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Upper Extremity Asymmetries in Collegiate Tennis Players Compared to an Athletic Control of Runners

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Abstract

International Journal of Exercise Science 18(3): 1151-1165, 2025. https://doi.org/10.70252/MDRK9289 Previous research on limb asymmetries of athletes participating in dominant-sided sports lacks an athletic control group. This study aimed to determine the magnitude of upper limb asymmetries in dominant-sided athletes (tennis players) compared to nondominant-sided athletes (cross-country runners). Men and women university athletes (10 tennis, 11 cross-country) participated. Dual-energy x-ray absorptiometry (DXA) was used to measure bone mineral content (BMC), bone mineral density (BMD), and lean mass (LM) of the whole body, upper extremities, and forearms. Circumference measurements were taken at mid-biceps and widest part of the forearms. Bony breadth of the elbow was measured with sliding calipers placed at the medial and lateral epicondyles. Grip strength was assessed with a dynamometer. Mixed-model ANOVA was used to analyze data between dominant/nondominant sides and between sports. There were no significant differences in age ($p = .150$), height ($p = .783$) or body mass ($p = .066$) between teams. No differences were shown between sports for total body BMC ($p = .544$), total body BMD ($p = .535$), or total body LM ($p = .843$). Sport × side interaction was significant ($p < .05$) for lower arm circumference, elbow bony breadths, total upper extremity LM, total upper extremity BMC, total upper extremity BMD, forearm BMC, ultra-distal forearm BMC, mid-distal forearm BMC, one-third forearm BMC, and ultra-distal forearm BMD. Morphological differences between sports were localized to the arm. Sport specificity influences mass and volume (circumference, LM, BMC) of the limb, with BMD particularly enhanced in ultra-distal forearm.

Keywords: Athlete, body composition, bone, Dual-Energy X-Ray Absorptiometry, grip strength

Introduction

Interlimb asymmetries (e.g., side-to-side imbalances) are common and sometimes noticeable between dominant and non-dominant sides, or injured and non-injured limbs.[1] These asymmetries can develop naturally throughout maturation, due to injury, or as a result of training. Asymmetries can be categorized as strength, skill, or morphological asymmetries.[2] Most morphological, or physical, asymmetries are associated with body composition differences – particularly lean and bone mass asymmetries.[1,3,4] The physical dimensions of the right and left sides of the human body are rarely perfect mirror images. For example, a study of a large sample of adult skeletons from six continents showed a consistent right-biased asymmetry for upper limb bone dimensions.[5] The magnitude of a bilateral asymmetry is influenced by the type and volume of activity and individual does.[6] Morphological asymmetries are sometimes assessed with circumference measures or anthropometric sliding calipers; however, dual-energy x-ray absorptiometry (DXA) provides a more comprehensive analysis. In addition to assessing total body composition, DXA can provide detailed analysis of the fat mass and lean mass (LM) of contralateral body segments. Additionally, bone-specific content can be measured with DXA.

Within sport, training can lead to adaptations and development of asymmetries. Training adaptations can excessively focus, usually unintentionally, on one side of the body. This occurs particularly in sports that emphasize a dominant side (e.g., baseball pitchers, football punters), resulting in an imbalance of lean and bone masses. Training adaptations and asymmetries can be particular depending on the nature of the sport.[7] Softball players, for example, primarily use their dominant arm to pitch. Repeated biomechanical forces induce bone adaptations within the mid-humerus, resulting in an increase in lean and bone mass.[8] Although training can affect large segments and systems of the body, some adaptations are localized. These localized adaptations are considered "site-specific" in response to years of training and competition, while other sites remain unaffected.

A prominent example of site-specific adaptation is bone. Bone adapts to mechanical loading and high-impact volume.[7] Years of training and skeletal adaptations result in improved bone quality, with increased bone mineral content (BMC) and bone mineral density (BMD). Tennis players are a prime example of site-specific bone adaptations. Repetitive high-volume impact and loading of the tennis racket induces adaptations to players' bones, specifically their dominant upper extremity.[4] Bone adaptations essentially result in the increased quality of bone, but this adaptation is localized to the site that was most active or stressed.

Bone adaptation research has determined upper limb asymmetries through the mid-humerus or entire upper extremity across several sports (e.g. tennis, softball, gymnastics).[8-10] These asymmetries were determined through custom analysis or pre-programmed DXA analyses of the entire upper extremity.[8-10] Surprisingly, few studies of dominant-sided athletes have included forearm-specific analysis, despite the forearm being the recommended site to evaluate BMD and BMC of the upper extremity.[11] Particularly in high-volume, dominant-handed collegiate sports, the forearm would most likely exhibit the most adaptation from impact.[12] Forearm-specific analyses are capable of separating the forearm into three regions of interest to provide detail into which area of the upper extremity might be most affected or adaptable to repeated ball-racket impacts. In addition, there is minimal research that compares highly trained, dominant-handed collegiate athletes to an equally athletic control group with no upper limb dominance. The primary aim of this study was to quantify the amount and percentage of BMD, BMC, and LM asymmetries in the upper extremities of National Collegiate Athletic Association (NCAA) Division I tennis players compared to an equally athletic control group (also NCAA Division I athletes) with no sport side dominance. Anthropometric and grip strength imbalances were also evaluated. We hypothesize that there will be a greater magnitude of asymmetry in the dominant-sided athletes, with adaptations localized specifically to the forearm.

Methods

Study Design and Participants

An observational, cross-sectional study examined whole body and forearm asymmetries in NCAA Division I tennis athletes, a primarily upper body, high-volume impact and loading sport. BMC, BMD, and LM asymmetries were assessed. Results from the dominant-sided experimental group were compared to a control group of athletes with no sport-specific dominant side or upper body high-volume impact or loading in their sport.

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Utah State University (protocol #13655 approved July 2023). The research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.[13] Eligible participants provided a written informed consent for the experimental protocol (#13655). Subjects were compensated twenty-five dollars for their time. Data collection commenced in subjects' off-season in November and December. Data analysis occurred in the following months.

A power analysis was calculated through G*Power software program (version 3.0.10; Heinrich Heine Universität Düsseldorf, Germany) to estimate sample size. An a priori sample estimate of a repeated measures analysis of variance (ANOVA) analyzing the within-between interaction assuming an alpha of 0.05 and power of 0.95 was run. The correlation between right and left sides of the body and the effect size were conservatively estimated to be 0.85 and 0.25, respectively. Given these parameters, the calculated total sample size was 18.

Participants came from a convenience sample of Utah State University NCAA Division I athletes. The dominant-sided athletes were recruited from the men's (n = 3) and women's (n = 7) tennis teams for the experimental group, while the men's (n = 5) and women's (n = 6) cross-country teams served as the athletic control group. In total, 21 athletes participated. Ages ranged from 18 – 23 y. Exclusion criteria included pregnancy, amenorrhea, major injury of the upper extremity within the past year (major surgery or bone fractures), missing a limb, and metal in or on the body (screws, rods, permanent jewelry, etc.).

Protocol

Demographic information including age, race, sport, position, dominant upper extremity, years of competitive experience, class standing, and self-report of menstrual cycle regularity were collected. Height was measured to the nearest 0.1 cm with a wall-mounted stadiometer (Seca 222, Seca Corp., Chino, CA), and weight was measured to the nearest 0.1 kg with a digital scale (Seca 869, Seca Corp., Chino, CA). Body composition assessments were performed with a DXA machine (Horizon W, Hologic, Inc., Marlborough, MA). The DXA machine was calibrated with the manufacturer-provided spine phantom. Subjects wore light clothing (e.g., shorts and T-shirt) without metal and removed any jewelry or additional metal. A state licensed bone densitometry operator appropriately positioned and scanned the subjects per standardized procedures consistent with the manufacturer's guidelines. Three scans were conducted: whole body, dominant forearm, and non-dominant forearm. For the whole-body scan, the subject was centered on the table, supine, with arms at their sides, hands pronated (palms on table), and feet slightly rotated inwards. For the forearm scans, the subject was seated next to the table with their arm placed on the scanning table. The forearm scans provided a detailed analysis of the distal part of the forearm, divided into three regions of interest: ultra-distal (the most distal site of the radius), distal one-third (33%), and mid-distal (an intermediate region between ultra-distal and one-third) (Figure 1).[11] BMD, BMC, and LM were obtained from the DXA machine's software (APEX System Software Version 5.6.0.5).

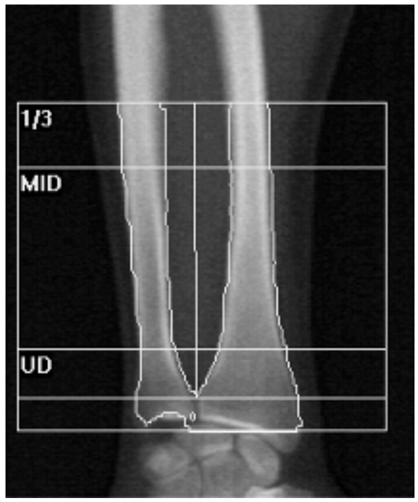

Figure 1. DXA scan of forearm and regions of interest (UD = ultra-distal, MID = mid-distal, 1/3 = one-third distal).

Circumferences were measured to the nearest 0.1 cm on the dominant and non-dominant upper limbs with an anthropometric tape measure with a Gulick spring-loaded handle (Fabrication Enterprises, Inc., White Plains, NY). Upper arm circumference measurements were measured at the mid-humerus, mid-acromial-radial landmark, with the arm relaxed.[14] Lower arm circumferences were measured distal to the elbow at the maximal girth of the forearm.[14] Elbow bony breadth was measured to the nearest 0.1 cm with a sliding caliper (Lafayette 01291, Lafayette Instrument Co., Lafayette, IN) placed at the medial and lateral epicondyles of the humerus.[14]

Grip strength was assessed to the nearest 0.5 kg with a handgrip dynamometer (TKK 5001, Grip-A, Takei, Tokyo). Grip size of the dynamometer was adjusted for each subject's comfort (middle phalange of index finger approximately flat on top of the handle). The subject was in a standing position with feet hip-width apart and arms fully extended at their sides.[15] Three trials were recorded and averaged. There was one minute of rest between trials, alternating between the dominant and non-dominant sides. All measurements were taken in a single session. Each session averaged 30 min.

Statistical Analysis

Data were assessed for outliers. SPSS software (Version 29, IBM, Inc., Chicago, IL) was used for all statistical analyses. An independent *t*-test was done to evaluate mean differences between tennis players and runners for descriptive characteristics. A mixed model ANOVA was done to compare dominant and non-dominant arms within subjects and between groups (control vs dominant-sided athletes) with sex as a covariate for each variable of interest including: BMC, BMD, LM, anthropometric measurements, and grip strength. Significant findings were indicated as *p*-value below 0.05. The percentage difference between dominant and non-dominant limbs was calculated as an indication of the magnitude of difference.

Results

Descriptive characteristics of the sample are in Table 1. The tennis players had more years of competitive experience than the runners [$t(19) = 4.60$, $p < 0.001$], but there were no significant differences in age [$t(19) = -1.50$, $p = 0.150$], height [$t(19)$, $p = 0.783$] or body mass [$t(19)$, $p = 0.066$] between teams.

Table 1. Descriptive characteristics of study sample. Data are mean ± SD.

	Tennis Players	Runners
Age (years)	19.8 ± 0.9	20.9 ± 2.2
Height (cm)	172.2 ± 11.5	173.4 ± 7.9
Body mass (kg)	69.0 ± 5.3	62.8 ± 8.6
Body mass index (kg/m^2)	23.4 ± 1.9	20.8 ± 1.6
Competitive experience (years)	12.6 ± 1.6	7.9 ± 2.8

Table 2. Morphological asymmetry values for NCAA tennis players (n = 10) versus controls (n = 11). Data are mean ± SD.

	Tennis Players			Controls		
Variable	**D value**	**ND value**	**PD (%)**	**D value**	**ND value**	**PD (%)**
Anthropometry						
Cir upper arm (cm)*	27.7 ± 1.5	27.6 ± 1.9	0.2 ± 4.1	25.6 ± 2.5	25.7 ± 2.7	0.0 ± 3.0
Cir lower arm (cm)*†‡	25.4 ± 1.7	24.1 ± 1.5	5.3 ± 1.5	23.9 ± 2.1	23.5 ± 1.9	1.6 ± 1.8
Elbow bony breadth (cm)‡	6.0 ± 0.5	5.9 ± 0.5	2.5 ± 3.6	6.2 ± 0.5	6.2 ± 0.6	-1.2 ± 2.6
DXA – Upper Limb						
Lean mass (g)†‡	2522.5 ± 666.6	2246.8 ± 695.2	13.8 ± 7.8	2471.4 ± 627.1	2353.3 ± 652.8	5.7 ± 5.0
BMC (g)†‡	184.25 ± 34.06	144.72 ± 25.05	27.3 ± 6.4	165.29 ± 35.91	152.24 ± 33.54	8.8 ± 4.4
BMD (g/cm^3)†‡	0.846 ± 0.051	0.747 ± 0.037	13.3 ± 3.9	0.790 ± 0.081	0.784 ± 0.080	0.8 ± 2.7
DXA – Forearm						
UD BMC (g)†‡	1.85 ± 0.35	1.55 ± 0.23	18.5 ± 11.0	1.72 ± 0.34	1.60 ± 0.28	6.9 ± 6.6
UD BMD (g/cm^3)‡	0.471 ± 0.058	0.446 ± 0.046	5.9 ± 9.4	0.460 ± 0.067	0.463 ± 0.069	-0.7 ± 3.8
MID BMC (g)†‡	5.20 ± 1.25	4.53 ± 1.01	14.9 ± 9.0	5.17 ± 1.25	5.00 ± 1.08	2.9 ± 4.2
MID BMD (g/cm^3)	0.614 ± 0.062	0.607 ± 0.059	1.1 ± 5.1	0.635 ± 0.065	0.628 ± 0.051	1.0 ± 3.7
1/3 BMC (g)†‡	3.83 ± 0.41	3.50 ± 0.36	9.4 ± 7.6	3.78 ± 0.72	3.74 ± 0.70	1.0 ± 3.7
1/3 BMD (g/cm^3)	0.718 ± 0.053	0.706 ± 0.055	2.0 ± 5.6	0.717 ± 0.062	0.709 ± 0.050	1.0 ± 3.4
Forearm BMC (g)†‡	9.09 ± 1.78	7.88 ± 1.33	15.2 ± 8.0	8.86 ± 1.96	8.55 ± 1.69	3.2 ± 3.8
Forearm BMD (g/cm^3)	0.599 ± 0.054	0.586 ± 0.051	2.4 ± 5.8	0.606 ± 0.064	0.604 ± 0.055	0.3 ± 3.1
Performance						
Grip strength (kg)†	31.0 ± 6.5	28.2 ± 7.1	11.4 ± 11.8	31.6 ± 9.7	28.9 ± 9.2	10.4 ± 6.4

D: dominant side; ND: nondominant side; PD: percentage difference; Cir: circumference, BMC: bone mineral content; BMD: bone mineral density; Forearm is divided into three segments: UD (ultra-distal), MID (mid-distal), 1/3 (one-third); *Significant main effect of sport ($p < .05$; tennis > control); †Significant main effect of side ($p < .05$; dominant > nondominant); ‡Significant interaction effect ($p < .05$).

There were no differences between tennis players and athletic controls for total body BMC (2632.36 ± 443.38 g vs. 2515.52 ± 423.61 g; $p = 0.544$), total body BMD (1.24 ± 0.09 g/cm^3 vs. 1.22 ± 0.09 g/cm^3; $p = 0.535$), or total body LM (46.3 ± 7.7 kg vs. 45.6 ± 8.8 kg; $p = 0.843$). Main effects of sport and contralateral differences are detailed in Table 2. The sport × side interaction was significant for lower arm circumference ($p < 0.001$), elbow bony breadth ($p = 0.018$), total upper extremity LM ($p = 0.006$), total upper extremity BMC ($p < 0.001$), total upper extremity BMD ($p < 0.001$), forearm BMC ($p < 0.001$), ultra-distal forearm BMC ($p = 0.004$), mid-distal forearm BMC ($p < 0.001$), one-third forearm BMC ($p = 0.002$), and ultra-distal forearm BMD ($p = 0.015$). For all significant interactions, there were higher values for the dominant arm of the tennis players creating larger contralateral asymmetries for the tennis players compared to the runners. These significant interactions are graphically represented in supplemental figures at the end of this manuscript. The main effect of side was significant ($p < 0.001$) with greater values for the dominant arm compared to the nondominant side for lower arm circumference, total upper extremity LM, total upper extremity BMC, total upper extremity BMD, BMC for the ultra-distal, mid-distal, and one-third forearm, as well as the total forearm, and grip strength. The only significant main effect between groups was the tennis players had larger upper ($p = 0.010$) and lower ($p = 0.019$) arm circumferences compared to runners.

Discussion

This study supports the hypothesis that dominant-sided athletes have greater asymmetry compared to a control group, additionally supporting evidence of site-specific training adaptations to the dominant forearm. Many collegiate athletes have years of experience, resulting in long-term exercise adaptations specific to their sport. The main findings of the present investigation were that upper extremity lean mass (LM), bone mineral content (BMC), and circumferences are significantly greater for tennis players compared to age-, height-, and weight-matched athletic controls. This is supported by additional research,[16,17] confirming a morphological asymmetry in the upper dominant limb of the tennis athletes. Sports specificity is the likely cause for the one-sided development in mass and volume of the upper extremity in the tennis athletes. These adaptations can be attributed to primary use and training of the dominant extremity over an extended period of time.[3] The years of competitive experience for the tennis players in this study ranged from 9 to 15 years, which is more than half of their lives.

Another main finding from this study is the evidence of site-specific bone adaptation. Aside from sport-specific adaptations localized to the dominant upper extremity, there were specific adaptations within the forearm sites. All sites of the dominant forearm had greater BMC asymmetry for tennis players compared to runners, but only the ultra-distal site of the dominant forearm of tennis players had a significantly larger bone mineral density (BMD). This finding parallels that of Ireland et al[17] They used peripheral quantitative computed tomography to study upper limb muscle and bone asymmetries in elite junior tennis players. Asymmetrical increases in BMC were observed throughout the racket arm, but were most prominent at the distal radius. The increase of BMD for the racket arm was limited to the distal radius. Our findings and those of Ireland et al[17] correspond to the notion that areas of bone that do not experience targeted high impact or loading will not increase BMD.[7] This supports the principle that bone improvements are site-specific in response to external forces.[7]

This phenomenon is reinforced by Wolff's Law, which describes the process of bone tissue formation and remodeling in response to mechanical forces that act on it.[12] Research suggests that these responses can differ based on the type of bone that is experiencing mechanical force.[7] Bone can be further categorized into cortical and trabecular bone, the compact outer shell and the spongy structure within bone, respectively. Research findings suggest that in response to an external force, cortical bone reacts by increasing in size (or content) and trabecular bone responds by increasing in density.[7] This may explain why the ultra-distal site, primarily made up of trabecular bone,[18] experienced increased BMD. Additionally, the mid- and one-third sites, primarily consisting of cortical bone,[17] experienced increased BMC.

Our findings suggest that sport asymmetries are unique to training. Softball players, specifically overhand throwers, exhibited greater bone adaptations in the mid-humerus, compared to windmill pitchers.[8] This can be attributed to repetitive overhand and underhand throwing mechanics and forces acting on the upper extremity.[8] In comparison to tennis players, the high impact and loading of the racket induces further adaptations in the forearm rather than the humerus.[7,10] Even though the forces contributing to adaptations may differ, tennis and softball athletes saw an increase in mass and volume of the primary area; namely, BMC, LM, and circumference.[8,9] In addition, training technique, such as a one-handed versus two-handed backhand in tennis, influences the magnitude of asymmetry.[19] Tennis players that primarily use a one-handed backhand experienced almost four times greater cortical volume compared to two-handed backhand counterparts.[19] This confirms that even within a sport, the position on the team and training technique can influence adaptations.

Anthropometric measures were affected in the dominant side of the tennis players. These measures included lower arm circumference, elbow bony breadths, LM, and BMC. Morphological asymmetries are pronounced in dominant-sided sport,[16,17,20] regardless of age.[16,21] Research has found that even young, adolescent, elite tennis players display morphological asymmetries between upper limbs,[16,21,22] suggesting that high-volume impact training effects can be rapid. Our findings are similar to those of past studies,[9,19,20] with pronounced morphological asymmetry of the dominant side.

Surprisingly, grip strength was not significantly different between groups. Grip strength was expected to be higher in the tennis group compared to the control, due to the nature of the sport and previous findings.[16,19,20,23] This contradiction may be due to similar athleticism between the sport groups in the present study. Previous research[24] found significant grip strength differences between athletic and general populations but not necessarily between athletic groups. In addition, recent research has found that morphological asymmetries do not entirely account for functional (or skill) asymmetries.[16] This finding may account for the significant sport × side asymmetry in LM, but not a significant sport × side interaction for grip strength. Interestingly, grip strength in the non-dominant hand of the tennis group was lower than the control. Although this was not significant, it may suggest lack of use of the non-dominant hand, leading to further functional asymmetry.

There is the (mis)perception that bilateral asymmetries in athletes increase injury risk. However, research does not support this notion as several reviews[6,25-27] have concluded that there is no clear evidence supporting a relationship between increased injury risk and limb asymmetry. At best, any link between the two is equivocal and would most likely be specific to lower body strength imbalances.[26,27] Further, there is no clear criteria for defining an asymmetry or successful rehabilitation to symmetry.[2] Asymmetry values of 10-15% have most frequently been used to define "abnormal", but this threshold is not supported by evidence.[28] Also, this threshold is specific to strength imbalances; no similar threshold exists for anthropometric or morphological asymmetries. Although we did not measure injury statistics in this investigation, the magnitude of asymmetry observed can be a guide for clinicians. For example, if a physician or physical therapist is rehabilitating an injured tennis athlete, they might be expecting to observe limb differences below 10% before claiming success. However, our data shows that the average asymmetry of healthy NCAA Division I tennis players exceeded 10% for most variables of bone health and LM (see Table 2). Consequently, upper-body asymmetries that exceed 10% might be considered "normal" in this population.

The main limitation of this study was a small sample size. The sample size was large enough to answer the research question, but not large enough to separate the analyses by sex. Despite accounting for sex as a covariate in the analyses, one could argue that sex-specific differences in bone could affect the study results. However, tennis players and controls were matched for age, height, and body mass, and body composition variables such as bone-free LM are stronger predictors of bone characteristics than sex.[29] The skeletal responsiveness to mechanical loading is thought to be similar between men and women[29]; thus, it is unlikely that the proportion of limb asymmetries would differ by sex. Additionally, the findings are limited to highly trained, young adult, tennis players. The magnitude of dominant-nondominant asymmetries may be very different for youth or senior players.[4] The main strength of the study was the comparison of the experimental group to an equally athletic control group. Past research[9,16] has determined whole body asymmetries within subjects, but rarely in comparison to an equally athletic control group with no sport-side dominance. Other researchers investigating morphological asymmetries of athletes typically used a control group matched in age and sex, but not in physical size or athletic level.[8,10,16] The body composition and morphology of athletes versus the general population can vary widely, which would influence the magnitude of bone and LM adaptations between groups. By introducing an equally athletic control group, we were able to focus on the magnitude of asymmetry by sport-specific adaptations rather than physical activity levels. The finding that BMD asymmetry was localized to the ultra-distal forearm is novel and highlights that significant improvements in BMD are limited to the areas of impact or stress. As previously mentioned, although our results are specific to highly trained, young adult tennis players, these findings, to some extent, may be generalizable to highly experienced recreation or competitive players, in an upper limb dominant sport.[6] Future research might focus on other dominant-sided athletes to see if this pattern of increased BMD is limited primarily to the point of impact (e.g., the ankle of a football punter relative to BMD changes at the tibia and femur).

In summary, we found that physical asymmetries are more pronounced in dominant-sided sports than in controls, with bone and LM affected more than grip strength. In general, considering the upper extremities, the differences between the tennis and cross-country athletes were primarily localized to the forearm. Sport specificity appeared to influence mass and volume (circumference, bony breadths, LM, BMC) more than density. Although, at a closer glance, the BMD of tennis players was enhanced locally at the ultra-distal site of the dominant forearm.

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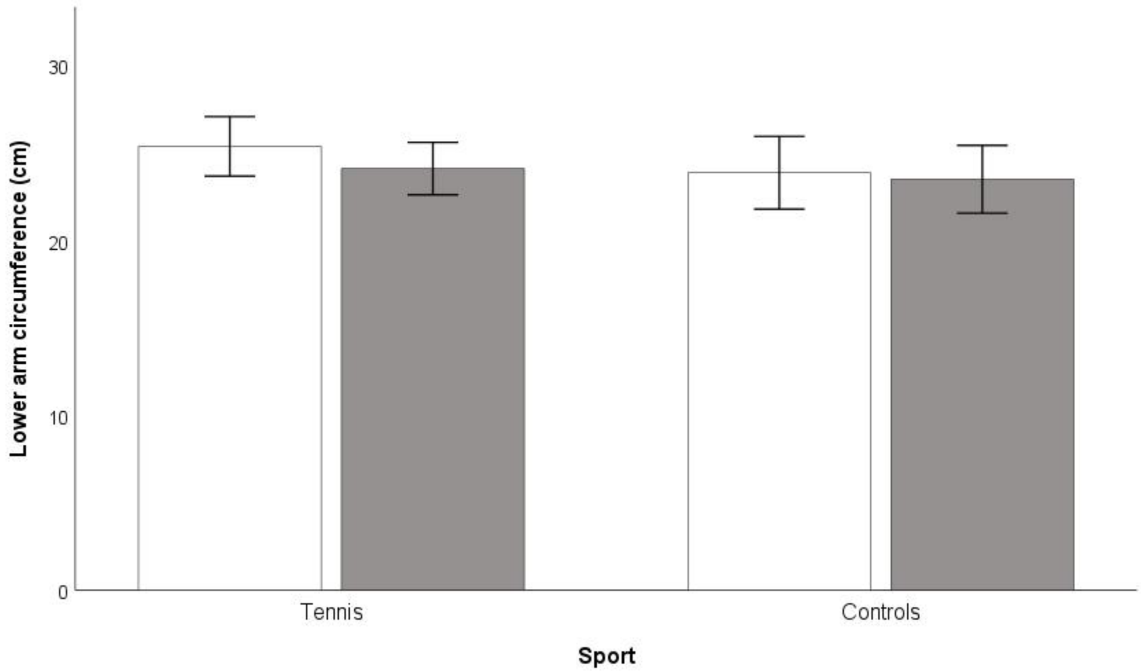
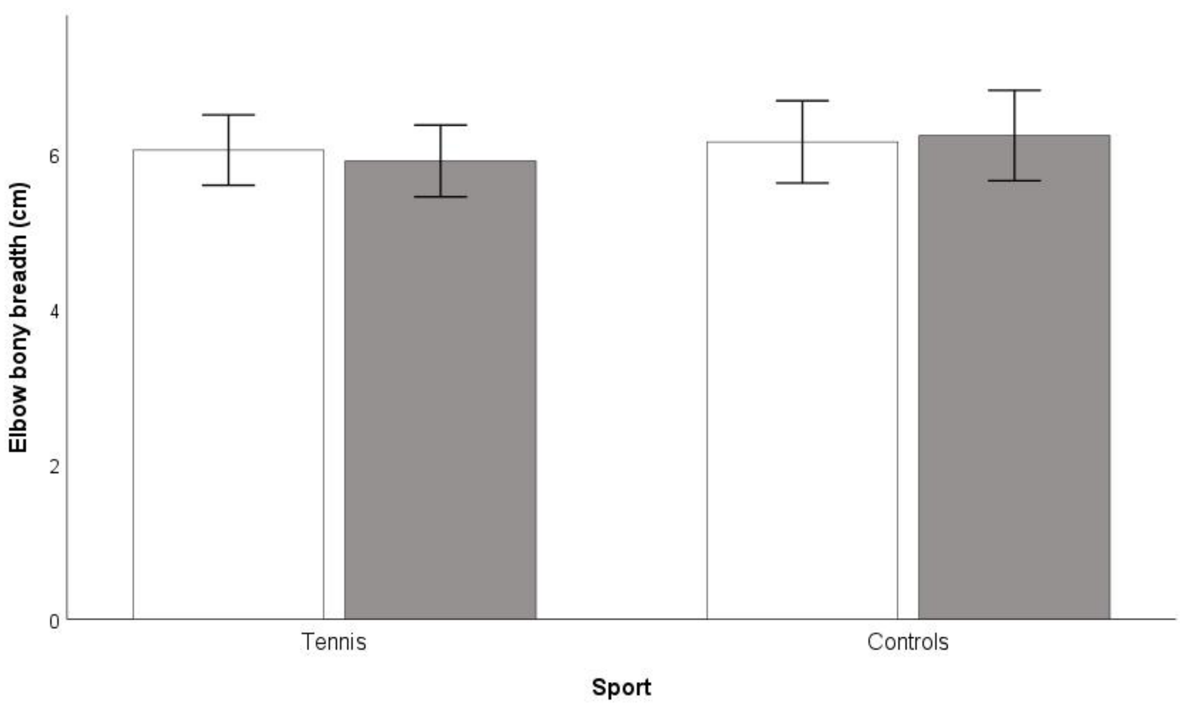
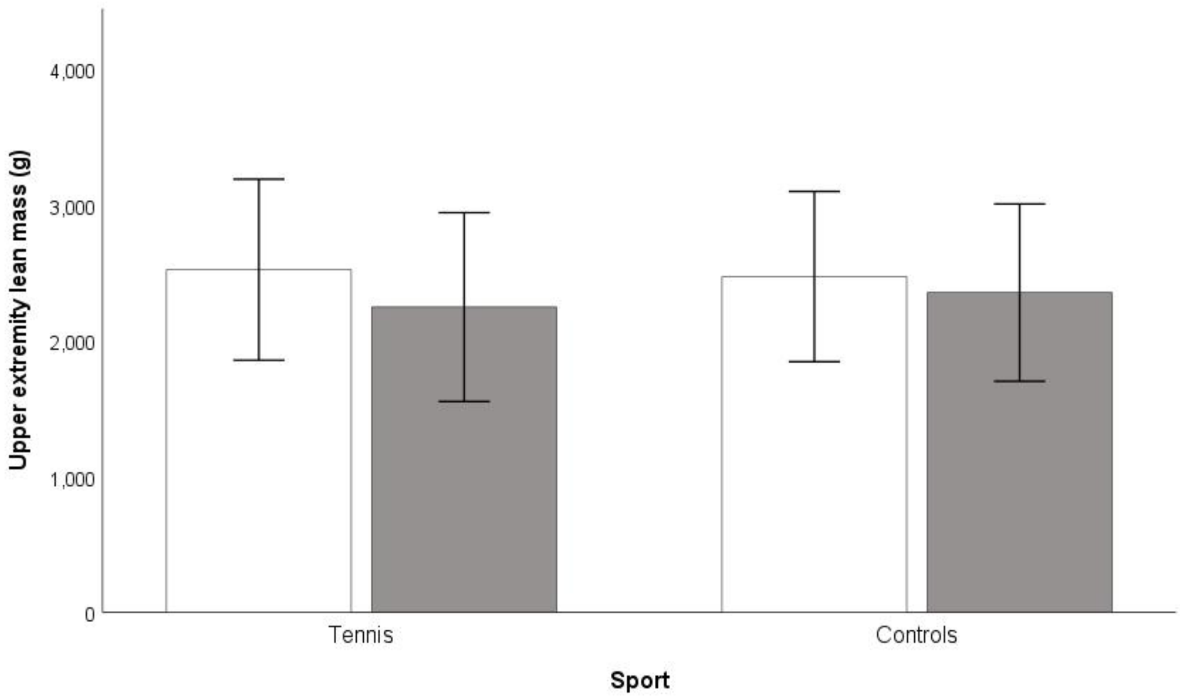
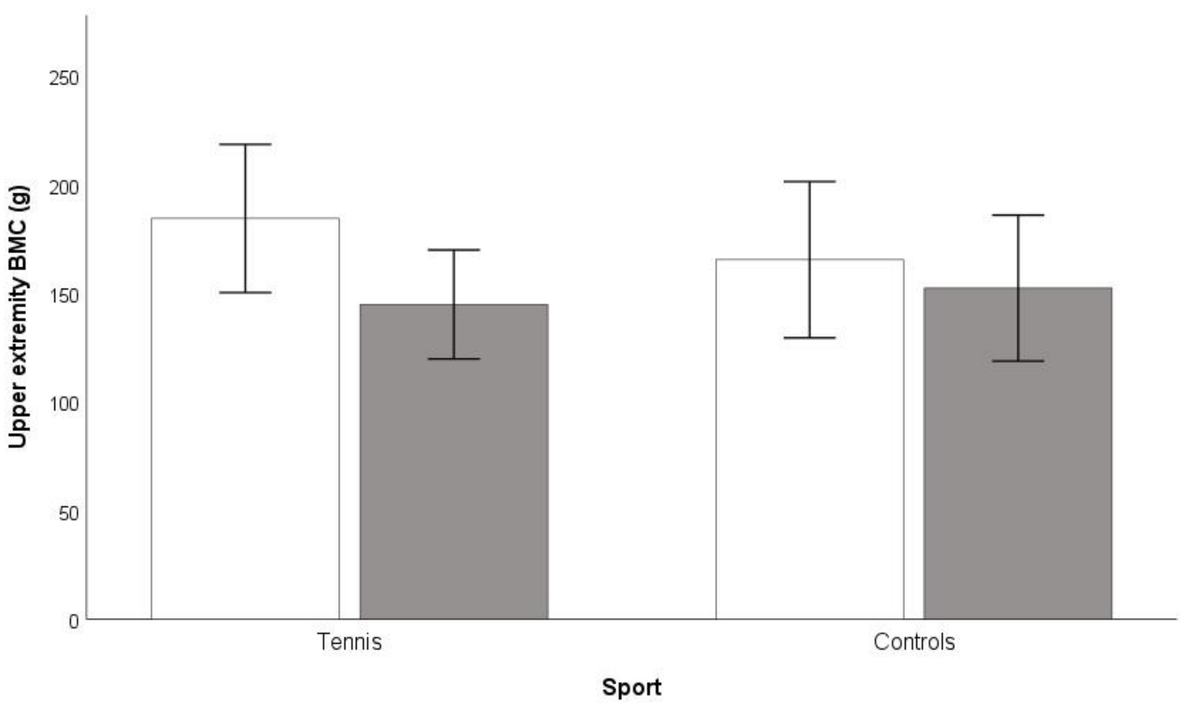
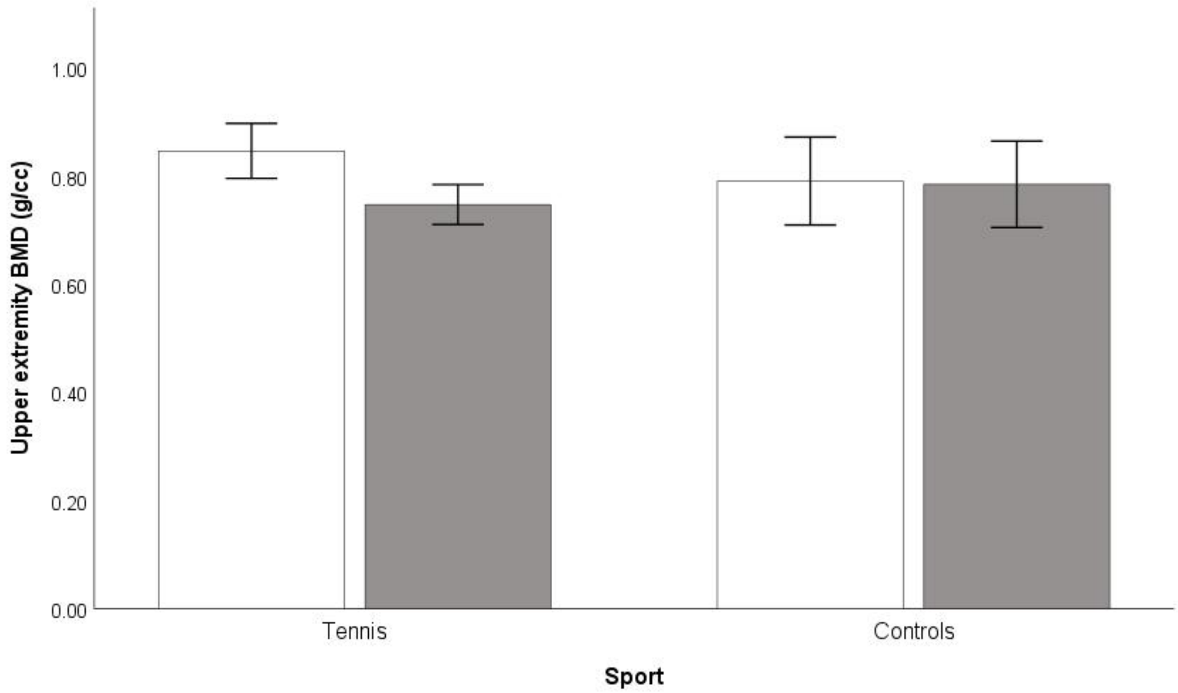
Supplemental Figures. The following figures depict variables with a significant interaction effect. The bar graphs show mean data and the error bars represent ± 1 SD. White bars are dominant side and grey bars are nondominant side.

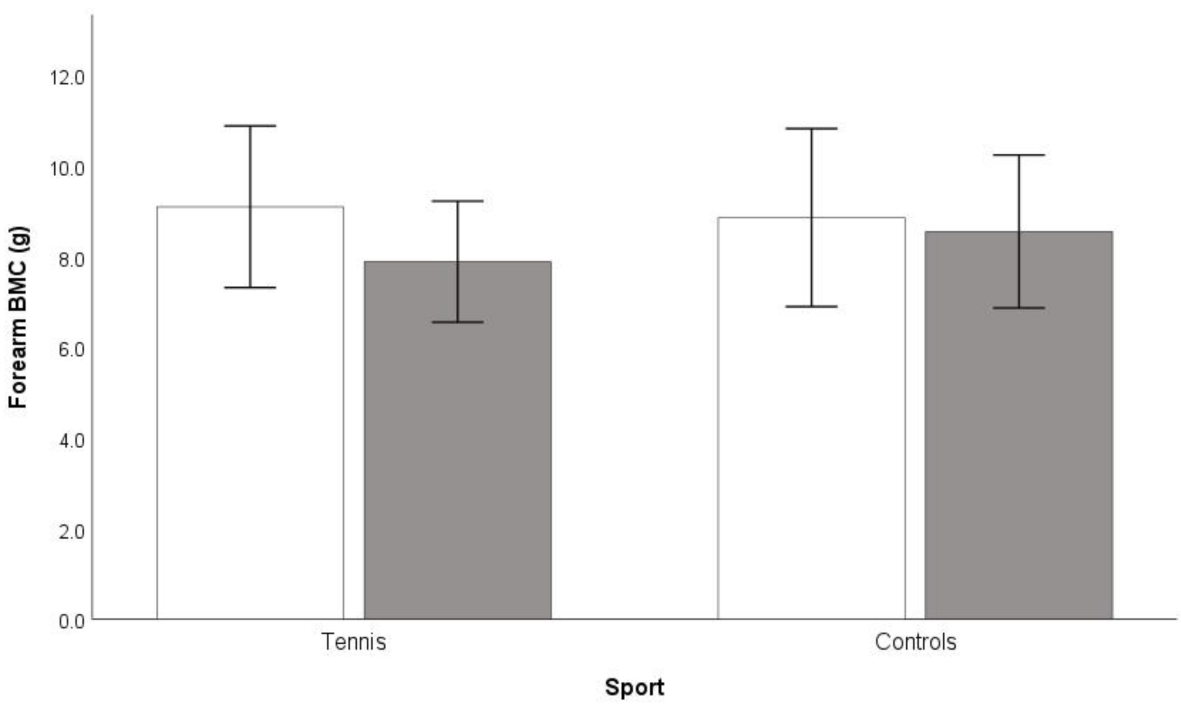


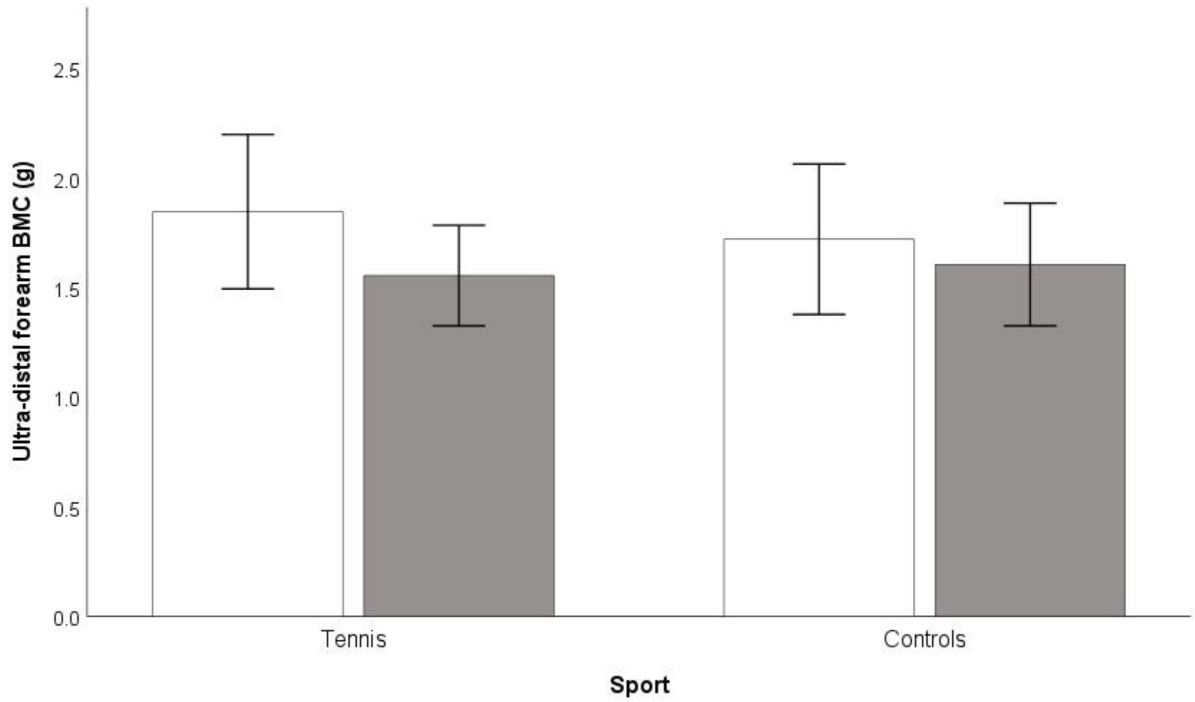


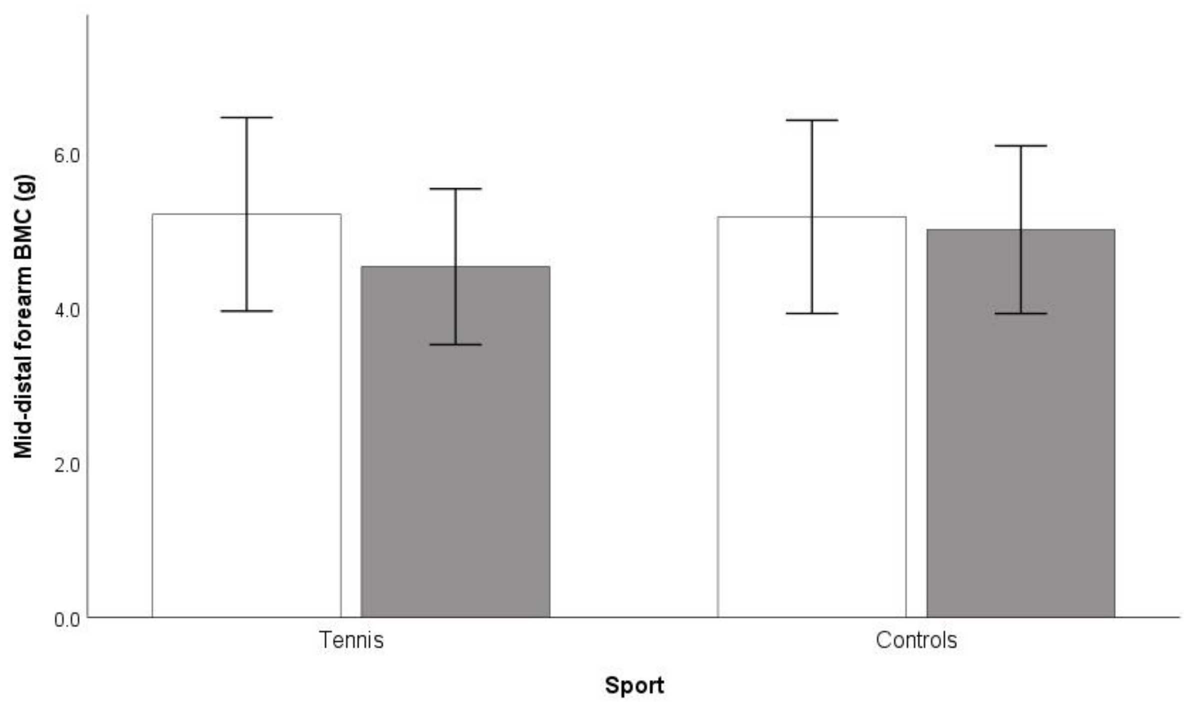

Upper extremity lean mass (g)
4,000
3,000
2,000
1,000
0
Tennis
Controls
Sport

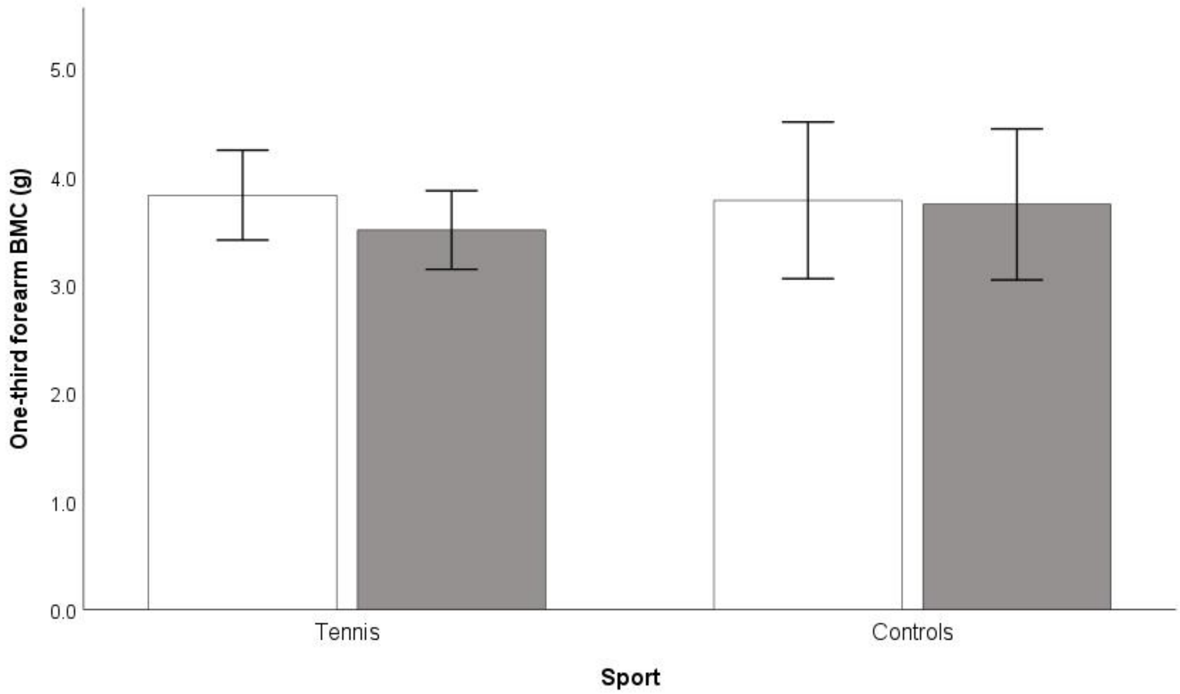

Upper extremity BMC (g)
250
200
150
100
50
0
Tennis
Controls
Sport

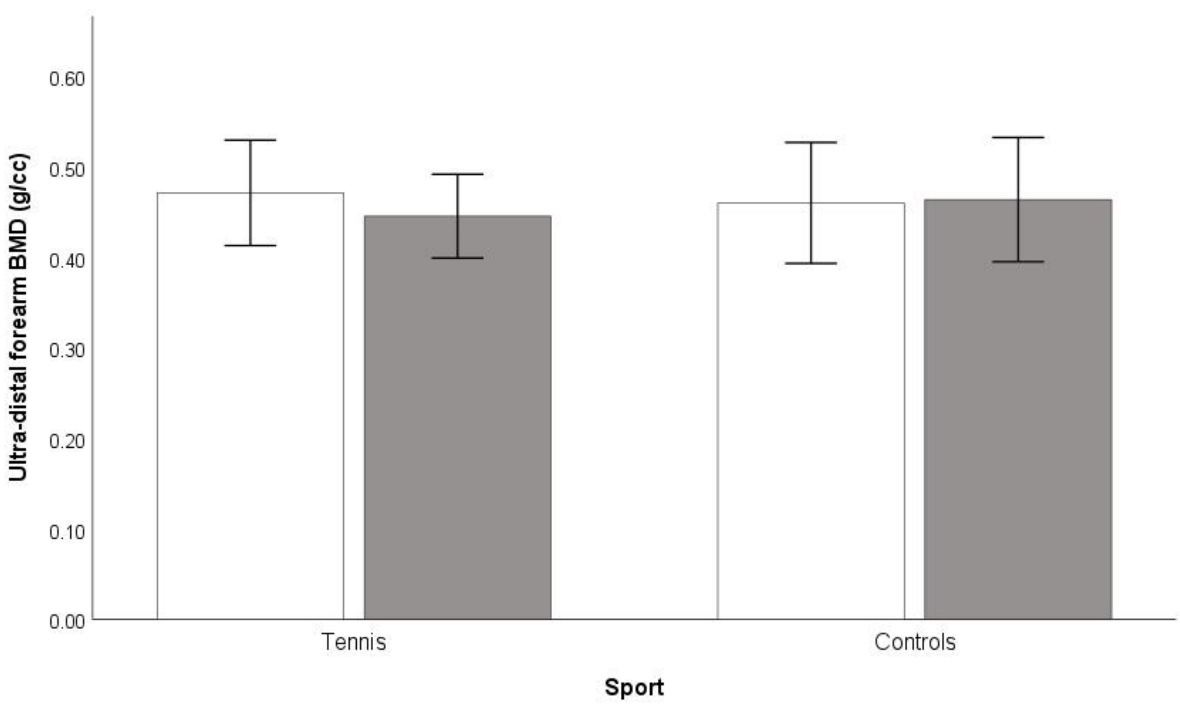

1.00
0.80
0.60
0.40
0.20
0.00
Upper extremity BMD (g/cc)
Tennis
Controls
Sport


12.0
10.0
8.0
6.0
4.0
2.0
0.0
Forearm BMC (g)
Tennis
Controls
Sport


Ultra-distal forearm BMC (g)
2.5
2.0
1.5
1.0
0.5
0.0
Tennis
Controls
Sport


Mid-distal forearm BMC (g)
6.0
4.0
2.0
0.0
Tennis
Controls
Sport


One-third forearm BMC (g)
5.0
4.0
3.0
2.0
1.0
0.0
Tennis
Controls
Sport


Ultra-distal forearm BMD (g/cc)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Tennis
Controls
Sport