Journal of Strength and Conditioning Research, 2002, 16(4), 556–560

Influence of Hip Orientation on Wingate Power Output and Cycling Technique

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ABSTRACT

The effect of altered hip orientation angle ([HOA] angle of hip joint center to bottom bracket relative to horizontal) on Wingate anaerobic test results and cycling technique while maintaining a constant body configuration angle (included angle between torso, hip, and bottom bracket) and maximum hip-to-pedal distance was examined. Nineteen recreational cyclists, all men, with no recent recumbent cycling experience completed 30-second Wingate tests in 3 recumbent positions (HOA = −20°, −10°, and 0°) and the standard cycling position (SCP) (HOA = 75°). Peak, average, and minimum power output, as well as fatigue index, were not significantly different across all positions ($p < 0.01$). Average hip and knee extension angles increased slightly, and ankle angle did not change as HOA increased. These findings indicate that although HOA does have a small effect on cycling kinematics, these effects are not large enough to alter short-term power output. Therefore, anaerobic power output may be evaluated and compared in the recumbent positions and the SCP.

Key Words: anaerobic power, cycling kinematics, recumbent

Reference Data: Reiser, R.F. II, M.L. Peterson, and J.P. Broker. Influence of hip orientation on Wingate power output and cycling technique. *J. Strength Cond. Res. 16(4):556–560. 2002.*

Introduction

The 30-second Wingate anaerobic power test was developed, validated, and historically administered in the standard cycling position (SCP), in which the person is seated above the pedals and bent over at the waist with torso support coming from the handlebars (2). With the recent popularity of recumbent cycling ergometers, in which the person is seated nearly horizontal behind the pedals with the torso elevated and supported by a backrest (Figure 1), it is now possible to administer the Wingate test in the recumbent cycling position (RCP). But the results obtained from Wingate tests administered in these 2 different positions may not be interchangeable.

Cycling in the RCP differs from cycling in the SCP in the way that the person is oriented relative to the pull of gravity and in the way that the person is seated (or constrained). The orientation of the person relative to gravity will alter the sensory input from vestibular as well as foot pressure receptors (8). Lower-extremity orientation will also alter the task mechanics because of gravity pulling down on the limbs while the person is mainly pushing forward on the pedals in the RCP compared with the SCP, in which gravity pulls in the direction that the person is pushing on the pedals. Seating is also different between the 2 positions, with the recumbent seat constraining the person's hip movement as well as providing a firm backrest to push against compared with the SCP. Alone, or in conjunction, these factors may cause a person to produce different levels of power output in the RCP and SCP, making it difficult to compare the results obtained from each Wingate test (these results are peak power, average power, minimum power, and fatigue index).

Recently, 2 separate investigations compared Wingate test results from subjects who cycled in the SCP as well as in the RCP (4, 6). O'Kroy (4) found no significant differences in power outputs from the 2 positions tested in men, and Reiser et al. (6) found no differences in the RCP compared with the SCP when the body configuration angle (included angle from bottom bracket to hip joint center to a midtorso marker [Figure 1]) was controlled in both positions. Whereas these investigations indicate that Wingate results are similar in men when tested in RCP or SCP, just 1 recumbent hip orientation was examined in each investigation, and O'Kroy (4) did not control for body configuration angle. Hip orientation is defined as the angle of the hip joint center relative to horizontal (Figure 1). Hip orientation is a critical factor because this parameter has a direct effect on the orientation of the lower extremity relative to gravity and may result in a continuum of test results with hip orientation. There-

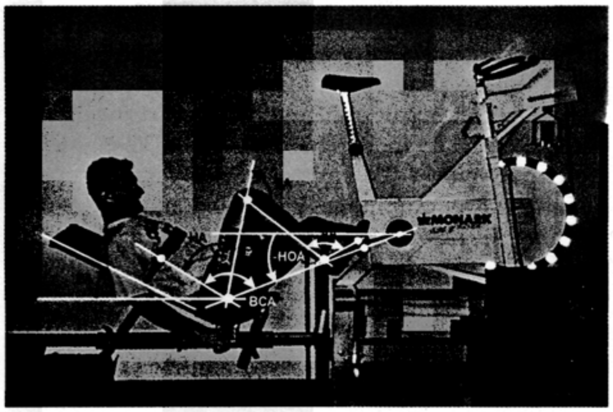

Figure 1. The variable seating device interfaced with cycling ergometer used in data collection of recumbent cycling positions with overlay of defined terms: AA = ankle angle; BA = backrest angle; BCA = body configuration angle; HA = hip angle; HOA = hip orientation angle; KA = knee angle. The same ergometer was used for the standard cycling position testing by placing it on the ground.

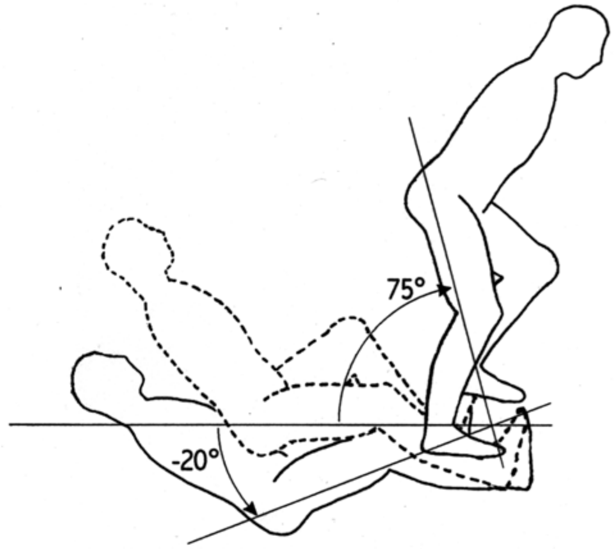

Figure 2. The range of hip orientation angles (HOAs) examined. Dotted figure represents the zero HOA position in which the hip is aligned horizontally with the ergometer's bottom bracket.

fore, it is necessary to compare a variety of recumbent hip orientation positions against the SCP, while controlling for other factors that influence power output, to ensure that hip orientation does not influence the power output through a broad range as previously determined by the single RCP comparisons of O'Kroy (4) and Reiser et al. (6).

The objective of this investigation was to compare the Wingate results and cycling technique from several different recumbent hip orientations against those obtained with the same subjects in the SCP. Cycling technique is of interest because of the many factors previously described that influence power output in the RCP compared with the SCP. Changes in cycling technique may be compensated by other factors to yield similar Wingate results in the various positions. By investigating cycling technique, we may be able to elucidate how these factors interact. Thus, we hypothesized that the Wingate results from tests performed in various RCPs would not differ from those obtained in the SCP. We also hypothesized that cycling technique would be altered by hip orientation with no significant influence on power output.

Methods

Experimental Approach to the Problem

To accommodate the changes in hip orientation angle (HOA) required of this study for the various RCPs and to maintain consistent body configuration angles and hip-to-pedal distances for different-sized individuals, a 4-degree-of-freedom, variable-seating device was interfaced with a Monark 824E bicycle ergometer (Monark Exercise AB, Varberg, Sweden) (Figure 1). Body configuration angle (6) and hip-to-pedal distance (7) must be controlled because of their influence on power output. The ergometer was equipped with 175-mm crank arms, similar to those used by most subjects on their own bicycles. Shimano Pedaling Dynamics-compatible clipless pedals (Shimano American Corporation, Irvine, CA) were incorporated to ensure a secure foot-to-pedal interface.

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, a test was administered in a random position to familiarize subjects with the apparatus and procedures. (Wingate pilot testing showed a 1-test learning curve with no further improvements after the second test.) Each of the remaining 4 sessions tested a different cycling position. Three of the cycling positions tested were recumbent with −20°, −10°, and 0° HOAs coupled with a backrest position that produced a 130° body configuration angle (Figure 2). The fourth position was an SCP with 75° HOA and no backrest so that the subjects could choose their own angle of torso lean (each subject was also allowed to adjust handlebar height and rotation).

The 130° body configuration angle was chosen because it was found to be optimal in a similar set of subjects as well as that self-selected by the subjects in the SCP (6). The −20° to 0° HOA combined with the 30° to 50° backrest angle, respectively, were selected for its similarity with the angle in some of the commercially available recumbent ergometers and bicycles.

Subjects

Nineteen male recreational cyclists participated in this study (mean ± *SD:* age = 26.8 ± 4.6 years, body mass

= 75.7 ± 8.8 kg, height = 1.80 ± 0.08 m). The maximum hip-to-pedal distance while cycling was set at the beginning of each cycling session at 105% of the standing leg length from greater trochanter to the floor. Subjects had performed no significant recumbent cycling training within the 3-month period before testing.

All subjects were tested in each cycling position with the testing sequence randomly determined. But 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 before 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 midtorso belt. No belts were worn during the SCP testing. The subjects, however, were required to remain seated during the entire SCP test.

To acquire lower-extremity kinematics while cycling, reflective markers were placed on each subject's right midtorso (mid–rib cage, in line with hip/shoulder axis), hip (approximating the greater trochanter), knee (lateral femoral epicondyle), ankle (lateral malleolus), and toe (head of fifth metatarsal). Markers were also placed on the ergometer at the crank center and pedal spindle center (Figure 1).

The 30-second Wingate test was administered with a test protocol similar to that used by the Coaching & Sport Science Division of the U.S. Olympic Committee (R.L. Wilber, personal communication, March 1998). This protocol was selected for its successful implementation with athletic populations. The test protocol consisted of a 5-minute warm-up with self-selected cadence and resistive load of 2.0% body mass in the test position of that session. During the warm-up period, 2 short sprints of 5-second duration with a load of 4.1% body mass were administered at the 3- and 4-minute marks. A 3-minute recovery period followed the warm-up before the initiation of the test. The recovery period allowed the subject to continue cycling with no resistance or to stop and stretch. To begin the test, each subject cycled at 60 rpm against zero load until, after a 5-second countdown, the resistance was increased to 8.5% body mass.

Power output was measured with the OptoSensor 2000 (Sports Medicine Industries, Inc., St. Cloud, MN). This system uses an optical sensor to measure rotation of the ergometer flywheel. Power was then calculated at 1-second intervals throughout the test on the basis of flywheel properties, flywheel kinematics, and the applied load to the flywheel (5). Also, during the test, subjects were videotaped by a camera positioned orthogonally to the plane of motion at a distance of approximately 3 m and operating at 60 Hz with a shutter speed of 0.001 seconds.

From each test, the 5-second intervals with the highest and lowest average power outputs were selected for the peak and minimum power outputs, respectively. The peak and minimum power were then used to calculate the fatigue index. The 30-second average power over the entire test was also calculated. Relative power output was calculated and reported by dividing all power calculations by the subject's body mass ($W \cdot kg^{-1}$ body mass).

The reflective markers were automatically digitized (Peak Performance System, Englewood, CO) at 30 Hz for 3 successive pedal revolutions beginning at top dead center. The 3 pedal revolutions that were digitized were those that crossed the 15-second point into the test. The 2-dimensional coordinate data were then smoothed at 5 Hz using a recursive low-pass Butterworth filter. Average HOA, body configuration angle, and maximum hip-to-pedal distance along with maximum, average, and minimum hip, knee, and ankle angles were all calculated from the coordinate data. Maximum- and minimum-value kinematic parameters are an average of the 3 maxima and minima, respectively, from the digitized pedal cycles, whereas the remaining kinematic parameters are an average over the entire 3 pedal cycles.

Statistical Analyses

The power output and kinematic data were tabulated for the 3 RCPs and the SCP. Mean and *SD* were calculated for each position. The 3 RCPs and SCP were then compared using repeated-measures analysis of variance with post hoc analysis using Tukey's Honestly Significant Diference. All significance was evaluated at the $p \leq 0.01$ level.

Results

The experimental setup was well controlled by the design (Table 1). Maximum hip-to-pedal distance was constant across all positions with an average of 105 ± 0%. Body configuration angle was maintained by the simultaneous changes in HOA and backrest within 3° of the experimentally designed 130° for all positions, including SCP. None of the body configurations were significantly different from each other. Hip orientation angle was also well controlled, staying within 3° of the prescribed values, and all HOAs were significantly different from each other.

Peak, average, and minimum power output (Figure 3) as well as fatigue index did not vary significantly across the 4 positions. Fatigue index exhibited the least fluctuation of all the Wingate parameters, with a value of 55% for all positions except for the −20° HOA RCP when it dropped slightly to 54%. Standard deviations for the average fatigue index values ranged from 4% to 6%.

The maximum, average, and minimum hip angles exhibited a slight increase in extension from RCP

Table 1. Summary of controlled kinematics (°; mean ± *SD*).†

	HOA			
	−20	−10	0	SCP
Hip-to-pedal (%)	105 ± 2	105 ± 2	105 ± 1	105 ± 2
Torso angle	30 ± 7*	39 ± 5*	47 ± 5*	124 ± 9*
HOA (measured)	−21 ± 2*	−13 ± 1*	0 ± 1*	77 ± 2*
Body configuration angle	129 ± 7	128 ± 6	133 ± 6	133 ± 9

† HOA = hip orientation angle; SCP = standard cycling position.
* $p < 0.01$ with all other positions.

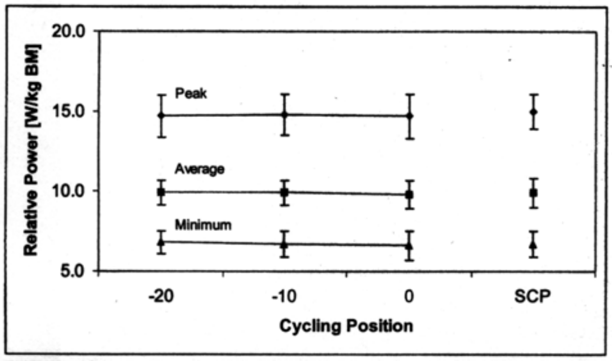

Figure 3. Peak, average, and minimum relative power output from 30-second Wingate tests in the 3 recumbent cycling positions compared with the standard cycling position (SCP) with 1 *SD* indicated above and below the average value. Recumbent cycling positions are indicated by their hip orientation angle. We found no significant differences in any of the 3 displayed parameters on comparing the different cycling positions.

Table 2. Summary of lower-extremity kinematics (°).

	Hip orientation angle			
	−20	−10	0	SCP†
Hip angle				
Maximum	108 ± 6*	107 ± 5*	112 ± 6*	119 ± 8
Average	90 ± 6*	89 ± 5*	93 ± 6	97 ± 9
Minimum	70 ± 8	69 ± 6*	73 ± 7	76 ± 12
Knee angle				
Maximum	112 ± 4	112 ± 5	111 ± 3	108 ± 7
Average	82 ± 3*	82 ± 4*	81 ± 4*	76 ± 7
Minimum	46 ± 5*	47 ± 5*	46 ± 5*	41 ± 9
Ankle angle				
Maximum	137 ± 10	135 ± 11	138 ± 11	137 ± 10
Average	123 ± 9	121 ± 8	122 ± 8	122 ± 7
Minimum	109 ± 9	107 ± 10	107 ± 7	107 ± 6

† SCP = standard cycling position.
* $p < 0.01$ with SCP only.

HOAs of −20° through 0° with the hip angles in the SCP being slightly greater (more extended) than in all the recumbent positions (Table 2). A slight inflection in the hip angle at the −10° HOA RCP was noticeable, consistent with the same inflection in the body configuration angle. None of the recumbent hip angles were significantly different. The SCP hip angles, however, were generally statistically different (6 of 9 comparisons) from those in the recumbent positions.

The maximum, average, and minimum knee angles did not change significantly across the recumbent positions but did tend to decrease slightly (increasing extension) as the HOA increased (Table 2). The knee angles of the SCP were consistently less (more extended) than those of the recumbent positions, and they were generally significantly different (6 of 9 comparisons) from those of recumbent positions.

The maximum, average, and minimum ankle angles exhibited no consistent changes across both the RCPs and SCP (Table 2). A slight inflection in the ankle angles of the −10° HOA RCP is noticeable in line with the body configuration angles and hip angles. But no statistical significance was found among any of the ankle angles.

Discussion

Cycling in the recumbent position does not seem to reduce, or improve, anaerobic power output compared with the SCP. Although Reiser et al. (6) found that an "optimal" RCP may be slightly (but not significantly) more powerful than the SCP, it was not verified here. Their optimal RCP was selected from the most powerful recumbent position of each subject. Their protocol found that 2, possibly 3, body configuration angle positions tested had similar power outputs. Daily variations in power output could account for 1 position being slightly more powerful than another. Selecting this optimal position 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 with the SCP. It has been suggested elsewhere that having a backrest to push against might allow the subject to produce more power (3). But this may not be the case at high joint angular velocities like those achieved in the Wingate test because of the force-velocity characteristics of muscle.

Small increases in hip extension accompanied by small increases in knee extension were evident as HOA increased. These changes are consistent with the findings of Brown et al. (1) and Reiser et al. (6). Brown et al. (1) and Reiser et al. (6) also noticed changes in ankle angles with HOA, whereas no differences in ankle angles were found here. Because changes in ankle angle with HOA were found to be small in previous studies, it is possible that the small variations in ankle angles from the slightly varying body configuration angles could have masked the effects of HOA on ankle angle.

A small inflection of the hip angles and ankle angles is noticeable in the −10° HOA RCP. This inflection coincides with a similar inflection in the body configuration angle data. Changes in the hip angle and ankle angle in coordination with the body configuration angle, with no apparent change in the knee angle, are consistent with the previous findings of Reiser et al. (6). Reiser et al. (6) found that changes in body configuration angle elicit consistent changes in hip angle and ankle angle but not in knee angle. The small variation in body configuration angle here is not expected to result in any significant changes in a person's power output. Reiser et al. (6) found that changes of body configuration angle on the order of 10–20° from optimal were needed to elicit changes in power output.

Although lower-extremity kinematics were altered slightly by changes in HOA, these changes were not enough to influence power output. This is consistent with the findings of Reiser et al. (6), who found no difference between similar body configuration angles of a −15° HOA RCP and the SCP. Additionally, Brown et al. (1) suggested that kinematic variations from altered hip orientations were not large enough to significantly alter muscle force production. Because muscle force production is probably not significantly altered nor is power output, the effects of the other parameters such as vestibular and foot pressure receptor influences are most likely negligible and do not combine to alter power output in practical RCP as compared with the SCP.

Practical Applications

The orientation of the person relative to gravity does have a small effect on lower-extremity cycling technique when cycling with maximal effort. These effects, however, are not large enough to produce significant changes in power output, at least in the practical range of positions tested for commercially available cycling ergometers. These results support previous findings that the RCP is effective for producing high levels of power output, similar to the SCP. Although HOA does not seem to influence power output from Wingate tests in men, care should be taken to ensure that the body configuration angle is maintained in the RCP to that which the subject would normally self-select in the SCP. Also, the hip-to-pedal distance should be controlled to minimize the influence of this parameter. (We found that subjects self-selected a hip-to-pedal distance in the RCP that was within 0.025 m of that selected in the SCP, so this parameter will generally be controlled by the subject.) Additionally, it also seems that a secure foot-to-pedal interface is necessary when testing for peak power output. If clipless pedals and cycling shoes are not available for testing, at a minimum, the subject's foot should be taped to the pedals.

A caution must also be entered relative to these results and their applicability to persons of different body size and gender. This study examined a relatively homogeneous group of men. A group of men of much different anthropometrics, such as football players, may experience different results. Women may also experience slightly different results in the RCP compared with the SCP, as shown by O'Kroy (4).

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Acknowledgments

Special thanks to Shimano for their support of this project and to R.L. Wilber, Ph.D., of the U.S. Olympic Committee's Coaching & Sport Science Division for his assistance with developing the testing protocol. Also, thanks to all participants, without whom this project would not have been possible. Support for the first author was provided by the Graduate Assistance in Areas of National Need program in the U.S. Department of Education (award P200A70433).

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