

1 *Original Investigation*

2 **Categorizing ten sports according to bone and soft tissue profiles in adolescents**

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1 **Categorizing ten sports according to bone and soft tissue profiles in adolescents**

2 **Abstract**

3 **Purpose:** Considering the different loading and training characteristics of the sports practiced
4 during growth, it is important to specify and categorize the bone and soft tissue adaptations in
5 adolescent athletes. This study aimed to categorize ten different loading sports and a non-sport
6 group and identify the differences in bone density and soft tissues. **Methods:** The sample
7 included 625 adolescents (10 to 17 years of age) of ten sports (soccer, basketball, volleyball,
8 track & field, judo, karate, kung-fu, gymnastics, baseball and swimming) and a non-sport
9 group. Dual energy X-ray absorptiometry assessed areal bone mineral density (aBMD), bone
10 mineral apparent density (BMAD) and soft tissues (lean soft tissue and fat mass). The results
11 were adjusted for sex, peak height velocity (PHV) status, lean soft tissue, fat mass and weekly
12 training volume. **Results:** The comparisons among groups showed that soccer had the highest
13 whole body aBMD (mean \pm SEM: $1.082 \text{ g/cm}^2 \pm 0.007$) and lower limbs aBMD (1.302 g/cm^2
14 ± 0.010). Gymnastics presented the highest upper limbs ($0.868 \text{ g/cm}^2 \pm 0.012$) and whole body
15 BMAD ($0.094 \text{ g/cm}^2 \pm 0.001$). Swimming presented the lowest aBMD values in all skeletal
16 sites (except at the upper limbs) and whole body BMAD. The soft tissue comparisons showed
17 that soccer had the highest lean soft tissue ($43.8 \text{ kg} \pm 0.7$). The lowest fat mass was found in
18 gymnastics ($8.04 \text{ kg} \pm 1.0$). **Conclusion:** The present study investigated and categorised for
19 the first time ten different sports according to bone density and soft tissue profiles. Soccer and
20 gymnastics sport groups found to have the highest bone density in most body segments and
21 both sports were among the groups with the lowest fat mass.

22 **Key Words:** ADOLESCENCE, BONE MINERAL DENSITY, EXERCISE, FAT MASS,
23 LEAN MASS, SPORT PARTICIPATION.

24

1 **Introduction**

2
3 Adolescence is a crucial period for accumulation of bone mass with evidence indicating
4 that 33% to 43% of the total bone mineral content (BMC) in adulthood is accumulated during
5 the years surrounding peak height velocity (PHV), depending on the skeletal site (1). These
6 circumpubertal years (-2 to + 2 years from age of PHV) are particularly important for the
7 assessment of somatic maturation (1). Exercise and dietary intake during adolescence play an
8 important role on the accumulation of bone mass during growth (2, 3). Also, exercise has the
9 potential to optimise bone health during growth by achieving the full potential of peak bone
10 mass and by reducing the risk of osteoporosis later in life (4), leading to substantial economic
11 and social gains (5).

12 Participation in sports during growth can have several positive effects on physiological,
13 metabolic and musculoskeletal health outcomes (6, 7). Evidence indicates that the type and
14 characteristics of the sports practiced during growth can have different adaptations on bone
15 mass and the highest benefits are observed in those who participate in weight-bearing sports
16 (3, 8–10). During weight-bearing sport participation the mechanical forces applied on the bone
17 matrix directly (ground reaction forces) or indirectly (via the muscle contraction) (10). The
18 muscle contractions and the osteogenic stimulus produced from high external forces during
19 exercise (ground reaction forces), such as jumps, sprints, acceleration and deceleration are
20 responsible for the adaptations in in bone mineral accrual (10). Most studies in the literature
21 focusing on sports participation and bone health during growth are comparing a specific sport
22 modality or limited number of sports with a control group (8, 11). Currently, there are a
23 considerable range of sports with few data available about its osteogenic properties, even
24 though they are widely practiced for children and adolescents worldwide, such as martial arts.
25 This background requires a comprehensive investigation about the site-specific skeletal
26 adaptations of the growing skeleton. However, there is no evidence regarding the bone

1 adaptations of the different loading sports practiced during growth and how these are
2 categorized according to the skeletal adaptations.

3 Dual-energy X-ray absorptiometry (DXA) is the clinically relevant method to use when
4 assessing bone health during growth, but differences in the size of the children or adolescents
5 can affect the interpretation of areal bone mineral density (aBMD). This is mainly because
6 aBMD is analysed in g/cm^2 and does not consider the bone volume (cm^3). Considering that
7 adolescents have evident size differences according to the sports practiced due to the natural
8 selection of each sport modality, the comparisons of aBMD can be affected (12). Therefore, it
9 is important to consider and adjust further for the size differences when comparing BMD of
10 children and adolescents. A more thorough investigation can be provided by using bone
11 mineral apparent density (BMAD) which reduces the confounding role of skeletal size and
12 provide an estimation of volumetric bone density proportional to the true bone volume (13).
13 Previous studies have considered the use of this technique (BMAD) to analyse the impact of
14 some sports, such as gymnastics (14) and cycling (15) on bone density of lumbar spine, femoral
15 neck and whole body in adolescents. However, the BMAD has not yet been used in
16 comparisons of bone health among different loading sports within the same study.

17 In addition to bone differences, previous evidence indicates that depending on the sport
18 practiced, the soft tissues, specifically lean and fat mass, differ according to the movement-
19 specific characteristics of the sport practiced (16). Wilkinson et al (17) found that adolescent
20 swimmers had higher lean mass when compared with footballers, cyclists and a control group.
21 Additionally, all sports groups (swimmers, footballers and cyclists) had lower fat mass than an
22 active age-matched control group. Understanding the relations of different sports on lean and
23 fat mass will allow the sports professionals and researchers to identify the body composition
24 status of young athletes and design effective interventions to improve it. However, there is a
25 lack of comprehensive evidence comparing the soft tissue of a large number of sports practiced

1 during adolescence. Considering that the majority of children and adolescents are involved in
2 different types of sports during this period of life (mainly in adolescence when sports
3 participation is the main manifestation of physical exercise), it is crucial to identify their
4 specific impact on bone health and soft tissues during this important period of life.

5 Thus, the objective of this study was to categorize adolescent athletes from ten different
6 loading sports (soccer, basketball, volleyball, tennis, track & field, judo, karate, kung fu,
7 gymnastics, baseball and swimming) and a non-sport group according to bone and soft tissues
8 profiles as well as to quantify the differences in bone density and soft tissues by controlling for
9 important confounders.

10 **Methods**

11 **Population**

12 The data of this cross-sectional study were collected as part of two studies from the
13 Laboratory of InVestigation in Exercise (LIVE) that was conducted in the city of Presidente
14 Prudente, São Paulo-Brazil from October 2013 to May 2018. After authorization of the local
15 authorities, researchers contacted and invited the non-sport group adolescents by inviting
16 schools of the Secretary of Education and in one Philanthropic Institution. The sport groups
17 were recruited from sport clubs (public and private) of the metropolitan area of Presidente
18 Prudente. The initial number of adolescents recruited was 678, and after exclusions (see
19 inclusion criteria), the sample was composed of 625 adolescents (184 females) with mean age
20 of 14.1 (13.9 to 14.2) years.

21 The inclusion criteria were: 1) chronological age between 10 and 17 years of age; 2) a
22 minimum of 6 months of participation in the specific sport (sport groups); 3) minimum
23 engagement of 3 or more hours per week (sport groups). The exclusion criteria were: 1)
24 currently taking medication that could affect bone metabolism; 2) organized involvement in

1 other sports on top of the specialized sport (sport groups); 3) organized involvement in sports
2 (presence of coach, training routine, competitions) (non-sport group).

3 The sample size estimation was performed using an equation previous used in other
4 studies (9, 18, 19), a bilateral student t test considering the difference between two dependent
5 means of cyclists (1.133 units [SD=0.217] in reference group and 1.002 units [SD=0.093] in
6 experimental group) of whole-body BMD (15). Taking into account a power of 90% and an
7 alpha of 5%, the sample size was estimated as a minimum of 9 adolescents per group.

8 The sport group comprised of 453 adolescents of 10 different sports: judo (n = 54
9 [females n=18]), karate (n = 41 [females n=21]), kung fu (n =39 [females n=10]), swimming
10 (n = 67 [females n=22]), basketball (n = 55 males), soccer (n = 100 males), volleyball (n = 32
11 [females n=30]), track and field (n = 27 [females n=11]), baseball (n = 22 [females n=1]) and
12 artistic gymnastics (n = 16 females), and the non-sport group comprised of 172 adolescents (55
13 females).

14 To participate in the study, adolescents were required to provide informed consent
15 forms signed by a parent or guardian. The Ethical Board of the Sao Paulo State University
16 (UNESP) approved the investigation (Process number 02891112.6.0000.5402) and all
17 procedures performed in this study were conducted in accordance with the 1964 Declaration
18 of Helsinki for human studies by the World Medical Association.

19 **Anthropometry**

20 Stature was measured using a stadiometer (Sanny, model American Medical of the
21 Brazil Ltda, Brazil, accurate to 0.1 cm). The body mass was measured using an electronic scale
22 (Filizzola PL 150, model Filizzola Ltda, Brazil with a precision of 0.1 kg). All measures were
23 assessed using standardized techniques by a single trained researcher. The technical errors of
24 measurement were 0.04% and 0.11% for body mass, height, respectively.

25

1 **Somatic Maturation**

2 Stature measurements and chronological age were used to calculate the maturity offset
3 years from age PHV using equation proposed by Moore et al. (20). This is a somatic biological
4 maturity indicator and reflects the maximum growth velocity during adolescence and the
5 coefficient of determination has been reported ($r^2 = 0.90$, $SE = 0.5$) (20). Lastly, aiming to
6 decrease the bias of estimation of PHV (21) mainly in samples with large age range (outside
7 the optimal band of estimation [1 year after/before the peak]), the adolescents were divided
8 into three categories: 1) Pre-PHV (maturity offset < -1); 2) At-PHV (maturity offset ≥ -1 and
9 ≤ 1) and 3) Post-PHV (maturity offset > 1). These categories were used as a somatic maturation
10 variable of the sample and considered as an adjustment variable in the analysis.

11 **Volume and Frequency of Training**

12 The athletes and coaches provided information about the time of training per day
13 (minutes trained daily) and frequency of training per week (number of days trained in a week).
14 These variables were used to calculate the weekly training volume, following the equation:
15 time of training per day x frequency of training per week. Training volume is a widely used
16 variable in studies involving sports training characteristics and able to affect the accumulation
17 of bone mineral density in adolescents (22).

18 **Bone Densitometry and Soft Tissue Assessment**

19 A whole body DXA scan (Lunar DPX-NT; General Electric Healthcare, Little
20 Chalfont, Buckinghamshire, UK) was used to assess aBMD (g/cm^2), lean soft tissue (kg) and
21 fat mass (kg) of whole body at the university laboratory in a temperature-controlled room by
22 using a GE Medical System Lunar software (version 4.7). A trained researcher performed all
23 scan and tested the scanner quality before the first exam of each day. The coefficient of
24 variation for this device was 0.66% (in whole body aBMD analysis, $n=30$ participants not
25 involved in this study), setting the lines (rois) in the extremities (upper limbs, lower limbs and

1 spine) as requested for the General Electric Healthcare company and stated in previous studies
2 (8) realized by a trained researcher. The scans were performed using a standardized protocol
3 with the participants remaining in the supine position and wearing only light clothing, without
4 shoes. Regional analysis for aBMD of upper limbs, lower limbs, spine and whole body (less
5 head) occurred off-line after the scans took place.

6 The BMAD (g/cm^3) is an approach to estimate the volumetric BMD and remove the
7 size differences. It can be calculated by dividing BMC by the three-dimensional bone volume
8 derived from its two-dimensional projected bone area (BA) and body height as proposed by
9 Katzman et al (13): $\text{BMAD}_{\text{TB}} = \text{BMC}/(\text{total body BA}^2/\text{body height})$.

10 **Statistical analysis**

11 All anthropometric characteristics, bone and soft tissue parameters were expressed as
12 mean values, standard deviation (SD) and 95% confidence intervals (95%CI). The data
13 normality was tested using the Shapiro-Wilk test. The comparisons of dependent variables
14 among groups were performed by using Generalized Estimating Equation Model (GEE) and
15 Bonferroni post-hoc test. All covariates were selected after checking for multicollinearity and
16 by including possible mediators of bone density based on previous evidence (22–24).
17 Specifically, when comparing bone density variables, the models were adjusted for sex, PHV
18 status, lean soft tissue, fat mass and weekly training volume. To quantify the differences the
19 results were presented by using percentage of difference. The data were analysed using the
20 SPSS software (version 24.0), and the level of statistical significance was set at a p value less
21 than 0.05.

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1 **Results**

2 **Table 1** shows the descriptive characteristics of each group and **Table 2** shows the bone
3 variables by sports modalities without adjustments. The adjusted comparisons of dependent
4 variables are presented in **Figure 1, Figure 2 and Figure 3**. The results of these comparisons
5 are presented hierarchically (from highest to lowest) in figures to facilitate a practical
6 categorization and visualization.

7 At whole body aBMD, the highest value was observed in soccer (1.082 g/cm²) and
8 lowest in swimming (0.959 g/cm²). The swimmers had significantly lower whole-body aBMD
9 compared to all groups (-4.9% to -11.3%). Kung fu presented significant lower whole-body
10 aBMD compared with soccer (-6.7%) and judo (-4.3%). Baseball, basketball, karate and non-
11 sport group had significant lower values at whole-body aBMD compared with soccer (-3.9%
12 to -6.5%) (**Figure 1, panel A**). Spine aBMD in the judo group was the highest (1.052 g/cm²),
13 while the swimming group had the lowest spine aBMD (0.971 g/cm²). In comparisons among
14 groups, the swimming group had significantly lower spine aBMD than judo (-7.7%), volleyball
15 (-7.3%) and soccer (-5.8%) (**Figure 1, panel B**).

16 At lower limbs aBMD soccer (1.302 g/cm²) and swimming (1.129 g/cm²) were the
17 sports with highest and lowest aBMD respectively. Swimmers had significantly lower limbs
18 aBMD compared to all groups (-5.4% to -13.3%). Baseball, kung fu, basketball, non-sport
19 group, karate, judo and volleyball had significant lower limbs aBMD compared with soccer (-
20 4.2% to -8.4%) (**Figure 1, panel C**). At the upper limbs aBMD, the highest value was observed
21 in gymnastics group (0.868 g/cm²) while the lowest upper limbs aBMD value was found in
22 basketball group (0.750 g/cm²). In the comparisons among the groups, basketball had
23 significantly lower upper limbs aBMD than gymnastics (-13.6%), judo (-12.1%), baseball (-
24 6.9%) and track & field (-6.5%). Swimming, kung fu and karate had significantly lower upper
25 limbs aBMD than gymnastics (-9.5% to -10.3%) and judo (-8.0% to -8.8%). Soccer, track &

1 field, volleyball, non-sport and baseball presented significantly lower upper limbs aBMD
2 compared to gymnastics (-7.2% to -8.8%) (**Figure 1, panel D**).

3 The whole-body BMAD (g/cm^3) results can be seen in **Figure 2**. The highest BMAD
4 value was observed in gymnastics group ($0.094 \text{ g}/\text{cm}^3$) and the lowest BMAD value was found
5 in the swimming group ($0.085 \text{ g}/\text{cm}^3$). Swimmers had significantly lower whole-body BMAD
6 compared to gymnastics (-10.0%), track & field (-9.0%), soccer (-8.9%), karate (-5.8%),
7 volleyball (-5.5%), judo (-5.4%), non-sport (-5.4%) and basketball (-4.5%) groups. Baseball
8 also had significantly lower whole-body BMAD than gymnastics (-7.4%), track & field (-
9 6.3%) and soccer (-6.3%). Kung fu had significantly lower whole-body BMAD than
10 gymnastics (-6.5%) and soccer (-5.4%). Basketball also had significantly lower whole-body
11 BMAD than gymnastics (-5.8%).

12 The soft tissues result showed that baseball had the highest value of fat mass (19.8 kg),
13 while gymnastics group had the lowest fat mass (8.0 kg). Gymnastics group had significantly
14 lower fat mass compared to baseball (-59.4%), kung fu (-49.0%), volleyball (-47.1%), judo (-
15 44.8%) and swimming (-41.4%) groups. Soccer also presented significantly lower fat mass
16 compared to baseball (-59.3 %), kung fu (-48.9%), volleyball (-46.9%), judo (-44.5%),
17 swimming (-41.3%), basketball (-38.7%) and karate (-32.0%). Lastly, track field had
18 significantly lower fat mass than baseball (-59.0%), kung fu (-48.5%), volleyball (-46.6%),
19 judo (-44.1%), swimming (-48.8%) and basketball (-38.3%) (**Figure 3, panel A**). The lean
20 soft tissue was the highest at the soccer group (43.8 kg), while baseball group had the lowest
21 lean mass (37.1 kg). The comparisons among groups showed that baseball, volleyball and
22 karate had significantly lower lean soft tissue than soccer (-11.2% to -15.3%), track & field (-
23 11.2% to -15.3%) and basketball (-8.7% to -12.9%), while non-sport, kung fu, judo and
24 swimming groups had significantly lower lean soft tissue than soccer (-7.1% to -11.2%)
25 (**Figure 3, panel B**).

1 **Discussion**

2 This study analysed the aBMD, BMAD, lean soft tissue and fat mass of adolescents of
3 ten different sports and categorised the sports according to the bone and soft tissue profiles.
4 The present study included sports that have not previously investigated for these outcomes and
5 by adjusting for potential covariates. The main findings showed that the soccer and gymnastics
6 groups had the highest aBMD and BMAD values at most skeletal sites. In contrast, the
7 swimming group had the lowest aBMD values at most skeletal sites. The main findings of the
8 soft tissue profiles showed that soccer had the highest lean soft tissue while gymnastics had the
9 lowest fat mass.

10

11 **Whole Body aBMD and BMAD**

12 Regarding aBMD values of whole body, the greatest differences observed in the present
13 study were between soccer and judo. Participation in these sports include high mechanical
14 stimulus which may justify these results. According the position statement from American
15 College of Sports Medicine (2004) (10), soccer is a ball sport and requires considerable
16 osteogenic movements, such as running, acceleration and deceleration, jumping, changes of
17 directions and lower leg impacts when touching and shooting the ball (25). The results of the
18 present study show that these weight-bearing movements appear to be beneficial not only for
19 lower limbs aBMD where the initial loading is applied, but also for the whole body aBMD.
20 These findings might be explained by the combined components included as part of the training
21 routine of these soccer players (26). In addition, judo is a martial art which includes high
22 frequency of different muscle contractions (eccentric, concentric and isometric), as well as
23 body rotations, physical contact with the opponent and frequent falls on the ground (27) and
24 these characteristics support the beneficial impact of this sport modality on bone health of
25 whole body aBMD. In contrast, swimming was the sport that presented the lowest whole-body

1 BMD, indicating that the absence of ground reaction forces during swimming training might
2 not be beneficial for whole body aBMD (28). The latter is recently supported by a systematic
3 review that included 64 studies across different ages and found that swimming participation
4 does not induce beneficial effects on different skeletal sites compared to controls (28).

5 The BMAD estimation allows the volumetric expression of aBMD by decreasing the
6 risk of overestimating participants with high stature and the risk of underestimating those with
7 short stature (13). Interestingly, the findings of the present study indicate that the gymnastics
8 presented the highest BMAD values among the groups, which was followed by soccer and
9 track & field. Considering that gymnasts had the second shortest stature among the groups, the
10 results of the present study removed the size bias and reinforces the importance of height
11 adjustment when comparing bone variables in children derived from DXA outcomes as
12 previously supported (29). In contrast, swimmers consistently were found to have significantly
13 lower BMAD values compared to most groups, which strengthens the hypothesis that
14 adolescents engaged in non-impact sport tend to have lower bone density, independently of the
15 body size. Although BMAD analysis is not a new method in the paediatric bone field, studies
16 involving this technique and comparing sport modalities in adolescents are scarce in the
17 literature. It is of our knowledge only one study in the literature, by Dyson et al. (14), that
18 observed that female gymnasts had higher BMAD at the whole body, femur neck and lumbar
19 spine compared to the control group, which corroborates our findings. However, there is no
20 evidence on other sports, which highlights the novelty of the evidence provided in the present
21 study.

22

23 **Lumbar Spine aBMD**

24 At the spine aBMD, all groups presented similar values except the swimming group
25 which had significantly lower lumbar spine aBMD compared to judo, volleyball and soccer.

1 The lumbar spine skeletal site receives tension in the bone matrix during most of the human
2 stand position actions, and this tension is increased during participation in sports that involve
3 rotation of the core body segment. However, the core movements of the body do not differ
4 considerably among sports which may justify the similarity between the groups. In contrast,
5 during participation in judo, volleyball and soccer there is a high weight-bearing load (jumps,
6 running, fast short movements, changes of directions and falls on the ground) applied to the
7 core body part and therefore lumbar spine which might improve this skeletal site (8, 30, 31).

8 In contrast, swimming practice involves rotation of the core part of the body but due to
9 hypogravity in the water all the forces applied in the lumbar spine are horizontal and mainly
10 applied in upper limbs (6, 32) and therefore do not induce adaptations. Studies in the literature
11 corroborate our findings (28), such as the recent manuscript developed by Bellver et al. (2019)
12 with female young adult athletes, competitors of World Championships and Olympic Games.
13 In this study, swimmers showed lower BMD in lumbar spine than soccer and volleyball players
14 although it was similar to the control group (31), denoting that effects of sports participation
15 on bone health during adolescence remained similar in early adulthood.

16

17 **Lower Limbs aBMD**

18 In the analyses of the lower limbs aBMD, soccer players had the highest aBMD values
19 which were significantly higher compared to most groups studied (except with track & field
20 and gymnastics). Soccer is a sport modality in which the lower limbs are predominantly used
21 as part of the movements needed to achieve a high-level performance. These specific
22 performance outcomes, such as running, jumping, changes of direction, acceleration and
23 braking, and many small impacts of touching and shooting the ball (25) have high osteogenic
24 potential to induce bone adaptations. Previous cross-sectional and longitudinal studies found
25 that soccer practice induces positive adaptations to improve bone formation and consequently

1 aBMD (3, 8). These previous findings are in line with the results of the present study. Similarly,
2 some previous studies also have found that swimmers have similar or lower bone outcomes in
3 lower limbs even compared to the control group (3, 8). During swimming practice, the lower
4 limbs are used as stabilizer and float (32), which limits the muscular contractions and
5 consequently, the stress in the bone matrix.

6

7 **Upper Limbs aBMD**

8 At the upper limbs gymnastics had significantly higher aBMD values compared to all
9 groups, except judo which presented the second highest aBMD. The female artistic gymnastics
10 is a sport with high amount of movements involving tension, compression and torsion in the
11 upper limbs. These movements performed during the practice involve jumps, muscular
12 contractions and impulse forces. The arms are predominantly used during the vault and uneven
13 bars apparatus movements which generate greater impact at the distal and proximal portions of
14 the radius (33), increasing trabecular and cortical bone mineral density BMD mainly in the
15 forearm (33). Besides that, a study by Helge & Kanstrup (2002) (34) comparing rhythmic
16 against artistic gymnasts observed significantly higher values of aBMD at the distal radius in
17 artistic gymnastics athletes attributing these results to direct impact on the upper limbs during
18 the practice, which might be the case for the findings observed in gymnasts of the present study.

19 The higher aBMD values at the upper limbs in judo participants compared to karate,
20 kung fu and swimming has been debated in the literature in a recent systematic review (30) and
21 the results showed the judo as beneficial sport for site-specific BMD accrual in children and
22 adolescents, including the upper limbs (30). Ito et al. (27) for example, found significantly
23 higher aBMD for upper limbs in judokas compared to the control group and attributed these
24 results to the movements performed during the practice of the modality and fall techniques.

1 The differences observed in aBMD in this study between basketball and baseball might
2 be explained by the movement patterns of baseball which involve direct and indirect impact
3 with upper limbs, especially during pitches and rebound (35). Lastly, the upper limbs was the
4 unique segment in which the swimmers did not present the lowest values, perhaps due to this
5 body region concentrates all the propulsion force during the practice (6, 32), causing variations
6 of muscular contractions and improve BMD (6).

7

8 **Soft tissues**

9 There is evidence in the literature that the body composition and muscular fitness affect
10 the bone health, but the direction is not clear for fat mass (36). Besides that, Forero-Bogotá et
11 al. (37) showed that a poor bone health is significantly related to low lean mass. Thus,
12 understanding the impact of different sports on body composition is crucial for bone health
13 during growth and to improve performance in specific sports.

14 The comparison of soft tissues showed that soccer, gymnastics and track & field
15 presented the lowest fat mass from the groups studied. Soccer is a sport with intermittent
16 training patterns, and it includes aerobic and anaerobic components during practice.
17 Considering that long distance running is the predominant part of the game (38), this could
18 explain the low fat mass values for these soccer players. For instance, in a study by Seabra et
19 al. (39) in which a 6-month soccer intervention on obese male adolescents proved effective for
20 reducing body fat. Similarly, track & field is a sport that involves up to 21 different disciplines
21 and most of these disciplines require a high metabolic demand through two main energy
22 pathways (aerobic and anaerobic) (40), justifying the low fat mass observed in this group.

23 In gymnastics, the specific physical characteristics in athletes are needed to allow the
24 performance of technical moves and to succeed in the sport (41). Due to the high variability of
25 the movements performed in gymnastics, athletes with a genetic predisposition of short stature,

1 lower body mass and low fat mass have increased chances to perform the exercises well and
2 therefore are continuing to participate in the sport (39).

3 The lean soft tissue was higher in soccer compared to the most other groups in the
4 present study. In general, sports with the highest values of aBMD at most skeletal sites had
5 also the highest lean mass and lowest body fat mass in the present study, mainly soccer. Lean
6 mass is the strongest predictor of bone density at different skeletal sites (whole body, lumbar
7 spine, lower limbs and upper limbs) in athletes (42) and therefore is crucial to understand the
8 differences between the different sports practiced during adolescence. Although there are no
9 studies comparing the lean soft tissue of a large number of sports practiced during adolescence,
10 the literature has also shown that soccer players have higher lean soft tissue compared to other
11 sports (such as swimming, karate and judo) (8) and control group (31). This result can be
12 explained by the fact that soccer involves a large amount of muscle contractions
13 (predominantly in the lower limbs) mainly in the control of the ball and maintain balance (38),
14 in addition to training performed out of game with the aim of improving neuromuscular
15 adaptations and muscle hypertrophy (38).

16 Additionally, each sport has distinct training characteristics, including training volume.
17 Recent literature has shown that increased training volume results in changes of body
18 composition and increase of BMD in adolescents soccer players (22). For this reason, the
19 present study adjusted for weekly training load, allowing the comparisons between the sports
20 to be more homogeneous and to understand the direct relation of sport and bone density.

21

22 **Strengths and limitations**

23 The literature was scarce in studies involving adolescents practicing a high number of
24 different loading sports and this is the first study to compare 10 different sports, some of which
25 for the first time, and a control group. The strengths of this study include the large sample size

1 and the inclusion of many sports which allowed us to categorize the sports according to bone
2 density and soft tissue profiles. The present study controlled for the important covariates of
3 sex, PHV, lean soft tissue, fat mass and weekly training volume (22–24) as these variables have
4 a strong relationship with bone mass and development which indicates the strong internal
5 validity of the results presented.

6 However, it is important to highlight that the cross-sectional results cannot make any
7 causal inferences about sport participation. The findings can only show the cross-sectional
8 status and the differences of bone and soft tissues between the sports compared. To analyse the
9 effects of growth and maturation alongside the possible training effect, longitudinal studies are
10 needed to indicate the long-term effect of each sport on bone and soft tissue profiles in
11 comparison to a control group without the causality limitations of cross-sectional studies.
12 However, there is a limited number of longitudinal studies conducted, with smaller number of
13 sports groups compared and number of participants included (3, 43, 44). Randomized
14 controlled trial studies are lacking because most children and adolescents are already engaged
15 in different sports and activities which makes difficult the allocation to specific training hours
16 of a single sport. Besides that, the method of estimating age of PHV might have an estimation
17 error, due to the range of the chronological age of the groups included, which are outside the
18 optimal band of estimation (1 year after/before the peak). For this reason, to minimise the
19 estimation error the results were adjusted by the categorical variables of PHV (Pre-PHV, At-
20 PHV and Post-PHV) (21), however, future studies are encouraged to consider recruiting
21 participants from narrower age ranges preferably close to the PHV. Moreover, the sample size
22 did not allow for sex specific comparisons and for this reason the analyses have been adjusted
23 by sex. Finally, the genetic predisposition of different bone density and soft tissues could not
24 be controlled.

1 Lastly, the study did not control habitual physical activity in which might affect bone
2 density and soft tissues, but previous evidence indicates that the sport specific training
3 components are stronger predictors of bone density over and above the contribution of physical
4 activity (42), beyond the lack of control of resistance training practice which can affect the
5 bone mineral accrual.

6 7 **Conclusion**

8 In summary, soccer and gymnastics groups had the highest BMAD and aBMD at most
9 skeletal sites. In contrast, swimming had the lowest aBMD at most skeletal sites. The soft tissue
10 findings indicated that soccer had the highest lean soft tissue while volleyball, baseball and
11 karate had the lowest lean soft tissue. Finally, baseball and volleyball groups had the highest
12 fat mass, while soccer and gymnastics had the lowest fat mass. This study provides new
13 collective findings about the bone and soft tissue profiles of ten different sports practiced
14 during adolescence and categorize the sports according to highest and lowest values.

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3
4 **Conflict of Interest**

5 The authors declare that they have no competing interests.

6 The authors declare that the results of this study are presented clearly, honestly, and without
7 fabrication, falsification or inappropriate data manipulation. Besides that, the results of this
8 study do not constitute endorsement by the American College of Sports Medicine.

9 Author contributions: RRA collected the data (including DXA scans) and drafted the
10 manuscript. RAF designed the study, coordinated the data collection and critically reviewed
11 the manuscript and approved the final version. PHN and SMV contributed to the acquisition
12 of data and critically reviewed the manuscript and approved the final version. AOW
13 contributed to the acquisition of data, statistical expertise and critically reviewed the
14 manuscript and approved the final version. DV designed the study, had the conceptual idea of
15 the study and planned the data analysis, interpretation and critically reviewed all parts of the
16 manuscript.

17

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22 BONE Study. *J Bone Miner Res*. 2017;32(11):2269–77.
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Table 1. Descriptive characteristics of the sample stratified by sports (N=625)

Descriptive characteristics	Basketball n=55 Mean (SD)	Soccer n=100 Mean (SD)	Swimming n=67 Mean (SD)	Volleyball n=32 Mean (SD)	Karate n=41 Mean (SD)	Judo n=54 Mean (SD)	Kung Fu n=39 Mean (SD)	Baseball n=22 Mean (SD)	Gymnastics n=16 Mean (SD)	Track & Field n=27 Mean (SD)	Non- sport n=172 Mean (SD)
Number of males/females	55/0	100/0	45/22	2/30	20/21	36/18	29/10	21/1	0/16	16/11	117/55
Chronological age (years)	13.8 (1.3)	15.0 ^a (1.8)	13.2 ^b (1.8)	15.0 ^{a,c} (1.1)	13.1 ^{b,d} (1.8)	13.1 ^{b,d} (1.8)	13.4 ^{b,d} (1.7)	12.1 ^{a,b,d} (1.6)	13.6 (1.7)	15.6 ^{a,c,e,f,g,h,i} (1.8)	14.5 ^{c,e,f,g,h} (2.3)
Body mass (kg)	65.8 (17.4)	63.8 (13.2)	55.6 ^{a,b} (13.2)	59.1 (10.8)	50.4 ^{a,b} (14.0)	54.4 ^{a,b} (13.7)	57.8 (12.9)	51.1 ^{a,b} (15.4)	45.6 ^{a,b,c,d,f,g} (7.7)	62.6 ⁱ (17.1)	55.8 ^{a,b,i} (14.4)
Height (cm)	176.3 (10.3)	173.3 (10.6)	163.3 ^{a,b} (10.5)	165.6 ^{a,b} (6.6)	157.5 ^{a,b,d} (11.0)	157.7 ^{a,b,d} (12.0)	162.5 ^{a,b} (10.4)	153.0 ^{a,b,c,d} (12.1)	156.2 ^{a,b,d} (8.2)	171.9 ^{c,e,f,g,h,i} (10.3)	163.3 ^{a,b,h,j} (11.5)
Age from PHV (years)	0.8 (1.2)	1.4 (1.5)	0.4 ^b (1.5)	2.7 ^{a,b,c} (1.1)	0.3 ^{b,d} (1.7)	0.0 ^{b,d} (1.7)	0.4 ^{b,d} (1.7)	-1.2 ^{a,b,c,d,e,f,g} (1.3)	1.3 ^{d,h} (1.5)	2.4 ^{a,c,e,f,g,h} (1.6)	1.1 ^{d,f,h,j} (1.9)
Lean soft tissue (kg)	49.5 (9.1)	52.5 (10.4)	40.7 ^{a,b} (9.6)	36.1 ^{a,b} (4.9)	35.2 ^{a,b} (7.9)	36.3 ^{a,b} (10.4)	38.8 ^{a,b} (9.0)	34.1 ^{a,b} (7.7)	32.5 ^{a,b,c,g} (5.3)	49.5 ^{d,e,f,g,h,i} (13.0)	38.4 ^{a,b,i,j} (9.6)
Fat mass (kg)	12.6 (12.0)	7.9 (3.5)	11.8 ^b (7.7)	20.1 ^{a,b,c} (9.1)	12.0 ^d (8.2)	14.0 ^b (8.1)	15.6 ^b (10.4)	13.9 (10.1)	9.3 ^{d,g} (3.9)	9.5 ^d (7.5)	13.8 ^{b,d,i} (9.5)
Training parameters:											
Days per week	4.4 (1.5)	4.7 (1.0)	5.8 ^{a,b} (0.7)	2.9 ^{a,b,c} (1.2)	4.1 ^{b,c,d} (0.9)	3.1 ^{a,b,c,e} (0.5)	2.5 ^{a,b,c,e,f} (0.9)	3.7 ^{b,c,g} (1.1)	3.0 ^{a,b,c,e} (0.9)	5.6 ^{a,b,d,e,f,g,h,i} (0.7)	--
Time per day (minutes)	182.9 (45.0)	163.3 (31.5)	164.0 (33.7)	121.9 ^{a,b,c} (28.4)	139.0 ^a (56.4)	104.2 ^{a,b,c,e} (40.9)	106.4 ^{a,b,c} (41.5)	191.4 ^{d,e,f,g} (58.8)	206.3 ^{b,c,d,e,f,g} (48.8)	161.1 ^{d,f,g} (40.9)	--
Training volume (minutes per week)	836.6 (364.1)	775.5 (225.6)	947.0 ^b (245.3)	373.1 ^{a,b,c} (207.8)	559.0 ^{a,b,c,d} (230.1)	339.7 ^{a,b,c,e} (239.0)	262.1 ^{a,b,c,e} (156.1)	716.8 ^{c,d,f,g} (275.4)	626.3 ^{c,d,f,g} (259.7)	914.4 ^{d,e,f,g,i} (277.1)	--

Comparisons among groups using the Estimating Equation Model (GEE). SD (Standard deviation); APHV (age at peak height velocity); Training volume is the multiplication of the amount of training days per week by time trained per day. The letters denote significant difference between groups following the order of the sports modalities in the table (left to right) (eg. a = significant difference compared to the first sport modality in the table [basketball], b = difference compared to second sport modality in the table [soccer]; $p < 0.05$).

Table 2. Descriptive bone characteristics of the sample (without adjust by confounders) (N=625).

	Basketball	Soccer	Swimming	Volleyball	Karate	Judo	Kung Fu	Baseball	Gymnastics	Track & Field	Non- sport
	n=56	n=100	n=67	n=32	n=41	n=54	n=39	n=22	n=16	n=27	n=172
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)
Number of males/females	55/0	100/0	45/22	2/30	20/21	36/18	29/10	21/1	0/16	16/11	117/55
aBMD (g/cm²)											
DXA- Upper limbs	0.821 (0.111)	0.880 ^a (0.148)	0.775 ^b (0.105)	0.802 ^b (0.087)	0.731 ^{a,b,d} (0.090)	0.800 ^{b,e} (0.166)	0.760 ^b (0.081)	0.725 ^{a,b} (0.090)	0.802 (0.089)	0.884 ^{c,e,g,h} (0.141)	0.773 ^{b,j} (0.117)
DXA- Lower limbs	1.340 (0.165)	1.446 ^a (0.177)	1.134 ^{a,b} (0.132)	1.238 ^{a,b,c} (0.106)	1.170 ^{a,b} (0.152)	1.172 ^{a,b} (0.165)	1.163 ^{a,b} (0.119)	1.103 ^{a,b,d} (0.149)	1.182 ^{a,b} (0.124)	1.386 ^{c,d,e,f,g,h,i} (0.200)	1.185 ^{a,b,j} (0.162)
DXA- Spine	1.065 (0.157)	1.108 (0.166)	0.977 ^b (0.139)	1.151 ^c (0.134)	0.982 ^{b,d} (0.160)	0.996 ^{b,d} (0.158)	0.971 ^{b,d} (0.154)	0.888 ^{a,b,d} (0.132)	1.040 (0.160)	1.123 ^{c,e,g,h} (0.169)	1.002 ^{b,d,h,j} (0.172)
DXA- Whole body-LH	1.095 (0.23)	1.180 ^a (0.141)	0.965 ^{a,b} (0.108)	1.052 ^{b,c} (0.089)	0.974 ^{a,b} (0.116)	0.995 ^{a,b} (0.141)	0.980 ^{a,b} (0.097)	0.927 ^{a,b,d} (0.116)	0.997 ^b (0.102)	1.139 ^{c,e,f,g,h,i} (0.155)	0.994 ^{a,b,j} (0.126)
BMAD (g/cm ³)	0.090 (0.006)	0.095 ^a (0.006)	0.088 ^{a,b} (0.005)	0.088 ^b (0.005)	0.090 ^{b,c} (0.006)	0.089 ^{b,c} (0.006)	0.087 ^b (0.005)	0.088 ^b (0.005)	0.094 ^{c,d} (0.006)	0.095 ^{c,d,f,g,h} (0.006)	0.089 ^{b,c,i,j} (0.007)

Comparisons among groups using the Estimating Equation Model (GEE). SD (standard deviation); DXA (Dual-energy X-ray absorptiometry); Whole body-LH (whole body less head); BMAD (bone mineral apparent density). The letters denote significant difference between groups following the order of the sports modalities in the table (left to right) (eg. a = significant difference compared to the first sport modality in the table [basketball], b = difference compared to second sport modality in the table [soccer]; p<0.05)

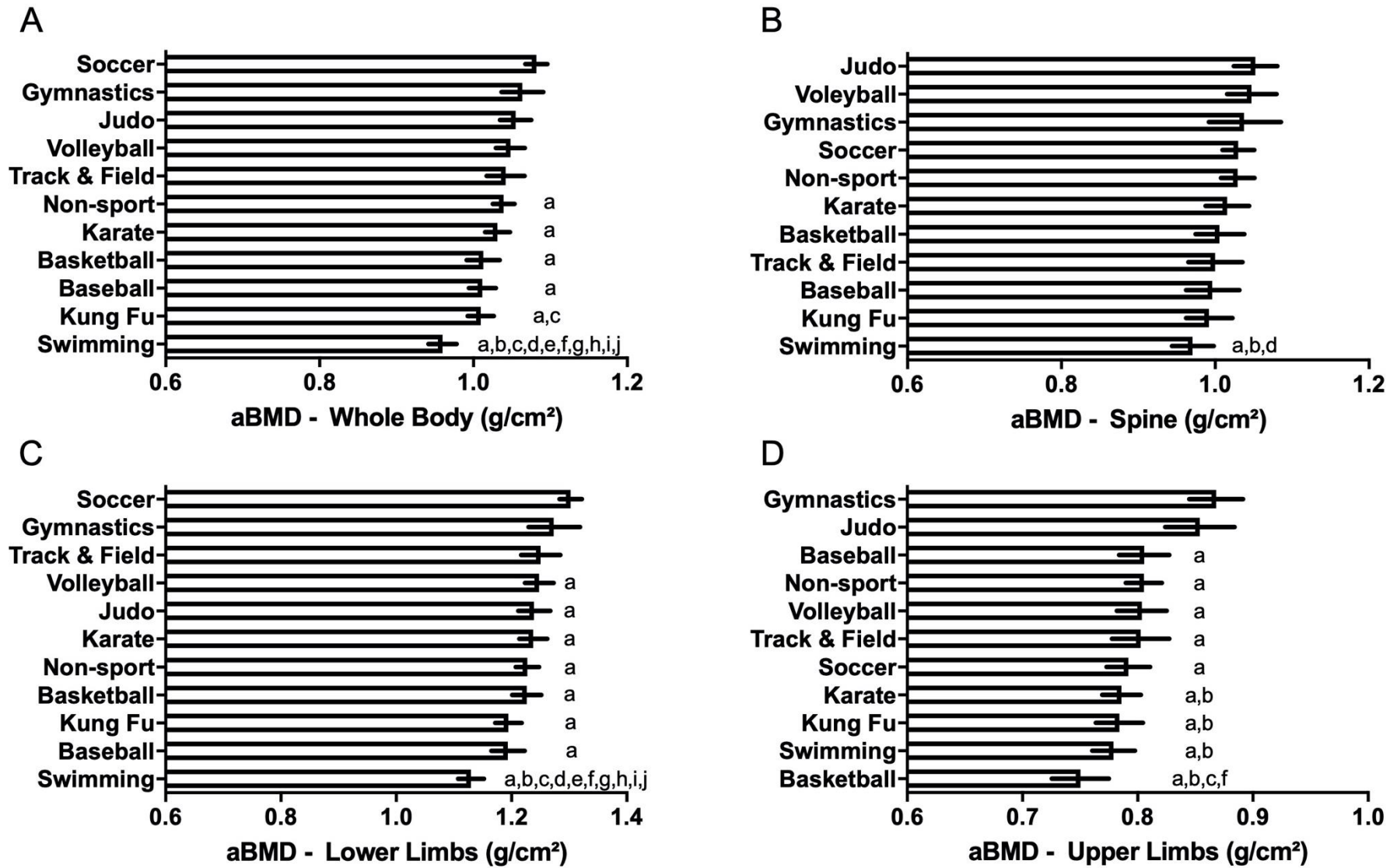


Figure 1. Comparisons of BMD (g/cm²) among 10 sports and non-sport group categorized hierarchically (from highest to lowest) using the Estimating Equation Model (GEE) adjusted by sex, PHV status, lean soft tissue, fat mass and weekly training volume. The letters denote significant lower values between groups following hierarchical order (eg. a = significant lower values compared to the first sport modality, b = difference compared to second sport modality; p<0.05).

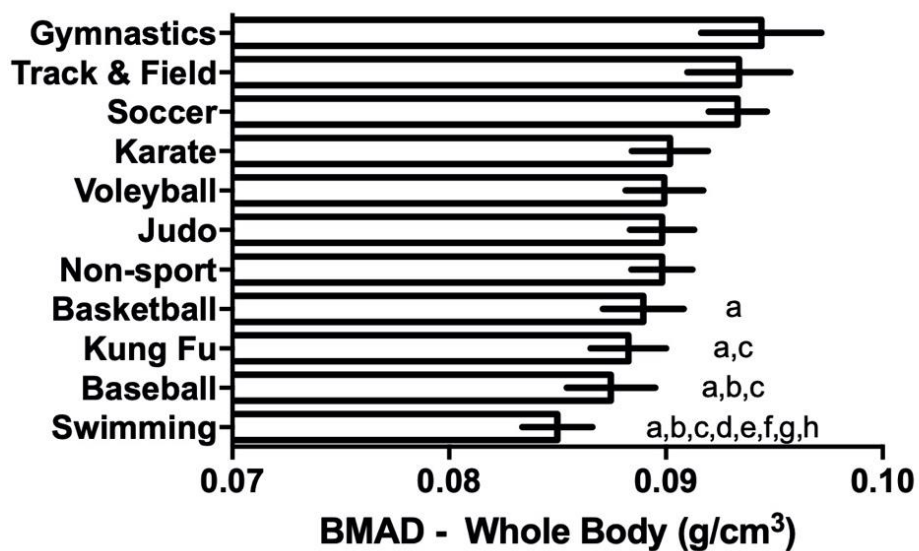


Figure 2. Comparisons of Bone Mineral Apparent Density (BMAD) (g/cm^3) among 10 sports and non-sport group categorized hierarchically (from highest to lowest) using the Estimating Equation Model (GEE) adjusted by sex, PHV status, lean soft tissue, fat mass and weekly training volume. The letters denote significant lower values between groups following hierarchical order (eg. a = significant lower values compared to the first sport modality, b = difference compared to second sport modality; $p < 0.05$).

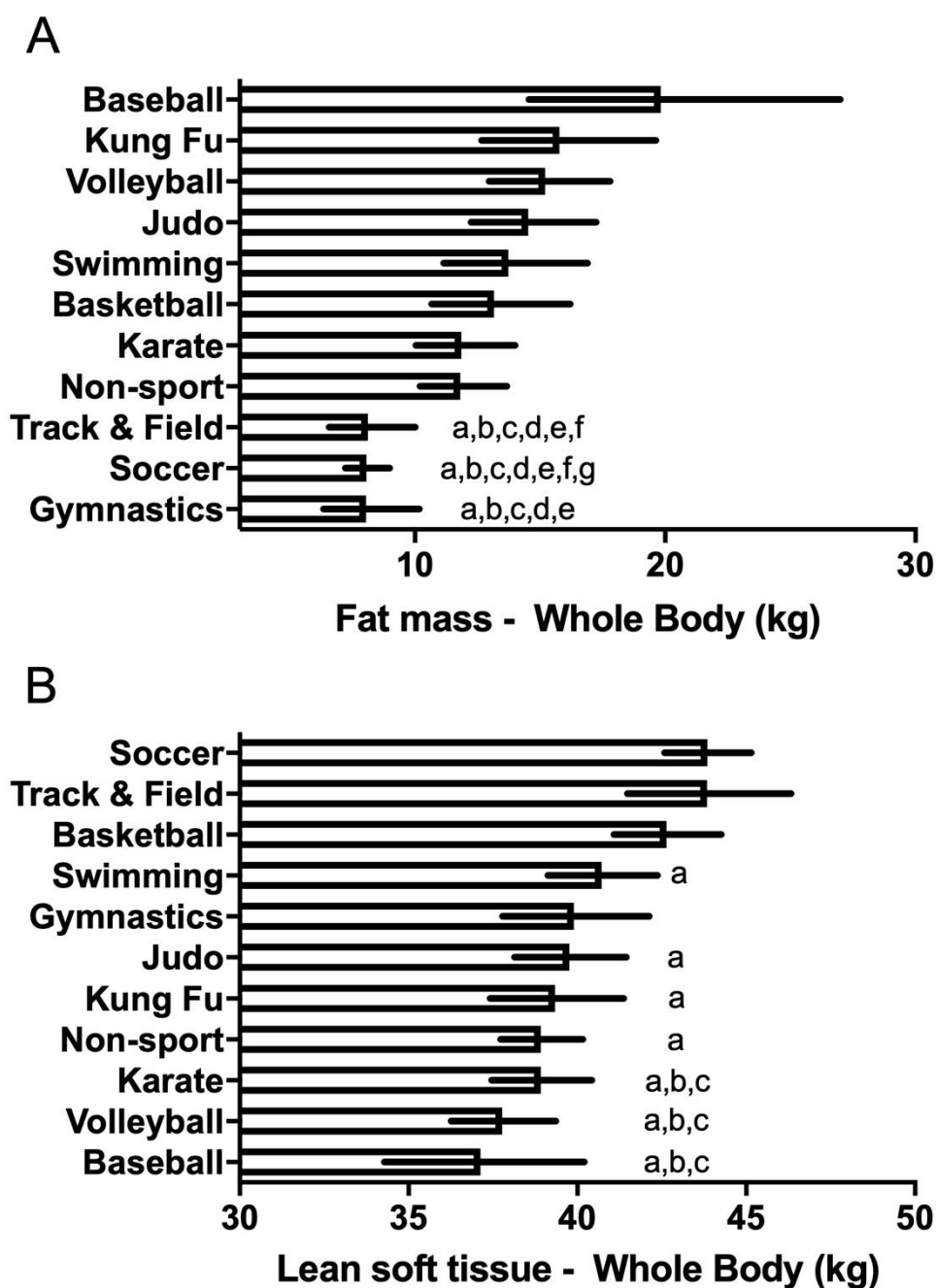


Figure 3. Comparisons of soft tissues (kg) among 10 sports and non-sport group categorized hierarchically (from highest to lowest) using the Estimating Equation Model (GEE). The results adjusted by sex, PHV status, weekly training volume and lean soft tissue (A), and the results were adjusted by sex, PHV status, weekly training volume and fat mass (B). The letters denote significant lower values between groups following hierarchical order (eg. a = significant lower values compared to the first sport modality, b = difference compared to second sport modality; $p < 0.05$).