Longitudinal Assessment of NCAA Division I Football Body Composition by Season and Player Age

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Dedication

To my parents. Mom, at a young age you unknowingly motivated me to strive for an education beyond a Bachelor's degree. It is surreal to be at the point of achieving my Master's degree all of these years later. Thank you for being a positive influence in my life and shaping me into the person I am today. Dad, thank you for always pushing me to be the best version of myself and for fueling my passion of health and wellness. Further, your hard work, leadership, and determination is inspiring. Thank you both for your unconditional love and support and always encouraging me to achieve my dreams. My appreciation and admiration for the two of you is beyond words.

Abstract

PURPOSE: Longitudinal assessment of football player body composition would identify developmental and structural changes in respect to position demands, however no study has examined changes by season and age. The purpose of this study was to examine longitudinal body composition changes by position, categorized by season and age, using dual X-ray absorptiometry (DXA) in NCAA Division I football players. **METHODS:** Seven hundred and forty-two collegiate male football athletes aged 17-24 years ($\bar{X}_{age}$= 19.9±1.3 yrs) participated in this study. Following height and body mass measurement, each athlete completed a DXA scan to assess percent body fat (%BF), fat mass (FM), lean soft tissue mass (LM), bone mineral density (BMD), and visceral adipose tissue mass (VAT) using a GE Lunar iDXA (General Electric Medical Systems, Madison, Wisconsin, USA). DXA scans were analyzed by the same technician using enCore™ software (platform version 16.2, General Electric Medical Systems, Madison, WI, USA), and body mass distribution ratios of total upper mass to lean leg mass ratio (TULLR), lean upper mass to lean leg mass ratio (LULLR), upper total mass to legs total mass ratio (ULR), and gynoid lean mass to leg lean mass ratio (GLR) were calculated. Athletes were categorized into Linemen (offensive and defensive linemen), Big Skill (quarterbacks, linebackers, and tight ends), Skill (running backs, defensive backs, and wide receivers), or Special Teams (punters, kickers, and long snappers). One scan per athlete was used in Pre-Season (June-September), In-Season (October-November), Post-Season (December-February), and Spring Season (March-May). Separate repeated one-way analysis of variance (ANOVA) with linear mixed-effects models assessed total and regional body composition differences across age, position groups, and seasons. TukeyHSD post hoc tests were used to determine significant differences among position groups, while adjusting for multiple comparisons ($p<0.05$). Prediction equations for %BF, LM, FM, and VAT mass were computed using linear mixed-effects models. **RESULTS:** Linemen had the greatest %BF, FM, VAT, LM, and BMD ($p<0.05$) compared to other groups for each season and age. From Pre-Season to Post-Season, %BF, FM, LM, ULR, and GLR decreased for each position group ($p<0.05$). From Post-Season to Spring Season, %BF and VAT decreased while LM, LULLR, and GLR increased within each position group ($p<0.05$). %BF, FM, VAT, LM, TULLR, LULLR, and GLR increased, while ULR decreased, with player age in all position groups ($p<0.05$). Prediction equations and graphs for %BF, LM, FM, and VAT were computed. Each position group experienced small to moderate increases as age progressed. **CONCLUSION:** The results of this study indicate that body composition significantly worsened from Pre-Season to Post-Season and improved from the Pre-Season and Post-Season to the Spring Season. In addition, players increased %BF, FM, VAT, and LM as they progressed through their college career. These findings allow coaches to understand how body composition fluctuates by season and age given player position group. Future studies are needed to determine how player year of eligibility, nutrition, and position-specific workouts influence body composition by season and age.

Key Words: Dual X-ray Absorptiometry, Body Composition, Prediction Equation

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List of Abbreviations

ADP: Air displacement plethysmography

BIA: Bioelectrical Impedance Analysis

%BF: Percent body fat

BMC: Bone mineral content

BMD: Bone mineral density

BMI: Body mass index

C-CAR: Consortium of College Athlete Research

DXA: Dual X-ray absorptiometry

FM: Fat mass

GLR: Gynoid lean mass to leg lean mass ratio

LM: Lean soft tissue mass

LULLR: Lean upper mass to lean leg mass ratio

NCAA: National Collegiate Athletic Association

SF: Skinfold

TBW: Total body water

TULLR: Total upper mass to lean leg mass ratio

ULR: Upper total mass to legs total mass ratio

VAT: Visceral adipose tissue

CHAPTER 1: INTRODUCTION

American football is a dominant sport within the National Collegiate Athletic Association (NCAA) at the Division I level (Lockie et al., 2016). Research has shown that body composition, a known contributor to successful athletic performance, is related to speed, strength, and cardiovascular endurance within collegiate and professional football players (Melvin et.al, 2014; Pincivero and Bompa, 1997). There is a common perception that football players must be "big" to have success on the field, especially for positions like offensive and defensive linemen. However, the "ideal" size of players varies by player position and positional requirements (Skinner et al., 2013). Therefore, it is advantageous to measure and monitor percent body fat (%BF), lean soft tissue mass (LM), fat mass (FM), visceral adipose tissue (VAT), and bone mineral density (BMD) to identify body composition differences and changes by position. This would further allow coaches and players alike to understand and assess sport performance and individual health and wellness (Ackland, 2012).

Several methods have been utilized to measure body composition within football players, including but not limited to, bioelectrical impedance analysis (BIA), skinfolds (SF), air displacement plethysmography (ADP), and dual X-ray absorptiometry (DXA). BIA, SF, and ADP are two-component models that distinguish between fat-free mass (ie., LM, BMD, and water) and FM (Toombs et al., 2011; Malina, 2007). Although two-component methods of body composition measurements are typically less expensive and portable compared to other body composition methods, they mainly rely on prediction equations and therefore may not be the most accurate models for measurement (Malina, 2007). The DXA is a three-component model that can distinguish between FM, LM, and

BMD (Toombs et al., 2011; Malina, 2007). However, there is a small amount of radiation and accommodating large persons can be difficult, but the reproducibility and accuracy of the machine is acceptable for regional and whole-body body composition assessments (Lee and Gallagher, 2008). Due to a focus on maximizing football player conditioning and fitness for optimal performance, the utilization of the DXA can pinpoint areas of improvement within body composition. With those results, coaches and practitioners can then alter training accordingly to further optimize performance (Anzell et al., 2013). Therefore, it would be advantageous to understand positional body composition differences in order for those athletes to properly train for their position and perform at their highest level.

Previous studies have demonstrated that offensive and defensive positions of comparable positional demands mirror each other, meaning that their body composition is similar (Kraemer et al., 2005; Dengel et al., 2014; Bosch et al., 2017). Wide receivers, running backs, and defensive backs are typically categorized together as a Skill position group; linebackers, tight ends, quarterbacks, kickers, and long snappers are typically categorized together as a Big Skill position group; and offensive and defensive linemen are typically categorized together as the Linemen position group (Lockie et al., 2016; Sierer et al., 2008; Stodden and Galitski, 2010; Vitale et al., 2016). Research has shown that Skill players typically have lower %BF and total body mass to total LM ratios than other positions, given the need for these players to be able to have the core attributes of speed, agility, and maneuverability be successful on the field (Dengel et al., 2014; Pincivero and Bompa, 1997; Wilmore and Haskell, 1972). Big Skill players are considered to be transitional players given they typically have speed, size and strength intermediate of Skill and Linemen position groups (Berg, Latin, and Beachle, 1990; Pincivero and Bompa, 1997). As a reflection of this diverse position group, Big Skill players have been found to have FM similar to Linemen players and LM similar to Skill players (Pincivero and Bompa, 1997; Wilmore and Haskell, 1972). Finally, Linemen are required to repeatedly hit, tackle, and block their opponent with large force at high speeds (Pincivero and Bompa, 1997; Wilmore and Haskell, 1972). Overall, Linemen generally have the highest %BF and VAT of all positions, with defensive linemen having lower %BF and higher LM than offensive linemen to allow for quicker movements on the field (Bosch et al., 2014; Wilmore and Haskell, 1972). While important for coaches and players to understand how body composition serves as a major role in supporting the demands of their respective positions, only understanding general positional differences is problematic. There is no information about how players are growing and developing within their positions during their collegiate years. Understanding the growth and development about college football players is especially crucial given they are considered high profile and impressionable athletes that are still developing (Jonnalagadda, Rosenbloom, and Skinner, 2001).

Longitudinal assessment of body composition would allow coaches to identify developmental changes over time with the goal of enhancing player performance (Coyler et al., 2016). Seasonal and yearly changes by position and/or year of eligibility have been examined by previous studies. However, the sample sizes of these studies are small leading to potential inaccuracies, and changes in body composition by age within and among position groups has yet to be examined.

Therefore, the primary objective of this study was to retrospectively examine longitudinal body composition using DXA in NCAA Division I football players. The longitudinal assessment of body composition in football players would allow for coaches to understand the physiological changes their athletes likely experience to then set realistic body composition expectations for these athletes. Furthermore, the development of prediction equations would provide realistic career goals for incoming and current players at the college level, reduce the need for consistent DXA scans to monitor body composition changes given injury or throughout the course of a season, and allow universities without access to traditional body composition methods predict their player's body composition in real time.

The specific aims of this study are:

(1) Determine if body composition significantly changes with playing season, within and among position groups;

(2) Determine if body composition significantly changes with player age, within and among position groups;

(3) Demonstrate equations that can predict body composition by player position.

The following chapters of this thesis include a literature review, methodological explanation, results summary, discussion, and conclusion.

Chapter two details a comprehensive literature review related to the importance of body composition assessment of football players, methods of measuring total and regional body composition, the assessment of positional differences among football players, and longitudinal assessment of body composition of football players.

Chapter three includes information on the study's methodology including information on the study population, scan procedures, variables of interest, and statistical analyses.

Chapter four summarizes the results of the study. Longitudinal analysis of season by position group, position group by season, age by position group, and position group by age, as well as the prediction equations for %BF, LM, FM, and VAT, are included.

Chapter five includes a discussion of study results. The results of the current study are reviewed, along with a comparison of how the findings from this study vary in consistency with what has been reported previously. Further, the importance of longitudinal body composition studies for football players and further health implications are presented. Finally, limitations of the research and recommendations for future studies are reviewed.

Chapter six provides final conclusions. A summary of major findings is included, followed by specific recommendations for improvements in future studies.

CHAPTER 2: LITERATURE REVIEW

Importance of Body Composition Assessment of American Football Players

American football is one of the most popular sports in North America and is growing in popularity around the world. This sport requires a large physical demand, and therefore body size and maximal strength are traditionally considered the most important factors when recruiting football players (Pincivero and Bompa, 1997). However, speed, strength, and cardiovascular endurance has been shown to be related to body composition within collegiate and professional football players (Melvin et al., 2014; Pincivero and Bompa, 1997). Therefore, body composition is a contributor to successful football performance and is an important assessment for understanding individual health and wellness, as well as an indicator of sport performance (Ackland, 2012). Football players are stereotypically expected to be “big,” and therefore these expectations have caused the issue of players adding mass and being considered obese, especially in positions where a larger frame is seen to be advantageous (Skinner et al., 2013). The addition of mass is rarely quantified by the type of mass (lean and/or fat) or where these changes in mass are occurring within the players. Previous research has identified that offensive and defensive linemen accumulate fat mass within the abdominal region (Bosch et al., 2014; Buell et al., 2008). Increased abdominal fat mass increases the risk of metabolic syndrome, which can lead to complications such as diabetes and coronary heart disease (Buell et al., 2008). Therefore, the quantification of body composition changes in football players over time and by position would be advantageous for coaches and professionals working with athletes to gain awareness regarding the impact of their program and make appropriate adjustments to improve body composition.

Methods and Application of Assessing Total and Regional Body Composition

Various methods have been developed to assess body composition in athletes for the purposes of tracking performance, monitoring the progress of injury rehabilitation, and identifying health concerns. The methods commonly utilized to assess body composition in athletes include BIA, SF, ADP, and DXA (Bilsborough et al, 2014). These methods can be further categorized into two-component and three-component models. Both two-component and three-component models have been used to measure body composition within football players, many with the goal of understanding the connection between player performance and their physical characteristics, as well as address any changes that may occur from playing football (Bosch et al., 2014; Dengel et al., 2014; Lockie et al., 2016; Bosch et al., 2017). While each model has their strengths and weaknesses, both have been widely used to measure body composition within the football player population.

Two-component models can distinguish between fat-free mass (ie., LM, bone mass, and water) and FM, whereas three-component models can distinguish between FM, LM, and bone mass (Toombs et al., 2011; Malina, 2007). Even though two-component methods have been validated and are commonly used given they are generally inexpensive and portable, the accuracy of body composition measurements increases with additional components. Therefore, the three-component model DXA has been determined a favorable method of measurement and has been utilized to determine body composition differences among collegiate and professional football players (Binkley et al., 2015; Bosch et al., 2014;

Bosch et al., 2017; Dengel et al., 2014; Melvin et al., 2014; Trexler et al., 2017; Turnagöl, 2016).

Total and Regional Body Composition Differences Among Player Positions

A common perception by the public is that football players are becoming larger as the years progress, however this may not be true for all player positions (Kraemer et al., 2005). As validated by several studies, body fat is largely related to player position, given the diverse demands each position requires (Kraemer et al., 2005; Bosch et al., 2014; Dengel et al., 2014; Bosch et al., 2017). Many player positions are similar in physical requirements and therefore are typically divided into three main position groups. Typically, wide receivers, running backs, and defensive backs are categorized together as a Skill position group; linebackers, tight ends, quarterbacks, kickers, and long snappers are categorized together as a Big Skill position group; offensive and defensive linemen are categorized together as the Linemen position group (Lockie et al., 2016; Sierer et al., 2008; Stodden & Galitski, 2010; Vitale et al., 2016). Traditionally, Skill players are smallest in size and lowest in strength and %BF, which may be attributed to the need for agility, maneuverability, and ability to reach high speeds on the field (Pincivero & Bompa, 1997; Wilmore & Haskell, 1972). The Big Skill group contains positions that are considered transitional between Skill and Linemen players (Pincivero & Bompa, 1997). Therefore, these players contain strength, speed, and size intermediate of Skill and Linemen players, with LM similar to Skill players and FM similar to Linemen players (Berg, Latin, & Beachle, 1990; Pincivero & Bompa, 1997; Wilmore & Haskell, 1972). Linemen are largely dependent on power, as they are required to repeatedly hit, tackle, and block their opponent with large force at high speeds (Pincivero and Bompa, 1997; Wilmore and Haskell, 1972). Understanding the requirements of each position group is imperative in understanding how body composition plays a role in these positions, and therefore coaches can adapt training programs to best improve their players in their respective positions.

Several studies have examined differences in total and regional body composition differences by player position. Dengel et al. (2014) examined body composition differences among National Football League players and prospects before summer training camp. The researchers found that offensive and defensive positions mirrored each other and specific body composition results reflected the needs of their respective positions, such as %BF, LM, and ULR. Defensive backs and wide receivers had lower total body mass to LM ratios lower than other positions, which is potentially due to the speed and agility are core attributes necessary for these positions. Further, tight ends, a transitional position that both runs routes and blocks, had greater LM, similar %BF, similar regional lower body LM, and a higher amount of upper body LM when compared to running backs and linebackers. Finally, offensive and defensive linemen were observed to be similar in LM, bone mass, and ULR, however the defensive linemen had a lower %BF than the offensive linemen. Bosch et al. (2017) used DXA results from 467 NCAA Division I football players to create normative total and regional body composition data as well as examine positional total and regional differences. In that study, offensive linemen had significantly higher VAT than other positions, except for defensive linemen and running backs. When looking at body composition and body mass ratio differences between mirroring positions, no significant differences were observed except between offensive and defensive linemen for fat measures (%BF, FM, trunk FM, legs FM), ULR, and TULLR, which is similar to the findings of Dengel et al. (2014). While the results of these studies identify body composition positional make-up differences, these studies do not investigate how body composition changes over the year.

Binkley et al. (2015) examined body composition changes of 53 football players through an NCAA Division I competitive season and the off-season and found that the trunk, arms, and legs lost LM, while FM was gained in the legs of all players after the competitive season. Further, the spring season testing session resulted in LM gains in the legs for all players, however only the non-line players (all players that do not play on the line) and underclassmen had significant LM gains in the arms. The arms and legs of all players experienced a loss in FM; however, the loss in trunk FM was only significant in the underclassmen. Given that Linemen are largely dependent on power to block and hit, Skill players must be agile and quick to maneuver around opposing players, and Big Skill players have a skill combination of Linemen and Skill players, the differing requirements of these position groups are largely reflected by the body composition results of these studies. However, only understanding general positional differences is problematic, as it does not provide information about how players are growing and developing within their positions during their college career. Therefore, it is important to analyze longitudinal changes among positions groups and players so composition trends can be recognized, and coaches can better train their athletes to achieve success on and off the field.

Longitudinal Assessment of Body Composition

Monitoring athletes over time can allow coaches to identify body composition changes with the end goal to enhance performance (Coyler et al., 2016). Coaches often incorporate position-specific training regimens into practice, and therefore it is important for athletes to obtain the appropriate body composition for their position to be successful on the field (Anzell et al., 2013; Sierer et al., 2008). A variety of longitudinal studies have been conducted with football players by observing the effects of strength and conditioning programs, as well as morphological and performance profiles. Jacobson et al. (2013) conducted a study looking at the impact of strength and conditioning on anthropometric and physical characteristics over the college career of 92 Linemen and 64 Skill players (defensive backs and wide receivers), analyzing data from 2005-2011. The researchers found that after the first year Linemen became significantly leaner and Skill players increased their body mass, while maintaining LM, particularly between year one and year two. This could be in part that many of these first-year players might be freshmen or "redshirt" freshmen that did not see the field as frequently or play at all, thus having more time to train in the weight room (Stodden and Galitski, 2010). Stodden and Galitski (2010) assessed changes in anthropometric (%BF, LM, body mass) and performance measures (40-yd dash, proagiligy, bench press, chin-ups, vertical jump, and power index) of 84 football players over four years of strength and conditioning training by position group (Skill, n=29; Big Skill, n=25; Linemen, n=30). Results showed that each group significantly improved almost all anthropometric and performance measures after one year of training. Not many changes were observed after the first year of the strength and conditioning program except that Linemen increased their body mass, which was due to increases in LM and %BF. The cause of the increase in %BF was unknown but speculated to be the results of poor dietary choices in order to gain increases in body mass (Stodden & Galitski, 2010). With common perceptions that offensive and defensive linemen must be "big" to have success on the field (Skinner et al., 2013), there can be rapid, unhealthy increases in FM rather than LM. Increases in FM, especially in the abdominal region, can cause an increased risk for complications such as high blood pressure, insulin resistance, and impaired glucose metabolism, which can potentially lead to coronary heart disease and diabetes (Buell et al., 2008). This again demonstrates the importance for tracking body composition over time in addition to positional differences.

Anzell et al. (2013) conducted a meta-analysis to look at collegiate and professional football body composition changes, derived from previously published journal articles, from 1942 to 2011. The researchers found that that increases in body weight were significant for both college players and professional players from 1942 to 2011. The researchers also found that %BF significantly increased for college players from 1959 to 2011, specifically for the combination of all of the positions as well as for mixed linemen including offensive and defensive linemen, tight ends, and linebackers. The increases and improvements observed from 1942 to 2011 could be due to increases in education surrounding strength and conditioning, improvements in nutrition, use of ergogenic aids, and positional rule changes that altered how specific positions played the game. Overall, this study has supported the speculation that collegiate and professional football players have increased in size. However, the results from Anzell et al. (2013) should be interpreted with caution given the large timespan and results observed from more current and better relatable studies to date.

Several studies have been conducted to examine body composition changes over seasons. Bolonchuk and Lukaski (1987) determined %BF significantly decreased from preseason to postseason whereas density and lean body weight significantly increased. In a more recent study, Binkley et al. (2015) investigated body composition changes over the course of a competitive NCAA Division I football season and off-season by position and year of eligibility. Post-season, LM and body mass decreased, absolute FM displayed no changes, but %BF increased. Specifically, underclassmen and linemen lost less weight than upperclassmen and non-line players. The different results for %BF and LM observed between Binkley et al. (2015) and Bolonchuk and Lukaski (1987) are most likely due to differences in body composition measurement tool, respectively Binkley et al. (2015) measuring with DXA and Bolonchuk and Lukaski (1987) measuring with SF. The team overall increased LM and decreased absolute FM and %BF over the spring season. Specifically, underclassmen in line positions and non-line positions experienced an increase in LM. Further, all players decreased their %BF and absolute FM except for non-line players. A study conducted by Trexler et al. (2017) used DXA to measure body composition of 57 NCAA Division I football players over a single year, and 13 NCAA Division I football players over a four-year career in each season. The researchers found that LM increased from the end of the off-season in late May to mid-July, as well as from mid-July to the following March. Incremental increases in bone mineral content (BMC) and BMD were also observed, with off-season values significantly lower than the following

March, over time. There were no significant changes in weight, but %BF, FM, and gynoid mass, which overlaps the trunk and leg regions and includes the hips and upper thighs (Stults-Kolehmainen et al., 2013), increased from the off-season to the end of the off-season in late May, however each decreased at mid-July and the following March measurements. When looking at composition changes across a career, weight was found to significantly increase from years 1-2 and 2-3, but not from 3-4. LM, BMC, and BMD significantly increased, with higher increases seen in linemen versus non-line for LM and higher increases seen in non-line versus linemen for BMC and BMD. This study concludes that favorable changes in body composition such as increases in LM, BMD, and BMC, with no drastic increases in FM, may be expected over the course of one year as well as across career. The collective results from these studies distinguish trends within the literature and give an understanding to coaches as to what they may expect from their athletes, especially from preseason to postseason. However, each of these studies have small sample sizes, ranging from 13-79 participants, and different season definitions making it difficult to create direct comparisons among the results.

To date, no study has retrospectively examined longitudinal, positional football body composition data by season and age. Further, no studies have provided prediction equations to predict %BF, LM, FM, and VAT by position given age, height, and weight. Previous studies have looked at seasonal and yearly change, both by position and/or year of eligibility, however, the sample sizes are small leading to potential inaccuracies. Binkley et al. (2015) analyzed 53 players from preseason to postseason and postseason to spring season, Trexler et al. (2017) analyzed 57 players over one year and 13 athletes over a 4-

year period, Bolonchuk and Lukaski (1987) analyzed 79 players from preseason to postseason, Stodden and Galitski (2010) analyzed 84 players at 4 defined main training phases over 5 years, and Jacobson et al. (2013) analyzed 156 players from one testing session every year for 7 years of player participation. The total number of players for Trexler et al. (2017), Binkley et al. (2015), Stodden and Galitski (2010), and Jacobson et al. (2013) were further categorized their players into either individual position, position groups, or upperclassmen/underclassmen for some or all of analysis, decreasing the analyzed sample sizes.

Therefore, the purpose of this study was to retrospectively examine longitudinal body composition changes categorized by season, position and age, using DXA in NCAA Division I football players. This thesis will explore compositional differences, giving insight into positional changes by age and season to further add to the literature about what composition changes and differences can be expected after a particular season or age group.

CHAPTER 3: METHODS

Study Participants

Seven hundred and forty-two collegiate male football athletes, aged 17-24 years (mean age 19.9 ± 1.3 yrs), were included in this study (Table 1). These athletes represented five different NCAA Division I Universities within the Consortium of College Athlete Research (C-CAR), including: University of Kansas, University of Minnesota, Texas Christian University, University of Nebraska, and the University of Texas at Austin. Each participant was categorized into one of four position groups: Linemen, Big Skill, Skill, and Special Teams. The Linemen group consisted of offensive and defensive linemen. The Big Skill group consisted of linebackers, tight ends, and quarterbacks. The Skill group consisted of defensive backs, running backs, and wide receivers. The Special Teams group consisted of punters, kickers, and long snappers. Each athlete gave written informed consent prior to participation, and consent from a parent/legal guardian was obtained for participants under the age of 18. Approval for retrospective statistical analysis of preexisting DXA scan data from each participating University was given by the University of Minnesota Institutional Review Board.

Scan Procedures

All participants were scanned between 2008-2018 at their respective University. Total and regional body composition was measured using standard procedures (GE Healthcare Lunar) in the total-body supine position on a GE Lunar iDXA (General Electric Medical Systems, Madison, Wisconsin, USA). Participants were instructed to maintain hydration levels and abstain from eating and caffeine four hours prior to their

DXA scan. Scans were completed at least two hours after a practice session, before a practice session, or on rest days. Age and ethnicity were recorded for each participant, and height and body mass were measured using a stadiometer and electronic scale, respectively, prior to their DXA scan and were used to calculate body mass index (BMI).

DXA scan files from all participating Universities were sent to the University of Minnesota for analysis. The same technician analyzed all scans using enCore™ software (platform version 16.2, General Electric Medical Systems, Madison, WI, USA), and regional body composition was measured using automatically created region of interest boxes. Mass distribution ratios were calculated from these values, including: gynoid lean mass to leg lean mass ratio (GLR), upper total mass to legs total mass ratio (ULR), total upper mass to lean leg mass ratio (TULLR), and lean upper mass to lean leg mass ratio (LULLR). The sum of trunk, measured from the chin to the top of the iliac crest, and arm masses is referred to as "upper body", and total mass includes lean soft tissue, fat mass, and bone mass for all ratios. Visceral adipose tissue (VAT) mass was measured using CoreScan (General Electric Medical Systems, Madison, WI, USA).

A traditional year in football consists of four main seasons. For this study, the seasons were defined as follows: Pre-Season (July-September), In-Season (October-November), Post-Season (December- February), and Spring Season (March-May). Pre-Season consisted of 1,037 scans, In-Season consisted of 21 scans, Post-Season consisted of 856 scans, and Spring Season consisted of 659 scans. For this study, only one scan per participant was used for each season. If a participant received more than one scan during a season in a given year, their scans were randomized and only one scan was analyzed.

Further, if players were assigned more than one position in a season across their career, they were not included in analysis.

Statistical Analyses

R software (R Foundation for Statistical Computing, Vienna, Austria) was used to conduct all statistical analyses. Table 1 displays calculated mean ± standard deviations for baseline measurements and characteristics of participants. One-way analysis of variance (ANOVA) with TukeyHSD (honest significant difference) post hoc tests assessed differences between position groups in Table 1 (significance of $p<0.05$). Separate repeated ANOVA with linear mixed-effects models assessed total and regional body composition differences across age, position groups, and seasons, including percent fat (%BF), total lean soft tissue mass (LM), total fat mass (FM), bone mineral density (BMD), VAT, GLR, ULR, TULLR, and LULLR. TukeyHSD post hoc tests were used to determine significant differences among position groups, while adjusting for multiple comparisons (significance of $p<0.05$). Prediction equations for %BF, LM, FM, and VAT mass were computed using linear mixed-effects models. Age, height (m), weight (kg), and position group serve as fixed effects and player ID served as the random effect.

CHAPTER 4: RESULTS

Longitudinal Analysis of Position Groups by Season

For each season, %BF (Figure 1), FM, and VAT ($p<0.0001$) was significantly higher in the Linemen players compared to Big Skill, Skill, and Special Team players. Big Skill and Special Team players, respectively, had significantly higher %BF, and FM than Skill players. LULLR ($p<0.05$) and GLR ($p<0.001$) was significantly lower in the Linemen players compared to Big Skill, Skill, and Special Team players. Special Team players had significantly higher LULLR and GLR than Big Skill and Skill players. A lower LULLR and GLR indicates a greater amount of leg LM in comparison to upper LM and gynoid LM, respectively. TULLR was significantly lower for Skill players compared to Big Skill, Linemen, and Special Team players. Big Skill players had a significantly lower TULLR than Linemen and Special Team players ($p<0.001$). A lower TULLR indicates lower total upper body mass in comparison to leg LM within the athlete. ULR was significantly lower for Skill players compared to Linemen and Special Team players, and Big Skill players had a significantly lower ULR than Linemen and Special Team players ($p<0.01$). A lower ULR indicates a greater amount of total leg mass in comparison to total upper mass within the athletes. Significant differences were observed between all groups within each season for LM and BMD ($p<0.01$). Specifically, Linemen players had a significantly higher LM and BMD than Big Skill, Skill, and Special Team players; Big Skill players had a significantly higher LM and BMD than Skill and Special Team players; Skill players had a significantly higher LM and BMD than Special Team players within each season. *Raw data appears in Tables 2-8 in the appendix.*

Longitudinal Analysis of Season by Position Groups

For each position group, %BF (Figure 2) and FM significantly decreased from Pre-Season and Post-Season to Spring Season ($p<0.001$). VAT significantly decreased from Post-Season to Spring Season ($p<0.01$). LM significantly decreased from Pre-Season to Post-Season, but significantly increased from Post-Season to Spring Season ($p<0.0001$, Figure 3). LULLR significantly increased from Post-Season to Spring Season ($p<0.01$) and ULR was significantly lower in the Post-Season than in the Pre-Season ($p<0.001$). GLR was significantly lower in the Post-Season compared to the Pre-Season, and significantly higher in the Spring Season versus the Post-Season ($p<0.05$). There were no significant differences between seasons within position groups for BMD and TULLR ($p>0.05$). *Raw data appears in Tables 9-15 in the appendix.*

Longitudinal Analysis of Position Groups by Age

For each age group, Linemen players had a significantly higher %BF and FM ($p<0.0001$) than Big Skill, Skill, and Special Teams players, and Big Skill and Special Teams players had significantly higher %BF and FM than Skill players. Linemen players had a significantly greater amount of VAT in comparison to Big Skill, Skill, and Special Team players within each age group ($p<0.0001$, Figure 4). Skill players had a significantly lower TULLR in comparison to Big Skill, Linemen, and Special Team Players, and Big Skill players had a significantly lower TULLR in comparison to Linemen and Special Team Players ($p<0.01$). Special Team, Big Skill, and Skill players had a significantly greater LULLR than Linemen ($p<0.0001$). Skill players had a significantly lower ULR in comparison to Linemen and Special Team players, and Big Skill players had a significantly lower ULR than Linemen players ($p<0.001$). Linemen players had a significantly lower GLR than Big Skill, Skill, and Special Team players, and Big Skill and Skill players had significantly lower GLR than Special Team players ($p<0.01$). There were significant differences between all position groups within each age group for LM and BMD ($p<0.0001$). Specifically, Linemen players had a significantly higher LM and BMD than Big Skill, Skill, and Special Team players, Big Skill players had a significantly higher LM and BMD than Skill and Special Team players, and Skill players had a significantly higher LM and BMD than Special Team players within each age group. *Raw data appears in Tables 16-22 in the appendix.*

Longitudinal Analysis of Age by Position Group

For each position group, %BF and FM increased from 18 years to 22 years ($p<0.05$). VAT increased from 18 years to 23 years ($p<0.05$, Figure 5). LM increased from 17 years to 22 years ($p<0.05$, Figure 6). BMD increased from 17 years to 24 years ($p<0.05$, Figure 7). TULLR increased from 18 years to 22 years ($p<0.05$), ULR decreased from 17 years to 22 years ($p<0.05$), and GLR increased from 17 years to 22 years ($p<0.05$). There were no significant differences observed between age groups within position groups for LULLR ($p>0.05$). *Raw data appears in Tables 23-30 in the appendix.*

Prediction Equations

Prediction equations were developed to predict the %BF, LM, FM, and VAT of a collegiate football player given age (y), height (kg), weight (kg) and player position group. The Linemen position group, chosen at random, served as the reference group for each equation. Each equation is comprised of variables for age (A), height (H), body weight (W), Big Skill (BS), Skill (S), and Special Team (ST). The position groups are present within each equation to identify the specific position group of the player measured in the equation. A "1" is placed in which position group is applicable to the player measured and a "0" is placed when a group is not applicable to the player measured.

$$\%BF = 26.07 - 0.1985(A) - 22.93(H) + 0.3768(W) + 0.745(BS) + 0.367(S) + 5.41(ST)$$

$$LM(kg) = -4.015 + 0.3591(A) + 22.75(H) + 0.3273(W) - 0.08317(BS) - 0.7834(S) - 5.214(ST)$$

$$FM(kg) = 12.95 - 0.3511(A) - 27.28(H) + 0.6265(W) + 0.01017(BS) + 0.5591(S) + 5.153(ST)$$

$$VAT(kg) = -0.2439 + 0.02484(A) - 0.8962(H) + 0.01807(W) - 0.06744(BS) + 0.05122(S) + 0.09695(ST)$$

CHAPTER 5: DISCUSSION

Summary of Findings

The objectives of this study were to: (1) determine if body composition significantly changes with playing season, within and/or among position groups; (2) determine if body composition significantly changes with player age, within and/or among position groups; and (3) demonstrate equations that can predict body composition by player position. To our knowledge, this is the first study to retrospectively examine longitudinal, positional football body composition data by season and player age, as well as created prediction equations to predict %BF, LM, FM, and VAT by position given age, height, and weight in NCAA Division I football players using DXA.

The results of this study indicate that out of the four position groups the Linemen players had the greatest %BF, FM, VAT, LM, and BMD ($p<0.05$) in each season and age. Further, body composition significantly worsened from the Pre-Season to the Post-Season and improved from the Pre-Season and Post-Season to the Spring Season for all position groups. Finally, players in all position groups increased %BF, FM, VAT, LM, and BMD as they aged.

Overall, %BF, FM, VAT, LM, and BMD were all highest in Linemen players across all seasons and ages, which is in agreement with previous literature (Bosch et al., 2017; Dengel et al., 2014; Stodden and Gatliski, 2010; Turnagol, 2016). Similar to the results of Bosch et al. (2017), LULLR and GLR were lowest in Linemen players across all seasons and ages, meaning that Linemen players have a greater amount of leg LM in comparison to upper body LM and gynoid LM, respectively. Given that Linemen players are required to tackle and block their opponent, this position must carry the most total body mass and have the greatest amount of LM in the legs to carry out the requirements of this position (Pincivero and Bompa, 1997; Wilmore and Haskell, 1972). Similar to the findings of Bosch et al. (2017), TULLR was lower for Skill players compared to the other position groups and lower for Big Skill players compared to Linemen and Special Team players for all seasons and ages. This indicates that Skill players had a lower amount of total upper body mass in compared to leg LM in comparison Big Skill, Linemen, and Special Team players. Further, Big Skill players had a lower amount total upper body mass compared to leg LM in comparison to Linemen and Special Team players, which is consistent with the understanding that these players typically have strength, speed, and size intermediate of Skill and Linemen players. The need to be agile and quick is important for Skill players to run down the field and receive or defend the pass, therefore, it is important for these individuals to have a greater amount of lean leg mass than total upper mass (Pincivero & Bompa, 1997). Finally, ULR was lower in Skill players than Linemen and Special Team players for all seasons and ages, lower in Big Skill players than Linemen and Special Team players for all seasons, and lower in Big Skill players than Linemen players in all ages. This indicates Skill players had a greater amount of total leg mass compared to total upper mass than Linemen and Special Team players, and Big Skill players had a greater amount of total leg mass compared to total upper mass than Linemen and Special Team players. However, previous research with professional and collegiate players has indicated ULR to be lowest in Linemen players compared to other groups (Dengel et al., 2014; Turnagol, 2016). These results might be different due to the literature comparing individual positions or grouping positions differently compared to this study, as well as the analysis of professional football players versus collegiate players.

Longitudinal analysis of seasons by position group resulted in %BF and FM significantly decreasing from Pre-Season and Post-Season to Spring Season for all position groups. Previous studies also demonstrated %BF decreased from Pre-Season to Post-Season (Bolonchuk & Lukaski, 1987), whereas other studies showed increases (Binkley et al., 2015). This discrepancy might be due to differences in the definitions of pre-, post seasons as well as differences in defining position groups. Bolonchuk & Lukaski (1987) did not define positions or position groups and scanned their NCAA Division I collegiate players two days before the start of fall practice (preseason) and 13 weeks after the preseason test (postseason). Binkley et al. (2015) defined their groups as linemen and non-line, as well as upperclassmen and underclassmen. Furthermore, preseason scans took place one to two weeks before the start of fall practice, postseason scans took place within one week after the last game of the season, and spring season scans took place approximately 145 days after the postseason scan. This study defined four distinct position groups and four seasons, randomizing scans within each season for measurement given the complexity of analyzing data from five different programs.

VAT significantly decreased from the Post-Season to the Spring Season for all position groups. These findings suggest that the In-Season and work in the Post-Season result in decreases in FM. LM significantly decreased from Pre-Season to Post-Season, however significant increases were observed from Post-Season to Spring Season for LM for all position groups. The decreases observed in LM from Pre- to Post-Season is in agreement with the results from Binkley et al. (2015), but in disagreement with Trexler et al. (2017) and Bolonchuk & Lukaski (1987) who observed increases in LM from Pre- to Post-Season. Increases in LM from Post-Season to Spring Season may be due to focusing on gaining LM in Post-Season training, versus during the In-Season the focus is on technique and skill to improve player performance (Trexler et al., 2017). The discrepancies observed might be again due to smaller sample sizes and differences in season and position group definitions among studies, as previously described.

Very limited research has analyzed body composition ratios to the extent of this study. In this study, LULLR increased from Post-Season to Spring Season, meaning that players had a greater amount of upper LM than leg LM in Spring Season compared to Post-Season. ULR was lower in the Post-Season than the Pre-Season for all position groups. This means that players had a greater amount of total leg mass in comparison to total body upper mass in the Post-Season versus the Pre-Season. Finally, GLR was lower in the Post-Season than the Pre-Season, and higher in the Spring Season than the Post-Season, for all position groups. This means that all position groups had a greater amount of leg LM compared to gynoid LM in the Pre-Season and Spring Season versus the Post-Season.

Longitudinal analysis of age by position group demonstrated that each body composition variable analyzed gradually increased as player age increased within each position group. Increases in LM and BMD may be the result of strength training and doing position-specific training on the field, causing players to build LM and subsequent BMD (Trexler et al., 2017). Increases in %BF, FM, and VAT may be contributed to coaches encouraging players to increase size. Although there are currently no known studies that specifically analyzed player age and body composition, similar findings were found between previous research and this study. Most studies found that significant increases in body composition, particularly %BF and LM, were seen primarily within the beginning and middle of a player's career (Anzell et al., 2013; Jacobson et al., 2013; Stodden & Galtiski, 2010; Trexler et al., 2017), which is consistent with the results of this study that significant differences were primarily observed starting at age 19 and continuing through age 22. Increases in TULLR represent a greater amount of total upper mass than leg LM as players age. Decreases in ULR represent a greater amount of total leg mass than total upper mass as players age. Increases GLR represent a greater amount of gynoid LM than leg LM as players age.

Prediction equations were created based off of the given dataset for %BF, LM, FM, and VAT by position group. Prediction figures were created based off of these equations and are located in the appendix. Small to moderate increases were seen for each position groups as age progressed following trends discovered within the longitudinal analysis.

Importance of Findings

This study demonstrated the importance of understanding how a football player's body composition changes over the seasons and ages, and how each position group is different from each other. Decreases in LM analyzed from the Pre-Season to the Post-Season might warrant coaches to reassess training in the In-Season and nutritional intake to maintain LM of their athletes. Additionally, coaches may consider testing for muscular imbalances in the Post-Season to be addressed during training in the off-season (Binkley et al., 2015). Decreases in %BF, FM, and VAT from the Pre-Season and Post-Season to the Spring Season indicate that training in the In-Season and Post-Season may favorably decrease body fat (Bolonchuk & Lukaski, 1987). Despite seasonal changes, each body composition variable analyzed increased with age. While the absolute numbers of the body composition variables by position were different, the trends for age and season changes were the same. Therefore, coaches may expect similar body composition fluctuations to occur among position groups by age and season.

From an overall health perspective, it is important to recognize the expectation of players being "big", as obesity has become a concern in football players (Skinner et al., 2013; Wilmore and Haskell, 1972). The results from the current study indicate that Linemen players were the largest out of the four position groups and was the only group classified as obese (> 24% body fat) (Bosch et al., 2014). Linemen players are usually required to gain weight and often times not educated on or concerned with what type of mass should contribute to the weight gain. Increases in FM particularly within the abdominal region, are associated with metabolic syndrome (Buell et al., 2008; Wilkerson, Bullard, & Bartal, 2010). Studies have noted that football players have a high risk of cardiovascular disease risk factors despite the high intensity and volume of activity, which can provide negative long-term health risks for these individuals (Baron et al., 2011; Wilkerson, Bullard, & Bartal, 2010). Overall, coaches may consider focusing on building LM in players who need to gain weight and provide nutritional education to avoid unhealthy increases in FM.

Limitations of Present Study

Despite the novice and notable results of this study, limitations exist. The inclusion of five different NCAA Division I schools was favorable to create a large and diverse sample, however this required various locations and technicians to measure the body composition of these players. Having one common scanning location and time frame with the same technician may have increased the reliability and validity of the DXA scans. In addition, the current study did not monitor nutrition or exercise for the participants included in this study. Further, the year of eligibility per player was not identified within this dataset. The inclusion of this information may have provided a clearer understanding as to why body composition changed between seasons and increased with age in this study.

This study grouped all mirroring offensive and defensive positions together in four distinct position groups. Previous research has found no significant differences for body composition and body mass ratios between mirroring positions, except between offensive and defensive linemen for fat measures (%BF, FM, trunk FM, legs FM), ULR, and TULLR (Bosch et al., 2014; Dengel et al., 2014). These findings indicate that the offensive and defensive linemen be evaluated separately for FM and fat ratios to possibly increase the accuracy of results and position representation. However, this was not feasible in the current study due to a low sample size and scan number per season when separating offensive from defensive line. Addressing these limitations for future studies may increase the relatability and validity of the results.

Future Directions

To improve the outcomes and analysis of this study, a few modifications and suggestions are advisable for future studies. Documenting workouts, providing strength and conditioning benchmark tests, and monitoring athlete nutrition in addition to body composition assessments would be valuable. To optimize player performance in games, it is advisable to continually update training programs with some guidance from periodic strength and power tests. These periodic tests tend to classify players into positions, as these tests often provide position-specific results (Fry & Kraemer, 1991). In addition, nutrient needs and physique requirements vary individually based upon position and level of participation on the team (Holway and Spriet, 2011; Jonnalagadda, Rosenbloom, and Skinner, 2001). Therefore, documenting workouts and performing strength and power tests, as well as monitoring nutrition, at time of DXA scanning would allow coaches to understand in depth how and why the body is changing and adapting. From the results these coaches can then modify to further improve the body composition and performance of their players.

Furthermore, it would be valuable to recognize player year of eligibility in addition to age of the players. In terms of player experience and eligibility, players are typically grouped into redshirt freshmen (8-9 months), freshmen (2 years), sophomore (3 years), junior (4 years), and senior (5 years), given the number of years the athlete has been associated with the program (Chapman, Whitehead, Binkert, 1998; Lockie et al., 2016). Redshirt and underclassmen players typically do not play on or see much of the field, as they are developing to fit the needs of their specific positions. Therefore, documenting player year of eligibility in addition to age would aid future research in understanding the impact of a potential learning curves, the effect of playing time, and further exploration of current observed trends.

CHAPTER 6: CONCLUSIONS

In conclusion, this study lends support for conducting longitudinal studies to assess the body composition changes by season and age on defined position groups in American football. This study has also demonstrated the support for providing predictive equations regarding important measures of body composition that can then be used to predict valid changes in body composition given age, body mass, and height by position group. The results of this study indicate that the Linemen players had the greatest %BF, FM, VAT, LM, and BMD ($p<0.05$) out of the four position groups in each season and age. Further, body composition worsened from the Pre-Season to the Post-Season and improved from the Pre-Season and Post-Season to the Spring Season for each position group. Finally, players increase their %BF, FM, VAT, LM, and BMD as they age. The discrepancy of results reported among the literature and this study warrant additional research to be conducted, however it is advisable that future literature define seasons and position groups consistently for accurate results.

Table 1. Characteristics of Study Participants

	Linemen	Big Skill	Skill	Special Teams	Total
n	838	632	942	157	2569
Age (y)	20.0 ± 1.3	19.9 ± 1.3	19.9 ± 1.3	20.1 ± 1.3	19.9 ± 1.3
Body Weight (kg)	129.1 ± 13.6[a]	102.5 ± 8.3[b]	88.9 ± 8.5[c]	92.0 ± 8.6[d]	105.6 ± 20.1
Height (m)	1.9 ± 0.1[a]	1.9 ± 0.1[b]	1.8 ± 0.1[c]	1.8 ± 0.1[d]	1.9 ± 0.1
BMI (kg/m^2)	35.3 ± 3.8[a]	29.4 ± 2.2[b]	27.1 ± 2.5[c]	27.1 ± 2.7[c]	30.3 ± 4.6
Percent Body Fat (%)	27.1 ± 6.2[a]	18.6 ± 4.2[b]	14.2 ± 4.0[c]	19.9 ± 5.9[d]	19.8 ± 7.4
Total Fat Mass (kg)	34.8 ± 10.2[a]	18.9 ± 4.9[b]	12.6 ± 4.3[c]	18.4 ± 6.6[b]	21.7 ± 11.7
Total Lean Mass (kg)	88.7 ± 6.5[a]	79.6 ± 6.2[b]	72.9 ± 6.2[c]	70.1 ± 5.0[d]	79.5 ± 9.4

Abbreviations: BMI, body mass index
n = total number of DXA scans
Different letters denote significant differences ($p < 0.05$) between position groups.
Body weight, height, BMI, % body fat, total fat mass, and total lean mass are presented as mean ± SD.
Position groups are defined as follows: Linemen: offensive and defensive linemen; Big Skill: linebackers, tight ends, and quarterbacks; Skill: defensive backs, running backs, and wide receivers; Special Teams: punters, kickers and long snappers.

Figure Legend

Figure 1. Longitudinal assessment of position groups within seasons for percent body fat (%). Black Bar = Linemen, Dark Gray Bar = Big Skill, Light Gray Bar = Skill, White Bar = Special Team.

Figure 2. Longitudinal assessment of seasons within position groups for percent body fat (%). Circle = Linemen, Triangle = Big Skill, Square = Skill, Diamond = Special Team.

Figure 3. Longitudinal assessment of seasons within position groups for total lean soft tissue mass (kg). Circle = Linemen, Triangle = Big Skill, Square = Skill, Diamond = Special Team.

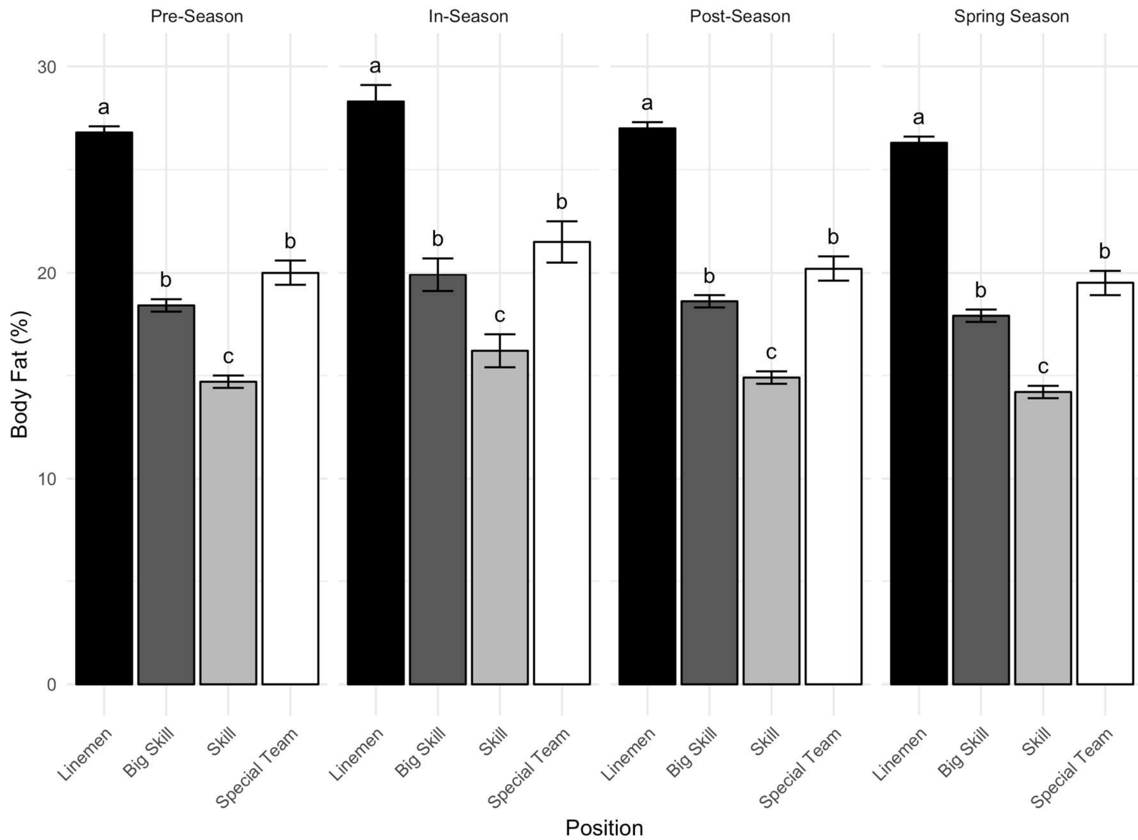
Figure 4. Longitudinal assessment of position groups by age (y) for visceral adipose tissue (kg). Black Bar = Linemen, Dark Gray Bar = Big Skill, Light Gray Bar = Skill, White Bar = Special Team.

Figure 5. Longitudinal assessment of age (y) by position groups for visceral adipose tissue (kg). Circle = Linemen, Triangle = Big Skill, Square = Skill, Diamond = Special Team.

Figure 6. Longitudinal assessment of age (y) by position groups for total lean tissue mass (kg). Circle = Linemen, Triangle = Big Skill, Square = Skill, Diamond = Special Team.

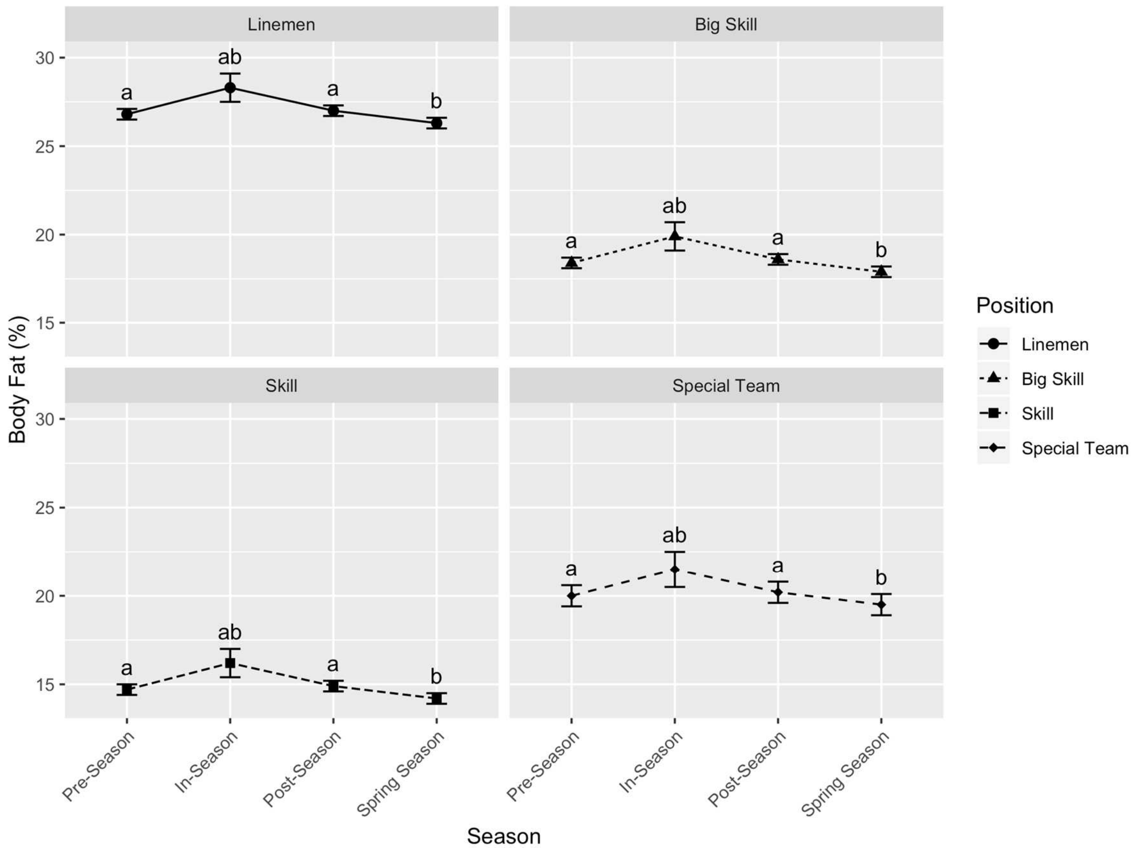
Figure 7. Longitudinal assessment of age (y) by position groups for bone mineral density (g/cm^2). Circle = Linemen, Triangle = Big Skill, Square = Skill, Diamond = Special Team.

Figure 1. Longitudinal assessment of position groups within seasons for percent body fat (%)



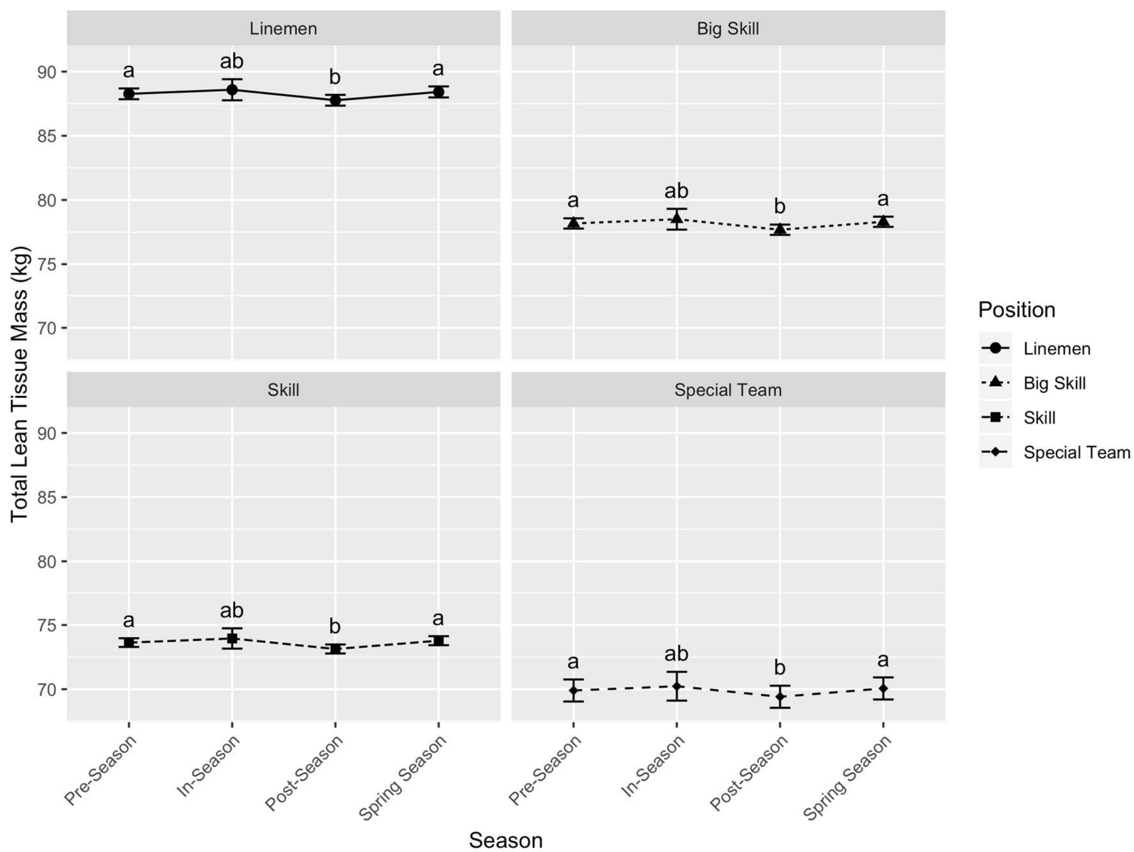
Different letters denote significant differences ($p < 0.0001$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Linemen (black bars): offensive and defensive linemen; Big Skill (dark gray bars): linebackers, tight ends, and quarterbacks; Skill (light gray bars): defensive backs, running backs, and wide receivers; Special Teams (white bars): punters, kickers, and long snappers.

Figure 2. Longitudinal assessment of seasons within position groups for percent body fat (%)



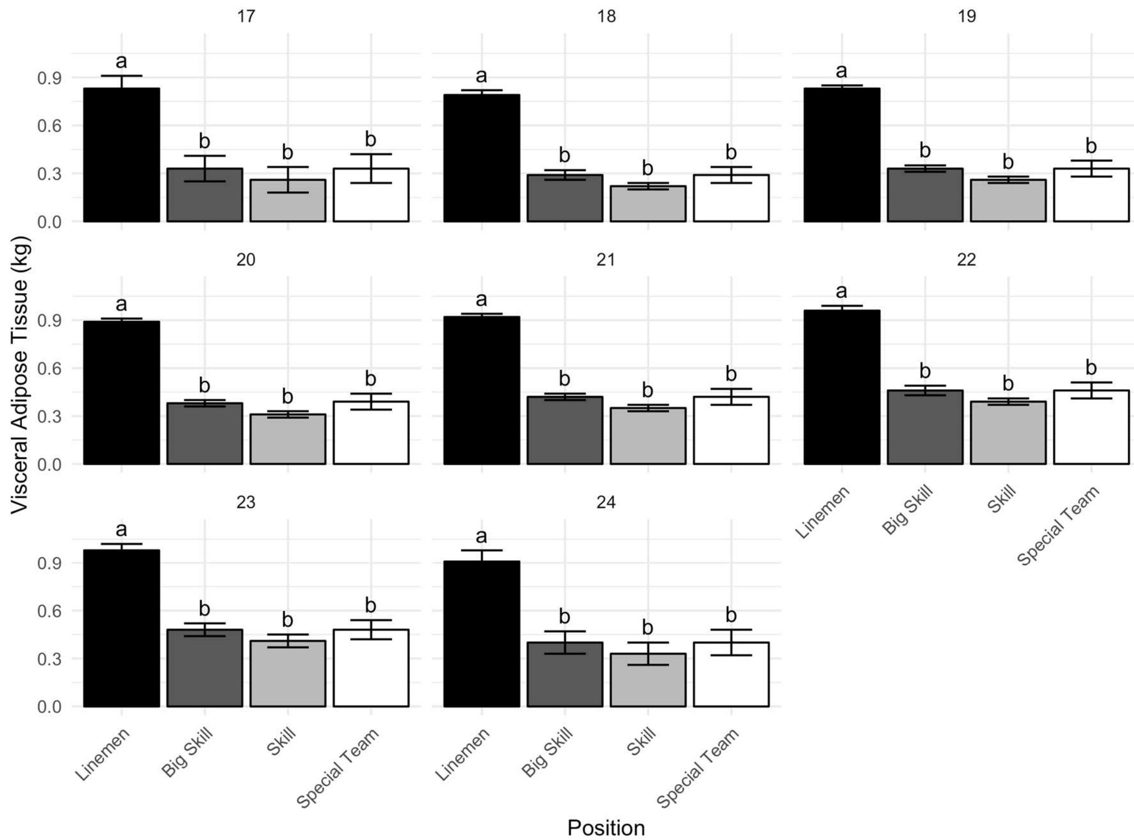
Different letters denote significant differences ($p < 0.0001$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Linemen (solid circles): offensive and defensive linemen; Big Skill (solid triangles): linebackers, tight ends, and quarterbacks; Skill (solid squares): defensive backs, running backs, and wide receivers; Special Teams (solid diamonds): punters, kickers and long snappers.

Figure 3. Longitudinal assessment of seasons within position groups for total lean soft tissue mass (kg)



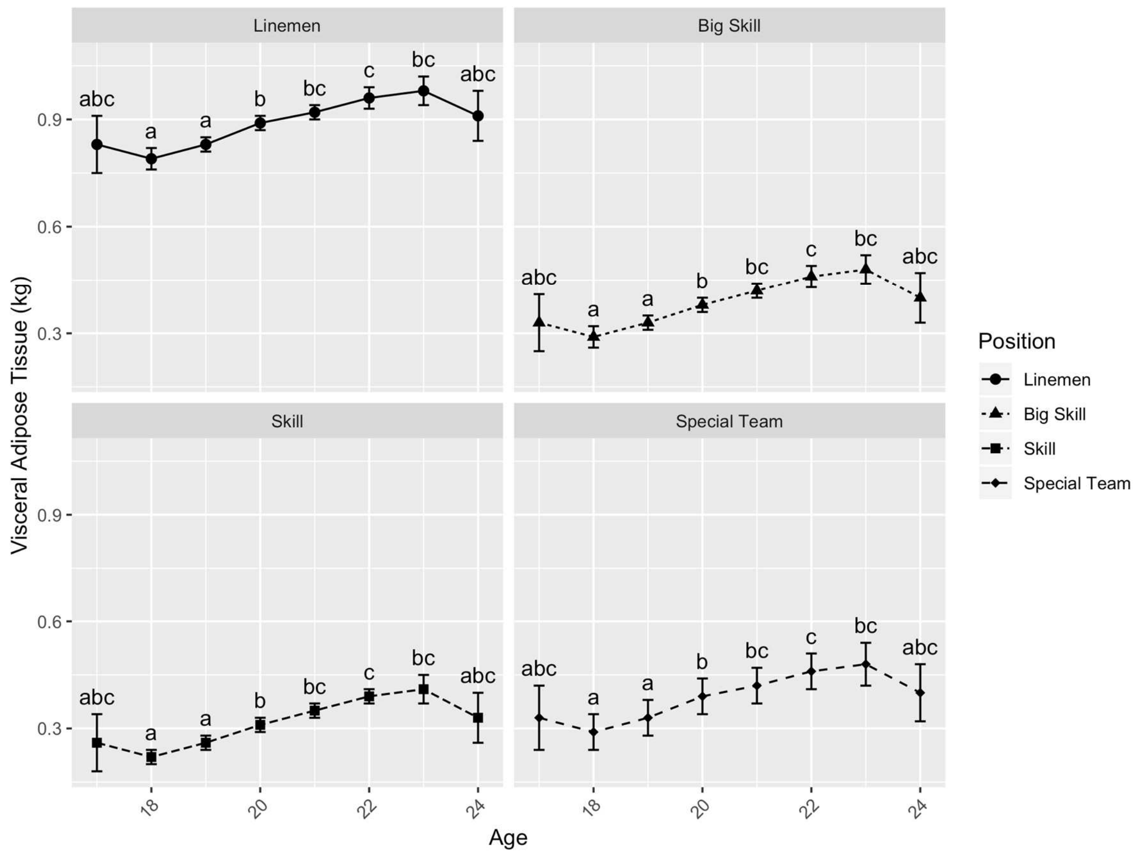
Different letters denote significant differences ($p < 0.0001$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Linemen (solid circles): offensive and defensive linemen; Big Skill (solid triangles): linebackers, tight ends, and quarterbacks; Skill (solid squares): defensive backs, running backs, and wide receivers; Special Teams (solid diamonds): punters, kickers and long snappers.

Figure 4. Longitudinal assessment of position groups by age (y) for visceral adipose tissue (kg)



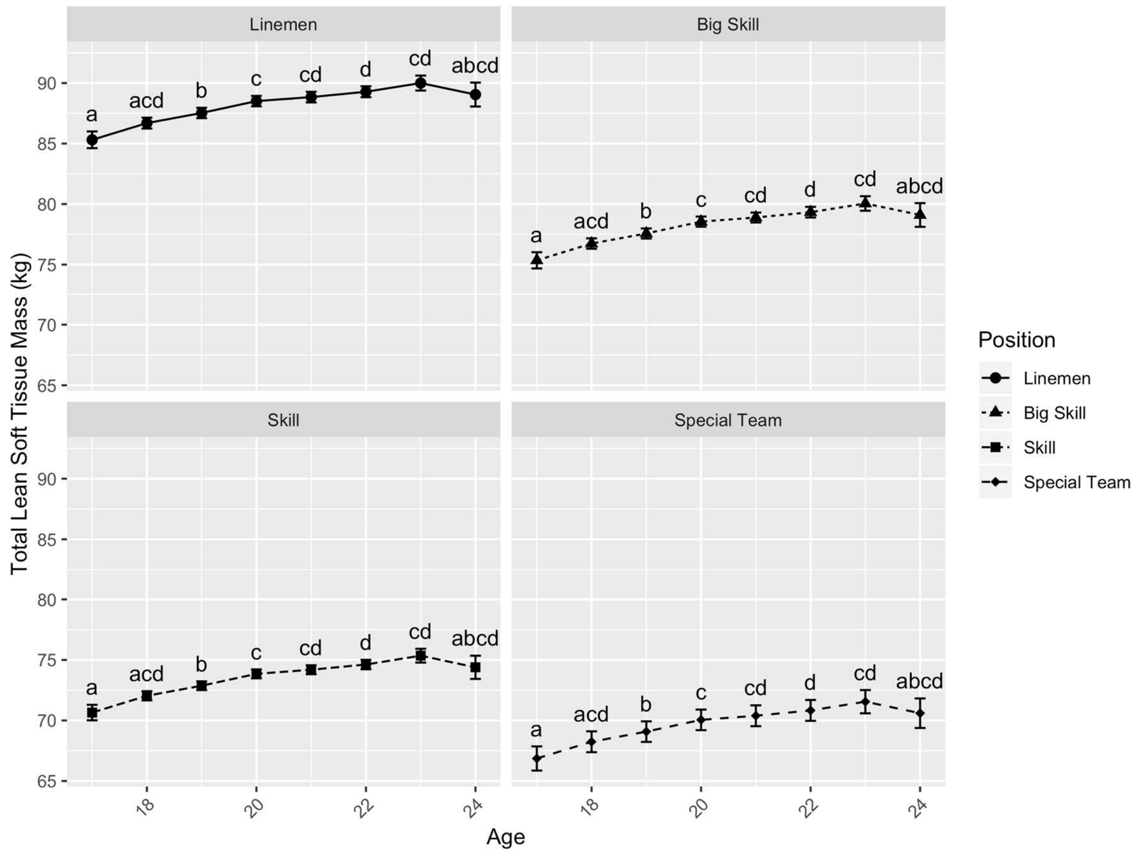
Different letters denote significant differences ($p < 0.0001$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Linemen (black bars): offensive and defensive linemen; Big Skill (dark gray bars): linebackers, tight ends, and quarterbacks; Skill (light gray bars): defensive backs, running backs, and wide receivers; Special Teams (white bars): punters, kickers, and long snappers.

Figure 5. Longitudinal assessment of age (y) by position groups for visceral adipose tissue (kg)



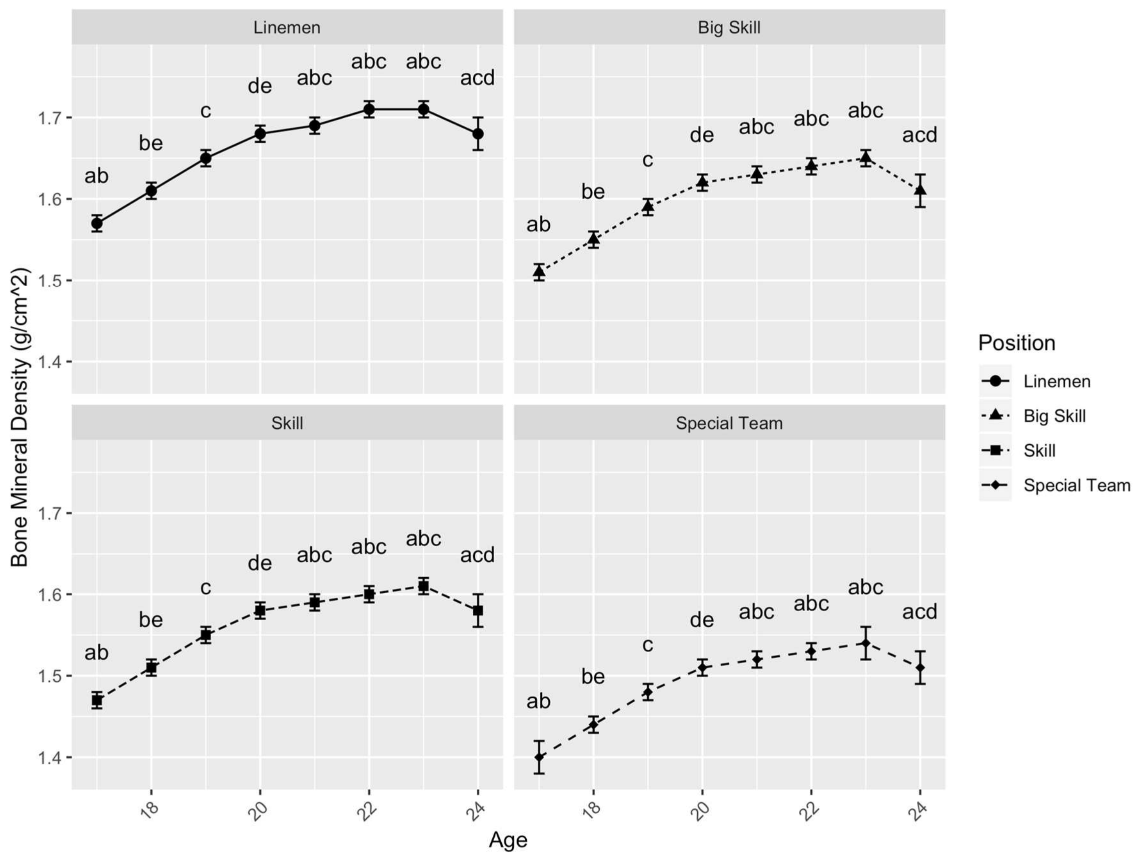
Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Linemen (solid circles): offensive and defensive linemen; Big Skill (solid triangles): linebackers, tight ends, and quarterbacks; Skill (solid squares): defensive backs, running backs, and wide receivers; Special Teams (solid diamonds): punters, kickers and long snappers.

Figure 6. Longitudinal assessment of age (y) by position groups for total lean soft tissue mass (kg)



Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Linemen (solid circles): offensive and defensive linemen; Big Skill (solid triangles): linebackers, tight ends, and quarterbacks; Skill (solid squares): defensive backs, running backs, and wide receivers; Special Teams (solid diamonds): punters, kickers and long snappers.

Figure 7. Longitudinal assessment of age (y) by position groups for bone mineral density (g/cm^2)



Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Linemen (solid circles): offensive and defensive linemen; Big Skill (solid triangles): linebackers, tight ends, and quarterbacks; Skill (solid squares): defensive backs, running backs, and wide receivers; Special Teams (solid diamonds): punters, kickers and long snappers.

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APPENDIX

Table 2. Longitudinal assessment of position groups within seasons for percent body fat (%)

Season	Skill	Big Skill	Linemen	Special Teams
Pre-Season	14.7 ± 0.3^{a}	18.4 ± 0.3^{b}	26.8 ± 0.3^{c}	20.0 ± 0.6^{b}
In-Season	16.2 ± 0.8^{d}	19.9 ± 0.8^{e}	28.3 ± 0.8^{f}	21.5 ± 1.0^{e}
Post-Season	14.9 ± 0.3^{g}	18.6 ± 0.3^{h}	27.0 ± 0.3^{i}	20.2 ± 0.6^{h}
Spring Season	14.2 ± 0.3^{j}	17.9 ± 0.3^{k}	26.3 ± 0.3^{l}	19.5 ± 0.6^{k}

Different letters denote significant differences ($p < 0.0001$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 3. Longitudinal assessment of position groups within seasons for visceral adipose tissue mass (kg)

Season	Skill	Big Skill	Linemen	Special Teams
Pre-Season	0.29 ± 0.02[a]	0.35 ± 0.02[a]	0.87 ± 0.02[b]	0.37 ± 0.05[a]
In-Season	0.38 ± 0.05[c]	0.45 ± 0.05[d]	0.96 ± 0.05[e]	0.46 ± 0.07[d]
Post-Season	0.29 ± 0.02[f]	0.36 ± 0.02[f]	0.87 ± 0.02[g]	0.37 ± 0.05[f]
Spring Season	0.26 ± 0.02[h]	0.33 ± 0.02[i]	0.84 ± 0.02[j]	0.34 ± 0.05[h]

Different letters denote significant differences ($p < 0.0001$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 4. Longitudinal assessment of position groups within seasons for total fat mass (kg)

Season	Skill	Big Skill	Linemen	Special Teams
Pre-Season	13.33 ± 0.37^{a}	18.76 ± 0.44^{b}	34.50 ± 0.44^{c}	18.57 ± 0.89^{b}
In-Season	15.65 ± 1.09^{e}	21.08 ± 1.12^{f}	36.82 ± 1.12^{g}	20.89 ± 1.36^{f}
Post-Season	13.49 ± 0.38^{i}	18.92 ± 0.45^{j}	34.66 ± 0.45^{k}	18.72 ± 0.89^{j}
Spring Season	12.59 ± 0.38^{m}	18.02 ± 0.45^{n}	33.76 ± 0.45^{o}	17.83 ± 0.89^{n}

Different letters denote significant differences ($p < 0.0001$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 5. Longitudinal assessment of position groups within seasons for total upper mass to lean leg mass ratio

Season	Skill	Big Skill	Linemen	Special Teams
Pre-Season	2.04 ± 0.01[a]	2.14 ± 0.01[b]	2.33 ± 0.01[c]	2.28 ± 0.03[c]
In-Season	2.01 ± 0.04[d]	2.11 ± 0.04[e]	2.30 ± 0.04[f]	2.25 ± 0.05[f]
Post-Season	2.04 ± 0.01[g]	2.14 ± 0.01[h]	2.33 ± 0.01[i]	2.28 ± 0.03[i]
Spring Season	2.04 ± 0.01[j]	2.14 ± 0.01[k]	2.32 ± 0.01[l]	2.27 ± 0.03[l]

Different letters denote significant differences ($p < 0.001$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 6. Longitudinal assessment of position groups within seasons for lean upper mass to lean leg mass ratio

Season	Skill	Big Skill	Linemen	Special Teams
Pre-Season	1.69 ± 0.01[a]	1.68 ± 0.01[a]	1.59 ± 0.01[b]	1.75 ± 0.02[c]
In-Season	1.65 ± 0.03[d]	1.65 ± 0.03[d]	1.55 ± 0.03[e]	1.71 ± 0.03[f]
Post-Season	1.68 ± 0.01[g]	1.68 ± 0.01[g]	1.58 ± 0.01[h]	1.74 ± 0.02[i]
Spring Season	1.70 ± 0.01[j]	1.69 ± 0.01[j]	1.60 ± 0.01[k]	1.76 ± 0.02[l]

Different letters denote significant differences ($p < 0.05$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 7. Longitudinal assessment of position groups within seasons for upper total mass to legs total mass ratio

Season	Skill	Big Skill	Linemen	Special Teams
Pre-Season	1.85 ± 0.01[a]	1.90 ± 0.02[a]	2.01 ± 0.02[bc]	2.03 ± 0.03[c]
In-Season	1.77 ± 0.04[d]	1.82 ± 0.04[d]	1.93 ± 0.04[ef]	1.95 ± 0.05[f]
Post-Season	1.82 ± 0.01[g]	1.87 ± 0.02[g]	1.99 ± 0.02[hi]	2.01 ± 0.03[i]
Spring Season	1.83 ± 0.01[j]	1.89 ± 0.02[j]	2.00 ± 0.02[kl]	2.02 ± 0.03[l]

Different letters denote significant differences ($p < 0.01$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 8. Longitudinal assessment of position groups within seasons for gynoid lean mass to leg lean mass ratio

Season	Skill	Big Skill	Linemen	Special Teams
Pre-Season	0.47 ± 0.002[a]	0.46 ± 0.002[a]	0.45 ± 0.002[b]	0.49 ± 0.004[c]
In-Season	0.46 ± 0.007[d]	0.46 ± 0.007[d]	0.44 ± 0.007[e]	0.48 ± 0.008[f]
Post-Season	0.46 ± 0.002[g]	0.46 ± 0.002[g]	0.44 ± 0.002[h]	0.48 ± 0.004[i]
Spring Season	0.47 ± 0.002[j]	0.46 ± 0.002[j]	0.45 ± 0.002[k]	0.49 ± 0.004[l]

Different letters denote significant differences ($p < 0.001$) between position groups within seasons. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 9. Longitudinal assessment of seasons within position groups for percent body fat (%)

A

Season	Skill
Pre-Season	14.7 ± 0.3^{a}
In-Season	16.2 ± 0.8^{ab}
Post-Season	14.9 ± 0.3^{a}
Spring Season	14.2 ± 0.3^{b}

B

Season	Big Skill
Pre-Season	18.4 ± 0.3^{a}
In-Season	19.9 ± 0.8^{ab}
Post-Season	18.6 ± 0.3^{a}
Spring Season	17.9 ± 0.3^{b}

C

Season	Linemen
Pre-Season	26.8 ± 0.3^{a}
In-Season	28.3 ± 0.8^{ab}
Post-Season	27.0 ± 0.3^{a}
Spring Season	26.3 ± 0.3^{b}

D

Season	Special Teams
Pre-Season	20.0 ± 0.6^{a}
In-Season	21.5 ± 1.0^{ab}
Post-Season	20.2 ± 0.6^{a}
Spring Season	19.5 ± 0.6^{b}

Different letters denote significant differences ($p < 0.0001$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 10. Longitudinal assessment of seasons within position groups for visceral adipose tissue (kg)

A

Season	Skill
Pre-Season	0.29 ± 0.02[ab]
In-Season	0.38 ± 0.05[ab]
Post-Season	0.29 ± 0.02[a]
Spring Season	0.26 ± 0.02[b]

B

Season	Big Skill
Pre-Season	0.35 ± 0.02[ab]
In-Season	0.45 ± 0.05[ab]
Post-Season	0.36 ± 0.02[a]
Spring Season	0.33 ± 0.02[b]

C

Season	Linemen
Pre-Season	0.87 ± 0.02[ab]
In-Season	0.96 ± 0.05[ab]
Post-Season	0.87 ± 0.02[a]
Spring Season	0.84 ± 0.02[b]

D

Season	Special Teams
Pre-Season	0.37 ± 0.05[ab]
In-Season	0.46 ± 0.07[ab]
Post-Season	0.37 ± 0.05[a]
Spring Season	0.34 ± 0.05[b]

Different letters denote significant differences ($p < 0.01$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 11. Longitudinal assessment of seasons within position groups for total fat mass (kg)

A

Season	Skill
Pre-Season	13.33 ± 0.37[a]
In-Season	15.65 ± 1.09[ab]
Post-Season	13.49 ± 0.38[a]
Spring Season	12.59 ± 0.38[b]

B

Season	Big Skill
Pre-Season	18.76 ± 0.44[a]
In-Season	21.08 ± 1.12[ab]
Post-Season	18.92 ± 0.45[a]
Spring Season	18.02 ± 0.45[b]

C

Season	Linemen
Pre-Season	34.50 ± 0.44[a]
In-Season	36.82 ± 1.12[ab]
Post-Season	34.66 ± 0.45[a]
Spring Season	33.76 ± 0.45[b]

D

Season	Special Teams
Pre-Season	18.57 ± 0.89[a]
In-Season	20.89 ± 1.36[ab]
Post-Season	18.72 ± 0.89[a]
Spring Season	17.83 ± 0.89[b]

Different letters denote significant differences ($p < 0.0001$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 12. Longitudinal assessment of seasons within position groups for total lean tissue mass (kg)

A

Season	Skill
Pre-Season	73.63 ± 0.34[a]
In-Season	73.95 ± 0.79[ab]
Post-Season	73.13 ± 0.35[b]
Spring Season	73.78 ± 0.35[a]

B

Season	Big Skill
Pre-Season	78.17 ± 0.40[a]
In-Season	78.50 ± 0.81[ab]
Post-Season	77.68 ± 0.40[b]
Spring Season	78.3 ± 0.40[a]

C

Season	Linemen
Pre-Season	88.27 ± 0.42[a]
In-Season	88.59 ± 0.82[ab]
Post-Season	87.77 ± 0.42[b]
Spring Season	88.42 ± 0.43[a]

D

Season	Special Teams
Pre-Season	69.90 ± 0.86[a]
In-Season	70.23 ± 1.12[ab]
Post-Season	69.41 ± 0.86[b]
Spring Season	70.06 ± 0.86[a]

Different letters denote significant differences ($p < 0.0001$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 13. Longitudinal assessment of seasons within position groups for lean upper mass to lean leg mass ratio

A

Season	Skill
Pre-Season	1.69 ± 0.01^{ab}
In-Season	1.65 ± 0.03^{ab}
Post-Season	1.68 ± 0.01^{a}
Spring Season	1.70 ± 0.01^{b}

B

Season	Big Skill
Pre-Season	1.68 ± 0.01^{ab}
In-Season	1.65 ± 0.03^{ab}
Post-Season	1.68 ± 0.01^{a}
Spring Season	1.69 ± 0.01^{b}

C

Season	Linemen
Pre-Season	1.59 ± 0.01^{ab}
In-Season	1.55 ± 0.03^{ab}
Post-Season	1.58 ± 0.01^{a}
Spring Season	1.60 ± 0.01^{b}

D

Season	Special Teams
Pre-Season	1.75 ± 0.02^{ab}
In-Season	1.71 ± 0.03^{ab}
Post-Season	1.74 ± 0.02^{a}
Spring Season	1.76 ± 0.02^{b}

Different letters denote significant differences ($p < 0.01$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 14. Longitudinal assessment of seasons within position groups for upper total mass to legs total mass ratio

A

Season	Skill
Pre-Season	1.85 ± 0.01[a]
In-Season	1.77 ± 0.04[ab]
Post-Season	1.82 ± 0.01[b]
Spring Season	1.83 ± 0.01[ab]

B

Season	Big Skill
Pre-Season	1.90 ± 0.02[a]
In-Season	1.82 ± 0.04[ab]
Post-Season	1.87 ± 0.02[b]
Spring Season	1.89 ± 0.02[ab]

C

Season	Linemen
Pre-Season	2.01 ± 0.02[a]
In-Season	1.93 ± 0.04[ab]
Post-Season	1.99 ± 0.02[b]
Spring Season	2.00 ± 0.02[ab]

D

Season	Special Teams
Pre-Season	2.03 ± 0.03[a]
In-Season	1.95 ± 0.05[ab]
Post-Season	2.01 ± 0.03[b]
Spring Season	2.02 ± 0.03[ab]

Different letters denote significant differences ($p < 0.001$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 15. Longitudinal assessment of seasons within position groups for gynoid lean mass to leg lean mass ratio

A

Season	Skill
Pre-Season	0.47 ± 0.002[a]
In-Season	0.46 ± 0.007[ab]
Post-Season	0.46 ± 0.002[b]
Spring Season	0.47 ± 0.002[a]

B

Season	Big Skill
Pre-Season	0.46 ± 0.002[a]
In-Season	0.46 ± 0.007[ab]
Post-Season	0.46 ± 0.002[b]
Spring Season	0.46 ± 0.002[a]

C

Season	Linemen
Pre-Season	0.45 ± 0.002[a]
In-Season	0.44 ± 0.007[ab]
Post-Season	0.44 ± 0.002[b]
Spring Season	0.45 ± 0.002[a]

D

Season	Special Teams
Pre-Season	0.49 ± 0.004[a]
In-Season	0.48 ± 0.008[ab]
Post-Season	0.48 ± 0.004[b]
Spring Season	0.49 ± 0.004[a]

Different letters denote significant differences ($p < 0.05$) between seasons within position groups. All values reported as means ± se. Seasons are defined as follows: Pre-Season: July-September; In-Season: October-November; Post-Season: December-February; Spring Season: March-May. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 16. Longitudinal assessment of position groups by age (y) for percent body fat (%)

Age	Skill	Big Skill	Linemen	Special Teams
17	13.6 ± 0.6[a]	17.3 ± 0.6[b]	25.7 ± 0.6[c]	18.9 ± 0.8[b]
18	14.5 ± 0.3[d]	18.2 ± 0.4[e]	26.6 ± 0.4[f]	19.8 ± 0.7[e]
19	15.0 ± 0.3[g]	18.8 ± 0.3[h]	27.1 ± 0.3[i]	20.3 ± 0.6[h]
20	15.0 ± 0.3[j]	18.8 ± 0.3[k]	27.1 ± 0.3[l]	20.3 ± 0.6[k]
21	15.3 ± 0.3[m]	19.1 ± 0.3[n]	27.4 ± 0.3[o]	20.6 ± 0.6[n]
22	15.4 ± 0.3[p]	19.1 ± 0.4[q]	27.5 ± 0.4[r]	20.7 ± 0.7[q]
23	14.9 ± 0.5[s]	18.6 ± 0.6[t]	27.0 ± 0.6[u]	20.2 ± 0.8[t]
24	13.6 ± 0.9[v]	17.3 ± 1.0[w]	25.7 ± 0.9[x]	18.9 ± 1.1[w]

Different letters denote significant differences ($p < 0.0001$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 17. Longitudinal assessment of position groups by age (y) for visceral adipose tissue (kg)

Age	Skill	Big Skill	Linemen	Special Teams
17	0.26 ± 0.08[a]	0.33 ± 0.08[a]	0.83 ± 0.08[b]	0.33 ± 0.09[a]
18	0.22 ± 0.02[c]	0.29 ± 0.03[c]	0.79 ± 0.03[d]	0.29 ± 0.05[c]
19	0.26 ± 0.02[e]	0.33 ± 0.02[e]	0.83 ± 0.02[f]	0.33 ± 0.05[e]
20	0.31 ± 0.02[g]	0.38 ± 0.02[g]	0.89 ± 0.02[h]	0.39 ± 0.05[g]
21	0.35 ± 0.02[i]	0.42 ± 0.02[i]	0.92 ± 0.02[j]	0.42 ± 0.05[i]
22	0.39 ± 0.02[k]	0.46 ± 0.03[k]	0.96 ± 0.03[l]	0.46 ± 0.05[k]
23	0.41 ± 0.04[m]	0.48 ± 0.04[m]	0.98 ± 0.04[n]	0.48 ± 0.06[m]
24	0.33 ± 0.07[o]	0.40 ± 0.07[o]	0.91 ± 0.07[p]	0.40 ± 0.08[o]

Different letters denote significant differences ($p < 0.0001$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 18. Longitudinal assessment of position groups by age (y) for total fat mass (kg)

Age	Skill	Big Skill	Linemen	Special Teams
17	11.55 ± 0.86^{a}	16.99 ± 0.89^{b}	32.67 ± 0.89^{c}	16.73 ± 1.17^{b}
18	12.93 ± 0.43^{d}	18.37 ± 0.50^{e}	34.05 ± 0.50^{f}	18.12 ± 0.92^{e}
19	13.66 ± 0.41^{g}	19.10 ± 0.48^{h}	34.78 ± 0.48^{i}	18.84 ± 0.91^{h}
20	13.71 ± 0.42^{j}	19.15 ± 0.48^{k}	34.84 ± 0.48^{l}	18.89 ± 0.91^{k}
21	14.13 ± 0.42^{m}	19.58 ± 0.48^{n}	35.26 ± 0.48^{o}	19.31 ± 0.91^{n}
22	14.27 ± 0.46^{p}	19.71 ± 0.51^{q}	35.39 ± 0.52^{r}	19.45 ± 0.92^{q}
23	13.66 ± 0.74^{s}	19.10 ± 0.78^{t}	34.78 ± 0.78^{u}	18.84 ± 1.10^{t}
24	11.82 ± 1.30^{v}	17.26 ± 1.33^{w}	32.94 ± 1.32^{x}	17.00 ± 1.52^{w}

Different letters denote significant differences ($p < 0.0001$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 19. Longitudinal assessment of position groups by age (y) for total upper mass to lean leg mass ratio

Age	Skill	Big Skill	Linemen	Special Teams
17	1.96 ± 0.03[a]	2.06 ± 0.03[b]	2.24 ± 0.03[c]	2.19 ± 0.04[c]
18	2.02 ± 0.01[d]	2.12 ± 0.02[e]	2.30 ± 0.02[f]	2.25 ± 0.03[f]
19	2.04 ± 0.01[g]	2.14 ± 0.02[h]	2.32 ± 0.02[i]	2.27 ± 0.03[i]
20	2.05 ± 0.01[j]	2.15 ± 0.02[k]	2.33 ± 0.02[l]	2.28 ± 0.03[l]
21	2.06 ± 0.01[m]	2.16 ± 0.02[n]	2.34 ± 0.02[o]	2.29 ± 0.03[o]
22	2.07 ± 0.02[p]	2.17 ± 0.02[q]	2.35 ± 0.02[r]	2.30 ± 0.03[r]
23	2.05 ± 0.03[s]	2.15 ± 0.03[s]	2.33 ± 0.03[t]	2.28 ± 0.03[t]
24	2.07 ± 0.05[u]	2.17 ± 0.05[v]	2.35 ± 0.05[w]	2.30 ± 0.05[w]

Different letters denote significant differences ($p < 0.01$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 20. Longitudinal assessment of position groups by age (y) for lean upper mass to lean leg mass ratio

Age	Skill	Big Skill	Linemen	Special Teams
17	1.65 ± 0.02[a]	1.64 ± 0.02[a]	1.55 ± 0.02[b]	1.71 ± 0.02[a]
18	1.68 ± 0.01[d]	1.67 ± 0.01[d]	1.58 ± 0.01[e]	1.74 ± 0.02[d]
19	1.69 ± 0.01[g]	1.68 ± 0.01[g]	1.59 ± 0.01[h]	1.74 ± 0.02[g]
20	1.69 ± 0.01[j]	1.68 ± 0.01[j]	1.59 ± 0.01[k]	1.74 ± 0.02[j]
21	1.69 ± 0.01[m]	1.68 ± 0.01[m]	1.59 ± 0.01[n]	1.74 ± 0.02[m]
22	1.69 ± 0.01[p]	1.68 ± 0.01[p]	1.59 ± 0.01[q]	1.75 ± 0.02[p]
23	1.69 ± 0.02[s]	1.68 ± 0.02[s]	1.59 ± 0.02[t]	1.75 ± 0.02[s]
24	1.71 ± 0.03[v]	1.71 ± 0.03[v]	1.61 ± 0.03[w]	1.77 ± 0.03[v]

Different letters denote significant differences ($p < 0.05$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 21. Longitudinal assessment of position groups by age (y) for upper total mass to legs total mass ratio

Age	Skill	Big Skill	Linemen	Special Teams
17	1.89 ± 0.03^{a}	1.93 ± 0.03^{ac}	2.05 ± 0.03^{b}	2.07 ± 0.05^{bc}
18	1.84 ± 0.02^{d}	1.89 ± 0.02^{df}	2.01 ± 0.02^{e}	2.03 ± 0.04^{de}
19	1.85 ± 0.02^{g}	1.90 ± 0.02^{gi}	2.02 ± 0.02^{h}	2.04 ± 0.03^{hi}
20	1.82 ± 0.02^{j}	1.86 ± 0.02^{jl}	1.98 ± 0.02^{k}	2.00 ± 0.03^{kl}
21	1.78 ± 0.02^{m}	1.82 ± 0.02^{mo}	1.94 ± 0.02^{n}	1.97 ± 0.04^{no}
22	1.76 ± 0.02^{p}	1.81 ± 0.02^{pr}	1.93 ± 0.02^{q}	1.95 ± 0.04^{qr}
23	1.77 ± 0.03^{s}	1.81 ± 0.03^{su}	1.93 ± 0.03^{t}	1.95 ± 0.04^{tu}
24	1.80 ± 0.05^{v}	1.84 ± 0.05^{vx}	1.96 ± 0.05^{w}	1.99 ± 0.06^{wx}

Different letters denote significant differences ($p < 0.001$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 22. Longitudinal assessment of position groups by age (y) for gynoid lean mass to leg lean mass ratio

Age	Skill	Big Skill	Linemen	Special Teams
17	0.45 ± 0.005[a]	0.45 ± 0.005[a]	0.43 ± 0.005[b]	0.47 ± 0.006[c]
18	0.46 ± 0.002[d]	0.45 ± 0.003[d]	0.44 ± 0.003[e]	0.48 ± 0.005[f]
19	0.46 ± 0.002[g]	0.46 ± 0.002[g]	0.44 ± 0.002[h]	0.48 ± 0.004[i]
20	0.47 ± 0.002[j]	0.47 ± 0.002[j]	0.45 ± 0.002[k]	0.49 ± 0.004[l]
21	0.47 ± 0.002[m]	0.47 ± 0.002[m]	0.45 ± 0.002[n]	0.49 ± 0.004[o]
22	0.47 ± 0.002[p]	0.46 ± 0.003[p]	0.45 ± 0.003[q]	0.49 ± 0.005[r]
23	0.46 ± 0.004[s]	0.46 ± 0.004[s]	0.44 ± 0.004[t]	0.48 ± 0.006[u]
24	0.46 ± 0.008[v]	0.46 ± 0.008[v]	0.44 ± 0.008[w]	0.48 ± 0.008[x]

Different letters denote significant differences ($p < 0.01$) between position groups within age. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 23. Longitudinal assessment of age (y) by position groups for percent body fat (%)

A

Age	Skill
17	13.6 ± 0.6[ab]
18	14.5 ± 0.3[a]
19	15.0 ± 0.3[ab]
20	15.0 ± 0.3[ab]
21	15.3 ± 0.3[b]
22	15.4 ± 0.3[b]
23	14.9 ± 0.5[ab]
24	13.6 ± 0.9[ab]

B

Age	Big Skill
17	17.3 ± 0.6[ab]
18	18.2 ± 0.4[a]
19	18.8 ± 0.3[ab]
20	18.8 ± 0.3[ab]
21	19.1 ± 0.3[b]
22	19.1 ± 0.4[b]
23	18.6 ± 0.6[ab]
24	17.3 ± 1.0[ab]

C

Age	Linemen
17	25.7 ± 0.6[ab]
18	26.6 ± 0.4[a]
19	27.1 ± 0.3[ab]
20	27.1 ± 0.3[ab]
21	27.4 ± 0.3[b]
22	27.5 ± 0.4[b]
23	27.0 ± 0.6[ab]
24	25.7 ± 0.9[ab]

D

Age	Special Teams
17	18.9 ± 0.8[ab]
18	19.8 ± 0.7[a]
19	20.3 ± 0.6[ab]
20	20.3 ± 0.6[ab]
21	20.6 ± 0.6[b]
22	20.7 ± 0.7[b]
23	20.2 ± 0.8[ab]
24	18.9 ± 1.1[ab]

Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 24. Longitudinal assessment of age (y) by position groups for visceral adipose tissue (kg)

A

Age	Skill
17	0.26 ± 0.08[abc]
18	0.22 ± 0.02[a]
19	0.26 ± 0.02[a]
20	0.31 ± 0.02[b]
21	0.35 ± 0.02[bc]
22	0.39 ± 0.02[c]
23	0.41 ± 0.04[bc]
24	0.33 ± 0.07[abc]

B

Age	Big Skill
17	0.33 ± 0.08[abc]
18	0.29 ± 0.03[a]
19	0.33 ± 0.02[a]
20	0.38 ± 0.02[b]
21	0.42 ± 0.02[bc]
22	0.46 ± 0.03[c]
23	0.48 ± 0.04[bc]
24	0.40 ± 0.07[abc]

C

Age	Linemen
17	0.83 ± 0.08[abc]
18	0.79 ± 0.03[a]
19	0.83 ± 0.02[a]
20	0.89 ± 0.02[b]
21	0.92 ± 0.02[bc]
22	0.96 ± 0.03[c]
23	0.98 ± 0.04[bc]
24	0.91 ± 0.07[abc]

D

Age	Special Teams
17	0.33 ± 0.09[abc]
18	0.29 ± 0.05[a]
19	0.33 ± 0.05[a]
20	0.39 ± 0.05[b]
21	0.42 ± 0.05[bc]
22	0.46 ± 0.05[c]
23	0.48 ± 0.06[bc]
24	0.40 ± 0.08[abc]

Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 25. Longitudinal assessment of age (y) by position groups for total fat mass (kg)

A

Age	Skill
17	11.55 ± 0.86[ab]
18	12.93 ± 0.43[a]
19	13.66 ± 0.41[ab]
20	13.71 ± 0.42[ab]
21	14.13 ± 0.42[b]
22	14.27 ± 0.46[b]
23	13.66 ± 0.74[ab]
24	11.82 ± 1.30[ab]

B

Age	Big Skill
17	16.99 ± 0.89[ab]
18	18.37 ± 0.50[a]
19	19.10 ± 0.48[ab]
20	19.15 ± 0.48[ab]
21	19.58 ± 0.48[b]
22	19.71 ± 0.51[b]
23	19.10 ± 0.78[ab]
24	17.26 ± 1.33[ab]

C

Age	Linemen
17	32.67 ± 0.89[ab]
18	34.05 ± 0.50[a]
19	34.78 ± 0.48[ab]
20	34.84 ± 0.48[ab]
21	35.26 ± 0.48[b]
22	35.39 ± 0.52[b]
23	34.78 ± 0.78[ab]
24	34.94 ± 1.32[ab]

D

Age	Special Teams
17	16.73 ± 1.17[ab]
18	18.12 ± 0.92[a]
19	18.84 ± 0.91[ab]
20	18.89 ± 0.91[ab]
21	19.31 ± 0.91[b]
22	19.45 ± 0.92[b]
23	18.84 ±1.10[ab]
24	17.00 ± 1.52[ab]

Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 26. Longitudinal assessment of age (y) by position groups for total lean tissue mass (kg)

A

Age	Skill
17	70.65 ± 0.64[a]
18	72.04 ± 0.38[acd]
19	72.87 ± 0.36[b]
20	73.85 ± 0.37[c]
21	74.19 ± 0.37[cd]
22	74.62 ± 0.39[d]
23	75.35± 0.57[cd]
24	74.39 ± 0.96[abcd]

B

Age	Big Skill
17	75.35 ± 0.67[a]
18	76.74 ± 0.43[acd]
19	77.57 ± 0.42[b]
20	78.55 ± 0.42[c]
21	78.89 ± 0.41[cd]
22	79.33 ± 0.44[d]
23	80.05 ± 0.60[cd]
24	79.10 ± 0.98[abcd]

C

Age	Linemen
17	85.31 ± 0.69[a]
18	86.69 ± 0.45[acd]
19	87.53 ± 0.43[b]
20	88.51 ± 0.43[c]
21	88.84 ± 0.44[cd]
22	89.28 ± 0.45[d]
23	90.00 ± 0.62[cd]
24	89.05 ± 0.99[abcd]

D

Age	Special Teams
17	66.86 ± 1.00[a]
18	68.24 ± 0.86[acd]
19	69.08 ± 0.85[b]
20	70.05 ± 0.85[c]
21	70.39 ± 0.86[cd]
22	70.83 ± 0.86[d]
23	71.55 ± 0.96[cd]
24	70.60 ± 1.22[abcd]

Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 27. Longitudinal assessment of age (y) by position groups for bone mineral density (g/cm^2)

A

Age	Skill
17	1.47 ± 0.01^{ab}
18	1.51 ± 0.01^{be}
19	1.55 ± 0.01^{c}
20	1.58 ± 0.01^{de}
21	1.59 ± 0.01^{abc}
22	1.60 ± 0.01^{abc}
23	1.61 ± 0.01^{abc}
24	1.58 ± 0.02^{acd}

B

Age	Big Skill
17	1.51 ± 0.01^{ab}
18	1.55 ± 0.01^{be}
19	1.59 ± 0.01^{c}
20	1.62 ± 0.01^{de}
21	1.63 ± 0.01^{abc}
22	1.64 ± 0.01^{abc}
23	1.65 ± 0.01^{abc}
24	1.61 ± 0.02^{acd}

C

Age	Linemen
17	1.57 ± 0.01^{ab}
18	1.61 ± 0.01^{be}
19	1.65 ± 0.01^{c}
20	1.68 ± 0.01^{de}
21	1.69 ± 0.01^{abc}
22	1.71 ± 0.01^{abc}
23	1.71 ± 0.01^{abc}
24	1.68 ± 0.02^{acd}

D

Age	Special Teams
17	1.40 ± 0.02^{ab}
18	1.44 ± 0.01^{be}
19	1.48 ± 0.01^{c}
20	1.51 ± 0.01^{de}
21	1.52 ± 0.01^{abc}
22	1.53 ± 0.01^{abc}
23	1.54 ± 0.02^{abc}
24	1.51 ± 0.02^{acd}

Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 28. Longitudinal assessment of age (y) by position groups for total upper mass to lean leg mass ratio

A

Age	Skill
17	1.96 ± 0.03[ab]
18	2.02 ± 0.01[a]
19	2.04 ± 0.01[ab]
20	2.05 ± 0.01[ab]
21	2.06 ± 0.01[b]
22	2.07 ± 0.02[b]
23	2.05 ± 0.03[ab]
24	2.07 ± 0.05[ab]

B

Age	Big Skill
17	2.06 ± 0.03[ab]
18	2.12 ± 0.02[a]
19	2.14 ± 0.02[ab]
20	2.15 ± 0.02[ab]
21	2.16 ± 0.02[b]
22	2.17 ± 0.02[b]
23	2.15 ± 0.03[ab]
24	2.17 ± 0.05[ab]

C

Age	Linemen
17	2.24 ± 0.03[ab]
18	2.30 ± 0.02[a]
19	2.32 ± 0.02[ab]
20	2.33 ± 0.02[ab]
21	2.34 ± 0.02[b]
22	2.35 ± 0.02[b]
23	2.33 ± 0.03[ab]
24	2.35 ± 0.05[ab]

D

Age	Special Teams
17	2.19 ± 0.04[ab]
18	2.25 ± 0.03[a]
19	2.27 ± 0.03[ab]
20	2.28 ± 0.03[ab]
21	2.29 ± 0.03[b]
22	2.30 ± 0.03[b]
23	2.28 ± 0.03[ab]
24	2.30 ± 0.05[ab]

Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 29. Longitudinal assessment of age (y) by position groups for upper total mass to legs total mass ratio

A

Age	Skill
17	1.89 ± 0.03[ab]
18	1.84 ± 0.02[ab]
19	1.85 ± 0.02[a]
20	1.82 ± 0.02[b]
21	1.78 ± 0.02[c]
22	1.76 ± 0.02[c]
23	1.77 ± 0.03[abc]
24	1.80 ± 0.05[abc]

B

Age	Big Skill
17	1.93 ± 0.03[ab]
18	1.89 ± 0.02[ab]
19	1.90 ± 0.02[a]
20	1.86 ± 0.02[b]
21	1.82 ± 0.02[c]
22	1.81 ± 0.02[c]
23	1.81 ±0.03[abc]
24	1.84 ± 0.05[abc]

C

Age	Linemen
17	2.05 ± 0.03[ab]
18	2.01 ± 0.02[ab]
19	2.02 ± 0.02[a]
20	1.98 ± 0.02[b]
21	1.94 ± 0.02[c]
22	1.93 ± 0.02[c]
23	1.93 ± 0.03[abc]
24	1.96 ± 0.05[abc]

D

Age	Special Teams
17	2.07 ± 0.05[ab]
18	2.03 ± 0.04[ab]
19	2.04 ± 0.03[a]
20	2.00 ± 0.03[b]
21	1.97 ± 0.03[c]
22	1.95 ± 0.04[c]
23	1.95 ± 0.04[abc]
24	1.99 ± 0.06[abc]

Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Table 30. Longitudinal assessment of age (y) by position groups for gynoid lean mass to leg lean mass ratio

A

Age	Skill
17	0.45 ± 0.005[acd]
18	0.46 ± 0.002[a]
19	0.46 ± 0.002[c]
20	0.47 ± 0.002[b]
21	0.47 ± 0.002[bd]
22	0.47 ± 0.002[bc]
23	0.46 ± 0.004[abcd]
24	0.46 ± 0.008[abcd]

B

Age	Big Skill
17	0.45 ± 0.005[acd]
18	0.45 ± 0.003[a]
19	0.46 ± 0.002[c]
20	0.47 ± 0.002[b]
21	0.47 ± 0.002[bd]
22	0.46 ± 0.003[bc]
23	0.46 ± 0.004[abcd]
24	0.46 ± 0.008[abcd]

C

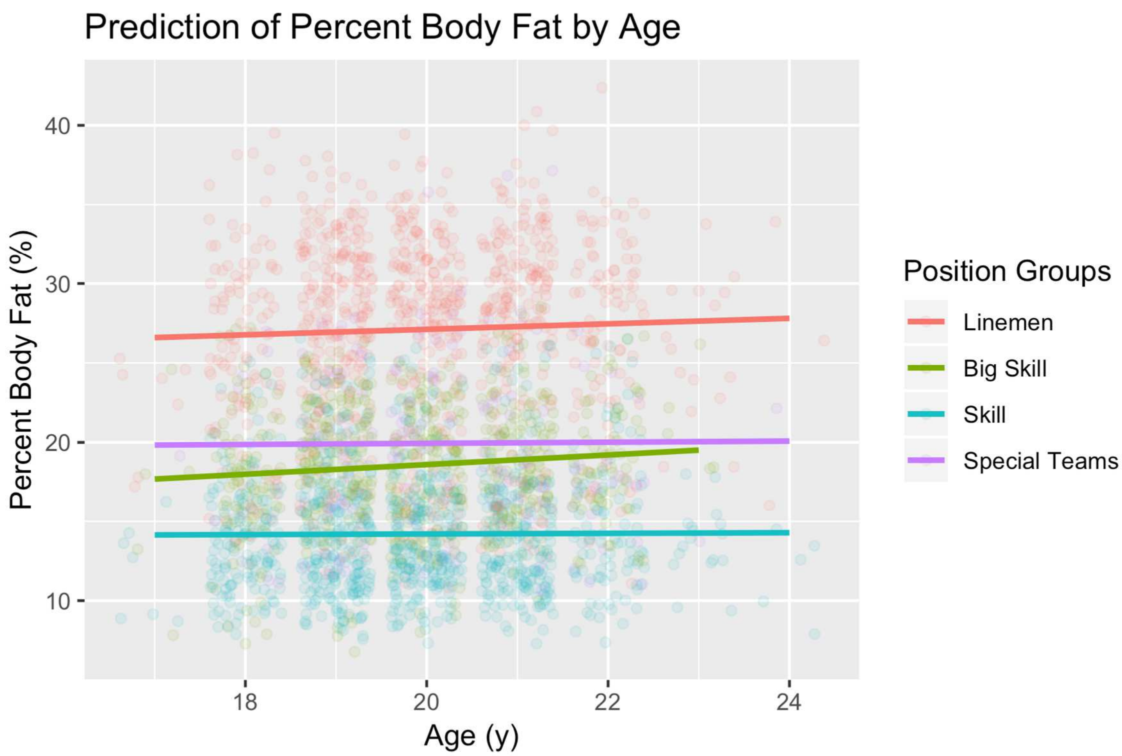
Age	Linemen
17	0.43 ± 0.005[acd]
18	0.44 ± 0.003[a]
19	0.44 ± 0.002[c]
20	0.45 ± 0.002[b]
21	0.45 ± 0.002[bd]
22	0.45 ± 0.003[bc]
23	0.44 ± 0.004[abcd]
24	0.44 ± 0.008[abcd]

D

Age	Special Teams
17	0.47 ± 0.006[acd]
18	0.48 ± 0.005[a]
19	0.48 ± 0.004[c]
20	0.49 ± 0.004[b]
21	0.49 ± 0.004[bd]
22	0.49 ± 0.005[bc]
23	0.48 ± 0.006[abcd]
24	0.48 ± 0.008[abcd]

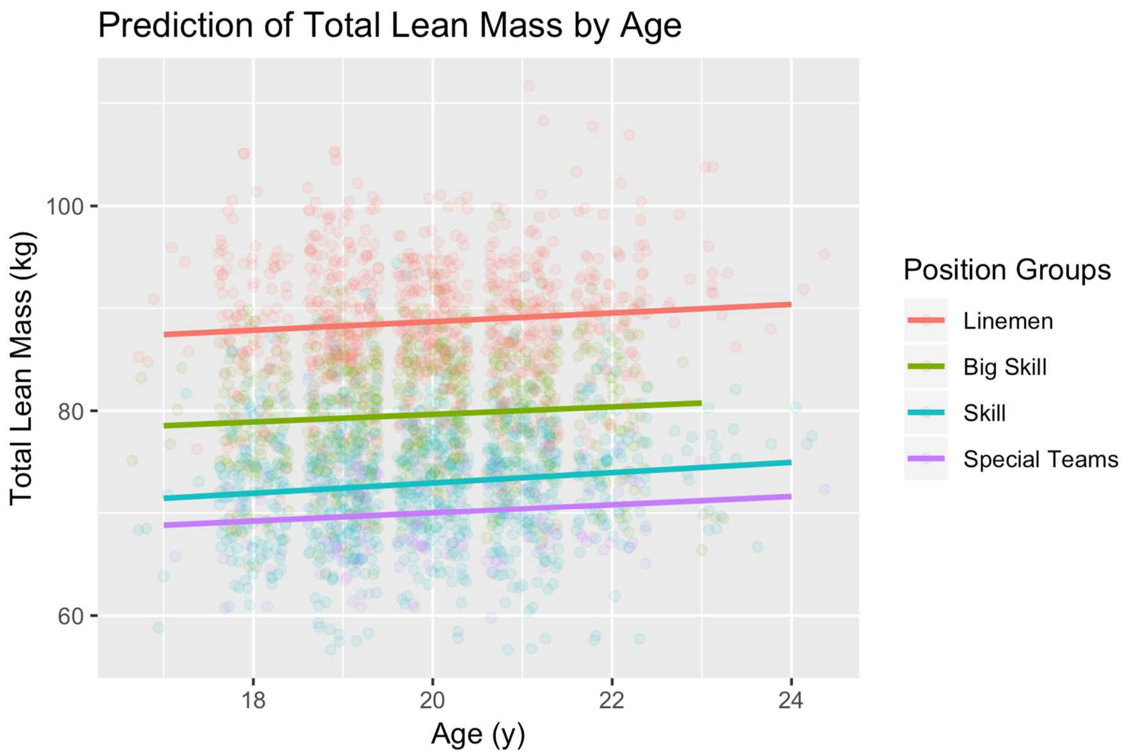
Different letters denote significant differences ($p < 0.05$) between ages within position groups. All values reported as means ± se. Position groups are defined as follows: Skill: defensive backs, running backs, and wide receivers; Big Skill: linebackers, tight ends, and quarterbacks; Linemen: offensive and defensive linemen; Special Teams: punters, kickers and long snappers.

Figure 8. Calculated percent body fat predictions for football players ages 17-24



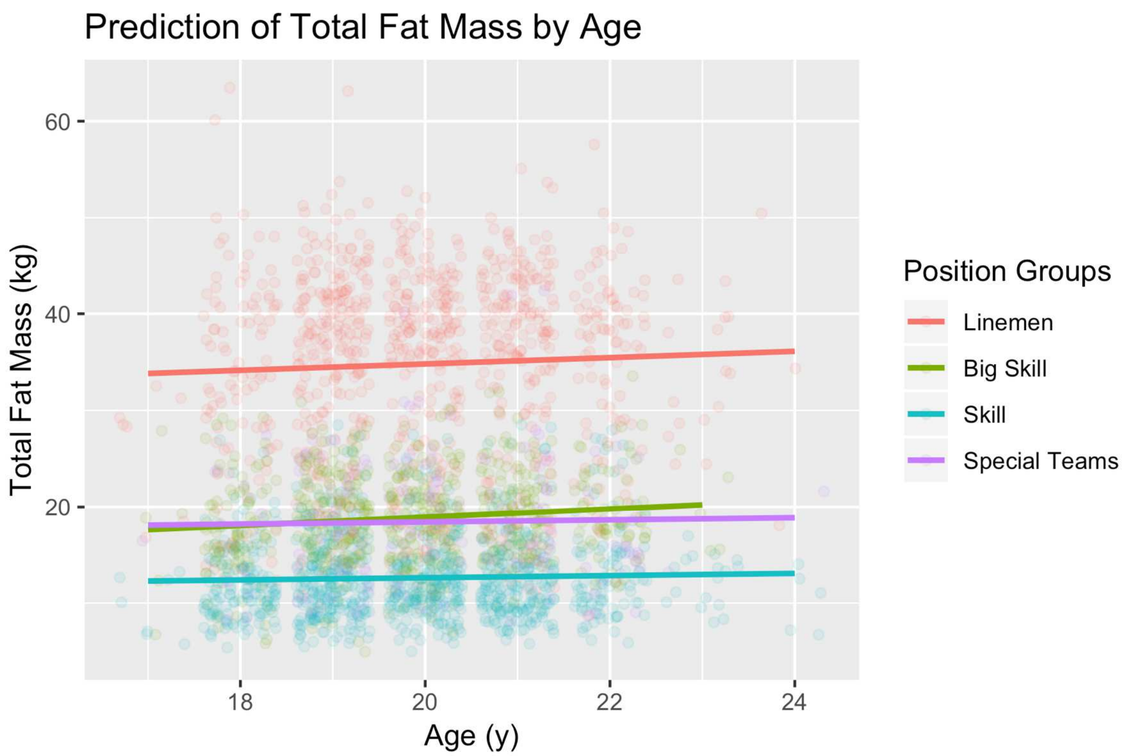
Position groups are defined as follows: Linemen (red line): offensive and defensive linemen; Big Skill (green line): linebackers, tight ends, and quarterbacks; Skill (blue line): defensive backs, running backs, and wide receivers; Special Teams (purple line): punters, kickers and long snappers.

Figure 9. Calculated total lean mass (kg) predictions for football players ages 17-24



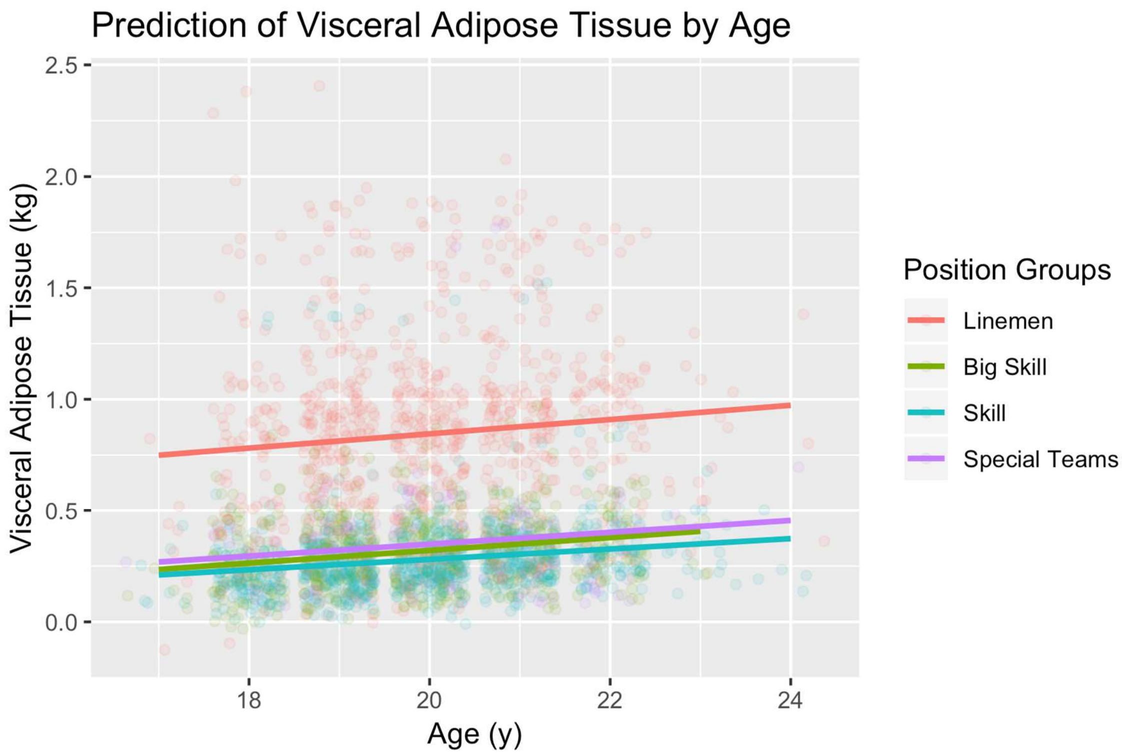
Position groups are defined as follows: Linemen (red line): offensive and defensive linemen; Big Skill (green line): linebackers, tight ends, and quarterbacks; Skill (blue line): defensive backs, running backs, and wide receivers; Special Teams (purple line): punters, kickers and long snappers.

Figure 10. Calculated total fat mass (kg) predictions for football players ages 17-24



Position groups are defined as follows: Linemen (red line): offensive and defensive linemen; Big Skill (green line): linebackers, tight ends, and quarterbacks; Skill (blue line): defensive backs, running backs, and wide receivers; Special Teams (purple line): punters, kickers and long snappers.

Figure 11. Calculated visceral adipose tissue (kg) predictions for football players ages 17-24



Position groups are defined as follows: Linemen (red line): offensive and defensive linemen; Big Skill (green line): linebackers, tight ends, and quarterbacks; Skill (blue line): defensive backs, running backs, and wide receivers; Special Teams (purple line): punters, kickers and long snappers.