EFFECT OF HIP ORIENTATION ON WINGATE ANAEROBIC POWER OUTPUT

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The effect on anaerobic power output of Hip Orientation Angle (HOA, angle of hip joint to bottom bracket relative to horizontal) while maintaining a constant Body Configuration Angle (BCA, included angle between torso, hip, and bottom bracket) and maximum hip-to-pedal distance was examined. In this way, changes in power output could be attributable to the altered pull of gravity on the lower extremity. Nineteen male recreational cyclists with no recent recumbent cycling experience completed 30 s Wingate tests in three recumbent positions (HOA of -20, -10, and 0°) and the standard cycling position (HOA = 75°), all with a 130° BCA. Neither peak, average, or minimum power were significantly different across all positions nor was fatigue index ($p < 0.01$). These findings suggest that anaerobic power is not altered by hip orientation.

KEY WORDS: cycling, recumbent, hip position, peak power

INTRODUCTION: The recumbent cycling position has become increasingly popular for both high-performance human-powered vehicles and sport/comfort cycles. Popularity for high-performance vehicles is mainly due to a recumbent's reduced aerodynamic drag compared to a fully-crouched, standard racing position (Gross *et al*. 1983). While a Recumbent Cycling Position (RCP) may have this advantage compared to the Standard Cycling Position (SCP), questions remain about power output in the recumbent position. The optimal Hip Orientation Angle (HOA, angle of hip joint to bottom bracket relative to horizontal – see Figure 1 for graphical representation of angles) for peak anaerobic power output is not known. An optimal design of a recumbent vehicle is not possible without this information. Additionally, it is unclear how power output in the RCP compares to the SCP, making it difficult to compare measured parameters in the two different positions.

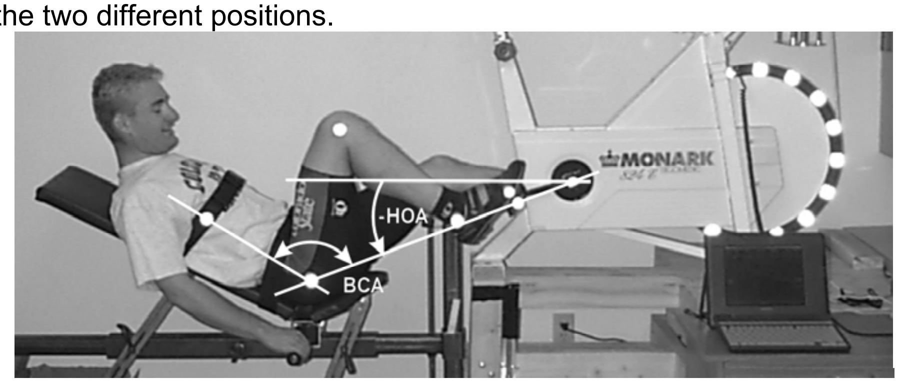

Figure 1 - Recumbent cycling system with overlay of hip orientation angle (HOA) and body configuration angle (BCA).

Altering the HOA changes the relative phasing of propulsive leg extension relative to the gravitational force pulling the leg down on the pedal. For example, in the SCP, leg extension occurs in phase with gravity acting on the leg segments to produce propulsive forces at the same time (Kautz and Hull, 1993). In contrast, a RCP with a HOA near 0° would have leg extension approximately 90° out of phase with the propulsive forces from gravity. The net propulsive effect from the gravitational forces on the cycling task will be zero, regardless of the HOA, due to the conservative nature of the system during a complete pedal cycle. However, the pull of gravity on the limbs in different orientations about the bottom bracket may cause the segmental angles of the lower extremity joints to vary. The variation is due to the altered forces on the leg segments. Alone, or in combination, the altered phasing of propulsive power components and lower-extremity kinematics may cause changes in power output.

Previously, Reiser *et al*. (In Press) investigated the effects on anaerobic cycling power output of altering the Body Configuration Angle (BCA, included angle between torso, hip, and bottom bracket) through changes in backrest angle while maintaining a constant HOA equal to -15°. In this way, power output variations were attributable to changes in the lower-extremity joint ranges of motion, primarily at the hip. Power output was shown to drop significantly as BCA was reduced from the angle that was self-selected by the subjects tested in the SCP. Additionally, recumbent cycling power output from the subjects was similar to the SCP when BCA was matched, suggesting that hip orientation does not affect cycling power output.

In a separate earlier investigation, Too (1994) isolated the effects on power output of gravity changes on the legs by altering the HOA and maintaining the same BCA while cycling. Power output in the -15° HOA was found to be significantly less than the power output in the 15° and 45° HOA positions. The power output in the 15° and 45° HOA positions, however, was not statistically different. This finding suggested that HOA may have an influence on the power output produced while cycling. However, several details of the study may have influenced these results, most notably, the absence of clipless pedals on the ergometer.

The conflicting results between Reiser, *et al*. (In Press) and Too (1994) suggest that further investigation is needed relating to the effects of different HOA on anaerobic power output. Without additional knowledge of the effects of gravity, the optimal recumbent cycling position cannot be determined. The objective of this investigation was to determine the effects on power output of altering the HOA while keeping the BCA constant. In this way, alterations in HOA will be the main effect in any power output differences. Additionally, in order to understand the relationships between recumbent cycling and the SCP more clearly, a comparison to the SCP was made.

METHODS: Nineteen male recreational cyclists participated in this study [age = 26.8 $\pm$ 4.6 yrs, (AVG $\pm$ STD) body mass = 75.7 $\pm$ 8.8 kg, height = 180 $\pm$ 8 cm]. The maximum Hip-to-Pedal Distance (HPD) while cycling was set at the beginning of each cycling session to 105% of the subject's standing leg length from greater trochanter to the floor. Subjects had performed no significant recumbent cycling training within the 3-month period prior to testing.

To accommodate the changes in HOA required of this study and maintain consistent BCA and HPD for different sized individuals, a custom built, variable-seating device was interfaced with a Monark 824E bicycle ergometer (Monark Exercise AB, Varberg, Sweden) (Figure 1). The ergometer was equipped with 175 mm crank arms and Shimano SPD® compatible clipless pedals.

Five test sessions were required of each subject. The first session was used to obtain university-approved informed consent along with information on cycling experience and health status. Additionally, anthropometric measures were made and a test administered in a random position to familiarize subjects with the apparatus and procedures (Wingate pilot testing showed a one-test learning curve with no further improvements after the second test). Each of the remaining four sessions tested a different cycling position. Three of the cycling positions tested were recumbent with -20, -10, and 0° HOA coupled with the backrest adjusted to maintain a 130° BCA. The fourth position was a SCP with 75° HOA and no backrest so that the subject could choose their own angle of torso lean.

All subjects were tested in each cycling position with the testing sequence randomly determined. However, the position tested in the familiarization session was repeated in the fifth session. There was a minimum of 24 hours between test sessions with each subject testing at the same time of each day with a minimum of exercise during the hours of that day prior to testing. Once testing commenced, all sessions were completed within a 14-day period. For each recumbent position, the subject was strapped to the seating device with both a hip and mid-torso belt. No belts were worn during the SCP testing. However, the subjects were required to remain seated during the entire SCP test.

To ensure that the HOA, BCA, and HPD was maintained while cycling, reflective markers were placed on each subject's right mid-torso (mid rib cage, in line with hip/shoulder axis), hip (approximating the greater trochanter), and ergometer crank and pedal spindle centers.
The 30-s Wingate test was chosen as the measure of maximal anaerobic power output, with the administered test protocol similar to that utilized by the Sport Science & Technology Division of the United States Olympic Committee (R.L. Wilber, personal communication, March 1998). The test protocol consisted of a 5 min warm-up with self-selected cadence and resistive load of 2.0% Body Mass (BM) in the test position of that session. During the warm-up period 2 short sprints of 5 s duration with a load of 4.1% BM were administered at the 3 and 4 min marks. A 3 min recovery period followed the warm-up prior to the initiation of the test. The recovery period allowed the subject to continue cycling with zero load or to stop and stretch. To begin the test, each subject cycled at 60 rpm against zero load until, after a 5 s countdown, the resistance was rapidly increased to 8.5% BM.
Power output during the test was measured with the OptoSensor 2000™ (Sports Medicine Industries, Inc., St. Cloud, Minnesota). This system used an optical sensor to measure rotation of the ergometer flywheel. Power was then calculated at 1 s intervals throughout the test based on flywheel properties, flywheel kinematics, and the applied load to the flywheel, taking into account the inertia of the flywheel (Reiser *et al*., 2000). Also during the test, a camera was positioned orthogonal to the plane of motion at a distance of approximately 3 m and operating at 30 Hz with a shutter speed of 0.001 s.
From each test, the 5 s intervals with the highest and lowest average power output were selected for the Peak (PP) and Minimum Power (MP) outputs, respectively. The PP and MP were then used to calculate the Fatigue Index (FI, calculated as the percent difference between PP and MP). The 30-s Average Power (AP) over the entire test was also calculated. All power calculations were normalized by dividing power by the subject's BM to report relative power outputs (W/kg BM).
The reflective markers were automatically digitized (Peak Performance System, Englewood, Colorado) at 30 Hz for three successive pedal revolutions beginning at top dead center. The 3 pedal revolutions digitized were those that crossed the 15 s point into the test. The 2-dimensional coordinate data were then smoothed at 5 Hz using a recursive lowpass butterworth filter. BCA, HOA, and HPD were computed to verify the experimental set-up.
The power output and kinematic data were tabulated for the 3 different recumbent positions (HOA from -20 through 0°) and the SCP. Average and standard deviations were calculated for each cycling position. The 3 recumbent positions and SCP were compared using repeated measures ANOVA. All significance was evaluated at the $P < 0.01$ level.

RESULTS: As per the experimental design, HOA, BCA, and HPD were well controlled. HOA values were all significantly different from each other and within 3° of their prescribed value (-21°, -13°, 0°, and 77°, respectively). BCA was maintained within 3° of the experimentally designed 130° for all positions, including SCP (129°, 128°, 133°, and 133°, respectively). None of the BCA were significantly different from each other. The HPD was constant across all positions at the experimentally prescribed 105%.
PP, AP, MP, and FI did not vary significantly across the four positions (Table 1).

DISCUSSION: Power output was not affected by HOA. This is consistent with the previous findings by Reiser, *et al*. (In Press) who found no difference between similar BCA of a -15° HOA recumbent position and 75° HOA SCP. Too (1994), in contrast, found significant differences between similar BCA positions with positive and negative HOA. However, Too (1994) incorporated toe-clips, rather than clipless pedals, into the experimental design. Toe-clips do not provide the secure interface provided by clipless pedals (Broker and Gregor 1996). The less-secure interface may be why power output in the low hip orientation position was less than that of the two other positions. With the foot effectively underneath the pedal in the -15° HOA, gravity tends to separate the foot from the pedal, and thus may cause reduced power output while cycling with toe-clips. When the foot is above the pedals, as in the 15° and 45° HOA positions, gravity is always acting to keep the foot in contact with the pedal.

Cycling in the recumbent position does not seem to reduce, or improve, anaerobic power output compared to the SCP. While Reiser *et al*. (In Press) found that an 'optimal' recumbent position may be slightly (but not significantly) more powerful than the SCP, it was not verified here. Their 'optimal' recumbent position was selected from the most powerful recumbent position of each subject. Their protocol found that two, possibly three, BCA positions tested had similar power output. Daily variations in power output could account for one position being slightly greater than another. Selecting this 'optimal' and comparing it against a position that was tested just once, like the SCP, could account for a slight increase in power output in the recumbent position compared to the SCP, when, in fact, having a backrest to push against may have no influence on power output.

Table 1 Relative Power Output (W/kg BM)

HOA		**-20**	**-10**	**0**	**SCP**
Peak	*AVG*	14.7	14.8	14.7	15.0
	STD	*1.3*	*1.3*	*1.4*	*1.1*
Average	*AVG*	9.9	9.9	9.8	9.9
	STD	*0.8*	*0.8*	*0.9*	*0.9*
Minimum	*AVG*	6.8	6.7	6.6	6.7
	STD	*0.7*	*0.8*	*0.9*	*0.8*
Fatigue	*AVG*	54	55	55	55
Index (%)	*STD*	*5*	*6*	*4*	*4*

CONCLUSIONS: These results support previous findings that the recumbent cycling position is as effective for producing as high levels of power output as the SCP, so that cycling anaerobic power tests may be performed in the recumbent or SCP with equal values to be expected. These results also support the previous findings that proper selection of BCA is more important for power output than HOA, suggesting that the design of a recumbent human-powered vehicle should maintain the BCA, but not be concerned about HOA for power output. Additionally, more investigation is still needed concerning the musculoskeletal kinematics and kinetics in order to understand why power output is or is not altered under these and previously examined experimental conditions. Furthermore, investigation is still needed into the effects of foot-to-pedal interface when the foot is effectively underneath the pedal while cycling.

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