Title

The effect of 12-month participation in osteogenic and non-osteogenic sports on bone development in adolescent male athletes. The PRO-BONE study.

Abstract

Objectives: Research investigating the longitudinal effects of the most popular sports on bone development in adolescent males is scarce. The aim is to investigate the effect of 12-month participation in osteogenic and non-osteogenic sports on bone development.

Design: A 12-month study was conducted in adolescent males involved in football, swimming and cycling and compared with an active control group.

Methods: 116 adolescent males (13.1±0.1 years at baseline): 37 footballers, 37 swimmers, 28 cyclists and 14 active controls were followed for 12 months. Bone mineral content (BMC) was measured by dual-energy x-ray absorptiometry, and bone stiffness was measured by quantitative ultrasound. Bone outcomes at 12 months were adjusted for baseline bone status, age, height, lean mass and moderate to vigorous physical activity.

Results: Footballers had higher improvement in adjusted BMC at the total body, total hip, shaft, Ward's triangle, legs and bone stiffness compared to cyclists (6.3 to 8.0 %). Footballers had significantly higher adjusted BMC at total body, shaft and legs compared to swimmers (5.4 to 5.6 %). There was no significant difference between swimmers and cyclists for any bone outcomes. Swimming and cycling participation resulted in non-significant lower bone development at most sites of the skeleton compared to controls (-4.3 to -0.6 %).

Conclusions: Football participation induces significantly greater improvements in BMC and bone stiffness over 12 months compared to cycling and swimming.

Keywords: Adolescence**;** Bone mass; Bone stiffness; Cycling; Football; Swimming; Weight-bearing exercise.

1. Introduction

Bone development occurs most rapidly during childhood and adolescence, with 80-90 % of peak bone mass (PBM) acquired by late adolescence depending on the site of the skeleton [1]. PBM is largely determined by genetics [2] and by modifiable factors, such as nutrition and physical activity (PA) [3, 4]. Exercise during this period of life can enhance bone mineral content (BMC) and bone mineral density (BMD) [5] and be maintained into adulthood [6]. Football, cycling and swimming are among the most popular sports performed by adolescents around the world [7]. However, participation in these sports may have different effects on bone development [8]. Participation in "osteogenic" sports, such us football, can augment BMC at the loaded sites of the skeleton [9, 10]. However, participation in "non-osteogenic sports", such as swimming and cycling, may have a negative or no impact on bone outcomes[11], which may compromise the achievement of a higher PBM and increase the risk of osteoporotic fractures in adulthood. From a public health perspective, understanding how the most popular sports worldwide among youth affect bone development is of great importance.

Cross-sectional studies have evaluated differences in BMC between adolescents engaged in different sports in comparison to a control group[11]. Specifically, footballers were found to have higher adjusted-BMC and BMD at most sites of the skeleton compared with age-matched controls [9]. In contrast, previous evidence found that adolescent male swimmers had lower adjusted-BMC and BMD at several sites compared to controls [12], but a recent systematic review concluded that swimmers have similar bone mass compared to sedentary controls [13]. Similarly, in a cross-sectional analysis we found that adolescent male swimmers and cyclists had lower bone outcomes compared to footballers [8]. However, other studies showed that cycling during adolescence may negatively influence bone health [11, 14]. To date, there are only a few longitudinal studies on this topic and it was found that 3 years of football participation increased femoral neck BMD by 10 % and improved femoral neck and intertrochanteric BMC twice as much compared to age-matched controls in prepubertal males [15]. Previously, 8 months of football training significantly improved bone outcomes at total body, intertrochanteric site, lumbar spine and femoral neck in female adolescent footballers, whereas 8 months of swimming training had no effect on bone outcomes in female adolescent swimmers [16].

Research investigating the longitudinal effects of the most popular sports on bone development in adolescent males is scarce [17]. It should be noted that a comprehensive analysis of potential confounders, such as lean mass and objectively measured moderate-to-vigorous PA (MVPA) should be used to control for important predictors of bone status in these sports[18].

In addition to Dual energy X-ray Absorptiometry (DXA), Quantitative Ultrasound (QUS) can indicate the risk of osteoporotic fractures at the calcaneus site that is particularly important for adolescent athletes due to their high prevalence of injuries [19, 20]. In a cross-sectional study, it was shown that swimming had no effect on bone stiffness compared to age-matched controls in adolescent males and females [12]. Also, in a cross-sectional analysis it was found that footballers had higher bone stiffness than controls but there were no differences in swimmers and cyclists compared to controls [8]. However, there is lack of longitudinal studies comparing the effects of osteogenic and non-osteogenic sports on QUS bone outcomes in adolescent males athletes [21]. Therefore, the purpose of this study is to investigate the effect of 12-month participation on BMC and bone stiffness in osteogenic (football) and that non-osteogenic sports (swimming and cycling) compared to an active control group after controlling for baseline bone outcomes, age, height, lean mass and MVPA.

2. Methods

The present study represents a 12-month analysis of sport participation as part of the PRO-BONE study, whose purpose and methodology have been described elsewhere [22]. For the present study, data obtained at baseline (T0) during autumn/winter 2014/15 and at follow-up (T1) during autumn/winter 2015/2016 were used (mean difference of visits = 372 days). Five participants were excluded because they did not complete the second visit (n=3) or they had missing data (n=2). For the present study, 116 adolescent males (37 swimmers, 37 footballers, 28 cyclists and 14 active controls not engaged in these sports more than 3 hour per week) aged 13.1 years ± 1.0 at T0 and 14.1 years ± 1.0 at T1 were included. The inclusion criteria at T0 were: 1) males 12–14 years old, engaged (≥3 h/week) in osteogenic (football) and/or non-osteogenic (swimming and cycling) sports for the last 3 years or more; 2) males 12–14 years old not engaged in any of these sports (≥3 h/week) in the last 3 or more years (control group). The exclusion criteria were at T0 were: 1) participants not taking part in another clinical trial; 2) participants not having any acute infection lasting until < 1 week before inclusion; 3) participants free of any medical history of diseases or medications affecting bone metabolism or injured; 4) white Caucasian ethnicity. Ethics approval received from the following committees: 1) the Ethics Review Sector of Directorate-General of Research (European Commission, ref. number 618496); 2) the Sport and Health Sciences Ethics Committee (University of Exeter, ref. number 2014/766) and 3) the National Research Ethics Service Committee (NRES Committee South West – Cornwall & Plymouth, ref. number 14/SW/0060).

A DXA scanner (GE Lunar Prodigy Healthcare Corp., Madison, WI, USA, 2006) was used to measure BMC (g), fat mass (g) and lean mass (g, excluding bone and fat mass). The total body scan was used to obtain BMC at the arms, legs, and total body (excluding head). Dual hip scans were performed to obtain BMC for total hip, femoral neck, Ward's triangle, trochanter and shaft sub-regions and the mean of right and left hip scans was used. The coefficient of variation (CV) for measurement reliability was not determined in the present study. Previous paediatric studies have shown that the DXA between-day CV was between 1.0 % and 2.9 % depending on the region [23]. In addition, QUS measurements were performed with a Lunar Achilles Insight (TM Insight GE Healthcare, Milwaukee, WI, USA). This portable device measures bone stiffness using ultrasound waves. QUS is a non-ionising radiation technique and evaluates bone stiffness based on broadband ultrasound attenuation (dB/MHz) and speed of sound (m/s) [24]. The real-time image of the calcaneus and the region of interest ensures that the measurement is reliable and valid to assess bone health as demonstrated in paediatric population [25]. Daily calibration was completed at all visits and measurements were taken according to the standard procedure provided by the manufacturer. The positioning was standardised between visits by using an adapter for the children's feet in order to get the same position of the calcaneus. Both feet were measured twice and the mean of the two measures was used for statistical analyses.

Stature (cm) and body mass (kg) were measured by using standard procedures and sexual maturity was self-reported using adapted drawings of the five stages of pubic hair development [26]. Physical activity was measured for seven consecutive days at T0 and T1 using wrist accelerometers (GENEActiv, GENEA, UK). The validity and reliability of the accelerometer has been established previously in children and adolescents [27]. Data were collected at 100 Hz and analysed at 1 s epoch intervals to establish time spent in MVPA using a validated cut-point [27]. Weekly training hours were obtained by face to face interviews at T0 at T1. In addition, the coaches indicated participation in weight-training exercises for a subsample of participants.

Statistical analyses were performed using the SPSS IBM statistics (version 21.0 for Windows, Chicago, IL, USA). Data were normally distributed and presented as mean and standard deviation. Data were analysed in two stages: 1) raw (unadjusted) data using one-way analysis of variance (ANOVA) with Bonferroni post hoc or Chi-Square tests at T0 and T1 to detect the differences in BMC, and 2) adjusted data using one-way analysis of covariance (ANCOVA) with Bonferroni post hoc to detect the differences between the groups at T1 after controlling for: bone status at T0, age, height, lean mass, MVPA and maturity status [18, 28, 29]. Paired t-tests were used to compare differences in values between T0 and T1. Preliminary analyses showed bone outcome results did not change when maturity was used as confounder instead of age. Thus, maturity was not included in the model. Percentages of difference between groups were used to quantify the magnitude of the differences. Significance was set at $p < 0.05$ and $p < 0.01$.

3. Results

Table 1 presents the descriptive characteristics of the participants at T0 and T1. From T0 to T1 all the descriptive characteristics significantly increased in all groups except MVPA in all groups and body fat percentage in sports groups that significantly decreased. Between-group differences at T1 showed that swimmers were older, taller, heavier and had more lean mass than the footballers and controls. Swimmers were more mature than footballers and controls. Swimmers trained more hours per week and had more years of training than cyclists. Footballers spent more time doing MVPA than swimmers and controls. In addition, footballers trained more hours per week and had more training years than cyclists and swimmers. Cyclists were older than controls and spent more time doing MVPA compared to swimmers and controls. Controls had a higher body fat percentage than all sports groups.

(Table 1 here)

Table 2 shows the adjusted BMC and bone stiffness at T0 and T1 between the groups and Figure 1 shows the adjusted BMC and bone stiffness differences (%) between the sports groups and controls at T1. At T1 footballers had significantly higher BMC at total body, shaft and legs compared to swimmers (5.4 to 5.6 %). Also, at T1 footballers had significantly higher BMC at total body, total hip, Ward's triangle, shaft and legs compared to cyclists (6.3 to 8.0 %). At T1 footballers had non-significantly higher bone outcomes than controls (3.3 to 8.4 %). The adjusted bone stiffness was significantly higher in footballers compared to cyclists (7.8 %) at T1. Swimmers and cyclists had similar bone outcomes at T1 (-0.6 to 4.3 %) and both groups had no significant differences at any of the bone outcomes compared to controls (-4.5 to 4.7 %).

(Table 2 and Figure 1here)

Supplementary table 1 shows the unadjusted change in bone outcomes at T0 and T1. At T1 BMC significantly increased at all skeletal sites in swimmers (10.3 to 21.0 %), footballers (13.6 to 23 %), cyclists (9.9 to 19.0 %) and controls (14.8 to 21.0 %) compared to T0. In addition, bone stiffness significantly increased in swimmers (4.5 %), footballers (6.9 %) and controls (5.1 %) from T0 to T1, but the increase was not significantly different in cyclists (0.9 %).

4. Discussion

The main findings of the present study are: 1) after 12 months of sports participation, footballers had significantly higher BMC and bone stiffness gains compared to swimmers and cyclists, and higher but non-significant BMC and bone stiffness compared to active controls; 2) after 12 months swimmers and cyclists had similar BMC and bone stiffness, and both groups had no significant differences in BMC and bone stiffness compared to controls.

The present study shows that after 12 months footballers had higher adjusted BMC compared to cyclists and swimmers at most skeletal sites. The only study comparing these sports was conducted in female adolescent swimmers and footballers and showed that 8 months period of sport-specific training increased total body BMD by 2.9 % in footballers, whereas BMD remained constant in swimmers [16]. The present study found that footballers had 2.4 % higher adjusted BMC compared to swimmers after 12 months. Cross-sectional evidence in adolescent males found that footballers had greater BMD at the femoral neck compared to swimmers [30]. The differences observed in BMC gains among the sports groups in the present study might be explained by the plyometric exercises included in the football training that can induce higher bone mass in adolescent athletes despite the reduced lean mass in footballers compared to swimmers [31]. In this regard, Larsen et al. found that a 10-month programme that included small-sided ball games improved BMD at the legs and total body compared to controls, and BMD at the legs compared to a circuit strength training [32].

In the present study, BMC development over 12 months was similar between adolescent male swimmers and cyclists at any skeletal sites. This is in line with studies showing that swimming and cycling seem to have no additional effect on bone growth [11, 12], which could be due to the low ground reaction forces produced during participation in the non-osteogenic environment. In regards to bone stiffness, the present study showed that footballers significantly increased bone stiffness compared to cyclists. The latter is in accordance with cross-sectional analysis from this cohort showing that footballers had significantly higher bone stiffness compared to swimmers and cyclists [8].

Football participation during adolescence may induce higher bone outcomes compared to leisure active controls according to cross-sectional evidence [9, 10]. However, evidence from a study in prepubescent boys found that footballers had non-significant but higher bone outcomes compared to active controls after 10 months of training [33]. These results are in line with our findings showing that footballers had higher (3.3 % to 8.4 %) but not significant bone outcomes compared to active controls after 12 months. It should be noted that the control group was physically active (MVPA= 64 min/day) and some controls engaged in other weight-bearing sports (< 3 hours per week) which might explain the non-significant difference compared to footballers. A previous cross-sectional study showed that footballers had significantly higher bone stiffness at lower extremities compared to active controls [34]. The differences in bone outcomes between adolescent footballers and controls might increase in the future due to the previous findings showing that 3 years of football training exhibited significantly greater adjusted BMC in total body, legs and intertrochanteric sites compared to age-matched controls [15].

Swimming is considered a non-osteogenic sport and does not promote positive changes on bone development above that observed due to growth. According to a recent meta-analysis, swimmers and sedentary controls have similar bone outcomes [13]. In addition, adolescent males that participated only in swimming had lower BMD and BMC at several sites of the skeleton compared to age-matched controls [12]. In the present study swimmers had similar BMC gains with active controls after controlling for relevant covariates (including T0 BMC). Similarly, we found swimmers to have similar bone outcomes with controls at baseline after controlling for the same covariates [8]. A possible explanation is that swimming has non-gravitational training characteristics and despite swimmers having augmented higher lean mass it was not enough to produce bone adaptations after 12-months of training [35]. Regarding bone stiffness, previous cross-sectional findings showed similar values between swimmers and controls [12].

Cycling is a widely practised sport that applies low mechanical forces to the skeleton during training [36] and the present analysis showed that cyclists had lower but non-significant adjusted BMC and bone stiffness than controls. Previous evidence exist only from cross-sectional studies indicating that adolescent female cyclists had similar or lower bone outcomes compared to non-athletic controls[16]. Another cross-sectional study found that males cyclists (< 17 years) had significantly lower BMC at the legs compared to age-matched controls [11]. According to the baseline cross-sectional analysis of this cohort, cyclists had non-significantly higher adjusted BMC at the most skeletal sites [8]. However, after one year cyclists had non-significant lower bone development in BMC and bone stiffness than controls. The differences observed in the current study might be explained by the non-osteogenic environment of both swimming and cycling and by the mechanical loading produced by the sports-specific patterns. In addition, participation in plyometric training or other weight-bearing activities might explain the difference on bone outcomes between adolescent athletes and needs further investigation to quantify the impact of weight training on bone outcomes.

The strengths of the present study are 1) the investigation of bone outcomes across osteogenic and non-osteogenic male adolescent groups over 12 months; 2) the combination of DXA and QUS, which provides a comprehensive insight into BMC and bone stiffness outcomes and 3) the rigorous methodology that enabled the inclusion of a selection of specific confounders which increases the internal validity of the study. A limitation of the present study is the lack of nutrition-related covariates and the two time points of the longitudinal assessment. However, we have observed that dietary intakes (total energy, protein and calcium) were no different between the groups at T0 and T1 (data not reported). In addition, despite the two measurements completed, this is the first stud to assess the differences in bone development of these sports over 12 months. Also, it should be noted that all sport groups were very active, but cyclists trained less compared to footballers and swimmers.

5. Conclusions

In summary, this is the first study to investigate the 12-month development on BMC and bone stiffness in adolescent males engaged in osteogenic (football) and non-osteogenic sports (swimming and cycling). The findings of this study suggest that 12 months of football participation induces greater BMC and bone stiffness compared to cycling or swimming participation. In addition, footballers had higher BMC although not significant compared to an active control group. Swimmers and cyclists had similar bone outcomes after 12 months, and both groups no significant differences in any of the bone outcomes compared to active controls. These findings suggest that participation in non-osteogenic sports during adolescence should be combined with weight-bearing activities in order to optimise bone development. Studies focusing on females and using specific interventions to improve bone mineralization in non-osteogenic sports during growth are needed.

Practical implications

- Football participation for 12-months induces significantly higher increase in bone mineral content and bone stiffness compared to cycling and swimming in adolescent males.
- Participation in cycling and swimming for 12-months has similar effects on bone development in adolescent males and both groups have non-significant lower bone outcomes compared to active controls.
- Cycling and swimming participation may compromise the optimal bone development during adolescence suggesting intervention studies are needed to improve bone development in adolescents participating in these sports.

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Abbreviations: BMC: Bone mineral content; BMD: Bone mineral density; DXA: Dual Energy X-Ray Absorptiometry; MVPA: Moderate to vigorous physical activity; PA: Physical activity; QUS: Quantitative ultrasound; PBM: Peak bone mass; T0: baseline measurements; T1: 12-months measurements.

Conflict of Interest: The authors have no conflict of interest to disclose.

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References

1. Gordon CM, Zemel BS, Wren TA, et al. The Determinants of Peak Bone Mass. *J Pediatr.* 2016.
2. Bonjour JP, Chevalley T, Rizzoli R, Ferrari S. Gene-environment interactions in the skeletal response to nutrition and exercise during growth. *Med Sport Sci.* 2007; 51:64-80.
3. Gracia-Marco L, Moreno LA, Ortega FB, et al. Levels of physical activity that predict optimal bone mass in adolescents: the HELENA study. *Am J Prev Med.* 2011; 40(6):599-607.
4. Mouratidou T, Vicente-Rodriguez G, Gracia-Marco L, et al. Associations of dietary calcium, vitamin D, milk intakes, and 25-hydroxyvitamin D with bone mass in Spanish adolescents: the HELENA study. *J Clin Densitom.* 2013; 16(1):110-117.
5. Behringer M, Gruetzner S, McCourt M, Mester J. Effects of weight-bearing activities on bone mineral content and density in children and adolescents: a meta-analysis. *J Bone Miner Res.* 2014; 29(2):467-478.
6. Baxter-Jones AD, Kontulainen SA, Faulkner RA, Bailey DA. A longitudinal study of the relationship of physical activity to bone mineral accrual from adolescence to young adulthood. *Bone.* 2008; 43(6):1101-1107.
7. Active People Survey 10: Sport England, UK Department of Health; 2016.
8. Vlachopoulos D, Barker AR, Williams CA, et al. The Impact of Sport Participation on Bone Mass and Geometry in Male Adolescents. *Med Sci Sports Exerc.* 2017; 49(2):317-326.
9. Zouch M, Vico L, Frere D, Tabka Z, Alexandre C. Young male soccer players exhibit additional bone mineral acquisition during the peripubertal period: 1-year longitudinal study. *Eur J Pediatr.* 2014; 173(1):53-61.
10. Ubago-Guisado E, Gomez-Cabello A, Sanchez-Sanchez J, Garcia-Unanue J, Gallardo L. Influence of different sports on bone mass in growing girls. *J Sports Sci.* 2015; 33(16):1710-1718.
11. Olmedillas H, Gonzalez-Aguero A, Moreno LA, Casajus JA, Vicente-Rodriguez G. Bone Related Health Status in Adolescent Cyclists. *Plos One.* 2011; 6(9):e24841.
12. Gomez-Bruton A, Gonzalez-Aguero A, Gomez-Cabello A, Matute-Llorente A, Casajus JA, Vicente-Rodriguez G. The effects of swimming training on bone tissue in adolescence. *Scand J Med Sci Sports.* 2015; 25(6):e589-602.
13. Gomez-Bruton A, Montero-Marin J, Gonzalez-Aguero A, et al. The Effect of Swimming During Childhood and Adolescence on Bone Mineral Density: A Systematic Review and Meta-Analysis. *Sports Med.* 2016; 46(3):365-379.
14. Rico H, Revilla M, Hernandez ER, Gomez-Castresana F, Villa LF. Bone mineral content and body composition in postpubertal cyclist boys. *Bone.* 1993; 14(2):93-95.
15. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Serrano-Sanchez JA, Dorado C, Calbet JA. High femoral bone mineral density accretion in prepubertal soccer players. *Med Sci Sports Exerc.* 2004; 36(10):1789-1795.
16. Ferry B, Lespessailles E, Rochcongar P, Duclos M, Courteix D. Bone health during late adolescence: effects of an 8-month training program on bone geometry in female athletes. *Joint Bone Spine.* 2013; 80(1):57-63.
17. Vlachopoulos D, Barker AR, Ubago-Guisado E, et al. Longitudinal Adaptations of Bone Mass, Geometry and Metabolism in Adolescent Male Athletes. The PRO-BONE Study. *J Bone Miner Res.* 2017.
18. Vlachopoulos D, Ubago-Guisado E, Barker AR, et al. Determinants of Bone Outcomes in Adolescent Athletes at Baseline: The PRO-BONE Study. *Med Sci Sports Exerc.* 2017; 49(7):1389-1396.
19. Krieg MA, Barkmann R, Gonnelli S, et al. Quantitative ultrasound in the management of osteoporosis: the 2007 ISCD Official Positions. *J Clin Densitom.* 2008; 11(1):163-187.
20. Frush TJ, Lindenfeld TN. Peri-epiphyseal and Overuse Injuries in Adolescent Athletes. *Sports Health.* 2009; 1(3):201-211.

21. Boreham CA, McKay HA. Physical activity in childhood and bone health. *Br J Sports Med.* 2011; 45(11):877-879.
22. Vlachopoulos D, Barker AR, Williams CA, Knapp KM, Metcalf BS, Gracia-Marco L. Effect of a program of short bouts of exercise on bone health in adolescents involved in different sports: the PRO-BONE study protocol. *BMC Public Health.* 2015; 15(1):361.
23. Johnson J, Dawson-Hughes B. Precision and stability of dual-energy X-ray absorptiometry measurements. *Calcif Tissue Int.* 1991; 49(3):174-178.
24. Baroncelli GI. Quantitative ultrasound methods to assess bone mineral status in children: technical characteristics, performance, and clinical application. *Pediatr Res.* 2008; 63(3):220-228.
25. Sioen I, Lust E, De Henauw S, Moreno LA, Jimenez-Pavon D. Associations Between Body Composition and Bone Health in Children and Adolescents: A Systematic Review. *Calcif Tissue Int.* 2016; 99(6):557-577.
26. Tanner JM, Whitehouse RH. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. *Arch Dis Child.* 1976; 51(3):170-179.
27. Phillips LR, Parfitt G, Rowlands AV. Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. *J Sci Med Sport.* 2013; 16(2):124-128.
28. Wilkinson K, Vlachopoulos D, Klentrou P, et al. Soft tissues, areal bone mineral density and hip geometry estimates in active young boys: the PRO-BONE study. *Eur J Appl Physiol.* 2017; 117(4):833-842.
29. Ubago-Guisado E, Vlachopoulos D, de Moraes ACF, et al. Lean mass explains the association between muscular fitness and bone outcomes in 13-year-old boys. *Acta paediatrica (Oslo, Norway : 1992).* 2017.
30. Silva CC, Goldberg TB, Teixeira AS, Dalmas JC. The impact of different types of physical activity on total and regional bone mineral density in young Brazilian athletes. *J Sports Sci.* 2011; 29(3):227-234.
31. Gunter K, Baxter-Jones AD, Mirwald RL, et al. Impact exercise increases BMC during growth: an 8-year longitudinal study. *J Bone Miner Res.* 2008; 23(7):986-993.
32. Larsen MN, Nielsen CM, Helge EW, et al. Positive effects on bone mineralisation and muscular fitness after 10 months of intense school-based physical training for children aged 8-10 years: the FIT FIRST randomised controlled trial. *Br J Sports Med.* 2016.
33. Zouch M, Jaffre C, Thomas T, et al. Long-term soccer practice increases bone mineral content gain in prepubescent boys. *Joint Bone Spine.* 2008; 75(1):41-49.
34. Falk B, Braid S, Moore M, Yao M, Sullivan P, Klentrou N. Bone properties in child and adolescent male hockey and soccer players. *J Sci Med Sport.* 2010; 13(4):387-391.
35. Maimoun L, Coste O, Philibert P, et al. Peripubertal female athletes in high-impact sports show improved bone mass acquisition and bone geometry. *Metabolism.* 2013; 62(8):1088-1098.
36. Olmedillas H, Gonzalez-Aguero A, Moreno LA, Casajus JA, Vicente-Rodriguez G. Cycling and bone health: a systematic review. *BMC Med.* 2012; 10:168.

Tables

Table 1.
Descriptive characteristics of the participants at baseline (T0) and after 12 months (T1) of sport participation

N = 116	Swimmers (N = 37)	Footballers (N = 37)	Cyclists (N = 28)	Controls (N = 14)
Age (yrs)				
T0	13.5 (1.0)^{b,dd}	12.9 (0.9)	13.2 (1.0)^{d}	12.3 (0.5)
T1	14.6 (1.0)^{b,dd,*}	13.9 (0.9)*	14.2 (1.0)^{d,*}	13.2 (0.5)*
Stature (cm)				
T0	165.1 (9.7)^{bb,d}	155.2 (9.3)	160.7 (10)	154.5 (9.9)
T1	171.6 (8.9)^{bb,dd,*}	162.7 (10.3)*	166.6 (10.7)*	160.7 (10.5)*
Body mass (kg)				
T0	51.9 (8.7)^{bb}	44.3 (7.9)	49.3 (12.5)	48.3 (13.0)
T1	58.9 (8.2)^{b,*}	50.8 (9.7)*	54.7 (12.5)*	55.2 (15.6)*
BMI (kg/m^2)				
T0	18.9 (1.6)	18.3 (1.4)	18.9 (3.3)	20.0 (3.4)
T1	19.9 (2.0)*	19.0 (1.8)*	21.0 (3.1)*	21.0 (3.7)*
Lean mass (kg)				
T0	41.1 (9.0)^{b,dd}	35.4 (7.2)	37.5 (7.5)	31.7 (5.5)
T1	47.8 (8.7)^{b,dd,*}	41.2 (9.2)*	42.9 (8.2)*	36.8 (7.1)*
Body fat (%)				
T0	17.3 (7.3)*	15.7 (5.6)*	18.0 (9.0)*	29.0 (10.5)^{aa,bb,cc}
T1	14.4 (6.4)	14.5 (6.0)	16.1 (9.2)	27.9 (10.9)^{aa,bb,cc}
Tanner stages (1-5; %)				
T0	(16/25/16/43/0)	(24/35/24/16/0)	(14/28/25/28/4)	(29/21/21/29/0)
T1	(5/11/11/51/22)^{b,d,*}	(6/16/35/43/0)*	(7/11/14/57/11)*	(0/21/43/36/0)*
Training (h/week)				
T0	9.4 (5.1)^{cc}	10.0 (2.3)^{cc}	5.2 (2.1)	-
T1	8.9 (3.6)^{cc}	9.4 (1.7)^{cc}	5.6 (2.0)	-
Years of training				
T0	5.9 (2.5)^{cc}	7.5 (2.3)^{a,cc}	3.9 (1.3)	-
T1	6.9 (2.5)^{cc,*}	8.5 (2.3)^{a,cc,*}	4.9 (1.3)	-
MVPA (min/day)				
T0	85.0 (30.9)*	119.8 (29.7)^{aa,dd,*}	106.5 (33.7)^{a,*}	83.2 (26.8)*
T1	62.9 (21.8)	92.4 (25.7)^{aa,dd}	85.6 (21.8)^{aa,d}	64.3 (18.1)

Values presented as mean (SD). BMI: Body mass index, MVPA: Moderate to vigorous physical activity. T0 = baseline values, T1 = 1 year values. Superscript letters denote a higher significant difference between sports: a (swimmers), b (footballers), c (cyclists), d (controls), ^{a,b,c,d} $p<0.05$, ^{aa,bb,cc,dd} $p<0.001$ and within each sports group at T0 and T1: * $p<0.05$.

Table 2.
Adjusted bone mineral content (BMC, g) and bone stiffness at baseline (T0) and after 12 months (T1) of sports participation in adolescent males

N = 116	Swimmers (N = 37)	Footballers (N = 37)	Cyclists (N = 28)	Controls (N = 14)
TBLH (g)				
T0	1453.9 (21.1)	1574.5 (21.5)^{a,c,d}	1459.9 (22.7)	1451.8 (34.4)
T1	1752.9 (20.9)	1846.7 (20.9)^{a,cc}	1737.0 (21.9)	1787.1 (33.6)
Total hip (g)				
T0	26.50 (0.50)	30.24 (0.51)^{aa,cc,d}	26.62 (0.53)	24.61 (0.79)
T1	32.04 (0.42)	33.53 (0.44)^{c}	31.26 (0.45)	31.70 (0.70)
Ward's (g)				
T0	2.15 (0.06)	2.48 (0.06)^{a,c,dd}	2.14 (0.06)	1.92 (0.1)
T1	2.66 (0.05)	2.74 (0.05)^{c}	2.55 (0.05)	2.63 (0.08)
Trochanter (g)				
T0	8.11 (0.23)	9.85 (0.23)^{aa,cc,d}	8.22 (0.24)	7.60 (0.36)
T1	10.99 (0.27)	11.38 (0.28)	10.59 (0.28)	10.50 (0.43)
Shaft(g)				
T0	14.16 (0.26)	15.71 (0.26)^{a,cc,d}	14.12 (0.27)	13.09 (0.41)
T1	16.20 (0.16)	17.09 (0.17)^{a,cc}	16.08 (0.17)	16.30 (0.27)
Arms (g)				
T0	209.27 (3.23)	207.24 (3.19)	211.98 (3.48)^{d}	193.43 (5.22)
T1	252.85 (2.95)	258.71 (2.85)	254.39 (3.15)	249.52 (4.84)
Legs (g)				
T0	215.69 (4.51)	253.79 (4.59)^{aa,cc,d}	223.08 (4.89)	216.31 (7.43)
T1	854.67 (9.67)	902.89 (9.82)^{a,cc}	836.26 (9.85)	873.90 (15.24)
Stiffness index				
T0	89 (2)	100 (2)^{a,c,d}	91 (2)	86 (3)
T1	97 (1)	101 (1)^{c}	93 (1)	98 (2)

Values are presented as mean (SE). TBLH: Total body less head. Superscript letters denote a higher significant difference with: a (swimmers), b (footballers), c (cyclists) and d (controls). ^{a,b,c,d} $p<0.05$ and ^{aa,bb,cc,dd} $p<0.001$. At T0 BMC values were adjusted for age, stature, MVPA and lean mass. At T1 BMC values were adjusted for age, stature, MVPA, lean mass and for baseline BMC (T0).

Supplementary table 1.
Unadjusted bone mineral content (BMC, g) and bone stiffness at baseline (T0) and after 12 months (T1) of sports participation in adolescent males

N = 116	Swimmers (N = 37)	Footballers (N = 37)	Cyclists (N = 28)	Controls (N = 14)
TBLH (g)				
T0	1622.8 (325.4)[dd]	1473.5 (338.6)	1478.9 (353.2)	1234.4 (347.9)
T1	1923.9 (327.8)[dd]	1791.3 (453.0)	1725.4 (396.2)	1504.8 (433.7)
Total hip (g)				
T0	28.79 (5.56)[dd]	28.78 (6.18)[dd]	27.31 (5.92)[d]	21.12 (5.55)
T1	33.52 (5.69)[dd]	34.56 (7.76)[dd]	31.17 (6.28)[d]	25.21 (6.49)
Ward's (g)				
T0	2.29 (0.50)[dd]	2.40 (0.59)[dd]	2.19 (0.51)[d]	1.64 (0.45)
T1	2.76 (0.63)[d]	2.92 (0.77)[dd]	2.51 (0.70)	1.98 (0.56)
Trochanter (g)				
T0	9.01 (2.35)[d]	9.31 (2.67)[dd]	8.49 (2.34)[d]	6.11 (2.17)
T1	11.41 (2.57)[d]	12.09 (3.84)[dd]	10.48 (2.76)[d]	7.73 (2.87)
Shaft (g)				
T0	15.31 (2.69)[dd]	14.94 (2.97)[d]	14.46 (2.96)[d]	11.49 (2.74)
T1	17.07 (2.59)[d]	17.30 (3.34)[dd]	16.05 (2.92)	13.49 (2.93)
Arms (g)				
T0	243.39 (64.01)[bb,dd]	188.34 (48.05)	210.62 (59.05)[d]	155.89 (40.58)
T1	297.38 (66.37)[b,dd]	235.65 (71.68)	254.04 (70.70)[d]	193.5 (57.54)
Legs (g)				
T0	775.78 (136.24)[d]	747.84 (175.02)	733.99 (171.45)	612.28 (179.47)
T1	906.04 (139.86)[d]	900.62 (224.16)	835.18 (177.26)	746.29 (217.99)
Bone stiffness				
T0	91 (12)	99 (11)[a,dd]	92 (23)	82 (11)
T1	95 (14)	106 (12)[a,cc,dd]	93 (14)	87 (14)

Values are presented as mean (SD). TBLH: Total body less head. Superscript letters denote a higher significant difference with: a (swimmers), b (footballers), c (cyclists) and d (controls). [a,b,c,d] $p<0.05$ and [aa,bb,cc,dd] $p<0.001$.

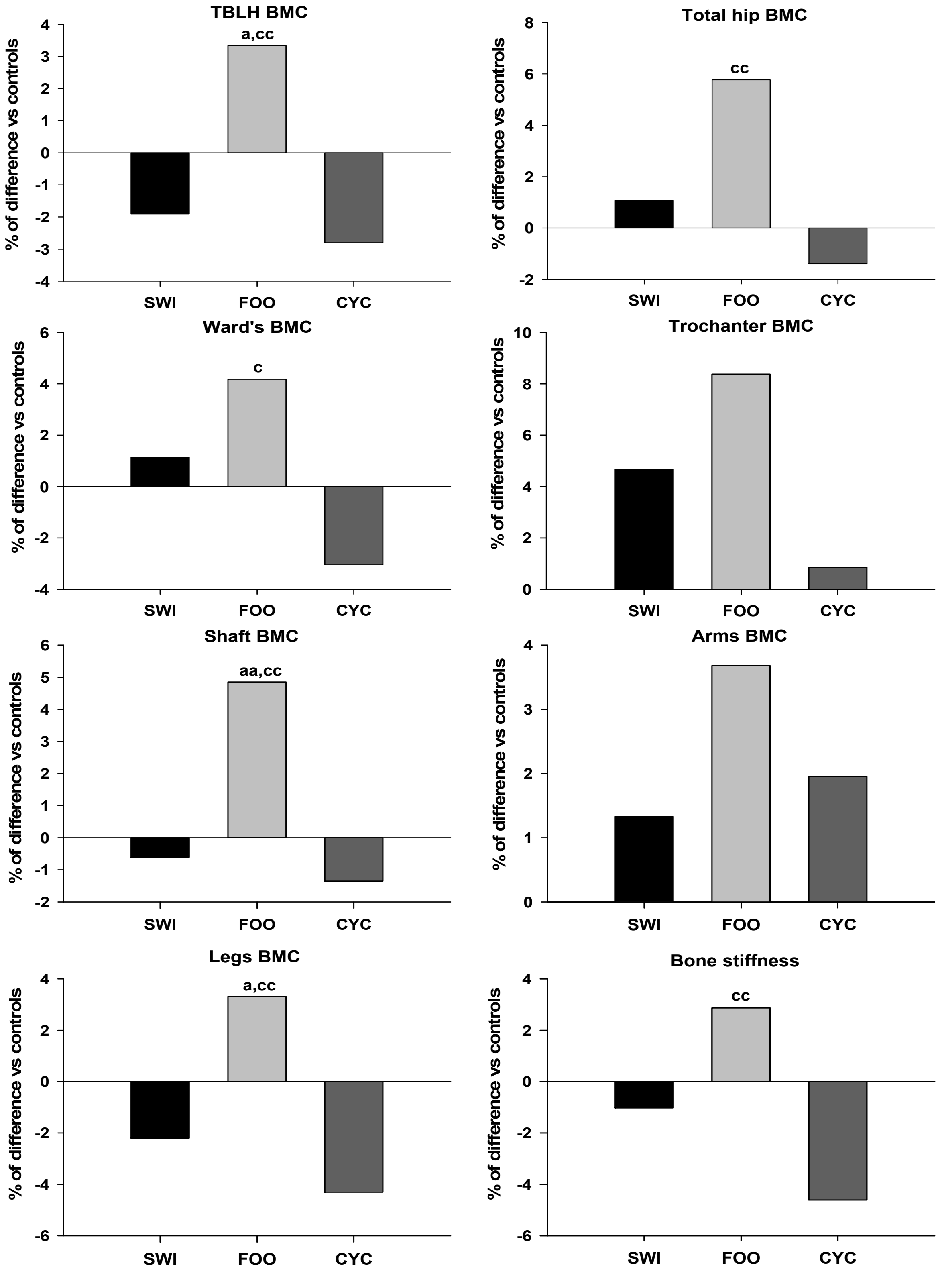

Figure 1. Differences (%) in adjusted bone mineral content (BMC) between the sports groups and controls after 1 year. The results adjusted for age, height, lean mass, moderate to vigorous physical activity and bone outcomes at baseline (T0). TBLH: Total body less head. Letters denote a significant difference with: a (Swimmers, SWI), b (Footballers, FOO), c (Cyclists, CYC) and d (Controls). [a,b,c,d] $p<0.05$ and [aa,bb,cc,dd] $p<0.01$.