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► To cite this version:

Ammar Nebigh, Imed Touhami, Moktar Chtara, Karuppasamy Govindasamy, Chandrababu Suresh, et al.. The impact of sport-discipline and sex on physical fitness and bone markers in athletes. International Journal of Sports Medicine, 2023, 10.1055/a-2038-3040 . hal-04021095

HAL Id: hal-04021095

<https://hal.science/hal-04021095v1>

Submitted on 12 Jul 2023

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The impact of sport-discipline and sex on physical fitness and bone markers in athletes

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Submission Style: Original Investigation

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Running head: Biochemical markers and fitness in track and field.

Counting:

Abstract: 329

Text only: 3884

Tables: 3

Figures: 0

1
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44 **Purpose:** This study was performed to determine the impact of sex and sport-discipline on
45 physical fitness and bone markers in young sub-elite track and field athletes.

46 **Methods:** One hundred and forty-four track and field sub-elite athletes (78 males aged
47 17.8 ± 1.6 years; 66 females aged 17.2 ± 1.9 years) volunteered to participate in this study
48 and were categorized according to their disciplines in endurance (EG: n=67) or power
49 athletes (PG: n=77).

50 **Results:** A significant main effect of sex was observed for C-telopeptide type I collagen (CTX)
51 ($F=11.37$; $p<0.001$; $\eta^2=0.10$, moderate), for osteocalcin (OC) ($F=8.58$; $p<0.004$; $\eta^2=0.09$,
52 moderate) and for N-terminal propeptide of procollagen type I (PINP) ($F=7.96$; $p<0.05$;
53 $\eta^2=0.07$, moderate). The average CTx, OC and PINP levels were significantly higher in males
54 compared with females ($0.05<p<0.001$; $\eta^2= 0.07$ to 0.10 , moderate). In addition, a significant
55 main effect of sport-discipline was observed only for PINP values ($F=10.16$; $p<0.002$; $\eta^2=0.09$,
56 moderate) with EG showing higher levels than PG. For jumping and sprinting tests, the PG
57 performed better than the EG. For the endurance test, EG had better performance than OG.

58 **Conclusion:** Endurance and power exercise practices can increase bone formation markers
59 (PINP, OC), but only anaerobic training (PG group) appears to positively impact on male track
60 and field athletes.

61

62 **Key words:** Gender difference; aerobic; anaerobic; physical parameters; bone markers.

63

64

65 INTRODUCTION

66 Bone deposition governs bone resorption throughout childhood and adolescence [1].
67 Accordingly, growth and maturation are critical for developing maximal bone mass [1].
68 Furthermore, high peak bone mass in youth is positively associated with bone fragility later in
69 life [2, 3]. Hence, childhood and adolescence represent important developmental stages to
70 maximize bone mass and strength [1]. Therefore, bone mass is known for its well-established
71 role as connective tissue that provides mobility for the body as well as supporting and protecting
72 vital organs [4]. These functions are recognized by the three main cell types in the skeleton:
73 osteoblasts, osteoclasts, and osteocytes [5].

74 Consequently, bone tissue is highly sensitive to mechanical stress [5]. Indeed, bone unloading
75 and loading are strictly involved in the differentiation and formation of osteoclasts and
76 osteoblasts and their respective roles in bone resorption and formation [3, 4, 6].

77 Under normal conditions, bone resorption and bone formation are coupled to maintain the
78 integrity of calcium homeostasis and maintain the integrity of the skeleton [6, 7]. Bone
79 remodeling is orchestrated by local micro-environmental factors, cytokines, growth factors and
80 systemic hormones (e.g., parathyroid hormone, vitamin D, calcitonin, estrogens etc.) in a
81 complex network of interactions [5, 8].

82 Indeed, bone-remodeling markers can be classified into bone formation markers and bone
83 resorption markers; thus, the variation of these markers reflects the actual situation of the bone
84 tissue [8]. Bone biochemical markers, as serum C-telopeptide type I collagen (CTX) and serum
85 N-terminal propeptide of procollagen type I (PINP), reflecting the cellular activities of bone
86 formation and resorption, are useful, both to monitor the acute exercise effects on bone
87 remodeling and to investigate the mechanisms of exercise-induced changes in bone mass that
88 occur during growth (in children) and aging (in seniors) [2, 3].

89 Certainly, physical exercise has been shown to have a substantial effect on bone turnover in
90 older men [9], women [10], and young boys [2]. Impact loading, which is inherent in various
91 sports (e.g., track and field), plays an imperative role in skeletal growth and shaping [11].
92 Preceding investigations of children and adolescents have revealed that impact-loading physical
93 activity is coupled with a better bone mineral density compared to nonimpact activities [12,
94 13].

95 In addition, sports participation involves a great number of muscle contractions, which produce
96 forces and mechanical loads responsible for the bone adaptations [14]. Another important factor

97 is the intimate relationship between the union of muscle tissue with bone tissue, which, when
98 contracted, can stimulate bone stress and consequently bone growth [12].

99 Physical inactivity is associated with muscular atrophy and the loss of bone mass and bone
100 mineral density [15]. In general, sedentary people have lower bone mass than physically active
101 individuals; however, the increases in bone mineral density and mass, resulting from either
102 endurance or resistance training, are comparatively low [7]. Various types of exercise (e.g.,
103 resistance training, speed and endurance) have different effects on bone mineral density and
104 mass [16, 17]. Nevertheless, even modest improvements in bone mass gained from endurance
105 or resistance training can help prevent or ameliorate the process of osteoporosis [15]. In aerobic
106 exercise, the osteocalcin level may be decreased by the fourth week and then recovered by the
107 eighth week, however, deoxypyridinolin continues to decrease [18]. In resistance-based exercise,
108 the levels of osteocalcin and deoxypyridinolin have been shown to be increased at both 4 weeks
109 and 8 weeks [18]. As such, multiple factors, including type, intensity, and duration of exercise,
110 have important effects on the rate of bone metabolism [19]. Moreover, the impact of additional
111 loading (i.e., intense or moderate exercise) on the skeleton is both variable and only crudely
112 understood. Bone response to exercise varies as a function of skeletal age, sex, diet,
113 reproductive hormone status and nature of the activity [20]. Furthermore, in athletes, the
114 practical goal of an exercise intervention is not merely to increase bone mass, but to reduce the
115 incidence of sustaining fractures [15].

116 According to the International Association of Athletics Federations (*IAAF*), athletics is defined
117 as a set of codified sporting events including running, jumping, throwing, and walking [21].
118 Thus, athletics is a versatile physical activity, which includes several disciplines, and few
119 studies have investigated the impact of performing these different disciplines on bone turnover
120 in elite male [16, 22] or female [23] athletes. Ryan et al. [22] observed that the markers of bone
121 formation did not differ between highly trained female athletes and sedentary controls. In
122 contrast, the markers of bone resorption were higher in the sedentary women compared to the
123 athletes. However, markers of bone turnover were negatively associated with regions of bone
124 mineral density (BMD) [22]. Indeed, levels of bone formation have been shown not to be
125 elevated in athletes and levels of bone turnover may not be predictive of subsequent changes in
126 bone mass in power athletes and endurance athletes [7, 16, 23]. However, the relationship
127 between aerobic and anaerobic performance with bone biochemical markers of formation and
128 resorption, considering gender differences, in athletes is not well characterized. Consequently,
129 the aim of this cross-sectional study was to investigate the effects of sex and sport-discipline

130 (i.e., endurance vs. power) on physical fitness performance and bone biochemical markers of
131 formation and resorption in young, sub-elite, track and field athletes. We hypothesized that
132 physical bone biochemical markers and fitness performances would be better in sub-elite male
133 athletes compared to sub-elite female athletes related to age and biological characteristics [7,
134 24, 25]. In addition, we expected better bone biochemical markers in power compared with
135 endurance athletes due to the higher impact loads power athletes experience in daily training
136 [17, 26].

137 **METHODS**

138 **Participants:** One hundred and forty-four track and field athletes (78 males aged $17.8 \pm$
139 1.6 years; 66 females aged 17.2 ± 1.9 years) volunteered to participate in this study.
140 Participant characteristics are shown in Table 1. Male and female sub-elite athletes were
141 recruited from eleven different track and field clubs and from the Tunisian youth national team.
142 Participating athletes were from six regional athletic centers throughout Tunisia.
143 On average, the athletes exercised eleven months per year for at least three years (3.9 ± 0.8
144 years), with four weekly 120 min sessions and one competition every 3 months. Athletes were
145 included in the study sample only if they had participated in national/international track and
146 field championships. The participating athletes were divided into two main groups: (i)
147 Endurance group (EG) that included 67 (n=32 males, 35 females) long distance runners whose
148 main events were the 5,000 and the 10,000 m run, and (ii) Power group (PG) that included 77
149 (n= 46 males, 31 females) whose main events were the sprint (60-m, 100-m) and jumping
150 events. No significantly differences were found between the EG and PG group relative to
151 weekly training volume.

152 All procedures were in accordance with the ethical standards of the latest version of the Helsinki
153 Declaration. The protocol was approved by the Ethics Committee of the Rabta Hospital, Tunis,
154 Tunisia, (approval number: IRB00005445, FWA00010074). All athletes filled out a
155 questionnaire in which they reported their injury history that needed medical treatment.
156 Moreover, the questionnaire additionally asked for the use of medication, known diseases, and
157 daily consumption of dairy products. As exclusion criteria, we defined a priori the presence of
158 chronic diseases (e.g., diabetes), usage of medication that affects the skeletal system. Written
159 informed consent was obtained from the participants, and if necessary, from their parents/legal
160 guardians prior to study participation.

161

162 **Anthropometric parameters:** The height and the body mass of each subject were measured
163 by a portable stadiometer (Seca Model 225, Hanover, MD) and digital scale (Tanita, Tokyo,
164 Japan), respectively. The total lean mass (kg) was measured by dual-energy X-ray
165 absorptiometry whole body densitometry.

166 **Puberty stage assessment:** The puberty stage was used as indicator for biological maturity
167 status. It was determined and recorded by a pediatrician experienced in the assessment of
168 secondary sex characteristics according to the method of Tanner [27]. According to their
169 pubescent status, the participating male and female athletes were ascribed to Tanner stage 5
170 (post pubertal) [27].

171 **Physical fitness characteristics**

172 **Vertical jump:** Each participant performed two kinds of maximal jumps: The squat jump
173 (SqJ), starting with knees bent approximately at 90° and without previous counter movement,
174 and the countermovement jump (CMJ), starting from a standing position allowing for counter
175 movement with the intention of reaching a knee bending angle of around 90° just before vertical
176 acceleration. All vertical jump heights were calculated based on the flight time [28]. Both flight
177 time and contact time were measured with an Opto-Jump System device (Microgate Bolzano,
178 Italy). The ICCs for test-retest trials were 0.93 and 0.95, for the SqJ and the CMJ, respectively.

179 **Horizontal jump:** For the standing long jump (SLJ), athletes stood behind the starting line and
180 were instructed to push-off vigorously and jump forward as far as possible on the track. The
181 distance jumped was measured in centimeters using a metal tape measure from the start line at
182 take-off to the position of the heel upon landing. The ICC for test-retest trials was 0.95.

183 **Linear sprint test:** The time needed to cover 10-m and 30-m at maximum speed was measured
184 with an infrared photoelectric cell (Cell Kit Speed Brower, USA) placed at the start-finish point
185 and on the 10-m or 30-m, respectively, approximately 0.4 m above the ground, and with an
186 accuracy of 0.001 s. The participants were motivated to run as fast as they could. They
187 performed three trials in total, and 3-min of recovery was allowed between repetitions. The best
188 (fastest) 30-m sprint time and the associated 10-m sprint time were selected for analysis. The
189 ICCs for test-retest trials were 0.96, and 0.97, for 10-m, and 30-m, respectively.

190 **Yo-Yo Intermittent Recovery Test Level 1:** The Yo-Yo IRT Level 1 test was performed
191 according to the processes described by Krusturp et al. [29]. Specifically, the athletes performed
192 a series of 20-m shuttle runs at a pace set by a calibrated audio metronome, with a 10 s standard
193 rest interval between shuttles. The time allowed for the shuttle runs progressively decreased,

194 that is, the speed was augmented. The test was terminated when the athlete was unable to
195 maintain the required speed. The distance covered in the shuttles was recorded for analysis. All
196 tests were conducted by the same investigators, scheduled at the same time of day, conducted
197 in the same order, and using the same apparatus.

198 **Biochemical markers**

199 All blood samples were obtained from the participants between 08:00 and 09:30 h, after an
200 overnight fast. Blood samples were centrifuged (2100 x g 10 min), and serum samples were
201 stored frozen at -20° C until analysis. The samples were shuffled before testing, and the level
202 of each biomarker was measured in duplicates (average of duplicates was used for analysis).

203 *Markers of bone formation:*

204 Osteocalcin (OC) is biosynthesized and secreted by osteoblasts and is therefore considered a
205 specific osteoblastic marker produced during bone synthesis. Serum levels of osteocalcin were
206 determined using the N-MID osteocalcin ELISA. Inter and intra-assay CVs were 10.8% and
207 3.1%, respectively.

208 Total procollagen type 1 N-terminal propeptide) (P1NP). Serum levels of total P1NP were
209 determined using electrochemiluminescence immunoassay “ECLIA” on Elecsys 2010 (Roche
210 Diagnostic GmbH). This assay detects both intact mono- and trimetric forms (total P1NP).
211 Norm values using this method for the P1NP are 16.27-73.87 ng/mL.

212 *Markers of bone resorption:*

213 Serum levels of C-telopeptide of the collagen of I type (CTX), as marker of bone resorption,
214 has increased in popularity as it can be measured from blood samples on automated platforms,
215 and given the increasing body of literature dealing with this biomarker, it may be regarded as
216 the biomarker of choice to examine osteoclastic bone resorption activity [30]. Bone resorption
217 was measured by the serum (Cross Laps ELISA, Nordic Bioscience, Diagnostics, Herlev,
218 Denmark), and inter and intra-assay CVs were < 9%.

219 **Statistical analyses**

220 Means and standard deviations (SD) were used to describe all variables. Data were analyzed
221 using multivariate analysis of variance (ANOVA) (2 [sex: males, females] x 2 [sport discipline:
222 power, endurance]). The level of significance was set at $p < 0.05$. If significant main effects or
223 interactions were present, Bonferroni post-hoc analyses were performed. Effect sizes were

224 calculated for all ANOVA with the use of partial eta-squared, where values of 0.01, 0.06, and
225 0.15 were considered as small, medium, and large cut-off points, respectively [31]. The
226 difference in performance between EG and PG for male and female athletes, in each variable,
227 was assessed using an independent t-test. Effect sizes (ESs) were calculated and characterized
228 according to the following scale: ≤ 0.2 , trivial; $> 0.2-0.6$, small; $>0.6-1.2$, moderate; $>1.2-2.0$,
229 large; and >2.0 , very large [32]. Intraclass correlation coefficients (ICCs) were obtained using
230 a two-way (rater and subject) random effects model and interpreted as poor (0–0.49), moderate
231 (0.5–0.69), high (0.7–0.89), and very high (0.9) [33]. Statistical analyses were performed using
232 SPSS software statistical package (SPSS Inc., Chicago, IL, version. 16.0).

233

234 **RESULTS**

235 ***Participants***

236 The anthropometric characteristics of both groups are shown in Table 1. No injuries were
237 recorded during testing.

238 ***Physical fitness***

239 A significant main effect for sex was detected for the considered variables (Table 2). Female
240 athletes performed worse in sprinting ($p<0.001$), jumping ($p<0.03$ to 0.001), and the yo-yo test
241 ($p<0.002$) compared with male athletes. Significant between subject effects for sport-discipline
242 were observed for SLJ ($F = 23.30$; $p<0.001$; $\eta^2=0.14$), SqJ ($F = 53.63$; $p<0.001$; $\eta^2=0.28$), CMJ
243 ($F = 45.98$ $p<0.001$; $\eta^2=0.25$), 10-m ($F = 22.43$ $p<0.001$; $\eta^2=0.11$), 30-m ($F = 25.20$ $p<0.001$;
244 $\eta^2=0.12$), and the Yo-Yo test ($F = 17.57$; $p<0.001$; $\eta^2=0.11$) (Table 2). For jumping and
245 sprinting tests, the PG performed better than the EG ($p<0.001$; $d= 0.81-1.27$, moderate to large).
246 For the Yo-Yo test, endurance athletes had better performance than power athletes ($p<0.001$;
247 $d=0.56$) moderate). No statistically significant sex-by-sport discipline interactions were
248 observed for any of the assessed variables.

249 ***Biochemical markers***

250 The biochemical markers of bone turnover are presented in Table 3. A significant main effect
251 of sex was observed for CTx ($F=11.37$; $p<0.001$; $\eta^2=0.10$) for OC ($F=8.58$; $p<0.004$; $\eta^2=0.09$)
252 and for P1NP ($F=7.96$; $p<0.004$; $\eta^2=0.07$). The average CTx, OC, and P1NP intakes were
253 significantly higher in males compared to females ($p<0.05$ to 0.001).

254 In addition, a significant main effect of sport discipline was observed only for P1NP ($F=10.16$;
255 $p<0.002$; $\eta^2=0.09$). No interactions (sex by sport discipline) were observed between sex and
256 sport discipline ($p>0.05$; $\eta^2=0.67$)

257

258 **DISCUSSION**

259 In this cross-sectional study, we found that male sub-elite track and field athletes outperformed
260 female sub-elite athletes in measures of physical fitness, irrespective of the group under
261 consideration (endurance or power). The PG performed better than the EG in sprint and jump
262 tests. In addition, we showed that mean values for bone biochemical markers in PG compared
263 with EG were significantly higher in males vs. females.

264 For the purpose of physical fitness evaluation, the study sample (sub-elite track and field
265 athletes) was divided into an endurance and a power group, according to the main track and
266 field discipline, athletes practiced. Athletes were allocated to the endurance group if their sport
267 discipline mainly demanded the aerobic metabolism (e.g., long distance running) and they were
268 allocated to the power group if their discipline demanded the anaerobic metabolism (e.g., long
269 and high jump, sprint) [24, 34].

270 Compared to females, the male sub-elite athletes attained better results in the physical fitness
271 tests. Jump, endurance, and sprint ability are among the most important performance variables
272 in both male and female athletes. Indeed, the results of the present study showed significant
273 differences between male and female sub-elite athletes for sprint (10-m, 30-m), jump (SqJ,
274 CMJ, and SLJ), and endurance performance during the Yo-Yo test. The gender stratified
275 physical fitness results are similar to previous data, which typically shows poorer aerobic
276 capacity and muscular fitness for females compared to males [24, 35]. By analyzing the
277 performances of male sub-elite athletes, for sprinting and jumping tests, the PG performed
278 better than the EG. For the Yo-Yo test, the EG performed better than the PG. These results are
279 concordant with previous findings showing that these differences in short-term maximal
280 performances between male and female athletes could be explained by higher body fat, less
281 muscle mass, and maximum oxygen uptake (VO_2max), and lower levels of hemoglobin in
282 females, compared to males [24, 36]. Moreover, a lower training load in female athletes, less
283 training experience and lower training quality, may potentially explain the observed sex
284 differences in the current study. In addition, the gender differences may be explained by
285 differences in energy metabolisms (i.e., higher fat as well as less carbohydrate and amino acid
286 oxidation) in females compared to males [36, 37].

287 Differences in endurance performance have been reported to depend on training status, period
288 of the season, and muscle power of the lower limbs in male soccer players [38]. Indeed, the
289 gender differences observed in the present study could also be explained by differences,
290 between male and female athletes, in the training status, length of the season, and the inclusion
291 of power training for the lower limbs; in addition, differences in drafting strategy can influence
292 athletic performances [39].

293 However, to our knowledge, limited research has examined the bone biochemical markers of
294 formation and resorption associated with physical fitness performances for both male and
295 female sub-elite athletes within the same study.

296 We sought to investigate variations in the bone biochemical markers in these athletes regardless
297 of the intensity and duration of the exercise. In the present study, we chose serum OC and P1NP
298 as bone formation markers and CTx as bone resorption markers. Serum levels of N-terminal
299 propeptide of procollagen type I and osteocalcin are currently among the most compelling
300 formation markers [5, 9]. The results of the current study suggest that a significant main effect
301 of sex was observed for markers of bone formation and of bone resorption. Our data revealed
302 that male sub-elite athletes have higher values in plasma formation of OC, P1NP and in plasma
303 resorption of CTx compared to female sub-elite athletes. In the literature, it has been well
304 established that prolonged mechanical loading increases bone mass, whilst brief exercise at low
305 or high intensity does not seem to have an instant measurable impact on bone metabolic
306 turnover in athletes [7], young boys [10], women [2] and old men [16].

307 Our results are also in agreement with several studies that have shown elevated levels of bone
308 metabolic turnover in male athletes with different types of exercise (e.g., running, swimming,
309 soccer) compared to female [7, 18, 23, 26]. Nevertheless, some studies have demonstrated the
310 modification of bone metabolic turnover with sex difference in athlete's population [35, 40,
311 41]. Matsumoto et al. [35] showed that the status of bone metabolic turnover in male judo
312 athletes in training may be hypermetabolic, as well as that of female judo athletes with regular
313 menses cycles. In light of this statement, it is important to highlight that bone remodeling may
314 be affected by the type of physical exercise.

315 In regard to the effect of sport-discipline and bone biochemical markers related to sex
316 differences, the significant marker was observed only for P1NP values in favor of the EG vs.
317 PG. The findings of our study are complemented by similar results by Malm et al. [42] who
318 established that elite endurance runners induced an immediate variation in bone markers after

319 marathon running, an endurance activity that combines long duration and high intensity.
320 Further, male athletes who practice sports generating high mechanical constraints on the body,
321 present a specific bone metabolism that includes high bone mass, as well as high bone turnover
322 [5]. This implies that bone remodeling may be affected by the type of physical exercise [7, 35].
323 Therefore, adding to the mechanical impact of physical exercise on bone turnover [5], exercise
324 components such as training intensity (strength or endurance) [16, 26] and volume seem to be
325 implicated [14]. Besides, sex difference may be modulating bone and collagen marker response
326 [16, 18].

327 When compared to age-matched counterparts in both genders, our anthropometric data revealed
328 that the females in the PG had significantly higher body mass and lean mass than the EG.
329 Similarly, the males in the PG had significantly higher body mass and lean mass compared to
330 the EG. As far as height is concerned, we found that female athletes in the PG were significantly
331 taller than females in the EG.

332 For anthropometric characteristics (i.e., body height and body mass), the findings of the present
333 study agreed with Matsumoto et al. [35] who showed that there were no significant differences
334 in body composition between the two groups for male athletes. Furthermore, a significant
335 difference in body composition was recognized between female athletes in the two groups
336 (endurance vs. power). Moreover, in a previous study, it was reported that male athletes had a
337 higher body-mass compared to female athletes [24].

338 Through this comparative study conducted on 78 males and 66 females (track and field
339 athletes), the following results support the view that there is an association between bone
340 remodeling activity, physical fitness parameters, and kind/type of sport practiced. However, the
341 relative effects of these factors on the athletics performances and bone remodeling biochemical
342 markers of males as compared to females remains to be fully explored, and clearly warrants
343 further study.

344 The current study has some limitations. First, the cross-sectional design prevents us from
345 analyzing any causal relationship, yet does enable a significant sample number (N = 144). In
346 addition, a limitation of this study is that it did not adjust the analyses by intensity of training
347 quantified and nutritional status, which are potential confounders [1, 8].

348 Finally, despite adjustment for initial confounding factors, we acknowledge that sport discipline
349 may affect bone mineral density measures differently. Our analysis did examine sex-related
350 differences. However, future studies may want to probe this issue in more depth by examining
351 biological age post puberty to better to better examine sexual maturation.

352 In contrast, the strengths of the study comprise that it included a large sample of more than 140
353 young, sub-elite, track and field athletes with indicators of objectively measured bone
354 biochemical markers and reliable assessment of physical fitness on different sex. In future
355 investigations, it might be interesting to develop this study longitudinally so as to see if there is
356 a cause–effect relation.

357 **PRACTICAL APPLICATIONS**

358 The results of this study suggest that anaerobic training (PG), throughout season results in
359 positive changes in sprint and especially for jumping performances in female and male sub-
360 elite athletes. However, aerobic training (EG) was effective in enhancing bone formation
361 markers in young sub-elite track and field athletes related to gender. Examination of fitness
362 profiles associated with bone biochemical markers in PG and EG could be a great importance
363 of optimal construction of physical and technical qualities in formation programs. Further
364 studies would be required to investigate the possible impact of training loads on physical
365 development and bone remodeling markers in young track and field athletes. In addition, the
366 effect of fitness level on performance during athletic events across the competitive standards of
367 age categories and the gender.

368

369 **CONCLUSION**

370 The present study showed a beneficial association between different types of sport disciplines
371 within track and field (power and endurance) on bone turnover markers (PINP, OC) in sub-
372 elite athletes. Further, this study demonstrated that female and male sub-elite athletes differed
373 in physical fitness performance, especially for jumping tests in the PG vs. EG. It appears that
374 endurance athletics may contribute to changes in bone turnover related to gender.

375

376 **Conflicts of interest:** The authors have no conflicts of interest to declare.

377

378 **REFERENCES**

- 379 1. *Hervás G, Ruiz-Litago F, Irazusta J, Irazusta A, Sanz B, Gil-Goikouria J, ... &*
380 *Zarrazquin I.* Bone health and its relationship with impact loading and the continuity of physical
381 activity throughout school periods. *Int J Environ Res Public Health* 2019;16: 2834
382
- 383 2. *Mohr M, Helge EW, Petersen LF et al.* Effects of soccer vs swim training on bone
384 formation in sedentary middle-aged women. *Eur J Appl Physiol* 2015;115: 2671-2679
385

- 386 3. *Rizzoli R, Bianchi ML, Garabédian M, McKay HA, Moreno LA.* Maximizing bone
387 mineral mass gain during growth for the prevention of fractures in the adolescents and the
388 elderly. *Bone* 2010; 46: 294–305
389
- 390 4. *Moser SC, van der Eerden BCJ.* Osteocalcin - a versatile bone-derived hormone. *Front*
391 *Endocrinol* 2019; 10:4–9
392
- 393 5. *Maimoun L, Sultan CH.* Effects of physical activity on bone remodelling. *Metabo Clinic*
394 *Experimental* 2011; 60: 373-388
395
- 396 6. *Eriksen EF.* Cellular mechanisms of bone remodeling. *Rev Endocr Metab Disord* 2010;
397 11: 219-227
398
- 399 7. *Maillane-Vanegas S, Luiz-de-Marco R, Narciso PH et al.* More than Sports
400 Participation: The Role of Ground Reaction Force, Osteocalcin and Lean Soft Tissue on Bone
401 Density Accrual in Adolescents: ABCD Growth Study. *J Clin Densitom* 2022; 25: 61-72
402
- 403 8. *Constable AM, Vlachopoulos D, Barker AR et al.* The independent and interactive
404 associations of physical activity intensity and vitamin D status with bone mineral density in
405 prepubertal children: The PANIC Study. *Osteopo Int* 2021; 32: 1609-1620
406
- 407 9. *Krustrup P, Nielsen JJ, Krustrup BR et al.* Recreational soccer is an effective health-
408 promoting activity for untrained men. *Br J Sports Med* 2009; 43: 825–831
409
- 410 10. *Nebigh A, Abed ME, Borji R et al.* Bone Turnover Markers and Lean Mass in Pubescent
411 Boys: Comparison Between Elite Soccer Players and Controls. *Ped Exer Sci* 2017; 29: 513–
412 519
413
- 414 11. *Tenforde AS, Fredericson M.* Influence of sports participation on bone health in the
415 young athlete: A review of the literature. *PMR* 2011; 3: 861–867
416
- 417 12. *Agostinete RR, Lynch KR, Gobbo LA et al.* Basketball affects bone mineral density
418 accrual in boys more than swimming and other impact sports: 9-mo follow-up. *J Clin Densitom*
419 2016; 19: 375–381
420
- 421 13. *Narciso PH, Werneck AO, Luiz-de-Marco R et al.* Influential role of lean soft tissue in
422 the association between training volume and bone mineral density among male adolescent
423 practitioners of impact-loading sports: ABCD Growth study. *BMC Pediatr* 2020; 28:1-7
424
- 425
- 426 14. *Vlachopoulos D, Barker AR, Ubago-Guisado E et al.* Longitudinal Adaptations of Bone
427 Mass, Geometry, and Metabolism in Adolescent Male Athletes: The PRO-BONE Study. *J*
428 *Bone Miner Res.* 2017; 32: 2269–2277
429
- 430 15. *Agostinete RR, Fernandes RA, Narciso PH et al.* Categorizing ten sports according to bone
431 and soft tissue profiles in adolescents. *Med Sci Sports Exerc* 2020 ;52: 2673-2681
432

- 433 16. *Bennell KL, Malcolm SA, Khan KM et al.* Bone mass and bone turnover in power athletes,
434 endurance athletes, and controls: a 12-month longitudinal study. *Bone* 1997;20: 477-484
435
- 436 17. *Ravnholt T, Tybirk J, Rye Jørgensen N et al.* High-intensity intermittent “5–10–15” running
437 reduces body fat, and increases lean body mass, bone mineral density, and performance
438 in untrained subjects. *Europ J Appl Physiol* 2018; 118:1221–1230
439
- 440
- 441 18. *Mark EL, Maria L, Urso RK et al.* Nindl. Influence of exercise mode and osteogenic index
442 on bone biomarker responses during short-term physical training. *Bone* 2009; 45: 0–776
443
- 444 19. *McKendry J, Joannisse S, Baig S et al.* Superior Aerobic Capacity and Indices of Skeletal
445 Muscle Morphology in Chronically Trained Master Endurance Athletes Compared With
446 Untrained Older Adults. *J Gerontol A Biol Sci Med Sci* 2020;75;1079-1088
447
- 448 20. *Jong HL.* The effect of long-distance running on bone strength and bone biochemical
449 markers. *J Exerc Rehabil* 2019;15:26-30
450
- 451
- 452 21. *Dictionary Oxford English (3rd ed).* Oxford english dictionary. Simpson: Ja & Weiner Esc,
453 1989: 3
454
- 455 22. *Ryan AS, Elahi D.* Loss of bone mineral density in women athletes during aging. *Calcif*
456 *Tissue Int* 1998; 63:287-292
457
- 458 23. *Burr DB, Yoshikawa T, Teegarden D et al.* Exercise and oral contraceptive use suppress the
459 normal age-related increase in bone mass and strength of the femoral neck in women 18-31
460 years of age. *Bone* 2000; 27:855-863
461
- 462 24. *Jones MT, Jagim AR, Haff GG et al.* Greater Strength Drives Difference in Power between
463 Sexes in the Conventional Deadlift Exercise. *Sports (Basel, Switzerland)* 2016; 4: 43
464
- 465
- 466 25. *Kyu Hwan Choi, Jong Ho Lee, and Dong Gyu Lee.* Sex-related differences in bone
467 metabolism in osteoporosis observational study. *Medicine (Baltimore)* 2021 ; 28: 100-121
468
- 469 26. *Woitge HW, Friedmann B, Suttner S et al.* Changes in bone turnover induced by aerobic
470 and anaerobic exercise in young males. *J Bone Miner Res* 1998; 13:1797
471
- 472 27. *Tanner JM.* Foetus into man. Harvard Press: Cambridge,1978:58 – 75
473
- 474
- 475 28. *Bosco C.* Strength assessment with the Bosco’s Test. *Ital Soci Sports Sci* 1999; 4:80-91
476
- 477 29. *Krustrup P, Mohr M, Amstrup T et al.* The yo-yo intermittent recovery test: Physiological
478 response, reliability, and validity. *Med Sci Sports Exer* 2003; 35:697–705

- 479
480
481 30. *Hlaing TT, Compston JE*. Biochemical markers of bone turnover - uses and limitations. *Ann*
482 *Clin Biochem* 2014; 51:189-202
483
484 31. *Cohen J*. *Statistical Power Analysis for the Behavioural Sciences*. Hillside NJ:
485 Lawrence Erlbaum Associates, 1998: 23–97
486
487
488 32. *Hopkins WG*. Measures of reliability in sports medicine and science. *Sports Med* 2000; 30:
489 1-15
490
491 33. *Munro BH*. Correlation coefficients: measuring the association of two variables. In:
492 *Statistical methods for health care research*. Philadelphia PA: Lippincott Williams &
493 Wilkins 2005: 465–475
494
495
496 34. *Hawley JA*. Molecular responses to strength and endurance training: are they incompatible?
497 *Appl Physiol Nutr Metab* 2009; 34: 355–361
498
499 35. *Matsumoto T, Nakagawa S, Nishida S et al*. Bone density and bone metabolic markers in
500 active collegiate athletes: findings in long distance runners, judoists, and swimmers. *Int J*
501 *Sports Med* 1997;18: 408-412
502
503 36. *Sandbakk O, Ettema G, Holmberg HC*. Gender differences in endurance performance by
504 elite cross-country skiers are influenced by the contribution from poling. *Scand J Med Sci*
505 *Sports* 2014; 24: 28-33
506
507 37. *Mc Kendry J, Breen L, Shad BJ et al*. Muscle Morphology and Performance in Master
508 Athletes: A Systematic Review and Meta-Analyses. *Ageing Res Rev* 2018: 45; 62-82
509
510 38. *Castagna C, Impellizzeri FM, Chamari K et al*. Aerobic fitness and yo-yo continuous and
511 intermittent tests performances in soccer players: A correlation study. *J Strength Cond Res*
512 2006; 20: 320-325
513
514 39. *Landers GJ, Blanksby BA, Ackland TR et al*. Swim Positioning and its Influence on triathlon
515 Outcome. *Int J Exerc Sci* 2008; 15:96–105
516
517 40. *Luiz-de-Marco R, Kemper H, Agostinete RR et al*. Sports participation and muscle mass
518 affect sex-related differences in bone mineral density between male and female adolescents:
519 A longitudinal study. *Sao Paulo Med J* 2019; 137: 75-81
520
521 41. *Agostinete RR, Werneck AO, Maillane-Vanegas S et al*. The mediating role of lean soft
522 tissue in the relationship between somatic maturation and bone density in adolescent
523 practitioners and non-practitioners of sports. *Int J Environ Res Public Health* 2021; 18:
524 3008
525

526 42. *Malm HT, Ronni-Sivula HM, Viinikka LU et al.* Marathon running accompanied by transient
527 decreases in urinary calcium and serum osteocalcin levels. *Calcif Tissue Int* 1993; 52:209-
528 211

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531 **The list of table legends:**

532

533 **Table 1.** Baseline characteristics of endurance and power athletes. Data are means \pm standard
534 deviations (SDs).

535 **Table 2.** Field fitness test performance of endurance and power athletes.

536 **Table 3.** Biochemical markers of bone turnover between endurance and power athletes.

537

1 **Table 1.** Baseline characteristics of endurance and power athletes. Data are means \pm standard
 2 deviations (SDs).

Variables		Endurance	Power
		athletes (n=67)	athletes (n=77)
Age (years)	Males	17.7 \pm 2.2	17.9 \pm 1.3
	Females	17.0 \pm 2.4	17.5 \pm 1.8
	Total	17.3 \pm 2.3	17.7 \pm 1.5
Height (cm)	Males	169.3 \pm 9.9	173.4 \pm 8.7
	Females	161.8 \pm 6.9	166.7 \pm 5.5 **
	Total	165.4 \pm 9.2	170.7 \pm 8.2***
Body mass (kg)	Males	63.2 \pm 7.7	70.6 \pm 9.9**
	Females	55.9 \pm 8.1	63.5 \pm 8.4***
	Total	59.4 \pm 8.7	67.8 \pm 9.9***
Lean mass (kg)	Males	52.3 \pm 8.6	59.62 \pm 9.3**
	Females	45.0 \pm 8.0	51.66 \pm 7.97
	Total	48.5 \pm 9.0	56.42 \pm 9.57
Training volume (h/wk)	Males	8.0 \pm 1.2	8.00 \pm 0.8
	Females	8.0 \pm 0.5	7.85 \pm 0.5
	Total	8.0 \pm 0.9	7.92 \pm 0.6

3

4 Significant differences between endurance and power athletes: **: $p < 0.01$, ***: $p < 0.001$.

5

Table 2. Field fitness test performance of endurance and power athletes.

Tests		Endurance athletes	Power athletes	Main effect p-value (η^2)		Interaction
				<i>Sex</i>	<i>Sport-Discipline</i>	Sex x Sport Discipline p-value (η^2)
Sprint 10-m (s)	Males	1.88 ± 0.22	1.80 ± 0.36*	0.001 (0.10)	0.001 (0.11)	0.52 (0.003)
	Females	2.01 ± 0.23	1.91 ± 0.21*			
	Total	1.94 ± 0.23	1.85 ± 0.29*			
Sprint 30-m (s)	Males	4.48 ± 0.47	4.40 ± 0.31*	0.001 (0.09)	0.001 (0.12)	0.43 (0.004)
	Females	4.91 ± 0.35	4.57 ± 0.61**			
	Total	4.67 ± 0.52	4.48 ± 0.48*			
SLJ (cm)	Males	225.16 ± 18.63	239.15 ± 26.76**	0.001 (0.20)	0.001 (0.14)	0.22 (0.001)
	Females	196.77 ± 23.96	220.55 ± 23.24***			
	Total	210.33 ± 25.74	231.66 ± 26.86***			
SqJ (cm)	Males	28.78 ± 7.63	36.69 ± 6.59***	0.03 (0.08)	0.001 (0.28)	0.52 (0.003)
	Females	25.67 ± 4.92	34.41 ± 6.68***			
	Total	27.16 ± 6.50	35.55 ± 6.64***			
	Males	30.59 ± 7.00	37.80 ± 7.52***			

CMJ (cm)	Females	27.61 ± 4.87	35.63 ± 6.90***	0.02	0.001	0.76
	Total	29.04±6.12	36.71±7.32***	(0.07)	(0.25)	(0.001)
Yo-Yo	Males	2040 ± 202**	1669 ± 157	0.003	0.001	0.93
IR1 (m)	Females	1680 ± 169*	1327 ± 224	(0.09)	(0.11)	(0.001)
	Total	1835 ± 598 ***	1498 ± 614			

SLJ: Standing long jump (cm); SqJ: Squat jump test (cm); CMJ: Counter-movement jump (cm); Yo-Yo IR1: Yo-Yo intermittent recovery test level-1 (m);

Significant main effects of sex or sport discipline; *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Table 3. Biochemical markers of bone turnover between endurance and power athletes.

Markers		Endurance athletes	Power athletes	Main effect p-value (η^2)		Interaction
				Sex	Sport discipline	Sex x Sport Discipline p-value (η^2)
CTx (μ /l)	Males	0.31 \pm 0.20	0.33 \pm 0.16	0.001 (0.10)	0.787 (0.001)	0.634 (0.002)
	Females	0.23 \pm 0.14	0.23 \pm 0.10			
	Total	0.27 \pm 0.18	0.29 \pm 0.15			
OC (ng/ml)	Males	37.58 \pm 18.83	35.19 \pm 15.50*	0.004 (0.09)	0.184 (0.013)	0.423 (0.005)
	Females	32.02 \pm 17.51	26.42 \pm 7.05*			
	Total	34.68 \pm 18.23	32.26 \pm 13.60*			
P1NP (ng/ml)	Males	278.47 \pm 239.13	194.23 \pm 110.24*	0.05 (0.07)	0.002 (0.09)	0.996 (0.000)
	Females	225.74 \pm 166.07	141.24 \pm 78.77**			
	Total	250.92 \pm 204.38	172.89 \pm 101.99**			

CTx: C-telopeptide type I collagen (μl); OC: serum osteocalcin (ng/ml); PINP: N-terminal propeptide of procollagen type I (ng/ml).

Significant main effects of sex or sport discipline and sex-by-sport discipline interactions: *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.