UNIVERSITY OF THE
WEST *of* SCOTLAND
UWS

UWS Academic Portal

Assessing differences in cardio-respiratory fitness with respect to maturity status in highly trained youth soccer players

Doncaster, Greg; Iga, John; Unnithan, Viswanath

[Link to publication on the UWS Academic Portal](#)

1   **Assessing differences in cardio-respiratory fitness with respect to**

2   **maturity status in highly trained youth soccer players**

3   **Abstract**

4   **Purpose:** Examine differences in measures of cardio-respiratory fitness and determinants of

5   running economy with respect to maturity status, in a group of highly trained youth soccer

6   players.

7   **Methods:** Twenty-one highly trained youth soccer players participated. On separate visits,

8   players' peak oxygen uptake, running economy, at three different speeds (8km·h^{-1}, 80% GET

9   and 95% GET), and pulmonary oxygen uptake kinetics (VO_2 kinetics) were determined. Players

10   also performed a Yo-Yo Intermittent Recovery test level 1 (Yo-Yo IR1). Players were

11   categorised as either 'pre-PHV' or 'mid-PHV' using the measure of maturity offset.

12   Independent t-tests and Cohen's d effect sizes were then used to assess differences between

13   groups.

14   **Results:** The mid-PHV group were significantly taller, heavier and advanced in maturity status.

15   Absolute measures of VO_{2peak} were greater in the mid-PHV group, however, when expressed

16   relative to body mass, FFM and theoretically derived exponents, VO_{2peak} values were similar

17   between groups. Pre-PHV group presented a significantly reduced VO_2 response, during

18   relative submaximal running speeds, when theoretically derived exponents were used, or

19   expressed as % VO_{2peak}. VO_2 kinetics (*tau*) were faster during a low (standing) to moderate (95%

20   GET) transition in the pre-PHV group. Yo-Yo IR1 performance was similar between groups.

21   **Conclusion:** While measures of VO_{2peak} and Yo-Yo IR1 performance are shown to be similar

22   between groups, those classed as Pre-PHV display a superior running economy at relative

23   submaximal running speeds and faster *taus* during a low-moderate exercise transition, than

24   their more mature counterparts.

Introduction

The growing professionalism of sport has resulted in an advancement in the application of early specialization and systematic training of talented young athletes, with the aim of achieving elite professional status (26). Consequently, a large emphasis is placed on the talent identification and talent development of young soccer players (38). This has resulted in research which aims to identify, examine and analyse the key physical and physiological characteristics of elite youth soccer players that are associated with superior soccer performance (38). However, confounding variables of growth and maturation complicate the analysis and interpretation of these measures within youth populations as well as the provision of coaching and training prescription toward these diverse populations. Indeed, both physiological and anthropometric changes can occur during adolescence, particularly during rapid periods of growth and maturation, these changes then impact upon physical performance and confound the issues of talent development and identification (17).

Currently, there is a plethora of research examining the impact of maturational differences in anaerobic fitness characteristics (speed, acceleration, jump power, etc.) (12, 17), highlighting the physical dominance of players who are at an advanced stage of maturity (26, 12). Although youth soccer players will compete within their respective age groups (same chronological age), the impact of growth and maturation can result in large variations in skeletal age within male youth soccer players aged between 10-18 years old. Subsequently, those individuals which are of an advanced maturity status will often appear as the taller, heavier and more physically developed individuals. This can often result in a selection bias towards players of an advanced maturity status, due to their superior levels of speed, power and strength (26, 27), leading to talented, but physically less mature players not attaining their full potential and dropping out of the game (12).

50 Research has highlighted the dominance of early maturing individuals in anaerobic fitness

51 characteristics (27). The energy provision required for competitive soccer performance,

52 however, is predominantly derived from aerobic energy sources (19). While an improved

53 ability to activate anaerobic energy resources will result in superior performance in one-off

54 explosive actions during match-play (sprints), an enhanced ability to utilise aerobic energy

55 resources will (theoretically) result in an improved tolerance to fatigue and an ability to

56 maintain levels of high intensity activities, and therefore maintain physical performance for a

57 prolonged period of time (33). Therefore, while the less mature player may be unable to

58 metabolically activate anaerobic energy sources, they will however, have the capacity to

59 sustain high intensity activities via primarily aerobic energy pathways (33). Yet, there is little

60 information regarding the impact of maturation with respect to detailed measures of cardio-

61 respiratory fitness, in highly trained youth soccer players. Moreover, recent research has

62 highlighted the importance of appropriate scaling to successfully accommodate the nonlinear

63 relationship between body size descriptors and VO_{2peak} (10, 25, 1). Adopting the traditional

64 ratio-standard method ($mL \cdot kg^{-1} \cdot min^{-1}$) results in an adjusted VO_{2peak} which is not independent

65 of body size, therefore research advocates the use of allometric scaling, when interpreting VO_2

66 data, to remove the confounding influence of body size, in individuals at different stages of

67 maturation (10).

68

69 Therefore, the purpose of this study was to examine inter-group differences in ratio-standard

70 and allometrically-adjusted measures of submaximal and peak cardio-respiratory fitness and

71 determinants of running economy with respect to maturity status, in a group of highly trained

72 youth soccer players. It was hypothesized that, when appropriately scaled, measures of VO_{2peak}

73 would be unaffected by maturity status. Players of a lower maturity status, however, would

74 present a reduced VO_2 response during all submaximal running speeds, when appropriately

75 scaled. Similarly, it was hypothesised that less mature players would display superior VO_2

76 kinetics (faster *taus*), than their more mature counterparts.

77

78 **Methods**

79 *Participants and Anthropometry*

80 Twenty one highly trained youth soccer players aged between 12 and 14 years volunteered to

81 participate in this study. All participants were outfield players from the same Category One

82 Premier League Football Academy. Prior to the commencement of the study, all players

83 completed medical health questionnaires and training history questionnaires. Table 1 displays

84 all anthropometric and screening measures. Maturity status was quantified using self-

85 assessment Tanner Stage method (30, 36) and maturity offset (31). Sum of 4 skinfolds was

86 assessed using Harpenden skinfold calipers (Cranlea, Birmingham, UK) to measure skinfold

87 thickness at the biceps, triceps, subscapular and superilliac according to the procedures outlined

88 by ISAK (28). Percent body fat was then estimated using the equation of Siri (35), this

89 information was then subsequently used to estimate individuals' fat free mass (FFM). Players

90 and their parents were informed about all procedures and requirements involved in the study

91 before opting to provide written informed consent and assent from parents and participants,

92 respectively. Ethical approval was granted from the local university ethics committee.

93

94 *Calculation of Maturity Offset*

95 Players were categorised into pre-PHV and mid-PHV groups using the calculation of maturity

96 offset (31). Measurements obtained to gain an estimate of each individual's maturity offset

97 included stretch standing stature and stretch sitting stature, to the nearest mm (Seca 217,

98 Birmingham, United Kingdom) as well as body mass, to the nearest 0.1 kg (Seca 761,

99 Birmingham, United Kingdom). As described by Mirwald et al. (31) two measurements were

100 taken for each anthropometric measure, with a third required if the first two measures differed

101 by more than 4 mm for measures of stature and 0.4 kg for weight. For each anthropometric

102 measure these were then averaged. All measurements were obtained by a sport practitioner

103 experienced in the assessment of such procedures. This data was then inputted into a specially

104 designed Microsoft Excel Spreadsheet which employed the maturity offset equation of

105 Mirwald et al. (31) to provide an estimated value for the years from peak height velocity (PHV)

106 for each individual.

107

108 Once the maturity offset was known, participants were classified as either pre-PHV or mid-

109 PHV. Players who were $\geq$-4.0 and <-1.0 year away from their respective period of PHV were

110 classified as pre-PHV ($n = 10$), while those who were between $\geq$ -1.0 and < +0.99 years from

111 their predicted PHV were classified as mid-PHV ($n = 11$). The maturity offset measure gives

112 an indication to an individual's maturity status, as such, those who were classified as mid-PHV

113 were at an advanced stage of maturation, when compared to their counterparts who were

114 classified as pre-PHV.

115

116 **Table 1:** Anthropometric and screening measures (n =21)

117   ***Insert Table 1 Here***

118

119 *Study Design*

120 Players' anthropometric measurements were collected first, followed by laboratory then field

121 tests. The players visited the laboratory on 4 separate occasions. During the first visit, players

122 performed an incremental, ramp treadmill protocol for the assessment of players' gaseous

123 exchange threshold (GET), VO_{2peak} and the speed corresponding to 60% of the difference

124 between GET and VO_{2peak} (60%Δ). Players then returned to the laboratory for a second time,

125 following a minimum of 24 hours of recovery. On the second visit, players were required to

126 run for 4 min, at progressive sub-maximal intensities (8km·h^{-1}, 80%GET and 95%GET), with

127 2 min passive recovery between speed increments. Players returned to the laboratory on two

128 further occasions, each following a minimum of 24 hours of recovery. These two visits to the

129 laboratory were identical and required the participant to complete a work-to-work protocol (rest

130 - 95%GET – 60%Δ) on a motorised treadmill for the assessment of their pulmonary oxygen

131 uptake kinetics (VO_2 kinetics). Following all laboratory tests and a minimum of 48 hours

132 recovery, players completed a maximal Yo-Yo Intermittent Recovery test level 1 (Yo-Yo IR1)

133 (6). For each participant, all testing was completed at the same time of day (± 2 hours), with

134 the ranges for room temperature, humidity and pressure corresponding to 18.7 – 22.8 ºC, 62 -

135 63 % and 1011 - 1021 mmHg respectively, for laboratory testing.

136

137 *Assessment of Peak Oxygen Uptake and Gaseous Exchange Threshold*

138 Upon arrival to the laboratory and following the necessary screening procedures, participants

139 were fitted with a Polar Heart rate monitor (Polar Electro, Kempele, Finland) and face-mask

140 (Hans Rudolph, Hans Rudolph, Kansas City, USA), which was connected to an online gas

141 analysis system (Cortex MetaMax 3B, Cortex Biophysik GmbH, Leipzig, Germany). The

142 online gas analyser was calibrated prior to each visit according to the manufacturer's

143 instructions, using a known gas concentration and a 3-L syringe for manual volume calibration

144 of the ventilation sensors. Prior to each test, participants completed a standardised 10 min warm

145 up consisting of 4 min running at 8km·h^{-1}, 3 min of dynamic stretches (mainly focusing on the

146 lower body) and a further 2 min of sub-maximal running before a final minute for the

147 participant to perform their own stretches. Following this, and a full description of the test and

148 safety procedures, participants began to run at a speed of 8km·h^{-1} at a 1% incline (21) on a

149 motorised treadmill (HP Cosmos, Pulsar, Sportgerate GmbH, Nussdorf, Germany). The speed

150   of the treadmill was increased by $1 km \cdot h^{-1}$ every two minutes, this continued until participants

151   reached 90% of their age predicted heart rate max ($207 - (0.7 \times age)$) [16]. At this point, the

152   treadmill speed remained constant whilst the incline of the treadmill was increased by 1% every

153   minute until volitional exhaustion; this procedure was employed to avoid over-striding and

154   potential early termination and inaccurate assessment of participant's VO_{2peak}. This method has

155   been successfully used before to elicit VO_{2peak} during treadmill running in young athletes [40].

156   Rolling 15 sec averages were calculated for the final minute of the test, with the highest 15 sec

157   average during the test being regarded as VO_{2peak} [5].

158

159   The gaseous exchange threshold (GET) was identified using the V-slope method (V_E (ordinate),

160   VO_2 (abscissa). Two regression lines were created based upon the relationship between VCO_2

161   and VO_2. The intercept point between the two regression lines was then visually identified,

162   with the VO_2 value at the intercept (GET) being extrapolated to the abscissa. To identify the

163   speed at GET, a regression line was formulated for VO_2 and running velocity, for each

164   individual. The GET was assessed by two individual researchers (experienced in the detection

165   of GET), demonstrating 81% agreement (17 out of 21). For the remaining four participants, a

166   third researcher, also experienced in the detection of GET, was approached to verify the GET

167   [15]. The individual's VO_2 at GET was then inputted into the individual's respective regression

168   equation to calculate the running velocity at GET. The V-slope method has been shown to be

169   a reliable method for detecting and identifying the gaseous exchange threshold in children [15].

170

171   ***Assessment of Running Economy***

172   On the subsequent visit to the laboratory, and following a minimum of 24 hours recovery,

173   participants' RE was assessed at three progressive sub-maximal intensities (one absolute:

174   8km·h^{-1} and two relative: 80%GET and 95%GET exercise intensities), with 2 min passive

175   recovery between each intensity. Prior to testing, participants were fitted with a Polar Heart

176   rate monitor and face-mask, which was connected to the pre-calibrated online gas analysis

177   (Cortex) system. Following a standardised 10 min warm-up and a full description of the test

178   procedures, participants began to run at the lowest exercise intensity (for 3 of the participants

179   the velocity at 80%GET was lower than 8km·h^{-1}), with the gradient of the treadmill set at 1%

180   (21). Participants ran at this speed for 4 min, ensuring that a steady state was maintained for

181   the final minute (8). A 2 min passive recovery was then permitted, in which participants' heart

182   rate recovered to within 10% of pre-exercise levels. Pilot testing demonstrated that a 2 min

183   passive recovery was shown to provide sufficient time for players to recover, ensuring there

184   were no ensuing effects on the subsequent exercise bouts. During this recovery period, the

185   treadmill speed was increased to the next progressive speed (higher intensity of 8km·h^{-1} or

186   80%GET). Again, participants exercised at this speed for 4 min, attaining a steady state, before

187   undertaking a further 2 min recovery. Following the final 2 min of recovery, participants

188   completed another 4 min period of sub-maximal running at the highest intensity (95%GET).

189   Extraction of the appropriate measures for assessing RE included applying rolling 15 sec

190   averages for the final minute of each sub-maximal exercise intensity to ensure that a steady

191   state had been attained. Current results revealed that all participants (100%) attained a steady

192   state ($<$ 2 mL·kg^{-1}·min^{-1}, in the final minute of exercise) for each sub-maximal exercise

193   intensity. Following the identification of a steady state, RE was defined as the average VO_2

194   during the final minute of each exercise bout (8). Relative oxygen consumption (VO_2) was

195   obtained for each exercise intensity as well as determinants of RE: minute ventilation (V_E) and

196   ventilatory equivalent ($V_E VO_2$).

197

198   Measures of VO_2 in both the maximal graded exercise test and the assessment of running

199   economy, for each sub-maximal running speeds, were normalized using 1) ratio-standard

200   scaling to body mass (mL·kg BM^{-1}·min^{-1}) and fat free mass (mL·kg FFM^{-1}·min^{-1}), 2) allometric

201   scaling, using theoretically derived exponents (9, 25; $b = 0.67$ and $b = 0.75$) and, 3) a measure

202   relative to participants' VO_{2peak} ($\%VO_{2peak}$).

203

204   ***Assessment of oxygen uptake kinetics***

205   On the two remaining visits to the laboratory, each participant completed a series of exercise

206   transitions to a higher intensity on the motorised treadmill. Each series consisted of 3 min

207   unloaded (standing), 4 min running at an intensity equivalent to 95% GET (moderate intensity)

208   and a run to exhaustion at an intensity equivalent to 60%Δ (severe intensity). Prior to the test,

209   participants were familiarised with the transition to each speed given sufficient time to practise

210   until they felt comfortable with both transitions (unloaded – moderate and moderate – severe).

211   Following familiarisation to the speed transitions, participants were fitted with a Polar Heart

212   rate monitor and face mask, which was connected to an online expired gas analysis system.

213   During the test, verbal encouragement was provided throughout for participants to continue for

214   as long as possible, however no visual feedback relating to exercise duration, was given to the

215   participants during the test.

216

217   For the unloaded to moderate transition the treadmill was set at the relevant intensity for each

218   individual, while the participant straddled the treadmill. The participant was then given a 10

219   second countdown at the end of the unloaded phase, at which point they lowered themselves

220   onto the moving treadmill and began exercising. For the transition from moderate to severe

221   intensity the participant remained running on the treadmill. The time taken for each exercise

222   transition was in all cases < 5 seconds, thus having minimal effects on the VO_2 kinetic response

223   as this would be contained within the cardiodynamic phase of the oxygen uptake response to

224   an increase in intensity (40).

225

226   *Mathematical modelling of oxygen uptake kinetics*

227   Prior to the modelling of the VO_2 kinetics errant breaths (coughing, swallowing, sighing, etc.)

228   were removed from the raw data set so as not to distort or skew the underlying physiological

229   response. Errant breaths were defined as a breath that was different to the mean of the

230   surrounding four breaths by more than four times the standard deviation of the same

231   surrounding four data points (22). Both data-sets from each stage (unloaded – moderate and

232   moderate – severe) were time aligned and ensemble averaged to enhance the underlying

233   physiological response characteristics for all intensities. Each ensemble average was then

234   linearly interpolated second-by-second prior to the modelling process. Custom written software

235   in Microsoft Excel, using the Solver function, was utilised for all modelling processes.

236

237   Pulmonary oxygen uptake kinetics for the unloaded to moderate and moderate to severe

238   transitions were modelled separately, due to the difference in the characteristics of the kinetic

239   response for each increase in intensity. For both, unloaded – moderate and moderate – to severe

240   transitions, the goal of the modelling process was to isolate the fundamental phase (39) of VO_2

241   kinetic response (equation 1). To eliminate the influence of the cardiodynamic phase on the

242   modelling of VO_2 kinetics, the initial 20 seconds from the unloaded to moderate phase and

243   initial 15 seconds of the moderate to severe phase were removed prior to the modelling process.

244   A time delay of 20 seconds is often employed to accommodate the cardiodynamic phase (39);

245   however, a 15 second time delay was adopted for the moderate to severe transition due to

246   elevated baseline blood flow incurred from the prior moderate intensity (7). Following the

247 cardiodynamic phase, VO_2 kinetics were assumed to develop initially via a single exponential

248 term (fundamental phase), following a delay relative to the start of exercise of the form:

249

250 $$V_{O_{2(t)}} = V_{O_{2(b)}} + A_{VO_2} \times (1 - \exp^{-(t-TD)/\tau}) \qquad [1]$$

251

252 Where $V_{O_{2(b)}}$ is the baseline VO_2, which was taken as the last 30 seconds of oxygen uptake

253 during 3 minutes unloaded phase. A_{VO_2} represents the asymptotic amplitude of the fundamental

254 component of the response; τ is the time constant of the fundamental component and TD is the

255 time delay similar, but not equal to the cardiodynamic-fundamental phase transition time. For

256 the unloaded – moderate transition, the fundamental phase was considered *a priori* to

257 encapsulate the entire 4-minute transition since exercise was undertaken below the GET. For

258 the moderate – severe transition, the fitting strategy was designed to identify the onset of the

259 "slow component" of the response to exercise, and thus isolate the fundamental component.

260 Starting at 60 s, the fitting window was therefore widened by 1 s until the end of exercise with

261 the time constant and reduced chi-square value of the curve of best fit for each time window

262 plotted against time. The onset of the slow component could then be identified as the coincident

263 point at which a plateau or minima in the value of τ and a minima in chi-square, followed by a

264 progressive increase in these values, could be determined as its value becomes affected by the

265 slow component. The time at which this occurred was used as the optimal fitting window with

266 which to determine the kinetics of the fundamental phase of VO_2 kinetics. The phase III of

267 oxygen uptake (steady state in the unloaded – moderate transition) was taken as the sum of

268 $V_{O_{2(b)}}$ and A_{VO_2}. The amplitude of the slow component during the moderate – severe transition

269 was calculated as VO_2 at exhaustion minus the phase III VO_2.

270

271 *Yo-Yo Intermittent Recovery Test Level 1*

272 For the Yo-Yo IR1 test, cones were placed 20 m apart, with a 5 m recovery zone marked out

273 at one end. The Yo-Yo IR1 test requires participants to run 2 x 20 m shuttle runs at increasing

274 speeds, interspersed with 10 seconds of active recovery. The pace of the test was controlled by

275 audio signals emitted from a CD player (Sony CFD-V7, Sony, Tokyo, Japan). For the maximal

276 Yo-Yo IR1 test players were required to run until volitional termination of the test or, when

277 they have twice failed to meet the designated cones in time with the audio signal, at which

278 point they are removed from the test. The test score is the distance covered at the point they

279 withdraw from the test. During the test, players were allowed to consume fluids ad libitum.

280 Current findings support the use of the Yo-Yo IR1 test as a valid measure of physical

281 performance, associated with soccer match-play, particularly within youth populations (6).

282

283 *Statistical Analysis*

284 A Shapiro Wilks test found the data to be normally distributed, therefore parametric statistical

285 calculations were applied. Following this, independent *t*-tests were conducted to assess the

286 differences between pre-PHV and mid-PHV groups, in anthropometric measures and measures

287 of cardio-respiratory fitness. Differences between groups were also compared using Cohen's *d*

288 effect sizes (ES) and thresholds (<0.5 = small; 0.5-0.8 = moderate; >0.8 = large) to aid

289 interpretation. Additionally, where appropriate, a qualitative descriptor, used to aid practical

290 inferences, was assigned to the following quantitative chances of benefit: 25-75% = benefit

291 possible; 75-95% = benefit likely; 95-99% = benefit most likely; >99% = benefit almost

292 certain. All statistical analysis was performed using SPSS version 21.0 (IBM SPSS statistics

293 for Windows, IBM, Armonk, New York) and Microsoft Excel (Microsoft Excel 2013,

294 Microsoft, Redmond, Washington) with the level of significance (alpha) set at 0.05.

295

296   **Results**

297   Differences in anthropometric and descriptive measurements revealed significant differences

298   and large effect sizes for stature, body mass, fat free mass and maturity offset, with the mid-

299   PHV group presenting greater values than the pre-PHV group, despite being of similar

300   chronological age (Table 2). Furthermore, years spent training also revealed significant and

301   large effect sizes between groups, but with the pre-PHV group demonstrating greater values

302   than the mid-PHV group, meaning that those identified as pre-PHV had reported to have spent

303   a greater amount of years of systematic training at a high level than the mid-PHV group.

304

305   **Table 2:** Differences in anthropometric and descriptive characteristics between those identified

306   as pre- and mid-PHV, in highly trained youth soccer players.

307   *** Insert Table 2 Here***

308

309   While absolute measures (L·min^{-1}) of $VO_{2\,peak}$ were shown to be greater in the mid-PHV group,

310   the difference between the two groups was eradicated when expressed relative to body mass,

311   fat free mass, as a %$VO_{2\,peak}$ or when using theoretically derived exponents (Table 3). In

312   addition, a moderate effect size was revealed for the velocity at GET, with the mid-PHV group

313   demonstrating a faster velocity when running at GET.

314

315   Limited differences were evident between the two groups for both, measures of cardio-

316   respiratory fitness and determinants of running economy when running at an absolute speed of

317   8km·h^{-1}. Similarly, no differences in running economy were evident for each submaximal

318   running speed when VO_2 was expressed in relation to body mass or fat free mass. For both the

319   relative submaximal exercise intensities, however, the pre-PHV group presented significantly

320   superior levels of running economy, when VO_2 data was scaled using theoretically derived

321 exponents. In support of this, the pre-PHV group also demonstrated a reduced fractional

322 utilisation (%VO_{2peak}) for the same relative submaximal exercise intensities (Table 3). Figure

323 1 displays a representative plot of the VO_2 for each of the three sub-maximal running speeds

324 and during each of the 2 min passive recovery phases.

325

326 **Table 3:** Differences between those identified as pre-PHV and mid-PHV, in measures of

327 cardio-respiratory fitness during the maximal graded exercise test and during both absolute

328 (8km·h^{-1}) and relative (80% and 95% GET) submaximal running speeds, using different

329 methods for normalizing VO_2.

330   ***Insert Table 3 Here***

331

332 **Figure 1:** Representative plot of the VO_2 for each of the three sub-maximal running speeds and

333 during each of the 2 min passive recovery phases

334   ***Insert Fig 1 Here***

335

336 Measures of VO_2 kinetics revealed a significant difference for the absolute amplitude (L.min)

337 and a large effect size for the phase II *tau,* during the low – mod transition, with the pre-PHV

338 group demonstrating faster oxygen uptake kinetics than the mid-PHV group. Figure 2 displays

339 a representative plot of the pulmonary oxygen uptake kinetics during the work-to-work

340 protocol.

341

342 **Figure 2:** Representative plot of the pulmonary oxygen uptake kinetics during the work-to-

343 work protocol, with the respective unloaded - moderate and moderate - severe time constants

344 (*taus*) (Doncaster et al., 2016).

345   ***Insert Fig 2 Here***

346 Finally, performance in the Yo-Yo IR1, a measure of soccer-specific endurance, was similar

347 between the two groups (mid-PHV: 1681 ± 304 vs. pre-PHV: 1572 ± 360 m, $P = 0.49$, $d =$

348 0.33), revealing a small effect size.

349

350 **Discussion**

351 The main finding from the current study was that highly trained soccer players of advanced

352 maturity status do not outperform their less mature counterparts, in key measures of cardio-

353 respiratory fitness and determinants of running economy. Instead, results show that players

354 identified as less mature (pre-PHV) display enhanced levels of cardio-respiratory fitness,

355 particularly when accounting for differences in body size.

356

357 In line with the existing literature (24, 26, 27), anthropometric and descriptive characteristics

358 found those players of an advanced maturity status (mid-PHV) to be physically taller and

359 bigger, presenting both a larger stature, body mass and estimated fat free mass than their less

360 mature counterparts (pre-PHV) of a similar age. The pre-PHV group, however, reported a

361 greater amount of training experience at a high level than their more mature counterparts.

362 Despite those identified as mid-PHV displaying a significantly greater absolute measure of

363 VO_{2peak}, when these data were expressed relative to: body mass (mL·kg BM^{-1}·min^{-1}), fat free

364 mass (mL.kg FFM^{-1}.min^{-1}) or when using theoretical exponents (mL.kg$^{-0.67}$.min^{-1} and mL.kg^{-}

365 $^{0.75}$.min^{-1}), the differences between the two groups were eliminated (Table 3). Similarly,

366 performance during the Yo-Yo IR1 test was comparable between the two groups, revealing

367 only a small effect size in the favour of the mid-PHV group. Results, however, do propose a

368 preference for oxidative metabolism in less mature players (pre-PHV), when compared to their

369 more mature counterparts (mid-PHV). Indeed, when running at relative sub-maximal

370 intensities (80% & 95% GET), normalized VO_2 values using theoretically derived exponents

371   ($b = 0.67$ and $b = 0.75$), the pre-PHV group revealed a significantly reduced VO_2 response for

372   a given relative sub-maximal intensity. In support of this, the pre-PHV group also presented a

373   reduced fractional utilisation ($\%VO_{2peak}$) when running at relative sub-maximal intensities

374   (80% & 95% GET), as well as faster VO_2 kinetics during low – moderate exercise transitions

375   (*tau*), in comparison to their more mature counterparts.

376

377   The results obtained from the tests employed within the current study would appear to be

378   indicative of highly trained youth soccer players. Relative measures of VO_{2peak} in the current

379   study are in-line with those of Cunha et al. (9), who reported values of 59.6 ± 4.3 mL·kg^{-1}·min^{-1}

380   in pubescent (Age: 13.4 ± 1.0 yr, Body Mass: 62.5 ± 9.9 kg) soccer players and Le Gall et al.

381   (24), who reported values of 59.2 ± 3.2 mL·kg^{-1}·min^{-1} in U14 international players (Age: 13.4

382   ± 0.4 yr, Body Mass: 52.5 ± 9.9 kg). Similarly, players' performance in the Yo-Yo IR1 test

383   within the current study is greater than figures reported within the literature for players of a

384   similar age and standard of performance. Indeed, Deprez et al. (11) and Deprez et al. (13)

385   reported scores of 1319 ± 366 m and 1270 ± 440 m for U13 high level youth soccer players,

386   respectively. Deprez et al. (11), however, did separate their cohort of U13 players into low,

387   average and high performers and reported scores of 886 ± 114 m, 1357 ± 100 m and $1714 \pm$

388   145 m in the Yo-Yo IR1, respectively. In this regard players' performance in the current study

389   of 1682 ± 304 m for the mid-PHV group and 1572 ± 360 m for pre-PHV group, could be

390   regarded as above average (11). Nevertheless, the current data demonstrates that the players

391   recruited within this study are indicative and therefore representative, of highly trained youth

392   soccer players.

393

394   Current results are in accordance with Cunha et al. (9) who also found that while those of

395   advanced maturity present higher absolute values (L.min^{-1}) of VO_{2max}, when expressed relative

396   to body mass ($mL{\cdot}kg\,BM^{-1}{\cdot}min^{-1}$) differences in measures of VO_{2peak} are removed (10, 25). As

397   in the present study, Cunha et al. (9) also analysed their data using theoretical exponents ($b =$

398   0.67 and $b = 0.75$), as well as their own experimentally derived exponent ($b = 0.90$), using

399   linear regression analysis, to scale participants' VO_2 response. While Cunha et al. (9) reported

400   a significant difference between pre- and post-pubescent youth soccer players, they also

401   reported that differences between groups could not be attributed to biological maturation in the

402   multiple linear regression analysis. Initial findings (2, 3, 4), examining the impact of maturation

403   on VO_{2max} reported that maturation positively affected measures of $VO_{2max,}$ however, authors

404   only expressed measures of VO_{2max} in absolute terms. In line with the present findings, recent

405   research (9, 10, 25) advocates the need for appropriate analytical procedures (scaling

406   techniques using lower-limb muscle volume) when assessing differences in VO_2 within

407   heterogeneous populations with respect to maturity status. Appropriately interpreted measures

408   of VO_{2peak} are unaffected by maturation in highly trained youth soccer players. Whether or not

409   this has implications for physical performance during soccer match-play requires further

410   investigation.

411

412   Present results suggest a reduced oxygen cost for a given relative submaximal running

413   intensity, in players identified as pre-PHV, when compared to their more mature counterparts.

414   There is a paucity of research to date which has examined differences in running economy

415   between individuals of different maturity status, particularly in team sport athletes. Segers et

416   al. (34), reported no differences in the oxygen cost (expressed in absolute terms, using

417   allometric scaling ($b = 0.59$) or as a %VO_{2peak}) of running between youth soccer players who

418   were identified as either 'early' or 'late' maturers, when running at absolute speeds of 8, 9.5

419   and $11km{\cdot}h^{-1}$ on a treadmill. The use of absolute running speeds however, in the study of Segers

420   et al. (34) may be inappropriate for youth populations as it is likely to result in different internal

421   responses, leading to large inter-individual variability and subsequently increased standard

422   deviations, masking any inter-group differences (32). The use of relative running intensities

423   however, will reduce the inter-individual variability and is a more appropriate method by which

424   youth soccer players' running economy can be assessed, in relation to maturity status. Indeed,

425   the improved levels of running economy and fractional utilisation at relative submaximal

426   intensities, in the present study, elucidates to an improved ability to utilise the aerobic

427   metabolism in those identified as pre-PHV, potentially compensating for the undeveloped

428   anaerobic metabolism (24, 27, 33), within the pre-PHV group. Ratel (33) suggests that younger

429   populations (e.g. children) have a reduced capacity for anaerobic activity (lower concentrations

430   of glycolytic enzyme activity [phosphofructokinase], lower muscle mass, reduced percentage

431   of type II muscle fibres) but an improved capacity for aerobic energy production (increased

432   oxidative phosphorylation enzyme activity [citrate synthase], increased percentage of type I

433   muscle fibres). The extent to which these physiological mechanisms are affected by high levels

434   of systematic team sport training requires further investigation.

435

436   Another means of evaluating an individual's aerobic fitness is via the assessment of VO_2

437   kinetics. The relative contribution of oxidative and non-oxidative energy supply during

438   exercise are dependent upon the characteristics of the VO_2 response to exercise, and is regarded

439   as an important indicator of aerobic function that influences an individual's capacity to perform

440   (22). Current results provide evidence to suggest superior VO_2 kinetics (faster *taus*) during a

441   low to moderate exercise transition, but not during a moderate to severe transition, in youth

442   soccer players identified as pre-PHV. Indeed, faster VO_2 kinetics (*tau*) during low to moderate

443   exercise transitions have been shown to be correlated with the volume and maintenance of high

444   speed activities during youth soccer match-play (14). With faster *taus* relating to a greater

445   volume and an improved ability to maintain high speed activities during youth soccer match-

446   play. Furthermore, research into adolescent male and female soccer players has demonstrated

447   faster VO_2 kinetics in soccer trained individuals in comparison to their untrained counterparts

448   (29, 37). Current results also support previous research which highlights faster *taus* in younger

449   populations, with such measures becoming progressively slower (i.e. larger *taus*) as individuals

450   transition from childhood, through adolescence and then to adulthood (23). Nevertheless, it

451   should be acknowledged that players' VO_2 kinetics profiles were averaged from two transitions

452   and that, where possible, multiple transitions should be encouraged as this will improve

453   confidence in the model parameter estimates (e.g. *tau*) (22).

454

455   In contrast to measures of anaerobic fitness components, such as speed, power and strength

456   (26, 27), where those of an advanced maturity status are shown to excel, measures of aerobic

457   fitness are shown to be either, similar between groups of differing maturity status or favour less

458   mature individuals, when appropriately scaled (9, 10, 25). This is supported by the present

459   result, which show no differences between pre- and mid-PHV groups in measures of soccer-

460   specific endurance (Yo-Yo IR1), as well as the absence of any relationship between players'

461   maturity offset and Yo-Yo IR1 performance (r = 0.16, $P > 0.05$). As noted by Malina et al. (27)

462   the years spent in formal training was a significant contributor to intermittent endurance

463   capacity (measured via the Yo-Yo IR1) in a cohort of 13-15 yr old, high level youth soccer

464   players. Therefore, as those in the pre-PHV group reported to have spent significantly more

465   years training than their more mature counterparts (pre-PHV: 5.9 ± 1.8 vs. mid-PHV: 3.7 ± 2.0

466   yr, $P < 0.05$, $d = 1.16$), any maturational differences between the two groups, in the current

467   results, may have been offset by the greater level of experienced training within the pre-PHV

468   group. Furthermore, Lovell et al. (26) reported trivial and small effect sizes in the Multi-stage

469   fitness test (MSFT), between players born in the first quarter of the year (Sept-Nov) and players

470   born in the final quarter of the year (June-Aug) in U13-U16 English academy youth soccer

471   players. Although, chronological age rather than maturity status was used to separate groups in

472   the study of Lovell et al. (26).

473

474   Despite the consensus for appropriate allometric scaling within the literature, and in particular

475   the support for experimentally derived components (9, 25), the current study only employed a

476   small sample size. Indeed, research suggests that relatively large sample sizes are required to

477   lower statistical inference errors, and that factors such as 'quality' and 'quantity' of the data,

478   as well as analysis method (e.g. nonlinear regression or linear regressions) are likely to

479   influence the allometric scaling exponent beta estimation (18). Given the small samples (pre-

480   PHV: n = 10, mid-PHV: n = 11) within the current study, an experimentally observed exponent,

481   for allometric scaling, was not possible. As a result, theoretical exponents ($b = 0.67$ and $b =$

482   0.75), estimates of Fat Free Mass and a fractional utilisation measure (%VO_{2peak}) were

483   employed to assess highly trained youth soccer players' VO_2 responses, in relation to maturity

484   status (i.e. pre-PHV vs. mid-PHV). Future research, however, where possible, should look to

485   develop their own experimentally observed exponents, for allometric scaling. Furthermore,

486   limitations associated with the calculations used for estimating body fat percentage, and

487   therefore FFM should also be acknowledged. Mainly the appropriateness of the algorithms

488   used (35), to the elite youth soccer players should be considered. Nevertheless, in the absence

489   of population specific algorithms, previous research examining body composition in

490   professional soccer players have employed these methods (20). Despite these limitations the

491   current study extends and improves upon the existing research by examining differences in

492   distinct measures of cardio-respiratory fitness, and determinants of running economy with

493   respect to maturity status and in a group of highly trained youth soccer players, in which there

494   has been an attempt to account for the effects of body size on VO_2.

495

496   While the present results do advocate the need for an enhanced aerobic capacity in highly

497   trained youth soccer players that are identified as pre-PHV. They also demonstrate that, youth

498   academy soccer players demonstrate high levels of soccer-specific endurance (Yo-Yo IR1),

499   irrespective of maturity status (41). An enhanced capacity for aerobic metabolism, in those

500   identified as pre-PHV may potentially transcend into levels of physical performance during

501   high intensity intermittent exercise that are in comparison to their more mature counterparts.

502   Nevertheless, coaches should be aware that potential differences in physical performance

503   between players identified as pre-PHV or post-PHV are likely to be a consequence of anaerobic

504   fitness capabilities and not aerobic fitness capabilities (24, 26, 41). An emphasis on such

505   anaerobic fitness capabilities (e.g. strength and speed), may be one reason why there is a

506   selection bias toward players of an advanced maturity status within these age categories (12-

507   14 yrs old), often referred to as the relative age effect within soccer (12, 17, 26).

508

509   **Conclusion**

510   In summary, current findings provide further evidence for differences in anthropometric and

511   descriptive measures between players identified as pre-PHV and players identified as post-

512   PHV, despite similar chronological age. The present data, however, also demonstrates that

513   players of an advanced maturity status (mid-PHV) do not outperform their less mature (pre-

514   PHV) counterparts in a range of measures and determinants of aerobic fitness. Rather, the

515   current data would suggest that those identified as pre-PHV have a superior ability to utilise

516   aerobic energy pathways during relative submaximal intensities, while also displaying faster

517   VO_2 kinetics (*tau*) when transitioning from a low to moderate exercise intensity. Despite the

518   potential for improved capacity for oxidative metabolism in the pre-PHV group, soccer-

519   specific endurance performance (Yo-Yo IR1) was similar between the two groups.

520 Nevertheless, these enhanced levels of cardio-respiratory fitness may partly explain the

521 comparable levels of high intensity-intermittent performance during the Yo-Yo IR1 test.

522

523 **Acknowledgements**

527

528 **References**

529   1. Armstrong N. Pediatric aerobic fitness and trainability. *Pediatr Exerc Sci.* 2017; 29(1):

530   8-13. https://doi.org/10.1123/pes.2017-0012.

531   2. Armstrong N, Welsman J. Assessment and interpretation of aerobic fitness in children

532   and adolescents. *Exerc Sport Sci Rev*.1994; 22(1): 435-76.

533   3. Armstrong N, Welsman J. Peak oxygen uptake in relation to growth and maturation in

534   11- to 17-year-old humans. *Eur J Appl Physiol*. 2001; 85(6): 546-551. doi:

535   10.1007/s004210100485.

536   4. Armstrong N, Welsman J, Nevill AM et al. Modelling growth and maturation changes

537   in peak oxygen uptake in $11 - 13$ yr olds. *J Appl Physiol.* 1999; 87(6): 2230-2236.

538   5. Astorino T, Robergs R, Ghiasvand F et al. Incidence of the oxygen plateau at VO_{2peak}

539   during exercise testing to volitional exhaustion. *J Exerc Physiol Online*. 2000; 3(4): 1-

540   12.

541   6. Bangsbo J, Iaia M, Krustrup P. The Yo-Yo intermittent recovery test: A useful tool for

542   evaluation of physical performance in intermittent sports. *Sports Med*. 2008; 38(1): 37-

543   51. doi: 10.2165/00007256-200838010-00004.

544   7. Buchheit M, Laursen PB, Ahmaidi, S. Effect of prior exercise on pulmonary O_2 uptake

545   and estimated muscle capillary blood flow kinetics during moderate intensity field

546   running in men. *J Appl Physiol.* 2009; 107(2): 460-70.

547   doi:10.1152/japplphysiol.91625.2008.

548   8. Cooke C. Maximal oxygen uptake, economy and efficiency. In: Eston R, Reilly T,

549   editors. *Kinanthropometry and Exercise Physiology Laboratory Manual: Tests,*

550   *Procedures and Data (3rd Edition)*. London: Routledge; 2009, pp. 174-212.

551   9. Cunha G, Lorenzi T, Sapata K et al. Effect of biological maturation on maximal oxygen

552   uptake and ventilatory thresholds in soccer players: An allometric approach. *J Sports*

553   *Sci.* 2011; 29(10): 1029-1039. doi: 10.1080/02640414.2011.570775

554   10. Cunha G, Vaz M, Geremia J, et al. Maturity status does not exert effects on aerobic

555   fitness in soccer players after appropriate normalization for body size. *Pediatr Exerc*

556   *Sci.* 2016; 28: 456-465. https://doi.org/10.1123/pes.2015-0133.

557   11. Deprez D, Buchheit M, Fransen J et al. A longitudinal study investigating the stability

558   of anthropometry and soccer-specific endurance in pubertal high-level youth soccer

559   players. *J Sports Sci & Med.* 2015*;* 14(2): 418-426.

560   12. Deprez D, Coutts A, Fransen J et al. Relative age, biological maturation and anaerobic

561   characteristics in elite youth soccer players. *Int J Sports Med.* 2013; 34: 897-903. doi:

562   10.1055/s-0032-1333262.

563   13. Deprez D, Coutts A, Lenoir M et al. Reliability and validity of the Yo-Yo intermittent

564   recovery test level 1 in young soccer players. *J Sports Sci.* 2014; 32(10): 903-910. doi:

565   10.1080/02640414.2013.876088.

566   14. Doncaster G, Marwood S, Iga J et al. Influence of oxygen kinetics on physical

567   performance in youth soccer. *Eur J Appl Physio.* 2016; 116(9): 1781-1794.

568   doi:10.1007/s00421-016-3431-x

569   15. Fawkner S, Armstrong N, Childs DJ, Welsman JR. Reliability of the visually identified

570   ventilatory threshold and V-slope method in children. *Pediatr Exerc Sci*. 2002;

571   14(2):181-192.

572   16. Gellish R, Goslin B, Olson R et al. Longitudinal modelling of the relationship between

573   age and maximal heart rate. *Med Sci Sports Exerc*. 2007; 39(5): 822-29.

574   doi:10.1097/mss.0b013e31803349c6.

575   17. Gil S, Badiola A, Bidaurrazaga-Letona I et al. Relationship between the relative age

576   effect and anthropometry, maturity and performance in young soccer players. *J Sports

577   Sci*. 2014; 32(5): 479-486. doi:10.1080/02640414.2013.832355.

578   18. Hui D, Jackson R. Uncertainty in allometric exponent estimation: a case study in scaling

579   metabolic rate with body mass. *J Theor Biol.* 2007; 249 (1).

580   doi:10.1016/j.jtbi.2007.07.003.

581   19. Iaia, FM, Rampinini E, Bangsbo J. High-intensity training in football. *Int J Sports

582   Physiol Perf*. 2009; 4(3): 291-306.

583   20. Iga J, Scott M, George K et al. Seasonal changes in multiple indices of body

584   composition in professional football players. *Int J Sports Med.* 2014; 35(12: 994-998.

585   doi: 10.1055/s-0034-1371833.

586   21. Jones A, Doust J. A 1% treadmill grade most accurately reflects the energetic cost of

587   outdoor running. *J Sports Sci*. 1996; 14(4): 321-27.

588   22. Jones AM, Poole DC. Introduction to oxygen uptake kinetics. In: Jones AM, Poole DC,

589   editors. *Oxygen Uptake Kinetics in Sport, Exercise & Medicine*. London: Routledge;

590   2005, pp. 3-35.

591   23. LeClair E, Berthoin S, Borel B, et al. Faster pulmonary oxygen uptake kinetics in

592   children vs adults due to enhancements in oxygen delivery and extraction. *Scand J Med

593   Sci Sports.* 2013; 23(6):705-12. doi:10.1111/j.16000838.2012.01446.x.

594   24. Le Gall F, Carling C, Williams M et al. Anthropometric and fitness characteristics of

595   international, professional and amateur male graduate soccer players from an elite

596   youth academy. *J Sci & Med Sport*. 2010; 13: 90-95. doi:10.1016/j.jsams.2008.07.004

597   25. Loftin M, Sothern M, Bonis M. Expression of VO_{2peak} in children and youth with special

598   reference to allometric scaling. *Sports Med*. 2016; 46:1451-1460. doi:10.1007/s40279-

599   016-0536-7.

600   26. Lovell R, Towlson C, Parkin G et al. Soccer player characteristics in English lower-

601   league development programmes: The relationships between relative age, maturation,

602   anthropometry and physical fitness. *PLOSone*. 2015; *10*(9), e0137238.

603   27. Malina R, Eisenmann JC, Cumming SP et al. Maturity-associated variation in the

604   growth and functional capacities of youth football (soccer) players 13-15 years. *Eur J*

605   *Appl Physiol*. 2004; 91: 555-562. doi: 10.1007/s00421-003-0995-z.

606   28. Marfell-Jones M, Olds T, Stewart A, et al. International Standards for Anthropometric

607   Assessment. Potchesfstroom: *International Society for the Advancement of*

608   *Kinanthropometry*. 2006, pp. 1-137.

609   29. Marwood S, Roche D, Rowland T et al. Faster pulmonary oxygen uptake kinetics in

610   trained versus untrained male adolescents. *Med Sci Sports Exerc*. 2010; 42(1): 127-34.

611   doi:10.1249/MSS.0b013e3181af20d0.

612   30. Matsudo S, Matsudo V. Self-assessment and physician assessment of sexual maturation

613   in Brazilian boys and girls: concordance and reproducibility. *Am J Hum Biol*. 1994; 6:

614   451-455.

615   31. Mirwald R, Baxter-Jones A, Bailey D et al. An assessment of maturity from

616   anthropometric measurements. *Med Sci Sports Exerc*. 2002; 34(4): 689-694. doi:

617   10.1097/00005768-200204000-00020.

618   32. Morgan D, Craib M. Physiological aspects of running economy. *Med Sci Sports Exerc.*
619   1992; 24(4): 456-461.

620   *33.* Ratel S, Duche P, Williams C. Muscle fatigue during high intensity exercise in children.
621   *Sports Med.* 2006; 36(12): 1031-65. doi:10.2165/00007256-200636120-00004.

622   *34.* Segers V, De Clercq, Janssens M, Bourgois J, Philippaerts R. Running economy in
623   early and late maturing youth soccer players does not differ. *Br J Sports Med.* 2008; 42:
624   289-294. doi:10.1136/bjsm.2007.035915.

625   *35.* Siri W. The gross composition of the body. *Adv Biol Med Phys.* 1956; 4: 239-280.

626   36. Tanner J. *Growth at adolescence (2nd edition).* Oxford: Blackwell Scientific, 1962.

627   37. Unnithan V, Roche D, Garrard M et al. Oxygen uptake kinetics in trained adolescent
628   females. *Eur J Appl Phys.* 2015; 115(1): 213-20.doi:10.1007/s00421-014-3005-8.

629   38. Unnithan V, White J, Georgiou A et al. Talent identification in youth soccer. *J Sports*
630   *Sci.* 2012; 30(15): 1719-1726. doi:10.1080/02640414.2012.731515.

631   39. Whipp B, Rossiter H. The kinetics of oxygen uptake: physiological inferences from the
632   parameters. In: Jones AM, Poole DC, editors. *Oxygen Uptake Kinetics in Sport,*
633   *Exercise & Medicine.* London: Routledge; 2005, p. 62-94.

634   40. Williams C, Carter H, Jones AM et al. Oxygen uptake kinetics during treadmill running
635   in boys and men. *J Appl Physiol.* 2001; 90(5): 1700-6.

636   41. Wrigley R, Drust B, Stratton G et al. Long-term soccer-specific training enhances the
637   rate of physical development of academy soccer players independent of maturation
638   status. *Int J Sports Med.* 2014: 35(13): 1090-1094. doi:10.1055/s-0034-1375616.

639

640

641

642

643 **Table 1:** Anthropometric and screening measures (*n* =21)

Variable	Mean ± Standard Deviation	90% Confidence Limits
Age (y)	13.2 ± 0.6	12.9 - 13.4
Stature (m)	1.59 ± 0.09	1.54 - 1.62
Body Mass (kg)	48.0 ± 10.2	43.9 - 52.4
Maturity Offset (y)	-0.8 ± 0.9	-1.2 to – 0.4
Tanner Stage	3 ± 1	2 - 3
Predicted Age at PHV	14.0 ± 0.7	13.7 – 14.3
Σ 4 Skinfolds (mm)	30.2 ± 5.4	28.0 – 32.4
Body Fat (%)	17.6 ± 2.2	16.7 – 18.6
Fat Free Mass (kg)	39.6 ± 8.7	35.8 – 43.3
Training Years (y)	4.8 ± 2.2	3.9 - 5.7
Training Hours (hrs.p.week)	12.4 ± 2.7	11.4 - 13.7

644 Note: PHV = Peak Height Velocity; Skinfold sites used for the Σ4 skinfolds were the biceps, triceps, subscapular
645 and superilliac.
646

647

648

649

650

651

652

653

654

655

656

657

658 **Table 2:** Table 2: Differences in anthropometric and descriptive characteristics between those identified as pre- and mid-PHV, in highly trained
659 youth soccer players.

	Mid-PHV ($n = 11$)		Pre-PHV ($n = 10$)		Difference		
	Mean ± SD	90% CL	Mean ± SD	90% CL	Sig.		Cohen's d
Age (yr)	13.4 ± 0.4	13.1 - 13.6	13.0 ± 0.7	12.5 - 13.4	$P = 0.12$	0.52	Moderate
Stature (m)	1.65 ± 0.08	1.60 - 1.69	1.52 ± 0.06	1.48 - 1.56	$P < 0.05$	1.83	Large
Body Mass (kg)	53.9 ± 10.7	48.2 - 60.5	41.6 ± 3.9	39.3 - 43.8	$P < 0.05$	1.53	Large
Tanner	3.2 ± 1.0	2.6 - 3.8	2.6 ± 0.5	2.3 - 2.9	$P = 0.11$	0.77	Moderate
Maturity Offset	-0.2 ± 0.7	-0.6 to 0.2	-1.5 ± 0.4	-1.7 to -1.3	$P < 0.05$	2.28	Large
Predicted Age at PHV	13.6 ± 0.6	13.2 - 13.9	14.4 ± 0.5	14.1 - 14.7	$P < 0.05$	1.45	Large
Σ Skinfolds (mm)	28.9 ± 4.2	26.6 - 31.4	31.6 ± 6.5	27.6 - 35.4	$P = 0.26$	0.49	Small
Body Fat (%)	17.2 ± 1.7	16.2 - 18.2	18.1 ± 2.6	16.5 - 19.8	$P = 0.32$	0.47	Small
Fat Free Mass (kg)	44.7 ± 9.3	39.2 - 50.2	34.0 ± 2.7	32.3 - 35.6	$P < 0.05$	1.62	Large
Training Years	3.7 ± 2.0	2.5 - 4.9	5.9 ± 1.8	4.8 - 6.9	$P < 0.05$	1.16	Large
Training Hours (per week)	12.3 ± 1.4	11.5 - 13.1	12.5 ± 3.7	10.3 - 15.1	$P = 0.85$	0.07	Trivial

660 Note: PHV = Peak Height Velocity; Skinfold sites used for the Σ4 skinfolds were the biceps, triceps, subscapular and superilliac.

661

662 **Table 3:** Differences between those identified as pre-PHV and mid-PHV, in measures of cardio-respiratory fitness during the maximal graded
663 exercise and during both absolute (8km·h^{-1}) and relative (80% and 95% GET) submaximal running speeds, using different methods for normalizing
664 VO$_2$.
665

	Mid-PHV (n = 11)		Pre-PHV (n = 10)		90% CI of Differences			Between Group Differences		Qualtitative Descriptor
	Mean ± SD	90% CL	Mean ± SD	90% CL	Lower	Upper	Sig.	Cohen's d		
VO_{2peak} (L·min^{-1})	3.09 ± 0.53	2.80 - 3.42	2.50 ± 0.29	2.31 - 2.67	-0.96	-0.25	$P = 0.005$	1.38	Large	Very Likely
VO_{2max} (mL·kg BM^{-1}·min^{-1})	58.6 ± 5.7	55.3 - 61.6	60.2 ± 4.9	57.3 - 63.2	-2.4	6.1	$P = 0.49$	0.30	Small	Unclear
VO_{2peak} (mL·kg FFM^{-1}·min^{-1})	70.1 ± 7.3	65.8 - 74.3	73.5 ± 5.4	70.1 - 76.9	-1.4	8.3	$P = 0.24$	0.56	Moderate	Unclear
VO_{2peak} (mL·kg$^{-0.67}$·min^{-1})	214.9 ± 21.0	202.5 - 227.3	205.6 ± 17.3	194.9 - 216.3	-23.9	5.3	$P = 0.29$	0.50	Moderate	Unclear
VO_{2peak} (mL·kg$^{-0.75}$·min^{-1})	156.4 ± 15.1	147.5 - 165.4	152.6 ± 12.5	144.9 - 160.4	-14.3	6.7	$P = 0.54$	0.28	Small	Unclear
Max V_EVO_2	32.0 ± 4.1	29.8 - 34.7	30.7 ± 1.7	29.7 - 31.8	-4.2	1.1	$P = 0.36$	0.41	Small	Unclear
Velocity at GET (km·h^{-1})	11.4 ± 1.0	10.8 - 11.9	10.7 ± 0.8	10.2 - 11.2	-1.5	0.1	$P = 0.10$	0.77	Moderate	Likely
VO_2 at GET (%VO_{2peak})	81.9 ± 4.9	79.2 - 84.6	82.3 ± 4.2	79.8 - 85.1	-3.4	4.2	$P = 0.83$	0.08	Trivial	Unclear
Running Economy										
VO_2 @ 8km/h (mL·kg BM^{-1}·min^{-1})	39.6 ± 4.2	37.3 - 41.9	39.4 ± 4.6	36.7 - 42.4	-3.9	3.4	$P = 0.94$	0.05	Trivial	Unclear
VO_2 @ 8km/h (mL·kg FFM^{-1}·min^{-1})	47.8 ± 4.6	45.0 - 50.5	48.1 ± 5.4	44.8 - 51.5	-3.4	4.2	$P = 0.87$	0.08	Trivial	Unclear
VO_2 @ 8km/h (mL·kg$^{-0.67}$·min^{-1})	146.9 ± 16.3	137.3 - 156.5	134.7 ± 16.5	124.5 - 144.9	-24.5	0.2	$P = 0.11$	0.78	Moderate	Likely
VO_2 @ 8km/h (mL·kg$^{-0.75}$·min^{-1})	106.8 ± 11.3	100.1 - 113.6	100.0 ± 12.0	92.5 - 107.4	-15.7	1.9	$P = 0.20$	0.62	Moderate	Likely
V_EVO_2 @ 8km·h^{-1}	26.2 ± 2.4	24.8 - 27.6	27.6 ± 1.6	26.7 - 28.8	-0.4	3.2	$P = 0.14$	0.69	Moderate	Likely
RER @ 8km·h^{-1}	0.89 ± 0.04	0.86 - 0.91	0.90 ± 0.03	0.88 - 0.92	-0.02	0.04	$P = 0.52$	0.28	Small	Unclear
%HRmax @ 8km·h^{-1}	77.1 ± 4.9	74.4 - 79.7	77.9 ± 5.4	74.7 - 81.1	-3.3	5.3	$P = 0.70$	0.15	Trivial	Unclear
%VO_{2peak} @ 8km·h^{-1}	67.7 ± 4.5	65.0 - 70.3	65.6 ± 7.7	61.2 - 70.4	-7.4	3.3	$P = 0.46$	0.33	Small	Unclear
VO_2 @ 80%GET (mL·kg BM^{-1}·min^{-1})	43.7 ± 5.1	41.0 - 47.0	42.2 ± 3.8	39.7 - 44.3	-5.4	1.9	$P = 0.43$	0.33	Small	Unclear
VO_2 @ 80%GET (mL·kg FFM^{-1}·min^{-1})	52.8 ± 5.9	49.3 - 56.3	51.7 ± 4.6	48.8 - 54.6	-5.2	2.9	$P = 0.64$	0.22	Small	Unclear
VO_2 @ 80%GET (mL·kg$^{-0.67}$·min^{-1})	162.2 ± 19.2	150.9 - 173.6	144.5 ± 13.4	136.2 - 152.8	-30.3	-5.1	$P = 0.025$	1.12	Large	Very Likely
VO_2 @ 80%GET (mL·kg$^{-0.75}$·min^{-1})	118.0 ± 13.5	110.0 - 126.0	107.3 ± 9.8	101.2 - 113.4	-19.7	-1.7	$P = 0.053$	0.95	Large	Likely
V_EVO_2 @ 80%GET	26.9 ± 2.1	25.6 - 28.1	27.9 ± 1.5	27.0 - 28.8	-0.5	2.5	$P = 0.28$	0.55	Moderate	Unclear
RER @ 80%GET	0.90 ± 0.03	0.88 - 0.92	0.91 ± 0.03	0.89 - 0.92	-0.01	0.03	$P = 0.45$	0.33	Small	Unclear
%HRmax @ 80%GET	82.4 ± 4.9	79.1 - 84.8	82.4 ± 4.1	79.8 - 84.7	-3.8	4.1	$P = 0.99$	0.00	no effect	Unclear
%VO_{2peak} @ 80%GET	74.8 ± 5.6	71.4 - 78.0	70.2 ± 4.5	67.4 - 72.8	-8.7	-0.2	$P = 0.049$	0.67	Moderate	Likely
VO_2 @ 95%GET (mL·kg BM^{-1}·min^{-1})	50.6 ± 5.0	47.9 - 53.4	48.6 ± 4.2	46.0 - 51.0	-5.8	1.7	$P = 0.33$	0.43	Small	Unclear
VO_2 @ 95%GET (mL·kg FFM^{-1}·min^{-1})	61.3 ± 5.6	58.0 - 64.6	59.6 ± 5.3	56.3 - 62.9	-5.8	2.4	$P = 0.49$	0.32	Small	Unclear
VO_2 @ 95%GET (mL·kg$^{-0.67}$·min^{-1})	188.3 ± 19.7	176.7 - 199.9	166.6 ± 15.2	157.2 - 176.0	-35.1	-8.3	$P = 0.011$	1.29	Large	Very Likely
VO_2 @ 95%GET (mL·kg$^{-0.75}$·min^{-1})	137.0 ± 13.5	129.0 - 144.9	123.7 ± 11.1	116.8 - 130.6	-22.7	-3.9	$P = 0.024$	1.13	Large	Very Likely
V_EVO_2 @ 95%GET	27.5 ± 2.6	25.9 - 28.9	27.8 ± 2.3	26.5 - 29.1	-1.6	2.3	$P = 0.77$	0.12	Trivial	Unclear
RER @ 95%GET	0.93 ± 0.04	0.91 - 0.95	0.93 ± 0.04	0.90 - 0.96	-0.03	0.03	$P = 0.99$	0.00	no effect	Unclear
%HRmax @ 95%GET	88.7 ± 4.3	86.0 - 91.0	89.2 ± 3.9	86.5 - 91.4	-2.9	4.0	$P = 0.77$	0.12	Trivial	Unclear
%VO_{2peak} @ 95%GET	86.6 ± 5.3	82.9 - 89.6	81.1 ± 7.4	75.9 - 85.0	-11.4	-0.1	$P = 0.06$	0.85	Large	Likely
VO_2 Kinetics										
low - mod *tau* (s)	22.0 ± 8.1	18.2 - 27.4	16.4 ± 5.6	13.6 - 20.0	-11.7	-0.06	$P = 0.08$	0.80	Large	Likely
low - mod amplitude (L·min^{-1})	1.91 ± 0.43	1.68 - 2.15	1.52 ± 0.19	1.41 - 1.63	-0.66	-0.14	$P = 0.016$	1.17	Large	Very Likely
mod - sev *tau* (s)	78.8 ± 61.0	47.1 - 119.6	47.6 ± 23.7	34.6 - 64.7	-73.4	2.9	$P = 0.15$	0.67	Moderate	Likely
mod - sev amplitude (L·min^{-1})	0.56 ± 0.21	0.44 - 0.69	0.44 ± 0.24	0.31 - 0.59	-0.32	0.07	$P = 0.22$	0.53	Moderate	Likely
Yo-Yo IR1 (m)	1682 ± 304	1512 - 1855	1572 ± 360	1364 - 1798	-402	188	$P = 0.49$	0.33	Small	Unclear

666   Note: VO$_{2peak}$= peak oxygen consumption; GET= gaseous exchange threshold; $V_E$$VO_2$= ventilatory equivalent; RER= respiratory exchange ratio; HR$_{max}$= maximal heart rate;

667   *tau*= time constant; Yo-Yo IR1= Yo-Yo intermittent recovery test level 1.