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RESEARCH ARTICLE **Open Access**

The effects of forward rotation of posture on heavy intensity cycling: Implications of UCI rule 1.3.013

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Abstract

UCI rule 1.3.013 limits the forward displacement of the nose of the saddle to 5cm rearward of the centre of the bottom-bracket. This study tests the effects of contravening this rule on 4km laboratory time trials and highlights biomechanical and physiological responses that could be of interest to coaches and bike fitters. Ten competitive male cyclists age 26±2 (mean±SD) yrs, height 180±5 cm, body mass 71±6 kg; $\dot{V}O_{2max}$ 70.9±8.6 ml·kg^{-1}·min^{-1}) completed 4km time trials and heavy intensity bouts. Riding posture was rotated forward where the nose of the saddle was 0, 2, 4, and 6cm to the rear of the bottom bracket (P_0, P_2, P_4 and P_6). End time, power, cardiorespiratory responses, lower appendage kinematics and crank torque kinetics were measured. There was no significant effect of position on 4 km time trials completion time or power($P>0.05$). During 4 km time trials and heavy intensity bouts, gas exchange variables and lower limb range of motion were unchanged ($P>0.05$). Trunk lean angle, cardiac output and stroke volume were greater at P_6 than other positions ($P<0.05$). Angular velocity of the hip over top dead centre (350-10°) and the peak torque angle were greater at P_0 than other positions ($P<0.05$). Peak and mean torque were unchanged ($P>0.05$). Results indicate that contravening rule 1.3.013 does not bring about improvements to 4km laboratory TTs. The rearward shift in peak crank torque most likely occurs as a function of altered muscle activation. Haemodynamic variations are possibly related to changes in peripheral resistance at the most forward position. Further work is necessary to allude to probable improvements in aerodynamics.

Keywords: seat tube angle, UCI rule, stoke volume, VO_2, bike fitting

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Introduction

For competitive cyclists, the optimal riding position is attained through the arrangement of the bicycle's contact points; seat, handlebars and pedals. Bicycle seats are normally attached by clamping the rails underneath the seat to an extension of the bicycle's seat-tube. Although finite adjustment to the horizontal position of the seat may be achieved by sliding the rails through this clamp, the angle of the seat-tube ultimately dictates the potential range of horizontal seat positions. As such, seat-tube angle, taken as the angle between the seat-tube and a rearward horizontal vector, is a crucial consideration in the selection of bicycle frame geometry (Figure 3). For road bicycles, manufacturers generally set seat-tube angle in the range of 72 - 74°. In time trial (TT) bicycles this angle is increased, where a more forward riding position and handle bar extensions are used to improve aerodynamics (García-López et al. 2008). In scientific research, the effective seat-tube angle is ordinarily the modification made to cycles or ergometers in order to change the vertical position of the saddle. Silder et al. (2011) investigated the effect of seat-tube angle on muscle activation and lower limb kinematics (73, 76 and 79°); demonstrating no change in joint ranges of motion. However, the mean activity of the rectus femoris, as assessed through surface electromyography, was significantly greater at both 76° and 79° compared to 73° and occurred later during the upstroke of the crank cycle at seat tube angles of 76° and 79°. Price and Donne (1997) studied the effects of seat-tube angle on lower limb kinematics and oxygen uptake, observing an increased hip range of motion when seat tube angle was increased from 68° to 80° with a concurrent increase in $\dot{V}O_2$. Bisi et al. (2012) found no change in lower limb kinematics, $\dot{V}O_2$ or muscle activity using a narrower range of angles; 73.5° and 78°. In the aforementioned studies (with the exception of Silder et al. (2011)) vertical and/or horizontal position of the handlebars were fixed with manipulation of the seat-tube angle. However, it is common place in TT cycling to rotate the entire cycling posture forward (around the axis of the bottom bracket) in order to attempt to maintain range of motion of the lower limb joints; with the assumption that power output and metabolic cost are not affected in the same way as separately reducing trunk lean angle (Ashe et al. 2003, Grappe et al. 1998) or forward projection of the saddle (Price and Donne 1997) (Figure 1). To this end the work of Fintelman et al. 2014 demonstrates that, when cycling in variable wind conditions at velocities in excess of 32 km·hr^{-1}, reducing trunk angle can decrease net energy expenditure due to a reduction in frontal area, regardless of an increase in metabolic cost.

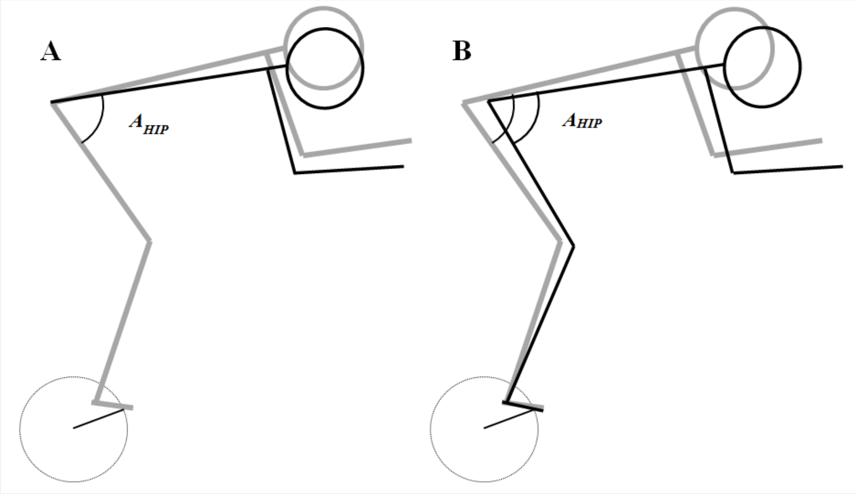

Figure 1. Demonstrating (A) reduction in trunk angle and hip angle (A_{HIP}) and (B) rotation of posture around the bottom bracket axel in order to reduce trunk angle without reducing A_{HIP}.

Crucially, the allowed horizontal position of the saddle for bicycles used in international competition is dictated by the Union Cycliste Internationale (UCI). More specifically, UCI Rule 1.3.013 states that "The peak of the saddle shall be a minimum of 5 cm to the rear of a vertical plane passing through the bottom bracket spindle. This restriction shall not be applied to the bicycle ridden by a rider in a Flying 200 m, Flying Lap, Team Sprint, track sprint event, keirin, 500 metres or 1 kilometre time trials; however, in no circumstances shall the peak (front) of the saddle extend in front of a vertical line passing through the bottom bracket spindle." (Union Cycliste Internationale 2014) (Figure 2). Currently, riders may claim only one morphological exemption relating to the forward projection of the saddle or handle bars where the handlebars may not be further than 75 cm in front of the axle of the bottom bracket. However, the UCI do not give reference to any specific research in support of the ruling parameter. This rule may well have come about following the UCI scrutiny of Graeme Obree's bicycle during the 1994 track cycling world championships, when officials insisted his saddle was set back so the nose of the saddle was aligned with the bottom bracket axle. This resulted in Obree borrowing a shorter saddle to maintain his forward position.

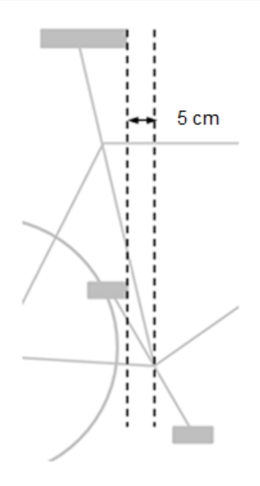

Figure 2. Showing the limit of UCI rule 1.3.013; "The peak of the saddle shall be a minimum of 5 cm to the rear of a vertical plane passing through the bottom bracket spindle." (Union Cycliste Internationale 2014).

The aim of this study was to test the effect on cycling performance, of rotating the cycling posture forward to positions, where the horizontal displacement of the saddle contravenes the ruling parameter, during high intensity time trials as well as steady state bouts. It is postulated that by rotating the entire posture forward to positions where UCI rule 1.3.013 is contravened, the range of motion of the lower limb joints will not be significantly altered (thereby not affecting metabolic cost) and cycling performance will not be affected. During all exercise bouts cardiorespiratory variables, crank torque kinetics and lower limb kinematics were measured to offer mechanisms for any potential changes in performance. It is intended that this study could also be of interest to 'bike fitting' practitioners and coaches working with cyclists in events where UCI legislation does not apply (triathlons, duathlons etc.) and who are seeking to make performance gains through alteration to riding posture.

Materials and methods

Participants

Following local institutional ethical approval, 10 competitive male well-trained cyclists gave informed consent to participate in the study; age 26 ± 2 (mean ± SD) yrs, height 180 ± 5 cm, body mass 71 ± 6 kg; maximum oxygen uptake ($\dot{V}O_{2max}$) 73.8 ± 5.2 ml·kg^{-1}·min^{-1}; power at $\dot{V}O_{2max}$ 450 ± 27 W). Cyclists had a minimum racing history of 2 yrs and were selected on the basis of either the possession of a second or higher category British Cycling Federation (or international equivalent) licence or with a time of 21 min or under for a 16.1 km TT (completed within the previous 12 months). Participants were required to refrain from training and racing for the 48hr period prior to the initial experimental visit and to abstain from all training between subsequent tests. Participants were instructed to consume a light carbohydrate meal and ample fluids at least 3hr prior to each visit, whilst abstaining from caffeine in the preceding 24hr prior to each test.

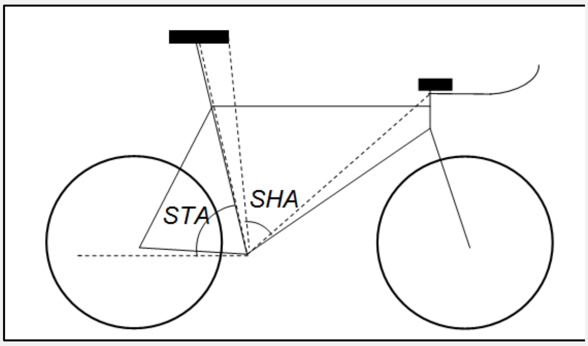

Figure 3. Angle between the nose of the saddle, bottom bracket spindle and centre of the handlebars (*SHA*) and the seat tube angle of the bicycle (*STA*)

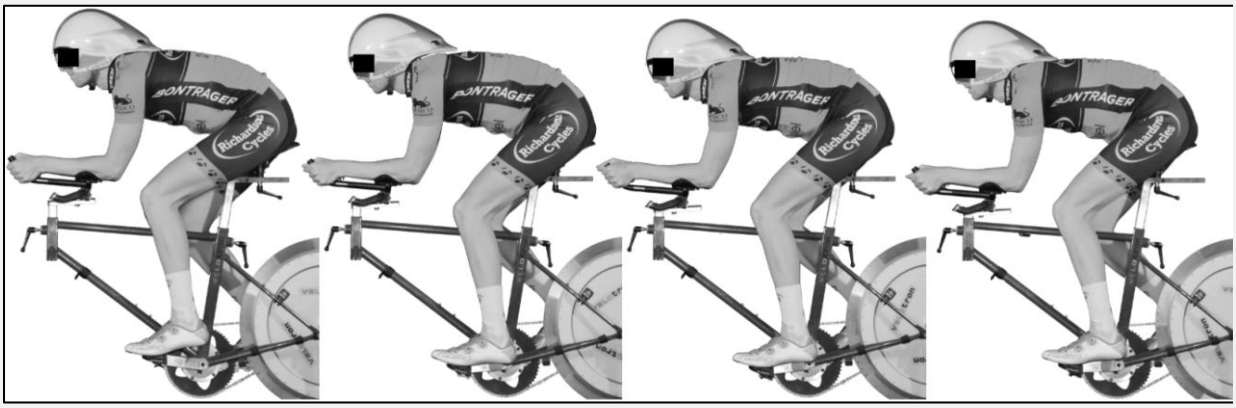

Figure 4. Comparison of all positions of forward rotation; left to right – P_6, P_4, P_2, P_0.

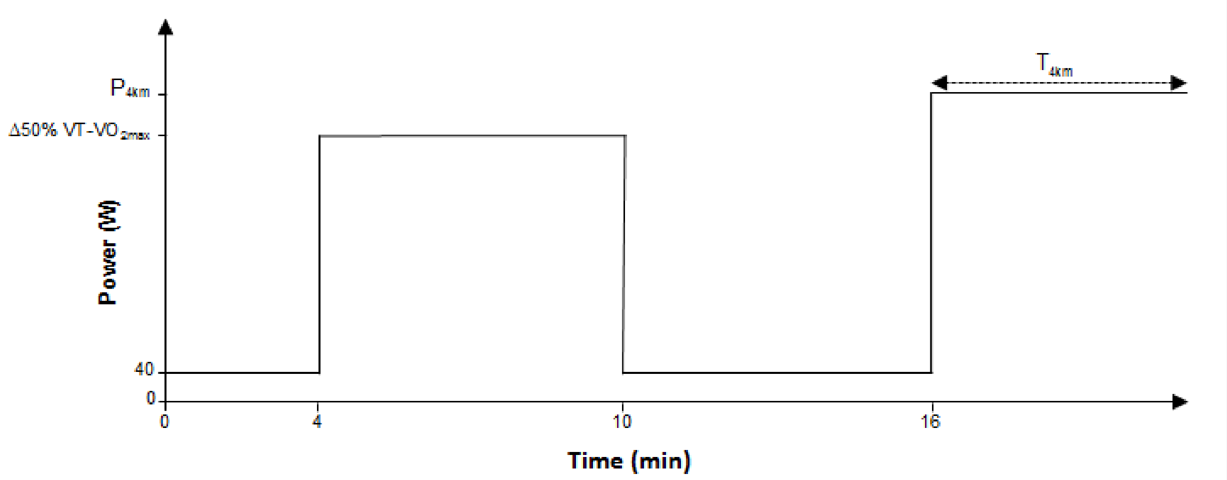

Figure 5. Schematic of workload profile for experimental visits.

Maximal exercise test

Prior to the 4 experimental visits, subject visited the lab and completed a maximal exercise test on an electronically braked cycle ergometer (Racermate, Velotron, USA) fitted with aerodynamic bars (Ambrosio, UK) and a racing saddle (Prolink, Selle Italia, Italy) in order to establish maximum aerobic power output, maximum oxygen uptake ($\dot{V}O_{2max}$) and gas exchange threshold (GET). Following a self-selected warm-up the test was initiated by a square wave transition from rest to a 1 minute workload of 150 W, after which workload was progressively increased at a rate of 1W·2 s^{-1}. Participants were instructed to maintain a cadence of 90±5 rpm throughout the test. The test was terminated at volitional exhaustion or when the participant was unable to maintain cadence within the required range. Saddle and handlebar position was duplicated from the participants' own bicycles. During the same visit, following the maximal exercise test, participants were given a briefing and familiarisation period to become accustomed to Velotron ergometer gear changing system ahead of the experimental visits.

Experimental procedures

The remaining four visits took place over a period of no more than three weeks after the initial visit and all at the same time of day as the initial visit. Participants were required to exercise on the same electronically braked cycle ergometer. Participants attended the laboratory with their own bicycles for the maximal exercise test when the exact horizontal and vertical displacements of the saddle nose and centre of the handlebars, relative to the bottom bracket spindle, were measured using an adjustable ruler and spirit level system (X/Y Tool, Serotta, USA). Saddle tilt angle was also measured using a digital inclinometer (Duratool, UK). Participants used this self-selected position for the maximal exercise test. The exact horizontal and vertical displacements of the saddle nose and centre of the handlebars, relative to the bottom bracket spindle, were measured using an adjustable ruler and spirit level system (X/Y Tool, Serotta, USA). The inclination of the saddle from the horizontal was also measured using a digital inclinometer (Duratool, UK). These coordinates and saddle inclination were then entered into a specially compiled spreadsheet (Excel, Microsoft, USA) where the angle between the saddle, bottom bracket and handlebars was calculated. It was then possible to calculate the resultant positions of the handlebars and saddle as well as the angle of saddle inclination, were they to be rotated around the bottom bracket with the angle between the saddle, bottom bracket and handlebars and the displacements from the bottom bracket kept constant. Four rotated positions were considered such that the nose of the saddle was at 0, 2, 4 and 6 cm rearward of the bottom bracket (P_0, P_2, P_4 and P_6 respectively) (Figure 3, Figure 4). Precise positioning of the saddle and handlebars was then achieved using real-time static coordinate data from a three dimensional motion capture system (Codamotion, Charnwood Dynamics Ltd, UK) with markers placed at fixed points on the saddle and the handlebars and on the centre of the bottom bracket.

A counterbalanced order of testing was created for cycling position prescription to which riders were randomly assigned in order to reduce potential training and learning effects. Participants were blind to the condition of saddle position to prevent an anticipatory response. During each visit participants completed a 6 min warm-up at a power output equivalent to 50% of that at which gas exchange threshold was elicited. Immediately following the warm-up, participants undertook a 4 min active recovery period at a workload of 40 W followed by a 6 min heavy intensity bout (gas exchange threshold power plus 40% of the difference between gas exchange threshold and power at VO_{2max} power). Following heavy intensity bouts a 6 min recovery bout (50% gas exchange threshold) proceeded a 1 minute period of complete rest during which time the ergometer software was switched into TT mode. Following the rest period, the 4 km time trial began (Figure 5). During all heavy intensity bouts participants maintained a constant cadence that was self-selected prior to the first experimental visit (101.09 ± 7.32 $rev \cdot min^{-1}$) but during recovery and warm up bouts as well as 4 km time trials, participants freely chose cadence. The Velotron ergometer allows the participant to select a virtual gear by activation of a toggle switch located on the handlebar. Throughout 4 km time trials participants were given feedback of gear selection, cadence and distance covered; information that they would receive during a field TT. However, time and power output were not displayed in order to prevent an overt pacing strategy.

Gas exchange measurement

During the maximal exercise test and TT expired carbon dioxide ($\dot{V}CO_2$), oxygen uptake ($\dot{V}O_2$), breathing frequency (B_f), minute ventilation (VE) and respiratory exchange ratio (RER) were recorded from expired air using a breath by breath gas analysis system (Metalyzer, Cortex, Germany). The gas analysis system was calibrated before each visit for volume and flow using a 3 L calibration syringe (Hans Rudolph, USA) and for concentration using a gas of known concentrations. Raw breath by breath data for all variables was exported to spreadsheet software (Excel, Microsoft, USA). Outlying breath by breath data points that may be caused by superfluous respiratory movements were removed using a rolling filter with limits of mean ±2SD, applied to each 15 s sampling period for all variables (Gordon et al. 2010) and $\dot{V}O_{2max}$ was taken as the highest 30 s mean $\dot{V}O_2$ value measured during the maximal exercise test. Gas exchange threshold was determined using the excess $\dot{V}CO_2$ method (Gaskil et al. 2011). During the heavy bout mean values were taken for all gas exchange variables from 3 – 6 min. During 4 km time trials 15 s mean values for all gas exchange variables were taken at distances of 500 m, 1500 m, 2500 m and 3500 m.

Cardiac response measurement

Throughout 4 km time trials heart rate (HR), stroke volume and cardiac output ($\dot{Q}$) were recorded on a 5 s mean basis, using thoracic bioimpedance technology (PhysioFlow Type PF05L1, Manatec, France). Three sets of electrodes (Physioflow PF50, Manatec, France) were attached to the skin following preparation with an abrasive skin preparation gel (Nuprep, Weaver, USA). Electrode leads were fixed to skin using surgical tape in order to prevent movement artefacts in the signal. All raw data was exported to spreadsheet software (Excel, Microsoft, USA) where mean values for all HR, stroke volume and $\dot{Q}$ were calculated. During the heavy bout mean values were taken for HR, stroke volume and $\dot{Q}$ during the heavy bout mean values were taken for all cardiac variables from 3 – 6 min. During 4 km time trials 15 s mean values for HR, stroke volume and $\dot{Q}$ were calculated at distances of 500 m, 1500 m, 2500 m and 3500 m.

Blood lactate measurement

Upon completion of heavy intensity bouts and 4 km time trials a 5 µl sample of capillary blood was taken from the participant's right forefinger and analysed for lactate concentration (BLa) using a portable lactate analyser (Lactate Pro LT-1710, Arkray, Japan).

Kinematic variable measurement

Right lower limb and trunk kinematics were recorded (at 200Hz) using a three dimensional motion capture system (Codamotion, Charnwood Dynamics Ltd, UK). Active markers were attached on the posterior inferior calcaneus, lateral aspect of the 5th metatarsal joint, lateral aspect of the lateral malleus of the fibula, lateral aspect of the lateral epicondyle of the femur, lateral aspect of the greater trochanter of the femur and acromion process. Markers were also placed on the crank arm and the centre of the crank axel (on the bicycle) in order to calculate degrees of crank rotation. Maximum and minimum values as well as mean range of motion were calculated during the TT for the first 10 consecutive pedal revolutions of a 15 s sample for foot angle, ankle angle, knee angle and hip angle. Measurements were taken at 5 min during heavy intensity bouts and at 500 m, 1500 m, 2500 m and 3500 m during 4 km time trials. Angles are given where 0° is representative of full flexion. Additionally, mean trunk angle (taken between a vector drawn from the acromion process to greater trochanter and a horizontal vector drawn through the greater trochanter). All data was filtered using a low pass second order Butterworth filter with a cut-off frequency of 7 Hz. This cut-off frequency was obtained through residual analysis of all markers using the sum of least squares method (Winter 2009).

Crank torque measurement

Crank torque was measured using a crank dynamometer instrumented with 12 strain gauges (SRM Science, Schroberer, Germany). This crank was installed to replace the ergometer's original crank and was modified by the manufacturer to feature adjustable length crank arms. The crank dynamometer was interfaced with a demodulating device (Torque Analysis, Schroberer, Germany) which transformed the frequency, transmitted from the strain gauge instrumented cranks, to real time torque values (200 Hz). The crank dynamometer was calibrated by the manufacturer immediately prior to commencement of testing. Values for mean crank torque, peak crank torque, angle at peak crank torque, time at peak crank torque, mean crank torque from 350-10° and pedalling cadence were averaged across the first 10 consecutive pedal revolutions during a 15 s sample taken at 5 min during the heavy intensity bouts and at 500 m, 1500 m, 2500 m and 3500 m during 4 km time trials.

Statistical analysis

As intensity is potentially variable during time trial efforts, all physiological parameters are expressed relative to power output. After confirming normality of the data using a Shapiro-Wilk test, data was analysed using a two way repeated measures ANOVA to test the effect of forward rotation of positon during heavy intensity bouts and 4 km time trials (P_0, P_2, P_4 and P_6) and distance during 4 km time trials (500 m, 1500 m, 2500 m and 3500 m). Partial eta squared effect sizes (ηp^2) were computed for differences with statistical significance. All statistical analyses were performed using a statistics software package (SPSS Statistics 20, IBM, USA). Statistical significance level was set at *P*<0.05. Descriptive data is presented as mean ± standard deviation.

Results

Time trial performance

Effective seat-tube angles were; P_0 = 78.31 ± 0.41°, P_2 = 76.94 ± 0.46°, P_4= 75.45 ± 0.51°, P_6 = 73.97 ± 0.56°. There was no significant effect of position or trial order on 4 km time ($F(3)=0.33$, $P=0.084$, $\eta p^2=0.04$) (Table 1). Mean power output, mean gear size selection and mean cadence were not significantly affected by position ($F(3)=0.41$ $P=0.750$, $\eta p^2=0.04$; $F(3)=0.90$, $P=0.453$; $F(3)=0.93$, $P=0.404$, $\eta p^2=0.09$ respectively) or trial order ($P>0.05$) (Table 1).

Table 1. Mean (SD) TT time, power, mean cadence and mean gear size for laboratory 4 km TTs at all positions of forward rotation.

	TT Time (s)	TT Power (W)	Mean Cadence (rev·min^{-1})	Mean Gear Size (")
P_0	353.1 ± 14.0	351.0 ± 39.	105.2 ± 9.3	82.7 ± 7.8
P_2	353.3 ± 13.6	351.0 ± 39	103.6 ± 9.1	83.3 ± 8.5
P_4	352.0 ± 12.8	355.2 ± 38	104.3 ± 10.3	85.2 ± 9.7
P_6	353.6 ± 14.6	351.2 ± 41	105.6 ± 9.9	83.2 ± 8.7

Gas exchange responses

During heavy intensity bouts there was no significant effect of position on $\dot{V}O_2$ ($F(1.405)=1.52$ $P=0.535$, $\eta p^2=1.45$), $\dot{V}CO_2$ ($F(3)=1.31$, $P=0.293$, $\eta p^2=0.13$), RER

Table 2. Mean (SD) cardiorespiratory variables expressed relative to power output during heavy bouts (HVY) and laboratory 4 km TT for at all positions of forward rotation, at distances of 500 m, 1500 m, 2500 m and 3500 m.

		$\dot{V}O_2$ (ml·min^{-1}·W^{-1})	$\dot{V}CO_2$ (ml·min^{-1}·W^{-1})	RER	VE (ml·min^{-1}·W^{-1})	Bf (brs·min^{-1}·W^{-1})	HR (beats·min^{-1}·W^{-1})	SV (ml·W^{-1})	$\dot{Q}$ (ml·min^{-1}·W^{-1})
P_0	HVY	12.66 ± 0.96	14.02 ± 1.04	1.12 ± 0.08	405.07 ± 49.42	0.13 ± 0.03	0.49 ± 0.05	0.32 ± 0.06	49.84 ± 8.01
	500 m	7.13 ± 1.42	6.06 ± 1.07	0.96 ± 0.06	222.20 ± 33.01	0.12 ± 0.03	0.38 ± 0.11	0.27 ± 0.07	34.85 ± 11.01
	1500 m	12.54 ± 0.58	12.72 ± 0.65	1.02 ± 0.07	422.02 ± 43.90	0.14 ± 0.04	0.49 ± 0.07	0.32 ± 0.07	54.91 ± 11.43
	2500 m	13.54 ± 0.98	14.24 ± 1.28	1.05 ± 0.04	493.57 ± 60.38	0.17 ± 0.04	0.52 ± 0.07	0.33 ± 0.07	58.81 ± 11.51
	3500 m	13.49 ± 1.18	13.97 ± 1.24	1.04 ± 0.04	493.38 ± 70.43	0.18 ± 0.04	0.51 ± 0.06	0.33 ± 0.08	59.44 ± 13.37
	Mean TT	11.68 ± 1.04	12.20 ± 1.05	1.04 ± 0.06	407.25 ± 51.43	0.15 ± 0.04	0.48 ± 0.08	0.31 ± 0.07	52.00 ± 11.83
P_2	HVY	12.95 ± 0.58	13.84 ± 1.39	1.11 ± 0.10	402.08 ± 60.07	0.13 ± 0.04	0.49 ± 0.06	0.30 ± 0.05	46.45 ± 5.95
	500 m	7.01 ± 1.05	5.83 ± 0.79	0.92 ± 0.09	212.72 ± 22.31	0.12 ± 0.02	0.36 ± 0.06	0.25 ± 0.05	31.72 ± 7.73
	1500 m	12.91 ± 1.15	12.88 ± 1.18	1.00 ± 0.05	415.11 ± 55.74	0.14 ± 0.04	0.50 ± 0.07	0.3 ± 0.04	51.40 ± 6.11
	2500 m	13.43 ± 1.18	13.77 ± 1.11	1.03 ± 0.04	465.57 ± 69.04	0.17 ± 0.04	0.51 ± 0.07	0.33 ± 0.06	57.96 ± 10.51
	3500 m	13.14 ± 0.92	13.51 ± 0.8	1.03 ± 0.03	471.05 ± 62.50	0.17 ± 0.05	0.50 ± 0.06	0.32 ± 0.06	56.65 ± 9.51
	Mean TT	11.62 ± 0.25	11.5 ± 0.26	1.02 ± 0.06	391.11 ± 18.32	0.15 ± 0.04	0.47 ± 0.06	0.30 ± 0.05	49.43 ± 8.47
P_4	HVY	12.90 ± 0.70	14.17 ± 1.04	1.10 ± 0.06	415.49 ± 45.12	0.14 ± 0.03	0.49 ± 0.05	0.31 ± 0.05	48.56 ± 6.11
	500 m	7.65 ± 2.03	6.58 ± 2.32	0.92 ± 0.06	212.95 ± 29.71	0.12 ± 0.03	0.38 ± 0.06	0.28 ± 0.03	37.07 ± 7.69
	1500 m	12.97 ± 1.24	13.05 ± 1.13	1.01 ± 0.06	423.00 ± 72.61	0.15 ± 0.04	0.50 ± 0.07	0.32 ± 0.04	55.65 ± 6.60
	2500 m	13.48 ± 0.96	13.99 ± 0.73	1.04 ± 0.06	467.94 ± 66.93	0.16 ± 0.04	0.52 ± 0.07	0.33 ± 0.04	58.25 ± 7.83
	3500 m	13.25 ± 0.99	13.72 ± 1.05	1.04 ± 0.03	482.85 ± 77.04	0.17 ± 0.05	0.50 ± 0.07	0.30 ± 0.04	54.02 ± 7.03
	Mean TT	11.84 ± 0.51	11.84 ± 0.62	1.02 ± 0.05	396.69 ± 20.13	0.15 ± 0.04	0.48 ± 0.07	0.31 ± 0.04	51.25 ± 7.29
P_6	HVY	12.89 ± 0.56	14.11 ± 0.85	1.10 ± 0.06	410.82 ± 44.01	0.13 ± 0.03	0.49 ± 0.05	0.36 ± 0.05*	56.54 ± 5.76*
	500 m	6.87 ± 1.18	5.89 ± 0.84	0.93 ± 0.07	218.63 ± 36.62	0.12 ± 0.03	0.36 ± 0.08	0.31 ± 0.04	37.79 ± 7.20
	1500 m	12.5 ± 0.82	12.46 ± 0.8	1.00 ± 0.06	419.83 ± 55.33	0.14 ± 0.04	0.49 ± 0.06	0.35 ± 0.04	60.33 ± 5.92
	2500 m	13.53 ± 1.17	13.98 ± 1.16	1.03 ± 0.06	474.94 ± 71.56	0.16 ± 0.04	0.52 ± 0.07	0.37 ± 0.06	65.81 ± 9.08
	3500 m	13.27 ± 1.17	13.8 ± 0.91	1.04 ± 0.05	484.79 ± 71.30	0.18 ± 0.05	0.51 ± 0.07	0.37 ± 0.07	67.16 ± 11.45
	Mean TT	11.54 ± 0.28	11.53 ± 0.14	1.02 ± 0.06	399.55 ± 15.78	0.15 ± 0.04	0.47 ± 0.07	0.35 ± 0.05*	57.77 ± 8.41*

*significantly different to all other positions (p<0.05)

(F(1.61)=1.29, *P*=0.296, ηp^2=0.13), VE (F(2.02)=0.276 *P*=0.76, ηp^2=0.030) or B_f (F(3)=0.28, *P*=0.837, ηp^2=0.03). Similarly, during 4 km time trials there was no significant effect of position on $\dot{V}O_2$ (F(3)=0.54 *P*=0.660, ηp^2=0.06), $\dot{V}CO_2$ (F(1.33)=2.46, *P*=0.411, ηp^2=0.09), RER (F=1.69, *P*=0.194, ηp^2=0.09), VE (F(3)=1.67, *P*=0.198, ηp^2=0.16) or B_f (F(3)=0.09, *P*=0.967, ηp^2=0.01). During 4 km time trials there was a significant effect of distance on power output corrected values for $\dot{V}O_2$ (*P*<0.001), $\dot{V}CO_2$ (*P*<0.001), RER (*P*=0.01), V_E (*P*<0.001) and B_f (*P*<0.001). Pairwise comparisons revealed significant increases in $\dot{V}O_2$, $\dot{V}CO_2$ RER, V_E and Bf from 500 m to 1500 m and 1500 m to 2500 m (*P*<0.01). There was a significant increase from 2500 m to 3500 m for V_E (*P*=0.001) but not for $\dot{V}O_2$, $\dot{V}CO_2$ RER and Bf (*P*>0.05). There was no significant position-by-distance interaction effect on $\dot{V}O_2$, $\dot{V}CO_2$, RER, V_E or Bf (*P*>0.05) (Table 2).

Cardiac responses

There was no significant effect of position on HR during heavy intensity bouts (F(1.57)=0.453 *P*=0.62, ηp^2=0.048) or 4 km time trials (F(3)=1.71, *P*=0.188, ηp^2=0.16) (Table 4). There was a significant effect of position on stroke volume during heavy intensity bouts (F=6.63, *P*=0.002, ηp^2=0.42) and 4 km time trials (F(3)=4.04, *P*=0.017, ηp^2=0.31). There was a significant effect of position on $\dot{Q}$ during heavy intensity bouts (F(3)=6.36, *P*=0.002, ηp^2=0.41) and 4 km time trials (F(3)=3.71, *P*=0.024, ηp^2=0.29). During heavy intensity bouts, stroke volume was greater at P_6 than P_0, P_2 and P_4 (*P*=0.009, *P* =0.004, *P*=0.009 respectively) as was $\dot{Q}$ (*P*=0.015, *P*=0.003, *P*=0.008 respectively). Likewise, during 4 km time trials stroke volume was greater at P_6, than P_0, P_2 and P_4 (*P*=0.029, *P*=0.004, *P*=0.014 respectively) as was $\dot{Q}$ (*P*=0.048, *P*=0.005, *P*=0.026 respectively). There was a significant effect of distance on HR, stroke volume stroke volume and $\dot{Q}$ (*P*<0.001). Pairwise comparisons revealed that HR, stroke volume and $\dot{Q}$ were significantly greater at all other splits compared to 500 m (*P*<0.01) There was no significant position-by-distance interaction effect on HR, stroke volume or $\dot{Q}$ (*P*>0.05) (Table 2).

Blood lactate responses

There was no significant effect of position on BLa during heavy intensity bouts or 4 km time trials (F(3)=0.91 *P*=0.451, ηp^2=0.09; F(3)=1.53, *P*=0.230, ηp^2=0.15 respectively) 4 km time trials; P_0 = 12.8 ± 1.8 mmol, P_2 = 12.6 ± 2.0 mmol, P_4= 13.2 ± 1.7 mmol, P_6 = 12.6 ± 2.0 mmol. Heavy intensity bouts; P_0 = 9.6 ± 2.9 mmol, P_2 = 8.8 ± 2.5 mmol, P_4= 9.4 ± 2.8 mmol, P_6 = 9.1 ± 3.0 mmol.

Table 3. Mean (SD) lower limb ranges of motion (RoM), mean trunk lean, angular velocity of the hip from 350-10° of crank rotation (ωhip350-10) and rearward horizontal displacement of the greater trochanter relative to the bottom bracket axle (GTx) during heavy bouts (HVY) and laboratory 4 km TT for at all positions of forward rotation, at distances of 500 m, 1500 m, 2500 m and 3500 m.

		Ankle RoM (°)	**Knee RoM (°)**	**Hip RoM (°)**	**Trunk Lean (°)**	**$\omega_{hip350-10}$ (rad·s^{-1})**	**GT_x (mm)**
P_0	**HVY**	17 ± 4	71 ± 4	45 ± 2	17 ± 2*	-2.3 ± 0.3*	95 ± 13*
	500 m	18 ± 5	71 ± 4	45 ± 2	16 ± 2	-2.3 ± 0.3	100 ± 10
	1500 m	17 ± 6	71 ± 3	45 ± 3	17 ± 2	-2.4 ± 0.4	89 ± 19
	2500 m	16 ± 5	71 ± 3	46 ± 3	17 ± 2	-2.5 ± 0.4	85 ± 22
	3500 m	16 ± 5	71 ± 3	45 ± 3	17 ± 2	-2.4 ± 0.5	81 ± 23
	Mean TT	17 ± 5	71 ± 3	45 ± 3	17 ± 2*	-2.4 ± 0.4	89 ± 18*
P_2	**HVY**	17 ± 6	71 ± 3	45 ± 2	19 ± 3	-2.1 ± 0.4	123 ± 16*
	500 m	17 ± 5	71 ± 3	45 ± 2	19 ± 3	-2.1 ± 0.2	125 ± 15
	1500 m	17 ± 4	71 ± 3	45 ± 3	18 ± 3	-2.2 ± 0.4	118 ± 19
	2500 m	16 ± 4	71 ± 4	45 ± 3	18 ± 3	-2.2 ± 0.4	120 ± 14
	3500 m	16 ± 4	71 ± 3	45 ± 3	18 ± 3	-2.2 ± 0.5	115 ± 17
	Mean TT	16 ± 4	71 ± 3	45 ± 3	18 ± 3	-2.2 ± 0.4	119 ± 16
P_4	**HVY**	18 ± 6	71 ± 4	45 ± 4	20 ± 2⌖	-1.9 ± 0.3	148 ± 18*
	500 m	17 ± 5	71 ± 4	45 ± 3	20 ± 2	-2.0 ± 0.3	148 ± 15
	1500 m	16 ± 5	71 ± 4	45 ± 3	20 ± 2	-2.2 ± 0.4	145 ± 18
	2500 m	16 ± 5	71 ± 3	45 ± 2	20 ± 2	-2.1 ± 0.4	143 ± 20
	3500 m	16 ± 5	71 ± 4	45 ± 2	20 ± 3	-2.1 ± 0.4	141 ± 23
	Mean TT	16 ± 5	71 ± 4	45 ± 3	20 ± 2⌖	-2.1 ± 0.4	144 ± 19*
P_6	**HVY**	16 ± 4	72 ± 2	45 ± 2	21 ± 2⌖	-2.0 ± 0.4	165 ± 21*
	500 m	17 ± 5	71 ± 4	45 ± 3	20 ± 3	-1.9 ± 0.2	166 ± 21
	1500 m	18 ± 5	71 ± 4	45 ± 3	21 ± 2	-1.9 ± 0.3	155 ± 26
	2500 m	16 ± 4	71 ± 4	45 ± 4	21 ± 2	-2.1 ± 0.4	153 ± 31
	3500 m	17 ± 4	71 ± 4	45 ± 3	21 ± 3	-2.2 ± 0.5	153 ± 28
	Mean TT	17 ± 5	71 ± 4	45 ± 3	21 ± 3⌖	-2.1 ± 0.4	157 ± 26*

*significantly different to all other positions (p<0.05), ⌖significantly different P_2 (p<0.05)

Table 4. Mean (SD) crank torque kinetics during heavy bouts (HVY) and laboratory 4 km TT for at all positions of forward rotation, at distances of 500 m, 1500 m, 2500 m and 3500 m.

		Peak Torque (N·m)	Peak Torque Angle (°)	Mean Torque (N·m)	∆ Min – Peak (°)
P_0	**HVY**	54.9 ± 4.0	85.1 ± 9.6*	33.0 ± 2.8	73.4 ± 7.8
	500 m	57.3 ± 6.2	83.2 ± 7.9	34.0 ± 5.1	72.5 ± 7.0
	1500 m	54.2 ± 8.0	83.2 ± 8.9	31.4 ± 4.7	70.7 ± 6.2
	2500 m	55.4 ± 7.0	84.3 ± 9.9	32.2 ± 4.7	71.0 ± 6.9
	3500 m	58.2 ± 8.5	85.4 ± 9.1	33.7 ± 4.6	70.5 ± 8.2
	Mean TT	56.2 ± 7.4	84.0 ± 8.4*	32.8 ± 4.8	71.2 ± 7.1
P_2	**HVY**	54.0 ± 3.6	93.3 ± 16.4	33.4 ± 3.0	73.4 ± 7.9
	500 m	56.1 ± 6.4	90.8 ± 16.5	33.1 ± 4.9	71.6 ± 6.1
	1500 m	54.8 ± 7.4	91.4 ± 17.3	32.5 ± 5.3	71.8 ± 7.6
	2500 m	55.4 ± 5.3	92.2 ± 17.0	33.1 ± 4.5	72.4 ± 6.3
	3500 m	57.1 ± 6.5	90.5 ± 16.6	34.3 ± 4.1	70.5 ± 9.3
	Mean TT	55.9 ± 6.4	91.2 ± 16.7	33.2 ± 4.7	71.6 ± 7.3
P_4	**HVY**	55.8 ± 5.1	94.3 ± 17.3	34.2 ± 3.2	74.6 ± 7.7
	500 m	56.2 ± 7.2	96.6 ± 12.2	33.5 ± 4.5	73.4 ± 6.7
	1500 m	55.1 ± 6.8	93.8 ± 13.1	32.5 ± 4.9	72.0 ± 6.9
	2500 m	56.2 ± 5.2	95.0 ± 15.0	32.8 ± 4.3	72.8 ± 9.9
	3500 m	58.4 ± 6.1	93.5 ± 14.4	34.7 ± 3.9	72.4 ± 9.3
	Mean TT	56.5 ± 6.3	94.7 ± 13.7	33.4 ± 4.4	72.7 ± 8.2
P_6	**HVY**	55.6 ± 6.2	98.6 ± 17.2	33.9 ± 3.6	76.2 ± 9.7
	500 m	56.4 ± 8.0	94.3 ± 12.2	33.4 ± 6.2	71.1 ± 6.5
	1500 m	55.4 ± 7.4	97.1 ± 13.4	32.5 ± 5.0	71.2 ± 6.6
	2500 m	56.3 ± 6.6	96.0 ± 12.2	33.2 ± 4.8	71.9 ± 6.6
	3500 m	59.3 ± 8.1	95.2 ± 14.7	35.1 ± 5.0	72.8 ± 8.5
	Mean TT	56.9 ± 7.5	95.7 ± 12.6	33.6 ± 5.2	71.8 ± 7.1

*significantly different to all other positions (p<0.05).

Kinematic variables

There was no significant effect of position on hip, knee or ankle range of motion during heavy intensity bouts (F(3)=0.25, P=0.858, ηp^2=0.03, F(3)=0.894 P=0.457, ηp^2=0.09; F(3)=0.81, P=0.501, ηp^2=0.08 respectively) and 4 km time trials (F(3)=0.28 P=0.836, ηp^2=0.03; F(3)=0.49, P=0.692, ηp^2=0.05; df=3, F(3)=0.28, P=0.836, ηp^2=0.09 respectively) (Table 2). During the 4 km time trials there was no significant effect of distance or saddle position-by-distance interaction on hip, knee or ankle range of motion (P>0.05) (Table 2).

Mean trunk lean angle was significantly affected by position during heavy intensity bouts (F(1.38)=9.394, P=0.006, ηp^2=0.51) and 4 km time trials (F(3)=15.66 P=<0.000, ηp^2=0.64). Pairwise comparisons revealed that during heavy intensity bouts trunk lean angle at P_0 was significantly smaller than P_2, P_4 and P_6 (P=0.004, P<0.001, P<0.001 respectively) and P_2 was significantly greater than P_6 (P=0.043). However, during heavy intensity bouts there was no significant difference in trunk lean angle between P_2 and P_4 or P_4 and P_6 (P>0.05). Similarly, during 4 km time trials trunk lean angle at P_0 was significantly smaller than P_2, P_4 and P_6 (P=0.043, P<0.001, P<0.001 respectively) and P_2 was significantly smaller than P_4 and P_6 (P =0.022, P=0.011 respectively) but there was no significant difference between P_4 and P_6 (P =0.097). There was no significant effect of distance or position-by-distance interaction on trunk lean angle during 4 km time trials (Table 2). There was a significant effect of position on the mean angular velocity of the hip from 350-10° of crank rotation ($\omega_{hip350-10}$) during heavy intensity bouts (F(1.31)=, P=0.010, ηp^2=0.34) and 4 km time trials (F(3)=8.771, P<0.001, ηp^2=0.494). Pairwise comparisons revealed that during heavy intensity bouts $\omega_{hip350-10}$ P_0 was significantly greater than P_2, P_4 and P_6 (P<0.001, P=0.001, P=0.001 respectively). Similarly, during 4 km time trials $\omega_{hip350-10}$ was significantly greater at P_0 than P_2, P_4 and P_6 (P=0.039, P=0.034, P=0.001 respectively) and P_6 was significantly smaller than P_2 (P=0.018) but not P_4 (P>0.05). There was a significant effect of distance on $\omega_{hip350-10}$ (P=0.020) and pairwise comparisons revealed that $\omega_{hip350-10}$ at 500 m was significantly smaller than all other splits (P<0.05). There was no effect of position or distance or position-by-distance effect on $\omega_{hip350-10}$ (P>*0.05*) (Table 3). There was a significant effect of position on the rearward horizontal displacement of the greater trochanter relative to the bottom bracket during heavy intensity bouts (F(3)=67.43, $P<0.000$, $\eta p^2=0.88$) and 4 km time trials (F(3)=91.35, $P<0.000$, $\eta p^2=0.91$). Pairwise comparisons revealed that with each position of forward rotation (P_6 thru P_0) there was a significant decrease in horizontal displacement of the greater trochanter with ($P<0.05$). There was a significant effect of distance on horizontal displacement of the greater trochanter ($P=0.03$). Pairwise comparisons revealed that horizontal displacement of the greater trochanter at 500 m was significantly smaller than at 1500 m, 2500 m and 3500 m ($P<0.011$, $P=0.008$, $P=0.004$ respectively) and horizontal displacement of the greater trochanter at 3500 m was significantly greater than at 1500 m and 2500 m ($P=0.013$, $P=0.005$ respectively) but there was no significant difference between 1500 m and 2500 m ($P=0.243$). There was no significant effect of distance or position-by-distance interaction on horizontal displacement of the greater trochanter ($P>0.05$).

Crank torque variables

There was no significant effect of position on peak torque during heavy intensity bouts (F(3)=0.73, $P=0.545$, $\eta p^2=0.08$) and 4 km time trials (F(3)=0.35, $P=0.790$, $\eta p^2=0.04$) (Table 4). There was no significant effect of position on mean torque during heavy intensity bouts (F(3)=1.09, $P=0.371$, $\eta p^2=0.11$) and 4 km time trials (F(3)=0.41, $P=0.745$, $\eta p^2=0.04$) (Table 4). However, there was a significant effect of position on peak torque angle during heavy intensity bouts (F(2)=3.51, $P=0.029$, $\eta p^2=0.28$) and 4 km time trials (F(3)=4.04, $P=0.026$, $\eta p^2=0.31$). Pairwise comparisons revealed that at P_0 peak torque occurred at a significantly earlier angle than at P_6 during heavy intensity bouts and 4 km time trials ($P=0.038$, $P=0.041$ respectively). There was no significant effect of distance or position-by-distance interaction on peak torque angle ($P=0.237$ and $P=0.199$ respectively). There was no effect of position on degrees of rotation from minimum to peak torque during heavy intensity bouts (F(3)=1.20, $P=0.330$, $\eta p^2=0.12$) or 4 km time trials (F(3)=0.62, $P=0.611$, $\eta p^2=0.07$). There was no effect of distance, or position-by-distance on degrees of rotation from minimum to peak torque ($P>0.05$) (Table 4) (Figure 6).

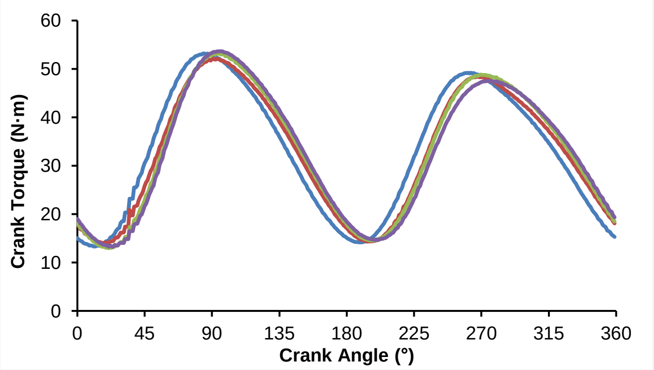

Figure 6. Ensemble data for all participants for crank torque over crank angle during HVY. Showing P_0 – blue line, P_2 – red line, P_4 – green line, P_6 – purple line.

Discussion

The aim of this study was to test the effects of rotating cycling posture forward to positions where UCI rule 1.3.013 was contravened during heavy intensity cycling. This rule stipulates that the horizontal position of the nose of the saddle may be no less than 5 cm to the rear of a horizontal vector originating at the centre of the bottom bracket spindle. It was hypothesised that by maintaining the range of motion of the lower limb joints there would be no significant change in performance when participants performed laboratory 4 km TTs where the nose of the saddle was at 0, 2, 4 and 6 cm behind the bottom bracket spindle. Participants also completed fixed workload heavy cycling bouts. The key finding was that, with forward rotation of posture from permitted to unpermitted positions, simulated laboratory 4 km TT performance remained unchanged.

When riders seek a more aerodynamic position they will adjust seat and handlebar position concurrently to minimise changes to lower limb range of motion, metabolic cost and comfort (Underwood 2011). Hence, in order to reflect 'real world' positional changes, during this study the handlebars as well as the saddle were rotated forward around the bottom bracket. Accordingly, during heavy intensity bouts and 4 km time trials there were no changes to hip, knee and ankle range of motion but trunk lean angle was reduced significantly ($\eta p2=0.51$ and $\eta p2=0.64$ respectively) as the position rotated forward. As a consequence or changing trunk lean angle, key metabolic responses (HR, $\dot{V}O_2$, $\dot{V}CO_2$, RER, V_E and Bf) were not significantly affected. Additionally during heavy intensity bouts there was no change to any of these metabolic responses confirming the participants were not cycling with a metabolic reserve that is indicative of a pacing effect during any one experimental condition. In support of these findings Silder et al. (2011) also found no difference in HR or $\dot{V}O_2$ with similar seat tube angles to the current study (73-79°). Throughout laboratory based TTs, participants are able to modulate their virtual speed, when the perceived capacity to produce power is altered, achieved by selecting a different virtual gear (changing flywheel resistance), varying power output and/or changing cadence. It is postulated that due to the unchanging metabolic demand (during heavy intensity bouts and 4 km time trials) this perceived capacity remained unaffected and as a result there was no influence of position (or trial order) on power output, gear selection or cadence. Distance related increases in gas exchange and cardiac responses are in keeping with previous research and can be attributed to changes in core temperature (Parkin et al. 1999) and the contributions of different metabolic pathways (Bangsbo et al. 1990). However, there was no distance-position interaction on any of the independent variables.

There was a significant effect of distance on the horizontal displacement of the greater trochanter (relative to the bottom bracket), where the greater trochanter displaced closer to the bottom bracket throughout 4 km time trials. This suggests the participants were shifting forward on the saddle throughout the trial. However, there was no significant position-by-distance interaction; suggesting that this forward shift occurred uniformly in each position.

During both heavy intensity bouts and 4 km time trials, stoke volume and cardiac output were significantly reduced in the forward position compared to P_6. Without changes to the oxygen demand at the muscle these differences are most likely due to an increase in peripheral resistance, subsequent reduction in venous return and end diastolic volume. To this end, a decreased end diastolic volume will lead to a decreased stroke volume (Glower et al. 1985) and when heart rate remains unchanged cardiac output will decrease concurrently. It is postulated that in the forward positions (compared to P_6) peripheral resistance was augmented due to additional pressure exerted on blood vessels traveling over the hip, brought about by significant increase in angular velocity of the hip joint (increased muscle activity). Although this response occurred at no extra metabolic cost (in terms of $\dot{V}O_2$) during short duration heavy intensity cycling, future research is necessary to clarify the mechanism and implications for longer events.

Peak torque angle occurred significantly earlier at P_0 than at P_6 in both heavy intensity bouts and 4 km time trials with large effect sizes (ηp^2=0.28 and ηp^2=0.31 respectively). There was however no difference in the degrees of rotation between minimum and peak torque, indicating a rearward phase shift in crank torque kinetics when the position is rotated forward. This likely occurs as a function of increased muscle activity during the recovery phase of the pedal stroke (180-360°) as shown by Silder et al. (2011) who demonstrated an increase in rectus femoris activity between seat-tube angles of 73° and 79° as it functions as a hip flexor during the recovery phase. Such an increase in muscle activity around the top of the pedal stroke may well lead to an earlier development of torque as the hip joint will be orientated for torque development earlier in the crank cycle. This postulation is supported by the current results where the angular velocity of the hip over the top of the pedal stroke (350-10°) towards the development of torque was significantly greater at P_0 (seat tube angle=78.31 ± 0.41°) when compared to P_6 (seat tube angle=73.97 ± 0.56°) with a large effect size. When their participants used a TT position compared to a normal road position with the same seat tube angle, Dorel et al. 2009 observed a reduced trunk lean angle and a forward shift in crank torque kinetics rather than the rearward observed herein. Hence, it is likely that the current alterations in crank kinetics are related to seat tube angle rather than trunk lean angle. Future research is necessary to clarify changes in muscle activity patterns related to these positional changes.

Previous research has demonstrated that, due to a reduction in aerodynamic drag, a decrease in the energy cost of cycling at high velocities is likely when trunk lean angle is reduced (Fintelman et al. 2014), despite an increase in the metabolic cost (Ashe et al. 2003, Grappe et al. 1998). Hence, it is postulated that with the current changes to cycling posture (reduction in trunk lean with maintenance of lower limb range of motion), which occurred without significant change to metabolic cost, the net energy cost of cycling at a given velocity will be reduced due to reduction in aerodynamic drag. However, future research is necessary to quantify such improvements in frontal surface area. This may be achieved by using such methods as outlined by Debraux et al. (2009), where frontal surface area is estimated through planimetry of photographs.

The method by which crank torque kinetics was measured in the current study does not separate radial and tangential forces unlike a strain gauge instrumented pedal. This limitation prevents the estimation of patellofemoral and tibiofemoral forces which would be valuable in understanding the risk of injury associated with such positional changes (Bini, 2012). Furthermore, use of instrumented pedals may improve the resolution in the measurement of peak torque and peak torque angle (Bini and Hume, 2014).

This study aimed to investigate the effects of the positional changes in well-trained cyclists. As with other similar works the need for a consistent sample of well-trained cyclists has resulted in a relatively small sample size (Grappe et al. 1998; Peveler and Green, 2011; Van Sickle and Hull, 2007). Hence, future work is required to investigate specific position related effects in a larger cohort.

Practical applications

Findings from the current study indicate that rotating cycling posture forward, to positions where the horizontal saddle displacement contravenes UCI rule 1.3.013, does not bring about an improvement to the rider's internal capacity to produce power.

At the most forward position where the saddle nose was directly above the bottom bracket spindle there was a rearward phase shift in crank torque kinetics. This shift may well be related to previously observed increases in hip-flexor activation during the recovery phase of the pedal stroke and correspond well to increases in the angular velocity of the hip at the top of the pedal stroke.

The significant reductions in trunk lean angle with forward rotations of posture suggest that aerodynamic improvements will be made as a function of reduced frontal surface area and coefficient of drag (Garcia-Lopez et al. 2008). Accordingly bike fitting practitioners and coaches working with cyclists competing in non-UCI sanctioned events, such as triathlons, may be interested to note, that using the method outlined herein, riders may reduce trunk angle significantly without increasing metabolic cost or reducing power output during heavy intensity time trials. However, further work is required to allude to the magnitude of aerodynamic improvements that are likely to occur as a result of such changes to trunk lean angle.

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