

THE EFFECT OF CRANK ARM LENGTH UPON THE  
ANAEROBIC POWER OF COMPETITIVE CYCLISTS

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## Introduction

The cycle ergometer is widely used as an exercise mode and testing device in physiological research. To define the ideal conditions for its use, various researchers have attempted to determine the optimal pedalling rate (Banister and Jackson 1967; Dickinson 1929; Hagberg et al. 1981; Seabury et al. 1977) or seat height (Nordeen-Snyder 1977; Shennum and deVries 1976). Similarly, Hamley and Thomas (1967) and Faria et al. (1978) have examined the effect of upper body posture on submaximal and maximal exercise variables. However, one aspect of positioning on an ergometer or bicycle that has not been the subject of extensive research is the effect of the length of the pedal crank arm. Thomas (1967), for example, chose to include crank arm length in overall determination of the effect of seat height. Carmichael et al. (1982) and Goto et al. (1982) have examined the effect of crank arm length on submaximal exercise variables but this research has not been extended to include maximal or supramaximal exercise. The purpose of this investigation, therefore, was to examine the effect of four different crank arm lengths (160, 170, 180, and 190 mm) on mean power, peak torque, and fatiguability during brief, maximal exercise, i.e., 45 second sprint bouts on a cycle ergometer.

## Methods

Four highly-trained competitive cyclists participated in this study after giving their informed consent. Their physical

characteristics are shown in Table 1.  $\dot{V}O_2$  max was determined during an incremental work test on a Collins electrically-braked ergometer using an automated gas analysis system. All cyclists had extensive road racing experience, though none competed regularly in track racing.

Testing was performed on a modified hydraulically-braked Fitron cycle ergometer (Cybex Div., Lumex Corp., N.Y.). Pedalling rate was maintained within very narrow limits of the selected (90) rpm by a variable-orifice hydraulic valve, with resistance variable and proportional to the subject's efforts. Torque was measured by a Cybex single channel recorder by incorporating a pressure potentiometer into the ergometer, while total work was determined with a Cybex Digital Work Integrator. The system was calibrated prior to all testing with the input of known torques. Repeated calibrations using this method indicated a coefficient of variation in the determination of total work output of 1.6%. This system has been described previously (Ivy et al. 1979).

The Fitron cycle was equipped with racing-style handlebars, saddle, and pedals with toe-clips and straps. The cyclists wore their cleated racing shoes for all trials. Measurements taken from the subject's racing bicycles were used to establish seat height and horizontal position. All measurements were made relative to the pedal axle; thus leg extension was kept constant throughout the range of crank arm lengths.

All testing was conducted over a four week period at the end of the cyclist's competitive season. The subject's were

Table 1. Physical Characteristics of Subjects

	Mean	S.E.	Range
Age (years)	27.3	2.5	23-34
Years Competing	3.5	1.3	2.5-9.0
Height (cm)	181.3	1.8	178-183
Weight (kg)	69.8	4.2	60.2-72.2
Max $\dot{V}O_2$ (L/min)	4.72	0.06	4.65-5.20
Max $\dot{V}O_2$ (ml/kg*min )	68.3	4.2	66.8-80.2

instructed to maintain their training during this time period and to refrain from exercise for the 24 hours preceeding each test. At least 72 hours intervened between all trials. Additionally, the order of all trials was randomized. The test-retest correlation coefficient for mean power for paired trials in pilot work was  $r=0.91$ .

Each subject performed two trials using each of the four crank lengths: 160, 170, 180, and 190 mm. After adjustment of the ergometer, the subject was allowed five minutes warmup at approximately 50%  $\dot{V}O_2$  max. After a one minute pause, the subjects began pedalling on command. Subjects were instructed to go "all-out" from the beginning of the test, and strong verbal encouragement was given to insure a maximal effort. An "all-out" pacing strategy has been shown to result in greater work production during cycling tasks 36-60 seconds in duration (Katch et al. 1976). Total work production during the test was used to calculate mean power, while peak torque and percent fatiguability were determined manually from torque curves (see Figure 1).

Two-way analysis of variance was used to determine statistical significance. A Student-Newman-Keuls post-hoc analysis was employed to locate any significant differences. The  $p=0.05$  level was used for all significance testing.

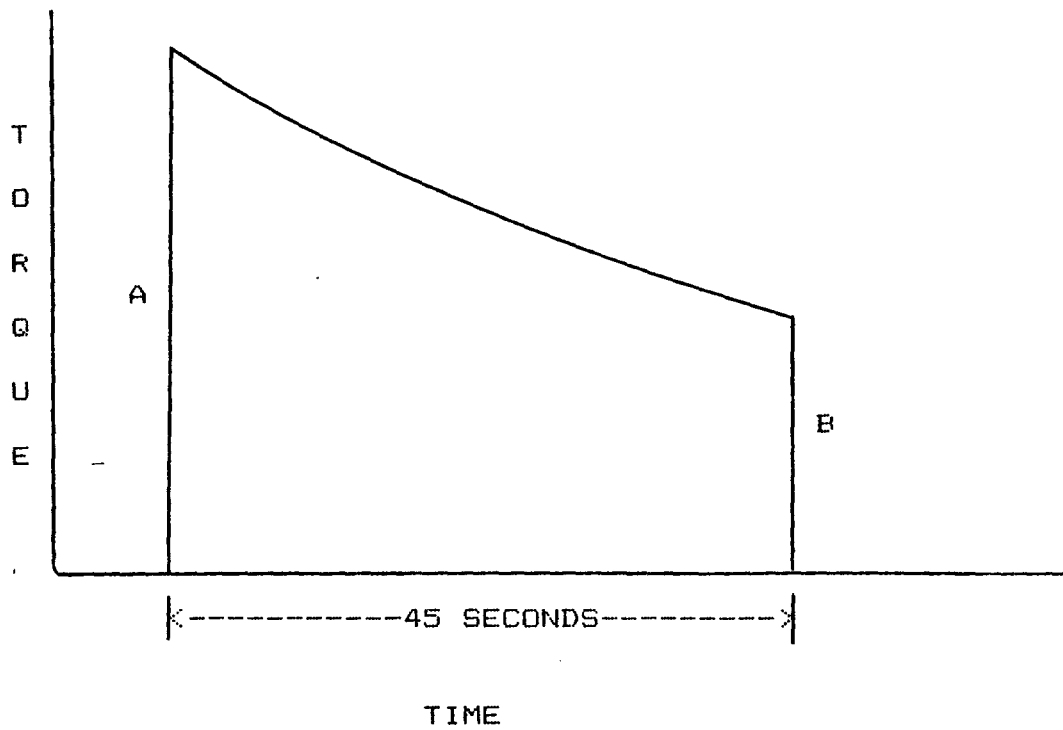
## Results

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The 180 mm crank arms resulted in significantly higher mean

FIGURE 1 SCHEMATIC REPRESENTATION OF TORQUE CURVE

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A = PEAK TORQUE

B = FINAL TORQUE

FATIGUABILITY (%) =  $(1.00 - (B/A)) \times 100\%$

power over the 45 second period when compared to the 160 mm crank arms, the shortest length tested (see Table 2). No significant differences existed, however, between the 160, 170, and 190 mm crank arms or between the 170, 180, and 190 mm crank arms, making selection of an optimal crank arm length on the basis of mean power alone difficult.

The peak torque generated at the very beginning of each trial was significantly greater for the three longest crank arm lengths compared to the 160 mm crank arms. Additionally, peak torques for the 180 and 190 mm crank arms were significantly higher than for the 170 mm crank arms. However, taking into account the length of the lever arm used to produce this torque, the calculated peak force that would have to be generated at a right angle to the pedal was significantly less for the longest crank than for the other three. These forces are approximately three-fourths the subject's bodyweight.

Peak torque decreased roughly 50% over the 45 second duration of the sprint, showing a general, but non-significant, increase in fatiguability with increasing crank length.

No relationship was found between any of the variables when compared with crank length expressed as a percentage of upper leg length or total leg length.

#### DISCUSSION

Although no physiological data was obtained in this study, data from several sources support the assumption that the cycling task was predominantly anaerobic. Inbar et al.

Table 2. Results - Mean±S.E.

Crank Length (mm)	160	170	180	190
Mean Power (watts)	576.5 ±28.5	589.6 ±17.0	601.6 <sup>a</sup> ±28.7	586.7 ±26.6
Peak torque (n:m)	86.5 ±5.2	91.1 <sup>a</sup> ±5.1	95.0 <sup>a,b</sup> ±4.6	94.2 <sup>a,b</sup> ±5.3
Peak force (n)	540.5 <sup>d</sup> ±32.5	535.8 <sup>d</sup> ±30.0	526.8 <sup>d</sup> ±25.6	495.8 ±27.9
Fatiguability (%)	49.0 ±5.3	49.3 ±6.1	50.9 ±5.9	51.5 ±6.5

a Significantly greater than 160mm value

b Significantly greater than 170mm value

c Significantly greater than 180mm value

d Significantly greater than 190mm value



(1976) have demonstrated that oxygen uptake during a 30 second maximal cycling test represented only 13% of the energy required. Similarly, Jacobs et al. (1982) have shown a six-fold increase in muscle lactate in female subjects using the same protocol. Assuming constant efficiency, the mean power output in the present study required approximately 150%  $\dot{V}O_2$  max. There is evidence that efficiency decreases as anaerobic metabolism increases, thus the energy requirement is possibly even higher (Wojcieszak et al. 1981).

The subjects in the present study averaged 588.6 watts for all trials. This is greater than the 488.3 watts reported by Katch et al. (1976) during a 60 second ergometer test, but similar to the 578.6 watts reported by Wojcieszak et al. (1981) for physical education students. It is less, however, than the 665.0 watts developed by untrained subjects during a 20 second isokinetic cycling sprint reported by Sargeant et al. (1981). These differences are probably due to the training level and experience of the subjects, and/or the duration of the work bout.

The finding that mean power decreases with excessively long cranks is not surprising. Goto et al. (1982) have demonstrated that even with constant pedal rpm, the angular velocity of the hip and knee joints increases curvilinearly with increasing crank length. Integrated EMG activity and oxygen consumption also increase disproportionately with long cranks. As a result of this increased speed of movement, the maximal force that can be generated is reduced (Sjogard 1982)

Kaneko and Yamazaki (1982) have shown that internal mechanical work is also increased as limb velocity increases, reducing efficiency. All of these factors combine to reduce power output with excessively long crank arms. Additionally, fatiguability has been shown to increase with higher rates of movement (Sargeant et al. 1981), although the differences in the present investigation were small and non-significant.

The penalty for using too short of a crank arm is also apparent from the present data. Despite equal or greater force generated at the pedal, the peak torques resulting from the use of 160 mm or 170 mm crank arms were significantly less than that generated with 180 mm and 190 mm crank arms, a direct result of the shorter lever arm. Hence, maximal power was reduced.

Apparently a compromise between the force that can be applied and the length of the lever arm is reached at 180 mm, resulting in peak power production. At a constant pedal rpm, longer crank arms result in a decrease in the maximal force, while shorter crank arms do not allow maximum leverage.

The finding that the optimal length is longer than that in common use is quite different from the results of Carmichael et al. (1982), who demonstrated that the optimal crank length in terms of submaximal efficiency is shorter than that in normally employed. Carmichael's data also indicate a significant relationship between optimal crank length and upper leg length. We have not observed any such relationship, although this may be due to the limited range of leg lengths in our subjects (89.2-93.5 cm).

The finding that the optimal crank length for short-term maximal work is not the most efficient for submaximal work is similar to the results of Katch et al. (1976), who demonstrated greater work production with an "all-out" cycling cadence, despite the reduced efficiency that results. Factors other than submaximal efficiency are apparently more important during supramaximal work.

The present results indicate an optimal crank arm length of 180 mm for supramaximal work at 90 rpm. Different pedalling rates may yield different results, as power production is dependent on the velocity of movement (Sargeant et al. 1981). More research with a wider range of subjects in terms of stature and training status should be undertaken.

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