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ROC Generated Thresholds for Field-Assessed Aerobic Fitness Related to Body Size and Cardiometabolic Risk in Schoolchildren

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Abstract

Objectives: 1. to investigate whether 20 m multi-stage shuttle run performance (20mSRT), an indirect measure of aerobic fitness, could discriminate between healthy and overweight status in 9–10.9 yr old schoolchildren using Receiver Operating Characteristic (ROC) analysis; 2. Investigate if cardiometabolic risk differed by aerobic fitness group by applying the ROC cut point to a second, cross-sectional cohort.

Design: Analysis of cross-sectional data.

Participants: 16,619 9–10.9 year old participants from SportsLinx project and 300 11–13.9 year old participants from the Welsh Schools Health and Fitness Study.

Outcome Measures: SportsLinx; 20mSRT, body mass index (BMI), waist circumference, subscapular and superilliac skinfold thicknesses. Welsh Schools Health and Fitness Study; 20mSRT performance, waist circumference, and clustered cardiometabolic risk.

Analyses: Three ROC curve analyses were completed, each using 20mSRT performance with ROC curve 1 related to BMI, curve 2 was related to waist circumference and 3 was related to skinfolds (estimated % body fat). These were repeated for both girls and boys. The mean of the three aerobic fitness thresholds was retained for analysis. The thresholds were subsequently applied to clustered cardiometabolic risk data from the Welsh Schools study to assess whether risk differed by aerobic fitness group.

Results: The diagnostic accuracy of the ROC generated thresholds was higher than would be expected by chance (all models AUC >0.7). The mean thresholds were 33 and 25 shuttles for boys and girls respectively. Participants classified as ‘fit’ had significantly lower cardiometabolic risk scores in comparison to those classed as unfit (p<0.001).

Conclusion: The use of the ROC generated cut points by health professionals, teachers and coaches may provide the opportunity to apply population level ‘risk identification and stratification’ processes and plan for “at-risk” children to be referred onto intervention services.

Introduction

The combination of excessive adiposity and poor aerobic fitness confers significant disease risk to youth [1]. The 2009 UK Chief Medical Officer’s report highlighted the importance of aerobic fitness as a health marker [2], and a growing body of literature describes aerobic fitness as a key, independent determinant of health [3]. Poor aerobic fitness and excessive adiposity are associated with similar health complications, in particular cardiometabolic disease [4]. Evidence suggests that fitness is associated with total and abdominal obesity, as well as cardiome-
Aerobic Fitness Thresholds in Children

Table 1. Descriptive characteristics for the SportsLinx Cohort.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Boys</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.8</td>
<td>0.4</td>
<td>9.8</td>
<td>0.4</td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
<td>18.2</td>
<td>3.3</td>
<td>18.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Waist Circumference (cm)</td>
<td>62.3</td>
<td>9.8</td>
<td>62.1</td>
<td>10.2</td>
</tr>
<tr>
<td>Triceps Skinfold (mm)</td>
<td>14.1</td>
<td>6.0</td>
<td>16.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Subscapular Skinfold (mm)</td>
<td>8.9</td>
<td>6.1</td>
<td>11.1</td>
<td>6.9</td>
</tr>
<tr>
<td>20mSRT performance (shuttles)</td>
<td>39.8</td>
<td>19.4</td>
<td>27.6</td>
<td>13.5</td>
</tr>
</tbody>
</table>

doi:10.1371/journal.pone.0045755.t001
array of cardiometabolic disturbances rather than focusing on one or two particular markers.

The following variables violated the assumptions of normality and were log-transformed prior to standardisation, then back transformed for presentation purposes: girls; waist circumference, systolic blood pressure (BP), total cholesterol to high density lipoprotein cholesterol (HDL-C) ratio (TC:HDL-C), glucose, insulin, adiponectin, C-reactive protein (CRP). Boys; waist circumference, systolic BP, diastolic BP, TC:HDL-C, glucose, insulin, CRP, adiponectin.

Two scores were calculated, including the following variables: Score 1. Waist circumference, systolic and diastolic BP, TC:HDL-C, insulin, glucose, adiponectin (inverted), CRP. Score 2. Waist circumference, systolic and diastolic BP, TC:HDL-C, insulin, glucose. The second score omitted CRP and adiponectin to maximise participant numbers. Selection of risk variables was based on the components of the International Diabetes Federation definition for metabolic syndrome [19], and CRP and adiponectin were included as both are potent markers of CVD risk [18].

Ethics Statement
The SportsLinx study (NRES Committee North West, Liverpool East) and the Welsh Schools Health and Fitness Study (Dyfed Powys Research Ethics Committee) have full ethical approvals from the respective Local NHS Research Ethics Committees. Informed, written parental consent and participant assent was obtained prior to participation for all children involved in the studies.

Statistical Analysis
Area under the curve (AUC) statistics and 95% confidence intervals were recorded for the ROC curve analyses. The CRF threshold or cut point for each model was defined as the coordinate that had the closest value to 1 for the difference between the true positive (sensitivity) and false-positive (1-specificity) values. The mean of the three generated CRF thresholds/cut points (number of completed shuttles) was calculated by sex and retained for further analysis. Participants from the Welsh Schools Health and Fitness Study were then classed as fit or unfit using the generated sex-specific cut points and analysis of covariance (age and sex as covariates) was completed to assess any differences in risk by fitness status for the whole group, and separately by sex (age as covariate). All analyses were conducted using SPSS V. 17 (SPSS Inc. Chicago, IL), and an alpha value of p≤0.05 was used to denote statistical significance.

Results
1. ROC Curve Analyses
The descriptive characteristics for the SportsLinx participants are displayed in Table 1. According to age and sex specific BMI cut points, 30.6% and 25.2% of girls and boys were classified as overweight. In terms of ethnicity, 85.8% of the cumulative SportsLinx sample were classified as White British.

The AUC, 95% confidence intervals and identified cut points (co-ordinate closest to 1), plus sensitivity and 1-specificity values are displayed in Tables 2 and 3 for the three ROC curve analyses by sex.

Figures 1 and 2 display the model one ROC curves for boys and girls, respectively. The diagnostic accuracy of the cut points for
identifying children at risk of overweight by all measures was higher than what would be expected by chance (for all models AUC >0.7).

The highest AUC values were observed for the per cent body fat models. Identified cut points were similar across the three models for boys and girls, and the mean cut point was 33 shuttles (mean of the three cut points = 33.2 shuttles) for boys and 25 shuttles for girls (mean of the three cut points = 24.8 shuttles).

### 2. Applying CRF Thresholds to Cardiometabolic Risk Data

Table 4 displays the descriptive characteristics of the Welsh cohort. For the whole cohort the prevalence of overweight was 31.2% for girls and 26.7% for boys. For the Welsh cohort, 87.2% of participants were classified as White British.

Clustered risk scores by fitness status and sex are displayed in Table 5. For both clustered risk scores, at the group level and separately by sex, those classified as fit had lower risk scores in comparison to those classified as unfit using the ROC generated cut points (p<0.001).

### Discussion

The aims of this study were to: 1. investigate whether 20mSRT performance could discriminate between healthy and overweight status in 9–10.9 yr old school children using ROC analysis, 2. investigate if cardiometabolic risk differed by the aerobic fitness threshold group by applying the ROC generated cut point to a second, cross-sectional cohort.

The generated ROC curves displayed acceptable AUC and 95% confidence interval limits, suggesting the resultant thresholds were not due to chance (all AUC >0.7) and effectively distinguished between overweight and normal weight participants on the basis of 20mSRT performance. The thresholds generated using three estimates of body size/fatness were similar, and the mean value from the analyses provides a simple aerobic threshold in boys and girls for practitioners to use in the field. The values proposed in the present study (<33 shuttles for boys [estimated VO2peak: 46.6 mL/kg/min] and <25 shuttles [estimated VO2peak: 41.9 mL/kg/min] for girls) are higher than those suggested by Ruiz et al [8] (42.1 mL/kg/min for boys and 37.0 mL/kg/min for girls) and Adegoboye et al (43.6 mL/kg/min for boys and 37.4 mL/kg/min for girls) [9]. In the present study VO2peak was estimated indirectly through 20mSRT performance rather than by direct assessment, and these differences in VO2 thresholds may reflect the alternative data collection processes (e.g. online gas analysis systems, cycle ergometer vs running assessments) utilised, and the body size measures used to determine the thresholds.

When applied to the Welsh Schools Health and Fitness Study cohort, participants classified as ‘low aerobically fit’, displayed significantly higher clustered cardiometabolic risk scores, than those who reached the aerobic fitness threshold. Other studies have described increased cardiometabolic risk in less aerobically fit individuals [20], [21]; however, these results are not from field-based assessments of aerobic fitness. The findings presented in this study describe thresholds that are supported by clinical markers, which when applied to a separate, differently aged cohort from the population that the ROC curves were originally generated from, showed differences in cardiometabolic risk between those reaching the thresholds and those who did not. The thresholds and the association between these ‘cut points’ and cardiometabolic risk provide a clear insight into the links between aerobic fitness and disease risk, and highlight the need for public health interventions to promote aerobic fitness. Such interventions may involve promoting vigorous physical activity to stimulate aerobic fitness [3,7], which has been alluded to in the most recent UK CMO guidelines for physical activity [22]. These thresholds are the first to be based on the widely used 20mSRT assessment, and provide a highly useful method of classifying aerobic fitness/risk in children.

There are some limitations to this study. Despite the large SportsLinx sample size, the age range included within analyses is narrow (9–10 years old), and therefore the application of the thresholds to a wider age range requires further investigation. However, when thresholds were applied to the Welsh Schools Health and Fitness Study cohort, who were slightly older children (11–14 years old), significant differences in clustered cardiometabolic risk scores were apparent, suggesting that there is value in applying the thresholds in the absence of cut points calculated

![Figure 2. ROC curve for model one, Girls (BMI and 20mSRT). doi:10.1371/journal.pone.0045755.g002](Image 58x482 to 296x730)

Table 4. Descriptive characteristics for the Welsh Schools Health and Fitness Study Cohort.

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>12.6 (0.8)</td>
<td>12.6 (0.7)</td>
</tr>
<tr>
<td>Stature (m)</td>
<td>1.6 (0.1)</td>
<td>1.5 (0.1)</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>49.0 (13.0)</td>
<td>50.0 (11.6)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>20.1 (3.8)</td>
<td>20.9 (3.9)</td>
</tr>
<tr>
<td>Waist Circumference (cm)</td>
<td>68.9 (9.8)</td>
<td>68.7 (10.0)</td>
</tr>
<tr>
<td>20 m SRT Score (shuttles)</td>
<td>53.5 (22.2)</td>
<td>37.2 (15.9)</td>
</tr>
<tr>
<td>Systolic Blood Pressure (mmHg)</td>
<td>115.6 (12.7)</td>
<td>114.6 (12.8)</td>
</tr>
<tr>
<td>Diastolic Blood Pressure (mmHg)</td>
<td>66.2 (11.5)</td>
<td>66.8 (11.1)</td>
</tr>
<tr>
<td>Total Cholesterol : HDL</td>
<td>2.7 (0.7)</td>
<td>2.8 (0.9)</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>4.9 (0.4)</td>
<td>4.9 (0.4)</td>
</tr>
<tr>
<td>Insulin (mmol/L)</td>
<td>8.8 (8.1)</td>
<td>11.0 (7.4)</td>
</tr>
<tr>
<td>Adiponectin</td>
<td>3354.2 (2040.5)</td>
<td>4275.1 (2495.3)</td>
</tr>
<tr>
<td>C-Reactive Protein</td>
<td>1.1 (2.8)</td>
<td>0.9 (1.7)</td>
</tr>
</tbody>
</table>

| doi:10.1371/journal.pone.0045755.t004 |
may ensure that children can be referred onto intervention services effectively using a simple, low cost aerobic fitness assessment in the field.

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Author Contributions

Conceived and designed the experiments: LMB NET JSB GS. Performed the experiments: AR GK NET. Analyzed the data: LMB SB. Wrote the paper: LMB NET SJF KT GS.

Table 5. Mean risk scores (SE) by fitness status and sex.

<table>
<thead>
<tr>
<th></th>
<th>Fit</th>
<th>Unfit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group</td>
<td>Boys</td>
</tr>
<tr>
<td>Clustered Risk Score 1</td>
<td>N=220</td>
<td>-1.13 (.26)*</td>
</tr>
<tr>
<td>Clustered Risk Score 2</td>
<td>N=300</td>
<td>-0.76 (19)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N=125</td>
</tr>
</tbody>
</table>

*Fit < unfit, p<0.001.
doi:10.1371/journal.pone.0045755.t005

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22. Department of Health (2011) Start Active, Stay Active: A report on physical activity for health from the four home countries’ Chief Medical Officers.