Research Square

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The Association between Swimming Exercise and Adolescent Bone Density and Body Composition: A Retrospective Exploratory Study Based on DXA

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Abstract

Background

Swimming is a non-weight-bearing sport, and its effects on bone health during adolescence remain controversial. This study aimed to compare bone mineral density (BMD) and body composition between adolescent swimmers and non-swimmers, accounting for potential confounders.

Methods

A retrospective analysis was conducted using dual-energy X-ray absorptiometry (DXA) data from 27 adolescents (12 swimmers and 15 non-swimmers, aged 9.7–14 years). Whole-body and regional BMD, muscle mass, and fat mass were assessed. Analysis of covariance (ANCOVA) was used to examine the independent effect of group after adjusting for age, height, and body weight.

Results

Before adjustment, swimmers exhibited significantly lower whole-body, femoral, and trunk BMD compared to non-swimmers ($p < 0.05$). After adjusting for covariates, group had a persistent and significant effect on whole-body BMD ($F = 19.18$, $p < 0.001$, partial $\eta^2 = 0.466$), femoral BMD ($F = 25.91$, $p < 0.001$, partial $\eta^2 = 0.541$), and trunk BMD ($F = 19.93$, $p < 0.001$, partial $\eta^2 = 0.475$). Upper limb BMD did not differ significantly between groups ($p = 0.080$). Furthermore, swimmers demonstrated a significantly higher upper-to-lower limb muscle ratio (0.328 vs. 0.241, $p < 0.001$) and lower fat mass across all regions ($p < 0.001$).

Conclusions

Adolescent swimmers had lower BMD at weight-bearing sites and a higher upper-to-lower limb muscle ratio than non-swimmers, independent of age, height, and weight. These findings suggest that swimming alone may provide insufficient osteogenic stimulus for weight-bearing bones. Adolescent swimmers may benefit from incorporating weight-bearing or impact-loading exercises to optimize bone health.

Introduction

Adolescence is a critical period for bone mineral accrual, as the bone mass gained during this stage largely determines peak bone mass and influences the risk of osteoporosis and fragility fractures in later life[1–4]. Physical activity, particularly exercise that generates high mechanical loading, is recognized as a potent stimulus for bone development[5–8]. However, not all sports confer equal benefits to the skeleton[9–11].

Swimming is a highly popular non-weight-bearing sport characterized by a hypogravitational environment[12, 13]. While it offers excellent cardiovascular and metabolic benefits, its osteogenic potential remains a subject of debate[13–15]. A previous systematic review and meta-analysis by Gomez-Bruton et al reported that child and adolescent swimmers presented similar bone mineral density (BMD) values to sedentary controls but significantly lower BMD than athletes engaged in high-impact sports[16]. Furthermore, swimming imposes specific mechanical demands on the upper body, which may lead to site-specific adaptations in body composition, such as a relatively greater development of upper limb muscle mass compared to the lower limbs[17, 18].

However, most existing evidence derives from European and North American populations. Data utilizing the gold-standard dual-energy X-ray absorptiometry (DXA) in Chinese adolescent swimmers are relatively scarce[19]. Additionally, due to the inherent differences in body size between swimmers and the general population, comparing BMD and body composition without adequately controlling for confounding factors such as age, height, and body weight can lead to biased conclusions[12, 20, 21].

Swimming is a widely practiced sport among children and adolescents, with well-documented benefits for cardiorespiratory fitness and metabolic health[22].

Therefore, the present study aimed to retrospectively analyze DXA data from a Chinese adolescent swimming training base to compare site-specific BMD and body composition between swimmers and non-swimmers. We hypothesized that swimmers would exhibit lower BMD at weight-bearing sites (femur and trunk), a higher upper-to-lower limb muscle ratio, and lower whole-body fat mass than non-swimmers, independent of body weight.

Methods

Study Design and Ethical Statement

This was a retrospective, exploratory, controlled quantitative study. Secondary analysis was performed on DXA body composition data previously collected during routine health examinations to compare bone mineral density (BMD), muscle mass, fat mass, and bone minera l content between adolescent swimmers and non-swimmers. The study did not involve any new intervention, measurement, or contact with participants.

The study was approved by the Sports Science Experiment Ethics Committee of Beijing Sport University (Approval No. 2026496H). Given the retrospective nature of the study, the anonymization of all data prior to analysis, and the infeasibility of obtaining informed consent, the ethics committee granted a waiver of informed consent.

Participants

Data were obtained from routine health examinations conducted at the National Ice and Snow Sports Training and Research Base (Erqi Base, Beijing Sport University) in July 2023. A total of 27 adolescents were included, comprising 12 swimmers (7 males, 5 females) and 15 non-swimmers (9 males, 6 females), aged 9.7–14 years.

Inclusion criteria: (1) Swimmers: adolescent athletes who had undergone systematic swimming training at the Base for ≥ 1 year, with a training frequency of ≥ 5 sessions/week and ≥ 1.5 hours per session; (2) Non-swimmers: adolescents of the same age range at the same base who did not participate in systematic sports training (including swimming); (3) Both groups had completed DXA measurements with complete and valid data.

Exclusion criteria: (1) Missing or evidently erroneous key DXA indicators (BMD, muscle mass, fat mass); (2) Non-swimmers with a history of ≥ 6 months of systematic swimming training; (3) Known diseases affecting bone metabolism or current use of medications affecting bone metabolism; (4) DXA scans of inadequate image quality.

Data Acquisition and Anonymization

During an internship at the Base, the researcher obtained permission from **the staff member who was** responsible for DXA assessments at the base, to use the anonymized data from these health examinations. Prior to analysis, all data were anonymized: names, dates of birth, contact information, and any other directly identifiable personal information were removed. Each participant was assigned a unique study ID with no mapping or linkage to their true identity. Only sex, age, height, weight, and DXA-derived measurements were retained.

Measurements

All variables were derived from DXA reports and included: (1) BMD: whole-body, upper limb, femur, and trunk BMD (g/cm²); (2) Muscle mass: whole-body, upper limb, femur, and trunk muscle mass (g); (3) Fat mass: whole-body, upper limb, femur, and trunk fat mass (g); (4) Bone mineral content: whole-body, upper limb, femur, and trunk bone mineral content (g)[23].

The upper-to-lower limb muscle ratio was calculated as upper limb muscle mass (g) divided by femur muscle mass (g).

Equipment

A dual-energy X-ray absorptiometry (DXA) scanner (Lunar iDXA, GE Healthcare, Madison, WI, USA) equipped with enCORE software version 16 was used for whole-body scans. Daily quality assurance (QA) calibration was performed before each testing session according to the manufacturer's instructions.

Statistical Analysis

All statistical analyses were performed using R version 4.6.1, with a two-sided significance level of $\alpha = 0.05$.

(1) Descriptive statistics: Continuous variables are presented as mean ± standard deviation (for normally distributed data) or median (interquartile range) (for non-normally distributed data). Categorical variables are presented as frequencies (percentages).

(2) Normality testing: The Shapiro-Wilk test was used to assess data distribution.

(3) Between-group comparisons: Independent samples t-tests were used for normally distributed data; Wilcoxon rank-sum tests were used for non-normally distributed data.

(4) Analysis of covariance (ANCOVA): Group was the independent variable, with age, height, and weight as covariates, to examine the independent effect of group on BMD, muscle mass, fat mass, and bone mineral content. Adjusted means (standard error), F values, p values, and partial eta squared (partial η^2) are reported.

(5) Effect sizes: Cohen's d and partial η^2 were calculated to assess the practical significance of differences.

(6) Correlation analysis: Pearson or Spearman correlation analyses were used to examine the association between muscle mass and BMD.

Results

Participant Characteristics

A total of 27 adolescents were included in the study, comprising 12 swimmers (7 males, 5 females) and 15 non-swimmers (9 males, 6 females). Baseline characteristics and body composition parameters are presented in Table 1. There were no significant differences in age (11.33 ± 1.23 vs 11.99 ± 1.11 years, $p = 0.155$) or height (154.33 ± 9.13 vs 159.40 ± 8.14 cm, $p = 0.140$) between the two groups. However, body weight was significantly lower in swimmers than in non-swimmers (40.75 ± 7.67 vs 52.55 ± 10.39 kg, $p = 0.003$, SMD = 1.292).

Table 1
Baseline characteristics and body composition parameters of the study participants.

Variables	Non-swimmers (n = 15)	Swimmers (n = 12)	*P* value	SMD
Age (years)	11.99 ± 1.11	11.33 ± 1.23	0.155	0.564
Height (cm)	159.40 ± 8.14	154.33 ± 9.13	0.140	0.586
Body weight (kg)	52.55 ± 10.39	40.75 ± 7.67	0.003	1.292
Bone mineral density (g/cm²)				
Whole-body BMD	0.95 ± 0.12	0.84 ± 0.07	0.010	1.103
Upper limb BMD	0.56 ± 0.10	0.52 ± 0.06	0.255	0.465
Femoral BMD	1.05 ± 0.14	0.89 ± 0.12	0.004	1.259
Trunk BMD	0.83 ± 0.13	0.71 ± 0.10	0.011	1.086
Muscle mass (g)				
Whole-body muscle	35332.40 ± 7549.57	30300.25 ± 4936.02	0.058	0.789
Upper limb muscle	3289.53 ± 1137.79	3186.25 ± 674.50	0.784	0.110
Femoral muscle	12705.40 ± 2876.63	9663.58 ± 2007.90	0.005	1.226
Trunk muscle	16181.20 ± 3501.07	14611.00 ± 2167.95	0.187	0.539
Fat mass (g)				
Whole-body fat	15238.00 ± 5339.97	8922.33 ± 3716.14	0.002	1.373
Upper limb fat	1760.00 ± 527.16	1159.00 ± 460.52	0.005	1.214
Femoral fat	6012.73 ± 2153.03	3673.42 ± 1406.24	0.003	1.286
Trunk fat	6573.13 ± 2766.04	3319.83 ± 1917.65	0.002	1.367
Bone mineral content (g)				
Whole-body BMC	1886.49 ± 415.29	1557.94 ± 284.53	0.028	0.923
Upper limb BMC	213.77 ± 70.35	196.70 ± 43.35	0.469	0.292
Femoral BMC	728.38 ± 164.13	567.79 ± 139.40	0.012	1.055
Trunk BMC	547.35 ± 145.21	427.45 ± 103.49	0.024	0.951

Data are presented as mean ± standard deviation.*p*-values were obtained from independent samples *t*-tests.*n*: number of participants; SMD: standardized mean difference; BMD: bone mineral density; BMC: bone mineral content. Bold values indicate statistical significance ($p < 0.05$).

Bone Mineral Density

Before adjustment, swimmers had significantly lower whole-body BMD (0.84 ± 0.07 vs 0.95 ± 0.12 g/cm², $p = 0.010$), femoral BMD (0.89 ± 0.12 vs 1.05 ± 0.14 g/cm², $p = 0.004$), and trunk BMD (0.71 ± 0.10 vs 0.83 ± 0.13 g/cm², $p = 0.011$) compared with non-swimmers. No significant difference was observed for upper limb BMD ($p = 0.255$).

After adjusting for age, height, and weight, ANCOVA revealed that group had a highly significant effect on whole-body BMD ($F = 19.18$, $p < 0.001$, partial $\eta^2 = 0.466$), femoral BMD ($F = 25.91$, $p < 0.001$, partial $\eta^2 = 0.541$), and trunk BMD ($F = 19.93$, $p < 0.001$, partial $\eta^2 = 0.475$), with adjusted means consistently lower in swimmers (Table 2, Fig. 1). The group difference in upper limb BMD did not reach statistical significance ($F = 3.37$, $p = 0.080$, partial $\eta^2 = 0.133$).

Table 2
Adjusted means (standard error) of bone mineral density, muscle mass, and fat mass between the two groups after controlling for age, height, and weight.

Variable	Non-swimmers (n = 15)	Swimmers (n = 12)	*F* value	*P* value
Bone mineral density (g/cm²)				
Whole-body BMD	0.910 (0.019)	0.894 (0.021)	19.18	< 0.001
Upper limb BMD	0.525 (0.015)	0.565 (0.017)	3.37	0.080
Femoral BMD	1.005 (0.024)	0.948 (0.027)	25.91	< 0.001
Trunk BMD	0.786 (0.020)	0.762 (0.023)	19.93	< 0.001
Muscle mass (g)				
Whole-body muscle	32327.75 (822.05)	34056.06(938.14)	20.01	< 0.001
Upper limb muscle	2886.03 (154.99)	3690.62 (176.88)	0.24	0.631
Femoral muscle	11565.19 (348.63)	11088.84(397.86)	40.65	< 0.001
Trunk muscle	14846.16 (391.52)	16279.81(446.81)	8.59	0.008
Fat mass (g)				
Whole-body fat	13093.70 (826.54)	11602.70(943.26)	31.18	< 0.001
Upper limb fat	1526.84 (85.44)	1450.45 (97.51)	26.42	< 0.001
Femoral fat	5260.15 (392.17)	4614.15(447.55)	19.00	< 0.001
Trunk fat	5454.75 (416.21)	4717.81(474.98)	32.62	< 0.001

Data are presented as adjusted means (standard error). Analysis of covariance (ANCOVA) was used to examine the independent effect of group after adjusting for age, height, and weight. BMD: bone mineral density; *F*: *F*-statistic; **p**: *p*-value; partial η^2: partial eta squared.

Muscle Mass

After controlling for age, height, and weight, group had a significant effect on femoral muscle mass (F = 40.65, p < 0.001, partial η^2 = 0.649) and trunk muscle mass (F = 8.59, p = 0.008, partial η^2 = 0.281). Adjusted femoral muscle mass was lower in swimmers than in non-swimmers (11088.84 ± 397.86 vs 11565.19 ± 348.63 g), whereas trunk muscle mass was higher in swimmers (16279.81 ± 446.81 vs 14846.16 ± 391.52 g). No significant difference was found for upper limb muscle mass (F = 0.24, p = 0.631). Whole-body muscle mass was slightly higher in swimmers after adjustment (34056.06 ± 938.14 vs 32327.75 ± 822.05 g, F = 20.01, p < 0.001, partial η^2 = 0.476) (Table 2).

Fat Mass

After adjusting for age, height, and weight, group had a highly significant effect on all fat mass indices (p < 0.001). Adjusted whole-body fat (11602.70 ± 943.26 vs 13093.70 ± 826.54 g), upper limb fat (1450.45 ± 97.51 vs 1526.84 ± 85.44 g), femoral fat (4614.15 ± 447.55 vs 5260.15 ± 392.17 g), and trunk fat (4717.81 ± 474.98 vs 5454.75 ± 416.21 g) were all significantly lower in swimmers than in non-swimmers (Table 2).

Upper-to-Lower Limb Muscle Ratio

The upper-to-lower limb muscle ratio was significantly higher in swimmers [median 0.328 (IQR: 0.310–0.358)] than in non-swimmers [median 0.241 (IQR: 0.213–0.270)] (Wilcoxon rank-sum test, W = 16, p < 0.001).(Figure 2) This indicates that swimming training promotes relatively greater upper limb muscle development compared with the lower limbs.

Correlation Between Muscle Mass and BMD

Whole-body muscle mass was significantly positively correlated with whole-body BMD in both swimmers (r = 0.72, p < 0.01) and non-swimmers (r = 0.81, p < 0.001). The correlation coefficients did not differ significantly between the two groups (Fisher z test, p > 0.05).

Discussion

This study compared bone mineral density (BMD), muscle mass, fat mass, and bone mineral content between adolescent swimmers and non-swimmers using DXA. The main finding was that swimmers had significantly lower BMD at weight-bearing sites, including the whole body, femur, and trunk, even after adjusting for age, height, and weight. In contrast, upper limb BMD did not differ between groups. Swimmers also had a higher upper-to-lower limb muscle ratio and lower fat mass at all measured regions. These findings suggest that swimming is associated with site-specific differences in bone and body composition during adolescence.

The lower BMD observed in swimmers is consistent with previous evidence. A meta-analysis by Gomez-Bruton et al. (2015) reported that young swimmers had similar BMD to sedentary controls but lower BMD than athletes in high-impact sports. Our results extend these findings by showing that even compared with non-swimmers who did not participate in systematic training, swimmers had lower BMD

at the femur and trunk[14, 17, 18]. The lack of difference in upper limb BMD may reflect the greater involvement of the upper limbs during swimming, which could partially counteract the absence of weight-bearing loading at this site[9, 24].

The mechanisms underlying these differences are likely multifactorial. Swimming is a non-weight-bearing activity, and the skeleton is exposed to minimal gravitational and impact loading. According to the mechanostat theory, bone adapts primarily to mechanical strain, and activities that generate high ground reaction forces are more osteogenic than non-weight-bearing exercise[1, 25]. The lower femoral and trunk BMD in swimmers may thus reflect insufficient osteogenic stimulation at these sites. In addition, swimmers had significantly lower body weight than non-swimmers. Although ANCOVA adjusted for weight, residual confounding by body composition or other unmeasured factors cannot be excluded. Nevertheless, the persistence of group differences after adjustment suggests that swimming itself, rather than weight alone, contributes to the observed BMD pattern.

The higher upper-to-lower limb muscle ratio in swimmers is consistent with the sport-specific demands of swimming, which preferentially engage the upper body. This finding supports the notion that swimming promotes region-specific muscle development[18, 24]. The lower fat mass across all regions in swimmers is also in line with the high energy expenditure associated with regular swimming training and has been reported in previous studies of young athletes[26, 27].

From a practical perspective, these results suggest that adolescent swimmers may benefit from additional weight-bearing or impact-loading exercises to optimize bone health. Current guidelines for youth athletes recommend incorporating diverse loading patterns, particularly during the peripubertal years when bone is most responsive to mechanical stimuli[28, 29]. Coaches and clinicians working with young swimmers should be aware that swimming alone may not provide sufficient osteogenic stimulus to maximize peak bone mass.

Several limitations should be acknowledged. First, the sample size was small (n = 27), which limits statistical power and generalizability. Second, the cross-sectional retrospective design precludes causal inference. Third, although we adjusted for age, height, and weight, other potential confounders such as pubertal status, dietary intake (calcium and vitamin D), training history, and bone turnover markers were not available[29, 30]. Fourth, the non-swimmers were not necessarily sedentary; they may have engaged in other physical activities that could influence bone and body composition[31]. Finally, the study was conducted at a single training base, and the findings may not be generalizable to other populations.

Conclusion

In conclusion, adolescent swimmers in this study had lower BMD at weight-bearing sites and a higher upper-to-lower limb muscle ratio than non-swimmers, independent of age, height, and weight. These findings suggest that swimming should be complemented with weight-bearing or impact exercises to promote bone health during growth. Prospective studies with larger samples and comprehensive

assessments of pubertal status, nutrition, and physical activity are warranted to confirm these observations.

Declarations

Ethics approval and consent to participate

The study was approved by the Sports Science Experiment Ethics Committee of Beijing Sport University (Approval No. 2026496H). Given the retrospective nature of the study, the anonymization of all data prior to analysis, and the infeasibility of obtaining informed consent, the ethics committee granted a waiver of informed consent.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to privacy protection for minors, but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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This research received no external funding.

Authors' contributions

CMM and CTX conceptualized the study, contributed to data acquisition, performed the statistical analysis, and drafted the manuscript. WL provided supervision and critically revised the manuscript. All authors read and approved the final manuscript.

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Figures

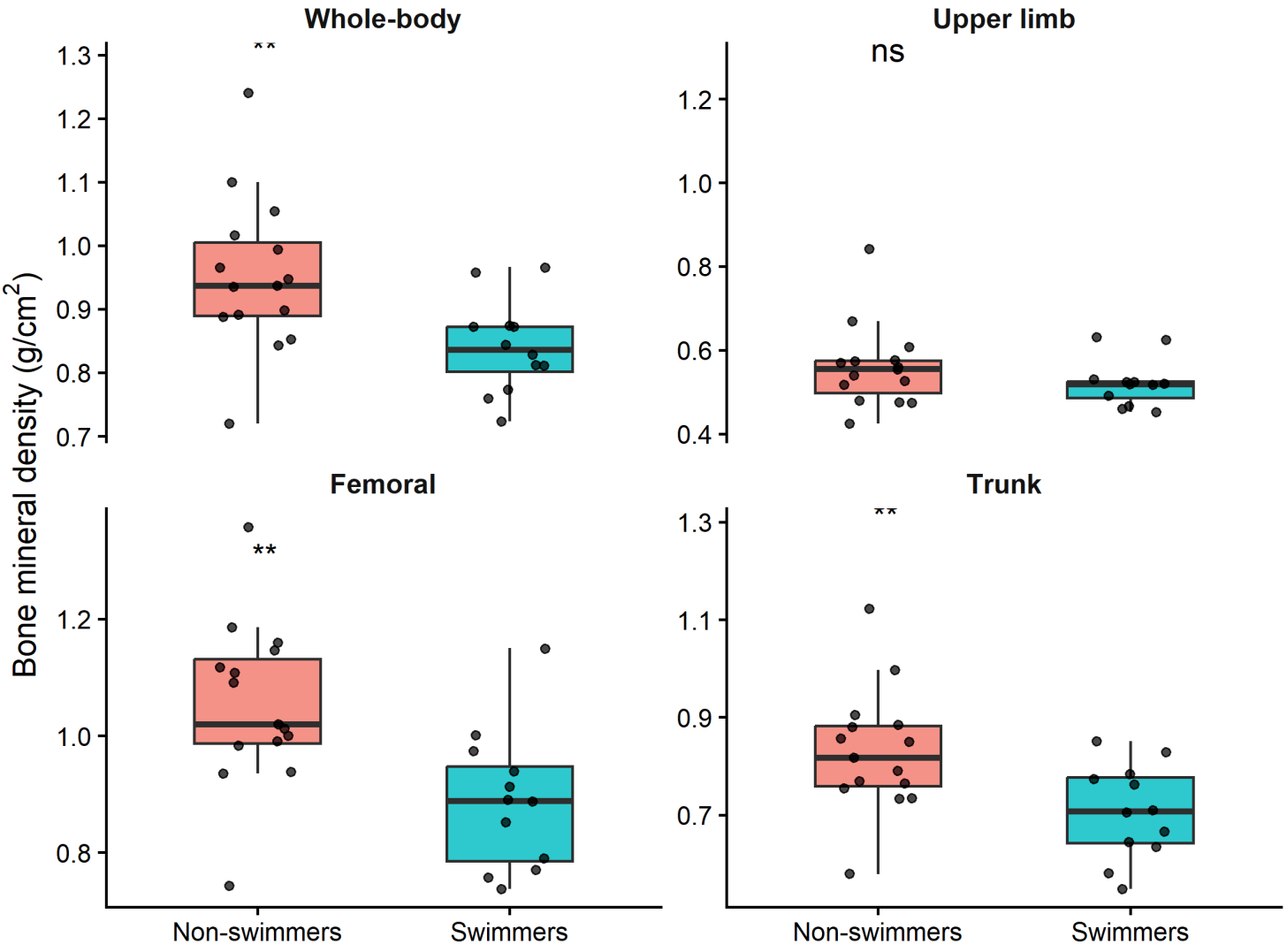


Figure 1

Comparison of bone mineral density across different body regions between non-swimmers and swimmers. Data are presented as box plots with individual data points. p-values were calculated using independent samples t-tests. *** p < 0.001; **p< 0.01; ns, not significant.

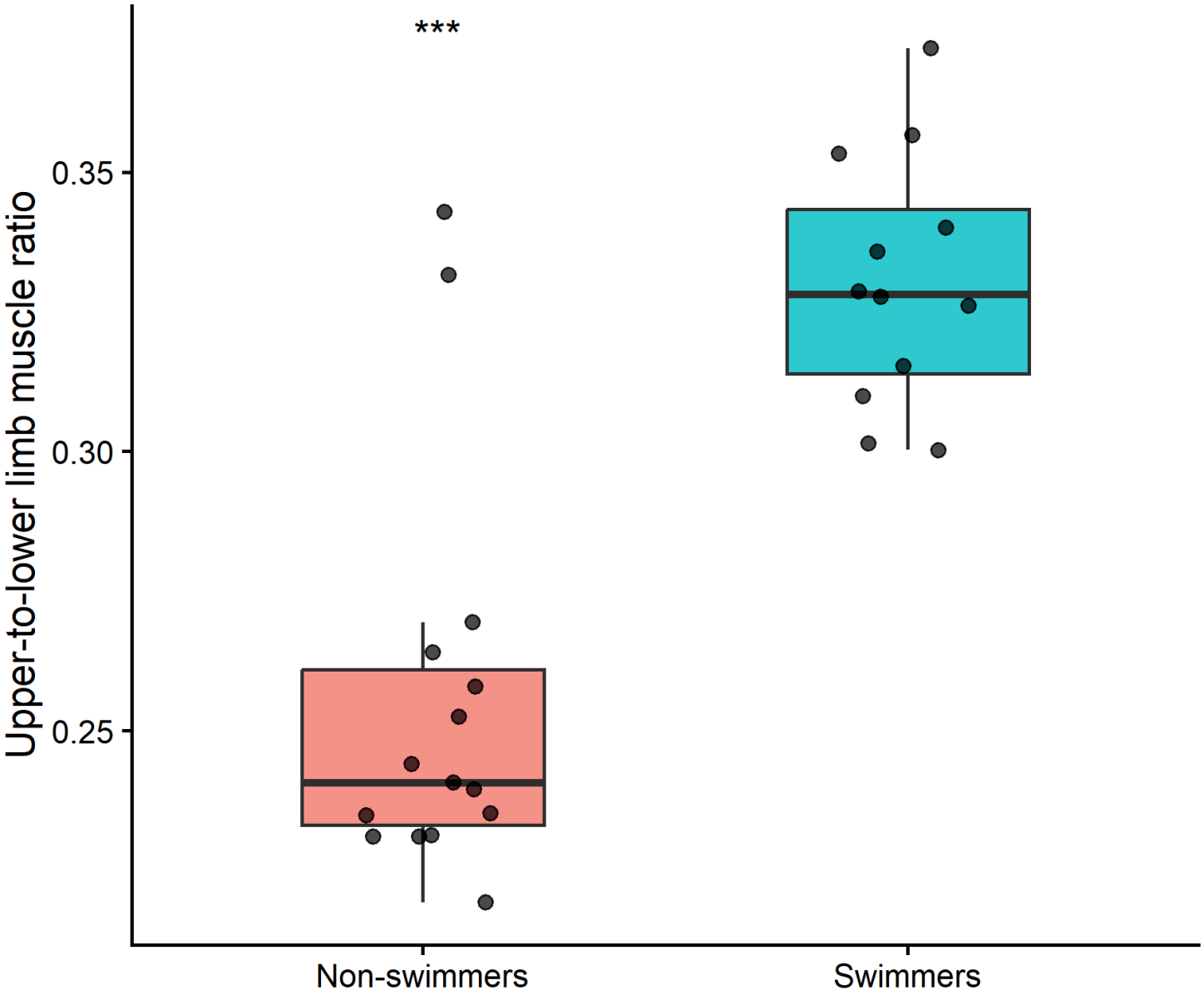


Figure 2

Comparison of the upper-to-lower limb muscle ratio between non-swimmers and swimmers. Data are presented as box plots with individual data points. *** $p < 0.001$ (Wilcoxon rank-sum test).