A Nonmotorized Treadmill Test to Assess Children's Short-Term Power Output

Nicola C. Sutton, David J. Childs, Oded Bar-Or, and Neil Armstrong

The purpose of this study was to develop a nonmotorized treadmill sprint test (ExNMT) to assess children’s short-term power output, to establish the test's repeatability, and to compare the results to corresponding Wingate anaerobic test (WAnT) measurements. Nineteen children (aged 10.9 ± 0.3 years) completed 2 ExNMTs and 2 WAnTs. Statistical analysis revealed coefficients of repeatability for the ExNMT that compared very favorably with the WAnT for both peak power (26.6 vs. 44.5 W) and mean power (15.3 vs. 42.1 W). The validity of the ExNMT as a test of anaerobic performance is reflected by significant correlations (p ≤ .05) with the WAnT (peak power, r = 0.82; mean power, r = 0.88) and reinforced by the relatively high post-exercise blood lactate concentrations (7.1 ± 1.3 vs. 5.6 ± 1.5 mmol · L⁻¹ for the ExNMT and WAnT, respectively). This study has developed a promising laboratory running test with which to examine young people’s short-term power output.

Young people's aerobic performance in relation to growth and maturation is well-documented (3, 5, 24), but secure data on their anaerobic performance are sparse due to the problems of assessing and interpreting the short-term power output of children and adolescents (5, 6, 27).

The components of anaerobic performance normally investigated are peak power (PP), the maximum rate at which energy is transferred to the external system, and mean power (MP), the total work done during the performance test divided by the time taken. The Wingate anaerobic test (WAnT), which involves pedaling a cycle ergometer against a constant braking force with maximal effort for 30 s, is widely recognized as a reliable criterion test of PP and MP (9, 22). However, with young people there are intrinsic problems associated with the WAnT, particularly with regard to load optimization (5, 6). Power is the product of force and velocity, and as each combination of braking force and pedal revolutions may produce a different power output, optimal performance on the WAnT is dependent upon the selection of an appropriate braking force for each subject.

N.C. Sutton, D.J. Childs, and N. Armstrong are with the Children’s Health and Exercise Research Centre at the University of Exeter, Exeter, EX1 2LU, UK. O. Bar-Or is with the Children’s Exercise and Nutrition Center at McMaster University, Hamilton, Ontario, L8N 3Z5, Canada.
Using a Monark 814 E cycle ergometer, a braking force of 0.74 N \cdot kg^{-1} body mass is commonly used with children and adolescents \((7, 17)\), but the limitations of setting a braking force in relation to body mass when performance is better related to muscle mass are readily apparent \((25, 26)\). The complex changes in body composition during growth and maturation make the identification of an appropriate braking force for young people particularly troublesome. This was clearly illustrated in a recent study \((29)\) that determined the thigh muscle volume of 9-year-old children using magnetic resonance imaging. A common body mass–related braking force was applied to both boys and girls, but further analysis revealed that despite their similar body mass, the girls were exercising against a braking force which was, on average, 19% higher than that of the boys in relation to their thigh muscle volume. Individual differences varied by 49%. This discrepancy concerning the application of body mass–related braking forces may have clouded our understanding of changes in PP and MP in relation to growth and maturation.

Moreover, cycle ergometer tests of anaerobic performance are cycling-specific and therefore may not provide a valid assessment of running performance. Consequently, there is a distinct need for the development of a sprinting anaerobic test that provides valid measurements of short-term power output.

The most secure data on young people’s aerobic performance have been obtained during treadmill running \((3, 5)\), but assessment of power output while running on a motorized treadmill is problematic \((8)\). A nonmotorized treadmill, however, has the potential to provide a running model for the assessment of children’s and adolescents’ anaerobic performance. The use of a nonmotorized treadmill has been advocated for both adults \((13, 18, 23)\) and young people \((4, 18, 28)\), but the methodology has not been developed and reported fully, particularly for use with children, and the test-retest reliability of the protocols has not been reported adequately.

The purposes of this study were therefore to develop a nonmotorized treadmill running test of young people’s anaerobic performance, to establish the repeatability of the test, and to compare performance on the running test with performance on a WAnT.

**Equipment and Protocol Development**

Power variables were calculated from the horizontal force exerted by the subject (measured using a strain gauge) and the belt velocity of the treadmill. Although some aspects of the model were based upon equipment and methods proposed by Lakomy \((23)\), several components were original designs developed during pilot work.

**Wall Bracket.** A permanent anaerobic testing system was constructed by attaching the tether and strain gauge arrangement to a wall bracket drilled into the wall behind the treadmill.

**Safety Frame.** A free-standing metal frame was fabricated and erected around the treadmill from which a safety harness could be attached (see Figure 1).

**Treadmill Belt Velocity Sensor.** An electronic sensor was fitted to monitor the treadmill belt velocity. An optical shaft encoder (RS Components, Corby, UK) was mounted onto the front shaft of the treadmill, producing 100 pulses per shaft revolution. The shaft encoder output was connected to a frequency-to-voltage converter (National Instruments, Newbury, UK) to produce a voltage output directly proportional to pulse frequency. Consequently, the signal voltage \((0–5 \text{ V})\) could be directly
Figure 1 — A schematic diagram of the ExNMT test apparatus. Diagram reproduced with the permission of the Children’s Health and Exercise Research Centre, University of Exeter, UK.

related to the angular velocity of the shaft. Knowing the distance traveled by the treadmill belt in one rotation of the shaft allowed the calculation of belt velocity.

**Strain Gauge.** Initially, the range of horizontal forces that would be generated by the subjects was unknown. A strain gauge (Novatech Measurements, St. Leonards-on-Sea, UK) with a measurement range of 0–40 kg (accuracy of 0.008 kg) was used following experimental trials. The strain gauge was connected to the subject via an extensible tether, a metal clip, and a belt around the subject’s waist.

**Strain Gauge Calibration.** The equipment was set up as detailed in Figure 2. The output from the strain gauge was calibrated by measuring the voltage output of the sensor with tether arrangement attached with no mass applied and with various known masses applied. The relationship between voltage and force applied on the strain gauge was then calculated. A pilot calibration study confirmed that the voltage response of the strain gauge, with the elastic tether, metal clasp, and belt included, remained linear up to a loading of 15 kg.

**Interface Between Velocity Sensor, Strain Gauge, and Computer.** The output voltages from the force sensor and velocity sensor were connected to a multifunction interface card including an 8-channel, 12-bit analogue-to-digital converter, which was installed in an IBM-compatible 80486 computer. Using a custom software application developed using LabVIEW (National Instruments, Newbury, UK) programming software, the signal voltages from both sensors were scanned at 100 Hz and converted to measurements of velocity and force production.

**Visual Velocity Display.** To standardize the velocity of the rolling start and provide additional motivation throughout the test, a system was designed to inform the subject of the treadmill belt velocity during the sprint test. The velocity of the treadmill, recorded within the software, was reconverted to a scaled voltage using a digital-to-analogue converter on the interface card and output to the ana-
logue-to-digital converter of a second computer, then scaled to produce a velocity displayed on a monitor located directly in front of the subject at eye level. Pilot work established the tendency of young subjects to look downwards while sprinting, and this display encouraged them to keep their heads up and look forward during the test, which more closely emulates a normal running action. For the information of both the subject and tester, the numerical display changed color when the test was initiated and returned to its original color when data capture was terminated.

**Internal Resistance Motor.** To standardize the internal resistance of the treadmill prior to each trial, a 750-W motor was connected to the front shaft of the treadmill by engaging an electrical clutch. The motor revolved the belt at a constant velocity and was run for 5 min prior to each trial to ensure standardization was achieved. Before the trial commenced, the motor clutch was disengaged from the treadmill.

**Safety Harness.** Due to the nature and intensity of the test, the safety of the subject had to be ensured in the event of a stumble or fall during the test. A lightweight, cushioned, fully adjustable climbing belt was fastened comfortably around the chest, passing under the arms. An additional strap with a secure clasp at one end was passed under the belt, over the shoulders, and fastened onto the back of the belt. This effectively prevented the harness belt from slipping down during the test. A rope system, fastened onto the top bars of the treadmill safety frame, was then connected to the back of the harness belt using a metal clasp. The harness system was assembled to ensure that the subject would be suspended above the treadmill belt in the event of a trip or fall.

**Pilot Study**

On completion of the equipment and protocol development, a pilot study was conducted to investigate the effectiveness of the entire testing system, which we have called the Exeter Nonmotorized Treadmill test (ExNMT), and its applicability to pediatric subjects. The main aims of the study were to determine whether the children would be able to sprint maximally on the treadmill for 30-s; to investigate the reliability of the test protocol; and to identify any methodological/equipment problems in order to resolve them before subsequent studies. Eighteen children (8 boys and 10 girls), with a mean (± SD) age of 8.6 ± 0.3 years, completed two 30-s sprint tests conducted on consecutive days. Mean (± SD) PP (averaged over 1 s) for tests
1 and 2 was 205.3 ± 37.4 W and 210.5 ± 34.9 W, respectively. Corresponding values for MP were 142.8 ± 23.0 W and 144.4 ± 23.9 W. Coefficients of repeatability (11, 12) were 28.4 W for PP and 14.1 W for MP. This study demonstrated that the children were able to complete the test protocol satisfactorily and identified the repeatability of PP and MP. Moreover, no major methodological problems were encountered.

Principal Study

Subjects

Subjects in this study were recruited from a local middle school. Nineteen children (9 boys and 10 girls) volunteered to participate in the study, and written informed consent was obtained from both the child and their parent/guardian. The mean (± SD) age, stature, and mass of the subjects was 10.9 ± 0.3 years, 1.41 ± 0.07 m, and 34.1 ± 6.1 kg, respectively. All techniques and protocols used in the laboratory had previously been approved by the Exeter District Health Authority Ethical Committee.

Methodology

Chronological age was computed from the date of birth and the date of testing. Stature and body mass were measured during the habituation session. All children were fully habituated to the environment and exercise protocols during a full-day habituation session conducted in the testing week.

Four children were tested per week. Each child completed one ExNMT and one WAnT on both testing days. Two of the subjects performed the tests on the two consecutive days following the habituation day. The remaining two children completed the tests on the 3rd and 4th days following habituation. In order to standardize any psychological/physiological bias that the first test may have had on performance of the second test, the testing order was reversed each week. A standardized warm up was completed before each test. Seven ExNMTs were examined using video and digitizing techniques to quantify the vertical movement of the center of gravity throughout one complete gait cycle. The movement of the end of the tether closest to the belt was taken to reflect the displacement of the center of gravity in order to investigate the effect of vertical displacement upon power output.

ExNMT. The warm up consisted of (a) walking on the nonmotorized treadmill ("Tramp" model, Woodway GmbH, Germany) until a velocity of 1.67 m · s⁻¹ (6 km · h⁻¹) was maintained, followed by a short sprint of 4–5 s, (b) cycling for 2 min on an unloaded cycle ergometer at 60 rpm, and (c) several leg muscle stretches. The single sprint warm-up was adopted because pilot work demonstrated that multiple sprints adversely affected subsequent performance.

For the test, the subjects walked up to 1.67 m · s⁻¹ while looking at the visual velocity display. As soon as this velocity was reached, the tester shouted, "Three, two, one, go!" The data capture software program was activated simultaneously with the word go. Accompanied with standardized verbal encouragement and motivation, the subjects were required to sprint as fast as possible on the word go and continue sprinting for 30-s. Following the test, the subjects were encouraged to walk slowly to aid recovery. Power output was calculated as the product of
horizontal force and treadmill belt velocity. Variables calculated were peak power output (averaged over 1 s) and mean power over 30 s.

WAnT. The warm up required the subject to pedal at 60 rpm on a Monark 814 E friction braked cycle ergometer (Monark AB, Varberg, Sweden) against the limited resistance of the flywheel for 3 min. At the end of each minute, the subject completed a sprint of 3–5 s against the test resistance, followed by several leg muscle stretches. The resistance applied to the flywheel was set equivalent to 0.74N·kg⁻¹.

The test commenced with a “rolling” start, and when a cadence of 60 rpm was reached, the tester immediately shouted, “Three, two, one, go!” while simultaneously applying the resistance to the flywheel and activating the data capture software. Subjects were required to pedal maximally for 30-s. On completion of the test the subject was instructed to pedal slowly to aid recovery. Peak power over any 1-s period during the test and mean power output over 30-s were calculated.

Following each test, duplicate fingertip blood samples were taken 2-min postexercise and immediately assayed for lactate concentration using a whole-blood automated and self-calibrating analyzer (YSI 2300 Stat Plus, Yellow Springs Instruments, OH).

Filming Procedure. The ExNMT testing area was defined using a Peak Performance Technologies (Englewood, CO) 24-point calibration frame. Each of the seven ExNMT trials was videotaped and recorded using two genlocked video cameras (Panasonic DP800 and Panasonic DP200 models) operating at 25 Hz. Two points on the elastic tether were digitized throughout one complete gait cycle (heel strike to heel strike of the same foot) using the Peak Motus (Peak Performance Technologies, Englewood, CO) analysis software package.

Data Analysis

Data from all tests were stored and analyzed using SPSS (SPSS, Chicago, IL) computer statistical package. Pearson correlation coefficients were computed to explore whether a significant association existed between paired MP and PP variables obtained during the ExNMT and WAnT. Descriptive statistics are expressed as mean (± SD). Paired t tests were used to analyze differences between ExNMT and WAnT PP, MP, and posttest lactates with significance set at the p ≤ .05 level (unless stated otherwise). Coefficients of repeatability (11, 12) for PP and MP in both the ExNMT test and WAnT were calculated as twice the standard deviation of the differences between repeated measures:

$$\sqrt{\frac{\sum \text{differences}^2}{n}} \times 2$$

Results

Power output data for tests 1 and 2 on the ExNMT and WAnT are summarized in Table 1. A typical ExNMT power output curve is displayed in Figure 3. The repeatability coefficients (11, 12) for the ExNMT were 26.6 W for PP and 15.3 W for MP. The WAnT data presented are from 18 subjects. Data from only 18 subjects were used due to one data set being identified as a clear outlier (in both PP and MP) and, therefore, subsequently removed. The repeatability coefficients were 44.5 W for PP and 42.1 W for MP.
Table 1  Descriptive Power Output and Blood Lactate Concentration Data ($M \pm SD$) for ExNMT and WAnT (Tests 1 and 2)

<table>
<thead>
<tr>
<th>Variable</th>
<th>ExNMT ($n = 19$)</th>
<th>WanT ($n = 18$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Test 1)</td>
<td>(Test 2)</td>
</tr>
<tr>
<td>Peak power output (W)</td>
<td>211.1 ± 38.4</td>
<td>214.2 ± 40.8</td>
</tr>
<tr>
<td>Mean power output (W)</td>
<td>150.7 ± 28.8</td>
<td>149.6 ± 29.7</td>
</tr>
<tr>
<td>Blood lactate concentration</td>
<td>7.1 ± 1.3</td>
<td>7.0 ± 1.5</td>
</tr>
<tr>
<td>(mmol · L$^{-1}$)</td>
<td>($n = 17$)</td>
<td>($n = 17$)</td>
</tr>
</tbody>
</table>

Figure 3 — A typical ExNMT test power curve.

Mean ($\pm SD$) blood lactate concentrations in both tests of the ExNMT and WAnT are detailed in Table 1. The sample size is slightly reduced in the second test of both exercises due to the failure of 2 subjects to provide a fingertip blood sample. Mean blood lactate concentrations produced following the ExNMT were significantly higher ($p \leq 0.01$) than post-WAnT blood lactate values.

A significant ($p \leq 0.01$) correlation ($r = 0.82$) was detected between peak power generated on the ExNMT and peak power produced during the WAnT. A similar outcome was evident for mean power ($r = 0.88$). It should be noted that the PP and MP values used were actually the mean PP and mean MP values, respectively, from test 1 and 2.

Digitization of seven ExNMT trials revealed that the vertical displacement of the elastic tether did not exceed 5 cm throughout the complete gait cycle. This deviation resulted in a maximum error in power output of less than 2.5%.
Discussion

The children quickly habituated to the ExNMT and even the 8 year olds found little difficulty in maximal running on the treadmill following practice. The safety harness enhanced the children's confidence, particularly during habituation, although it was rarely activated. Of the 74 ExNMT trials performed in the pilot and principal study, the harness was used four times. These trials were aborted and, after an appropriate rest period, the tests were repeated. The strain-gauge-tether arrangement was found to be comfortable, and the deviation of the tether, caused by the rise and fall of the subject's body throughout each stride, and any resultant error in the measurement of power output (<2.5%) had a small effect upon overall performance. The importance of a thorough habituation procedure has also been emphasized since previous studies observed a significant learning effect between duplicate nonmotorized treadmill sprint tests (18, 20) and an inability to complete a 30-s run (18).

PP and MP values generated during the WAnT in the present study are in accordance with previous reports on boys and girls of a similar age (10, 15). Limited data are available detailing children's power output during similar nonmotorized treadmill sprint tests. Both Van Praagh (28) and Fargeas (19, 20) reported PP data in children who were trained or elite sports performers. Similarly, Falk et al. (18) measured PP and MP in highly trained boys and girls aged 11–17 years. Differences in both the subject characteristics and protocols adopted in these studies preclude any meaningful comparisons with PP and MP values obtained in the present study.

The PP and MP generated during the running test were significantly less than those generated during cycling. This is in accord with a study of trained children that compared running PP and PP generated during a force-velocity cycle test (20). These results are in contrast to the findings of Falk et al. (18), where the greater power output during sprinting compared to WAnT values may be explained by the methods used to calculate total power output.

Several studies have reported the test-retest reliability of the WAnT by computing correlation coefficients. It should be noted, however, that it is inappropriate to use correlation coefficients to quantify the degree of test-retest reliability. In their "citation classic" paper, Bland and Altman (11), highlighted the problems of using such an analysis to study repeatability data and pointed out that correlation is a measure of the strength of relationship between two measures, not of the agreement between them. It would be quite amazing if there was not a significant relationship between scores in a test-retest model.

Although the use of the Bland and Altman techniques (11, 12) for assessing the variation in repeated measurement by the same method on the same subject is increasing in pediatric exercise science (1, 2, 14), we are unaware of any previous study that has reported repeatability coefficients for young people's test-retest WAnT scores, and no appropriately analyzed studies of nonmotorized treadmill scores have been published. The present data demonstrate repeatability coefficients for both PP and MP for the ExNMT that compare very favorably with the WAnT.

The validity of the WAnT as a measure of anaerobic performance is based upon its high correlation with young people’s performances in a range of predominantly anaerobic tasks and high post-WAnT blood lactates (22). In the present study, the high correlation coefficients demonstrate the relationship between the ExNMT and the WAnT. The blood lactates following the ExNMT test were significantly higher than those following the WAnT, and although different recov-
ery procedures preclude a meaningful comparison between lactate values, the high anaerobic component of the ExNMT is clearly illustrated. In conclusion, the repeatability, relationship with the WAnT, and significant anaerobic component as reflected by blood lactate concentrations, establish the ExNMT as a means of measuring short-term power output during running. The thorough habituation procedures and safety precautions adopted in the ExNMT identify it as an appropriate treadmill running test for use with children. The ExNMT, therefore, offers a promising laboratory model for research into children’s short-term power output during maximal sprint running. Longitudinal studies of young people using both running (ExNMT) and cycling (WAnT) protocols may clarify our understanding and provide new insights into the anaerobic performance of children and adolescents.

References


**Acknowledgments**

Dr. Bar-Or was on sabbatical leave in Exeter when this work was undertaken. We acknowledge the financial support of the Economic and Social Research Council and the University of Exeter Research Fund. We are grateful to Mark Sheppard and Dr. Paul Grimshaw for assistance with gait analysis.