JEP online
Journal of Exercise Physiology **online**

Official Journal of The American
Society of Exercise Physiologists (ASEP)

ISSN 1097-9751
An International Electronic Journal
Volume 7 Number 5 2004

Metabolic Responses to Exercise

INFLUENCE OF BODY MASS ON RESISTIVE FORCE SELECTION DURING HIGH INTENSITY CYCLE ERGOMETRY: INTERRELATIONSHIPS BETWEEN LABORATORY AND FIELD MEASURES OF PERFORMANCE.

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ABSTRACT

INFLUENCE OF BODY MASS ON RESISTIVE FORCE SELECTION DURING HIGH INTENSITY CYCLE ERGOMETRY: INTERRELATIONSHIPS BETWEEN LABORATORY AND FIELD MEASURES OF PERFORMANCE. **Julien Baker, Bruce Davies**. **JEP**online. 2004;7(5):44-51. The purpose of this study was to compare high intensity performance measures obtained from field tests with high intensity cycle ergometry power values when resistive forces were determined from total body mass (TBM) or fat free mass (FFM). Male soccer players (N = 11) volunteered as subjects. Cycle ergometry testing involved subjects cycling maximally for 6 s duration against resistive forces using a TBM or FFM protocol in conjunction with the British Association of Sport and Exercise Sciences recommended resistive force guidelines (BASES) for male soccer players of 80 g/kg. The field tests examined consisted of a 30 m sprint, and both horizontal and vertical jump tests. Significant correlations existed between cycle ergometry peak power outputs (PPO) using both the TBM and FFM protocols and all field measures of performance ($p < 0.01$). PPO pedal revolutions (PR) were significantly greater when the FFM protocol was compared to the TBM method of resistive force selection ($p < 0.01$). Significant reductions in resistive forces were observed for the FFM protocol ($p < 0.01$). The time to reach PPO significantly deceased ($p < 0.05$) using the FFM protocol. These findings suggest that increases in PPO are observed during high intensity cycle ergometry when resistive forces reflect the active muscle tissue utilized during the test. The findings also suggest that the cycle ergometry tests are highly related to field measures of high intensity ability. Coefficient of determination values (R^2) demonstrated that more of the variance in performance between the field tests and the cycle ergometer protocols was accounted for using the FFM method of resistive force selection. The sprinting and jumping tests were also significantly related ($p < 0.01$) indicating that they may be used interchangeably as predictive measures of high intensity performance.

Key Words: Exercise, Muscle Power, Strength

INTRODUCTION

Sports coaches and athletes are constantly searching for improvements in performance assessment methods that enhance athletic ability. Over the last two decade's athletes have become more powerful and athletic performances have continued to improve in conjunction with improvements in exercise training prescription. This has resulted in an increased interest in the measurement of anaerobic ability. Accurate anaerobic power assessment is paramount for athletes, as many sports involve rapid rest to high intensity exercise transitions such as sprinting and jumping movements. In addition, many team sports require participants to produce maximal or near maximal sprints of very short durations (e.g.1 – 7 s) (35,11). For example, the majority of sprints performed during a soccer match are less than 20 m in distance or approximating 3.5 s to complete (5). The sudden release of large amounts of energy to produce such high intensity performances can be provided in the main by the non-mitochondrial energy pathways involving ATP – PCr degradation and glycolysis.

Many measurement techniques have been used to quantify anaerobic capacity and power. These measures range from simple field assessments such as jumping tests, shuttle runs and sprints (23) to more sophisticated laboratory based measures such as photo electrically timed stair climbing (21) treadmill sprinting (13) and cycle ergometry (7,8). Probably the most popular exercise mode, cycle ergometry, has been widely used as the criterion measure to validate and equate laboratory based measures of power to anaerobic ability measured in field situations. In the assessment of high intensity exercise performance, strong linear relationships have been recorded between laboratory and field measures of anaerobic ability (8,9,26,2). However, other studies have found little or no statistical significance (32,35,4) for these relationships.

Previously, power outputs obtained during cycle ergometry have been expressed relative to total body mass (18,24,30), as indices of leg volume (20,27), or thigh cross sectional area (23,15). Traditionally, the resistive forces used for a high intensity cycle ergometry power tests have been determined from total body mass, (the multiplication of total body mass by a ratio standard normally 75 g/kg (1). However, many studies (17,16,25, 33,18,19,3) have questioned the optimal resistive force used in the assessment of high intensity ability. Increases in resistive forces in conjunction with optimization protocols have been beneficial in increasing the peak power outputs obtained (PPO). Expressing the power values recorded during high intensity cycle ergometry in relation to the volume of the leg has been used in an attempt to relate the power outputs to the active muscle tissue utilized during the exercise task (17,20). More recently, researchers have questioned the total body mass method of resistive force selection, and it has been clearly demonstrated that fat free mass or active muscle tissue may be a better alternative in the assessment of high intensity ability (18, 31, 3). The aim of this study was to evaluate the 6 s cycle ergometry performance of eleven moderately trained soccer players when resistive forces were calculated from total body mass (TBM) or fat free mass (FFM). A further aim was to examine their linear relationship to jumping and sprinting ability.

METHODS

Subjects

Eleven male university students (moderately trained soccer players) volunteered to participate in the study. Ethical procedures were approved by the University ethics committee and after being fully informed of the nature of testing and experimental procedures each subject read and signed an informed consent form. Subjects' age, height, body mass and body composition were recorded prior to testing (see Table 1).

Experimental Overview

Testing was completed over a four week time period. Week 1 consisted of cycle ergometer and field test habituation periods. These were performed at the same relative time interval as the experimental protocols themselves. Anthropometric data was also collected and recorded during this period. Cycle ergometry testing and field measures commenced in weeks 2, 3 and 4. Testing of each subject was carried out at the same time of day after an 8 hour overnight fast to avoid circadian and dietary influences on performance, also all subjects were instructed to avoid heavy exercise during the 24 hours preceding the tests.

Anthropometric Measures

Individual subject body mass, stature and body composition was determined using a calibrated balanced weighing scale (Seca, UK), stadiometer (Seca, UK). Nude body mass was measured to the nearest 0.1 kg and stature to 0.1 cm. Body density was assessed using underwater techniques as described previously (10). Relative body fat was estimated from body density (28). Residual lung volume was measured using a simplified oxygen re-breathing method (34). FFM mass was determined by subtracting fat mass from TBM.

Terminology

Throughout the study peak power output (PPO) refers to the highest amount of power produced during the test and is measured in Watts. PR refers to the highest pedal revolution recorded during the test (rev/min).

Cycle Ergometry

A cycle ergometer (Monark 864) was calibrated prior to data collection (14). Subjects were randomly assigned in a crossover design to the TBM or FFM resistive force. The appropriate resistive force was calculated by multiplying individual TBM or FFM by a ratio standard of 80 g/kg. This ratio standard was selected as it represents the standard resistive force recommended for the anaerobic assessment of soccer players by the British Association of Sport and Exercise Sciences (12). Each subject returned to perform the remaining test with one week intervening between experimental conditions. Saddle heights were adjusted to accommodate partial knee flexion of between 170° to 175° (with 180° denoting a straight leg position) during the down stroke. Feet were firmly supported by toe clips and straps. All subjects were instructed to remain seated during the test and were verbally encouraged to perform maximally.

All subjects performed a standardized 5 min warm up prior to experimental data collection (19). Subjects were given a rolling start at 60 rev/min for a 5 s period prior to resistive force application. On the command 'go', the subjects began to pedal maximally, the resistive force applied simultaneously, and data capture initiated. Indices of performance were calculated from flywheel revolutions using an inertia corrected computer program (14). Peak power output (PPO), time to PPO (T/PPO) and pedal revolutions (PR) for both the TBM and FFM protocol were stored on computer and saved for future analysis. Data transfer was made possible using a mounted sensor unit and power supply attached to the fork of the ergometer located opposite the flywheel. The sampling frequency of the sensor was 18.2 Hz.

Sprint Test

Subjects were required to run between markers placed 30 m apart in a sports hall. Individual sprint times were recorded by the same experimenter using a digital stopwatch. Subjects were required to complete three maximal efforts in total. The fastest of the three times was used as the criterion measure. Reliability for timing was established during a pilot study prior to data collection using a test retest method ($r = 0.94$, $p < 0.01$).

Jump Tests

Vertical and horizontal jump test were also performed in a sports hall. The best of three values was used as the criterion measure in both tests. Procedures for test administration and design have been outlined elsewhere (6). Established reliability for the jump tests was $r = 0.92$, $p < 0.01$.

Statistical Procedures

Data were analyzed using a computerized statistical package (SPSS, Surrey England). Conformation that all dependent variables were normally distributed was assessed via repeated Kolmogorov-Smirnov tests. Students paired t-tests were used to determine any differences observed between power outputs, pedal revolutions and resistive forces using the TBM and FFM protocol. Pearson’s product moment correlation was employed to investigate the degree of linear relationship between field tests and the two cycle ergometry experimental conditions. Significance was accepted at the $p < 0.05$ level. Data are presented as means ± SD.

RESULTS

Subject anthropometric data and field test results are presented in Table 1. Significant differences ($p < 0.01$) were recorded between subjects TBM and FFM (78 ± 10 kg TBM vs. 65 ± 7 kg FFM). The cycle ergometry performance data is presented in Table 2.

Differences ($p < 0.01$) were observed between the PPO measures recorded during the two different methods of resistive force selection (1235 ± 138 Watts TBM vs. 1379 ± 146 Watts FFM). Significant differences ($p < 0.01$) were also recorded for resistive force selection (6.2 ± 0.8 kg TBM vs. 5.2 ± 0.6 kg FFM) and pedal revolutions (123 ± 9 rev/min TBM vs. 139 ± 8 rev/min FFM). Differences ($p < 0.05$) were also observed for the time to reach PPO (3.3 ± 0.7 s TBM vs. 2.6 ± 6 s FFM) when the two protocols were compared.

Table 1. Physiological and anthropometric characteristics of subjects. Also included are field test results.

Variable	*Mean ± SD*
Age (yr)	20 ± 6
Stature (cm)	183 ± 8
Mass (kg)	77 ± 10*
Body Fat (%)	16 ± 5
Fat Free Mass (kg)	65 ± 7*
Horizontal Jump (cm)	224 ± 26
Vertical Jump (m)	0.54 ± 0.1
30 m Sprint (secs)	4.67 ± 0.3

Values are Means ± SD
* Indicates significance at $p < 0.01$

Significant linear relationships between the TBM and FFM cycle ergometer protocols and the field tests are presented in Table 3. Significant relationships were found between 30 m sprint times and cycle ergometry PPO values ($r = 0.78$, $p < 0.01$; $R^2 = 60\%$ TBM vs. $r = 0.82$, $p < 0.01$; $R^2 = 67\%$ FFM). Vertical jump tests were correlated with TBM and FFM peak power outputs ($r = 0.72$, $p < 0.01$; $R^2 = 51\%$; $r = 0.81$, $p < 0.01$ $R^2 = 66\%$, respectively), as was horizontal jumping ($r = 0.74$, $p < 0.01$; $R^2 = 54\%$; $r = 0.77$, $p < 0.01$; $R^2 = 59\%$ respectively). Significant correlations were also observed between the 30 m sprint test and both jumping tests (vertical jump $r = 0.88$, $p < 0.01$; $R^2 = 77\%$, horizontal jump $r = 0.89$, $p < 0.01$; $R^2 = 79\%$). Horizontal and vertical jump tests were also interrelated ($r = 0.98$, $p < 0.01$; $R^2 = 96\%$).

Table 2. Peak power outputs (PPO), resistive forces (R force), time to PPO (T PPO) and pedal revolutions (P revs) recorded for the TBM and FFM resistive force selection procedure.

Variable	*TBM*	*FFM*	*Sig*
PPO (W)	1234 ± 137	1379 ± 145	$p < 0.01$
T PPO (s)	3.3 ± 0.7	2.6 ± 0.6	$p < 0.05$
R Force (kg)	6.2 ± 0.8	5.2 ± 0.5	$p < 0.01$
P revs (rev/min)	123 ± 8.8	139 ± 7.5	$p < 0.01$

Values are Means ± SD

The R^2 values obtained for the cycle ergometer protocols and the field tests measured indicate that the FFM method of resistive force selection accounted for more of the variance in performance when compared to the TBM experimental condition.

Table 3. Correlation matrix for all performance variables.

	30 m	*H/J*	*V/J*	*PPO (TBM)*	*PPO (FFM)*
30 m	1.00	0.89*	0.88*	0.78*	0.82*
H/J			0.98*	0.74*	0.77*
V/J				0.72*	0.77*
PPO (TBM)					0.96*
PPO (FFM)					1.00

* Indicates significance at $p < 0.01$

DISCUSSION

Significant differences ($p < 0.01$) were recorded between individual subject's TBM and FFM (78 ± 10 kg TBM vs. 65 ± 7 kg FFM). Results from this study demonstrate that significant increases in PPO ($p < 0.01$) can be obtained when resistive forces were determined using a FFM resistive force selection protocol. This finding clearly demonstrates the negative effect on high intensity cycle ergometer performance when resistive forces are calculated from body mass and not composition. The non-productive fat mass appears to bias individual performance during high intensity cycle ergometry resulting in under achievement when peak power output assessment is desirable. This may have serious implications, not only in the measurement of anaerobic ability in athletic populations, but also in the pathology of muscular disease.

Significant correlations were observed between the field tests of high intensity performance and both the TBM and FFM cycle ergometry protocols ($p < 0.01$). The strengths of the correlations indicate that PPO values obtained from the 6 s maximum cycle ergometry test using the TBM and FFM method of resistive force selection indicate that they are both related to sprinting and jumping ability. The results demonstrate that subjects with higher PPO are superior sprinters and jumpers. This suggests that cycle ergometry is measuring a similar aspect of intense exercise performance as the jumps and sprints. These findings are in agreement with other researchers (7,26,2) who have recognised a relationship between high intensity cycle ergometry and sprinting ability. Interestingly, the coefficient of determination values (R^2) recorded for the FFM protocol for sprinting ability and both vertical and horizontal jumping ($R^2 = 60\%$ TBM vs. $R^2 = 67\%$ FFM ; $R^2 = 51\%$ TBM vs. $R^2 = 66\%$ FFM ; $R^2 = 54\%$ TBM vs. $R^2 = 59\%$ FFM respectively) indicate that more of the variance in performance was accounted for using this method of resistive force selection. This observation may be related to the fact that the FFM protocol approximates more closely to muscle contraction dynamics and contraction times associated with the sprinting and jumping tests. This can be verified by the decrease in time to reach PPO, the increase in pedal velocity and the greater power outputs recorded using this protocol.

The results from this study agree with other authors (18,31,3) who suggest that individual subjects FFM or active muscle tissue should be used when determining resistive forces used during high intensity cycle ergometry. This is in contrast to other researchers who found poor relationships between laboratory measures of cycling power and sprinting ability. Wragg et al. (35) found poor correlations between incremental treadmill sprinting ability and a repeated sprint test. Watson et al. (32) found 40 s cycle ergometry to be poorly correlated with repeated sprint ice skating ability. However, sprint tests in both studies included an agility component, i.e. a turn or change in direction that may have influenced the results. These considerations strengthen support for evaluating high intensity ability through a battery of sport specific field tests in conjunction with laboratory-based measures. The present study found significant relationships between all field measures of high intensity performance ($p < 0.01$). The jump test results were extremely interrelated which suggests that both tests used the same instantaneous component of power and used the same three extensor muscle groups (22). Vertical and horizontal jumping ability also corresponded with sprinting ability ($p < 0.01$), which suggests that the sprint and jump tests may be used interchangeably as measures of anaerobic performance. This supports previous findings by Baker and Davies (4) who observed significant correlation's between vertical and horizontal jump tests and sprinting performance ($P < 0.01$). Horizontal jumping was found to be a slightly better predictor of sprinting ability, which agrees with the findings of Tharp et al. (29). This may be related to the direction of the muscle propulsive force during horizontal jumping. The propulsive force may be acting in a direction more related to running ability than vertical jumping and may be reflecting a specificity of contraction component that relates to the direction of the task. Therefore, when indicators of running ability and laboratory procedures may not be available (e.g. in an injury situation) horizontal jumping may be the preferred measure of sprint related performance due to its simplicity. It is important to remember that high intensity cycle ergometry is advantageous in that it provides a quantitative measurement of anaerobic power and capacity while providing a fatigue profile for any given time period. This information would be particularly beneficial in relation to team sports such as soccer and basketball that involve short bursts of energy.

However, if sprinting ability is the main objective it is simpler to measure sprint time as opposed to any indirect marker of high intensity ability. Baker and Davies (4) observed no significant relationships between 30 s maximal cycle ergometry PPO and a 30 m straight line sprint. These authors concluded that the cycle ergometer test used in their study may have been measuring different components of high intensity ability to that of the field tests. These differences may be explained by contrasts in subject training status and resistive load selection. Baker and Davies (4) used elite trained international sprinters who may have been more powerful and had greater running efficiency than the moderately trained soccer players examined in this study. This may have weakened the strengths of the relationships observed with sprint performance. In addition, the resistive forces used in the previous study did not reflect FFM. The observed correlations between the cycle ergometry and field tests in this study indicate that the resistive forces used for soccer players must have closely replicated that of the forces exerted by the muscle mass when performing the weight bearing sprint and jump tests. The resistive load of 80 g/kg used in the present study appears to approximate more closely to the 75 g/kg employed in previous studies that have observed correlations between cycle ergometry and field tests of high intensity ability (8,2). This compares to a much heavier load of 120 g/kg used by Baker and Davies (4) for their elite male sprinting group and may help to explain the lack of significance observed. The shorter exercise time period used in this study may also have contributed to a more accurate reflection of sprinting and jumping ability than a 30 sec cycle ergometer test. Although it is recognized that PPO will probably be reached in the very early stages of a 30 s test it is conceivable that subjects may pace themselves during a 30 s protocol in the knowledge that the test duration is demanding. This may have a corresponding negative effect on any correlation analysis performed between the recorded PPO and measures of high intensity ability.

CONCLUSIONS

The findings of the present study suggest that high intensity cycle ergometry can be used in the evaluation of sprinting and jumping ability. When cycle ergometry resistive forces were calculated from the FFM component of body composition a significantly increased PPO was achieved when this protocol was compared to the TBM method of resistive force selection. The increased power values obtained were probably due to the resistive force matching the capacity of the active muscle tissue mass resulting in lighter flywheel loads allowing subjects to reach a higher pedal velocity during the FFM experimental condition. The R^2 values obtained between the FFM resistive force selection protocol and the field tests indicate that this method of resistive force selection accounted for more of the variance in performance when compared to the TBM protocol. This suggests that the FFM experimental conditions may be approximating more closely the contraction times and speeds associated with the sprint and jump tests. The findings from this study suggest that high intensity cycle ergometry can be a useful tool in the evaluation of high intensity performance especially when the resistive forces used reflect FFM. The linear relationships observed in this study between the field measures of power and cycle ergometry suggest that the field measures can be used as valid indicators to assess high intensity performance.

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