THE USE OF FORCE PEDALS FOR ANALYSIS OF CYCLING SPRINT PERFORMANCE

Simon G. S. Coleman, University of Edinburgh, U.K.,
Tudor Hale, Chichester Institute of Higher Education, Chichester, U.K.

INTRODUCTION: Force pedals have been used in the analysis of cycling technique and performance for over one hundred years. Sharp (1896), gave details of a design by Scott which measured the pressure on the top plate of the pedal by the use of a spring and marker on a revolving drum. Results showed vertical pedal forces of 100 lbs (446 N) to 150 lbs (669N) when cycling on the level and uphill.

Hoes, Binkhorst, Smeekes-Kuyl & Vissers (1968) used strain-gauges on pedal top-plate and crank to measure the vertical pedal force and crank deformation. Crank position was measured using magnets and the subjects pedalled at 60 rpm while forces and positions were recorded. Peak forces were noted at 90° past Crank Top Dead Centre (TDC) and negative forces were found between 180° and 360° past TDC.

The studies of Hull and co-workers (Hull and Davis, 1981, Borlouchi and Hull, 1985) used a sophisticated octagonal 6-axis dynamometer of strain-gauges to measure pedal forces during cycling at cadences between 63 and 100 rpm at constant power. Crank and pedal positions were monitored with cogs attached to continuous-turn potentiometers. Maximum vertical pedal force was found to decrease as cadence increased, and the anterior-posterior forces showed forward shear during the downstroke (TDC to BDC),but backward shear during the upstroke. This was shifted from 30° past TDC at 60 rpm, to 100° past TDC at 100 rpm - a fact the authors put down to increased inertial effects at higher cadences.

Piezo-electric pedals have also been used (Broker, Gregor & Schmidt, 1993) to examine changes in pedal force application patterns in learning. It was found that giving subjects pedal force feedback increased the learning of effective cycling, but this was not continued over a long period.

The major limitation of all of the above studies is that they considered cycling at constant submaximal cadences. No work has yet been carried to examine the pedal forces during supramaximal sprinting. Therefore it was the aim of this study to design and construct a pair of force pedals for use in sprint cycling on a cycle ergometer.

METHODS AND PROCEDURES: A pair of force pedals were designed and constructed using two piezoelectric force transducers (Kistler 8067) mounted in aluminium alloy L168. Orthogonal forces were able to be measured in vertical (F_z), antero-posterior (F_x) and medio-lateral (F_y) directions. The pedals were then statically calibrated a Kistler Force-Displacement unit. Vertical loads of 0 to 2000 N, and anterior-posterior medio-lateral loads of -2000 to 2000N were used, with regression lines of applied load against voltage output being calculated.

Crank and pedal angles were monitored utilizing continuous turn potentiometers. The crank angle device used two 52-toothed nylon cogs, whereas the pedal spindles were connected directly to the potentiometers with alloy sleeves. Angles

were then compared with those calculated using video recording and digitization by using paired t-tests with α-level set at 0.01.

The pedals were then mounted on a Monark 864 ergometer, which had been modified by the addition of a Mavic bottom bracket, Campagnolo chainset and cranks, a continuously adjustable seat pin and racing handlebars.

Ergometer flywheel angular velocity was also measured using a precision DC motor with a 38mm rubber wheel which contacted the flywheel rim.

The subjects were 9 national and international sprint cyclists (mean age 26.5 ± 2.7yr, height 1.80 ± 0.06m, mass 82.0 ± 6.6kg) who performed on the ergometer against a load of 9% body mass. Initial pedal cadence was 130 rpm and the subjects sprinted maximally for 10s. The load, initial cadence and duration were chosen to simulate a track 200m sprint as closely as possible.

Data were sampled at 100Hz on 10 channels using a 12-bit analogue-digital converter and an Acorn Archimedes A310 microcomputer. Specially-written software then filtered the crank and pedal angles using a 4th order Butterworth filter with the cut-off at twice the maximum pedal frequency. Effective (tangential to the crank) and Ineffective (radial to the crank) forces were calculated, as well as other variables such as the Instantaneous Index of Effectiveness (Sanderson, 1991) and the flywheel power output (Coleman and Hale, 1998).

RESULTS: The correlation coefficients of the regression lines for the calibration of the pedals varied from 0.999990 to 0.999999. There were no significant differences between any of the crank angle and pedal angles recorded by the potentiometers and those calculated from video digitization.

Mean flywheel velocity was 58.56 ± 3.30 rad.s^{-1} with the maximum being 65.18 ± 3.45 rad.s^{-1}. Mean flywheel power was 1101.94 ± 101.93 W with a maximum (0.01s) value of 2459.29 ± 336.66 W

The mean and maximum effective and ineffective forces are shown for both the left and right pedal below, in Table 1;

	Right Effective Force (N)	Right Ineffective Force (N)	Left Effective Force (N)	Left Ineffective Force (N)
Mean	224.57	-22.35	246.99	-85.14
SD	45.46	30.68	39.07	55.29
Max	851.38	526.58	880.03	463.90
S.D.	148.16	58.06	126.62	77.02

Table 1 Mean and maximum effective and Ineffective forces

The crank torques were then calculated by multiplying the effective forces by the crank length (0.170 m). The torques from both pedals were then added together and multiplied by the crank angular velocity to give the power output from the two pedals. These data are shown in Table 2.

	Right Crank Torque (N.m)	Left Crank Torque (N.m)	Crank Velocity (rad.s^{-1})	Power Output (W)
Mean	38.07	41.42	15.19	1214.22
SD	7.23	6.45	0.79	236.32
Max	143.88	148.62	17.69	2484.21
S.D.	24.05	20.35	0.56	430.81

Table 2 Mean and maximum crank torques, crank velocity and power output

Finally, the Instantaneous Index of Effectiveness (IIE) was calculated as the ratio of effective force to total force for both pedals at each time interval of 0.01s. IIE values were 0.43 ± 0.11 and 0.45 ± 0.10 for the right and left pedals respectively. For the two pedals combined the IIE was 0.64 ± 0.07.

DISCUSSION: The high correlations for the pedal calibration showed that the design enabled the accurate measurement of pedal forces. The fact that there were no significant differences between crank and pedal angles calculated by potentiometer and video analysis meant these variables were being measured accurately by potentiometer.

Power outputs compared well with those obtained from tests such as the Wingate Anaerobic Test. The high maximal power values are as a result of two factors. Firstly the figures presented in this study were for single 0.01s time intervals whereas the values for maximal power outputs for the Wingate Anaerobic Test are given as five-second parameters; a fact that is clearly unrealistic for supra-maximal sprinting over 10s. Secondly, and probably more importantly, the flywheel power values incorporate the inertial torque involved in flywheel acceleration or deceleration; a term that is usually totally ignored in the Wingate Anaerobic Test (Coleman and Hale, 1998).

Maximum effective force values were slightly greater than the cyclists' bodyweight - this has previously been noted by Soden and Adeyefa (1979) when cycling at 120 rpm (12.57 rad.s^{-1}) at a power output of 772 W. The present study used a higher pedal rate (15.19 rad.s^{-1}) at a power output of 1102W, so it is unsurprising that the forces are also higher (865N vs 580N). Closer examination of the forces showed that some cyclists seemed to apply very large (>1000N) forces over a short section of the pedal cycle, whereas others managed to manipulate pedal and crank angle to allow application of effective force over a greater range of crank angles.

The Instantaneous Index of Effectiveness figures were much higher than those recorded by Sanderson (1991) who found values of 0.2 for 60 rpm at 235W and 'approximately zero' for higher pedal rates. However, this parameter has been criticised by the same author as not being useful indicator of performance as it is too easily affected by variation at very small pedal forces.

CONCLUSION: From this study it is possible to conclude that cyclists apply large (over one bodyweight) forces during sprinting. The force application patterns are individualised, and this is reflected in Instantaneous Index of Effectiveness values. However, this variable needs further investigation before it is used as a measure of cycling effectiveness. In sprinting, it may simply be that the highest power-weight ratio is the most useful variable for consideration.

REFERENCES:
Bolourchi, F., Hull, M. L. (1985). Measurement of Rider Induced Loads during Simulated Bicycling. *International Journal of Sports Biomechanics* **1**, 308-329.
Broker, R. J., Gregor, R. J., Schmidt, R. A. (1993). Extrinsic Feedback and the Learning of Kinetic Patterns in Cycling. *Journal of Applied Biomechanics* **9**, 111-123.
Coleman, S. G. S., Hale, T. (1998). The Effect of Different Calculation Methods of Flywheel Parameters on the Wingate Anaerobic Test. *Canadian Journal of Applied Physiology.* In press.
Hoes, M. J. A. J. M., Binkhorst, R. A., Smeekes-Kuyl, A. E. M. C., Vissers, A. C. A. (1968). Measurement of Forces Exerted on Pedal and Crank during Work on a Bicycle Ergometer at Different Loads. *International Zeitschrift für Angewandte Physiologie Einschließlich Arbeitphysiologie* **26**, 33-42.
Hull, M. L., Davis, R. R. (1981). Measurement of Pedal Loading in Bicycling: I.-Instrumentation. *Journal of Biomechanics* **14**, 843-856.
Sanderson, D. J. (1991). The Influence of Cadence and Power Output in the Biomechanics of Force Application during Steady-Rate Cycling in Competitive and Recreational Cyclists. *Journal of Sports Sciences* **9**, 191-203.
Sharp, A. (1896). Bicycles and Tricycles. Cambridge, MA: MIT Press (reprinted 1977).
Soden, P. D., Adeyefa, B. A. (1979). Forces Applied to a Bicycle during Normal Cycling. *Journal of Biomechanics* **12***,* 527-541