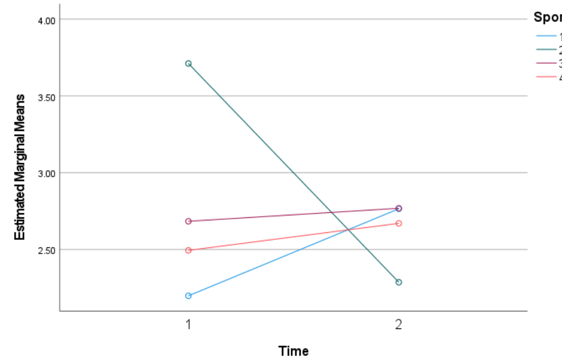
3.5.4.3 Figure 5: Profile Plots for Inter-Sport Analysis of Symmetry Index in Female Athletes

Arm Lean Mass Symmetry Index



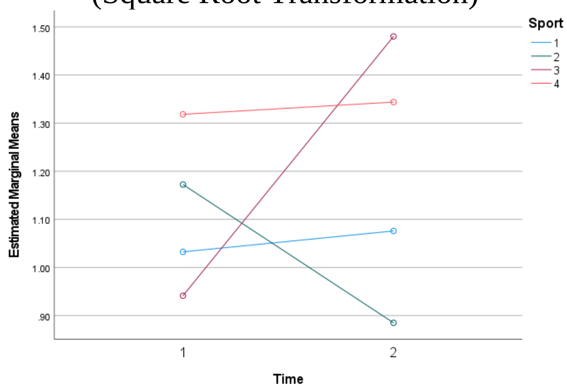
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Leg Lean Mass Symmetry Index



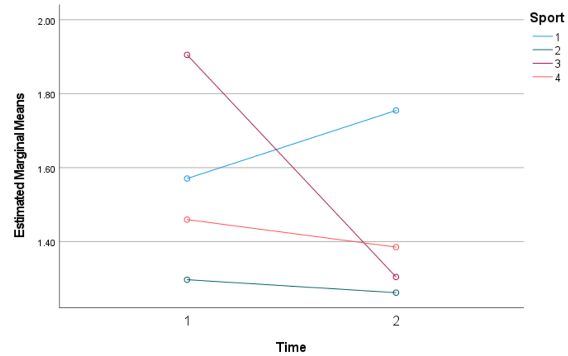
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Calf Circumference Symmetry Index
(Square Root Transformation)



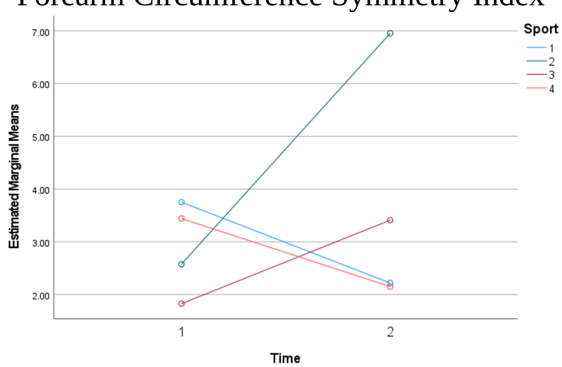
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Thigh Circumference Symmetry Index



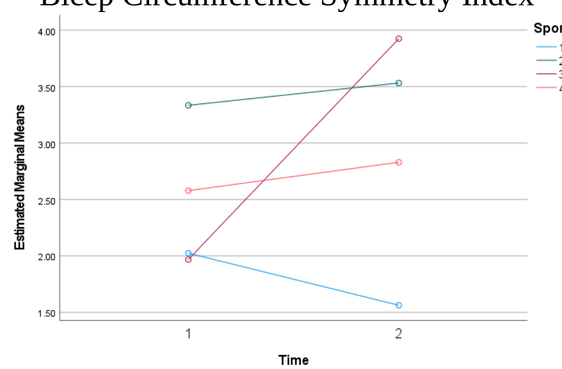
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Forearm Circumference Symmetry Index



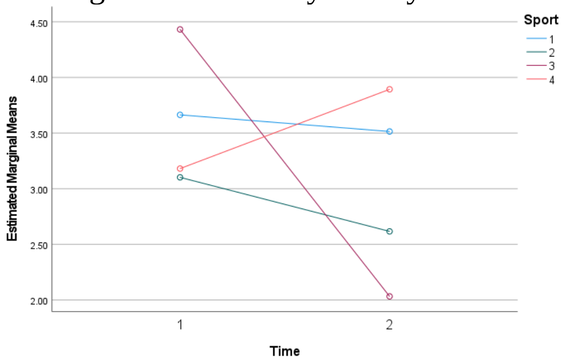
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Bicep Circumference Symmetry Index



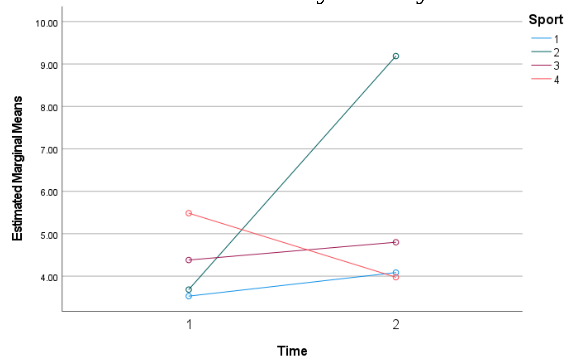
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Leg Surface Area Symmetry Index



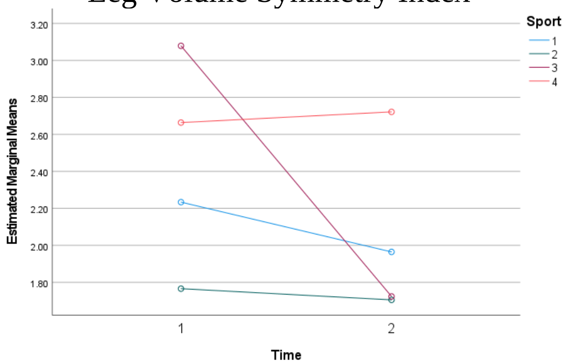
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Arm Surface Area Symmetry Index



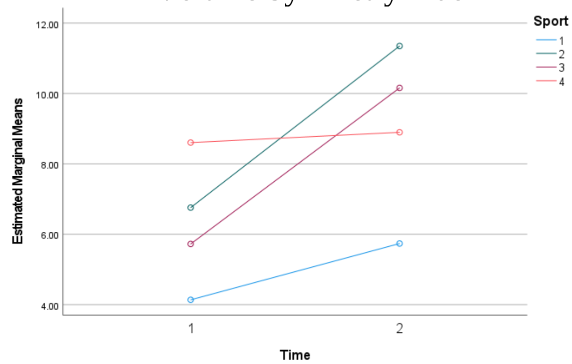
1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Leg Volume Symmetry Index



1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

Arm Volume Symmetry Index



1: Cross-Country 2: Gymnastics
3: Basketball 4: Lacrosse

3.5.4.4 Table 41: Descriptive Statistics from Inter-Sport Analysis of Symmetry Index in Female Athletes

	Sport	N	Pre-Season			Post-Season		
			Mean	SD	Median	Mean	SD	Median
Arm Lean Mass Symmetry Index	Cross-Country	9	3.13	2.45	2.85	3.73	1.89	3.48
	Gymnastics	15	4.94	2.92	5.04	3.27	2.06	2.73
	Basketball	7	6.43	5.27	5.69	5.36	4.46	4.24
	Lacrosse	29	4.17	3.34	2.98	3.77	2.62	3.67
Leg Lean Mass Symmetry Index	Cross-Country	9	2.20	1.14	2.47	2.77	1.33	2.76
	Gymnastics	15	3.71	2.13	3.31	2.29	1.67	2.58
	Basketball	7	2.68	1.40	2.68	2.77	2.60	2.34
	Lacrosse	31	2.49	1.98	1.99	2.67	2.09	2.32
Calf Circumference Symmetry Index	Cross-Country	9	1.42	1.40	0.88	1.25	0.66	0.87
	Gymnastics	12	1.67	1.15	1.65	1.03	0.84	0.79
	Basketball	7	1.11	0.90	0.98	2.49	1.85	1.63
	Lacrosse	18	1.95	1.17	2.01	2.04	1.14	2.16
Thigh Circumference Symmetry Index	Cross-Country	9	1.57	1.13	0.77	1.75	1.04	2.09
	Gymnastics	12	1.30	1.18	1.08	1.26	1.75	0.54
	Basketball	7	1.90	0.97	1.91	1.30	1.00	1.43
	Lacrosse	18	1.46	1.07	1.21	1.39	1.00	1.41
Forearm Circumference Symmetry Index	Cross-Country	8	3.75	2.23	2.70	2.22	1.71	2.14
	Gymnastics	12	2.58	1.64	2.22	6.95	5.11	7.74
	Basketball	7	1.83	2.17	0.81	3.41	2.08	3.99
	Lacrosse	18	3.44	2.45	3.06	2.15	1.75	1.95
Bicep Circumference Symmetry Index	Cross-Country	9	2.02	1.53	1.54	1.56	0.87	1.42
	Gymnastics	12	3.33	2.28	3.32	3.53	2.94	3.05
	Basketball	7	1.97	1.56	1.22	3.92	2.29	2.88
	Lacrosse	18	2.58	2.06	1.67	2.83	2.47	2.92
Leg Surface Area Symmetry Index	Cross-Country	9	3.66	1.02	3.33	3.51	1.45	3.09
	Gymnastics	12	3.10	1.42	3.17	2.62	1.44	2.46
	Basketball	7	4.43	1.72	4.68	2.03	1.34	2.61
	Lacrosse	18	3.18	1.66	2.94	3.89	1.23	3.87
Arm Surface Area Symmetry Index	Cross-Country	8	3.53	2.18	2.98	4.09	2.32	3.32
	Gymnastics	12	3.68	2.86	2.87	9.19	4.23	9.42
	Basketball	7	4.38	3.48	2.91	4.80	3.16	4.44
	Lacrosse	18	5.49	4.82	3.53	3.98	4.57	2.53
Leg Volume Symmetry Index	Cross-Country	9	2.23	1.79	2.00	1.96	1.27	2.10
	Gymnastics	12	1.77	1.36	1.38	1.71	1.76	0.91
	Basketball	7	3.08	1.62	2.96	1.72	1.41	1.54
	Lacrosse	18	2.66	1.88	2.58	2.72	1.80	2.42
Arm Volume Symmetry Index	Cross-Country	8	4.14	5.11	2.90	5.74	3.24	5.03
	Gymnastics	12	6.76	5.52	5.97	11.35	8.64	10.11
	Basketball	7	5.72	3.74	3.85	10.16	6.27	7.61

Sport	N	Pre-Season			Post-Season		
		Mean	SD	Median	Mean	SD	Median
Lacrosse	18	8.61	6.77	6.59	8.90	7.88	6.29

4.0 Discussion

The purpose of this study was to investigate the changes in the sLM and AM of NCAA Division 1 athletes that occur over the course of a season of competition or training. Additionally, this study aimed to investigate the magnitude of asymmetry in these athletes and assess how these asymmetries change over a season. The last purpose of this study was to validate the measurements from the 3DBS with sLM values from the DEXA.

It was hypothesized that the sLM variables and anthropometric variables, from each of the extremities, will change over the course of a season. In addition to this hypothesis, it was hypothesized that the measurements from the 3DBS will correlate with the measures from the DEXA. For example, forearm circumference, bicep circumference, arm surface area, and arm volume will correlate with arm LM, and calf circumference, thigh circumference, leg surface area, and leg volume will correlate with leg LM. These sLM and AM, as well as the degree of asymmetry were hypothesized to all be sport specific. The last hypothesis, that was made a priori, is that bilateral asymmetries will increase over the course of the season and be sport specific.

4.1 Segmental Lean Mass: Changes in Over a Season

SLM was assessed before and after a season of competition, with the exception of the football athletes, who were assessed over a six-month period in the off-season. Overall, for the average of the whole cohort tested, all sLM variables increased over a season of competition. This supports the hypothesis of these sLM variables changing over the course of a season of competition or training.

Male cross-country athletes only saw a significant increase in laLM. The female cross-country athletes had a significate increase in laLM and raLM. Even though there was not any articles found that described changes in sLM over a season, there was a study by Dobrosielski et al.[20] which describes NCAA Division 1 women's athletes sLM measurements. Arm LM was described as being 3.84kg ± 0.43 and leg LM was 12.88kg ± 1.50.[20] Comparisons between studies are hard to make due to the combined mass of both extremities, the time of season when testing occurred not being listed, and the study taking place over multiple years. When comparing the combined means of the population from this study, the female cross-country athletes in our cohort seems to have overall more LM than the cohort used by Dobrosielski et al.[20]. There are too many extraneous variables which are uncontrolled for between the study cohorts to say why our cohorts' athletes had more LM, but it could have been a training intervention administered in the years after the previously mentioned study took place. The rationale behind this speculation is due to the fact that it has been found that in female cross-country athletes, low amount of LM are associated with an increased injury risk.[46,75]

In terms of comparing the male and female cross-country athletes, there was a significant effect of time on right and laLM. For both groups, as the season progressed the LM of both arms increased. The cause of the increase is not known. Due to the nature of the sport, it is unlikely that the increase in LM came from competition, since cross-country athletes are lower extremity athletes and there typically are no loads placed on the arms from participating in the sport. We can postulate that the cross-country team participates in strength training each week during the competitive season, which would explain the increase in arm LM. The cross-country athletes do not report to campus until close to the fall, so they may have had adaptations from training with the Pitt strength and conditioning team compared to any strength training that they did independently, over the summer. There was also a significant effect of sex on all sLM variables assessed. It was seen that at both testing time points, the arm mass in males was about 1kg higher than the females and leg LM was about 3kg higher.

The female gymnast sample of this study saw decreases across all variables over the course of the season, although raLM and llLM were the only variables to show a significant difference. In a study by Dobrosielski et al.[20], their gymnasts had 5.05kg ± 0.70 of arm LM and 14.16kg ± 1.58 of leg LM. The gymnasts in this study had similar values when taking the combined means of laLM and raLM from each point in the season.

The female basketball athletes did not see any significant changes over the season even though raLM, rlLM, and llLM trended downwards, but laLM had a downward trend based off of the mean and an upward trend based off of the median. In the study by Dobrosielski et al.[20], female basketball athletes had 5.45kg ± 0.98 of arm LM and 17.92kg ± 3.07 of leg LM. The athletes in this study's sample tended to have more LM in both the legs and the arms. In terms of changes over a season, Carbuhn et al.[10] did not find a significant difference between pre-season (55.8kg ± 5.8) to post-season (54.2kg ± 5.6). These results, even though they describe whole-body LM, agree with the results of this study. Poliszczuk et al.[71] describes the LM of the left and right upper extremities (Left 3.31kg ± 0.57 Right: 3.25kg ± 0.51) in female basketball athletes. Even though the means are slightly lower than those from this study, the results are very similar. The slight decrease in the values is most likely attributed to the age of their population, 17-19 years old, which are younger than the collegiate athletes tested in this study. Conversely, Fields et al.[25] found that there was an increase in LM from their pre-season testing point to in-season testing, which disagrees with the results found in this study. In-season testing is being used to compare samples with this study since their testing points were five months apart, which is like this study, and the off-season testing point was conducted nine months following pre-season testing. Stanforth et al.[92] had similar findings with there being an increase in whole-body LM over the course of a season, even though it was not a significant change. In terms of changes over the course of a season, the results from this study agree with Carbuhn et al.[10] and Stanforth et al.[92] by which there was no significant change in LM from pre-season and post-season testing periods.

Female lacrosse athletes experienced increases in all sLM variables, although only llLM and rlLM had increases large enough to be significant. The sample of female lacrosse athletes from Dobrosielski et al.[20] had 4.76kg ± 0.63 of arm LM and 15.17kg ± 2.09 of leg LM. These combined values are slightly less than the combined means that were found during this study. Zabriskie et al.[106] tracked changes in body composition across a season and found no significant change from pre-season to post-season, even though the trend was slightly decreasing. These results go against the findings of this study in terms of the direction of change and the degree of change, but this could be due to the fact that whole-body body composition was assessed, and the LM of the extremities was not isolated in the results.

In football athletes, there were increases across all the variables, with llLM, raLM, and laLM all having a significant increase. Trexler et al.[100] saw a significant increase in LM when comparing the measurements from their March testing session to the pre-season testing session. These two testing sessions are compared to this study since it is the closest to matching the time of year when testing was conducted. Even though whole-body LM was assessed, the change in LM, being a significant increase, agrees with this study's findings. Similarly to Trexler et al.[100], and Raymond et al.[74] assessed segmental body composition in NCAA Division 1 football athletes.

They found that from their sample, arm LM was 12.2kg ± 1.6, and leg LM was 31.0 ± 3.8. When compared to this study, the athletes who were part of the study done by Raymond et al.[74] had slightly more LM in both the arms and legs than the participants who were part of this study's sample.

4.2 Anthropometric Measurements: Changes in Over a Season

When assessing changes in AM over the whole study sample, there were significant increases seen in lCC, lFC, rFC, lBC, rBC, rlSA, laSA, llV, rlV, and laV. Increases were also seen in rCC and raSA, but the increases seen in these variables were not significant. Significant decreases were seen in lTC, rTC, and llSA. For these three variables, the means trended upwards while the medians trended downwards. With the significant change, the direction of the change was based on the median values. RaV also saw a decrease over the course of the season, but this change was not big enough to be significant. The mean and median trended the same ways as the three variables that decreased.

In male cross-country athletes, significant changes were only seen in an increase in lTC and rTC. All other variables did not demonstrate a significant change. Of the variables that did not have a significant change, lCC, rCC, rFC, lBC, rBC, llSA, rlSA, raSA, llV, and rlV all showed an upward trend. While lFC, laSA, laV, and raV showed a downward trend. The mean and medians changed in opposite directions for rCC and lFC.

For the female cross-country athletes, significant increases were seen in all variables except lFC, llSA, raSA, laV, and raV. Of these variables that did not show a significant change, all had an increasing trend, with the mean and median trending in opposite directions for raV.

Inter-sex comparisons showed that in all anthropometric variables assessed for, except rTC, lTC, and lBC, the male cross-country athletes displayed greater measurements than the female athletes. Additionally, time was assessed in the analysis, which showed that lCC, rTC, lTC, rFC, rBC, lBC, rlSA, llSA, rlV, and llV all increased over the season in cross-country athletes. The adaptations to the lower extremities can be attributed to the demands on the lower extremities that comes with running high milage. The increases in rFC, rBC, and lBC cannot confidently be attributed to the demands of the support since there is not a weight-bearing demand of the upper extremities. It cannot be said what these adaptations were attributed to, but it is speculated that they could be caused by in-season weight training.

Female gymnasts saw significant increases in lCC, lFC, rFC, lBC, rBC, llSA, and laSA. Non-significant increases were seen in rCC, rlSA, raSA, llV, rlV, and laV. Non-significant decreases were seen in lTC, rTC, and raV, with the first two variables listed showing mean and median changes in opposite directions.

Female basketball athletes had increases in lCC, rCC, lTC, lFC, rFC, lBC, rBC, llSA, rlSA, laSA, and llV. There was an increase, not significant, in rTC, rlV, and raV. Non-significant decreases were seen in raSA, and laV. RaV, laV, and raSA all showed trends in opposite directions in the means and medians from pre-season to post-season.

Female lacrosse athletes saw significant increases were seen in lTC, rTC, rFC, and rlSA. Non-significant increases were seen in lCC, rCC, lBC, rBC, llSA, raSA, llV, rlV, laV, and raV. Decreases, which were not significant, were seen in lFC and laSA. Both lBC and rBC had a decreasing mean while the median increased from pre-season testing to post-season testing.

All the changes seen in the athletes mentioned above took place over a season of competition. For football changes were assessed over a period of training, which was outside of the NCAA season for competition. Significant increases were only seen in laV and raV. While significant decreases were seen in lCC, rCC, rFC, rBC, and rlSA. Non-significant increases were seen in lBC, and laSA. Decreases between testing sessions were seen in lTC, rTC, lFC, llSA, raSA, llV, and rlV. Increasing means while the medians decreased were seen in both lTC and rTC.

These results partially support the hypothesis that was made a priori. With most of the variables showing a significant change across all the athletes when assessed as one group, as well as female cross-country, gymnastics, and basketball athletes, there are some samples that are close to supporting the hypothesis that variables will change over the course of a season. There are also the other samples, such as female lacrosse and male football athletes which do not support the hypothesis.

The results from football were not expected. With the athletes not being in a season of competition, it was thought that there would be increases, more so than the other sports, since there is not a focus on competition when in the off-season. It was thought that since the athletes are out of season, there would be a greater focus on strength training. Although, the AM account for FM and LM, and with FM not being assessed, it could be attributed to the decrease in AM.

In terms of comparing these results to previous literature, there are no other studies, at the time of writing, that assess AM in the populations tested in this study. Also, there are no studies that have used a 3DBS to assess athletes in the same way that this study has. Prior studies that have looked at AM in elite athletes assessed Australian rowers.[85,86] 3DBSs have also been used to assess applicable positions which are sport specific in gymnasts, figure skaters, and ski jumpers.[87]

4.3 Correlations Between Anthropometric Measurements and Segmental Lean Mass

From the variables that were assessed, the correlation between pre-season laLM and pre-season lBC was strong (r = 0.764). All other variables assessed from pre-season and all the variables that were assessed at post-season had very strong correlations (r = 0.810-0.951). The highest correlation was between the raLM and rFC that was assessed at the pre-season testing sessions. These results support the hypothesis that measurements from the 3DBS will correlate with sLM values from DEXA. On the other hand, the weak correlations between changes in sLM and AM, which were only seen in 4 of the anthropometric variables assessed, would refute the hypothesis made a priori.

With the few weak correlations seen in the changes in variables over time, it would be safe to assume that these measurements alone should not be used to predict sLM. Additionally, the only significant correlations are seen in the right extremity, which tends to be the dominant side in most of the population. This could be due to the fact that the dominant extremity tends to be used more and will have less variation in adaptations seen, compared to the non-dominant limb, which could show the effects of training in a more pronounced manner.

In terms of relating circumferential measurements to lean body mass, this is the first study to examine the correlation between these measurements and lean body mass. A previous study by Ng et al.[66] both found strong correlations between sLM and measurements derived from a 3DBS. These results agree with the correlations found in this study, but there are limitations when comparing this study to the previously mentioned study. This study used equations to estimate LM from a 3DBS, as well as an equation to calculate sLM from DEXA scans. It should also be noted that the study by Ng et al.[66] did not use the same 3DBS as the one used in this study. Tinsley et al.[98] used the Size Stream SS20 3DBS but they examined the relationship between whole body

LM and bioimpedance spectroscopy. This study was able to find a concordance correlation coefficient of 0.95 when comparing the estimated total body LM from equations using measurements from the Size Stream SS20 scanner and bioimpedance spectroscopy. The results from both studies seem to agree with the correlations found in this study, but due to the fact equations were used, the results from this study cannot be compared directly with the results from the two previous studies. This is because this study did not use any equations to derive any measurement of sLM from the 3DBS.

A study done by Sager et al.[81] used a variety of measurements from a 3DBS to try and predict LM in young males and they found that the best variables to use for predicting total body LM was right forearm volume, which accounted for the highest fraction of variation from measurements generated by a 3DBS. They also assessed a variety of girth measurements, but none of the measurements were able to demonstrate a high level of accountability in the fraction of variation. This could be potentially due to the fact that they were attempting to predict whole-body LM using these measurements. Nevertheless, they were able to come to the conclusion that skeletal muscle mass was best predicted by limb size, such as length, girth, or volume.[81] From their conclusion, it is safe to postulate that these measurements may serve well in an equation for predicting sLM, but no one has tried to formulate this equation.

With limb volume seeming to be a significant variable when predicting whole-body LM[81], limb volume should also be a strong predictor of sLM. This is further supported by Bourgeois et al.[9] showing that volumetric measurements from 3DBS are reliable when compared to an equation do derive segmental volumetric measurements from a DEXA. In this study, even though they did not have the 3DBS that was used in this study, the three scanners that were used had a r^2 from 0.69 - 0.91 when estimating segmental volume of each limb.[9] In terms of the scanner used in this study, Tinsley et al.[99] found that the Size Stream SS20 tended to overestimate segmental volume, but the measurements are comparable to the calculated segmental volume from a DEXA. With volumetric measurements being generally reliable, and the very strong correlations between segmental volume and sLM, there is potential to use these measurements in a way to calculate segmental volume.

It was previously mentioned in this study that the surface area of the extremities that is generated by the Size Stream SS20 are reliable.[54] But there are no studies that have tried to relate this measurement with LM. With the correlations from this study being very strong ($r = 0.835 – 0.944$) in raw values and weak to no correlation in changes in variables, it would be reasonable to surmise that a formula could be generated from the limb surface area, limb volume, and circumference measurements to accurately estimate sLM from a 3-dimensional body scan. This could lead to a single scan that, highly trained athletes or even military personnel could use to get measurements for uniform fitting, as well as sLM asymmetries which could be used to predict injury risk or optimize performance.[94,101]

4.4 Anthropometric Measurements and Segmental Lean Mass: Sport Specific Analysis

In the male athlete sample of this study, it was seen that football athletes have larger amounts of LM across all sLM variables and larger AM when compared to the cross-country athletes at both testing timepoints.

For the female athlete sample, when comparing across all sports in the one-way ANOVA, all sLM variables were highly significant. When comparing female cross-country athletes to female gymnasts, the gymnasts had significantly more raLM and laLM at the pre-season testing point only. When assessing cross-country athletes against basketball athletes, the basketball athletes had more sLM across all variables at both testing timepoints. Lacrosse athletes had significantly larger sLM across all variables when compared to cross-country athletes at pre-season testing but following their respective seasons of competition lacrosse athletes displayed larger rlLM. Basketball athletes had significantly larger sLM, across all variables, when compared to the female gymnasts, as well as the lacrosse athletes at pre-season and post-season. The last comparison, lacrosse athletes and gymnasts, showed that the lacrosse athletes had significantly more rlLM at post-season testing only.

Dobrosielski et al.[20] compared the LM of NCAA women's athletes and they found that cross-country athletes had less arm LM than basketball, gymnastics, and lacrosse athletes. These results agree with the data collected before the season, in this study, and for post-season, the only agreement seen is between cross-country and basketball athletes. In terms of leg LM, they found that basketball was the only sport to have significantly more LM than cross-country athletes.[20] These results agree with the findings of this study across both testing timepoints, but it does not agree with the higher leg LM in lacrosse athletes which was seen before a season and after a season in rlLM. When comparing gymnasts to lacrosse athletes, they found that there was no difference when comparing both arm and leg LM between gymnasts and lacrosse athletes. They also found that there was not a difference between the arm LM of gymnasts and basketball athletes, but basketball athletes had more leg LM.[20] The no difference seen between gymnasts and lacrosse athletes almost completely agrees with this study, since there was only a significant difference seen in right leg LM at the post-season testing timepoint. When comparing the gymnasts and basketball athletes in this study, basketball athletes had greater LM across all variables at both timepoints. Between this study and the study done by Dobrosielski et al.[20], there is agreement in the comparisons in leg LM but not in arm LM. This study found that lacrosse athletes have less sLM, across all variables assessed for at both time points, when compared to basketball athletes. This agrees with the comparison in leg LM but not arm LM from Dobrosielski et al.[20]. There are some limitations when comparing this study and the previously mentioned study. The first limitation was that the study by Dobrosielski et al.[20] did not assess each extremity separately, and used a combination of the LM from both extremities in their analysis. Also, it is not known when in the season the athletes were assessed.

When looking at differences in AM in female athletes, comparing across all sports in the one-way ANOVA, all anthropometric measurement variables were highly significant. Comparing sports, basketball athletes presented with the greatest AM and the smallest AM were shown in cross-country athletes, except for llV and rlV, where gymnasts were only slightly smaller with no statistical significance. Overall, throughout all variables assessed for at both timepoints, basketball athletes were significantly larger than cross-country athletes. Between basketball athletes and gymnasts, at pre-season and post-season basketball athletes had larger values in all variables besides lFC, lBC, and rBC. Basketball athletes were also significantly larger than lacrosse athletes in all variables assessed at pre-season, and at post-season they were larger in all variables except rCC, lFC, lBC, and rBC. When comparing lacrosse athletes to gymnasts, there was no statistical difference seen in all the preseason measurements, but following the season, the lacrosse athletes had larger lTC, rTC, lFC, and rlV. Between lacrosse and cross-country athletes, lacrosse athletes were larger in all variables assessed pre-season except lCC, rCC, rlSA, and raV. Following a season of competition, lacrosse athletes had a larger lTC and rTC. Between gymnasts and cross-country athletes, gymnasts were larger at preseason in lFC, rFC, lBC, rBC, laSA, and laV, but at post season, they only had large lFC and rFC.

With the hypothesis that anthropometric measurements will be sport specific, it is safe to say that the hypothesis can be rejected with similarities between different teams at numerous variables. It should be noted that the comparisons of these measurements are dependent on the time of season tested so it could be said that the sport does have a significant effect on the presentations of these measurements, but it cannot be said that they are sport specific. With regards to the comparison of these results with previous literature, as mentioned above, there are no studies which assess these AM in these specific athletic populations.

4.5 Bilateral Asymmetry: Changes Over a Season and Sport Specific Analysis

The male athletes in this study's sample saw only one significant difference, which was in post-season thigh circumference. It was found that cross-country athletes had a lower SI when compared to the thigh circumference SI of football athletes. For all other values from pre-season that were not significant, cross-country athletes presented with a greater asymmetry in arm LM and calf circumference when compared to football athletes. At post-season cross-country athletes had a greater asymmetry in leg LM, forearm circumference, and arm volume when compared to their football counterparts.

In female athletes, no statistical difference was seen between sports in asymmetry variables assessed from pre-season testing. At post-season testing, gymnasts had the largest forearm circumference asymmetry as well as arm surface area asymmetry and were significantly larger than cross-country and lacrosse athletes. Gymnasts showed the smallest calf circumference asymmetry, and it was significantly smaller than the asymmetry in basketball athletes. Basketball athletes also had the smallest leg surface area asymmetry, and it was significantly smaller than the asymmetry seen in lacrosse athletes.

Generally, across all variables, gymnasts seemed to present with the lowest amount of asymmetry, followed by lacrosse athletes, then cross-country, and then the most asymmetrical athletes were the basketball athletes. For cross-country and lacrosse athletes, the data seems to show that there is a general decrease in asymmetry while gymnasts and basketball asymmetry increases. It should be noted that this is based off comparing the means between the teams and no statistical tests.

Across the male athletes, there was a significant decrease in arm LM asymmetry from pre-season to post-season. The explanation for this is not easily found. The analysis was done using the whole male sample in a 2-way ANOVA. With the male sample consisting of cross-country and football athletes, there are two unrelated sports being compared. Also, the football athletes were tested around a season of training and the sample size was much larger when compared to cross country (Football: N = 43; Cross-Country: N = 12). Therefore, the cause of the decrease could be due to the football athletes skewing the data, but from the descriptive statistics, a decrease is seen in the subjects from both sports.

In the female athletes, gymnasts had the greatest increase in forearm circumference SI followed by basketball athletes. Cross-country and lacrosse both became more symmetrical in forearm circumference over the season. In terms of asymmetry in leg surface area, basketball athletes were the most asymmetrical going into the season, but following the season they were the most symmetrical in the variable. The lacrosse athletes became more asymmetrical over the season, finishing with the highest degree of asymmetry. Both cross-country and gymnastics became slightly more symmetrical over the course of the season. Moving to the upper extremity by looking at the SI of arm surface area, gymnasts were the second most symmetrical before the season, but they finished the season as the most asymmetrical by a large margin. Lacrosse athletes were the only team to see decreases in asymmetry while the other two sports saw slight increases. For the significant main effect of time, which was seen in arm volume, asymmetry increased across all teams. Lacrosse showed the smallest increase, while gymnasts and basketball athletes showed the largest increase in asymmetry, with gymnasts having the largest degree of asymmetry following the season. The increase of upper extremity asymmetry in gymnasts could be attributed to the athletes favoring a side as they perform in events. This result does align with this studies finding gymnasts having a high degree of forearm circumference and arm surface area asymmetry. Although it should be noted that this does not agree with the degree of asymmetry seen in the arm LM of gymnasts, being the second most symmetrical.

In terms of the inter-sport analysis of the symmetry index values from cross-country athletes, the lack of results shows that the asymmetry that presents does not significantly change over time nor is there a difference in the change experienced between sex. Even though there were changes in symmetry index values, in similar and different directions depending on the variables assessed, the lack of statistical significance restricts the conclusions which are able to be made, such as the conclusion which sex has no effect on asymmetry presented in athletes which participate.

Looking at the overall cohort, with the lack of differences in asymmetry before the season and significant differences emerging after the season, it can be assumed that the asymmetries emerged due to the sport-specific tasks that are demanded of the athlete while participating in their respective sports, but it should be noted that in season training data was not available at the time of analysis. These results agree with the hypothesis made that asymmetries would present in a sport specific manner and increase over the course of a season. Even though, when the hypothesis was made, the prediction that the asymmetries would show after a season was not hypothesized, but it was thought that the asymmetries would present at pre-testing and exacerbate over the course of the season. In terms of relating this data to previous literature, there is no previous literature to compare this data to.

4.6 Limitations

Within this study, there were a few limitations. The first, and most influential on the results, is the low number of subjects for certain sports and measurements. Even though the total number of valid measurements from the subjects was appropriate for an analysis of all athletes, with there being 69 subjects with pre-season and post-season 3-dimensional body scans and from 120-153 athletes with valid pre-season and post-season DEXA scans, the number of subjects per each sport was lack luster. The discrepancy in the sample size of DEXA scans was due to either the athletes not fitting in the scan region, or the subject was not in proper position, leading to parts of the extremities being outside the designated zones and the LM of the extremity being estimated. In terms of the specific sport sample sizes, female lacrosse and male football athletes were the only two samples which had more than 28 subjects. All the other sports had 15 or less subjects. For the 3-dimensional body scans, no sample size exceeded 20 subjects. The small sample sizes limited the power of the statistical tests.

Another limitation was the season in which the football athletes were tested around. Since the athletes from the football team were not tested around their season of competition, comparisons with the other sports are hard to make. Additionally, training data was not available. This leaves gaps in the type of training the athletes undertook during the season where they were assessed. This data could explain some of the adaptations seen in the athletes that were not expected regarding the sport which the subject participated in. Another limitation was the lack of injury data available. Access to this data was only given for the female basketball athletes. This was not included in the analysis due to the difficulty of discerning the data. Additionally training data was not included in this study. This data could have also led to a more robust discussion with connections between asymmetries seen and the injuries experienced, as well as the adaptations seen and the training load of the athletes. These injuries could have also been the cause of outliers in the data, but without the data this assumption cannot be connected. The last limitation is the fact that FM was not assessed in the scope of this study. This could have explained the high correlations in the raw values in sLM and AM, but the weak or non-significant correlations between the changes in variables.

4.7 Directions for Future Research

More research is needed in segmental body composition, AM, and asymmetries between limbs. There are few descriptive studies with the general presentation of segmental body composition values, nor are there many with asymmetries of sLM in the populations assessed. Additionally, building on this gap, there is little to no previous literature, depending on which variables, that describes how these variables would change over the course of the season. More research is needed into the general presentation of asymmetries of elite athletes. This study shows the general presentation of asymmetries, there is validation needed to be able to conclusively describe the general presentation of asymmetries.

There is a lack of general anthropometric presentations due to the fact that 3DBS are relatively novel, and more research is needed to find the potential uses of this technology. With more research in the field of 3-dimensional anthropometric assessments, there is potential for equations to be made which will closely estimate sLM. Additionally, there is potential for 3DBSs to be used for injury risk assessment, but the variables that could predict injury are not generally accepted, nor has there been a correlation established between any anthropometric measurement and injury. With the potential use for estimating segmental body composition and predicting injury risk, the widespread use of 3-dimensional body scanning could be emerging for sports medicine assessments while measuring the athletes, or even war fighters for uniform fittings.

4.8 Conclusion

The purpose of this study was to investigate sLM, AM, and the magnitude of bilateral asymmetry of each variable in division one athletes. Normative data was found and described for all sports assessed and compared between sports. Additionally, this study set out to establish the correlations between the anthropometric variables assessed and sLM. Strong to very strong correlations were found when comparing all AM to the LM of the limb that the measurements were derived from, while few, weak correlations were found when using the change in variables. Although these were found, a future study with stronger sample sizes is needed to validate the results found. Also, more research is still needed to implement the 3DBS into widespread use. More research into 3DBS could lead to the development of an injury screen, that could be used during a pre-participation uniform fitting. This injury screen could be used to identify individuals from an athletic or military population, that may need additional training interventions, from a quick scan.

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