Does the Twenty Meter Shuttle-Run Test Elicit Maximal Effort in 11- to 16-Year-Olds?

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The aim of this study was to determine if maximal effort, evidenced by peak HR was attained during the 20m shuttle-run test in a naturalistic setting. Shuttle-run test performance and peak HR were measured in 208 volunteers (11–16 years). Peak HR was 196 (95% confidence interval (C.I.) 194–198 bpm). The relationship between test performance and peak HR was assessed by regression. There was a weak, but statistically significant relationship between test performance and peak HR ($R^2 = .029$, $p = .029$) but with such a low coefficient of determination (less than 5% criterion), poor performances were not associated with low peak HR values or underestimation of maximal performance. Peak HR values (196 bpm) were higher than cited criterion values (185 bpm) for maximal effort in laboratory studies. In a naturalistic setting, the 20m shuttle-run test elicits a maximal effort in most children.

The valid prediction of maximum oxygen uptake from the twenty meter shuttle-run test (20mSRT) relies on the production of a maximal effort by the participant (8). There are concerns that the 20mSRT may underestimate participants’ true maximal capacities (6,17). In children, motivational issues may negatively influence aerobic test performance (8,10). Validation studies of the original 20mSRT in children used the attainment of peak heart rate (HR) in the laboratory setting as one of the criteria for a maximal effort (11). Several groups (3,9,10) have validated maximal oxygen uptake prediction from the revised 20mSRT but only one group (10) has attempted to ascertain the achievement of peak HR during the test.

McVeigh et al. (10) used 95% of age-related (220-age) heart rate as a criterion measure to evaluate peak HR achievement and found that 94% of 13- to 14-year-old children achieved this value. The authors also found that some children achieved higher peak HR during poorer 20mSRT performances (compared with repeat tests) but provided no quantitative analysis of these findings.

Peak HR during exercise varies in children depending on the test type and the environment (2). Typical reported values range from 195 to 210 bpm, are independent of age (19) and level of fitness (15). A lower limit of 185 bpm has been used as a criterion for achievement of a maximal effort in the laboratory (1,7,13). The

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aim of the current study was to test the following hypotheses. First, that a maximal effort, evidenced by peak HR, is attained at the end of the 20mSRT by schoolchildren of different sexes, ages, and weight categories. Second, that effort, as indicated by a higher peak HR, is not associated with better 20mSRT performance. The latter hypothesis is based on quantitatively analyzing the relationship between HR and performance discussed qualitatively by McVeigh et al. (10). To accept the hypotheses we put forward two criteria that the present data should fulfill. To support the first hypothesis, peak HR would have a lower 95% confidence interval (95%C.I.) > 185 bpm at the end of the 20mSRT. To support the second hypothesis, that regression analysis would demonstrate peak HR was not importantly associated with performance; as shown by a low coefficient of determination (< 5% criterion).

Materials and Methods

Participants

After gaining parental consent, 208 volunteers age 11–16 years (104 boys and 104 girls) were selected as an opportunity sample designed to be representative in sex, age, and weight category of a larger cohort in an ongoing study (East of England Healthy Hearts Study). Measurements were taken during regularly scheduled physical education classes in summer 2007. The study was approved by the university ethics committee.

Protocol

Anthropometry. Stature was measured and recorded to the nearest millimeter. Mass was recorded to the nearest 0.1 kg. Children were dressed in gym clothing without shoes. Body Mass Index (BMI) was calculated (kg · m⁻²) and translated into age- and sex-specific z-scores (5) and classified according to the International Obesity Task Force (IOTF) criteria (4).

Twenty Meter Shuttle-Run Test Performance and Creation of Age- and Sex-Specific Z-Scores. The 20mSRT was performed as the FITNESSGRAM PACER (12), a modified version of the original protocol (8). Volunteers ran 20m shuttles in time to an audible signal at an initial speed of 8.5 km · h⁻¹ increasing by 0.5 km · h⁻¹ each minute. All testing was carried out by researchers accompanied by school physical education staff on the school’s outdoor, tarmac-surfaced hard court area. Testing was carried out in groups of up to 30 with a ratio of five participants to one researcher. Participants were not practiced in the 20mSRT for the purpose of this study, but all had participated in the test before as part of their physical education. The recorded instructions on the PACER CD informed participants to “run for as long as possible” and this was reiterated by a researcher at the beginning of each test. Researchers acted as “spotters” during the test and recorded the participants’ final shuttle count at either the point of volitional exhaustion, or when they failed to maintain the given pace for the second time. The number of completed shuttles was then converted to running speed in km · h⁻¹ at the final completed stage (16). To allow for direct comparison in aerobic capac-
ity between participants of different sexes and ages within our sample, sex- and age-specific z-scores were created: Each individual’s score was ranked relative to the global mean and standard deviation for children of that age and sex, which were obtained from Olds and colleagues (14). A positive z-score is indicative of a higher test score compared with the mean score for children of the same sex and age, a z-score of zero equals the mean score, and a negative z-score indicates a poorer than average score. The formula to calculate a z-score is:

\[ z = \frac{x - m}{sd} \]  

(1)

Where \( x \) = individual score achieved; \( m \) = age- and sex-specific mean from reference data (14); \( sd \) = standard deviation of the age- and sex-specific mean (14).

For example, an 11-year-old girl obtained a final running speed of 12 km · h\(^{-1}\), her z-score is calculated as follows:

\[ z = \frac{12 - 10.135}{1.001} = 1.84 \]  

(2)

As another example, a 16-year-old boy also obtained a final running speed 12 km · h\(^{-1}\), his z-score is calculated as follows:

\[ z = \frac{12 - 12.122}{1.462} = -0.08 \]  

(3)

Even though the two participants’ actual running performance was identical, their age- and sex-specific z-scores differ widely (Equation 2 and 3). The use of z-scores for data analysis allows for comparison of participants’ performance relative to their expected physiological capabilities.

Heart Rate Monitoring. Participants wore heart rate monitors (Polar S610, Polar Electro Ltd.) throughout the 20mSRT. Peak HR was recorded as the highest HR achieved within 5 s of test termination (being unable to maintain pace or at voli-tional termination).

Data Analyses

Statistical analyses were performed using SPSS 14.0 for Windows. One-Sample Kolmogorov-Smirnov Test confirmed normal distributions. Means and 95% C.I. were created for all variables and the relationship between 20mSRT performance (z-scores) and peak HR was examined using linear regression analysis. An alpha value of \( p < .05 \) was assumed to show statistical significance.

Results

Descriptive characteristics for all volunteers are shown in Table 1. IOTF classification showed that 4% of children were underweight, 73% were of normal weight, 20% were overweight and 3% obese. Volunteers achieved a mean 20mSRT z-score
of 0.427 (95% C.I. 0.317–0.537). Peak HR attained was 196 (95% C.I. 194–198 bpm; Table 1). Regression analysis showed a weak, positive relationship between peak HR and 20mSRT $z$-score ($R^2 = .029, p = .029$). Peak HR accounted for 2.9% of the variance in 20mSRT performance. The equation yielded a mean Y-intercept value of 195 bpm (95% C.I 188–201 bpm; Figure 1).

**Discussion**

**Group Characteristics**

The aim of this study was to quantitatively evaluate the physiological effort that volunteers put in during the 20mSRT test of aerobic capacity. To make an externally valid estimate of this, a diverse opportunity sample of schoolchildren were selected from a larger cohort. The present data represented a large sample of healthy high school students with a wide range of aerobic capacity test scores (20mSRT range: 8th—99th percentile), and adiposity (BMI range: 0.1st—99th percentile). There was a tendency (mean $z = 0.51; 95\% \text{ C.I.} 0.36–0.66$) for the volunteers to have higher than age- and sex-predicted BMI values. Participants from all four IOTF weight classifications were represented (Table 1). The rate of underweight and overweight was broadly similar to those reported in English schoolchildren but obese volunteers were slightly underrepresented (18). There was a wide range of 20mSRT $z$-scores. The mean value ($z = 0.43, 95\% \text{C.I.} 0.32–0.54$) showed some bias toward better than age- and sex-predicted aerobic test performance. Despite such shortcomings, this sample is larger, more representative, and the test conditions more naturalistic than in previous studies of this type.

**Table 1 Descriptive Statistics (Mean ($\pm$ SD), 95% C.I., and Range)**

For Schoolchildren Age 11–16

<table>
<thead>
<tr>
<th></th>
<th>Mean ($\pm$ SD)</th>
<th>95% Confidence Intervals</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n = 208$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>12.7 (1.8)</td>
<td>11.9–14.7</td>
<td>11–16</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>51.8 (12.7)</td>
<td>49.1–52.2</td>
<td>24.8–93.0</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>157.5 (12.3)</td>
<td>156.0–159.0</td>
<td>133.5–195.0</td>
</tr>
<tr>
<td>BMI (kg·m$^{-2}$)</td>
<td>20.1 (3.1)</td>
<td>19.7–20.6</td>
<td>13.4–30.5</td>
</tr>
<tr>
<td>BMI $z$-score</td>
<td>0.51 (1.1)</td>
<td>0.36–0.66</td>
<td>−3.9–3.0</td>
</tr>
<tr>
<td>20mSRT score (km·h$^{-1}$)</td>
<td>11.2 (1.1)</td>
<td>11.1–11.4</td>
<td>9.0–14.0</td>
</tr>
<tr>
<td>20mSRT $z$-score</td>
<td>0.43 (0.8)</td>
<td>0.32–0.54</td>
<td>−1.41–3.42</td>
</tr>
<tr>
<td>Peak HR (bpm)</td>
<td>196 (12.2)</td>
<td>194–198</td>
<td>158–219</td>
</tr>
</tbody>
</table>

*Note.* BMI = Body Mass Index (kg·m$^{-2}$); BMI $z$-score = based on the UK90 reference data (11); 20mSRT = twenty meter shuttle-run test; 20mSRT $z$-scores are based on international reference data of Olds et al. (14).
Achievement of Maximal Effort

The valid assessment of aerobic capacity relies on the attainment of a maximal effort at the end of the 20mSRT (8). In children, motivational issues may negatively influence aerobic test performance (8,10). There are concerns that the 20mSRT may underestimate participants’ true maximal capacities. Alternative protocols such as using ramped shuttle increments (17) or more continuous, square-shaped incremental field tests (6) elicit slightly (~0.5 km \cdot h^{-1}) higher maximal running velocities in adults. Attainment of peak HR is one of numerous criteria used for attainment of maximal effort in exercise testing. The present data suggest that, in children of the age studied here, a maximal test performance is reached in >95\% of the population according to HR response. In the current study, peak HR data were analyzed as a continuous variable as opposed to as a categorical variable as has been done previously (10). The average peak HR achieved in the current study was 196 (95\% C.I. 194–198) bpm; within the range

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Figure 1 — The relationship between 20mSRT performance and peak HR in 208 schoolchildren age 11–16 years.

20mSRT - Twenty meter shuttle-run test
20mSRT z-scores are based on international reference data of Olds et al. (14).
of typical values reported 195–210 bpm (19). In validating the 20mSRT against a maximal progressive treadmill test, Liu et al. (9) recorded a mean peak HR of 195 bpm (in 12- to 15-year-olds) in the laboratory. The present study used a non-age-related criterion HR (185 bpm) taken from the literature (1,7,13). This is superior to the 220-age criterion used previously (10), which is only recommended for use in participants over 18 years. The lower 95% C.I. for peak HR in the current study was well in excess of the 185 bpm value seen in the literature and these data fulfill our first criterion and therefore, support our first hypothesis.

The Relationship Between Peak HR and 20mSRT Performance

The present sample comprised children with heterogeneous levels of 20mSRT performance (Table 1) and we wanted to know if those who did less well on the test did so due to lesser effort as would be evidenced by lower peak HR. No effort to quantify this relationship has been made previously in the literature.

There was a positive relationship between peak HR and 20mSRT performance (Figure 1), but the variance in performance associated with differences in peak HR was small (2.9%). The Y-intercept for HR was 195 (95% C.I. 188–201) bpm. The lower bound 95% C.I. was above the reference value of 185 bpm used to denote achievement of peak HR. It seems that effort accounts for very little of the shared variance with test performance in this group. From our findings we can predict that most children and adolescents, including those who attain low scores, are still expected to reach a peak HR >185 bpm in the 20mSRT. The shared variance was well below our 5% criterion. These data fulfill our second criterion and therefore, support our hypothesis.

Limitations

The major limitation in the current study arises from the opportunity sampling of participants. Efforts were made to choose participants who were representative of the larger sample from which they were drawn, but some positive selection bias may have occurred. Despite obtaining a sample with a full and representative range of BMI values, children with higher than expected age- and sex-predicted aerobic capacity have been tested. This is undoubtedly due to the voluntary nature of the study itself. A second limitation is that some volunteers achieved low HRs (as low as 158 bpm). Figure 1 also shows two potential outliers (bottom right quadrant) with low HR values but very high relative aerobic test performance. Both cases were female and these low HR scores could be the product of social pressure felt by girls to not out-perform their peers or not wishing to continue running alone during the test. A final shortcoming of the current study is that only peak HR was recorded. Further research should analyze the continuous HR response throughout the 20mSRT. This will give an indication of the proportion of participants who achieve a plateau in HR during the test and thus possibly provide better understanding of interindividual variation in effort and HR response to this test.
Conclusion

In conclusion, the current study suggests the 20mSRT provokes a maximal effort in children in the naturalistic environment. This appears to be true for overweight and obese children as well as those of normal weight and is also true across a wide range of 20mSRT scores. This makes the prediction of aerobic capacity from the test results valid in such a setting.

References


