Section: Original Research

Article Title: Running event, age and competitive level as predictors of dual energy x-ray absorptiometry-derived body composition and bone health markers in female runners

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ABSTRACT:

The aim of this study was to assess the impact of running discipline, competitive level (COMP), and age on body composition measures in female athletes. A total of *n*=51 female runners (age: 30.9 ± 5.7 years, stature: 166.7 ± 5.7 cm, body mass (BM): 57.1 ± 8.2 kg) completed a full body dual energy x-ray absorptiometry (DXA) scan in a cross-sectional design. One-way ANOVA or Kruskal–Wallis was used to identify differences in DXA measures and independent variables. Stepwise regression determined the contribution of independent variables on DXA measures. Body fat percentage (BF%) and fat mass (FM) differed based on COMP (BF%: $H_{(2)} = 17.451$; FM: $H_{(2)} = 17.406$, both $p \leq 0.0001$). COMP modestly predicted BF% and FM (BF%: $R^2_{adj} = 0.316$, $F_{(1,50)} = 22.660$; FM: $R^2_{adj} = 0.300$, $F_{(1,50)} = 21.029$, both $p \leq 0.0001$). Bone mineral density (BMD) and BMD Z-score (BMD_Z) did not differ between age, running discipline or COMP (Age: BMD: $F_{(2,50)} = 2.825$, BMD_Z: $F_{(2,50)} = 2.215$; running discipline: BMD: $F_{(3,50)} = 1.145$, BMD_Z: $F_{(3,50)} = 1.474$; COMP: BMD: $F_{(2,50)} = 0.074$, BMD_Z: $F_{(2,50)} = 1.297$, all $p \leq 0.05$). Age and running discipline modestly predicted BMD and BMD_Z (BMD: $R^2_{adj} = 0.179$, $F_{(1,50)} = 5.264$; BMD_Z: $R^2_{adj} = 0.173$, $F_{(1,50)} = 4.545$, both $p \leq 0.05$). These findings indicate COMP may be a predictor of BF% and FM. Age and running discipline appear predictors of bone health markers. Such findings may enable medical and sport science practitioners to tailor interventions relating to realisation of training adaptations, performance and health.

Keywords: DXA, Lean Mass, Bone Mineral Density, Endurance Athletes

INTRODUCTION:

Body composition is often assessed to provide an indication of an athlete's fitness and health status (44). Traditionally, body composition is estimated using two- (e.g., skinfolds; SF, bioelectrical impedance; BIA, air displacement plethysmography; ADP) or, three- (e.g., BIA, dual-energy X-ray absorptiometry; DXA) compartment models to calculate fat-free mass (FFM), lean mass (LM), fat mass (FM), and in the case of DXA, bone mineral density (BMD) and bone mineral content (BMC) (43,44). Multicompartment model measurement techniques provide an accurate measure of body composition, and tracking changes in such indices can be useful for evaluating the effectiveness of dietary and/or conditioning interventions, with such body composition alterations associated with enhancements in cardiorespiratory fitness (2,5) and strength (26,39) which may be deemed favorable in certain sporting contexts.

When compared to other methodologies of measuring body composition, DXA is widely regarded as the gold standard non-invasive method of measuring FM, FFM and separating FFM into LM and bone (40). Likewise, the method has also shown greater accuracy when ascertaining body composition measures relative to ADP (21,22), BIA (33) and SF (45) analyses, with DXA being highly correlated with both magnetic resonance imaging and computed tomography when measuring muscle mass (11). For these reasons, and by accounting for the variability in bone density that often exists in female populations, DXA may be a superior methodology for use with athletic females (44). In relation to female athletes, DXA scan technology has been previously used to monitor both body composition and bone health in collegiate and high-level endurance runners (4,6,9,13,16) however further data pertaining to body composition and bone health markers within these cohorts is still relatively scarce compared to their male counterparts. Accurate measurement and assessment of bone health in female athlete populations is of increasing importance due to the growing awareness of low energy availability (LEA) and the consequences of this on bone mineral content (18,35). Negative bone health consequences potentially arising from LEA are well identified in physically active women (30,32) with female athletes experiencing LEA more likely to develop low BMD (30,32). For this reason, it is therefore beneficial to have accurate information concerning measures of body composition in athletes for both health and performance purposes.

With this in mind, the aims of this study were to a) profile whole body and regional body composition and bone health markers via DXA in female middle distance and endurance runners within the United Kingdom across differing age, running discipline and competitive level (COMP), b) determine potential differences between whole body and regional body composition and bone health markers within these cohorts and c) to determine whether the running discipline undertaken, age or COMP are predictors of whole body and regional body composition and bone health markers within these cohorts. Such outcomes may enable medical, sport science and nutrition practitioners to tailor suitable interventions and advice relating to the realization of training adaptations and performance.

METHODS:

Experimental approach to the problem:

Using a cross-sectional approach, body composition markers of female middle and endurance runners were measured via DXA scans. The study obtained institutional ethical approval and informed consent was sought from participants prior to study involvement. Whole body and regional body composition variables of body mass, FM, LM, BMD and BMC were collected via DXA scans as a one-off measure. Notably, DXA technology offers high precision and reliability when compared to other body composition methods such as BIA and anthropometry (11,29). All scans were performed by the same qualified technician, between July and August 2021.

Participants:

Participants were recruited from local athletics or running clubs via social media advertisements and word of mouth, using a convenience sampling method. Participants were athletes aged 18 - 40 years, who participated in regular running activities at a recreational or competitive level, who were not currently pregnant, with no injuries nor experiencing any peri menopausal or menopausal symptoms. Participants were asked to self-report their COMP. As per the methods of Sharps *et al*. (38), professional athletes ($COMP_{PRO}$) were defined as any athlete undertaking ≥10 h of training per week whose athletic performance has achieved the highest level of competition (e.g. Olympics, international/national representation) and receiving a full-time wage for sport undertaken. Competitive athletes ($COMP_{COMP}$) were defined as any athlete undertaking ≥6 hours of training per week with a view to participate in official competitions (e.g. university, club level athletes or higher) and whose full-time job was not that of a full-time athlete (23,38). Recreational athletes ($COMP_{REC}$) were defined as those undertaking ≥4 hours of training per week who did not receive any money for partaking in sport and participated for enjoyment (23,38). Participants were grouped into one of the following age categories; 18 – 24 years, 25 – 30 years and 31 – 40 years. Primary running discipline undertaken was also self-reported (<3000m, 3000 m to 10 km, 10 miles to half-marathon, and marathon/ultramarathon) and then categorized based on participant responses as per the methods of Dervish *et al*. (8) for the purpose of analysis.

Dual-energy X-ray absorptiometry (DXA):

For each measurement, participants were asked to attend the laboratory in a rested state (minimum of 12 hours since last high intensity exercise session) and having fasted overnight (minimum of 12 hours), to eliminate changes in lean and total mass that corresponded to a volume of food/drink consumed prior to scanning (27,28,29). Prior to scans being undertaken, participants were screened for any existing injuries and/or pregnancy that may have precluded them from the scan. Anthropometric variables of stature and body mass were measured via portable stadiometer (Seca, Hamburg, Germany) to the nearest 1 mm and a calibrated weighing scales (Seca, Hamburg, Germany) to the nearest 0.1 kg, respectively. These data were inputted into the DXA computer for initial participant characteristics.

DXA scans (DPX-L Lunar Prodigy, GE Medical Systems, Lunar Madison, Wisconsin, USA) assessed whole body and regional FM, LM, body fat percentage (BF%), BMD and BMC through tissue X-ray absorption from two X-ray energy peaks (enCORE 2008, version 12.30.008 software) (40). During the DXA procedure, participants were exposed to low levels of ionizing radiation (0.4 µGy per 1 full-body scan); thus posing minimal risk to health with exposures being comparable to that of everyday activity over a 24 h period at sea level (28,29). During the scans, participants were required to lay supine on the DXA bed, with their hands in a pronated position by their sides (as per manufacturer instructions) and to wear minimal clothing to improve the accuracy of scan results as per the methods of (28,29). Regions of interest were automatically created with Encore™ software, before being manually checked, and then adjusted if necessary, by the same researcher each time to avoid measurement errors.

Statistical Analysis:

All data were analyzed via SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp). Normality was assessed via Shapiro-Wilks test. A one-way ANOVA was used to identify differences in whole body DXA variables (LM, BMD, BMD Z-scores (BMD_Z) and BMC means between primary running discipline, age category and COMP) and regional DXA variables for the arms, legs, trunk, android and gynoid (regional fat percentage; RF%, LM, BMC). Kruskal–Wallis was used to identify differences in whole body DXA variables (body mass (BM), BF% and FM means between primary running discipline, age category and COMP) and regional DXA variables for the arms, legs, trunk, android and gynoid (RF%, Total Tissue, FM, BMC). Post-hoc testing was conducted where appropriate. Following this, a stepwise regression analysis was carried out to determine the contribution of age category, primary running discipline and COMP to body composition and bone variables from the DXA scan. A variance inflation value (VIF) of less than five was considered acceptable (34).

RESULTS:

Participant demographics can be seen in Table 1. A total of *n*=51 female runners were recruited. All 51 female runners (age: 30.9 ± 5.7 years, stature: 166.7 ± 5.7 cm, body mass (BM): 57.1 ± 8.2 kg) completed the study.

Whole Body - Body Composition Markers:

Results of body composition markers via a whole body DXA scan can be seen in Table 1. LM did not differ based on age (LM: $F_{(2,50)}$ = 0.789, p≥0.05), running discipline (LM: $F_{(3,50)}$ = 1.974, p≥0.05) or COMP (LM: $F_{(2,50)}$ = 0.074, p≥0.05). BM differed based upon age (Age: $H_{(2)}$ = 7.362, p≤0.05) and COMP (Comp: $H_{(2)}$ = 14.433, p≤0.005). BF% and FM differed based upon COMP (BF%; Comp: $H_{(2)}$ = 17.451, p≤0.0001, FM; Comp: $H_{(2)}$ = 17.406, p≤0.0001). Post-hoc pairwise comparisons indicated that $COMP_{COMP}$ had lower BF% and FM vs. $COMP_{REC}$ (both p≤0.0001). Stepwise multiple regression demonstrated COMP modestly predicted BF% and FM (BF%: R^2_{adj} = 0.316, $F_{(1,50)}$ = 22.660, p≤0.0001, VIF = 1.00; FM: R^2_{adj} = 0.300, $F_{(1,50)}$ = 21.029, p≤0.0001, VIF = 1.00; Table 2). Both age and COMP modestly predicted BM (R^2_{adj} = 0.313, $F_{(2,50)}$ = 12.386, p≤0.0001, VIF = 1.00; Table 2).

Whole Body - Bone Health Markers:

Results of bone health markers via a whole body DXA scan can be seen in Table 1. BMD and BMD_Z did not differ based on age (BMD: $F_{(2,50)}$ = 2.825, BMD_Z: $F_{(2,50)}$ = 2.215, both p≥0.05), running discipline (BMD: $F_{(3,50)}$ = 1.145, BMD_Z: $F_{(3,50)}$ = 1.474, both p≥0.05) or COMP (BMD: $F_{(2,50)}$ = 0.074, BMD_Z: $F_{(2,50)}$ = 1.297, both p≥0.05). BMC differed based on age (Age: $F_{(2,50)}$ = 4.273, p≤0.05) and COMP (COMP: $F_{(2,50)}$ = 5.347, p≤0.05). Tukey's post-hoc tests showed that $COMP_{COMP}$ athletes had lower BMC than $COMP_{REC}$ athletes (p≤0.05). Stepwise multiple regression demonstrated age and running discipline modestly predicted BMD and BMD_Z (BMD: R^2_{adj} = 0.179, $F_{(1,50)}$ = 5.264, p≤0.05, VIF = 1.00, BMD_Z: R^2_{adj} = 0.173, $F_{(1,50)}$ = 4.545,

$p \leq 0.05$, VIF = 1.00; Table 2), with both age and COMP modestly predicted BMC ($R^2_{adj} = 0.256$, $F_{(2,66)} = 9.471$, $p \leq 0.001$, VIF = 0.94; Table 2).

Regional Analysis – Body Composition Markers:

Results of regional body composition analysis via a whole body DXA scan be seen in Table 3. RF% for arms, legs, android or gynoid did not differ based upon age ($RF\%_{Arms}$: $F_{(3,47)} = 0.289$, $RF\%_{Legs}$: $F_{(3,47)} = 2.182$, $RF\%_{Android}$: $F_{(3,47)} = 1.406$, $RF\%_{Gynoid}$: $F_{(3,47)} = 2.293$, all $p \geq 0.05$) and running distance ($RF\%_{Arms}$: $F_{(3,47)} = 1.929$, $RF\%_{Legs}$: $F_{(3,47)} = 2.099$, $RF\%_{Android}$: $F_{(3,47)} = 2.272$, $RF\%_{Gynoid}$: $F_{(3,47)} = 2.140$, all $p \geq 0.05$), however did differ based upon COMP ($RF\%_{Arms}$: $F_{(2,47)} = 7.198$, $RF\%_{Legs}$: $F_{(2,47)} = 7.347$, $RF\%_{Android}$: $F_{(3,47)} = 5.229$, $p \geq 0.05$ $RF\%_{Gynoid}$: $F_{(2,47)} = 7.135$, all $p \leq 0.05$). $RF\%_{Trunk}$ did differ based upon COMP ($RF\%_{Trunk}$: $H_{(2)} = 9.696$, $p \leq 0.05$). Total tissue for arms, legs, trunk, and gynoid differed based upon COMP ($Tissue_{Arms}$: $H_{(2)} = 13.443$, $Tissue_{Legs}$: $H_{(2)} = 12.097$, $Tissue_{Trunk}$: $H_{(2)} = 13.107$, $Tissue_{Gynoid}$: $H_{(2)} = 13.298$, all $p \leq 0.05$), with total tissue for android differing based upon age and COMP (age: $Tissue_{Android}$: $H_{(2)} = 6.406$, COMP: $Tissue_{Android}$: $H_{(2)} = 12.428$, both $p \leq 0.05$). LM for arms, legs and trunk did not differ based upon age (LM_{Arms}: $F_{(2,47)} = 2.405$, LM_{Legs}: $F_{(2,47)} = 0.298$, LM_{Trunk}: LM: $F_{(2,47)} = 0.147$, all $p \geq 0.05$), running discipline (LM_{Arms}: $F_{(3,47)} = 0.423$, LM_{Legs}: $F_{(3,47)} = 0.256$, LM_{Trunk}: $F_{(3,47)} = 1.300$, all $p \geq 0.05$) or COMP (LM_{Arms}: $F_{(2,47)} = 2.957$, LM_{Legs}: $F_{(2,47)} = 0.856$, LM_{Trunk}: LM: $F_{(2,47)} = 0.296$, all $p \geq 0.05$). $LM_{Android}$ or LM_{Gynoid} did not differ based age ($LM_{Android}$: $H_{(2)} = 1.470$, LM_{Gynoid} $H_{(2)} = 0.131$, both $p \geq 0.05$), COMP ($LM_{Android}$: $H_{(2)} = 1.182$, LM_{Gynoid} $H_{(2)} = 1.184$, both $p \geq 0.05$) or running distance ($LM_{Android}$: $H_{(2)} = 3.934$, LM_{Gynoid} $H_{(2)} = 1.340$, both $p \geq 0.05$). Stepwise multiple regression demonstrated that age and COMP modestly predicted total android tissue and total fat in arms and total android tissue, respectively (Fat_{Arms}: $R^2_{adj} = 0.179$, $F_{(1,47)} = 5.778$, $p \leq 0.05$, VIF = 1.00, $Tissue_{Anrdoid}$: $R^2_{adj} = 0.286$, $F_{(1,47)} = 19.823$, $p \leq 0.0001$, VIF = 1.00; Table 2).

Regional Analysis – Bone Health Markers:

Results of regional bone health marker analysis via a whole body DXA scan be seen in Table 3. BMC for arms and legs did not differ by age (BMC_{Arms}: $F_{(2,47)} = 1.605$, BMC_{Legs}: $F_{(2,47)} = 0.781$, both $p \geq 0.05$) or running distance (BMC_{Arms}: $F_{(2,47)} = 0.158$, BMC_{Legs}: $F_{(2,47)} = 0.567$, both $p \geq 0.05$), however did differ by COMP (BMC_{Arms}: $F_{(2,47)} = 5.911$, BMC_{Legs}: $F_{(2,47)} = 4.158$, both $p \leq 0.05$). BMC for trunk, android or gynoid did not differ based upon age (BMC_{Trunk}: $H_{(2)} = 2.477$, $BMC_{Android}$: $H_{(2)} = 1.896$, BMC_{Gynoid}: $H_{(2)} = 2.342$, all $p \geq 0.05$) or running distance (BMC_{Trunk}: $H_{(2)} = 1.492$, $BMC_{Android}$: $H_{(2)} = 1.108$, BMC_{Gynoid}: $H_{(2)} = 3.927$, all $p \geq 0.05$), however did differ based upon COMP (BMC_{Trunk}: $H_{(2)} = 10.832$, $BMC_{Android}$: $H_{(2)} = 9.696$, BMC_{Gynoid}: $H_{(2)} = 7.834$, all $p \leq 0.05$).

****INSERT TABLE 1 ABOUT HERE****

****INSERT TABLE 2 ABOUT HERE****

DISCUSSION:

The primary aims of this study were to profile body composition and bone health markers via DXA in female middle-distance and endurance runners within the United Kingdom across differing age, running discipline and COMP, to determine potential differences between body composition and bone health markers within these cohorts. Additionally this study aimed to determine whether running discipline, age or COMP are predictors of body composition and bone health markers within these cohorts. For body composition, our whole body findings suggest BF% differs based upon COMP in female athletes, and that COMP is a predictor of BF% and FM (~30%; Table 2). Similarly, differences in BM between female athletes differs based upon age and COMP, with these variables being modest predictors (~30%; Table 2) of BM. LM appears to be unaffected by age, running discipline and COMP. From a regional analysis perspective total android tissue appears to be influenced by both age and COMP. Regarding whole body bone health markers, both BMD and BMD_Z differ based upon athlete age and running discipline, and these variables being a modest predictor (17 – 18%) of both BMD and BMD_Z. Our findings show that $COMP_{COMP}$ athletes have lower BMC when compared to recreational counterparts ($p \leq 0.05$), and both age and COMP were a modest predictor of BMC (~26%; Table 2). Regional analysis of BMC indicates that trunk, android and gynoid are influenced by COMP.

Despite emphasis often placed on the importance of body composition from a sports performance and health perspective (2,39,44), data pertaining to body composition and bone health markers in female athletes is still relatively scarce. Further female-specific research is needed in relation to these markers, specifically as the number of women participating in sport and exercise is increasing in many countries (10). In relation to body composition and bone health markers, Santos *et al*. (36) developed body composition reference values for male and female athletes from both SF and DXA-derived measurements. However, despite a range of sports being represented in the Santos *et al*. (36) study, runners were grouped with athletes from other track and field disciplines (including sprinting, hurdling, and field-events), therefore any interpretation from these findings against the findings in the present study may not be suitable comparisons. Whilst further research in females across a range of sports, age categories and COMP is still required, the present study offers novel information in relation to body composition and bone health of female middle-distance and endurance runners. To the best of the authors' knowledge, this is the first study to identify independent variables of age, running discipline and COMP as a predictor of body composition and bone health markers within these cohorts.

Body Composition Markers:

Our findings indicate that both whole body and regional body composition markers of body fat and total tissue (i.e. whole body: BF% and FM, regional: $RF\%_{Arms}$, $RF\%_{Trunk}$, $Tissue_{Arms}$, $Tissue_{Legs}$, $Tissue_{Trunk}$ and $Tissue_{Gynoid}$) were primarily influenced by COMP (~11% - 30%; Table 2) for female runners included within this study. The mean FM values for runners observed in the present study were comparable with those observed by both Carbuhn *et al*. (4) and Herbert *et al*. (13) (FM: 11.9 ± 0.9 vs. 12.2 ± 3.2 kg vs. 12.6 ± 7.1 kg). The values presented by Herbert *et al*. (13) were measured within high-level runners, and further support our findings and subsequent post-hoc comparisons, that COMP may be influencing factors of FM variables within female running cohorts. More specifically to BF%, our post-hoc testing indicated that COMP is a factor of difference between BF%. The differences in BF% observed within the present study are comparable to those observed by Carbuhn *et al*. (4) in female collegiate runners. Similarly, our LM findings are higher than those observed by Herbert *et al*. (13) (LM: 38.7 ± 3.6 vs. 41.8 ± 3.7 kg). The exact reasons underpinning these similarities (in the case of BF%) and discrepancies (in the case of LM) require further investigation, however, speculatively, higher training load, training volumes and seasonal training phases in increasing levels of $COMP_{PRO}$ vs. $COMP_{COMP}$ vs. $COMP_{REC}$ may explain these findings (14). Within a sporting context, where performance outcomes are often based upon physiological determinants, such as maximal power or speed for a given duration, relative to BM (12,13) and time to complete a specific distance (i.e. middle or endurance running) is often viewed as a desirable objective, aiming to optimize LM and BF%, with body fat often viewed as 'dead weight' (18) may be viewed as favorable training optimization for athletes.

Bone Health Markers:

The total BMD values presented in the current study are lower than those observed by Klomsten Andersen *et al*. (19) in both runners and cyclists (Runners: 1.283 ± 0.09 g·cm^2 vs. 1.174 ± 0.1 g·cm^2, Cyclists: 1.195 ± 0.1 g·cm^2 vs. 1.156 ± 0.1 g·cm^2), and those observed by Herbert *et al*. (13) for both BMD and BMD_Z in female runners (BMD: 1.203 ± 0.08 g·cm^2; BMD_Z: 1.05 ± 0.9) and their non-athlete controls (BMD: 1.191 ± 0.1 g·cm^2; BMD_Z: 1.02 ± 1.2). It should be noted that within the Klomsten Andersen *et al*. (19) study, a mix of male and female athletes were included within the study design, with DXA-derived indices not presented by sex, meaning that any direct comparison must be treated with caution. Exercise can be considered osteogenic, with athletes that have higher BMD exhibiting favorable adaptations of bone microarchitecture, particularly at weight-bearing sites, and greater bone strength than their sedentary counterparts (1,32,37). These findings are supported from our regional analysis that indicates that COMP is a modest predictor of BMC across both android and gynoid measures. It has previously been suggested that athletes involved in sports involving lower-impact, repetitive loading cycles (e.g. endurance running) or non-weight-bearing sports (e.g. cycling and swimming) do not typically elicit any exercise-induced skeletal benefits (33) when compared to athletes from sports that generate higher intensity loading forces which enhance bone mineral accretion (17,20). This may explain the findings in the present study in relation to BMD. Negative bone health outcomes are associated with LEA and are well identified in physically active women and are discussed in relation to conditions such as the female athlete triad (7,30) or relative energy deficiency in sport (25). More specifically, female athletes experiencing LEA are likely to develop low BMD (30) and alterations in bone microarchitecture and bone strength (1), which may increase risk of osteoporosis and fractures (25). Research in female athletes has suggested that 18 – 24 year olds have a higher risk of LEA and disordered eating than their older counterparts (8,38). Whilst LEA was not assessed within the present study, our findings indicate that 18 – 24 year olds have the lowest total BMD within the tested age categories of the present study, and speculatively, may suggest that medical professionals and practitioners may wish to consider LEA screening or targeted interventions within these cohorts in relation to low BMD and associated health implications alongside body composition monitoring, and presents an area of future research development. Additionally, our regional analysis indicates differences were observed between COMP groups, and COMP was a predictor of BMC. These findings suggest that practitioners may wish to consider competitive level as a potential factor in conjunction with the potential of LEA when screening for bone health markers in female runners.

Limitations and Future Directions:

The present study is not without limitations. Firstly, the study aimed to recruit female runners from a range of differing age categories (between 18 – 40 years) and competitive levels, however, 18 – 24 year olds and professional-level athletes are under-represented in the current study (Table 1). Therefore, whilst these data provide some insight into body composition and bone health markers of these cohorts, translating these findings to all athletes within these under-represented categories must be done so with caution. Due to the low sample size of professional endurance runners recruited to this study, further sub-group analysis could not be undertaken (e.g. effects of age and running distance with COMP as the ranking or dominant factor). As a result, this in itself presents an area of direction for future research within higher levels of competitive female endurance runners. Secondly, despite DXA being widely deemed the gold standard method for body composition analyses due to its accuracy and repeatability (37), the method is not without its limitations. Our findings suggest the possible role of age and COMP on FM within these cohorts. Research indicates that with increasing fat mass comes increased risk of error via DXA (3). Additionally, the potential effects of the menstrual cycle on indices of body composition were not considered within this study. Although the effects of such changes on the accuracy of body composition measures via DXA scan are not fully understood (28), the influence of menses on the reliability of body composition estimates appears minimal in a cohort of pre-menopausal females (15,31,41), and within accepted measurement error of a DXA scan; whether this is true for female runners, remains to be investigated. Within these limitations, is the fact that DXA manufacturers' body composition estimation algorithms are not developed from athletic populations – meaning that values for more competitive and professional level athletes are compared against 'general population' reference values (29). Therefore, refining algorithms to better reflect body composition and bone health characteristics of athletic cohorts (both male and female) may increase the resolution and accuracy of future research. Lastly, additional screening for low energy availability (via validated tools such as the Low Energy Availability in Females Questionnaire; LEAF-Q; devised by Melin *et al*. (24)) or the inclusion of biochemical and/or exercise testing within female runners alongside body composition and bone health screening would further support findings from present study, and in itself, remains an opportunity for future research.

PRACTICAL APPLICATION:

Our findings suggest that running discipline undertaken has minimal influence on differences in body composition and bone health markers in female runners, with age and competitive level appearing to exercise greater influence on certain whole body and regional DXA variables, namely FM, BF%, BMD, BMD_Z, BMC (whole body) and $Tissue_{Android}$, BMC_{Trunk}, $BMC_{Android}$ and BMC_{Gynoid} (regional). Such findings may be of interest to medical, sport science and nutrition practitioners to tailor suitable educational resources and interventions, based upon age and competitive level of the athlete/s and advice relating to the realization of training adaptations, performance and health.

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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LEGENDS:

Table 1. Absolute values for all dependent variables derived from dual energy X-ray absorptiometry (DXA) scans.

Table 2. Results from regression analysis of independent predictors on dependent variables of whole body and regional analysis from a dual energy X-ray absorptiometry (DXA) scan of female, middle-distance and endurance runners

Figure 1. Grouped scatterplot depicting Body Fat Percentage plotted against Running discipline. A; < 3,000 m, B; 3,000 – 10,000 m, C; 10 miles – Half Marathon, D; Marathon to Ultradistance.

Figure 2. Grouped scatterplot depicting Fat Mass plotted against Running discipline. A; < 3,000 m, B; 3,000 – 10,000 m, C; 10 miles – Half Marathon, D; Marathon to Ultradistance.

Table 1. Absolute values for all dependent variables derived from dual energy X-ray absorptiometry (DXA) scans.

		Body Composition Marker				Bone Health Marker		
	DXA variable	**BM (kg)**	**BF%**	**FM (kg)**	**LM (kg)**	**BMD (g·cm^{2})**	**BMD$_{Z}$**	**BMC (kg)**
	Total (*n*=51)	57.1 ± 8.1	21.3 ± 8.2	12.6 ± 7.1	41.8 ± 3.7	1.174 ± 0.1	0.6 ± 0.9	2.490 ± 0.4
Running Discipline	< 3000m (*n*=8)	54.6 ± 3.6	18.7 ± 3.6	10.2 ± 2.5	41.6 ± 2.4	1.219 ± 0.1	1.2 ± 0.7	2.595 ± 0.3
	3000m – 10,000m (*n*=10)	56.3 ± 6.9	19.2 ± 8.5	11.1 ± 6.3	42.5 ± 3.3	1.168 ± 0.1	0.5 ± 1.0	2.424 ± 0.4
	10 miles – Half-marathon (*n*=21)	57.3 ± 8.3	24.2 ± 6.6	14.2 ± 5.9	40.5 ± 3.9	1.158 ± 0.1	0.4 ± 1.0	2.456 ± 0.4
	Marathon/Ultra (*n*=12)	58.9 ± 11.0	19.8 ± 11.5	12.6 ± 10.9	43.6 ± 3.7	1.178 ± 0.1	0.7 ± 1.0	2.536 ± 0.4
Age (years)	18 – 24 (*n*=5)	50.6 ± 3.8	15.7 ± 1.4	7.9 ± 0.7	40.3 ± 3.5	1.136 ± 0.1	0.2 ± 0.7	2.224 ± 0.2
	25 – 30 (*n*=18)	55.3 ± 5.5**	20.3 ± 6.2	11.4 ± 4.3	41.4 ± 3.5	1.149 ± 0.1	0.3 ± 0.9	2.357 ± 0.3
	31 – 40 (*n*=28)	59.4 ± 9.3**	23.0 ± 9.5	14.2 ± 8.6	42.3 ± 3.9	1.197 ± 0.1	0.9 ± 1.0	2.624 ± 0.4
COMP	Recreational (*n*=18)	63.0 ± 10.0	27.6 ± 8.8	18.0 ± 9.0	42.1 ± 3.8	1.199 ± 0.1	0.9 ± 1.0	2.712 ± 0.4
	Competitive (*n*=31)	53.9 ± 4.5	18.1 ± 5.5$^{\Delta}$	9.8 ± 3.3	41.6 ± 3.8	1.158 ± 0.1	0.5 ± 0.9	2.369 ± 0.3
	Professional (*n*=2)	51.9 ± 2.5	14.7 ± 4.3	7.7 ± 2.6	41.8 ± 0.0	1.201 ± 0.1	1.1 ± 0.8	2.490 ± 0.3

BF% = body fat percentage; BM = body mass (kg); BMC = bone mineral content (kg); BMD = bone mineral density (g·cm^{-2}); BMD$_{Z}$ = bone mineral density Z-scores; COMP = competitive level. FM = Fat Mass; LM = Lean Mass. All date are presented as mean ± SD. ** = denotes significance from 18 – 24 years, $^{\Delta}$ = denotes significance from COMP$_{Rec}$

Table 2. Results from regression analysis of independent predictors on dependent variables of whole body and regional analysis from a dual energy X-ray absorptiometry (DXA) scan of female, middle-distance and endurance runners

	Whole Body					***Regional Analysis***			
	B	**SE (*B*)**	***β***	***R^2***		***B***	**SE (*B*)**	***β***	***R^2***
Predictor – BM					**Predictor - $\text{Tissue}_{\text{Android}}$**	0.419	0.174	0.334*	0.112
Age (years) & COMP	3.128	1.456	.257*	.340	Age (years)				
Predictor – BF%					**Predictor - Fat_{Arms}**				
COMP	-8.487	1.783	-.562**	.316	COMP	-0.569	0.128	-0.549**	0.301
Predictor – FM									
COMP	-7.188	1.567	-.548**	.300					
Predictor – BMD									
Age (years) & Running discipline	-.025	.011	-.307*	.179					
Predictor – BMD_Z									
Age (years) & Running discipline	-.317	.140	.320*	.173					
Predictor – BMC									
Age (years) & COMP	.183	.074	.313*	.256					

BF% = body fat percentage; BM = body mass (kg); BMC = bone mineral content (kg); BMD = bone mineral density ($g \cdot cm^{-2}$); BMD_Z = bone mineral density Z-scores; COMP = competitive level, Fat_{Arms} = Total Arm Fat, $\text{Tissue}_{\text{Android}}$ = Total Android Tissue; * indicates statistical differences at $p \leq 0.05$ level; ** indicates statistical differences at $p \leq 0.005$ level

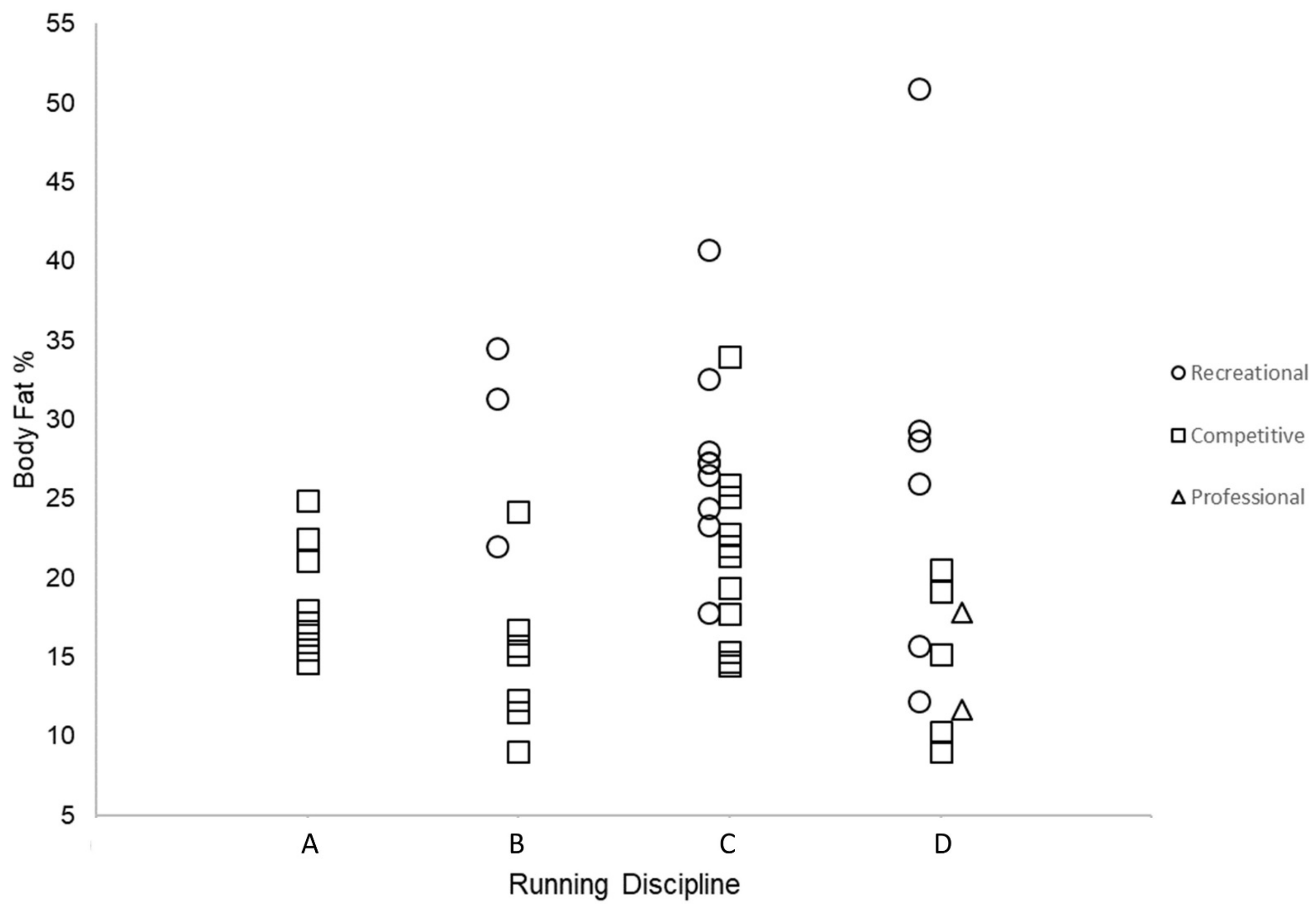
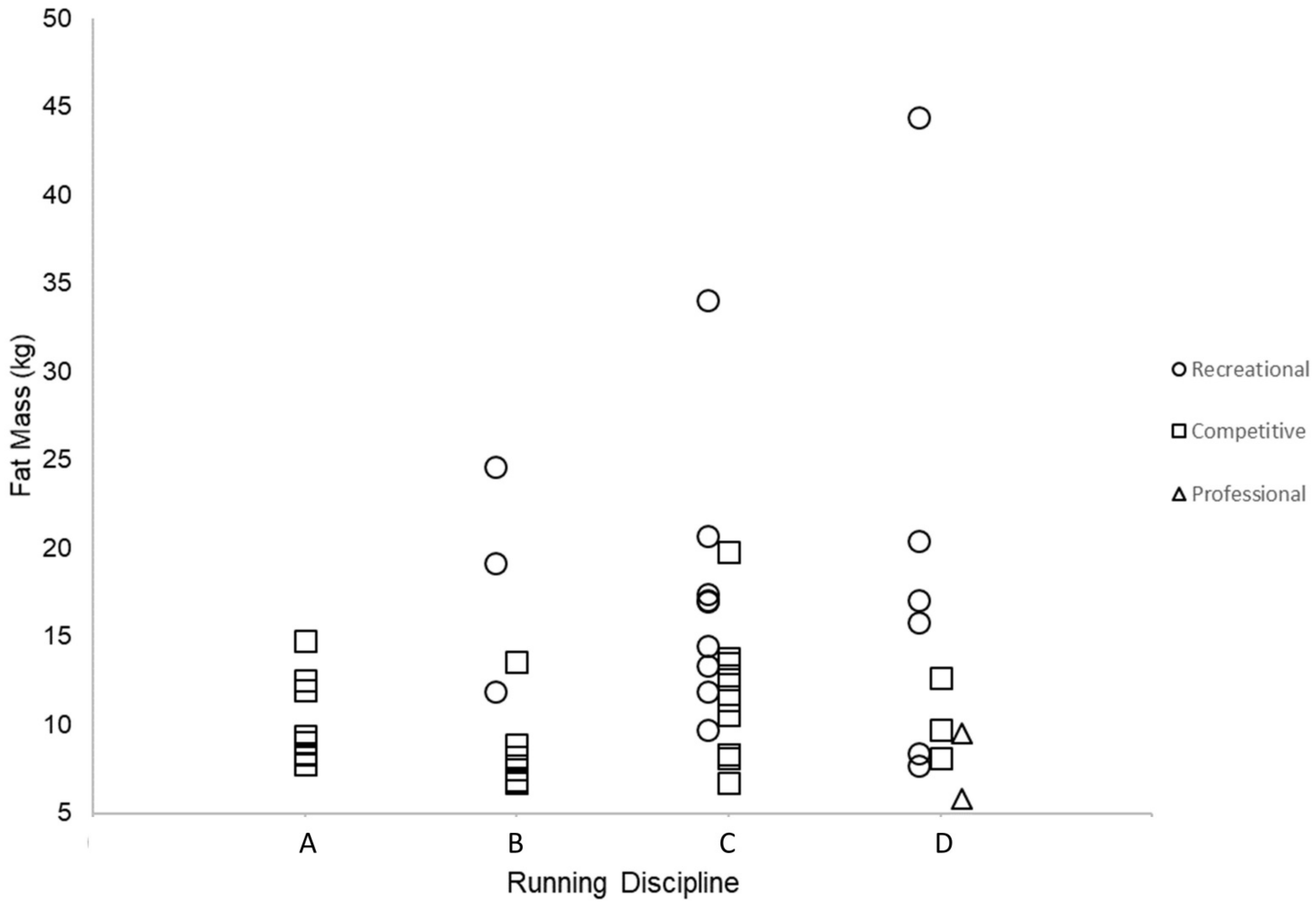


Figure 1. Grouped scatterplot depicting Body Fat Percentage plotted against Running discipline. A; < 3,000 m, B; 3,000 – 10,000 m, C; 10 miles – Half Marathon, D; Marathon to Ultradistance.



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537 **Figure 2.** Grouped scatterplot depicting Fat Mass plotted against Running discipline. A; < 3,000 m, B; 3,000 – 10,000 m, C; 10 miles – Half
538 Marathon, D; Marathon to Ultradistance.