David V.B. James ✉, Dan M. Wood, Tom C.B. Maberly and Mark De Ste Croix

Faculty of Sport, Health & Social Care

University of Gloucestershire

Oxstalls Campus

Oxstalls Lane

Gloucester

GL2 9HW

UK

Tel: 01452 876634

Fax: 01452 876648

email: djames@glos.ac.uk

✉ **Author to whom all correspondence should be addressed**

Title:

Optimised versus corrected peak power for friction-braked cycle ergometry in males and females

Running title:

Peak power for friction-braked cycle ergometry

Key words:

Peak power – friction-braked cycle ergometry – inertial correction

Abstract

The aim of this study was to compare optimisation and correction procedures for the determination of peak power output during friction-loaded cycle ergometry. Ten male and 10 female sports students each performed five 10 s sprints from a stationary start on a Monark 864 basket-loaded ergometer. Resistive loads of 5.0, 6.5, 8.0, 9.5, and 11.0 % body mass were administered in a counterbalanced order, with a recovery period of 10 min separating successive sprints. Peak power (PP) was greater and occurred earlier, with less work having been done prior to the attainment of PP, when data were corrected to account for the inertial and frictional characteristics of the ergometer. Corrected PP was independent of resistive load ($p > 0.05$), whereas uncorrected PP varied as a quadratic function of load ($p < 0.001$). For males and females, optimised PP (971 ± 122 and 668 ± 37 W) was lower ($p < 0.01$) than either the highest (1074 ± 111 and 754 ± 56 W) or the mean (1007 ± 125 and 701 ± 45 W) of the five values for corrected PP. Optimised and mean corrected PP were highly correlated in both males ($r = 0.97$, $p < 0.001$) and females ($r = 0.96$, $p < 0.001$). The difference between optimised and mean corrected PP was 37 ± 30 W in males and 33 ± 14 W in females, of which ~15 W was due to the correction for frictional losses. We conclude that corrected PP is independent of resistive load in males and females.

Introduction

The original procedure for sprint testing on a cycle ergometer is simple to perform, requiring only a friction-braked cycle ergometer and a stopwatch (Ayalon et al., 1974). There were however limitations, which researchers have sought to overcome through modifications to the original procedure. First, optical sensors and computer-based data logging systems are now typically used (in preference to visual observation) for the measurement of flywheel (as opposed to crank) displacement (e.g., Seck et al., 1995; Linossier et al., 1996; Martin et al., 1997; Coleman and Hale, 1998; Reiser et al., 2000, Duche et al., 2002). Second, optimisation procedures have been developed (Nadeau et al., 1983; Nakamura et al., 1985) to account for the fact that power output for the original protocol is load sensitive. Third, correction procedures have been developed (Lakomy, 1986; Coleman and Hale, 1998) to account for the energy that is stored in the flywheel during acceleration or released from the flywheel during deceleration. Fourth, the original starting protocol, which required subjects to accelerate to a maximal cadence against a minimal resistance prior to the start of the test, has been modified: stationary starts are now common (Seck et al., 1995; Arsac et al., 1996; Hautier et al., 1996; Linossier et al., 1996), as are tests in which the subject accelerates to a moderate (as opposed to maximal) cadence prior to the start of the test (Lakomy, 1986; Winter et al., 1996; Coleman and Hale, 1998; Reiser et al., 2000).

Nakamura et al. (1985) proposed an optimisation procedure for peak power. Each subject performed eight 10 s sprints against eight different resistive loads. The peak pedal cadence decreased linearly as the applied load increased, such that power output varied as a quadratic function of resistive load. Differential calculus was used to obtain both the optimised peak power and the associated optimal load from this quadratic relationship. Similar procedures have been adopted by other investigators to derive optimised peak power and the associated optimal load (Nadeau et al, 1983; Vandewalle et al., 1985; Winter et al., 1996).

Correction procedures that allow the work done in accelerating the flywheel to be taken into account in the measurement of power output were originally developed by Lakomy (1985; 1986) and later developed by Coleman and Hale (1998). Both procedures attempt to account for frictional losses due to the ergometer's bearings in addition to flywheel inertia. Although both studies account for frictional losses in different ways, the two approaches yield similar results (Coleman and Hale, 1998). Provided a moderate cadence or stationary start is used, peak power is higher and occurs earlier when data are corrected for the work done in overcoming the inertia of the flywheel (Lakomy, 1986; Reiser et al., 2000). Corrected PP is attained prior to the attainment of peak crank velocity (Lakomy, 1986; Seck et al., 1995; Linossier et al., 1996), whereas uncorrected PP is, by definition, attained when peak crank velocity is attained. It is possible that by the time peak crank velocity is reached during a maximal sprint, the active muscles have already begun to fatigue, resulting in reduced force development (Vandewalle et al., 1987; Seck et al., 1995). This could explain why corrected PP is typically higher than uncorrected PP.

Two studies (Seck et al., 1995; Winter et al., 1996) have compared optimisation with correction procedures for the determination of peak power. In both studies, subjects performed four maximal sprints against four different resistive loads for the determination of optimised (but uncorrected) PP. Corrected PP was determined for each (Seck et al. 1995) or just one (Winter et al. 1996) of these loads. Both groups found corrected PP to be higher than optimised PP: Seck et al. (1995) found both the highest and the mean of the four values for corrected PP to be ~10% higher than optimised PP; Winter et al (1996) found corrected PP to be ~10% and ~15% higher than optimised PP for males and females respectively. However, in both studies the averaging period differed between the two procedures. Seck et al. (1995) averaged over half a pedal revolution for the correction procedure but over one second for the optimisation procedure, whilst Winter et al. (1996) averaged over one second for the correction procedure but over one pedal revolution for the optimisation procedure. Clearly, the discrepancies in the way these data were analysed may have influenced the findings.

Seck et al. (1995) presented data for each of seven subjects showing corrected PP to be independent of resistive load across a four-fold range of loads. Linossier et al (1996) presented group data on 15 untrained males showing corrected PP to vary little across a similarly wide range of restive loads. They noted that there was 'no significant difference' between the corrected PP obtained at the different loads but gave no details of the statistical analysis. In contrast, Lakomy (1985) presented data on nine males and nine females showing corrected PP to decrease with increasing resistive load across a two-fold range of loads. The data were presented graphically and no statistical analysis was reported. It remains to be firmly established whether corrected PP is independent of resistive load in both males and females.

If correction procedures can be validly applied to a single sprint, regardless of resistive load, they offer practical advantages over optimisation procedures, which require a minimum of three sprints to be performed (Nakamura et al., 1985). Therefore, the aim of the present study was to compare optimisation with correction procedures for the determination of PP and other standard indices (cadence at PP, time to PP, work done to PP) in males and females. Of particular practical interest was the possibility that corrected PP might be independent of resistive load.

Methods

Subjects

Ten male and 10 female physically active sports students, who were familiar with laboratory testing, volunteered to participate in the study after being fully informed of the nature of the study. All protocols had previously been cleared by the Institution's ethics committee for use with healthy adults. All subjects completed a pre-test health questionnaire, prior to giving written consent. The respective characteristics (mean ± s) of the male and female subjects were: age, 21.3 ± 2.2 and 21.1 ± 0.7 years; height, 1.80 ± 0.06 and 1.66 ± 0.05 m; body mass, 76.7 ± 9.7 and 65.4 ± 7.3 kg.

General procedures

Subjects visited the laboratory in pairs. Three basket-loaded cycle ergometers (Monark-Crescent AB, Varberg, Sweden) were used: one for the sprints (model 864) and two for warming up and for active recovery between the sprints (model 824e). The saddle height of all ergometers was adjusted for each subject to ensure that the knee remained slightly flexed at the bottom of the down stroke and the ergometers were bolted to the floor. The initial warm up consisted of low intensity cycling at a comfortable cadence (typically 50 to 70 rev.min^{-1}) against a load of 2 kg for males (i.e., ~120 W) or 1.5 kg for females (i.e., ~90 W). A 5 s sprint was performed after 2 and 4 min of this 5 min warm up against the same applied load.

Immediately following the warm-up, the subject moved to the test ergometer and tightened the toe straps. The test began 1 min after the warm up ended. The subject was given a 10 s count down, followed by the ‘go’ command, on which the first 10 s sprint was started. Subjects were instructed not to pace the sprint, and to remain seated at all times. Each sprint started with the subject’s dominant leg stationary at ~60º past the top dead centre.

Subjects undertook a further four sprints, with a 10 min recovery interval between successive sprints. The recovery interval consisted of 3 min of low intensity cycling followed by 6 min of rest in a seated position. Prior to each sprint, subjects were given 1 min to transfer themselves to the test ergometer. The same 10 s count down preceded each sprint.

While one subject was recovering, the other was being tested. Applied loads of 5.0, 6.5, 8.0, 9.5, 11.0 % body weight (BW) were administered in a counterbalanced order (5 x 5 latin square; balanced for both order and carryover effects).

Ergometry

The cycle ergometer used for the test (model 864) was adapted to take a normal saddle and seat pin (continuously adjustable) and standard cranks, onto which standard pedals with toe straps were fitted. The flywheel used had a radius of 0.257 m and was found to have a mass of 9.2 kg. The moment of inertia was determined using ‘run-down’ tests. Against each of five resistive loads (masses of 0.5, 1.0, 1.5, 2.0 and 2.5 kg), the subject accelerated the flywheel until a pedal cadence of 140 $rev.min^{-1}$ was reached. The subject then stopped pedalling and the angular displacement of the flywheel was continuously sampled as it decelerated to a stop. Data from all five loads were used to produce a plot of average flywheel deceleration against resistive load (Lakomy, 1986). The slope of this relationship is the reciprocal of the flywheel's moment of inertia and the intercept is the frictional torque due to the flywheel bearings and free-wheel mechanism (Martin et al., 1997).

The run-down tests described above were performed for each subject and the estimates of flywheel moment of inertia and frictional torque obtained were used in the calculation of corrected power for that individual. Across all 20 subjects, the (mean ± s) moment of inertia was 0.397 ± 0.01 $kg \cdot m^2$. Using a slightly different run-down procedure, Coleman (1994) estimated the moment of inertia to be 0.396 and 0.411 $kg \cdot m^2$ for two Monark 864 ergometers.

The test load (% BW) was first converted to an equivalent mass and then rounded to the nearest 0.1 kg. Known masses were then added to a metal cradle. All masses were calibrated to within 2 g of the nominal mass, as was the cradle.

Flywheel displacement was measured using an optical sensor that emitted a voltage pulse in response to a change from either light to dark or dark to light. One hundred and eighty strips (90 black and 90 white, giving 90 pulses per revolution) were superimposed on one side of the flywheel and the output from the sensor was sampled at a frequency of 18.2 Hz. These data were captured using a dedicated program (Cranlea, Birmingham, UK) on a microcomputer and were used to calculate both flywheel velocity and pedal cadence. Information about the test load and the inertial and frictional characteristics of the ergometer was also entered so that power output could be calculated.

Data analysis

Since the torque at the cranks can only be validly determined from the resistive load if crank velocity is constant, a correction procedure was used. The software (Cranlea, Birmingham, UK) used in the present study uses the Coleman and Hale (1998) approach to correcting for flywheel inertia and frictional losses. The basis of this correction is the following equation:

$$\text{Power output (W)} = \omega \cdot (T_r + T_i + T_f) \qquad (1)$$

where T_r is the resistive torque due to the applied load (Nm), T_i is the inertial torque due to flywheel acceleration, T_f is the frictional torque due to the bearings and the chain drive (Nm) and ω is the angular velocity of the flywheel ($rad \cdot s^{-1}$). Flywheel velocity was calculated from flywheel displacement (sampled at a frequency of 18.2 Hz) and the resistive torque was calculated from the applied load. The inertial torque for the flywheel is the product of its moment of inertia ($kg \cdot m^2$) and its angular acceleration ($rad \cdot s^{-2}$). Flywheel moment of inertia was estimated using run-down tests as described above and angular acceleration was calculated from angular velocity. The same run-down tests were also used to derive an estimate for the frictional torque due to the flywheel bearings and free-wheel mechanism. Corrected power was then calculated using Equation 1. Uncorrected power was calculated as the product of flywheel velocity ($rad \cdot s^{-1}$) and resistive torque (Nm) (i.e., using equation 1 but ignoring T_i and T_f).

Both uncorrected and corrected power were calculated for each sampling period and exported, together with data for pedal cadence, to a spreadsheet for further analysis. The data were first interpolated to give one value for every 0.05 of a second (equivalent to sampling at a rate of 20 Hz). Moving averages were then determined using a 1 second window and a 0.05 second increment. From these data, values for PP, time to PP, and cadence at PP were determined, for both uncorrected and corrected data.

Work done was calculated for each sampling period (sampling rate = 18.2 Hz) by multiplying the corrected power for the period by the length of the period. The work done in successive sampling periods was summed to give the cumulative work done. Work done to PP was then calculated by determining the value of this cumulative work done function for the time immediately preceding that at which PP occurred.

To determine whether the influence of resistive load differed between corrected and uncorrected data, a 2 × 5 (method × resistive load) repeated measures ANOVA was performed. Separate ANOVAs were performed for males and females for each of the following variables: peak power, time to peak power, work done to peak power, and cadence at peak power. For each factor, the degrees of freedom were corrected for any violation of the sphericity assumption. This correction was performed in line with the recommendation of Huynh and Feldt (1976). That is, the Huynh-Feldt correction was used when an estimate of the true value for ε [the average of the Huynh-Feldt and the Greenhouse-Geisser ε (Howell, 1997)] was ≥ 0.75 and the Greenhouse-Geisser correction was used when this estimate was < 0.75. Significant interactions were followed up using separate (one-way) repeated measures ANOVAs for corrected and uncorrected data. Main effects for load were investigated using post-hoc trend analysis.

Optimised PP and the associated values for resistive load and cadence were calculated for each subject from the linear relationship between peak cadence and resistive load using the procedure outlined by Nakamura et al. (1985). This involved using the linear cadence-load relationship to derive a quadratic function relating uncorrected PP to resistive load. Differential calculus was then used to derive both the optimal load, from which the associated cadence was derived using the linear cadence-load relationship, and the optimised PP. Optimised PP was compared with firstly the mean and secondly the highest of each subject's five values for corrected PP using paired t-tests. The relationship between optimised PP and the mean of the five values for corrected PP was evaluated, with and without controlling for the influence of body mass, using partial and Pearson's correlations respectively. These analyses were performed separately for males and females.

All tests were performed at the 0.05 alpha level. Group data are presented as mean ± s.

Results

The power profile for the 10 s sprint differed depending on whether the data were corrected to take account of the inertial and frictional characteristics of the ergometer (Figures 1 and 2). Irrespective of test load or sex, peak power was higher and occurred earlier for corrected than for uncorrected data (Figure 2). However, the differences between the uncorrected and corrected profiles decreased as resistive load increased (Figure 2).

INSERT FIGURES 1 AND 2 ABOUT HERE

This tendency for the difference between uncorrected and corrected data to decrease as the resistive load increased is also evident in Figure 3, not only for peak power and time to peak power but also for work done to peak power and cadence at peak power.

INSERT FIGURE 3 ABOUT HERE

For males and females, a significant ($p < 0.001$) main effect for method was observed for each of the above variables. For peak power, corrected values were consistently higher, whereas for time to peak power, work done to peak power, and cadence at peak power, corrected values were consistently lower, than uncorrected values. Significant ($p < 0.001$) method × load interactions were also observed.

For peak power, corrected values were independent of resistive load (p = 0.15 and 0.09 for males and females respectively), whereas uncorrected values varied as a quadratic function of load ($p < 0.001$). For females, uncorrected peak power reached a peak within the range of resistive loads studied, with optimised PP occurring at a load of 10.2 ± 0.9% BW. For males, uncorrected peak power did not reach a peak within the range of resistive loads studied: optimised PP occurred at a load of 11.3 ± 1.3% BW. For females, optimised PP (668 ± 37 W) was lower ($p < 0.001$) than either the highest (754 ± 56 W) or the mean (701 ± 45 W) of the five values for corrected PP. For males, optimised PP (971 ± 122 W) was lower than either the highest (1074 ± 111 W; $p < 0.001$) or the average (1007 ± 125 W; P=0.004) of the five values for corrected PP. Optimised PP was highly correlated with the mean of the five values for corrected PP in both males ($r = 0.97$, $p < 0.001$) and females ($r = 0.96$, $p < 0.001$). Controlling for body mass had little effect on this relationship: partial correlations of 0.96 and 0.94 ($p < 0.001$ in both cases) were returned for males and females respectively.

Time to uncorrected peak power was independent of resistive load ($p = 0.57$ and 0.81 for males and females respectively), averaging 4.2 s in males and 4.8 s in females. In contrast, time to corrected peak power increased ($p < 0.001$) as a linear function of resistive load in both males and females, from ~1 s at 5% BW to ~3 s at 11% BW.

Work done to peak power followed a similar pattern to time to peak power. Work done to uncorrected peak power was independent of resistive load ($p = 0.76$ and 0.54 for males and females respectively), averaging 3600 J in males and 2800 J in females. In contrast, work done to corrected peak power increased ($p < 0.01$) as a linear function of resistive load in both males and females, from ~850 J at 5% BW to ~2100 J at 11% BW.

As expected, the cadence at uncorrected PP decreased as a linear function of resistive load ($p < 0.001$) in both males and females. In males, it decreased from ~180 rev. min^{-1} at 5% BW to ~120 rev. min^{-1} at 11% BW; in females it decreased from ~160 rev. min^{-1} at 5% BW to ~90 rev. min^{-1} at 11% BW. The cadence at corrected PP varied as a quadratic function of resistive load in both males and females ($p < 0.01$). It varied little across loads between 5 and 8% BW, averaging ~130 rev. min^{-1} in males and ~115 rev. min^{-1} in females. Thereafter it decreased, reaching ~110 rev. min^{-1} in males and ~90 rev. min^{-1} in females at a load of 11% BW. Extrapolation (males) or interpolation (females) of the linear relationship between resistive load and cadence at uncorrected PP to the optimal load of 11.3% BW (males) or 10.2% BW (females) revealed that the optimised PP would be expected to occur at a cadence of 115 ± 9 or 103 ± 9 rev. min^{-1} respectively.

Discussion

Across the range of resistive loads studied, corrected PP was independent of load, whereas uncorrected PP varied as a quadratic function of resistive load. The latter finding is consistent with previous research. Indeed the quadratic relationship between PP and resistive load is the basis of the 'optimisation' procedure (Nakamura et al., 1985; Vandewalle et al., 1985; Winter et al., 1996). However the present study is the first to show, using conventional statistical techniques, that corrected PP is independent of load in both males and females. We studied resistive loads ranging from 2.9 to 6.5 J per pedal revolution per kg BM ($J.rev^{-1}.kg^{-1}$), for which the peak cadence ranged from 120 to 180 $rev.min^{-1}$ in males and 90 to 160 $rev.min^{-1}$ in females. Similar load ranges have been used in previous studies (Nakamura et al., 1985; Vandewalle et al., 1985) for the determination of optimised power. The relationship between corrected PP and resistive load has been evaluated in three previous studies (Lakomy 1985; Seck et al., 1995; Linossier et al., 1996), of which only one was reported in a way that allowed resistive load to be expressed in $J.rev^{-1}.kg^{-1}$. Linossier et al. (1996) noted that there was 'no significant difference' between the corrected PP values obtained for resistive loads ranging from 1.8 to 7.1 $J.rev^{-1}.kg^{-1}$ but gave no details of the statistical analysis.

The finding that corrected PP is independent of resistive load has important implications for the assessment of peak power. First, it suggests that correction procedures can legitimately be used to derive an index of maximal power from a single short sprint on a friction-braked cycle ergometer. Correction procedures will therefore be less time consuming than optimisation procedures, for which multiple sprints against a range of resistive loads are required. However, optimised PP represents the highest point on the 'best fit' curve relating uncorrected PP to resistive load. The random fluctuations in PP that inevitably occur from one sprint to another are therefore 'smoothed out' when optimised PP is determined. This has two important implications. First, it suggests that test-retest reliability is likely to be higher for optimised than for corrected PP when the latter is derived from a single sprint. Second, it suggests that before corrected PP is compared with optimised PP the corrected data should be smoothed to minimise the influence of sprint-to-sprint fluctuations in PP. As corrected PP is independent of resistive load, this smoothing can be accomplished simply by taking the mean of the available values. Ideally, corrected PP would be determined for each of, and averaged across, the resistive loads used in the determination of optimised PP. In the present study, we derived both corrected and uncorrected PP for each of five resistive loads and used data from all five loads to derive optimised PP. The corrected measure that most closely corresponds to optimised PP is therefore derived from the mean of each subject's five values for corrected PP.

In the only previous study to have compared optimisation and correction procedures for the determination of peak power in both males and females, Winter et al. (1996) used data from four different resistive loads to derive optimised PP but determined corrected PP for just one of these loads. The two measures of PP were highly correlated but different: corrected PP was, on average, ~10% and ~15% higher than optimised PP in males and females respectively. Similar differences were observed in the present study when optimised PP was compared with the highest of the five values for corrected PP.

However, as explained earlier, it is more appropriate to compare optimised PP with the mean of these five values for corrected PP. Regardless of whether the influence of body mass was accounted for, this measure of corrected PP was highly correlated with optimised PP in the present study. However, in comparison to those reported by Winter et al. (1996), the differences between corrected and optimised PP were small (~4% in males and ~5% in females) when the mean of the five values for corrected PP was compared with optimised PP.

Both work done to PP and time to PP were independent of resistive load for uncorrected data and consistently higher for uncorrected than for corrected data. It seems likely therefore that both time and work done to PP will always be higher for optimised than for corrected PP, provided a resistive load of 11% BW or less is used for the assessment of corrected PP. This raises the possibility that subjects might already have started to fatigue by the time optimised PP is attained, thereby explaining the lower optimised PP values. Even at the highest resistive loads, over 1 kJ of additional work was done to get to optimised PP. When work efficiency is considered, this additional work is likely to lead to significant additional depletion of high-energy phosphate stores prior to the attainment of PP. Whether a moderate cadence rolling start would minimise the discrepancy in work done prior to the attainment of PP remains to be investigated.

Both the time taken to reach PP and the work done prior to the attainment of PP will be influenced by the inertial characteristics of the ergometer on which the test is performed. For a given increase in pedal cadence, the amount of kinetic energy stored in the flywheel is proportional to the moment of inertia of the flywheel and the gear ratio relating flywheel to pedal revolutions. In the present study, we used an aluminium flywheel (moment of inertia of 0.397 ± 0.01 kg.m^2) and a gear ratio of 52/14 (the standard Monark gear ratio). Seck et al. (1995) reported a value of 0.346 kg.m^2 for the inertia of their Monark 864 ergometer. Seck et al. (1995) found that the time to reach corrected PP and the work done prior to the attainment of corrected PP was significantly less than for optimised PP, but that corrected PP and optimised PP were similar. Linossier et al (1996) found for the ergomeca cycle ergometer used in their study that the flywheel inertia was 0.517 kg.m^2. An even higher value of 0.982 kg.m^2 has been reported for model 824 Monark ergometers (Reiser et al., 2000). Such a large value for the inertia of the flywheel of some ergometers may partly explain the practice of using a moderate cadence rolling start (e.g., Reiser et al., 2000). Comparison of the work done prior to attainment of PP is clearly not appropriate when differing start protocols are adopted.

In summary, this is the first study to show, using conventional statistical techniques, that corrected PP is independent of load in both males and females. An important practical implication of this finding is that PP may be validly determined with one short sprint on a friction-loaded cycle ergometer. Furthermore, corrected PP is higher and occurs earlier, with less work having been done, than optimised (but uncorrected) peak power. Correction procedures that account for the inertia of the flywheel allow PP to be assessed from a single test at a time when muscle power is still maximal. If cadence at PP is the index of interest, an optimised approach may be more appropriate.

References

Arsac, L.M., Belli, A. and Lacour, J-R (1996). Muscle function during brief maximal exercise: accurate measurements on a friction-loaded cycle ergometer. *European Journal of Applied Physiology,* **74**, 100-106.

Ayalon, A., Inbar, O., and Bar-Or, O. (1974). Relationships among measurements of explosive strength and anaerobic power. In *International series on sports sciences*. 1: Biomechanics IV (edited by R.C. Nelson and C.A. Morehouse), pp. 527-532. Baltimore: University Park Press.

Coleman, S.G.S. (1994) *The measurement of maximal power output during short-term cycle ergometry*. Unpublished PhD thesis, University of Loughborough.

Coleman, S.G. and Hale, T. (1998). The effect of different calculation methods of flywheel parameters on the Wingate Anaerobic Test. *Canadian Journal of Applied Physiology,* **23**, 409-417.

Duche, P., Ducher, G., Lazzer, S., Dore, E., Tailhardat, M. and Bedu, M. (2002). Peak power in obese and non-obese adolescents: effects of gender and braking force. *Medicine and Science in Sports and Exercise,* **34**, 2072-2078.

Hautier, C.A., Linossier, M.T., Belli, A., Lacour, J.R. and Arsac, L.M. (1996). Optimal velocity for maximal power production in non-isokinetic cycling is related to muscle fibre type composition. *European Journal of Applied Physiology,* **74**, 114-118.

Howell, D.C. (1997). *Statistical Methods for Psychology*. Wadsworth: Belmont.

Huynh, H. and Feldt, L.S. (1976). Estimation of the Box correction for degrees of freedom from sample data in the randomised block and split plot designs. *Journal of Educational Statistics,* **1**, 69-82.

Lakomy, H.K. (1985). Effect of load on corrected peak power output generated on friction loaded cycle ergometers. *Journal of Sports Sciences*, **3**, 240.

Lakomy, H.K. (1986). Measurement of work and power output using friction-loaded cycle ergometers. *Ergonomics*, **29**, 509-517.

Linossier, M.T., Dormois, D., Fouquet, R., Geyssant, A., and Denis, C. (1996). Use of the force-velocity test to determine the optimal braking force for a sprint exercise on a friction-loaded cycle ergometer. *European Journal of Applied Physiology*, **74**, 420-427.

Martin, J.C., Wagner, B.M. and Coyle, E.F. (1997). Inertial-load method determines maximal cycling power in a single exercise bout. *Medicine and Science in Sports and Exercise*, **29**, 1505-1512.

Nadeau, M., Brassard, A., and Cuerrier, J.P. (1983). The bicycle ergometer for muscle power testing. *Canadian Journal of Applied Sport Science*, **8**, 41-46.

Nakamura, Y., Mutoh, Y., and Miyashita, M. (1985). Determination of the peak power output during maximal brief pedalling bouts. *Journal of Sports Science*, **3**, 181-187.

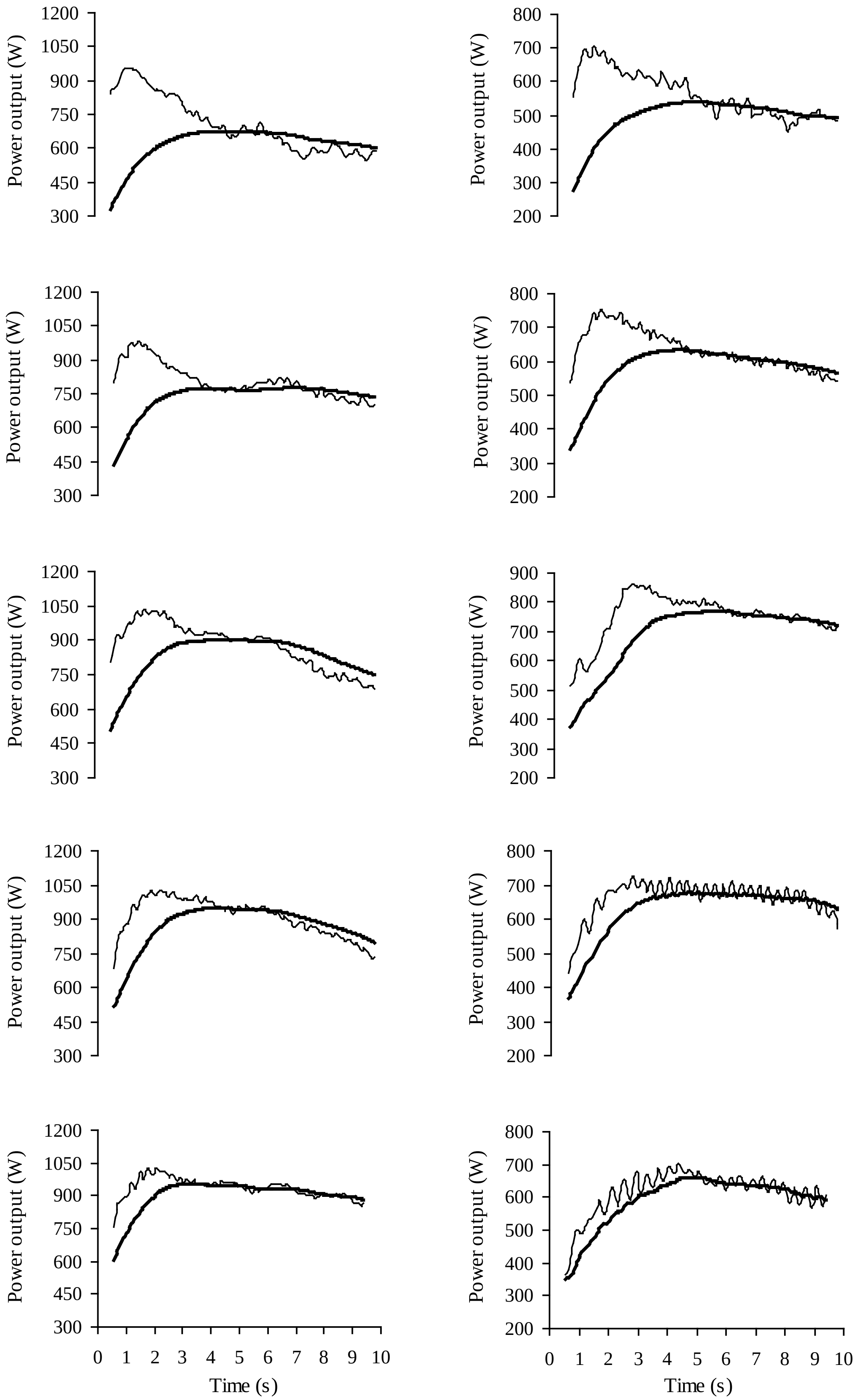
Reiser, R.F., Broker, J.P. and Peterson, M.L. (2000). Inertial effects on mechanically braked Wingate power calculations. *Medicine and Science in Sports and Exercise*, **32**, 1660-1664.

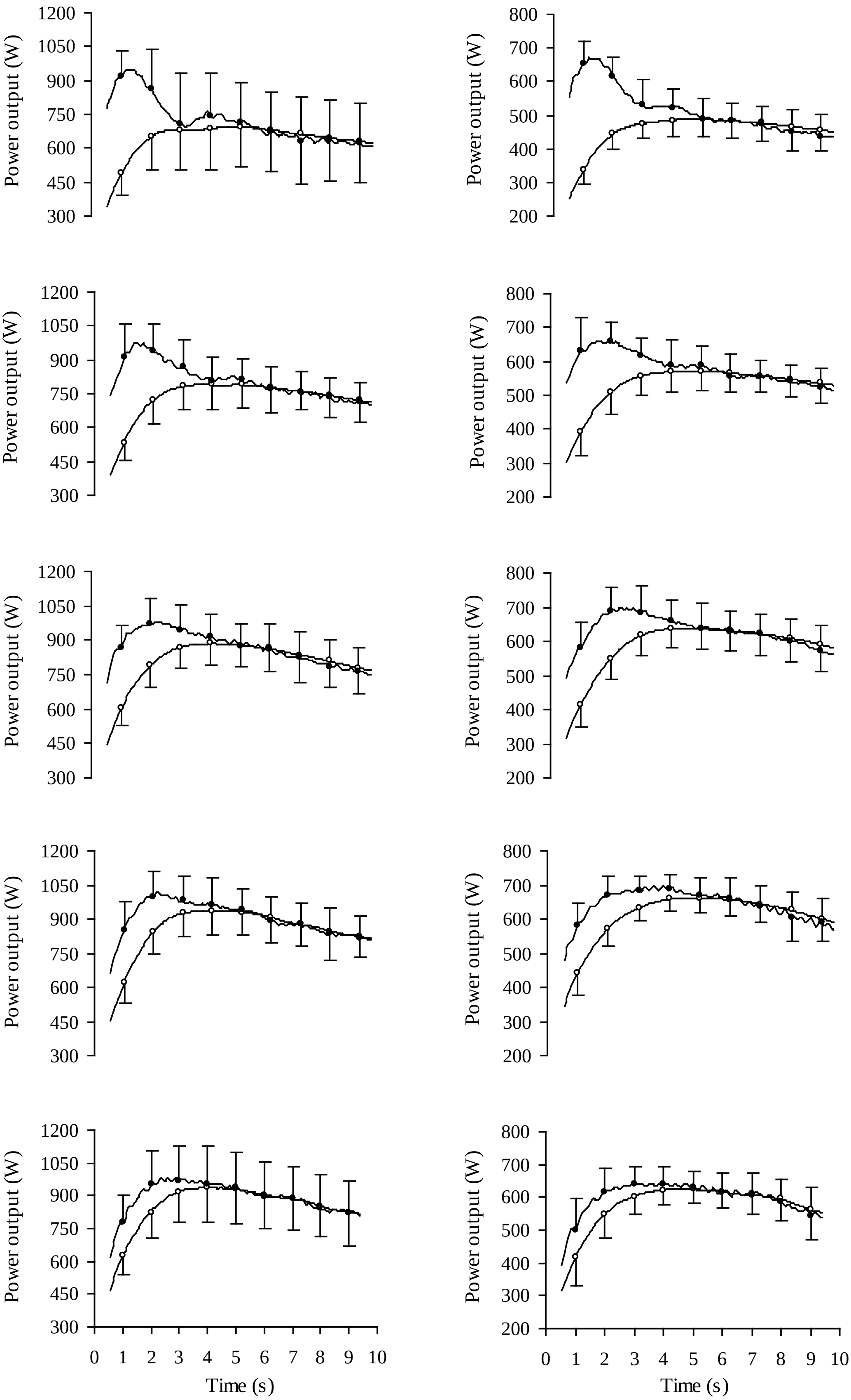
Seck, D., Vandewalle, H., Decrops, N., and Monod, H. (1995). Maximal power and torque-velocity relationship on a cycle ergometer during the acceleration phase of a single all-out exercise. *European Journal of Applied Physiology*, **70**, 161-168.

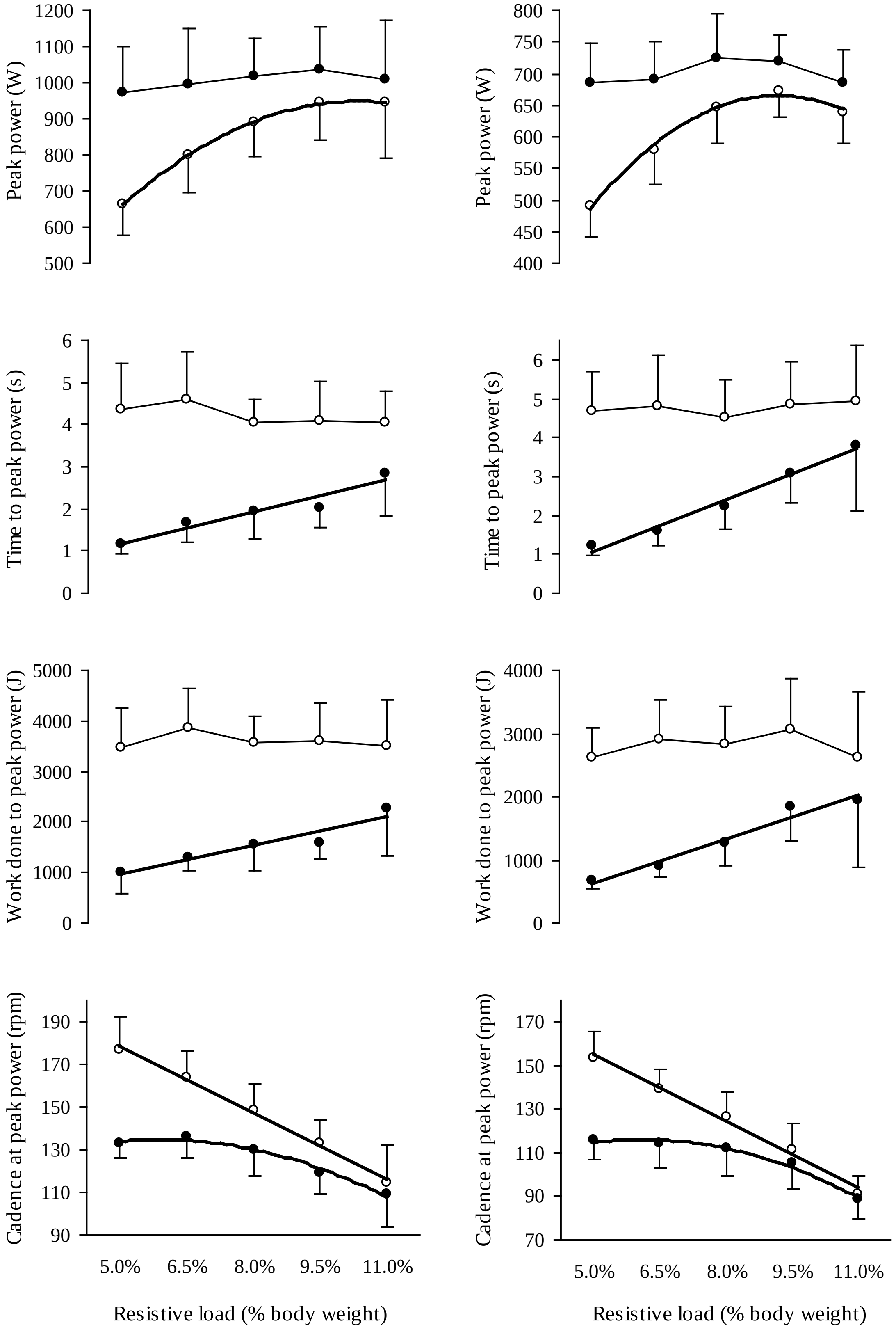
Vandewalle, H., Peres, G., and Monod, H. (1987). Standard anaerobic exercise tests. *Sports Medicine*, **4**, 268-289.

Vandewalle, H., Peres, G., Heller, J., and Monod, H. (1985). All out anaerobic capacity tests on cycle ergometers. A comparative study on men and women. *European Journal of Applied Physiology*, **54**, 222-229.

Winter, E.M., Brown, D., Roberts, N.K., Brookes, F.B., and Swaine, I.L. (1996). Optimized and corrected peak power output during friction-braked cycle ergometry. *Journal of Sports Sciences*, **14**, 513-521.


Power output (W)
1200
1050
900
750
600
450
300
800
700
600
500
400
300
200
0 1 2 3 4 5 6 7 8 9 10
Time (s)


Power output (W)
1200
1050
900
750
600
450
300
800
700
600
500
400
300
200
0 1 2 3 4 5 6 7 8 9 10
Time (s)


Peak power (W)
Time to peak power (s)
Work done to peak power (J)
Cadence at peak power (rpm)
5.0% 6.5% 8.0% 9.5% 11.0%
Resistive load (% body weight)
5.0% 6.5% 8.0% 9.5% 11.0%
Resistive load (% body weight)

Legends

Figure 1: Corrected and uncorrected power as a function of time for a 10 s sprint against resistive loads ranging from 5% (top) to 11% body weight in representative male and female subjects (left and right panels respectively). Both lines are based on a 1 s moving average (0.05 s averaging increment). The heavier line represents uncorrected power.

Figure 2: Corrected and uncorrected power (filled and unfilled circles respectively) as a function of time for a 10 s sprint against resistive loads ranging from 5% (top) to 11% body weight in males (left) and females (right). The line joining the data points represents group data for a 1 s moving average (0.05 s averaging increment). Error bars represent one standard deviation.

Figure 3: Corrected and uncorrected data (filled and unfilled circles respectively) for peak power, time to peak power, work done to peak power, and cadence at peak power as a function of resistive load in males (left) and females (right). A regression line describing the observed trend is used for each significant load effect; linear interpolation is used where no significant effect was found. Error bars represent one standard deviation.