

# Influence of crank length on cycle ergometry performance of well-trained female cross-country mountain bike athletes

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**Abstract** The aim of this study was to determine the differential effects of three commonly used crank lengths (170, 172.5 and 175 mm) on performance measures relevant to female cross-country mountain bike athletes ( $n = 7$ ) of similar stature. All trials were performed in a single blind and balanced order with a 5- to 7-day period between trials. Both saddle height and fore-aft position to pedal axle distance at a crank angle of  $90^\circ$  was controlled across all trials. The laboratory tests comprised a supra-maximal (peak power-cadence); an isokinetic (50 rpm) test; and a maximal test of aerobic capacity. The time to reach supra-maximal peak power was significantly ( $P < 0.05$ ) shorter in the 170 mm ( $2.57 \pm 0.79$  s) condition compared to 175 mm ( $3.29 \pm 0.76$  s). This effect represented a mean performance advantage of 27.8% for 170 mm compared to 175 mm. There was no further inter-condition differences between performance outcome measurements derived for the isokinetic (50 rpm) maximum power output, isokinetic (50 rpm) mean power output or indices of endurance performance. The decreased time to peak power with the greater rate of power development in the 170 mm condition suggests a race advantage may be achieved using a shorter crank length than commonly observed. Additionally, there was no impediment to either power output produced at low cadences or indices of endurance performance using the shorter crank length and

the advantage of being able to respond quickly to a change in terrain could be of strategic importance to elite athletes.

**Keywords** Propulsion · Cranks · Bike position · Levers

## Introduction

Previous research has demonstrated considerable variation in the optimal range of crank lengths for cycling performance (Conrad 1983; Inbar et al. 1983; Hull and Gonzalez 1988; Morris and Londeree 1997; Too and Landwer 2000; Martin and Spirduso 2001). Shorter crank lengths ( $\leq 170$  mm) tend to favour athletes with shorter leg lengths (Martin and Spirduso 2001), those preferring a faster cadence (Hull and Gonzalez 1988) and those interested in developing supra-maximal performances for short time periods (Inbar et al. 1983; Too and Landwer 2000). However, the impact of crank lengths on cycling performance remains equivocal, with the majority of studies (Conrad 1983; Morris and Londeree 1997) suggesting that there is no significant difference between using crank lengths of 165–180 mm irrespective of body size or stature at sub-maximal intensities (Hull and Gonzalez 1988).

Cross-country mountain bike racing (XCO) is a complex cycling discipline which is performed over a variety of terrains and surfaces often requiring the interaction of supra-maximal and sub-maximal efforts combined with high levels of skill. In contrast to other endurance cycling disciplines, XCO racing commences at a supra-maximal intensity whereby it is important to initially secure positional advantage over other competitors and subsequently at the periodic phases of a race where passing is possible. The inability to attain positional advantage prior to single

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track phases of the race may limit the performance of athletes impeded by slower competitors who hold positional advantage. Therefore, securing a good start is of considerable importance to XCO racing. Any biomechanical advantage such as crank length optimisation which facilitates a more rapid attainment of peak power could be critical in determining the outcome of a race. It is therefore interesting that female XCO athletes tend to use 175 mm crank arms (the common manufacturer setting on mountain bikes) during races and yet use 170 mm crank arms during road cycle training (as is common amongst females in road cycling and which comprises a large percentage of their total volume of training). Nevertheless, there remains very little research in this area, although the use of longer crank lengths during XCO race performances appears to defy logic amongst athletes seeking to gain positional advantage. It is also possible that smaller cranks such as 170 mm might impede endurance characteristics, high force movements or perhaps satisfy an intrinsic desire amongst athletes to follow the manufacturers' recommendations.

Presently, there have been no detailed experiments into the benefits for female XCO athletes using different crank lengths such as: 170, 172.5 or 175 mm when simultaneously measuring a range of physiological and performance criteria relevant to the sport. Therefore, the purpose of this study was to ascertain whether small alterations in crank length are enough to elicit important changes in performance measures specific to XCO and potentially the outcome of a race.

## Methods

Seven competitive female cyclists aged  $26 \pm 3.8$  years (mean  $\pm$  SD) volunteered to participate in the study (Table 1). All participants were fully informed about the procedures, time demands and risks associated with participation in the study, signed a consent form and

completed a pre-test questionnaire. The study was approved by the Central Regional Ethics Committee of New Zealand.

## Experimental design

A repeated measures design was used to compare the effects of three conditions: 170.0, 172.5 and 175.0 mm in a single blind and balanced order with a 5- to 7-day period between trials. The 175 mm condition was considered the control as this was the standard (manufacturer recommended) XCO length crank used during XCO-MTB by all subjects. All subjects were asked to maintain normal weekly training volumes leading up to each trial and refrain from strenuous training and the consumption of alcohol or caffeine 24 h prior to each test.

On the day of each trial, subjects reported to the laboratory at the same time of day and were instructed to perform their usual pre-race routine.

## Anthropometric measures

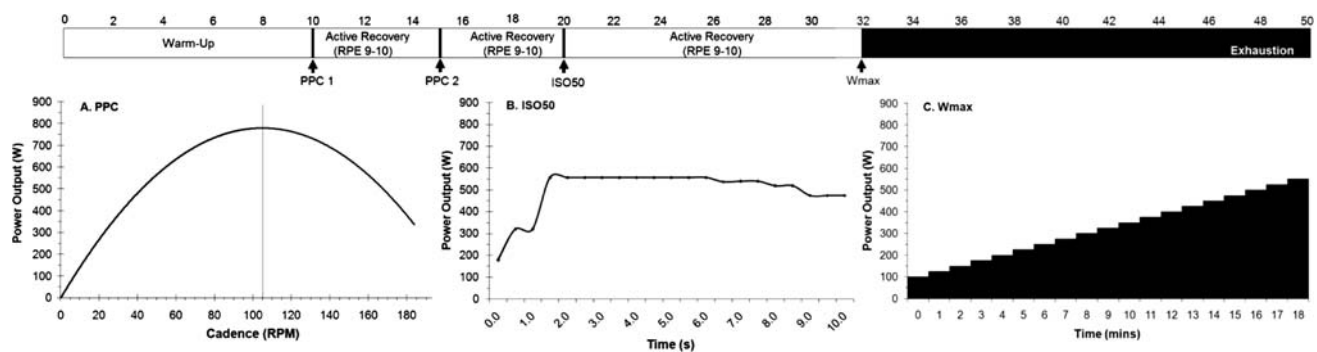
On arrival at the laboratory, each subject's height (cm) and body mass (kg) were taken. During the first visit, the cycle ergometer (SRM Germany) was set to individual requirements with any minor adjustments being made prior to a warm-up period and standardised for subsequent trials. During this period, retro-reflective markers were placed to the left side at the following anatomical landmarks: distal end of the fifth metatarsal (FM), a vertical line from the lateral malleolus (LM) to the heel (H), lateral condyle (LC) and the greater trochanter of the femur (GT). Total, upper and lower leg lengths were measured from the left side in a seated position on the cycle ergometer, with upper and lower leg measurements measured from the GT to H, the GT to LC, and LC to H, respectively. All data are presented in Table 1.

## Performance tests

Following a warm-up (10 min at a self-selected pace and standardised for subsequent trials), a series of laboratory performance tests commonly used amongst elite female XCO athletes (Wooles et al. 2003) for (1) peak power-cadence (PPC), (2) isokinetic 50 rpm (ISO50) and (3) endurance ( $W_{\max}$ ) were performed with each crank length (Fig. 1), whilst controlling for normal saddle-pedal axis height, at a crank arm angle of  $90^\circ$ , via adjustments to saddle height in relation to the crank arm–pedal axle joint. Subjects' normal joint angles were also attempted to be controlled through the movement of the saddle in a fore-aft direction with regard to the position of the pedal spindle to

**Table 1** Subject characteristics and baseline measures using 175 mm cranks, where crank length (CL) to leg length (LL) ratio is CL/LL

Characteristics	Mean $\pm$ SD
Age (years)	26.0 (9.5)
Body mass (kg)	59.3 (4.0)
Height (cm)	168.5 (5.4)
BMI ( $\text{kg m}^{-2}$ )	20.9 (1.6)
Upper leg length (mm)	433.0 (30.0)
Lower leg length (mm)	408.0 (14.0)
MTB crank length (mm)	175.0 (0.0)
CL:LL ratio for MTB	0.21 (0.1)
CL:LL ratio for Rd	0.20 (0.1)



**Fig. 1** Schematic representation of the laboratory trial and individual protocols (**a** peak power-cadence test (PPC), **b** ISO50 test and **c** endurance Ramp test ( $W_{\max}$ ))

the front of the knee with the crank at  $90^\circ$ . Subsequent changes in distance from the mid-point of the saddle to the centre point of the handle bars were also corrected for in an attempt to maintain normal torso angle. The warm-up period was considered sufficient to adapt to changes in crank length, as muscle co-ordination adaptation to changes in crank mechanics has been shown to occur within the first 10–20 revolutions (Neptune and Herzog 2000).

1. PPC test was performed in a seated position from a stationary start and with the preferred foot and favoured crank angle (standardised for each trial). Data recording frequency was set at 10 Hz and the ergometer was fitted with a 54-tooth chainring, whilst the internal gearing (Speedhub 500/14, Rohloff, Fulda, Germany) was set to 3. Athletes were asked to accelerate as fast and hard as they could from a 10-s countdown in order to simulate the effort required at the initiation of a race where ability to attain high peak powers quickly is vital for positional advantage. Each effort lasted 6 s and was separated by 5 min of easy pedalling [RPE scale level 9–10 (very light); Borg et al. 1985]. It was envisaged that peak power (W) would be achieved during the initial effort when inertia is greatest, whilst peak cadence (rpm) would be attained during the later part of the test when inertia is minimal. The rate of power development ( $W s^{-1}$ ) was calculated as peak power divided by the time to reach peak.
2. The ISO50 test (Wooles et al. 2003) was performed at a fixed cadence of 50 rpm, whilst the ergometer (operating in an isokinetic mode) had a 54 tooth chainring and a set internal gear of 14. The athletes were asked to pedal gently (100–150 W) at 50 rpm to familiarise themselves with the cadence for a 30-s period, a 10-s countdown was then given prior to commencement of the test whereupon applied maximal effort was required for a 10-s period (Fig. 1b).

Data recording frequency was set at 2 Hz. Maximal strength (W), mean strength (W), fatigue rating ( $W s^{-1}$ ), and root mean square (RMS) of net torque per revolution were recorded and averaged over the 10-s period throughout the test.

3. The  $W_{\max}$  test commenced at 100 W, increasing by  $15 W min^{-1}$  (Wooles et al. 2003). Subjects were asked to select a cadence (rhythm) for each trial that they were comfortable with and to try and keep it constant throughout each individual trial whilst being blind to the actual numerical figure of cadence (rpm). The purpose of this was to monitor the effect of crank length changes on the force–velocity relationship of muscular contraction. The test ended when the subject could no longer maintain the required power output (W). Throughout this test heart rate (Polar Electro, Kempele, Finland), expired air (Parvomedics Truemax 2400), and net torque production averaged over a 10-s period was measured. Expired air data averaged every 15 s enabled the calculation of  $VO_2$  peak, ventilatory threshold (VT) and respiratory compensation point (RCP), all of which have been used in the past as reliable indicators of endurance performance (Lucia et al. 2000). Maximal power output (W) was determined as the highest average power output obtained (over a 60-s epoch) during the final minutes of exercise ( $W_{\max}$ ).

### Statistical analysis

Data collected for each intervention were analysed by one-way repeated measures analysis of variance (ANOVA) with a Dunnett's multiple comparison post-test used to identify individual condition differences when compared to the control condition (175 mm) (GraphPad Prism 5). Significance level for statistical analysis was set at  $P < 0.05$  level.

## Results

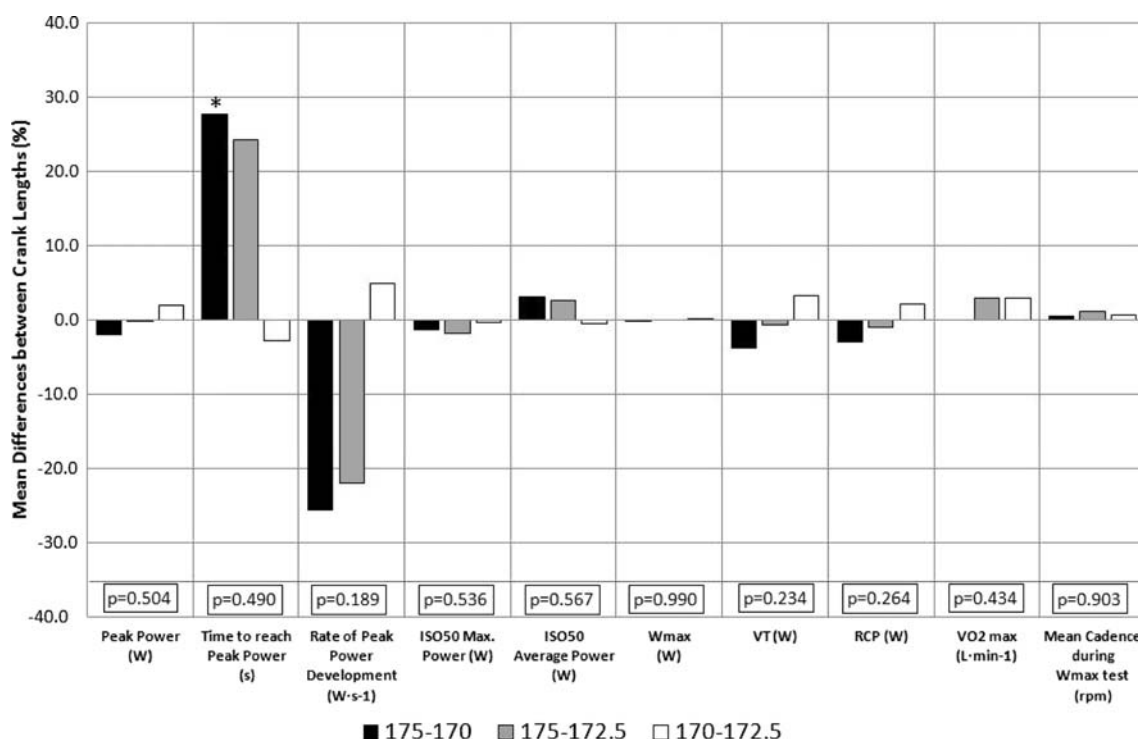
Repeated measures one-way ANOVA showed that there was a significant overall effect ( $P = 0.049$ ) of crank length on the time to reach peak power with mean  $\pm$  SD values of  $2.57 \pm 0.79$ ,  $2.79 \pm 0.70$  and  $3.29 \pm 0.76$  s for 170, 172.5 and 175 mm, respectively. Post hoc analysis demonstrated a difference in time to peak power in the PPC test between 175 and 170 mm conditions ( $P < 0.05$ ). This corresponded with a 27.8% difference between the performance of 170 and 175 mm conditions (Fig. 2). There were no other significant differences in performance across power, strength or endurance outcomes between the three conditions. Table 2 shows the mean (SD) results for each component tested for the three trials, while Fig. 2 illustrates the mean percentage difference between trials and the overall effect for each performance outcome measure.

## Discussion

The main finding of this study is that the time to reach peak power is significantly improved using the shortest crank length, while neither strength nor variables obtained from a routine laboratory ramp test were compromised in that condition. These data suggest that the 170 mm condition was influential in an outcome measurement that might be

of strategic importance to race performance of XCO. There were also large but non-significant effects of crank size on the rate of power development during the same test (Table 2; Fig. 2), suggesting a tendency for both more dynamic and powerful performance when using the shorter crank.

The importance of peak power as a performance variable in XCO races has been discussed elsewhere (Impellizzeri and Marcora 2007). In short-term laboratory experiments, it has previously been shown that the athletes who attain peak power earlier also tend to generate greater peak power (Stapelfeldt et al. 2004), this is presumably because of greater intramuscular fuel stores, but this process might also be aided using an optimal crank length. In practical terms this could mean the difference between winning and losing. Our findings highlight the importance of this observation and have implications for greater consideration of crank lengths amongst female XCO athletes. The ability to gain an advantageous position amongst the field of competitors may enable the athlete to perform at their own pace and avoid being impeded by slower competitors who hold positional advantage. In consideration of this, it is interesting to note that all our subjects were currently using 175 mm cranks on their race bikes, potentially limiting race performance (Inbar et al. 1983; Martin and Spirduso 2001; Too and Landwer 2000) at critical stages.



**Fig. 2** Comparisons of mean percentage differences between conditions 175–170 (darkly filled bar), 175–172.5 (lightly filled bar) and 170–172.5 (unfilled bar) with the overall effect (repeated measure one-way ANOVA) shown for each performance outcome measure

**Table 2** Mean  $\pm$  (SD) for performance measures using the 170, 172.5 and 175 mm crank lengths

	Mean $\pm$ (SD)		
Crank length (mm)	170.0	172.5	175.0
Peak power (W)	756.3 (78.1)	741.1 (85.8)	741.0 (71.7)
Time to reach peak power (s)	2.57 (0.79)*	2.79 (0.70)	3.29 (0.76)
Rate of power development ( $\text{W s}^{-1}$ )	324 (117)	309 (111)	241 (79)
ISO50 max. power (W)	501.7 (37.2)	503.8 (35.1)	495.0 (41.5)
ISO50 average power (W)	413.4 (34.0)	415.6 (35.7)	426.2 (50.7)
$W_{\max}$ (W)	302.0 (27.6)	301.5 (24.6)	301.5 (35.0)
VT (W)	175.8 (17.8)	170.2 (16.3)	169.2 (16.7)
RCP (W)	235.1 (18.2)	230.2 (21.7)	228.1 (25.4)
$\text{VO}_{2\max}$ ( $\text{L min}^{-1}$ )	3.3 (0.3)	3.2 (0.3)	3.3 (0.3)
Mean cadence during $W_{\max}$ (rpm)	87.5 (5.5)	87 (6.4)	88 (10.1)

\* Significantly different from 175 mm crank lengths ( $P < 0.05$ )

Previous research reports optimal crank length for peak power to be anywhere between 145 and 180 mm (Inbar et al. 1983; Too and Landwer 2000; Martin and Spirduso 2001). Interestingly, the data shown in Table 2 show that the relatively small difference in using a 170 mm crank compared to a 175 mm crank produced greater mean peak power (although not statistically significant) which may be meaningful to performance. This differs from past papers (Inbar et al. 1983; Martin and Spirduso 2001) that have suggested large changes in crank length only bring about small performance changes. However, no studies have examined the influence of crank length on factors such as time to peak power or rate of power development, probably due to earlier limitations in fast response technologies. This study attempted to examine performance from a holistic perspective which included the subject's ability to react to the initiation of the test as per the start of a race in a fixed gear. Also, as a result of changing crank lengths (but keeping a fixed gear for all trials), changes of resistance at the pedal may have occurred and limited the athlete's ability to reach peak power before reaching the descending limb of the power/cadence curve. In contrast, Table 2 highlights the large mean changes for crank length (when making comparisons with both 170 and 172.5 mm with 175 mm) and time to reach peak power and while the effect on peak power is smaller, it potentially provides athletes with enough of an advantage at key stages to gain position(s) over opponents. This is further highlighted through the rate of power development which is a more practical measure and shows similar effects (Table 2; Fig. 2). Due to the nature of XCO course design and terrain, athletes are required to respond with dynamic changes in power output at both fast and slow cadences whilst negotiating obstacles or steep inclines. In such instances, our findings highlight the potential benefit of the 170 mm cranks over the others at fast cadences.

While both peak power and performance during slow cadences (ISO50 test) may be critical to specific aspects of

race performance, overall race performance has been suggested to be more reliant on variables obtained from routine laboratory ramp tests (Bell and Cobner 2007). The results from this study show no significant difference when comparing such measures with crank length. This agrees with previous studies that measured economy at sub-maximal workloads, suggesting no difference in performance with changes in crank length from 165 to 180 mm with 2.5 mm increments (Conrad 1983) and 165 to 175 mm with 5 mm increments (Morris and Londeree 1997).

Female XCO athletes are perhaps unique in the cycling community as the majority of their training is performed on a road bicycle using 170 mm crank lengths yet they race on mountain bikes using 175 mm crank lengths. This may possibly lead to a non-specific training effect in terms of the rate of muscular contraction, muscle length and activation/relaxation kinetics. Functional movement studies of cycle design parameters, influenced via pelvic inclination (Impellizzeri et al. 2005); crank length (Conrad 1983; Inbar et al. 1983; Hull and Gonzalez 1988; Morris and Londeree 1997; Too and Landwer 2000; Martin and Spirduso 2001), seat height (Too 1994; Hamley and Thomas 1976; Gregor and Rugg 1986) and crank rotation (Nordeen-Snyder 1977) have shown performance can be influenced by geometrical alterations. During this study, both pelvic inclination and saddle height to pedal axle distance (seat height) was controlled in an attempt to maintain geometric position, while cadence was freely chosen (but monitored) and crank length was manipulated (blinded). This is important as adjustments in crank lengths by 5 mm (170–175 mm) lead to an increase in pedal circumference by 3%, potentially affecting the freely chosen cadence.

In conclusion, changes in crank length while attempting to control the athlete's position during bicycle ergometry could impact race performance based on an improvement in time to reach peak power and thus positional advantage at the outset of the race and also at key phases. In addition



to this important finding is the fact that small changes in crank length (175–170 mm) did not compromise indices of strength or endurance performance which could potentially influence other important aspects of XCO-MTB performance.

Future work may determine the dynamics of using shorter crank lengths on field-based race outcomes including athlete pacing strategies, the effects of crank length on start performance and positional advantage, and how training using different crank lengths could affect performance and pacing abilities.

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