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Review Article

Optimalresistive Force Selection and Upper Body Contribution in the Assessment of Power during High Intensity Cycle Ergometry: An Unresolved Issue

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Abstract

The purpose of this study is to outline and comment on the issue of optimal resistive force selection and the upper body contribution during high intensity performance using cycle ergometers. The paper provides an historical perspective of the experimental research in developing optimal resistive forces, and the upper body contribution to the test. To date, these issues are still unresolved and further work is needed to provide valid and reliable optimal resistive forces, and to consider the upper body contribution during anaerobic performance assessment of specific subject populations. Studies are needed to identify the optimal resistive force and velocity for subjects who span a wide range of body masses and abilities. These studies should include athletes of various specialties and proficiency. Further to this, the studies should also explore individuals with disabilities and muscular and neurovascular disorders such as, obesity, muscular sclerosis and muscular dystrophy.

Introduction

The assessment of the optimal resistive force used during cycle ergometry has been historically difficult because the relationship between force and mean power has been demonstrated to be parabolic. The value for resistive force traditionally used is either a standard (5.5 g.kg-1 total body mass using a Monark cycle ergometer) or is related to a body mass ratio [1]. Standardization of the Wingate test, to date, does not consider active muscle mass. Therefore, the question remains whether current resistance settings result in the highest and most accurate power profiles attainable. Choosing a force setting that would elicit the highest possible peak power for individual subjects is important and yet unresolved.

The original resistive force suggested was 75 g.kg-1 total body mass [2]. This force is equivalent to a mechanical work of 4.4 J.rpm.kg-1 total body mass. Katch, [3] used cycle ergometry to determine experimentally, whether body mass played a major role in predicting individual differences in work performed above the anaerobic threshold for the full duration of effort. The results obtained showed that body mass, leg volume, and leg mass were of little importance during the initial stages of performance but became more important as work output progressed. Evans and Quinney, [4] proposed an equation predicting optimal resistance from leg volume and total body mass.

It was concluded that the Evans - Quinney regression equation for optimal resistance settings produced higher power output scores than the relative mass Wingate scores. This may be partly explained by the higher resistive forces used in this protocol. This finding contrasted with other studies [3,5] who found leg volume to be of little importance during the early stages of a high intensity performance test. Nakamura *et al.* [6] suggested an optimization procedure for determining power output during very brief maximal pedaling exercise.

He suggested cycling against increases in resistive loads

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ranging from 28.1 to 84.2 Nm. The maximal pedaling rate was determined from the minimal time required for one rotation of the cycle wheel. Pedaling rate decreased linearly with increases in load.

The relationship between load and pedaling rate, was represented by two linear regression equations for each subject. One regression equation was determined from eight pairs of pedaling rates and loads (r = 0.98, $P < 0.05$), the other from three pairs (r = 0.97, $P < 0.05$). It was concluded that maximal power could be simply determined by performing maximal cycling exercise at three different loads. However, these findings did not consider individual training status or physiological subject variation. When the results of maximal tests performed against different resistive forces are expressed in units related to the data of a force velocity test performed on the same cycle ergometer, the optimal force is equal to approximately 47% of the maximal isometric force for men and women.

Patton *et al.* [5] found that maximal peak power was obtained with a resistance almost equal to the optimal resistance for mean power. This study investigated non-athletic military personnel and, although interesting, had low validity. Mannion and Jakeman, [7] compared glycolytic work capacity measured over a fixed time (30 sec) with work capacity attained during the time at which optimal velocity could be monitored (60 rpm) using a modified Wingate test. Peak velocity, mean velocity, peak power output and mean power output were calculated for each resistance setting. The results indicated that the velocity-based test represented a more physiologically relevant test of high intensity capacity. This finding may have been related to the speed of contractions observed during the velocity test and may have been more representative of high intensity performance. Evans *et al.* [4] used cycle ergometry to determine the resistance setting for maximal power testing. The power tests were performed on a modified Monark cycle ergometer. The purpose of the study was to compare power outputs achieved on relative Wingate resistance settings on individual subject power curves. A power *vs* force curve was determined for each subject by progressive increases in resistance throughout the test.

It was concluded that maximum power occurred from an optimal combination of resistance settings and pedal frequencies and suggested that both force and velocity need to be optimal if accurate power profiles are required.

The maximal anaerobic power of top athletes was the subject of an investigation by Crielaard and Pirnay, [8]. They compared the power profiles of elite sprinters, long distance runners and untrained students. Power values were calculated by the product of the rotational frequency of the wheel multiplied by load. The rotational frequency of the wheel was measured using an electronic photocell and integrator. The average peak power of the control group was 710W. Significantly lower results were obtained for long-distance runners, (551W) whereas significantly higher values were obtained by the sprinters (1021W). Conceptually, selecting the optimal force according to total body mass may not be the best approach fat-free mass or active muscle mass, for example may be better alternatives.

These methods may reflect more closely the relative contribution of muscle mass to power and force production [9]. It should also be noted that, when selecting a force that does not represent an actual optimal force, errors in power estimation will be introduced leading to inaccuracies in power calculation and quantification [5,10]. This has implications for the assessment of athletes and the clinical assessment of patient populations. Dotan and Bar-Or, [10] identified optimal loads for eliciting maximal power outputs during the 30-sec Wingate anaerobic test. Five randomized evenly spaced resistance loads, ranging from 2.43 to 5.39 J-1.rpm. kg-1 total body mass, were used. The measured variables were mean and peak power outputs, as well as absolute and relative measures of fatigue. Optimal loads were shown to depend on power output magnitude.

Results showed that although the Wingate test was rather insensitive to moderate variations in load assignment, improved results could be obtained by using optimum resistive forces as guidelines. The guidelines established could be modified according to individual body-build, composition and fitness levels.

Peak power and the power capacities of males and females have been studied by Simoneau *et al.* [11]. The power test used consisted of a 10-sec all out ergo cycle test, with resistance settings determined by individual subject's total body mass.

A similar protocol was used for the capacity test, the only difference being, that the subjects pedaled for 90-sec at maximal intensity, instead of 10-sec. In both tests, males exhibited greater capacities, and work outputs, when the results were expressed in watts or watts.kg-1 total body mass. The findings may have been more meaningful if the values obtained had been expressed in watts.kg-1 fat-free mass, enabling early direct comparisons with total body mass and active tissue. Using the Wingate test and the Evans-Quinney protocols, with and without toe stirrups, was the subject of a study by Lavoie *et al.* [12]. The Evans Quinney protocol which considers leg volume, as well as total body mass in establishing optimal load settings, has been shown to result in significantly higher power outputs than the body-mass relative Wingate protocol. Subjects performed a total of four maximal 30-sec power tests, utilizing the settings established by the Wingate protocol (75 g.kg-1 total body mass).

It was concluded that the Evans-Quinney load settings protocol, with toe stirrups, resulted in significantly higher power outputs than any of the other protocols tested. However, if the loads had been optimized, higher values for power may have been recorded. Also, if toe stirrups were used consistently for all tests, the differences in power profiles may have been smaller. Tharp *et al.* [13], measured capacity and power in elite young athletes using the Wingate anaerobic test. Test responses were obtained using a Monark cycle ergometer in conjunction with Wingate test procedures.

The resistance settings were adjusted for individual body mass (75 g.kg-1 total body mass). Results showed that male sprinters developed greater glycolytic capacity than distance runners. High intensity power and capacity were found to be related to age, mass, lean body mass, and surface area. It also appeared that the Wingate test could distinguish between sprint and endurance trained individuals.

Power output duringone-minute strenuous muscular performance was investigated in a study by Hakkinen *et al.* [14].

The study examined whether the power produced during various phases in a 60-sec cycle ergometer test reflected the different backgrounds of power lifters.

The power of the subjects (n = 14) was assessed by a 60-sec maximal test on a Monark cycle ergometer.

The friction force of the ergometer was 1/13 of the subject's total body mass. Power output (W.kg-1) was calculated every 15 seconds during the test. Findings indicated that the measurement of muscular power during 60-sec maximal work seemed useful in differentiating athletic groups, with different training backgrounds and agreed with the findings of Tharp *et al.* [13]. Vandewalle *et al.* [15] studied maximal glycolytic capacity using cycle ergometers. They examined the effects of braking force selection, on the results of a high intensity test, performed on a cycle ergometer. Subjects performed a force velocity test on the same cycle ergometer. The relationship between force and power was found to be parabolic. Results showed that maximal power and capacity could be evaluated with the same force. There were no differences recorded between men and women in the maximal power capacity test when force, mean velocity and mean power, were expressed as percentages of Fo (the intercept of the force velocity regression line with the force axis), Vo (the intercept of the regression line with the velocity axis) and Wm (maximal power). The findings also indicated that power assessment was related to both the force and velocity of contraction. Performance during the Wingate 30-sec test, and muscle morphology in males and females, has been the subject of a study by Froese and Houston, [16]. Performance indices and relationships with the muscle morphology of the vastus lateralis muscle was studied in 30 untrained male and female athletes. High intensity performance was measured by a 30-sec cycle ergometer test. Resistance settings were determined from a regression equation incorporating total body mass and leg volume. Absolute values for peak power, total work performed, power decrease and post blood lactate concentrations were significantly greater in male subjects. The results indicated a significant influence of muscle morphology *($P < 0.05$)* on short term high intensity work performance and that male subjects could generate greater power outputs than females. McCartney *et al.* [17] studied power output and fatigue in human muscle during maximal cycle exercise.

Maximum torque showed an inverse linear relationship to crank velocity between 60 and 160 rpm, and a direct relationship to thigh muscle mass measured by computer topography.

The decline in power output during the 30-sec test, was found to be greater at 160 rpm (58.7%) and the least at 60 rpm (23.7%). Power curves generated for each subject were analyzed for peak power output, time to peak power and fatigue rate index. Peak power output values ranged from 846 to 1289W. Correlation analysis revealed high test-retest reliability (r = 0.94, $P < 0.05$). Despite these findings, the issue of optimal loads or braking force selection during high intensity cycle ergometry needs further investigation. In addition to this, observations of subjects performing the tests revealed a reliance on the upper body, particularly in the early stages of the test. To examine this concept, Baker *et al.* [18] considered the influence of hand grip on the performance of high intensity cycle ergometry. Indices of mechanical power output were obtained from twelve subjects during high intensity leg cycle ergometry tests (20 second duration; 75 grams per kilogram total body mass) using two protocols: one with a standard handle-bar grip (with-grip), and one with supinated wrists (without-grip). Peak mechanical power, mean mechanical power, fatigue index and total mechanical work values were calculated for each subject during each test, and the sample mean differences associated with the two protocols were compared using paired Student t-tests. The with-grip protocol yielded significantly greater peak mechanical power output and greater fatigue index than the without-grip protocol (886 +/- 124W and 815 +/- 151W, respectively; and 35 +/- 10% and 25 +/- 8%, respectively; p<0.01). The electrical activity of the anterior forearm musculature was measured in the twelfth subject during the performance of each of the test protocols. While peak mechanical power output was greater during the with-grip protocol, than during the without-grip protocol, the electromyographs showed much greater forearm muscle activity during the with-grip protocol. Thus, the protocol which allowed for the greatest measure of peak leg power output was also associated with considerable arm muscle activity.

This was an interesting finding, as it appeared that the hand grip provided greater fixation to the saddle for subjects during the test and that the greater fixation observed provided greater downward deflections of the legs contributing to the power profiles generated. The findings also indicate that upper body strength may be contributing to the measurement of leg power using cycle ergometry.

These findings should be considered when biochemical and physiological measurements are obtained from arm blood samples. The isometric contractions of the arms recorded during the test will contribute to occlusion reperfusion dynamics and may prevent accurate biochemical interpretations for immediate post exercise blood collection protocols. This may result in blood samples representing biochemical parameters associated with upper body contractions only and not total body systemic blood profiles

To examine further the influence of muscle morphology on resistive force selection, Baker *et al.* [19] investigated power profiles, and selected biochemical parameters using resistive forces were derived from Total Body Mass (TBM) or Fat Free Mass (FFM). Cradle resistive forces for individual subjects during the study were obtained using optimization procedures for resistive force selection. TBM and FFM body composition indices were determined using hydrostatic weighing techniques.

Significant differences (P<0.05) were recorded for peak power outputs, pedal revolutions, and selection of cradle resistive forces when comparisons were made between protocols [953 (114) W vs 1,020 (134) W; 134 (8) rpm vs 141 (7) rpm; 6 (1) kg vs 5 (1) kg respectively). (P<0.05). Findings from the study indicated that larger power outputs were possible with minimal oxidative stress and muscle damage when resistive forces were derived from FFM compared to TBM.

To explore these findings in different populations, Baker *et al.* [20] investigated the anaerobic ability of subjects that were overweight and obese during cycle ergometer exercise of 10 s duration using resistive forces derived from TBM or FFM. Subjects were allocated to either protocol using a randomization protocol. Body composition characteristics were again determined using hydrostatic weighing.

University male students (age 22.3 +/- 2 yrs., body fat 27.1 +/- 2%) volunteered as subjects for the study (n = 11). Significant differences (P < 0.01) in Peak Power Outputs (PPO) were recorded between protocols (1029 +/- 98 W TBM vs. 1397 +/- 146 W FFM). The study findings indicated that larger power outputs were achievable using the FFM cradle protocol and that the FFM protocol seems to maximizeadenosine triphosphate-phosphocreatine (ATP-PC) as an energy source resulting in less contribution from anaerobic glycolysis when compared to TBM. Despite the findings obtained from prior experimentation, studies are still needed to identify the optimal resistive force and velocity for subjects who span a wide range of body masses and abilities.

Related to the findings observed for the upper body contribution to the test via the handgrip, Grant *et al.* 2015 investigated the effect of repeated cycling sprints on power profiles while assessing upper body muscle contribution and contractions. Eighteen physically active participants (males and females) performed 8 × 10 s repeated sprints while muscle activity was recorded via Surface Electromyography (sEMG) from the Brachioradialis (BR), Biceps Brachii (BB), Triceps Brachii (TB) and Upper Trapezius (UT). Measurements were obtained at rest, during a Functional Maximum Contraction (FMC) while participants were positioned in a seated position on the cycle ergometer during the repeated sprint protocol. Results suggested that mainly type I Muscle Fibers (MFs) were being recruited in the upper body musculature due to the submaximal and intermittent nature of the contractions.

Subsequently, there was no evidence of upper body fatigue across the sprints, which was reflected in the lack of changes in the median frequency of the power spectrum ($P<0{\cdot}05$).

Conclusion

In addition, to the problems outlined for resistive force selection based on TBM, there is also a significant contribution from the upper body during the assessment of high intensity exercise using cycle ergometers that contributes to errors in the estimation of power profiles.

Specific cradle resistive force selection and the upper body contribution needs to be evaluated for specific athletic population of different abilities including team sports, sprinters, track and field athletes, swimmers and individuals involved in aerobic activities. The upper body strength of participants needs consideration prior to engaging in a cycle ergometer test, as this feature of upper body muscularity clearly influences leg power profiles. Future research should evaluate athletes of various specialties and proficiency, while standardizing resistive force selection and the upper body contribution to the test. Upper body strength should be assessed and evaluated prior to participation in cycle ergometry experimentation. Redesign of high intensity cycle ergometers that include force transducers on the handle bar site may also provide a useful methodology for quantifying the upper body contribution to the test. This will provide important information in relation to the values obtained for leg power. In addition to athletic populations, individuals with disabilities, muscular disorders and neurovascular problems of all ages and genders should also be deemed suitable for anaerobic evaluation. These include individuals with obesity, muscular dystrophy, multiple sclerosis, and dementia.

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