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The Effect of Body Orientation on Cycling Performance

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INTRODUCTION

The design of human-powered vehicles has focused exclusively on the aerodynamic properties of the vehicle exceeding 65 mph, it's obvious as to the importance of minimizing aerodynamic drag. But, from an energetics perspective, how a cyclist should be positioned or what body orientation should be assumed to maximize performance is unknown.

Changes in body orientation will place the legs at a different angle with respect to the line of gravity, therefore affecting both the hemodynamics of blood flow and force contribution by the body weight. The effect on cycling performance and whether there may be an interaction effect between blood flow hemodynamics and body weight contribution in different body orientation is also unknown. The purpose of this investigation was to determine the effect of changes in body orientation on energy expenditure, cycling duration and total work output.

REVIEW OF LITERATURE

Most investigations comparing cycling performance with different body orientations have only examined the upright and supine orientation (Bevegard, Freyschuss, & Strandell, 1966; Bevegard, Holmgren, & Jonsson, 1960, 1963; Convertino, Goldwater, & Sandler, 1984; Granath, Jonsson & Strandell, 1964; Kubicek & Gaul, 1977). Depending on whether cycling performance is defined by maximal or submaximal work output, oxygen consumption, and/or efficiency, there is equivocation regarding the most effective cycling orientation. This equivocation may be attributed to factors such as: (1) the type of variables used to define cycling performance; (2) differences in test protocol (workload and pedalling frequencies); (3) a lack of standardization in the different test conditions (i.e. not controlling for changes in body configuration or seat to pedal distance); and (4) a greater contribution of body weight to cycling performance in the upright orientation compared to a greater effect of venous blood return to the heart in the supine orientation.

Generally, it would appear that a greater maximal work output and oxygen consumption can be obtained when cycling in an upright orientation than in a supine one (Astrand and Rodahl, 1977; Kubicek and Gaul, 1977). Whether this is also true when comparing an upright orientation to other cycling orientations have not been determined.

METHODS

A seating apparatus, allowing for manipulations in body orientation, seat tube angle, and seat to pedal distance was constructed and mounted onto a Monark bicycle ergometer. Ten male subjects (22-35 years of age) were tested in three different body orientations (60, 90, and 120 degrees), as defined by the angle formed between the seat-backrest and a horizontal line parallel to the ground.

In the 90 degree orientation; (1) the seat tube angle (the angle formed between the seat tube and a vertical line) was fixed at 75 degrees; and (2) the seat to pedal distance was adjusted to 100% (to within 3/4 of an inch or 1.905 cm) of each subjects' total leg length, as measured from the greater trochanter of the femur of the right leg to the ground. To obtain the 60 and 120 degree orientation, a 30 degree incline platform was constructed which allowed the entire cycling apparatus to be mounted at a 30 degree incline or decline.

In each orientation, the minimum and maximum hip, knee, and ankle angles were obtained for one pedal revolution. All subjects were tested in each of the three orientations according to a pre-selected sequence of workloads and pedalling frequencies with increments occurring every 3 minutes until exhaustion (Table 1). The testing sequences for the three orientations were randomly selected for each subject with a minimum of 24 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.

An open circuit gas exchange system was used to collect data in this investigation. This included a: 5300 Pneumoscan spirometer, CD-3A Carbon Dioxide Analyzer, and a Model 46 TUC Tele-Thermometer connected on-line to an IBM-PC micro-computer.

TABLE 1: Bicycle Ergometer Test Protocol

Brake Load (kp)	Pedal Rate (rpm)	Time (min)	Work Rate (kpm/min)	(watts)	(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	.439
5	80	30	2400	392.4	.526

Note: Work Rate = Brake Load X Pedal Rate
1 HP = 746 watts = 4562.4 kpm/min

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).

Observations of Table 2 would suggest that, except for the ankle angles, the mean joint angles measured in the three body orientations were generally within one standard deviation of each other. These differences were attributed to forward and backward sliding of the subjects on the bicycle seat in the 60 and 120 degree orientation, respectively, despite the use of restraining straps. Repeated measures MANOVAs, used to determine whether these differences were significant, found only the mean and maximum ankle angles significantly different (p.01)

Presented in Table 3 are the results of the maximal energy expenditure, cycling duration, and total work output with changes in body orientation. Energy expenditure was determined from oxygen consumption values.

With repeated measures MANOVAs, no significant differences (p.05) were found in energy expenditure, cycling duration, or total work output with changes in body orientation.

TABLE 2: Hip, Knee, and Ankle Angle at Three Body Orientation

	Body Orientation (deg)					
	60		90		120	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Hip (deg)						
mean	75.5	(5.4)	75.5	(6.6)	82.0	(4.3)
min	57.6	(6.9)	55.3	(5.7)	62.0	(4.8)
max	93.3	(6.0)	95.7	(8.2)	101.0	(7.1)
ROM	36.7	(9.0)	41.0	(4.2)	39.9	(8.5)
Knee(deg)						
mean	103.7	(7.9)	104.7	(6.7)	109.7	(4.5)
min	64.7	(5.7)	65.4	(5.0)	68.9	(5.0)
max	142.0	(12.6)	144.0	(9.4)	150.4	(6.5)
ROM	75.9	(10.1)	78.6	(9.9)	81.5	(7.3)
Ankle (deg)						
mean	87.0	(5.3)	96.3	(6.9)	102.2	(7.5)
min	78.8	(3.7)	82.6	(10.9)	91.9	(11.2)
max	95.1	(9.4)	103.4	(6.2)	112.5	(7.1)
ROM	16.3	(9.6)	21.8	(10.9)	20.6	(11.4)

TABLE 3: Maximal Energy Expenditure, Cycling Duration, and Total Work Output at Different Body Orientations

	Body Orientation (deg)		
	60	90	120
Maximal Energy Expenditure (kcal/min)			
Mean	20.4	20.8	20.5
(SD)	(3.4)	(3.9)	(3.6)
Cycling Duration (min)			
Mean	15.38	15.12	14.69
(SD)	(4.3)	(4.1)	(4.1)
Total Work Output (kpm)			
Mean	15876	15426	14764
(SD)	(7303)	(6988)	(6969)

Although no significant differences were found in selected cycling performance variables with changes in orientation, trends in data obtained from rest and submaximal workloads suggest possible explanations for those results. Observation of Table 4 indicate a small, but non-significant hemodynamic effect on energy expenditure at rest; as evidenced by decreasing energy expenditures with increasing body orientations.

TABLE 4: Energy Expenditure at Rest and at Different Unloaded Cadences with Changes in Body Orientation

	Body Orientation (deg)					
	60		90		120	
Energy Expenditure (kcal/min)						
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Rest	1.9	(0.3)	1.8	(0.3)	1.7	(0.3)
60 rpm	3.4	(0.4)	3.0	(0.3)	3.0	(0.6)
70 rpm	3.7	(0.4)	3.5	(0.7)	3.7	(0.6)
75 rpm	3.8	(0.6)	3.9	(0.6)	4.0	(0.6)
80 rpm	3.9	(0.6)	4.2	(0.9)	4.3	(0.7)

The hemodynamic effect would probably be greater (in facilitating venous return to the heart) in the 120 degree body orientation with the trunk reclining and the legs elevated; and least in the 60 degree orientation where the effect of gravity, retarding venous return of blood from the legs to the heart, is greatest. Conversely, the reverse is true regarding force contribution to the pedals by the body weight. In a 60 degree body orientation, the weight contribution of the body would be greatest and it would be least in the 120 degree orientation.

At unloaded cadences of 75 and 80 rpms, decreasing energy expenditure from body orientations of 120 to 90 and 60 degrees, respectively, would suggest that the body weight contribution in the 60 degree orientation counteracts any hemodynamic benefits in the 120 degree orientation. This would also appear to be true for efficiency measures at submaximal workloads (Table 5).

TABLE 5: Work Efficiency at Different Body Orientations During the Last Minute at Submaximal Workloads of 360 and 720 kpm

	Body Orientation (deg)					
	60		90		120	
Work Efficiency (%)						
	Mean	(SD)	Mean	(SD)	Mean	(SD)
360	kpm	35.1	(7.3)	28.6	(4.9)	25.9
720	kpm	26.1	(3.0)	24.9	(3.9)	24.4

Work Efficiency =
(external work accomplished/(aerobic energy expenditure - energy expenditure during unloaded peddling)) x 100%

Significant differences (p.01) were found in work efficiency with changes in orientation at a submaximal workload of 360 kpm, but not at 720 kpm (although there's still an increasing trend in work efficiency from a body orientation of 120 to 60 degrees). As the workload increases, these differences in efficiency and energy expenditure decreases. There are several, possible explanations for this.

First, the relative contribution of the body weight to pedal force production decreases with increasing workloads (although the absolute contribution remains unchanged). Therefore, in the 60 degree body orientation, body weight contributions were less relative to the overall force required for a greater workload.

Secondly, at greater workloads, the hemodynamic effect of venous return to the heart might become more important and critical in maintaining a given workload and to performance. Thus, the lower relative contribution of body weight combined with the greater effect and importance of hemodynamics at greater workloads result in increasing energy expenditures at the 60 degree body orientation. The reverse would then be true with increasing workloads in the 120 degree body orientation. The greater importance and contribution of more favourable hemodynamic orientation, combined with the lesser importance of body weight at greater workloads, would result in a lower energy expenditure and greater work efficiency when compared to the 90 or 60 degree body orientation. In other words, the contribution of body weight and hemodynamic effects on cycling performance in different body orientations are counteracted by each other at higher workloads.

Thirdly, no significant differences in energy expenditure and work efficiency was found at a workload of 720 kpm or in maximal aerobic energy expenditure at the maximal workload with different body orientations because, body orientation may not be a significant variable. On the other hand, there may be differences, but not significant ones because the manipulation of body orientation may not have been large enough.

CONCLUSIONS

It was concluded that, within the limitations of this investigation, changes in body orientation did not have a significant effect on cycling performance as defined by energy expenditure, cycling duration, and total work output. However, there may be an interaction effect between body weight contribution to pedal force production and blood flow hemodynamics with changes in body orientation.

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