The Biomechanical Effects of Crank Arm Length on Cycling Mechanics

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Introduction

The anthropometry of an individual’s segment dimensions provides important information when designing equipment that requires the interaction between a person and object, or workspace. The bicycle must be designed to fit the human body as incorrectly dimensioned equipment limits comfort and the ability to function at optimal levels, thereby having a detrimental effect on performance (Burke & Pruitt, 1996). From previous studies it has been concluded that shorter riders should be using shorter cranks and taller riders should be using longer cranks in order to optimise both the physiology (Carmichael, 1981) and the biomechanics (Hull & Gonzalez, 1988; Gonzalez & Hull, 1989) of the cyclist. Using the equation derived by Carmichael (1981), it was calculated that someone 163 cm tall should be riding a bike equipped with 140 mm cranks. However, the industry standard for crank lengths is 170 mm, irrespective of rider or bicycle size. This would suggest that, in contradiction to previous research, there is not a strong relationship between rider size and crank length. It would be expected that as both lower limb anthropometry and crank length are modified, the range of motion of the lower limb joints would be altered. Such changes would be reflected in alterations of segmental kinematics and segment energies. The segmental energy changes induced by altering crank length would therefore result in whole body aerobic cost fluctuations which could be analysed to determine their role in dictating optimal crank length. It seems reasonable to conclude that the dimensions of the lower limbs play a role in modifying both the physiological and biomechanical responses of a rider. The hypothesis of the current investigation was that there exists a relationship between lower limb anthropometry (total leg length, thigh length, shank length) and the crank length permitting the lowest heart rate at a given power output.

Methods

The participants (n=16) were avid cyclists with eleven currently competing in triathlons, mountain bike races and road races. In addition to experience, participants were chosen on the basis of their height in order to ensure that a wide range of sizes was obtained (Cavanagh & Kram, 1989).

The experimental protocol included six criterion rides, each at a different crank length in 20 mm increments from 120 mm to 220 mm, on a bicycle mounted on a Schwinn Velodyne. All rides took place at a cadence of 90 rpm and at a power output that elicited a heart rate response of approximately 155 bpm while riding at a crank length of 160 mm. The absolute seat height, as measured from the top of the pedal platform to the top of the seat, was kept constant at 100% trochanteric height (the distance from the greater trochanter to the floor) (Nordeen-Snyder, 1977). Each subject reported to the lab for one 3-hour testing session. After a self-selected warm-up while pedalling with the 160 mm cranks, the subject rode for approximately five minutes in order to determine the power output that elicited a heart rate response of approximately 155 bpm. The participants then performed the six criterion rides, each lasting approximately six minutes. Pedal forces and heart rate were measured and videotape was recorded and subsequently digitised and kinematic variables calculated. The resulting data were filtered using a second order, dual pass Butterworth filter with a cut-off frequency of five Hz.

In the determination of the optimal crank length for each subject, an average heart rate was calculated over minute five for each crank length. The data (average heart rate for each crank length) were then differentiated and the crank length (to the nearest mm) at which the zero differential occurred was considered to be the optimal crank length as this point represented the
crank length at which the minimum heart rate occurred. The effect of the average effective force and the average linear velocity of the foot on the heart rate were examined in order to resolve the biomechanical mechanisms governing the effects of altering crank length on heart rate. The average linear velocity of the foot was determined by calculating the average of the resultant linear velocity of the end of the crank throughout one entire crank cycle. A multiple regression was used to determine the degree of relationship between the average effective force and the average linear velocity of the foot and the heart rate elicited at each of the six crank lengths. This procedure was completed six times, once for each of the six crank lengths tested.

Results and Discussion

The results of the current study demonstrated that heart rate increased in a parabolic manner when crank length was increased from 120 mm to 220 mm (Figure 1). However, it was clear that shorter cranks of approximately 120 mm to 160 mm elicited statistically similar physiological responses. Additionally, there was a second group of cranks, from approximately 160 mm to 180 mm, that also produce heart rates and VO2s that were not significantly different from one another. However, 180 mm, 200 mm and 220 mm cranks all elicited statistically different heart rates. It was then interesting to note that 100% of the subjects in Carmichael’s study (1981) had optimal crank lengths that were within the 150 mm to 180 mm range where he showed no significant differences in heart rate to exist between crank lengths. As well, 87.5% of the subjects in the current study had optimal crank lengths in the range of 120 mm to 160 mm where no differences in heart rate occurred between crank lengths. This led to the conclusion that, despite the fact that there existed a relationship between optimal crank length and some measure of leg length, almost all subjects’ optimal crank lengths fell within a range of cranks that elicited heart rates that were not statistically different from one another and that were very close to the industry standard of 170 mm.

The correlation between optimal crank length and thigh length was non-significant. Both the correlation between optimal crank length and shank length and between optimal crank length and total leg length were significant (p<.05, r=.552 and r=.434 respectively). These results indicated that there was a significant linear relationship between optimal crank length and each of shank length and total leg length. The average effective force and average linear velocity of the foot are presented in Table 1. A multiple regression was used to determine whether average effective force and average linear velocity of the foot, or a combination thereof, would predict the heart rate elicited while riding with a particular length of crank arm. The only significant predictor (p=.008) of heart rate was the average effective force, at a crank arm length of 120 mm.

It was hypothesised that the linear velocity of the foot would cause an increase in heart rate while the effective force would cause a decrease in heart rate, combining to result in unique heart rates at each crank length. It was therefore hypothesised that the heart rate elicited at each crank length would be a function of both linear velocity of the foot and effective force. It was determined that neither the linear velocity of the foot nor the effective force were significantly correlated to heart rate across all crank lengths. Upon reflection, it was believed that there were other undetermined mechanisms that were governing the changes seen in heart rate. The segmental
energies of the thigh, shank and leg did not explain the relationship between optimal crank length and anthropometry but may lead to a clearer understanding as to why there was an increase in heart rate at the longer crank arm lengths. The total energy expenditure of the body, as measured by heart rate, was influenced by the energy expenditure of each of its parts, including the lower limbs. Therefore, the segmental energies of the thigh, shank and leg must have at least partially contributed to the changes taking place in heart rate, which occurred when crank length was altered.

It was concluded that there were no significant differences in the physiological responses to riding at crank lengths of approximately 120 mm to 160 mm. On the contrary, when crank length was lengthened to 180 mm and beyond, significantly different physiological responses were elicited when cycling at each different crank length. In conjunction, almost all of the optimal crank lengths of the individuals in the current study fell within the range of cranks that do not elicit significantly different physiological responses from one another, which are very close to the industry standard crank length of 170 mm. From the results of the current study and from those reported in recent literature, it was concluded that there was a weak correlation between optimal crank length and a measure of leg length, provided that the ranges of crank lengths and leg lengths used are appropriately large. Therefore, there was an ability of a certain measure of leg length to predict a portion of the variance in optimal crank length. In the current study, it was found that both shank length and total leg length could predict 51% of the variance in optimal crank length. It was the recommendation of the investigators of the current study that crank lengths need not be changed from the industry standard for individuals of various leg lengths. This was due to the fact that those crank lengths predicted from the leg length – optimal crank length relationship did not differ significantly in terms of physiological responses from crank lengths close to, and perhaps including, the current industry standard. In addition, other parameters such as power output (Inbar, 1983; Too, 2000) and joint moment cost functions (Gonzalez and Hull, 1989) are being optimised at or around the industry standard of 170 mm.

### Table 1. Mean segmental energy (joules), peak effective force (Newtons), linear velocity (m/s) and heart rate (HR) for each of six crank lengths from 120 to 220 mm.

<table>
<thead>
<tr>
<th></th>
<th>120 mm</th>
<th>140 mm</th>
<th>160 mm</th>
<th>180 mm</th>
<th>200 mm</th>
<th>220 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thigh (J)</td>
<td>66.6±13.2</td>
<td>67.6±13.1</td>
<td>69.3±13.2</td>
<td>69.7±14.0</td>
<td>72.1±13.6</td>
<td>75.2±14.4</td>
</tr>
<tr>
<td>Shank (J)</td>
<td>24.4±4.3</td>
<td>27.3±5.0</td>
<td>30.7±5.2</td>
<td>34.0±6.3</td>
<td>37.8±6.5</td>
<td>42.7±7.0</td>
</tr>
<tr>
<td>Leg (J)</td>
<td>91.0±17.4</td>
<td>94.9±18.0</td>
<td>100.0±18.4</td>
<td>103.7±20.2</td>
<td>109.9±20.0</td>
<td>118.2±21.5</td>
</tr>
<tr>
<td>Fe (N)</td>
<td>38.8±9.3</td>
<td>31.9±11.7</td>
<td>27.9±10.8</td>
<td>25.9±7.5</td>
<td>21.3±8.3</td>
<td>24.6±9.5</td>
</tr>
<tr>
<td>LV (m/s)</td>
<td>1.2±0.03</td>
<td>1.4±0.03</td>
<td>1.6±0.02</td>
<td>1.8±0.03</td>
<td>2.0±0.04</td>
<td>2.2±0.03</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>153.0±5.8</td>
<td>152.9±6.2</td>
<td>154.8±5.5</td>
<td>156.4±5.6</td>
<td>159.8±6.4</td>
<td>164.6±6.3</td>
</tr>
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References