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1 Utility of international normative 20 m shuttle run values for identifying youth at
2 increased cardiometabolic risk.

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21

22 **Running Title:** CRF and cardiometabolic risk

23

24

25

26 **Abstract**

27 The purpose of this study was to examine the ability of international normative
28 centiles for the 20 m shuttle run test (20mSRT) to identify youth at increased
29 cardiometabolic risk. This was a cross-sectional study involving 961 children aged
30 10–17 years (53% girls) from the United Kingdom. Receiver operating characteristic
31 (ROC) curves determined the discriminatory ability of cardiorespiratory fitness
32 percentiles for predicting increased cardiometabolic risk. ROC analysis
33 demonstrated a significant but poor discriminatory accuracy of cardiorespiratory
34 fitness in identifying low/high cardiometabolic risk in girls (AUC = 0.58, 95% CI:
35 0.54–0.63; $p = 0.04$), and in boys (AUC = 0.59, 95% CI: 0.54–0.63; $p = 0.03$). The
36 cardiorespiratory fitness cut-off associated with high cardiometabolic risk was the
37 55th percentile (sensitivity = 33.3%; specificity = 84.5%) in girls and the 60th
38 percentile (sensitivity = 42.9%; specificity = 73.6%) in boys. These 20mSRT
39 percentile thresholds can be used to identify children and adolescents who may
40 benefit from lifestyle intervention. Nonetheless, further work involving different
41 populations and cardiometabolic risk scores comprising of different variables are
42 needed to confirm our initial findings.

43

44 **Key Words:** Cardiorespiratory fitness; Fit; Adolescents; Cardiovascular Disease.

45

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50 or not-for-profit sectors.

51 **Introduction**

52 Cardiorespiratory fitness (CRF) is an important marker of cardiovascular health as it
53 provides a measure of the capacity of both the cardiovascular and respiratory
54 systems as well as an individual's ability to undertake prolonged and exhaustive
55 exercise (Ruiz et al., 2016). In adults, CRF is strongly associated (independent of
56 weight status and physical activity) with all-cause and cardiovascular mortality
57 (Celis-Morales et al., 2017; Katzmarzyk, Church, Janssen, Ross, & Blair, 2005) and
58 its importance for good health is well established (Blair et al., 1989). In youth, low
59 CRF levels are associated with unhealthy cardiometabolic risk profiles, albeit weakly
60 (Ekelund et al., 2007). Genetic factors influence the extent to which CRF can be
61 developed (Bouchard, 2012), but recent findings have also demonstrated the
62 mediating effects that moderate-vigorous physical activity (MVPA) (Carson,
63 Tremblay, Chaput, & Chastin, 2016; Fairclough et al., 2017), total sedentary time
64 (Carson et al., 2016) and specific sedentary patterns (Júdice et al., 2017) has upon
65 measures of physical fitness and indicators of cardiometabolic risk. As such,
66 providing opportunities for youth to increase their MVPA and CRF as well as
67 limiting their sedentary behaviour seems prudent to ensure optimal health.

68

69 Evidence from tracking studies suggests that low CRF in youth is significantly
70 linked to all-cause mortality in adulthood (Högström, Nordström, & Nordström,
71 2016; Sato, Kodama, Sugawara, Saito, & Sone, 2009). Since CRF tracks moderately
72 well from youth to adulthood (Ortega et al., 2012; Twisk, Kemper, & Mechelen,
73 2002), there have been recent calls for the measurement and surveillance of CRF
74 (Ruiz et al., 2016; Tomkinson et al., 2016) to be adopted by clinicians, nurses and

75 Physical Education practitioners who are tasked with identifying individuals at most
76 need of lifestyle intervention.

77

78 Despite CRF being a common component in many youth fitness test batteries
79 (Artero et al., 2012), CRF standards are rarely used by schools, clinicians or nurses
80 to identify individuals with poor health profiles or to provide individualized
81 feedback to students through school reports. One plausible explanation for this is the
82 availability of national and international standards for BMI, a simplistic measure that
83 can be easily and quickly captured by several individuals without the need for
84 specialised training or understanding. Moreover, substantial evidence has found that
85 obesity worsens nearly all of the major cardiometabolic risk factors (Alpert, Omran,
86 Mehra, & Ardhanari, 2014; Bastien, Poirier, Lemieux, & Després, 2014). It is little
87 wonder that monitoring weight status and the introduction of initiatives to manage
88 obesity levels are often at the cornerstone of government strategies.

89

90 To encourage practitioners to include CRF assessments in youth cardiometabolic
91 risk screening assessments, Tomkinson et al. (2016) recently proposed harmonised
92 reference values by creating international normative centiles for the 20 m shuttle run
93 test (20mSRT), generated on more than 1.1 million youth from 50 countries. The
94 20mSRT is a widely used field test of CRF, is able to test multiple individuals
95 simultaneously, and demonstrates strong-to-very strong test-retest reliability and
96 moderate-to-strong validity against gas-analysed peak oxygen uptake ($\dot{V}O_{2peak}$)
97 (Tomkinson & Olds, 2008, 2007). To the best of our knowledge, no study has
98 examined the predictive utility of the age- and sex-specific 20mSRT international
99 normative centiles to identify individuals at increased cardiometabolic risk. Thus, the

100 aim of this study was to examine the predictive ability of the recent 20mSRT
101 international normative centiles to identify youth at increased cardiometabolic risk.

102

103 **Methods**

104 *Participants and settings*

105

106 Data were derived from cross-sectional studies evaluating the health status of
107 Scottish and Welsh youth, with detailed methods described elsewhere (Brophy et al.,
108 2012; Buchan & Baker, 2017). The study sample consisted of a Welsh cohort of
109 Caucasian schoolchildren (n = 463 boys and 640 girls, 12.6±0.7 years of age) who
110 were selectively recruited from 10 secondary schools during the 2009/10 school
111 year. As we were concerned with the influence ethnicity would have upon
112 cardiometabolic risk profiles (Winkleby et al., 1997), 85 non-Caucasian children
113 were removed from the analysis. Despite being significantly younger, no differences
114 in BMI or cardiometabolic risk were found between included and excluded
115 participants. The Scottish cohort of Caucasian schoolchildren (n = 226 boys and 178
116 girls, 13.8±2.9 years of age) were recruited from three secondary schools and one
117 primary school between 2010 and 2014.

118

119 Studies were approved by the University of the West of Scotland (Ref:
120 REAG040909/BUCHAN/53) and by the Local NHS Research Ethics Committee-
121 Dyfed Powys REC (Ref: 07/wmw01/12) in Wales. After excluding those participants
122 who were absent from data collection or who withdrew blood sampling consent or
123 who identified as being non-fasted, 961 youth (10–17 years of age, 53% girls) with
124 complete cardiometabolic risk data were included. We decided to only include

125 participants with complete cardiometabolic risk data to avoid imputation of
126 biological variables and improve the stability of our results.

127

128 *Measures*

129 Stature was measured using a portable stadiometer (Seca Stadiometer, Seca Ltd,
130 Birmingham, UK), body mass was measured without shoes to the nearest 0.1 kg
131 using calibrated electronic weighing scales (Seca 880 and 770, Digital Scales, Seca
132 Ltd, Birmingham, UK), with body mass index (BMI) subsequently derived.
133 Participants were classified as overweight or a normal weight using BMI centiles
134 relative to the age- and gender-specific UK 1990 BMI population reference data
135 (Cole, Freeman, & Preece, 1995). Using the LMSgrowth software provided by the
136 Child Growth Foundation (Pan & Cole, 2010), normal weight was defined as below
137 the 85th centile and overweight at or above the 85th centile. LMSgrowth is a
138 Microsoft Excel add-in designed for use with growth references based on the
139 Lambda Mu Sigma (LMS) method which summarises data in terms of three smooth
140 age-specific curves. The M and S curves correspond to the median and coefficient of
141 variation of the variable of interest at each age whereas the L curve allows for the
142 age dependent skewness in the distribution of the variable (McCarthy, Jarrett, &
143 Crawley, 2001). The age-sex specific UK 1990 BMI LMS parameters provided with
144 the LMS growth software allowed for the creation of exact percentile and z-score
145 values for the subjects measured values.

146 Waist circumference (WC) (cm) was measured in a standing position midway
147 between the lower rib and the anterior superior iliac spine following a normal
148 expiration (Ledoux, Lambert, Reeder, & Després, 1997). WC-z scores were

149 calculated relative to the UK 1988 age- and gender-specific reference data
150 (McCarthy et al., 2001) available within the LMSgrowth software provided by the
151 Child Growth Foundation (Pan & Cole, 2010).

152 Systolic and diastolic blood pressure (BP; mmHg) were measured using Omron
153 M10-IT and Omron M6 automatic BP monitors (Omron Healthcare UK Ltd, Milton
154 Keynes, UK). According to the manufacturers, the M10-IT device is equivalent to
155 the clinically validated M6 device (Topouchian, El Assaad, Orobinskaia, El Feghali,
156 & Asmar, 2006). The average of the second and third measures was used as the
157 criterion value. CRF was measured using the 20mSRT with relative peak oxygen
158 uptake ($\dot{V}O_{2\text{peak}}$, mL/kg/min) subsequently determined using a widely used
159 prediction equation that has been validated on youth of similar age and ethnicity as
160 those in this study:

$$161 \quad \dot{V}O_{2\text{peak}} \text{ (mL/kg/min)} = 31.025 + 3.238 \text{ speed} - 3.248 \text{ age} + 0.1536 \text{ speed} \times \text{age}$$

162 where speed is the running speed of the last completed stage (km/h) and age is age at
163 last birthday (Leger, Mercier, Gadoury, & Lambert, 1988). Thereafter, sex- and age-
164 specific CRF centiles were calculated for each participant using the LMSgrowth
165 software provided by the Child Growth Foundation (Pan & Cole, 2010) using LMS
166 parameters provided by the 4th author (Tomkinson et al., 2016).

167

168 *Metabolic measures*

169 Qualified phlebotomists collected venous blood samples between 8 am and 12 pm
170 following an overnight fast and 30 min seated rest. In Scotland, blood samples were
171 allowed to clot and then centrifuged at 4,000 rpm for 10 minutes. Samples were then
172 analysed within 3 months using the following standard procedures. Triglycerides

173 were measured by enzymatic methods (Randox, Antrim, UK) and a Camspec M107
174 spectrophotometer (Camspec, Leeds, UK). Concentration of high-density lipoprotein
175 cholesterol (HDL-c) was determined after precipitation of very low density and low-
176 density lipoproteins by the addition of phosphotungstic acid in the presence of
177 magnesium ions. Glucose was measured using the glucose oxidase method (Randox,
178 Antrim, UK) and analysed using a Camspec M107 spectrophotometer (Camspec,
179 Leeds, UK).

180 In Wales, blood samples were allowed to clot and then centrifuged at 3,500 rpm for
181 10 min and analysed immediately. Triglycerides and glucose were measured by
182 routine enzymatic techniques using the Vitros 950 System (Ortho-Clinical
183 Diagnostics, Amersham, Bucks). The concentration of HDL-c was determined after
184 precipitation of very low-density and low-density lipoproteins with dextran sulphate
185 and magnesium chloride using the ILAB™ 600 System (Instrumentation Laboratory
186 Company, Lexington, MA, USA). Metabolic measurements were taken on a separate
187 day to all other measurements.

188 *Cardiometabolic risk score*

189 A continuous cardiometabolic risk score was constructed using the following
190 variables: triglycerides, WC, HDL-c, glucose and blood pressure. Triglycerides and
191 HDL-c variables were normalized by the natural logarithm before constructing the
192 cardiometabolic risk score. Each variable was standardized as follows: standardized
193 value = (value – mean)/SD, separately for individual age-sex groups (e.g., 10-year-
194 old boys). The standardized HDL-c value was multiplied by –1 to indicate higher
195 risk with increasing value whereas the standardized values of systolic and diastolic
196 blood pressure were averaged. Standardized scores were subsequently summed to

197 construct a cardiometabolic risk score for each participant with a lower score being
198 indicative of a healthier risk profile. This computed cardiometabolic risk score
199 follows previous recommendations that support the inclusion of key metabolic
200 syndrome components within continuous cardiometabolic risk scores (Eisenmann,
201 2008). Individuals with a cardiometabolic risk score +1 SD above the mean were
202 identified as having increased cardiometabolic risk, similar to previous studies
203 (Ramírez-Vélez et al., 2017; Sardinha et al., 2016).

204

205 *Statistical analysis*

206 Descriptive data are presented as mean (95% confidence intervals (CI)). Data were
207 checked for normality with transformations performed where necessary.

208 Triglycerides and HDL-c data were skewed and subsequently logarithmically
209 transformed. Receiver operating characteristic (ROC) curve analyses were
210 performed to examine the discriminatory ability of CRF percentiles to predict
211 increased cardiometabolic risk quantified by the area under the curve (AUC).

212 Although there were no formal sample size calculations undertaken prior to the
213 collection of data, sample size estimates for studies involving diagnostic tests were
214 undertaken in MedCalc 12.5 (MedCalc software, Mariakerkem Belgium). We used
215 the lower limit of AUC values previously reported for boys and girls (Ruiz et al.,
216 2015), with 80% power, 5% significance and a ratio of sample sizes of low/high
217 cardiometabolic risk groups of 6. For boys, 105 participants (15 high
218 cardiometabolic risk; 90 low cardiometabolic risk) were required and for girls, 497
219 participants (71 high cardiometabolic risk; 426 low cardiometabolic risk) were
220 required. The most sensitive cut-off value for the detection of increased
221 cardiometabolic risk was obtained from the Youden index with greater accuracy

222 reflected in a higher score. ROC AUC values of ≥ 0.90 were considered excellent,
223 0.80–0.89 good, 0.70–0.79 fair, and < 0.70 poor (Metz, 1978). Analyses were
224 conducted for boys and girls separately. The AUCs for boys and girls were produced
225 using MedCalc 12.5 (MedCalc software, Mariakerkem Belgium) whereas all other
226 data were analysed using IBM SPSS Statistics 23 (IBM, Chicago, IL, USA) with $P <$
227 0.05 considered statistically significant.

228 **Results**

229 The descriptive characteristics of the study participants are displayed in Table 1. The
230 prevalence of overweight was 32% in boys and 37% in girls ($p = 0.07$). ROC
231 analysis demonstrated a significant but poor discriminatory accuracy of CRF in
232 identifying low/high cardiometabolic risk in girls (AUC = 0.58, 95%CI: 0.54–0.63; p
233 = 0.04), and in boys (AUC = 0.59, 95%CI: 0.54–0.63; $p = 0.03$) (Figure 1). The CRF
234 cut-off associated with high cardiometabolic risk was the 55th percentile (sensitivity
235 = 33.3; specificity = 84.5) in girls and the 60th percentile (sensitivity = 42.9;
236 specificity = 73.6) in boys. The 60th percentile in boys aged 10–17 years ranged from
237 48.1 to 45 mL/kg/min (Table 2). The 55th percentile in girls aged 10–17 years ranged
238 from 45.6 to 34.7 mL/kg/min (Table 2). By referring to an age and sex-specific
239 reference table (Table 2), practitioners, clinicians and researchers can easily
240 determine whether an individual has met the health-related CRF cut-point by
241 referring to several common metrics.

242 **Discussion**

243 Findings from the ROC analysis demonstrated a significant but poor discriminatory
244 accuracy of CRF for identifying the presence of cardiometabolic risk in youth. Our
245 findings are in agreement with others involving European youth (Mesa et al., 2006;

246 Moreira et al., 2011; Ruiz et al., 2015) although it should be noted that the AUCs
247 from this study were far from excellent and below most of those reported in the
248 previously noted studies. It is possible that the relatively lower AUCs observed in
249 this study are due to a different combination of risk factors used to construct the
250 cardiometabolic risk scores. As noted elsewhere (Lang, Tremblay, Léger, Olds, &
251 Tomkinson, 2016), different combinations of risk factors can yield different results,
252 with individuals potentially classified as apparently healthy using one set of risk
253 factors and unhealthy using another. It is also possible that between-study
254 differences are due to age and sex differences between study cohorts. Further work
255 may wish to consider the discriminatory accuracy of the international normative
256 20mSRT percentile values using multiple cardiometabolic risk profiles to confirm
257 our findings.

258

259 Participants in this study were apparently healthy with no previously diagnosed
260 cardiometabolic disorders which may have contributed to the lower than expected
261 discriminatory ability of the international normative centiles. Since 46% of the
262 participants had a CRF level above the 80th percentile in relation to the international
263 normative 20mSRT centiles, the reported AUCs could have been greater had there
264 been more participants with poorer CRF levels and more variable health risk (e.g.,
265 including individuals diagnosed with cardiometabolic abnormalities) included. In
266 healthy adults, it has been shown that high CRF provides better health protection
267 than low CRF (Katzmarzyk, Church, & Blair, 2004; Lee, Artero, Sui, & Blair, 2010)
268 but in youth, findings suggest that the association between CRF and CMR tends to
269 improve in late adolescence (Ondrak, McMurray, Bangdiwala, & Harrell, 2007).
270 Given the mean age of our cohort, it is also plausible that the reported AUCs may

271 have been higher if a greater number of older adolescents with variable health risk
272 were included.

273

274 From the optimal CRF cut-offs for both boys and girls, we observed relatively high
275 specificity (74% and 85%) but low sensitivity (43% and 33%) respectively. This
276 suggest that 73.6% and 84.5% of participants with low cardiometabolic risk were
277 correctly identified whereas 42.9% and 33.3% of participants with high
278 cardiometabolic risk were correctly identified. The low sensitivity of the CRF
279 thresholds was surprising but is likely reflective of the age of the cohort and there
280 being insufficient time for the younger participants to develop detrimental risk
281 profiles (McMurray, 2013). Moreover, fatness is typically the most significant
282 contributor to cardiometabolic risk in younger children (Jago et al., 2010;
283 McMurray, 2013), and its these factors that likely explain the low sensitivity of these
284 CRF thresholds. Finally, since there is not one measure of efficient standards,
285 thresholds can be selected depending upon the desired result. In this study, the most
286 sensitive cut-off value was determined based on the value that maximized the sum of
287 both the sensitivity and specificity to reduce the likelihood of false negative and false
288 positive misclassifications. If the desire was to ensure high sensitivity then it is likely
289 that different CRF thresholds would have been produced but to the detriment of their
290 specificity.

291

292 Encouragingly, the CRF percentile associated with increased cardiometabolic risk
293 was broadly similar between sexes, falling in the upper end of the range for moderate
294 CRF according to international standards for the 20mSRT (Tomkinson et al., 2016).
295 This is an important finding which suggest that participants with low baseline CRF

296 do not necessarily need to possess high CRF to improve risk profiles. Smaller
297 improvements in CRF can also improve risk profiles which may be perceived as less
298 daunting if participants currently fall below the 40th percentile for CRF according to
299 the international standards for the 20mSRT. Whilst these findings are not surprising,
300 to the best of our knowledge, this is the first study to examine the predictive utility of
301 the recently proposed international normative 20mSRT centiles to identify
302 individuals with increased cardiometabolic risk. This is an important first step in
303 establishing whether these international normative centiles can identify individuals
304 with increased cardiometabolic risk.

305

306 In youth, low CRF levels are known to be associated with increased cardiometabolic
307 risk (Ekelund et al., 2007). Moreover, CRF levels in adolescence are known to track
308 moderately well into adulthood (Ortega et al., 2012). It is important to note that CRF
309 in youth can be improved on average by 8–9% in response to an appropriate 12-
310 week training programme independent of sex, age and maturation (Armstrong &
311 Barker, 2011). Improvements in CRF can also be achieved with shorter training
312 programmes (Buchan et al., 2011; Lambrick, Westrupp, Kaufmann, Stoner, &
313 Faulkner, 2016). This 8-9% improvement in CRF can be approximated to an
314 increase of 20 centile points when using the recently proposed international
315 normative 20mSRT centiles (Tomkinson et al., 2016) and could be used as an
316 incentive for those wishing to improve their CRF. Nonetheless, the benefits of
317 undertaking such training programmes should not encourage participants to become
318 more sedentary given the emerging evidence and recommendations to reduce and
319 break-up sedentary-time to enhance physical fitness (Júdice et al., 2017; Marques,
320 Santos, Ekelund, & Sardinha, 2015). Particularly since the magnitude of

321 improvement is likely to be greater in those that are sedentary with low baseline
322 CRF (Armstrong & Barker, 2011).
323
324 Schools are often cited as a setting to encourage children to become more physically
325 active and improve CRF (Ruiz et al., 2016), yet schools rarely assess CRF for the
326 purposes of health promotion or disease prevention. One plausible reason for this
327 could be the confusion surrounding the different approaches one can take to interpret
328 20mSRT performance which is a widely used measure of CRF in schools across the
329 world (Lang et al., 2016; Tomkinson & Olds, 2008, 2007). For instance, the
330 availability of least 10 available CRF criterion-referenced standards currently
331 available for children and youth for practitioners to use (Lang, Tremblay, Ortega,
332 Ruiz, & Tomkinson, 2017), all of which have been developed against different
333 criterion health-related measures in different youth populations, creates confusion.
334 Recently it has been proposed that CRF levels below 35 and 42 mL/kg/min for girls
335 and boys respectively could be used in the interim to identify children and youth at
336 risk of poor cardiovascular health (Ruiz et al., 2016). Moreover, the availability of an
337 age- and sex-specific table provided by Ruiz et al. (2016) allows practitioners to
338 easily determine whether youth achieve these health-related fitness standards.
339 Nonetheless, there are several concerns related to these proposed thresholds that
340 need to be considered.

341

342 Firstly, in their meta-analysis (Ruiz et al., 2016) the authors combine seven
343 published criterion-referenced standards to determine that fitness levels below 35
344 and 42 mL/kg/min for boys and girls should raise a red flag. Yet these criterion-
345 referenced standards were generated using varied methodologies comprising of

346 different combinations of submaximal-effort or maximal-effort, different exercise
347 modes, different $\dot{V}O_{2\text{peak}}$ prediction equations as well as field based or laboratory-
348 based assessment protocols. Since the use of prediction equations to estimate $\dot{V}O_{2\text{peak}}$
349 may elicit some degree of error (Moreira et al., 2011), each method used may
350 produce different results. Furthermore, evidence has shown that treadmill protocols
351 can elicit a $\dot{V}O_{2\text{peak}}$ as much as 9% higher than that observed if using cycle ergometer
352 protocols (Armstrong & Davies, 1981). Moreover, the use of age independent
353 thresholds proposed by Ruiz and colleagues, given the known changes in relative
354 $\dot{V}O_{2\text{max}}$ with age, particularly in girls (Armstrong & Welsman, 1994), may limit the
355 ability of these thresholds to correctly identify individuals at most risk.

356

357 When comparing our proposed age-and sex-specific thresholds (Table 2) to that of
358 Ruiz et al., (Ruiz et al., 2016), they fail to identify individuals (regardless of age or
359 sex) as presenting with increased cardiometabolic risk. The disparity in thresholds is
360 particularly evident for girls. For instance, during mid-adolescence (15 years) the
361 CRF threshold is reduced by ~17% compared to only ~5% for boys. This is further
362 exemplified when you examine the total reduction in thresholds from 10–17 years
363 which shows a reduction of ~24% for girls and ~7% for boys. Thus, failing to
364 account for changes in relative CRF with age, particularly in girls (Armstrong &
365 Welsman, 1994), may lead to incorrectly identifying youth with increased
366 cardiometabolic risk. Given the stigma of being incorrectly identified as
367 demonstrating unfavourable cardiometabolic risk profiles and the demands upon
368 limited resources this may have, it appears prudent in this cohort that a higher but
369 more specific CRF threshold is used.

370

371 To assist practitioners with identifying individuals with low CRF and in most need
372 of lifestyle intervention, we have devised a simple to use age-and sex-specific
373 reference table (Table 2) which provides age-and sex-specific CRF thresholds in
374 addition to the common metrics of speed (km/h), number of completed stages and
375 number of completed laps. As many practitioners will have little time to convert
376 20mSRT performance into relative $\dot{V}O_{2peak}$ values, we hope that the reference table
377 may be used to provide instantaneous feedback to individuals without the need for
378 complex and time consuming mathematical computations. Thereafter, CRF values
379 higher than the age- and sex- specific metric threshold can result in a green flag and
380 described as healthy given the relatively high specificity values noted in this study.
381 Nonetheless, CRF values below the metric threshold would not necessarily indicate
382 increased cardiometabolic risk owing to the low sensitivity of the proposed
383 thresholds.

384

385 This study is not without limitations. The cross-sectional design does not allow us to
386 confer causality whilst the lack of objectively measured physical activity, sedentary
387 behaviour and dietary habits, which are well-established confounders of several
388 indicators measured, are acknowledged. We also acknowledge the limitations of
389 using the z-score approach to calculate cardiometabolic risk. Whilst common within
390 paediatric research, the z-score approach is based on the premise that each input
391 variable is equally important in defining cardiometabolic risk, which may not be the
392 case. Despite our large study sample, we recruited from two locations within the UK
393 which limits the generalisability of our study findings. Moreover, over 46% of the
394 sample had a CRF level above the 80th percentile in relation to the international
395 normative 20mSRT centiles suggesting that participants were healthy and of good

396 CRF. It is likely that the reported AUCs noted in this study would have been greater
397 had there been more participants with poorer CRF and risk profiles included. Finally,
398 we did not consider psychosocial health outcomes when examining the predictive
399 utility of the international normative 20mSRT percentile values in this study. A
400 strength of this study was the use of a health-related, valid, and reliable field test to
401 examine the use of recently published international normative 20mSRT centiles to
402 establish their utility for identifying UK youth at increased cardiometabolic risk.

403

404 **Conclusion**

405 We propose optimal international normative 20mSRT percentile values that may
406 distinguish UK youth with increased cardiometabolic risk. As this is the first study to
407 investigate the utility of the international normative centiles, further work involving
408 different populations with various constructed cardiometabolic risk scores are
409 needed to confirm our findings. Moreover, further work should also consider
410 capturing other measures of health and well-being such as cognition, academic
411 achievement, behaviour as well as psychological health and quality of life. Finally,
412 our reference table (Table 2) allows practitioners to provide instantaneous feedback
413 to individuals in relation to their current CRF levels by expressing the age-and sex-
414 specific CRF thresholds into several age-and sex-specific 20mSRT metrics. In doing
415 so, we anticipate that this will negate the need for practitioners to undertake time
416 consuming mathematical computations.

417

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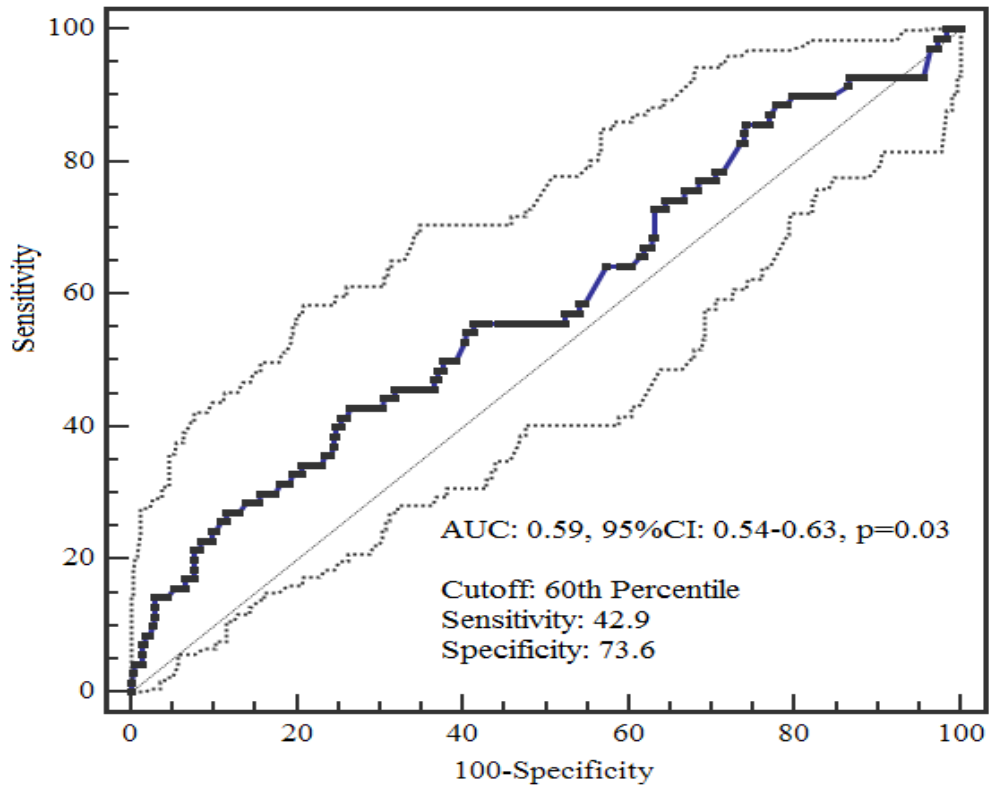
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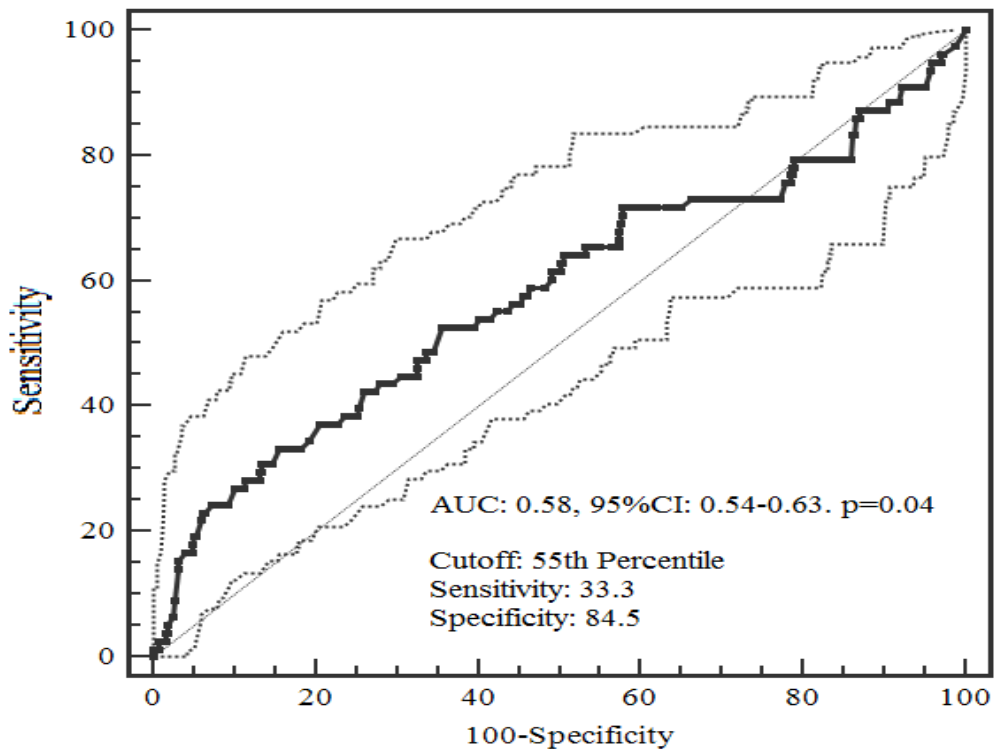
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616 Boys



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618 Girls

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621 Figure 1. Receiver operating characteristic curve summarising the utility of CRF to

622 identify low/high cardiometabolic risk scores in boys and girls. AUC indicates the

623 area under the curve (95%CI). Note: Bold line represents the AUC; dashed lines

624 represent the 95%CI.

625

626 Table 1. Descriptive characteristics of study participants with complete CRF and
 627 cardiometabolic risk data.
 628

| <u>Variable</u> | <u>Boys</u> n = 452 (47%) | <u>Girls</u> n = 509 (53%) |
|-----------------------------------|-------------------------------------|--------------------------------------|
| Age (years) | 13.2 ± 2.1 | 13.0 ± 1.8 |
| Height (cm) | 157.9 ± 13.0 | 155.1 ± 10.0 |
| Mass (kg) | 50.7 ± 14.1 | 50.4 ± 12.6 |
| WC-z | -0.03 ± 0.9 | -0.04 ± 0.9 |
| Systolic BP (mmHg) | 117 ± 14 | 115 ± 12 |
| Diastolic BP (mmHg) | 66 ± 11 | 66 ± 10 |
| Glucose (mmol/L) | 5.0 ± 0.7 | 4.9 ± 0.7 |
| Triglycerides (mmol/L) | 0.8 ± 0.4 | 0.8 ± 0.5 |
| HDL-c (mmol/L) | 1.6 ± 0.5 | 1.6 ± 0.6 |
| CRF (mL/kg/min) | 50.2 ± 5.6 | 45.1 ± 5.9 |
| Cardiometabolic risk z-score | -0.08 ± 2.9 | -0.05 ± 2.8 |
| High/Low cardiometabolic risk (n) | 70/382 | 78/431 |

629 Values presented as mean ± SD unless otherwise stated. WC = waist circumference;
 630 BP = blood pressure; HDL-c = high-density lipoprotein cholesterol; CRF =
 631 cardiorespiratory fitness.
 632

633

Table 2. Age- and sex-specific thresholds for healthy CRF for predicted $\dot{V}O_{2\text{peak}}$ (mL/kg/min) and three common 20mSRT metrics.

| Age (years) | Boys | | | | Girls | | | |
|----------------|--|--|--|--------------------------------|--|--|--|--------------------------------|
| | $\dot{V}O_{2\text{peak}}$ (mL/kg/min) | Speed (km/h) at last completed stage | Number of completed stage/minute | Number of laps completed | $\dot{V}O_{2\text{peak}}$ (mL/kg/min) | Speed (km/h) at last completed stage | Number of completed stage/minute | Number of laps completed |
| 10 | 48.1 | 10.38 | 4.76 | 38 | 45.6 | 9.86 | 3.72 | 29 |
| 11 | 47.3 | 10.55 | 5.10 | 41 | 44.1 | 9.90 | 3.80 | 29 |
| 12 | 46.8 | 10.78 | 5.56 | 45 | 42.6 | 9.95 | 3.90 | 30 |
| 13 | 46.4 | 11.00 | 6.00 | 49 | 41.0 | 9.97 | 3.94 | 31 |
| 14 | 46.0 | 11.22 | 6.44 | 53 | 39.5 | 10.01 | 4.02 | 31 |
| 15 | 45.7 | 11.44 | 6.88 | 58 | 37.9 | 10.03 | 4.06 | 32 |
| 16 | 45.4 | 11.65 | 7.30 | 62 | 36.4 | 10.07 | 4.14 | 32 |
| 17 | 45.0 | 11.83 | 7.66 | 66 | 34.7 | 10.07 | 4.14 | 32 |