THE EFFECT OF PEDAL CRANKARM LENGTH ON POWER PRODUCTION IN RECUMBENT CYCLE ERGOMETRY

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INTRODUCTION

It is well documented that recumbent human power vehicles are more effective aerodynamically than the standard cycling position (Kor, 1992; Kyle, 1982; Whitt & Wilson, 1982). With speeds of some human powered vehicles, such as the Vector Single, exceeding 60 mph (96.6km/h), and a present speed record of 68.73 mph (110.65 km/hr), established by the "Cheetah" (Kor, 1992), it is obvious as to the importance of minimizing aerodynamic drag (Gross, Kyle, & Malewicki, 1983). But, when the drag coefficient and effective frontal area has been reduced to 0.11 and 0.152 m^2, respectively, as in the Vector Single (compared to 1.1 and 1.83 m^2, respectively, for a standard upright bicycle), it is difficult to further reduce the aerodynamic drag (Gross et al., 1983).

To further improve performance, it becomes necessary to focus on some aspect other than the aerodynamic properties. The most logical area to esplore would be the human engine which powers the vehicle, and how the individual should be sealed, configured, oriented, and/or positioned to maximize power production and cycling performance (Too, 1990). Previous investigations have examined how power production in recumbent cycle ergometry is affected by inanipulations in seat-tube angle, trunk orientation, and seat-to-pedal distance (Too, 1991, 1993a,b, 1994). To, continue along this research focus, the purpose of this investigation was to determine the effect of changes in pedal crankarm length on power production in recumbent cycle ergometry.

METHODS AND PROCEDURES

Twenty healthy volunteer male subjects (mean age = 24.8 yr., SD = 4.4 yr.) were tested in five pedal crankarm length (110, 145, 180, 230, and 265 mm). The recumbent sealing position used, was defined by a 75 degree angle formed between the bicycle seat tube and a vertical line (perpendicular to the ground) passing through the pedal axis. To obtain this seating position, a variable position sealing apparatus, allowing for manipulations in seat tube angle (hip position), seat backrest angles, and seat to pedal distance, was constructed and interfaced to a Monark cycle ergometer (Too, 198811989). The seat-backrest was kept perpendicular to the ground and the seat-to-pedal distance adjusted, for each crankarm length tested, to remain 100% (to within 314 of an inch or 1.905 cm) of the total leg length as measured from the greater trochanler of the femur of the right leg to the ground. All subjects were tested in each of the five crankarm length conditions according to a randomly determined sequence, with a minimum of 34 hours rest between test sessions.

A computerized 30 second Wingate Anaerobic Power Test was used with a free weight Monark bicycle ergometer (Model 814E) having a resistance of 85 gmlkg of the subjects' body mass (5.0 jouleslpedal rev/kg BM). To initiate the test, the subject pedaled the cycle ergometer with no load. Once the ergometer's inertial resistance had been overcome, the resistance was instantaneously applied using calibration weights, and the subject pedaled as hard and as fast as possible for 30 seconds. During the test, each subject was strapped to the seat-backrest at the trunk and hips, pedal toe-clips were worn, and an optical sensor used, in conjunction with 16 reflective markers, was used to monitor and record ergometer flywheel revolutions. Peak power, mean power, and a fatigue index for the 30 second test were determined by a SMI (Sports Medicine Industry) Power Program. Peak power was calculated from the highest average flywheel velocity in any 5 consecutive seconds; mean power calculated from the average flywheel revolutions completed during the entire 30 second test; and the fatigue index calculated as the difference between the maximum (peak) and minimum power produced in the test.

RESULTS AND DISCUSSION

For each crankarm length, the resulting peak power, mean power, and fatigue index are presented in Table 1. It can be observed from Table 1 that peak power decreased with increasing crankarm lengths. The highest power produced, 1167.6 watts, was found with the shortest crankarm length (110 mm), while the lowest power produced (926.8 watts) was found with the longest crankarm length (265 mm). However, the largest mean power over the 30 second test (845.4 watts) was found with the middle crankarm length (180 mm). Increasing or decreasing crankarm lengths from the 180 mm crankarm length, resulted in a decrement in mean power. The amount of fatigue found, decreased from a high of 53.7% with the shortest crankarm length (110 mm) to a low of 34.4% with the longest crankarm length (265 mm).

Table 1. Peak power, mean power, fatigue index for the five crankarm length.

		Crankarm Length (mm)				
		110	145	180	230	265.
Power						
Peak (W)	M	1167.6	1149.2	1106.2	1029.1	926.8
	(SD)	(207.2)	(211.5)	(219.5)	(186.1)	(166.3)
Mean (W)	M	804.4	838.7	845.4	817.2	765.11
	(SD)	(295)	(203.9)	(168.5)	(160.9)	(132.1)
Fatigue Index (%)						
	M	53.7	49.5	45.8	40.8	34.4
	(SD)	(6.53)	(7.05)	(5.70)	(6.53)	(6.98)

Doubly multivariate repealed measures analysis of variance (DM MANOVAs) revealed that there were significant differences ($p < .01$) in peak power, mean power, and in fatigue index with changes in crankarm length. Post-hoc tests using orthogonal contrasts are presented in Table 2. From orthogonal contrasts, it was determined that: (1) peak power produced with the two shortest crankarm lengths

(110 and 145 mm) were significantly greater ($p < .05$) than the peak power produced at the three longer crankarm lengths (180,230, and 265 mm); (2) the highest mean power produced using the middle crankarm length (180 mm) was significantly greater ($p < .05$) than the mean power produced at the longer crankarm lengths (230 and 265 mm) and also significantly greater ($p < .05$) than that at the shortest crankarm length (110 mm), but not when compared to that at the 145 mm crankarm length; and **(3)** each change in crankarm length from the shortest (110 mm) to the longest (265 mm) resulted in a significant greater ($p < .05$) amount of fatigue.

Table 2. Orthogonal comparisons of peak power, mean power, and fatigue index for the five crankarm lengths.

Crankarm Lengths (mm)	110	145	180	230	265
110		@	* @	* @	* & @
145			* @	* @	* @
180	&			& @	& @
230					& @
265					

$p < .05$ * - peak power (W)
& - mean power (W)
@ - fatigue index (%)

It was believed that significant differences in recumbent cycling performance on an ergometer (as reflected by peak power, mean power, and fatigue index) with changes in crankarm length, were attributed to changes in joint kinematics. This assumption appears to be supported by the literature available on recumbent cycling ergometry power production (Too, 1991, 1993b). For example, Too (1991), having found significant differences in power production with systematic changes in seat tube angles (hip angles, hip position), suggested that these performance differences may be attributed to changes in force and power development as a result of changes in joint kinematics. Similarly, significant differences found in recumbent cycle ergometry power production with a systematic change in seat-to-pedal distance were attributed to changes in joint kinematics (Too, 1993b). It can be assumed that with changes in crankarm length, there will be a change in the range of motion, minimum, maximum, and mean joint angles of the hip, knee, and ankle during a pedal cycle. This, in turn, can be assumed to alter muscle length, muscle moment arm length, the muscle angle of pull, and the resulting interactions in the generation of force, torque, and power by different muscle groups.

APPLICATIONS

It appears that changes in pedal crankarm length by 35 mm can significantly affect recumbent cycling performance, as evidenced by changes in peak and mean power. The shortest crankarm length (110 mm) resulted in the largest peak power production (and fatigue index), whereas the middle crankarm length (180 mm) resulted in the largest mean power production. However, the second crankarm length (145 mm) was not significantly different in peak power from the 110 mm crankarm length and in mean power from the 180 mm crankarm length. Therefore, if the goal in recumbent cycle ergometry is: (1) maximizing power production in the shortest period of time, the 110 mm crankarm length is suggested; (2) development of the largest mean power over a 30 second interval, the 180 mm crankarm length is recommended; and **(3)** optimizing peak and mean power produclion, this would require a compromise between the 110 and 180 mm crankarm length, and the 145 mm crankarm length would be suggested and recommended.

It was concluded that the optimal crankarm length in the development of faster and more effective human powered vehicles, or to maximize performance in recumbent cycle ergometry, or in a recumbent cycling position, will be dependent on the goal of the activitg.

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