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RESEARCH ARTICLE

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Effects of saddle angle on heavy intensity time trial cycling: Implications of the UCI rule 1.3.014

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Abstract

The UCI dictates that during sanctioned events, the saddle of the bicycle may be at angle of no more than 3° of forward rotation, so as to prevent performance advantages (Rule 1.3.014). This research investigates the effects on performance when rotating the saddle beyond the mandated angle during a laboratory 4km time trial (TT). Eleven competitive male cyclists (age 26 ± 6 (mean ± SD) yrs, height 179.2 ± 6.7 cm, body mass 72.5 ± 6.7 kg; $\dot{V}O_{2max}$ 70.9±8.6 ml·kg^{-1}·min^{-1}) completed laboratory 4km TTs using saddle angles of 0°, 3° and 6°. Completion time and mean power were recorded, in addition to lower appendage kinematics, crank torque kinetics and cardiorespiratory responses. There were no significant changes in TT time, power output, cardiorespiratory variables or crank torque kinetics as a function of saddle angle (P>0.05). There were significant effects on minimum and maximum hip angle and the horizontal displacement of the greater trochanter (P<0.05). At 6° the maximum hip angle and forward displacement of the greater trochanter was greater compared to 0° and 3°. Minimum hip angle was greater at 6° than 3° (P<0.05). In conclusion, contravening UCI rule 1.3.014 by using a saddle angle beyond 3° does not result in performance advantages during a laboratory 4 km. However, tilting the saddle does appear to cause a forward displacement of the pelvis leading to an opening of the hip angle at the top and bottom of the pedal stroke.

Keywords: saddle angle, UCI rule, cardiorespiratory, VO_2, bike fitting.

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Introduction

In order for a cyclist to reach peak performance, physiological condition must be considered alongside biomechanical aspects such as the rider's control of the bicycle, pedalling technique and riding posture. In obtaining optimal riding posture, factors such as comfort (Christiaans et al. 1998), injury prevention (Bini et al. 2011), economy (Peveler et al. 2011) and aerodynamics (Caddy et al. 2015a; Candau et al. 1999; Fintelman et al. 2014) are considered. In time trial (TT) racing, riders compete alone to cover a set distance in the shortest time period. With drag force contributing to over ninety percent of the external resistive forces at speeds in excess of 14 m·s^{-1}, adopting a posture that improves aerodynamic efficiency is vital (Caddy et al. 2015a; Candau et al. 1999; Fintelman et al. 2014). Generally a more aerodynamic riding posture is achieved by rotating the riding position forward to reduce trunk lean angle and using specialist handlebar configurations (tribars) (Caddy et al. 2015; García-López et al. 2008).

The physiological and biomechanical impacts of manipulating saddle position have been extensively researched. Price and Donne (1997) found that oxygen uptake ($\dot{V}O_2$) during submaximal cycling was greater at a seat-tube angle of 80° (similar to that used in TT bicycles) compared to both 68° and 74°. This increased oxygen uptake may well be related to greater activation of the rectus femoris at more acute seat-tube angles (Silder, Gleason and Thelen, 2011). Such responses to more forward saddle positions (Price & Donne, 1997; Silder et al. 2011) support previous research showing increased metabolic cost associated with aerodynamic positions (Gnehm et al. 1997; Grappe, Candau et al. 1998; Jobson et al. 2008). Researchers have also manipulated the vertical position of the saddle, with Peveler and Green (2011) demonstrating that increasing saddle height, such that knee angle increases from 145° to 155° at bottom dead centre of the pedal stroke will reduce the oxygen uptake cost of submaximal cycling. Furthermore, Sanderson and Amoroso (2009) reported that at a saddle height below rider's self-selected position, there was a reduction in medial gastrocnemius and soleus muscle activation, but no changes in oxygen uptake ($\dot{V}O_2$) or performance.

Despite previous research investigating the effects of horizontal and vertical displacement of the saddle on physiological, aerodynamic and biomechanical variables, there is relatively little research investigating the influence of saddle angle on such factors. Salai et al. (1999) demonstrated that angling the saddle nose in the range of 10-15° can reduce lower back pain and increase comfort in recreational cyclists but did not link the effect of saddle angle to changes in performance.

Crucially, Union Cycliste Internationale (UCI) rule 1.3.014 stipulates that the saddle may be tilted to no more than an angle of 2.5° with a measurement tolerance of 0.5°, resulting in an acceptable angle of 3° (Union Cycliste Internationale, 2011; Union Cycliste Internationale, 2014). In support of this rule but not in light of available research, the Union Cycliste Internationale (2011) state "Ultimately the concept is to grant the rider sufficient freedom to allow a comfortable position to be adopted, reducing the pressure on the perineum, while avoiding any deviation through an excessively sloping saddle that could improve sporting performance to an unacceptable degree by the addition of a lumbar support. Furthermore, if the saddle is inclined too severely, this reduces the quality of the rider's position on the saddle, thus reducing its intrinsic function of providing a basic support for the rider on the bicycle". The principle aim of this study was to test the hypothesis that angling the saddle beyond 3° may provide a performance advantage during high intensity TT cycling as a function of augmented power output, with or without a reduced metabolic cost. Furthermore, in order to allude to any such changes in cycling performance and offer a much needed overview, physiological and biomechanical responses were also measured, to include crank torque kinetics, lower appendage kinematics and cardiorespiratory variables.

Materials and methods

Participants

Following local institutional ethical approval 11 competitive male cyclists gave informed consent to participate in the study; age 26 ± 6 (mean ± SD) yrs, height 179.2 ± 6.7 cm, body mass 72.5 ± 6.7 kg; maximum oxygen uptake ($\dot{V}O_{2max}$) 70.9 ± 8.6 ml·kg^{-1}·min^{-1}; power at $\dot{V}O_{2max}$ (W_{max}) 453.5 ± 34.1 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 past 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.

Maximal exercise test

During the first of four visits, participants 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, $\dot{V}O2max$ and gas exchange threshold (GET). Following a self-selected warm-up the test was initiated with a 1 min workload of 150 W, after which workload was progressively increased at a rate of 1 W.2 s^{-1}. Participants maintained 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 as well as saddle angle was duplicated from the participants' own bicycles.

Experimental Procedures

The remaining three visits took place over a period of no more than three weeks after the initial visit and all at the same time of day. Participants were required to exercise on the electronically braked cycle ergometer. Using an adjustable ruler and spirit level system (X/Y Tool, Serotta, USA) the horizontal and vertical position of the contact points of the ergometer (handlebars, saddle and pedals) were oriented relative to the crank shaft centre so as to duplicate the cyclists' own riding position. During all visits participants used their own shoes and specialist 'clipless' pedals. Using a digital inclinometer (Duratool, UK) the angle of saddle tilt was set, during each of the three experimental visits, such that a plane intersecting the highest and lowest point of the saddle was at either 0°, 3° or 6° of clockwise rotation from horizontal (Figure 1).

In order to facilitate the precise adjustment of saddle tilt angle the original saddle attachment bracket was replaced by a modified bracket that allowed the saddle to be tilted to a tolerance of 0.1°. A counterbalanced order of testing was created for saddle angle prescription to which riders were randomly assigned in order to reduce potential training and learning effects. Participants were blind to the condition of saddle angle to prevent an anticipatory response. During each visit participants completed a 6 min warm-up at a power equivalent to 50% of that at which GET was elicited. Immediately following the warm-up participants undertook a 6 min active recovery period at a workload of 50 W followed by 1 minute of complete rest during which time the ergometer software was switched into TT mode. Following the rest period the 4 km TT was commenced (Caddy et al. 2015b) The Velotron ergometer allows the participant to select a virtual gear by automatically adjusting the electromagnetic resistance and increasing the virtual speed in response to the activation of a toggle switch located on the handlebar. Participants were given a familiarisation session following the maximal exercise test where they

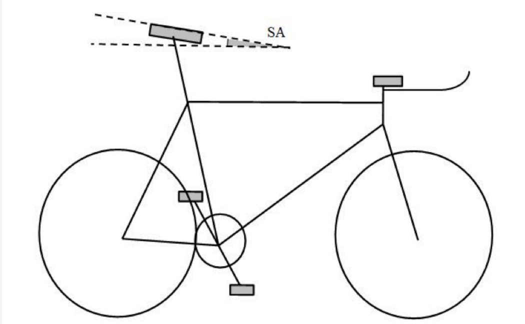

Figure 1. Measurement of saddle angle (SA)

could pedal freely and use the gear switch so as to become accustomed to the gearing system of the Velotron ergometer ahead of its use in the TT bouts. Throughout the TT 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 was 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 (Bf), minute ventilation (VE) and respiratory exchange ratio (RER) were measured or calculated 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 gas 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. GET was determined using the excess $\dot{V}CO_2$ method (Gaskill et al., 2001). During the TT 15 s mean values for all gas exchange variables were taken at distances of 500 m, 1500 m, 2500 m and 3500 m.

Blood lactate measurement

Upon completion of the TT 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 appendage and trunk kinematics were measured at distances of 500 m, 1500 m, 2500 m and 3500 m during the TT using a three dimensional motion capture system (Codamotion, Charnwood Dynamics Ltd, UK) at 200Hz. 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 in order to calculate degrees of crank rotation. Maximum and minimum values as well as mean range of motion (RoM) were calculated for the first 10 consecutive pedal revolutions (at 500 m, 1500 m, 2500 m and 3500 m) for foot angle, ankle angle, knee angle and hip angle. Angles are given where 0° is representative of full flexion i.e. reducing as the joint undergoes flexion. Additionally, mean trunk angle (taken between a vector drawn from acromion process to greater trochanter and a horizontal vector draw through the greater trochanter) and the mean horizontal and vertical displacement of the greater trochanter were also noted. 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).

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 HVY and TT4 (P0, P2, P4 and P6) and distance during TT4 (500 m, 1500 m, 2500 m and 3500 m). Partial eta squared effect sizes (ηp2) 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. For each main saddle angle related effect, effect sizes were calculated as partial eta squared (ηp2) and F-statistics are presented with degrees of freedom (F(df)). Descriptive data is presented as mean ± standard deviation.

Results

Time trial performance

There was no significant effect of saddle angle on 4 km TT performance ($F(2)=0.475$, $p=0.629$, $\eta p^2=0.045$) (Table 1). There was no significant effect of saddle angle on mean power ($F(2)=0.674$, $p=0.521$, $\eta p^2=0.063$), mean gear size selection ($F(2)=1.650$, $p=0.217$, $\eta p^2=0.142$) or mean cadence ($F(1.188)=1.832$, $p=0.203$, $\eta p^2=0.155$). There was also no significant effect of test order on 4 km TT performance ($p>0.05$).

Table 1. Average (Mean ± SD) across group for TT time, power, mean cadence and mean gear size for laboratory 4 km TTs using saddle angles of 0°, 3° and 6°.

	TT Time (s)	TT Power (W)	Mean Cadence (rev·min^{-1})	Mean Gear Size (")
0°	353 ± 11	350 ± 32	101.6 ± 5.8	84.07 ± 4.76
3°	353 ± 11	347 ± 30	100.3 ± 6.5	83.73 ± 4.99
6°	354 ± 10	347 ± 28	100.6 ± 6.0	84.52 ± 4.55

Gas exchange responses

There was no significant effect of saddle angle on $\dot{V}O_2$ ($F(2)=0.756$, $p=0.482$, $\eta p^2=0.070$), $\dot{V}CO_2$ ($F(2)=0.663$, $p=0.526$, $\eta p^2=0.062$), RER ($F(1.586)=0.775$, $p=0.474$, $\eta p^2=0.072$), VE (F(2)=, p=0., ηp²=0.) or Bf ($F(2)=2.220$, $p=0.135$, $\eta p^2=0.182$). There was a significant effect of distance on $\dot{V}O_2$, $\dot{V}CO_2$, RER, VE and Bf ($p<0.001$). Pairwise comparisons revealed significant increases in $\dot{V}O_2$ and $\dot{V}CO_2$ from 500 m to 1500 m and 1500 m to 2500 m ($p<0.01$). For RER, VE and Bf there were significant increases ($p<0.01$) with each distance split and all distances were significantly different from each other ($p<0.01$). There was no significant saddle angle-by-distance interaction effect on $\dot{V}O_2$, $\dot{V}CO_2$, RER, VE or Bf ($p>0.05$) (Table 2).

Blood lactate responses

There was no significant effect of saddle angle on BLa ($F(2)=1.577$, $p=0.231$, ηp2=0.136); 0°= 11.4 ± 2.7 mmol, 3°=11.8 ± 1.7 mmol, 6°= 12.3 ± 2.6 mmol (Table 2).

Kinematic variables

There was no significant effect of saddle angle, on hip ROM ($F(2)=1.014$, $P=0.381$, $\eta p^2=0.092$), knee ROM ($F(2)=2.382$, $p=0.118$, $\eta p^2=0.192$) or ankle ROM ($F(1.305)=0.778$, $p=0.427$, $\eta p^2=0.072$) (Table 3). There was no significant effect of distance or saddle angle-by-distance interaction effect on hip, knee or ankle RoM ($p>0.05$). There was a significant effect of saddle angle on minimum hip angle ($F(2)=4.547$, $p=0.024$, $\eta p^2=0.313$). Pairwise comparisons revealed a significant increase in minimum hip angle from 3° to 6° ($p=0.002$) but not from 0° to 6° although a trend was observed ($p=0.069$). There was a significant effect of distance on minimum hip angle ($p=0.048$) with a significant increase in minimum hip angle at 3500 m compared to all other splits ($p<0.05$). There was a significant effect of saddle angle on maximum hip angle ($F(2)=7.510$, $p=0.004$, $\eta p^2=0.429$). Pairwise comparisons revealed that maximum hip angle at 6° was significantly greater than both 0° and 3° ($p=0.023$ and $p<0.001$ respectively). There was a significant effect of distance on maximum and minimum hip angle ($p=<0.05$) with a significant increase in both at 3500 m compared to all other splits ($p<0.05$). There was no significant saddle angle-by-distance interaction effect on maximum or minimum hip angle ($p>0.05$). There was no effect of distance or saddle angle or saddle angle-by-distance effect on

Table 2. Average (Mean ± SD) across group for cardiorespiratory variables expressed relative to power output during laboratory 4 km TT for saddle angles of 0°, 3° and 6°, at distances of 500 m, 1500 m, 2500 m and 3500 m.6°.

		VO_2 ($ml \cdot min^{-1} \cdot W^{-1}$)	VCO_2 ($ml \cdot min^{-1} \cdot W^{-1}$)	RER	V_E ($ml \cdot min^{-1} \cdot W^{-1}$)	Bf ($brs \cdot min^{-1} \cdot W^{-1}$)	HR ($b \cdot min^{-1} \cdot W^{-1}$)	SV ($ml \cdot W^{-1}$)	Q ($ml \cdot min^{-1} \cdot W^{-1}$)
0°	500 m	4.93 ± 0.81	4.98 ± 0.71	1.02 ± 0.07	160.96 ± 18.30	0.10 ± 0.02	0.43 ± 0.04	0.27 ± 0.07	42.16 ± 10
	1500 m	11.78 ± 0.71	13.75 ± 1.11	1.17 ± 0.05	392.70 ± 32.57	0.13 ± 0.03	0.47 ± 0.06	0.29 ± 0.07	46.45 ± 12.70
	2500 m	12.38 ± 0.76	13.77 ± 1.09	1.11 ± 0.05	424.58 ± 32.39	0.14 ± 0.03	0.44 ± 0.12	0.31 ± 0.07	53.01 ± 9.56
	3500 m	12.55 ± 0.81	13.63 ± 0.92	1.09 ± 0.04	441.40 ± 32.41	0.15 ± 0.03	0.44 ± 0.13	0.30 ± 0.07	49.59 ± 17.04
	Mean	10.41 ± 3.3	11.53 ± 3.94	1.10 ± 0.08	354.91 ± 118.14	0.13 ± 0.03	0.45 ± 0.09	0.29 ± 0.07	47.8 ± 12.33
3°	500 m	4.96 ± 0.41	5.01 ± 0.52	1.01 ± 0.08	166.29 ± 19.04	0.10 ± 0.02	0.44 ± 0.05	0.27 ± 0.04	45.81 ± 8.56
	1500 m	11.95 ± 0.89	13.9 ± 1.32	1.16 ± 0.05	395.33 ± 44.78	0.13 ± 0.02	0.50 ± 0.05	0.30 ± 0.05	49.81 ± 8.23
	2500 m	12.46 ± 0.99	13.95 ± 1.12	1.12 ± 0.04	438.68 ± 34.51	0.14 ± 0.02	0.50 ± 0.05	0.30 ± 0.05	50.63 ± 6.69
	3500 m	12.94 ± 1.03	14.23 ± 0.99	1.10 ± 0.04	474.1 ± 26.98	0.16 ± 0.02	0.51 ± 0.06	0.30 ± 0.06	54.97 ± 10.63
	Mean	10.58 ± 3.4	11.77 ± 4.07	1.10 ± 0.08	368.6 ± 125.51	0.13 ± 0.03	0.49 ± 0.06	0.29 ± 0.05	50.31 ± 8.53
6°	500 m	4.98 ± 0.85	4.83 ± 0.88	0.97 ± 0.09	156.67 ± 28.83	0.10 ± 0.02	0.42 ± 0.04	0.27 ± 0.05	42.16 ± 10.00
	1500 m	11.80 ± 0.72	13.84 ± 1.31	1.17 ± 0.07	392.40 ± 48.3	0.13 ± 0.03	0.48 ± 0.07	0.31 ± 0.05	46.45 ± 12.70
	2500 m	12.52 ± 0.77	14.01 ± 1.00	1.12 ± 0.06	431.30 ± 43.14	0.14 ± 0.02	0.49 ± 0.06	0.31 ± 0.06	53.01 ± 9.56
	3500 m	12.69 ± 1.02	13.76 ± 1.06	1.09 ± 0.06	455.47 ± 43.68	0.15 ± 0.03	0.49 ± 0.07	0.30 ± 0.05	49.59 ± 17.04
	Mean	10.50 ± 3.34	11.61 ± 4.09	1.09 ± 0.10	358.96 ± 126.84	0.13 ± 0.03	0.47 ± 0.06	0.30 ± 0.05	47.8 ± 12.33

**See text for distance related pairwise comparisons.*

Table 3. Average (Mean ± SD) across group for Lower appendage range of motion (RoM), maximum angle (Max) and minimum angle (min) during laboratory 4 km TT for saddle angles of 0°, 3° and 6°, at distances of 500 m, 1500 m, 2500 m and 3500 m.

		Knee ROM (°)	Hip RoM (°)	Hip Max (°)	Hip Min (°)	Ankle RoM (°)	Trunk Mean (°)
0°	500 m	72 ± 5	46 ± 3	90 ± 6	44 ± 5	20 ± 5	21 ± 5
	1500 m	72 ± 6	46 ± 3	90 ± 6	44 ± 5	21 ± 4	21 ± 5
	2500 m	72 ± 5	46 ± 3	91 ± 6	44 ± 5	21 ± 5	21 ± 5
	3500 m	72 ± 5	47 ± 3	92 ± 6	45 ± 5	20 ± 4	21 ± 5
	Mean	72 ± 5	46 ± 3	91 ± 6	44 ± 5	20 ± 4	21 ± 5
3°	500 m	73 ± 6	46 ± 3	91 ± 5	44 ± 4	22 ± 6	21 ± 5
	1500 m	73 ± 6	46 ± 3	90 ± 5	44 ± 4	22 ± 4	21 ± 5
	2500 m	73 ± 5	47 ± 3	91 ± 5	44 ± 5	21 ± 5	21 ± 4
	3500 m	73 ± 5	47 ± 3	91 ± 4	44 ± 4	21 ± 5	21 ± 5
	Mean	73 ± 5	46 ± 3	91 ± 5	44 ± 4	22 ± 5	21 ± 5
6°	500 m	73 ± 5	47 ± 2	92 ± 5	45 ± 4	20 ± 4	20 ± 4
	1500 m	73 ± 5	47 ± 3	93 ± 5	46 ± 4	22 ± 2	21 ± 5
	2500 m	73 ± 5	47 ± 3	93 ± 4	46 ± 4	21 ± 3	21 ± 5
	3500 m	73 ± 5	47 ± 3	93 ± 5	46 ± 4	21 ± 5	21 ± 5
	Mean	73 ± 5	47 ± 3	93 ± 5*	46 ± 4**	21 ± 4	21 ± 5

**Sig diff from other angles, **Sig diff from 3°, See text for distance related pairwise comparisons*

Table 4. Average (Mean ± SD) across group for mean horizontal displacement (GT_x – relative to the bottom bracket), mean vertical displacement (GT_z – relative to the bottom bracket) and range of displacement (ΔGT_x, ΔGT_z) of the greater trochanter during laboratory 4 km TT for saddle angles of 0°, 3° and 6°, at distances of 500 m, 1500 m, 2500 m and 3500 m.

		ΔGTx (mm)	GTx (mm)	ΔGTz (mm)	GTz (mm)
0°	500 m	20 ± 8	163 ± 82	48 ± 13	822 ± 40
	1500 m	20 ± 6	162 ± 82	49 ± 11	821 ± 41
	2500 m	20 ± 7	159 ± 86	49 ± 10	821 ± 41
	3500 m	21 ± 7	149 ± 86	52 ± 12	820 ± 42
	Mean	20 ± 7**	153 ± 81	50 ± 11	823 ± 41
3°	500 m	23 ± 8	156 ± 87	48 ± 9	819 ± 41
	1500 m	24 ± 8	158 ± 90	49 ± 11	818 ± 39
	2500 m	23 ± 8	152 ± 87	50 ± 11	816 ± 40
	3500 m	23 ± 8	151 ± 89	50 ± 11	817 ± 40
	Mean	23 ± 7**	150 ± 85	49 ± 10	819 ± 40
6°	500 m	22 ± 9	151 ± 81	52 ± 9	827 ± 40
	1500 m	20 ± 8	143 ± 85	49 ± 9	825 ± 40
	2500 m	22 ± 8	141 ± 86	52 ± 8	824 ± 41
	3500 m	24 ± 10	137 ± 86	52 ± 8	823 ± 41
	Mean	22 ± 8**	137 ± 79*	51 ± 8	827 ± 40*

**Sig diff from other angles, **Sig diff from ΔGT_z, See text for distance related pairwise comparisons.*

mean trunk lean angle ($F(2)=0.039$, $p=0.96$, $\eta p^2=0.004$) (Table 3).

There was a significant effect of saddle angle on the mean horizontal displacement of the greater trochanter (relative to the bottom bracket) ($F(2)=5.582$, $p=0.012$, $\eta p^2=0.358$). Pairwise comparisons revealed that the mean horizontal displacement of the greater trochanter at 6° was significantly reduced in comparison to both

0° and 3° (*p*=0.023 and *p*<0.001 respectively) (Table 4). There was no significant effect of saddle angle on the mean vertical displacement of the greater trochanter (relative to the bottom bracket) (F(1.383)=3.230, *p*=0.086, ηp^2=0.244). There was a significant effect of distance on the the mean vertical and horizontal displacement of the greater trochanter (P<0.01). Pairwise comparisons revealed significant reductions in the mean horizontal and vertical displacement of the greater trochanter at 3500 m compared to 500 m and 1500 m and at 2500 m compared to 500 m and 1500 m (*p*<0.05). There was no significant saddle angle-by-distance interaction effect on either the mean vertical or mean horizontal displacement of the greater trochanter (*p*>0.05). Vertical range of displacement (maximum minus minimum) was significantly greater than horizontal range of displacement (*p*<0.001).

Discussion

The aim of this study was to test the effects of tilting saddle position forward to angles where UCI rule 1.3.014 was contravened during heavy intensity TT cycling. This rule states that in order to prevent performance advantages, riders may not tilt the saddle to an angle greater than 2.5° (3° with the inclusion of a measurement tolerance). However, to date no empirical evidence exists to suggest that contravening this rule may allow the rider an improvement in overall performance or economy, in terms of cardiorespiratory stress, in any cycling event. The crucial dependant variable, 4 km laboratory based TT time, was not affected when the UCI saddle angle rule was contravened (6°), nor was there a significant effect in terms of cardiorespiratory stress. Whilst subtle changes were observed in relation to hip kinematics and pelvic position as a function of altering saddle angle, these changes appear unlikely to impact on performance during heavy intensity TT cycling.

During laboratory based TTs the rider has control over the work rate (power output) but not the overall magnitude of work required to complete the exercise task. Thus, where the rider determines he/she is able to increase power output, either a higher gear ratio or cadence may be selected. Accordingly, there was no effect of saddle angle (or trial order) on power output, mean gear size or cadence with modification of the saddle angle. The lack of significant difference in 4 km TT time and power output with modification to saddle angle was reflected in all cardiorespiratory measures with no effect of saddle angle on $\dot{V}O_2$, $\dot{V}CO_2$, RER, VE, Bf, HR, SV, $\dot{Q}$ or BLa (Table 2). All participants completed all three TTs in a mean power greater than that elicited at GET, hence the intensity may be described as heavy (Jones & McConnell, 1999). Accordingly, the responses of $\dot{V}O_2$, $\dot{V}CO_2$, RER, VE, Bf, HR, SV, $\dot{Q}$, with increase in distance but not in mean crank torque are likely related to previously observed effects such as increase in core temperature (Parkin et al. 1999) and changes to the percentage contribution of different metabolic pathways (Bangsbo et al. 1990; Lucía et al. 2000; Saunders et al. 2000).

Altering the saddle angle did not change the RoM of the knee, hip or ankle. Likewise there was no effect on the mean trunk lean angle. This suggests that the frontal surface area of the rider is not likely to be effected as a result of saddle angle modification (Underwood et al. 2011). The only kinematic changes were observed at the hip joint where maximum hip angle (occurring at approximately bottom dead centre of the crank revolution) and minimum hip angle (occurring at approximately top dead centre of the crank revolution) were both greater at 6° compared with 0° and 3°. As observed by previous works (Price & Donne 1997; Silder et al. 2011) the increase in hip angle with no change in the knee and ankle angle is likely related to a decrease in the mean horizontal displacement between the greater trochanter and the crank shaft. As there was no change in the angle of trunk lean across saddle angle conditions, any changes in hip angle are likely a result of variation in flexion and extension of the thigh at the hip. Essentially, it was observed that when the rider is sitting further forward on the saddle, the hip angle will be greater at both top and bottom dead centre. As there was relative increase to both the minimum and maximum hip angle, hip RoM was not altered with changes in saddle angle, although this occurred at no extra metabolic cost.

A possible mechanism for the increase in the horizontal displacement of the greater trochanter at the acutely increased saddle angle (6°) is a 'sliding' motion of the pelvis; along the slope of the saddle toward the handlebars due to increase in the component of gravity acting down the slope of the saddle. This finding is in accordance with the Union Cycliste Internationale postulation that an acute saddle angle will alter the cyclist's position on the saddle, thereby compromising the function of the saddle as a support for the cyclist's mass (Union Cycliste Internationale, 2011). Furthermore, the increases in hip angle occurring at the top dead centre and bottom dead centre may well be related to a counteraction to the sliding motion, where the rider is moving back (rearward from the handlebars) on the saddle to increase the support offered by the saddle. Although this occurred with no extra metabolic cost during a relatively short TT (~353 s) further research is needed to allude to such responses over longer distances. As there was no change in pedal torque kinetics, correction of this sliding motion may be achieved through upper body muscle actions. It is relevant to note that the lack of significant change in the mean vertical displacement (height) of the greater trochanter at 6° does not directly support the notion that participants were 'sliding' forward on the saddle. Though the significantly greater range of vertical range of movement (compared to the horizontal) caused by a reaction to vertical pedal forces may negate any associated changes in the vertical direction. A significant decrease in the mean horizontal and vertical displacement of the greater trochanter occurred at the final split (3500 m), regardless of saddle angle, with a concurrent increase in peak and mean torque. These observations link well with the common phrase 'riding on the rivet'; meaning to ride at or close to maximum intensity in a more forward position. It is possible that this phenomenon occurs as the rider attempts to increase the number of recruited motor units to satisfy the increase in power production at a strategic point during a race. This postulation is supported by the work of Silder et al. (2011) who found an increase in the activity of rectus femoris muscle with a more forward displacement of the pelvis.

Future research is necessary to allude to effects of saddle angle on comfort and injury risk; with particular regard to longer efforts where these factors are more pertinent. Furthermore, a deeper understanding of the interaction between handlebar configuration and saddle angle would be beneficial to bike fitting practitioners.

Conclusions

Findings from the current study indicate that contravening UCI rule 1.3.014 by altering the saddle angle beyond 3° does not result in an improvement in performance during a laboratory based 4 km TT performed in the heavy exercise domain. This observation was reflected in unchanging cardiorespiratory parameters. The lack of variation in trunk lean angle does not suggest an aerodynamic improvement may occur with the current changes to saddle angle.

The forward sliding motion that is observed at the acute saddle angle of 6° fits well with the UCI supposition that the function of the saddle, as a support to the rider's mass, may be impaired when rule 1.3.014 is contravened. Furthermore, this forward sliding action of the pelvis is also likely to place the centre of mass further forward towards the handlebars; perhaps increasing pressure on the forward points of contact. This of course may be considered a disadvantage if it were to alter the handling properties of the bicycle or place extra stress on the trunk and upper appendage musculature over a prolonged period of time.

Despite no concurrent changes in physiological variables, the changes in hip kinematics seen herein may be of interest to sports medicine and bike fitting practitioners. Specifically, it should be considered that when the saddle is tilted as far as 6° from horizontal the rider's pelvis is likely to 'slide' forward on the saddle and increase the hip angle towards the top of the pedal stroke.

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