

Maximal shuttle running over 40 m as a measure of anaerobic performance

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Over the last decade increasing interest has been shown in the measurement of anaerobic power and capacity in athletic men. These physiological characteristics have been determined predominantly using cycle ergometry and treadmill sprinting. The purpose of the present study was to examine the relationship between 40-m maximal shuttle run times and performance indices obtained during treadmill sprinting and cycle ergometry. Moderate correlations were found between 10-m split times (the time taken to cover the initial 10 m of the shuttle course) and treadmill peak power outputs ($r = -0.67$; $P < 0.05$). Similar relationships were also found between the fastest 40-m time and mean power outputs generated on both the treadmill and cycle ergometer ($r = -0.67$; $P < 0.05$) and ($r = -0.75$; $P < 0.05$) respectively. The correlations remained unchanged when the values were adjusted for body weight ($W \text{ kg}^{-1}$). The results of the present study suggest that maximal 40-m shuttle running ability may reflect anaerobic indices of power and capacity, determined using standard laboratory procedures.

Keywords: Anaerobic performance, treadmill sprinting, shuttle running, cycle ergometry

Coaches, trainers and athletes are continually searching for optimum ways of identifying key elements which contribute to athletic performance. Many sporting activities depend upon the development of anaerobic power for short periods of time. Anaerobic performances which principally involve short bursts of exercise, such as sprinting or jumping, rely predominantly on the immediate energy provided by adenosine triphosphate (ATP), and creatine phosphate (CP), in addition to that supplied by anaerobic glycolysis.

The ability to utilize the high energy phosphate stores quickly may be considered as one aspect of anaerobic power.

However, the total amount of energy available to perform work in a given energy system is referred to as the capacity of the system¹ and may reflect the

total utilization of energy derived from ATP, CP and anaerobic glycolysis. Individual differences in power production may be the result of greater muscle mass, or a greater proportion of fast-twitch fibres². However no single measure of anaerobic power or capacity has achieved the popularity of $\dot{V}O_{2\text{max}}$ as the measure of aerobic power.

Procedures for measuring anaerobic power and capacity have ranged from simple field tests (jumps and sprints), to laboratory techniques, e.g. treadmill sprinting³, stair climbing⁴, vertical jumping⁵, cycle ergometry^{6,7} and isokinetic measurements⁸. Development of a 30-s cycle ergometer test⁹, and more recently a similar test performed on a non-motorized treadmill¹⁰, has enabled the measurement of the peak, mean and end power outputs (end power being the minimum power generated during the last second of each sprint) while assessing the fatigue associated with exercise of maximum intensity. The aim of the present study was to examine sprint performance during a 40-m shuttle run test, and to compare the values obtained with power output generated during treadmill sprinting and cycle ergometry each of 30-s duration.

Methods

Ten male subjects volunteered to participate in the present study. All were physically active and had varied sporting backgrounds. Experimental design and procedures were approved by the Ethical Committee at Loughborough University. Before testing, all subjects were fully familiarized with the experimental procedures, tested at the same relative time intervals (morning testing) and were informed that they were free to withdraw from the tests at any time. A rest day preceded each test, and subjects attended the laboratory having fasted overnight (for at least an 8-h period). Body weight and height were recorded before each test. Heart rate during laboratory and field tests was recorded using a short range telemetry system (Sport Tester PE3000, Polar Electro, Kempele, Finland). Blood lactate concentration was determined in capillary blood samples (20 μl) taken from a prewarmed finger. Three samples were taken: one before exercise, and two postexercise, one at 3 min following completion of the exercise period and another 3 min later. Samples were deproteinized in

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200 µl of 2.5% perchloric acid, centrifuged (Eppendorf Model 5412), frozen, stored at -20°C and analysed fluorometrically (Perkin-Elmer 1000M, Beaconsfield, UK) for blood lactate concentration, using the methods described by Maughan¹¹.

Field tests

1. Progressive shuttle run test (20-m PST)

Maximal oxygen uptake values ($\dot{V}O_{2max}$) of subjects were estimated using a 20-m progressive shuttle run test (20-m PST) for adults¹².

2. Maximal shuttle run test (40-m MST)

Subjects were required to run between markers placed 20 m apart. The start point was located at the mid-point of the markers (Figure 1). Before commencement of the test subjects were given a familiarization trial of five low-intensity runs following test procedures.

The 40-m MST protocol consisted of sprinting from the mid-point to the first marker, turning, running 20 m in the opposite direction to the second marker, turning and running again through the mid-point, a total distance of 40 m. Each sprint was started with a 5-s count down.

This procedure was repeated on each run with subjects completing eight sprints in total. A 20-s recovery period was allowed between each successive sprint. Individual 40-m and split 10-m times (distance covered from the centre of the course to the first marker) were recorded manually using a digital stopwatch by the same experimenter. Reliability for timing was established using a test retest method during a pilot study before the experiment itself. Subjects were encouraged to perform maximally on each occasion.

A fatigue index was determined for each subject after completion of the test. This was calculated as the difference between the mean of the fastest two and

the slowest two sprints expressed as a percentage of the fastest two sprints.

$$\text{e.g. } \frac{8.98 + 8.95}{2} - \frac{8.66 + 8.59}{2} = 0.34$$

$$\frac{0.34 \times 100}{8.62} = 3.94\%$$

Laboratory tests

Terminology

Throughout the study peak power output (PPO) refers to the highest 1-s value of power attained during each 30-s sprint. Mean power output (MPO) refers to the average power output for the 30-s period. End power output (EPO) refers to the value of power in the last second of each sprint.

Fatigue index (FI%) refers to the decrease in power over the test duration, and is expressed as a percentage, that is

$$\frac{\text{PPO} - \text{EPO}}{\text{PPO}} \times 100$$

Treadmill running

Treadmill sprints were performed on a non-motorized treadmill (Woodway Model AB, Medical Diagnostic Instrumentation, Salford, UK), which was calibrated before each sprint. The test consisted of sprinting maximally, from a rolling start, for a period of 30 s.

Values for peak power output, mean power output, end power output and fatigue index were calculated. All calculations were carried out using a microcomputer interfaced to the treadmill. Data capture and analysis were made possible using a computer program¹³. Detailed specifications, reliability and test protocol have been described previously¹⁴.

Cycle ergometer test

Subjects were required to pedal maximally on a cycle ergometer (Monark 868, Monark, Varberg, Sweden) against a standard load (75 g kg⁻¹ body weight) for a period of 30 s. Individual subject warm-up was followed by two consecutive periods of pedalling, both lasting 30 s, using two pedalling speeds (25 and 45 r.p.m. respectively) against a resistance of 1.5 kg. The ergometer test consisted of sprinting maximally for 30-s duration. Saddle heights were individually adjusted, and the feet were firmly supported by toeclips. Subjects were given a 3-s count down after which individual loads were applied and data capture initiated. Values for PPO, MPO, EPO and FI% were obtained on test completion using a computer program¹⁰. Validity and reliability of the cycle ergometer as a test of anaerobic power has been reported as $r = 0.93, P < 0.01$ (Reference 15).

Statistical analysis

The results are presented as mean(s.d.). Statistical significance was accepted at the $P < 0.05$ level. All

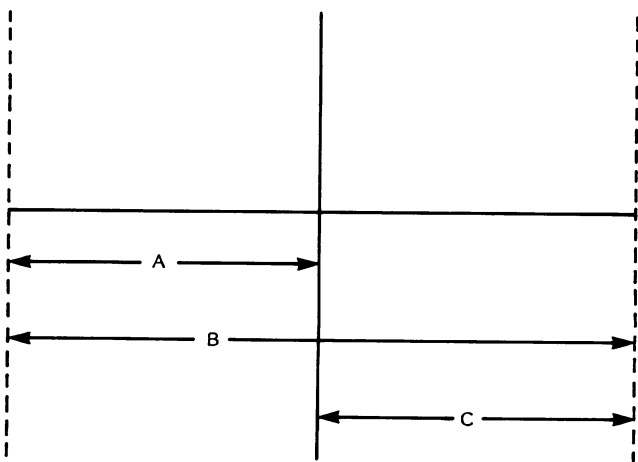


Figure 1. Course outline showing distance and direction taken by subjects, during the 40-m maximal intensity shuttle run test. A = 10 m, B = 20 m, C = 10 m

Table 1. Physiological characteristics of subjects

Subject	Age (years)	Weight (kg)	Height (cm)	$\dot{V}O_{2max}$ (ml kg ⁻¹ min ⁻¹)	HR(max) (beats min ⁻¹)
LH	30	65.25	168.1	54.8	180
GY	25	78.10	170.8	57.1	205
BB	25	72.35	171.2	53.1	197
PH	22	65.20	174.5	59.3	181
CC	26	68.90	177.0	57.6	203
JB	34	92.20	180.5	50.8	184
FM	25	69.60	185.3	56.0	192
SS	23	76.10	176.7	54.3	184
ST	23	79.10	168.0	45.2	192
SC	25	66.75	165.0	56.0	196
Mean(s.d.)	25.8(3.6)	73.4(8.4)	173.7(6.3)	54.4(4)	191(9)

*Estimated from a 20-m PST

Table 2. 40-m shuttle run times and 10-m split times (s), also peak power output (PPO), mean power output (MPO), end power output (EPO) and fatigue index (FI%) from 30-s maximal treadmill and cycle ergometer exercise, together with maximum heart rate values (beats min⁻¹) attained during the three tests

	40-m sprint times	10-m split times (40-m shuttle test)		Treadmill values	Cycle ergometer values
Fastest	8.730(0.66)	2.178(0.23)	PPO(W)	740(146)	793(59)
Mean	9.310(0.43)	2.4(0.76)	MPO(W)	480(38)	605(44.6)
Slowest	9.752(0.5)	2.589(0.23)	EPO(W)	234(72)	441(53.2)
FI%	8.78(5.29)	—	FI%	47.6(27.42)	44.3(5.96)
HR	181(10)	—	HR	182(10)	179(12)

Values are mean(s.d.)

statistical computations were carried out on a mainframe computer using the Minitab statistical package.

Test retest 40-m MST

A test-retest procedure was carried out to examine the reliability of the 40-m MST. Maximum heart rates, fastest times and blood lactate concentrations were used as variables. The subjects (n = 10) were tested on a second occasion using a double blind protocol. Pearson Product correlation coefficients were then calculated.

Results

Maximal oxygen uptake values estimated from the 20-m PST ranged from 45.2 to 59.3 ml kg⁻¹ min⁻¹ and the maximum heart rate attained during this test ranged from 180 to 203 beats min⁻¹ (Table 1). Overall results for the 40-m shuttle test, treadmill sprinting and cycle ergometry are shown in Table 2. The fastest recorded 40-m time was 7.27 s, with a mean(s.d.) value of 8.78(5.19) for fatigue index. The fastest 10-m split time was 1.8 s and the slowest 3.0 s. The highest PPO value recorded during treadmill sprinting was 1013 W, with a mean(s.d.) fatigue index value of 47.6(27.4). Maximum heart rate recorded during the treadmill test was 199 beats min⁻¹. Values obtained during the cycle ergometer test ranged from

886 W(PPO) to 676 W(EPO). The highest value for fatigue index during the cycle test was 53.5%. Heart rates ranged from 158–197 beats min⁻¹.

Peak blood lactate values for the three tests are shown in Table 3. The highest concentrations occurred after treadmill sprinting (20.2 mmol l⁻¹). Concentrations following cycle ergometry reached a maximum value of 16.5 mmol l⁻¹. Lactate values during the 40-m shuttle run reached 18.6 mmol l⁻¹ with a mean(s.d.) value of 13.7(3.2) mmol l⁻¹. Blood lactate concentrations measured postexercise for 40-m shuttle running, treadmill sprinting and cycle ergometry

Table 3. Peak blood lactate concentrations (mmol l⁻¹) obtained for individual subjects during the three tests

Subject	40-m shuttle	30-s treadmill sprinting	30-s cycle ergometry
LH	10.2	20.2	16.5
GY	9.2	11.0	11.21
BB	17.3	15.1	14.7
PH	14.5	17.5	9.3
CC	13.0	12.8	11.8
JB	11.7	12.6	12.1
FM	12.4	19.0	16.5
SS	18.6	19.0	15.6
ST	12.8	18.5	11.8
SC	12.0	17.3	15.4
Mean(s.d.)	13.7(3.2)	16.3(3.3)	13.5(2.5)

Table 4. Pearson product moment correlations between the fastest 40-m and 10-m times (s) attained during shuttle running, compared with peak power and mean power output values (PPO and MPO; W) generated during treadmill sprinting (TR) and cycle ergometry (CE)

	Fastest 40 m	Fastest 10 m	FI%
PPO(TR)	-0.43	-0.67*	-0.43
MPO(TR)	-0.67*	-0.39	0.74*
PPO(CE)	-0.58	-0.57	0.71*
MPO(CE)	-0.75*	-0.51	0.68*

* $P < 0.05$

showed high correlations ($r = 0.917$, $P < 0.01$). Correlations were also found between PPO(W) treadmill sprinting and fastest 10-m individual time recorded during the 40-m shuttle test ($r = -0.66$, $P < 0.05$). Fastest 40-m times were correlated with both treadmill and cycle ergometer MPO's(W) ($r = -0.67$, $P < 0.05$; $r = -0.75$, $P < 0.05$ respectively (Table 4)). Strong correlations were observed for heart rate values attained during the 40-m shuttle test and those recorded during treadmill sprinting, and cycle ergometry ($r = 0.91$, $P < 0.01$ and $r = 0.85$, $P < 0.01$ respectively).

Test-retest correlations for the 40-m MST were $r = 0.86$ ($P < 0.01$) for the fastest 40-m shuttle run times, $r = 0.95$ ($P < 0.01$) for maximum heart rate and $r = 0.98$ ($P < 0.01$) for peak blood lactate concentration (3 min and 6 min after exercise).

These high test-retest correlations indicate that the 40-m maximal shuttle run test may be both reliable and reproducible.

Discussion

The results showed that significant correlations existed between the fastest recorded 10-m times and PPO values attained during treadmill sprinting ($r = -0.67$, $P < 0.05$). Cheetham and co-workers³ found that during treadmill sprinting PPO values occurred in the first 1 to 3 s of the test, and the relationship between the 10-m time and the treadmill sprint indicated that both could possibly be measuring a similar component of anaerobic peak power. Similar correlations were obtained between the fastest 40-m shuttle run time and MPO values recorded on both the treadmill and the cycle ergometer ($r = -0.67$, $P < 0.05$; $r = -0.75$, $P < 0.05$).

These results are in agreement with the findings of Bar-Or and Inbar¹⁶ who showed that mean power outputs generated during their 30-s maximal test (Wingate test) were correlated with sprinting ability in boys ($P < 0.05$). Thompson and Garvie¹⁷ reported significant correlations between treadmill sprinting and individual sprint performance ($P < 0.01$). The design of the 40-m maximal shuttle run course which includes slowing down at the 10-m and 30-m stages may slightly weaken the relationship with 30-s maximal sprinting on the cycle ergometer and non-motorized treadmill. Nevertheless strong correlations were obtained which support the use of the test as a measure of anaerobic capacity.

Fatigue index profiles were found to be greater in both treadmill sprinting and the cycle ergometer test, compared to those obtained in the 40-m maximal shuttle run; this may be partly explained by the 20-s rest period between successive shuttle runs, and by the frictional and inertial characteristics of the ergometers which contribute to fatigue in these tests. The values recorded in this study compare with results obtained in a study by Holmyard and co-workers¹⁸ which showed that high-intensity exercise is affected by both the recovery period and the number of preceding sprints. Peak power outputs generated during treadmill sprinting were found to be only slightly lower than the values recorded for 30-s maximal cycle ergometry. Dotan and Bar-Or⁶ reported that high-power outputs during cycle ergometry were due to optimization of the resistive load. During treadmill sprinting, however, the resistance of the treadmill belt is fixed, and body weight is not supported. The correlations found between the laboratory tests and the 40-m maximal shuttle run, suggest that this field test can be used as a measure to assess both anaerobic capacity and anaerobic power.

However, differences in relative strengths of the correlations indicate that the 40-m sprint test may be measuring a slightly different component of anaerobic performance than the laboratory tests, and correlations obtained between the field and laboratory tests may be influenced by recovery duration and shuttle run design, which allows slowing down during turning procedures.

Blood lactate values following treadmill sprinting were similar to those observed by Cheetham and co-workers¹⁴, who found high peak lactate values in sprint trained athletes compared with endurance trained subjects. The greater lactate levels found during the running tests may be the result of greater muscle mass being utilized compared to that during sprint cycling. Other factors such as training status and muscle fibre composition may also affect lactate production and removal. Thompson and co-workers¹⁷ found blood lactate concentrations of sprinters highest at 4 min following cessation of exercise, while a physically active 'non-sprint' group recorded peak lactate values at 6 min postexercise. Peak lactate values in this study were found to occur at both 3 and 6 min after exercise in individual subjects. However, whatever differences or physiological factors influence peak lactate concentrations in individual subjects, all subjects in the present study performed the three maximal exercise tests over a similar time period and under similar environmental conditions. Relationships between fatigue index obtained during shuttle running and fastest 40-m times indicated that subjects who recorded the fastest times also exhibited the greatest fatigue. Studies by Thorstensson and co-workers¹⁹ have shown that individuals with muscles containing a high proportion of type II fibres are capable of faster maximal contraction velocity and greater force output, but are more prone to fatigue during maximal exercise.

Strong correlations were found between maximum heart rates attained during 40-m shuttle running, cycle ergometry and treadmill sprinting ($r = 0.85$; $P <$

0.01 and $r = 0.91$; $P < 0.01$ respectively). These findings suggest that the work intensities of each individual test are related, causing similar cardiovascular responses.

Beckenholt and Mayhew⁵ classified anaerobic power as being made up of two component parts, one associated with speed, the other with body mass.

While body mass must be considered during all tests, to a lesser extent during cycle ergometry where body weight is supported, during the present study when expressed in body-weight units ($W \text{ kg}^{-1}$) there were no differences in correlation coefficients between fastest 40-m shuttle times versus PPO, MPO (treadmill) or MPO (cycle ergometer). These findings indicate that although body mass is an important component in evaluating anaerobic performance, training specificity and the fibre type distribution within the muscle may make a greater contribution to force generation in activities requiring maximal effort over short periods²⁰.

The correlations observed between the high-intensity 40-m shuttle run ($P < 0.05$), and accepted laboratory standards used to measure anaerobic performance, indicate that the shuttle run may be of some value in quantifying anaerobic power and capacity. Sophisticated laboratory measures are not available. The 40-m maximal intensity shuttle test may be useful to athletes of most team sports, where the nature of their sport requires assessment of repeat sprint ability and agility and also to those athletes who require maximum power outputs over short durations.

In addition to the shuttle test being easy to administer, test-retest correlations indicated that the test was also reproducible. It was concluded therefore, that a 40-m maximal intensity shuttle run provided a viable protocol for the quantification of anaerobic performance during periods of short intensive work.

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