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**PHYSIOLOGICAL AND METABOLIC IMPLICATIONS OF RESISTIVE FORCE
SELECTION DURING HIGH INTENSITY CYCLE ERGOMETRY:
INTERRELATIONSHIPS WITH A NEW TEST OF MAXIMAL RUNNING ABILITY.**

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ABSTRACT

PHYSIOLOGICAL AND METABOLIC IMPLICATIONS OF RESISTIVE FORCE SELECTION DURING HIGH INTENSITY CYCLE ERGOMETRY: INTERRELATIONSHIPS WITH A NEW TEST OF MAXIMAL RUNNING ABILITY. **Julien Steven Baker and Bruce Davies.** **JEPonline** 2004;7(4):6-13. The purpose of this study was to analyse power values generated during 30 s of high intensity cycle ergometry exercise when cradle resistive forces were calculated from total body mass (TBM) or fat free mass (FFM). A further aim was to compare the power values generated with performance indices recorded during maximal running performance on a modified multi-stage fitness test and to validate the running test as a measure of anaerobic performance. Body density was calculated using underwater weighing procedures. Fat mass was estimated from body density values. Significant differences ($P < 0.01$) were observed between the TBM and FFM protocols for peak power output (PPO; 1264 ± 156 vs. 1366 ± 177 Watts, respectively). Significant differences ($P < 0.01$) were also recorded between the TBM and FFM protocols for resistive force selection and pedal revolutions (7.3 ± 1.2 vs. 6.2 ± 1.1 kg; 136 ± 8.7 vs. 144 ± 7.6 rev/min respectively). There were no differences ($P > 0.05$) recorded between mean power output (MPO) or fatigue index (FI %). Values recorded for the running test were 71.4 ± 7.5 s. Significant ($P < 0.01$) linear relationships were found between PPO and running times for both the TBM and FFM protocols with more of the variance accounted for during the FFM protocol. ($r = 0.70$, $P < 0.01$ $R^2 = 50\%$ TBM; Standard Error of Estimate (SEE) 100.3; $r = 0.88$, $P < 0.01$; $R^2 = 77\%$ FFM; SEE 86.8 respectively). Blood lactate concentrations increased significantly from rest to 5 min post exercise for all three experimental conditions and were highly correlated ($P < 0.01$). Results from the study suggest that higher PPO values are obtainable when resistive forces used in high intensity cycle ergometry exercise reflect lean tissue mass. Also, the running test proved to be an accurate measure for the quantification of high intensity running performance during periods of intense work.

Key Words: Running, Cycle ergometry, Body mass, Performance.

INTRODUCTION

Coaches, trainers and athletes are continually searching for optimum ways of identifying key elements that complement, and effect athletic outcomes. High intensity exercise performance, which principally involves short bursts of heavy exercise such as sprinting or jumping, relies predominantly on the phosphagen and glycolytic energy systems. The ability to produce ATP rapidly may be considered one aspect of "high intensity power". The total ATP yield from a given energy system is referred to as the capacity of the system (4). Individual differences in such energy capacities may result from differences in training, muscle mass, or the proportion of fast twitch muscle fibers (8).

Procedures for measuring and quantifying high intensity performances are varied. Such procedures have ranged from simple field tests, such as sprinting and jumping, to laboratory techniques comprising various modes of exercise, such as treadmill sprinting (5), stair climbing (13), vertical jumping, cycle ergometry (14), and various isokinetic measurements. Development of a 30 s cycle ergometer test (1) has enabled the measurement of the peak, mean and end power outputs, while observing fatigue profiles during exercise of maximum intensity. During the computation of resistive forces used in the assessment of power during high intensity cycle ergometer exercise, the assumption has been that the relationship between total body mass (TBM) and fat free mass (FFM) is the same. Recent research in our laboratory (2) has demonstrated that greater peak power outputs (PPO) are obtainable when resistive forces reflect the lean tissue component of body composition. Baker et al, (2) further demonstrated that variations in body composition between subjects may under or over estimate the resistive forces used in high intensity cycle ergometry when the forces are based on TBM computations. This may lead not only to spurious calculations of power output during high intensity cycle ergometry, but could also effect the validity and reliability of high intensity exercise field tests that have been validated in conjunction with high intensity cycle ergometry as the criterion measure.

The aim of this study was to examine any observed differences in high intensity friction loaded cycle ergometry power profiles using a TBM and FFM resistive force selection procedure and to investigate possible relationships with high intensity running performance using a modified aerobic shuttle run course as an indirect measure of anaerobic capacity. A further aim was to validate the running test as a measure of anaerobic performance.

METHODS

Subjects and Experimental Design

Male university soccer players (n = 16) volunteered as subjects. Mean \pm SD data for age, body mass, stature and % fat of the group can be found in Table 1.

Prior to testing, all subjects were habituated to the experimental procedures, were tested at the same time of day and were informed that they were free to withdraw from the experiment at any time. All study procedures were approved by the university Ethics Committee and all subjects read and signed an informed consent form prior to participation. A minimum of two rest days (no physical activity) preceded each test, and subjects attended the laboratory following an overnight fast in an attempt to control the influence of diet on performance.

Anthropometric Measures

Body mass, stature and body composition were determined using a calibrated balanced weighing scale (Seca, UK), stadiometer (Seca, UK) and underwater weighing respectively. Nude body mass was measured to the nearest 0.1 kg and stature to 0.1 cm. Body density was assessed using underwater measures as described previously (3). Relative body fat was estimated from body density (18). Residual lung volume was measured using the simplified oxygen re-breathing method (22). FFM mass was determined by subtracting fat mass from TBM.

Terminology

Throughout the study peak power output (PPO) refers to the greatest value for power recorded during the test. Mean power output (MPO) refers to the average power output during the 30 s test period. Fatigue index refers to the decrease in power over test duration, and is expressed as a percentage (FI %). PR refers to the highest pedal revolution recorded during the test.

Force Velocity Test

Prior to the 30 s cycle ergometer test a force velocity experiment was performed with one weeks rest between protocols to determine optimal resistive forces for TBM and FFM. The test consisted of six short maximal sprints (6-8 s) against the following randomly assigned resistive forces: 70, 75, 80, 85, 90 and 95 g/kg. Successive exercise bouts were separated by a 5 min rest period. The load that produced the highest PPO value for both the TBM and FFM protocol was considered to be optimal and was used in the 30 s cycle ergometer test. The optimal load selected for both the TBM and FFM protocol was verified using a test-retest method. Care was taken to ensure that problems outlined by Heiser (9) concerning resistive force transmission to the flywheel during the exercise period were minimal. Therefore, resistive forces exceeding 9 kg were not used. On completion of the force velocity tests, subjects were again assigned in a random fashion to the running test or to the remaining cycle ergometer TBM or FFM protocol. Rest periods of one week were observed between the three experimental conditions.

Cycle Ergometer Test Protocol

A cycle ergometer (Monark 864) was calibrated prior to warm up and data collection. The calibration procedure followed the guidelines for friction loaded cycle ergometers outlined by Coleman, (6). The same calibration procedures were followed for the force velocity tests and 30 s cycle ergometer protocols.

Saddle heights were adjusted individually to accommodate partial flexion of the knee between 170° to 175° (with 180° denoting a straight leg position) in middle dead centre during the down stroke. Feet were firmly supported by toe clips and straps, and subjects were instructed to remain seated during the test. All subjects were verbally encouraged to perform maximally during testing, and all performed a standardised 5 min warm up prior to data collection following procedures outlined by Jaskolska et al. (10). Subjects were given a rolling start at approximately 60 rev/min followed by a 3 s count down after which individual loads were applied and data capture initiated simultaneously.

Values for PPO, MPO, FI %, and PR were determined from flywheel revolutions using an inertia corrected computer program (6). Data transfer was made possible using a suitably mounted sensor unit and power supply attached to the fork of the ergometer. The sampling frequency of the sensor was 18.2 Hz. Validity and reliability of the cycle ergometer as a test of anaerobic capacity has been reported as $r = 0.93$ (15).

Running Test

Subjects were required to run maximally on a modified aerobic shuttle run course. The original distance of the course was 20 m as outlined by Leger et al. (11). The running test protocol comprised of running between two markers placed 15 m apart in a sports hall, at speed increases of 0.28 m/s each minute. A reduction in distance of 5 m was implemented as a result of pilot study findings, which concluded that the original 20 m distance appeared to be too long for the increase in running speeds emitted by the audiotape. The high intensity shuttle run start point was located on a line identified clearly by markers.

Before commencement of the test, subjects were given a familiarization trial of five low intensity runs simulating experimental conditions. The protocol consisted of running to the first marker, turning and running again in the opposite direction in time with beeps emitted from a modified audiocassette tape recorded at twice the speed of the original (11). Failure to make the line in the prescribed time on two occasions resulted in disqualification from the test. Turning procedures for all subjects were standardised prior to data collection. Before testing, the audiotape used in the test was checked for accuracy and reliability. The time from the start of the test to the disqualification point was recorded digitally by the same experimenter. Reliability for the running test was established using a test re-test method prior to data collection ($r = 0.91$, $P < 0.01$). Subjects were required to perform maximally on each occasion.

The total time taken from the commencement of the test to volitional exhaustion (when the subjects failed to reach the line in the prescribed time) was taken as the criterion measure. Heart rate recordings for each subject were measured pre and post exercise using a short-range telemetry system (Sport Tester 3000, Polar Electro, Finland).

Capillary Blood Sampling

Duplicate blood samples were collected at the same time of day and by the same investigator in an attempt to control for biological and between subject variation (16). To help control for plasma volume changes, all resting samples were taken following 30 minutes of supine rest. The 5 min post exercise samples were taken with subjects placed in a supine position on a clinical couch to minimise any risk of fainting. This procedure was followed for all three protocols. All capillary blood samples were corrected for plasma volume changes using the equations of Dill and Costill (7).

Samples from the right ear lobe were collected using a capillary tube. All blood samples were analysed immediately post retrieval. Blood lactate concentrations were determined using an analox (P-LM5) lactate analyser. Haematocrit was analysed by the Hawksley micro hematocrit reader. The hematocrit reader was cleaned with alcohol between each subject. -haemoglobin was collected in a hemocue and measured with a photometer.

Statistical Analyses

Parametric statistical analysis was used in this study following conformation of a normal data distribution (SPSS). Paired t-tests were used to analyse differences between power indices, resistive force selection and pedal revolutions recorded for the two cycle ergometer tests. Pearson's correlation analysis was utilised to identify the degree of linear relationship between the cycle ergometry protocols, blood lactate concentrations and running performance. Correlational analysis was also used to investigate any relationships between heart rate responses measured for the three tests. Significance was accepted at $P < 0.05$.

RESULTS

Physiological characteristics of the group are given in Table 1. Performance data for cycle ergometry and the running test are given in Table 2. Significant differences were found between PPO for both the TBM and FFM protocols ($P < 0.01$). There were no differences observed between MPO or FI between the cycle ergometry experimental

Table 1. Mean \pm SD for physiological characteristics of subjects.

Variable	Mean \pm SD
Age (yrs)	23.3 \pm 2.1
Stature (cm)	183.5 \pm 7.7
Mass (Kg FFM)	74.6 \pm 9.1
Mass (Kg TBM)	87.2 \pm 11.2
Body Fat %	12.5 \pm 3.4

Table 2. Mean \pm SD values for power output measurements, cradle forces and pedal revolutions recorded for both cycle ergometer protocols. Running results, heart rates and post exercise blood lactate concentrations are also given.

Variable	TBM	FFM	Running Test
PPO (Watts)	1264 \pm 156	1366 \pm 177*	
MPO (Watts)	878 \pm 107	857 \pm 119	
Pedal revs (rev/min)	136 \pm 8.7	144 \pm 7.6*	
FI%	35 \pm 5	38 \pm 8	
Blood L rest (mmo/L)	0.8 \pm 0.5	1.1 \pm 0.8	0.8 \pm 0.3
Blood L p/ex (mmol/L)	12.2 \pm 1	12.9 \pm 1.7	13.6 \pm 1.8
Mass on cradle (Kg)	7.3 \pm 1.2	6.2 \pm 1.1*	
HR rest (beats/min)	72 \pm 6	70 \pm 8	70 \pm 4
HR post (beats/min)	176 \pm 8	179 \pm 6	184 \pm 6
Running Time (s)			71.4 \pm 7.5

* $P < 0.01$ Indicates differences between the TBM and FFM protocol.

Table 3. Correlation matrix and Standard estimate of Error (SEE) for Peak power outputs for both protocols. Linear relationships for blood lactate concentrations recorded for the three experimental conditions (5 mins post exercise) and immediate post exercise heart rate data are also given.

	R/Test vs. PPO (TBM)	R/Test vs. PPO (FFM)	PPO TBM vs. PPO FFM
Power Outputs	0.70 (100.3)*	0.88 (86.8)*	
Blood Lactate	0.63 (1.5)*	0.72 (1.3)*	0.59 (1.6)*
HR Post	0.59 (6.4)*	0.88 (3.4)*	0.61 (6.2)*

* Indicates significance at $P < 0.01$

conditions. Differences were observed between resistive forces and pedal revolutions ($P < 0.01$) when the TBM and FFM protocols were compared. High correlations were recorded between TBM and FFM for PPO and shuttle run times ($P < 0.01$). Interestingly, the FFM resistive force selection procedure accounted for more of

the variance in performance when the running test was compared to both the TBM and FFM protocols (Figures 1 and 2). Blood lactate concentrations for all tests were highly correlated ($P < 0.01$) and increased significantly ($P < 0.01$) from rest to post exercise for all three experimental conditions (Tables 2, 3). Exercise heart rate values of 176 ± 8 beats/min (TBM), 179 ± 6 beats/min (FFM) and 184 ± 6 beats/min were recorded for cycle ergometry, and the running test respectively and were also highly correlated ($P < 0.01$).

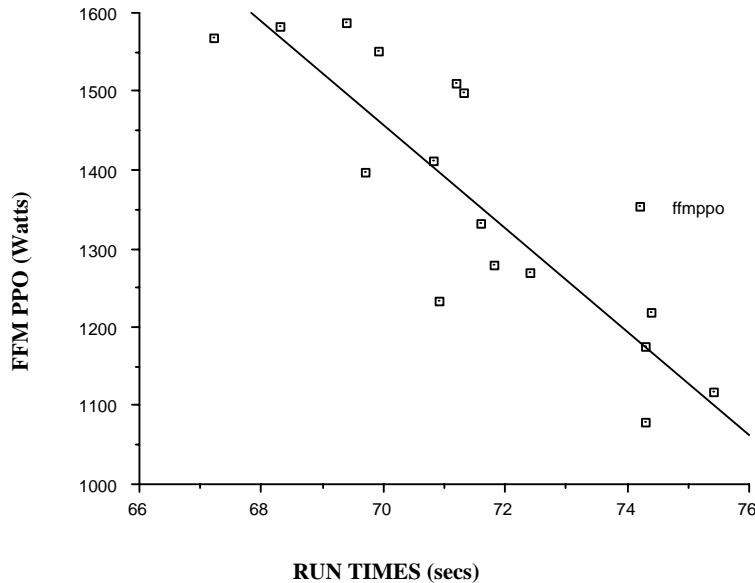


Figure 1. Graphical representation of linear relationship between PPO (Fat free mass) and running times recorded over the shuttle run course ($r = 0.88$, $P < 0.01$; $R^2 = 77\%$; Standard Error of Estimate (SEE) = 86.8 Watts).

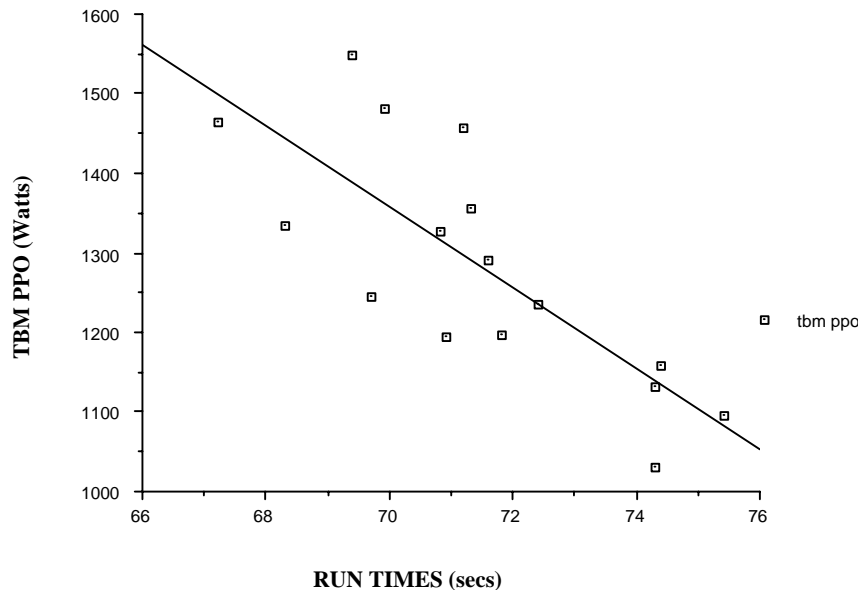


Figure 2. Graphical representation of linear relationship between TBM peak power output and running time. ($r = 0.70$, $P < 0.01$; $R^2 = 50\%$ Standard Error of Estimate (SEE) = 100.3 Watts).

DISCUSSION

Significant differences were found between PPO for both the TBM and FFM protocol ($P < 0.01$). The lighter resistive forces used during the FFM protocol resulted in a significantly greater pedal velocity when compared

to TBM ($P < 0.01$). The increase in pedal velocity contributed to the greater power outputs observed for the FFM protocol. This was consistent with resistive forces being significantly lighter during the FFM experimental condition ($P < 0.01$). Dotan et al, (8) reported that high power outputs during cycle ergometry were due to the optimisation of the resistive force. This was also true in the present study. However, the higher PPO values obtained for FFM resulted from an increase in pedal revolutions and a decrease in resistive force. These results are interesting when we consider that there were no differences observed for FI % between the TBM and FFM experimental conditions. The lack of significance observed may be the result of manipulations in resistive force selection that result in pedal velocity differences between the two protocols (higher resistive forces for TBM, and higher pedal velocities for FFM). These findings are in agreement with the suggestions of Wilkie (21) and Van Mil et al (20) who stated that force should be matched to the capacity of active muscle in order to exploit the full force velocity relationship. Significant linear relationships were recorded between the peak power output values for both the TBM and FFM protocols and the times recorded for the high intensity shuttle run test ($P < 0.01$).

These findings are in agreement with Cheetham et al. (5) who found strong linear relationships between running ability and high intensity PPO. More of the variation in performance was accounted for during the FFM protocol when running performances and both the TBM and FFM protocols were compared ($r = 0.70$, $P < 0.01$ $R^2 = 50\%$ TBM; $r = 0.88$, $P < 0.01$ $R^2 = 77\%$ FFM). The findings suggest that the FFM cycle ergometer protocol is more representative of high intensity performance than values that are inclusive of the fat component of body composition.

The design of the high intensity shuttle run course which includes slowing down at the end of each stage to facilitate turning, may weaken the relationship observed with the power outputs obtained during the cycle ergometry tests. However, strong correlations were recorded for both the TBM and FFM method of resistive force selection, which support the use of the test as a measure of high intensity running ability. During the quantification of high intensity performance the metabolic contribution of the aerobic system to energy supply during this type of activity has to be considered. Studies by Smith et al, (19) have suggested an aerobic contribution of 16% during a 30 s high intensity cycle ergometer test. Although inevitable, this high contribution is not desirable and may compromise the assessment of anaerobic capacity. The optimisation procedure for FFM may have maximised the anaerobic component and minimised the aerobic influence by virtue of the faster pedal velocities obtained. The higher power outputs may be the result of an increased utilisation of the phosphagen and/or glycolytic energy systems. It is unlikely that the increases in power observed for the FFM protocol was attributable to aerobic metabolism as the increase occurred in the first few seconds of exercise. Serrese et al, (17) and Smith et al, (19) have both suggested that aerobic metabolism plays a minor role in energy supply during high intensity exercise of 30 s duration until after 12 s.

The increase in contribution of aerobic metabolism to anaerobic performance as the exercise proceeds, may have contributed to energy supply during the running test and the cycle ergometer tests. This may be true in spite of the fact that the greater intensities of performance were observed in the early stages of the cycle ergometer tests and the later stages of the running test. In addition, aerobic metabolism may have been dominant in the early phases of the running test and may represent the low intensity performance required at this early stage. The greater contribution from anaerobic metabolism would have progressively increased as the intensity became more related to anaerobic ability. This would arise when the speed required to run each level of the course increased from the previous level. The values recorded for the high intensity shuttle run test (71.4 ± 7.5 s) suggest that all subjects reached a similar level of performance. This indicates that the audiotape speed may have been emitting beeps at a pace that was not attainable for most subjects at the volitional fatigue point. It also suggests that the subjects of the exercise group may have possessed similar physiological characteristics and were of a comparable training status.

During running performances power outputs can be divided into two components, a vertical component for lifting the centre of gravity and a horizontal component for propulsion. The vertical component was not

measured in this study. However, horizontal propulsive power is about 70% of the total external power at maximal running velocity (10). To some degree the running test values may be underestimated because velocity, force and power all increase and decrease during each stride depending on the phase of running (10). In spite of this, the strengths of the correlations obtained suggest that the FFM protocol represents a measure that is more related to high intensity running ability than the TBM protocol.

Body mass is an important component to consider in the assessment of high intensity performance, as the findings of this study demonstrate. However, other factors such as training specificity and the fiber type distribution within the muscle may also contribute to force generation over short time periods and need consideration (12). There were no differences in blood lactate concentrations pre or 5 min post exercise for the three experimental conditions. The TBM and FFM cycle ergometer test durations were the same, and the lack of statistical difference between the MPO values indicated that the magnitude of glycolytic activation was similar for both protocols. During the running test, despite the duration of performance being more than twice the magnitude of the cycle ergometer protocols, in the early stages of the test, the speeds observed are of a low intensity, and therefore may result in minimal lactate accumulation. Lactate production may exceed the rate of removal at higher levels of performance and accumulation may occur in the later stages as both speed and intensity of running increase. In addition, it is worth noting that both the TBM and FFM cycle ergometer protocols utilised maximal resistive forces, which may have contributed to the lactate values observed. Training status, muscle fibre composition and strength may also affect lactate production and removal. Heart rate values observed for the three protocols were highly correlated suggesting that the work intensities of each are related causing similar cardiovascular responses.

The correlations obtained between the high intensity shuttle run test and both the TBM and FFM cycle ergometry protocols indicate that the shuttle may be valuable in quantifying high intensity performance ability, when sophisticated laboratory measures are not available. The high intensity shuttle run test may be useful to individual athletes, and performers involved in most team sports, where the nature of the activity requires the assessment of high intensity running performance. The shuttle may also be used as a training aid to evaluate the success of training programmes where the emphasis is on the development of high intensity ability. In addition to the shuttle test being easy to administer, linear relationships obtained from test re-test procedures indicate that the test is both reproducible and reliable. The findings of this study indicate that a modified aerobic shuttle run test as a measure of anaerobic ability provided a viable protocol for the quantification of high intensity exercise during periods of short intensive work. The relative strengths of the correlations observed between the running tests and the different cycle ergometer protocols indicate that the FFM protocol was more related to running ability than the TBM procedure. Also, the cycle ergometer optimisation protocols examined, produced greater power outputs for FFM when compared to TBM. Loading procedures that relate to the active muscle tissue utilised during this type of exercise may need to be explored in preference to protocols that include both lean and fat masses.

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