OPTIMAL CRANK ARM LENGTH AND BODY POSITION FOR ROAD SPRINT CYCLING PERFORMANCE

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The purpose of the current study was to examine the effects of body position and crank arm length (CAL) on power production in road sprint cycling. Six well trained male cyclists were tested in the standing and seated positions, and with three CALs of 18, 20 and 22 % of leg length whilst out of the saddle. A modified six second Wingate test on a Velotron ergometer was used to measure power (Watts) and cadence (rpm), and a Vicon MX system was used to measure the hip and lower limb kinematics of the pedal cycle. A 4% increase in power was observed when riding out of the saddle and a CAL set at 18-20% of leg length was superior for this task. The coordination pattern employed was consistent between postures and with different CALs.

KEYWORDS: Road cycling, power, posture, crank arm length, coordination.

INTRODUCTION:

Professional road cyclists will typically complete 20 sprint efforts during flat stages which often occur at decisive moments in a race (Ebert, Martin, Stephens, Withers, 2006). The majority of these sprints are only 6-10 seconds in duration (Ebert et al. 2006), but a cyclist's ability to produce very high power outputs (1300 W) for this brief duration is essential (Faria, Parker & Faria, 2005; Mujika & Padilla, 2001). Cyclists commonly use the standing position when sprinting or breaking away, however the advantages of this position are unclear due to the reported increases in energy expenditure and heart rate (Rychon & Stray-Gundersen, 1991; Millet, Tronche, Fuster, Candau, 2002).

The 30 second Wingate Anaerobic protocol is the most commonly applied test of sprint cycling ability (e.g. Too & Landwer, 2000), but due to its fatiguing nature it is limited when testing numerous variables (Watt, Hopkins & Snow, 2002). Peak power generally occurs in the first three to five seconds of the 30 second Wingate Anaerobic test (Inbar, Bar-Or & Skinner, 1996). As the majority of road cycling sprints last less than 10 seconds (Ebert et al. 2006), a shorter version of the Wingate Anaerobic test would be more valid (Coso & Mara-Rodriquez, 2006). A number of authors have used much shorter sprint tests between four and eight seconds to determine peak power (e.g. Coso & Mara-Rodriquez, 2006; McGawley & Bishop, 2006).

Optimal pedalling rates (cadence) increase with increasing power output to at least 100 rpm during maximal efforts such as sprinting (Ebert et al. 2006). Inverse relationships exist between crank arm length (CAL) and cadence, and also a rider's leg length and optimal CAL (Martin & Spirduso, 2001). Cyclists may therefore be able to use different CAL's for different cycling tasks. Elite road cyclists are able to apply high power outputs to the pedals for extended periods of time, with peak torque occurring near the 3 o'clock position ($90\text{-}100^0$; Broker, 2003). It is often the cyclists who can efficiently apply power throughout their pedalling motion with reduced negative torque who are more successful (Broker, 2003). A neuromechanical factor that may be related to pedalling efficiency is the joint coordination variability. Movement variability has long been considered an undesirable artefact (Bartlett, Wheat & Robins, 2007) as greater movement variability can increase energy expenditure (Lay, Sparrow, Hughes, O'Dwyer, 2002). But within-joint or joint coupling (coordination) variability may play a functional role in reducing injury through variable loading of the musculoskeletal features of the joint (Kurz, Stergiou, Buzzi, Georgoulis, 2005), providing the flexibility to be able to adjust to changing environments (Bartlett et al. 2007).

The purpose of this study was firstly to validate a modified six second Wingate Anaerobic test with three minutes of passive recovery for road sprint cycling. The second purpose was to determine the biomechanical differences between seated and standing postures and, thirdly, to determine if a shorter CAL was superior for producing power at the higher cadences used in road sprint cycling when riding out of the saddle.

METHOD:
Six well trained male cyclists aged 20-39 years (Height: 178.70 ±2.77 cm, Mass: 73.70 ±3.95 kg, Leg Length: 84.87 ±1.76 cm) completed three trials in the seated and standing position, as well as five trials out of the saddle for each of the three CAL's of 18, 20, and 22% of leg length. Leg length was defined as the difference between standing and seated height. The testing conditions were block randomised between participants. A modified six second Wingate test, with three minutes of passive recovery, performed on a dynafit pro model Velotron cycle ergometer, (Racer Mate, Seattle, USA). Power Cranks (Power Cranks, Walnut Creek, CA) were fitted and used to measure power (Watts) and cadence (rpm). A Vicon MX motion analysis system (Oxford Metrics, Oxford, England, 200Hz) with a plug-in gait model of the lower extremity (15 anatomical markers) was used to determine the pelvis, hip, knee and ankle angles in the three, six, nine and 12 o'clock positions of the pedal cycle. The trial with the highest mean power output was utilised to examine the coordination variability for each participant across all conditions. Firstly, hip-knee and knee-ankle angle-angle diagrams were graphed. Secondly, a coupling coefficient, defined as the orientation of a resultant vector to the right horizontal of two adjacent data points on the angle-angle diagrams was calculated for the first ten pedal strokes in the 12, three, six and nine o'clock positions (Wilson, Simpson, Hamill & Van Emmerik, 2007). The standard deviation of these ten pedal strokes provided a measure of the variability of the joint couplings between the hip-knee and knee-ankle. Finally, a fatigue index was calculated for each trial ($FI(\%) = [(Power_{Peak} - Power_{Min}) / Power_{Peak}] \times 100$). Parametric and non-parametric statistical procedures (e.g. repeated measures T-tests and ANOVA, and Wilcoxon signed-rank test respectively) were employed using SPSS for Windows (version 14.0), based on the distribution of the scores, to determine significant differences between conditions.

RESULTS:
No order or fatigue effects were identified in the modified six second Wingate protocol during the five trials for each of the CALs (18, 20 & 22% leg length), or for the three tests in the seated and standing positions. The performance measures (power, cadence) from the Velotron ergometer are summarized in Tables 1 and 2.

Table 1. Peak, minimum and mean power output and cadence for the three CAL's tested when riding out of the saddle.

	18%		20%		22%		ANOVA Main Effect	
Power (Watts)	Mean	SD	Mean	SD	Mean	SD	F	p
Peak	1300	185	1304	108	1286	123	ns	
Minimum	859	76	845	67	818	89	7.61	0.010
Mean	984	84	979	72	955	81	5.79	0.021
Cadence (rpm)	Mean	SD	Mean	SD	Mean	SD	F	p
Peak	154	7	154	5	151	8	4.71	0.036
Minimum	144	7	144	7	143	8	ns	
Mean	152	7	152	6	149	7	5.86	0.021

Minimum power, mean power, peak cadence, and mean cadence were significantly less with the longer CAL when riding out of the saddle as shown in Table 1. Pairwise comparisons revealed no significant differences between the 18 and 20% CALs or the 20 and 22% CALs, with the exception of mean cadence (20 vs 22% CALs, p=0.037). Significant differences were found between the 18 and 22% CALs across all power measures (p<0.01), and mean cadence (p=0.016).

Mean power and peak cadence increased by 4% (p=0.001) and 2% (p=0.029) respectively when riding out of the saddle (standing position) as summarized in Table 2. The Vicon motion analysis indicated that an increase in the riders pelvic angle was the key difference between the seated and standing positions at three o'clock [left – $F(1,12)=6.227$, p=0.050], six o'clock [left – $F(1,12)=8.339$, p=0.016, right-$F(1,12)=11.119$, p=0.008], nine o'clock [left – $F(1,12)=11.518$, p=0.007, right-$F(1,12)=6.227$, p=0.032], and 12 o'clock [left – $F(1,12)=11.119$, p=0.008, right-$F(1,12)=8.339$, p=0.016]. No further consistent trends between the kinematics of standard versus seated cycling were evident for the hip, knee, and ankle.

The coordination descriptors are summarised in Table 3 across all conditions. Coordination variability was not significantly different between the seated and standing, or three CAL conditions, but it was observed that coordination variability was greater in the 12 (seated - $\bar{X}$= 10.2±6.4^0, standing - $\bar{X}$= 7.8±1.4^0) and six o'clock positions (seated - $\bar{X}$= 8.8±1.9^0, standing - $\bar{X}$= 10.2±4.6), when compared with the three (seated - $\bar{X}$= 2.5±1.4^0, standing - $\bar{X}$= 3.7±1.9^0) and nine o'clock positions (seated - $\bar{X}$= 2.6±1.7^0, standing - $\bar{X}$= 5.6±2.4^0).

<u>Table 2</u>. Peak, minimum and mean power output and cadence for the seated and standing positions at a CAL of 20% of leg length.

	Seated		Standing		T-test	
Power (Watts)	Mean	SD	Mean	SD	T	p
Peak	1227	116	1256	144	ns	
Minimum	833	56	837	54	ns	
Mean	926	67	967	72	5.76	0.001
Cadence (rpm)	Mean	SD	Mean	SD	T	p
Peak	150	9	153	8	2.79	0.039
Minimum	142	7	144	6	ns	
Mean	148	8	150	8	ns	

<u>Table 3</u>. Coordination variability for left and right hip-knee and knee to ankle joint couplings in the 12, three, six, and nine o'clock crank positions when seated and standing. Coordination variability was quantified as the standard deviation of ten coupling angles.

Seated	12	3	6	9
Left Hip-Knee (°)	5.7	0.8	6.7	1.1
Right Hip-Knee (°)	4.2	2.0	9.2	1.2
Left Knee-Ankle (°)	13.5	3.8	8.1	4.5
Right Knee-Ankle(°)	17.6	3.5	11.1	3.6
Mean (°)	10.2	2.5	8.8	2.6
SD	6.4	1.4	1.9	1.7
Standing	12	3	6	9
Left Hip-Knee (°)	6.2	1.3	6.3	2.9
Right Hip-Knee (°)	7.2	5.2	7.4	4.2
Left Knee-Ankle (°)	8.6	2.9	10.3	7.3
Right Knee-Ankle (°)	9.3	5.2	16.6	7.9
Mean	7.8	3.7	10.2	5.6
SD	1.4	1.9	4.6	2.4

DISCUSSION & CONCLUSION:

A six second Wingate sprint test with three minutes of passive recovery is more valid and effective for repeated measurements of anaerobic performance for road cyclists. This new protocol is less time consuming and fatiguing than the commonly used 30 second Wingate anaerobic cycling test. It also provides a closer simulation in the laboratory of the intensity and duration of the sprinting phases of a road race. However, many of the potential benefits of riding out of the saddle are dampened in the laboratory due to the bike being fixed in a stationary position where the cyclist is unable to generate the full ground reaction forces from the lateral sway of the bike and through the handlebars. Despite these limitations, a 4% increase in power can be gained in this position through the extra weight contribution that is applied to the pedals when not utilizing the seat, and through a more optimized pelvic angle that possibly engages a greater contribution of the larger and more powerful gluteul muscles. The power generated when riding out of the saddle can also be improved through small adjustments (less than 2 cm) to the length of the crank (CAL) for the preferred cadence of an individual during various cycling tasks. A CAL set at 18-20% of leg length was superior for standing sprint cycling. Therefore CAL's shorter (15 cm) than those typically manufactured need to be considered. The application of an optimal CAL formula based on anthropometry still has some merit as a rough guide; but there appears to be a range within which cyclists could change their CAL to suit the terrain or cycling task. The CAL, for example, would be shorter for sprinting and longer for lower cadence tasks such as climbing during road racing. Cyclists are able to maintain a relatively constant coordination pattern, independent of their riding position (seated, standing) and the CAL. Increased movement variability was observed at the 12 (top) and six (bottom) o'clock crank arm positions where a 'dead spot' occurs in the pedal cycle. This indicates that a changeable coordination pattern is employed when there is joint reversal and higher lower limb loading; a mechanism that is possibly more adaptive to changing conditions (extrinsic e.g. terrain; intrinsic e.g. fitness, fatigue) and reduces the repetitive stress on the individual joints. Future research should investigate the optimal CAL for cycling during other cycling tasks such as climbing and time trialling, and possibly a crank that can be electronically altered during a race where terrain or situation is varied.

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