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The Effect of Body Configuration on Cycling Performance

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BIOMECHANICS IN SPORTS VI

Proceedings of the 6th International Symposium on Biomechanics in Sports

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Introduction

In the 1930's, Francois Faure, a relatively unknown racing cyclist, defeated the world champion Lemoire, in a 4 km pursuit race. What was unique aboubt this feat, is that Faure used a supine recumbent bicycle and broke track records that had been established on conventional bicycles. In 1980, the single rider Vector tricycle established a new human powered speed record at 56.66 mph (25.33 m/s) with the cyclist seated in a supine recumbent position.

It is well documented that recumbent human power vehicles are more effective aerodynamically than the standard cycling position (Kyle, 1974, 1982; Kyle & Caiozzo, 1986; Kyle, Crawford & Nadeau, 1973; 1974; Whitt & Wilson, 1982). With speeds of some human powered vehicles exceeding 60 mph (96.6 km/hr) (Gross, Kyle & Malewicki, 1983), it is obvious as to the importance of minimizing aerodynamic drag. However, when the drag coefficient and effective frontal area have been reduced in some human powered vehicles to 0.11 and 0.5 square feet, respectively (compared to 1.1 and 6.0 square feet, respectively for a standard upright bicycle) (Gross et al., 1983), it is questionable as to: 1) how much lower the aerodynamic drag can be reduced; and 2) how significant such changes would be. The design of human powered vehicles has focused exclusively on the aerodynamic properties of the vehicle with the cyclist. To further improve performance, it becomes necessary to focus on some aspect other than the aerodynamic properties. The most logical area to explore would be the human engine which powers the vehicles.

Review of Literature

The functional effectiveness of force production by a muscle is dependent upon the interaction of the muscle length at a particular joint angle and the muscle moment force arm length at that angle. Changes in joint angles which alter this interaction will affect the production of force, resulting in changes in performance. It has been documented with isometric contractions that there are joint angles which optimize: 1) force production (Kulig, Andrews, & Hay, 1984; Lunnen, Yack and LeVeau, 1981); 2) muscle moment arm length (Nemeth & Ohlsen, 1985; Pohtilla, 1969); and 3) muscle length (Elftman, 1966). However, the optimal joint angles which maximize performance in a dynamic task such as cycling have never ben clearly established.

Investigations with a standard racing bicycle have often manipulated only the height of the seat (Hamley and Thomas, 1967; Nordeen-Snyder, 1977; Shennum & DeVries, 1976; Thomas, 1967); or the crankarm length (Inbar, Dotan, Trousil, & Dvir, 1983) which alters both the hip and knee angles. It is then unknown as to whether improved cycling performance is attributed to changes in hip angles, knee angles or both; and what the most effective ranges of hip and knee angles are for one pedal revolution. Therefore, the purpose of this investigation was to determine the effect of changes in hip angels on cycling performance as measured by cycling duration and total work output.

Methods

Sixteen male subjects (21-35 years of age) were tested in five different body positions (0, 25, 50, 75 and 100 degrees), as defined by the angle formed between the seat tube and a vertical line. By rotating the seat to maintain a backrest perpendicular to the ground, a systematic decrease in hip angle (body configuration) from the 0 to 100 degree positions was induced. The mean hip angles corresponding to the 0, 25, 50, 75 and 100 degree seat tube angles were 130.9, 113.4, 100, 76.8, and 59.9 degrees, respectively. For each seat tube angle, the seat to pedal distance was adjusted to remain 100% (to within 3/4 of an inch or 1.905 cm) of each subject's total leg length, as measured from the greater trochanter of the femur of the right leg to the ground. All subjects were tested in each of the five positions on a Monark bicycle ergometer according to a pre-selected sequence of workloads and pedaling frequencies, with increments occurring every 3 minutes until exhaustion (Table 1).

Table 1

Bicycle Ergometer Test Protocol

Brake Load (kp)	Pedal Rate (rpm)	Time (min)	Work Rate (kpm/min)	Work Rate (watts)	Work Rate (hp)
1	60	3	360	58.9	.089
2	60	6	720	117.7	.158
3	60	9	1080	176.6	.237
3	70	12	1260	206.0	.276
3.5	70	15	1470	240.4	.322
4	70	18	1680	274.7	.368
4.5	70	21	1890	309.0	.414
4.5	75	24	2025	331.0	.444
5	75	27	2250	367.9	.493
5	80	30	2400	392.4	.526
5.5	80	33	2640	431.0	.579

Note: 1. Work Rate (power) = Brake Load x Pedal Rate
2. 1 HP = 746 watts = 4562.4 kpm/min

The testing sequences for the 5 positions were randomly selected for each subject with a minimum of 48 hours between test sessions. All subjects were strapped to the seat-backrest at the waist and hips, and toe-clips were used during all test sessions.

Results and Discussion

For each seat tube angle, the mean, minimum, and maximum angles, and range of motion at the hip, knee, and ankle were obtained for one complete pedal revolution (Table 2).

Table 2

Hip, Knee, and Ankle Angles at Five Seat Tube Angles

		Seat Tube Angle (deg)				
		0	25	50	75	100
Hip Angle (deg)						
Mean	Mean	130.9	113.4	100.0	76.8	59.9
	(SD)	(5.25)	(3.72)	(5.49)	(4.38)	(4.85)
Minimum	Mean	112.2	94.0	81.0	56.5	37.6
	(SD)	(5.64)	(4.24)	(5.94)	(4.46)	(5.38)
Maximum	Mean	149.6	132.8	119.1	97.1	82.2
	(SD)	(5.64)	(4.49)	(7.80)	(6.82)	(5.85)
Range	Mean	37.4	38.8	38.1	40.6	44.6
	(SD)	(6.78)	(4.58)	(8.47)	(7.46)	(5.68)
Knee Angle (deg)						
Mean	Mean	95.5	97.9	103.3	103.6	103.8
	(SD)	(6.42)	(5.36)	(4.00)	(5.58)	(8.04)
Minimum	Mean	62.7	62.2	65.1	65.7	67.5
	(SD)	(5.85)	(5.91)	(1.78)	(5.74)	(6.22)
Maximum	Mean	128.3	133.7	141.6	141.6	140.1
	(SD)	(8.83)	(6.57)	(6.93)	(6.52)	(10.83)
Range	Mean	65.6	73.9	77.0	75.2	72.6
	(SD)	(7.73)	(12.0)	(5.89)	(4.96)	(7.69)
Ankle Angle (deg)						
Mean	Mean	113.5	95.3	93.6	96.0	91.8
	(SD)	(6.47)	(6.30)	(7.90)	(5.48)	(9.23)
Minimum	Mean	91.8	87.4	87.1	88.8	83.4
	(SD)	(9.23)	(6.04)	(8.86)	(7.23)	(11.49)
Maximum	Mean	135.3	103.1	100.2	103.2	100.1
	(SD)	(12.02)	(8.00)	(8.00)	(7.19)	(9.24)
Range	Mean	43.6	15.8	13.2	14.5	16.1
	(SD)	(17.09)	(6.55)	(6.00)	(9.37)	(9.53)

As can be observed from Table 2, there is a systematic decrease in hip angle with changes in seat tube angles, whereas the knee and ankle angles are fairly similar across seat tube angles. It was found with repeated measures MANOVAs that there were significant differences (p , .01) in cycling duration and total work output with changes in body position (seat tube angle) and body configuration (mean hip angle). It is apparent, from observations of Table 3, Figure 1 and 2 that: 1) peak cycling performance, as measured by total work output and cycling duration occur in the 75 degree position with a mean hip angle of 76.8 degrees; and 2) a quadratic trend in cycling performance exists with changes in hip angles.

Table 3

Cycling Duration and Total Work Output at Five Hip Angles

		Mean Hip Angles (deg)				
		130.9	113.4	100.0	76.8	59.9
Cycling Duration (min)						
	Mean	9.50	12.05	15.01	16.03	13.43
	(SD)	(2.926)	(3.589)	(4.317)	(4.403)	(4.736)
Total Work Output (kpm)						
	Mean	7368	10737	15327	16968	13201
	(SD)	(3751)	(4852)	(7290)	(7656)	(8120)

Trend analysis was used to identify the function which best described the characteristics of the two performance variables with changes in cycling position. Dunnett's Multiple Comparison Test, was used as a post-hoc test to compare the hip angle in the 75 degree position with each of the other cycling positions. It was concluded from post-hoc tests that: 1) hip angles in the 75 degree position resulted in a significantly greater cycling duration ($p < .05$) than in all the other positions; 2) except for the 50 degree position, hip angles in the 75 degree position resulted in a significantly greater total work output than in all the other positions ($p < .01$); and 3) a second order function best describes the change in total work output and cycling duration with changes in hip angles ($p < .01$).

Based upon the results of this investigation, it is concluded that the optimal mean hip angle which maximizes cycling duration and total work output with incrementing workloads is approximately 77 degrees, with a minimum of 57 degrees, a maximum of 97 degrees, and a hip angle range of motion of 41 degrees. Therefore, it is suggested, with all other things being equal, that coaches and cyclists explore the possible use of these hip angles to enhance cycling performance.

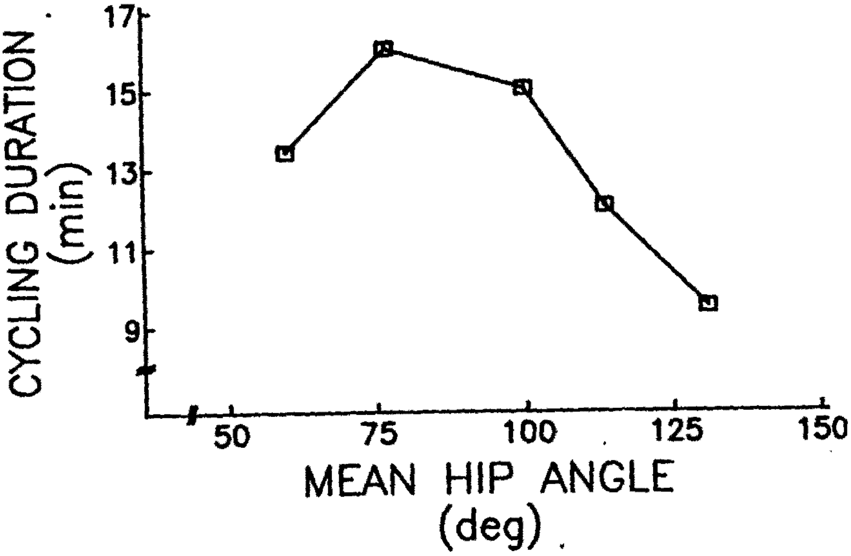

FIGURE 1: Cycling Duration with Changes in Body Configuration

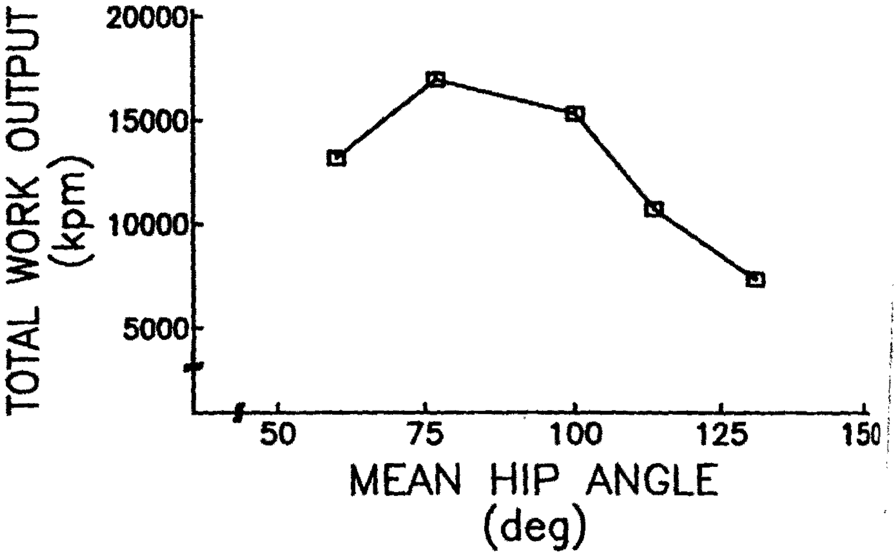

FIGURE 2: Total Work Output with Changes in Body Configuration

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