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The effect of the aerodynamic time-trial position on gross efficiency and self-paced time-trial performance

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Abstract: To investigate the physiological and metabolic effects of different torso angles (TA; while systematically controlling the aerodynamic time-trial position; AP), during submaximal exercise and self-paced time-trial efforts. Twelve participants completed four visits to the laboratory: Visit 1 being an incremental exercise test to identify power at maximal pulmonary oxygen uptake (PVO2max) and visits 2 to 4 being 20-min time-trials with pre and post gross efficiency (GE) tests, performed at three different TAs (0o, 12o, 24o). GEpre time-trial was significantly lower at the 0o TA, when compared to the 24o TA ($P = 0.04$) but not 12o TA ($P = 0.42$). GE was significantly lower post time-trials when compared to GEpre at all TA ($P < 0.001$). There was no effect of TA on the decrease in GE from pre to post time-trial ($P = 0.37$). Combined data from all TA revealed a significant weak positive correlation between GE and mean time-trial power output (PO; $R = 0.337$; $R2 = 0.114$; $P = 0.04$). Mean time-trial PO was significantly higher at the 24o TA, when compared to the 12o TA ($P = 0.01$) and 0o TA ($P < 0.01$). GE decreases during time-trial exercise, while lower TAs do not result in a greater the decrease in GE. Lowering TA results in a reduction in physiological performance at submaximal and time-trial intensity. There remains a trade-off between physiological functioning and aerodynamic drag.

Keywords: cycling time-trial; gross efficiency; endurance performance; torso angle

1. Introduction

Optimal time-trial performance requires an athlete to maximise power production and decrease the power demand (Jeukendrup & Martin, 2001). Power production is determined by the cyclist's physiological power supply (Joyner & Coyle, 2008), while the greatest resistive force experienced by time-trial cyclists is aerodynamic drag, which accounts for up to 96% of a rider's power output (PO) depending on road gradient (Martin et al. 1998). Meaningful reductions in aerodynamic drag can be achieved by reducing the rider's frontal area, which is predominantly the result of changing torso angle (TA; Chabroux et al. 2012; Lukes et al. 2005; Oggiano et al. 2008). Gracia-Lopez et al. (2008), found a significant decrease in aerodynamic drag of 14% to 16% when the height of the handlebars was lowered, and TA decreased. By using wind tunnel technology Underwood et al. (2011) showed that in an aerodynamic time-trial position (AP), the total aerodynamic drag experienced was largely influenced by TA, with an increase in drag area of approximately 16% when increasing TA from 2o to 20o. It has been proposed that the adoption of an AP, thereby minimising the frontal area of the cyclist could lead to a 6 minute 54 second time gain over a 40-km time-trial, when compared to an upright riding position (UP; Jeukendrup & Martin, 2001). Such an improvement would account for the difference between 1st and 52nd place at the

2016 UCI elite world time-trial championships, which was contested over a flat 40-km course.

It is important that the cyclist's physiological functioning is not significantly impaired by their chosen riding position, as it will likely impact on their power producing capacity and consequently their time-trial performance. The most common physiological measures reported by researchers when studying the effects of cycling position are pulmonary oxygen uptake (V̇O2) and heart rate (HR), which have been shown to be ecologically valid measures when used in a laboratory setting (Jobson et al. 2008). There have been numerous studies examining the physiological effects of riding position, unsurprisingly findings have been heterogeneous. With studies finding the AP to impair an individual's physiological functioning (Fintelman et al. 2014, 2015 & 2016; Richardson & Johnson, 1994; Gnehm et al. 1997; Sheel et al. 1996; Peveler et al. 2005; Evangelisti et al. 1995; Ashe et al. 2003), while other researchers have demonstrated the AP to have limited negative physiological and metabolic effects, when compared to UP riding positions (Berry et al. 1994; Duke et al. 2014; Dorel et al. 2009; Egana et al. 2006; Franke et al. 1994; Grappe et al. 1998; Hubenig et al. 2011; Origenes et al. 1993 Heil et al. 1997; Welbergen & Clijsen, 1990).

It is evident that the effect of the AP on all performance measures remains inconclusive. This is likely due to the heterogeneity of the cycling positions, the participants experience of riding in an AP, in addition to differences in methodologies employed. To the authors knowledge, the physiological effects of different TA (while systematically controlling the AP) are yet to be measured during a self-paced time-trial effort. Therefore, the first aim of this study was to determine the effects of different TAs (while systematically controlling the AP) on a 20-min laboratory time-trial performance. It was hypothesised that lower TAs (0o) would impair time-trial performance, when compared to larger TA.

Gross efficiency (GE) is the ratio of work generated to the total metabolic energy cost (Ettema & Loras, 2009; Horowitz et al. 1994; Jobson et al. 2012) and has been reported to explain 30% of the variation in PO during a cycling time-trial (Jobson et al. 2012). While maximal oxygen consumption (V̇O2max) and lactate threshold (LT) have received large amounts of attention with regards to time-trial performance (Lucia et al. 2004; Coyle et al. 1991; Bentley et al. 2001; Storen et al. 2013), GE has not been so well researched despite its importance in determining endurance performance (Jobson et al. 2012).

When comparing time-trial performance in two groups with similar V̇O2max, Coyle et al. (1991) found that the cyclists with a higher LT were able to generate 11% more power during a 1-hour laboratory time-trial, which in turn correlated with a 10% higher velocity during an actual 40-km road time-trial. It was suggested the reason the cyclists were able to produce a higher PO was because they generated more power per pedal revolution for a lower metabolic cost. In accordance with the findings of Coyle et al. (1991), Horowitz et al. (1994) showed that cyclists with a higher GE could maintain a 9% higher PO during a 1-hour time-trial, despite similar V̇O2 values. However, the effect of cycling position on GE was not examined in these studies (Coyle et al. 1991; Horowitz et al. 1994).

Prolonged endurance cycling has been shown to lead to significant decreases in GE (Hopker et al. 2016; de Koning et al. 2013; Mulder et al. 2015; Noordhof et al. 2015; Passfield & Doust, 2000), while the assumption of a constant GE during endurance exercise has also been brought into question (Hopker et al. 2016; de Koning et al. 2013; Mulder et al. 2015). In the studies of Mulder et al. (2015) and Noordhof et al. (2015), GE was found to be significantly reduced following time-trials of varying durations. Researchers have also shown the adoption of lower TA to reduce GE (Fintelman et al. 2015 & 2016). While the workload to overcome aerodynamic drag decreases with lower TA, this must be weighed up against the paralleled decreases in efficiency. However, interestingly no previous study has investigated the effects of TA (while systematically controlling the AP) on changes in GE observed following time-trial exercise. Thus, the second aim of the current study was to investigate GE during submaximal exercise before and after a 20-minute time-trial performed at different TAs (while systematically controlling the AP). It was hypothesised that lower TAs (0o) would result in a lower GE and would lead to a greater decrease in GE immediately following the time-trial, when compared to larger TAs (12o and 24o). This study will also provide further knowledge to the importance of GE in determining time-trial performance.

2. Materials and Methods

Participants

Twelve well trained cyclists with experience of riding in the AP (10 male, 2 female) were recruited to take part in the study. All participants had a minimum of two years training and racing experience and were in preparation for the next competitive season. Participants were also experienced with riding 10-mile time-trials and/or completing 20-minute tests. The study was completed with full institutional ethical approval, according to the Declaration of Helsinki standards. All participants provided signed informed consent prior to testing.

Study design

Participants visited the laboratory on four occasions: Visit 1 being an incremental exercise test to identify VO2max and power at VO2max (PVO2max), Visits 2 to 4 were laboratory based 20-min time-trials with pre and post GE tests, performed at three different TAs (0o, 12o, 24o) in a randomised order (using simple randomisation; Roberts and Torgerson, 1998). The visits were conducted on non-concurrent days, and participants were instructed to refrain from any exercise in the day prior to testing. The experimental protocols were performed at the same time of day to avoid any circadian variance. At each visit room temperature, humidity, and pressure (mmHg) were recorded. The participants were allowed to have an electric fan placed 2 m in front to provide cooling during all tests.

At all visits respiratory gas exchange data were assessed using breath by breath gas analysis (Metalyzer 3B; CORTEX Biophysik GmbH, Leipzig, Germany). Prior to all testing the analyser was calibrated according to the manufacturer recommendations. The Cyclus2 electromagnetically braked cycle ergometer (PO ± 2% maximal error; Rodger et al. 2016) was used at all visits and calibrated to the manufacturer's instructions (Leipzig, Germany). HR was assessed at all visits using Garmin HR monitors (Garmin, Kansas, USA).

Participants were instructed to arrive euhydrated for each visit as they would be unable to drink for the duration of the exercise testing. Participants were advised to arrive in a post-prandial state, having eaten at least 4-hours prior to testing, and were told to not consume caffeine 4-hours prior as it has been shown to effect GE (Cole et al. 2017) and alcohol 24-hours prior.

Visit 1: Maximal incremental exercise test

The participants completed a 10-minute warm-up at 100 W, after which the required cycling PO was increased by 20 W every 1-minute. The test continued until the participant reach volitional exhaustion (operationally defined as a cadence of <60 revolutions per minute for >5 s, despite strong verbal encouragement). PO and HR were measured continuously throughout the test, with rating of perceived exertion (RPE) measurements taken in the last 10-s of each 1-min stage (Borg, 1998). The participants VO2max was assessed as the highest VO2 that was attained during a 60-s period in the test. The average PO attained at VO2max (over the 60-s period) was used to determine the participants PVO2max. Following the VO2max test, participants were setup on the adjustable time-trial bike at the three TA and were allowed to experience riding at each TA position.

Time-trial bike setup

Measurements were taken from the participants own bike and replicated on the adjustable time-trial bike to be used in visits 2 to 4. The handlebar height was then adjusted on the time-trial bike to achieve the predefined TAs: 0o, 12o and 24o. TA was measured using a Bosch PAM 220 digital angle measure (Bosch, GmbH, Gerlingen, Germany) with an accuracy of ± 0.2o and was defined as the angle between horizontal lines, relative to the ground, intersecting the centre of rotation of the glenohumeral axis and the greater trochanter. The distance between the arm rests (inside edge to inside edge) was set at 8 cm for all participants. The shoulder angle was measured in the participants preferred riding position and was then maintained across all trials. Hip angle was measured at each TA and was defined as the angle between the thigh and torso, with the pedal position at 6 o'clock.

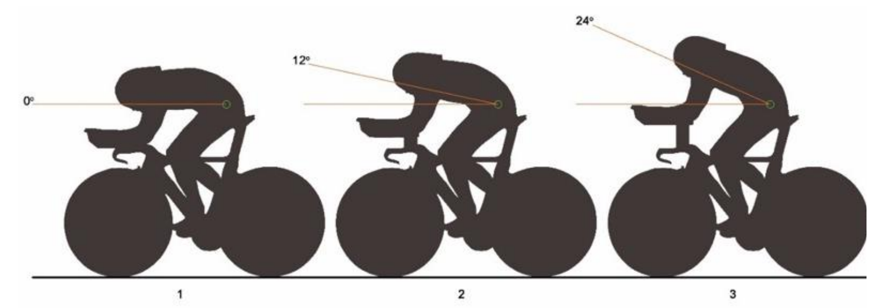


Figure 1. Diagram of different TA tested (Image 1: 0o TA. Image 2: 12o TA. Image 3: 24o TA).

It should be noted that out of the twelve participants, it was not possible for three of them to reach 0o TA due to physical or ergometer position limitations. In this situation the smallest reachable TA was used, ranging between 1o and 2.4o.

Visits 2 to 4: Self-paced time-trial and GE tests
Participants were required to complete a submaximal GE test followed by a 20-minute self-paced time-trial, GE was then measured again immediately following the time-trial. The schematic for the experimental protocol is displayed in figure 2. The experimental protocol was performed three times at each TA position: 0o, 12o and 24o relative to the ground (Figure 1), with the prescribed TA position maintained throughout all parts of the experimental protocol.

Only time elapsed was shown to the participants during the protocols, no other visual feedback or encouragement was provided. All protocols were conducted in the AP on an adjustable time-trial bike fitted to the Cyclus2 ergometer pre-programmed with the experimental protocol (Figure 2). The Cyclus2 controlled the participants PO during the submaximal GE tests and allowed participants to self-select work intensity during the 20-min time-trial.

The experimental protocol started with an incremental warm-up with 6-minutes at 100W, followed by 6-minutes at 45% of PVO2max. Exercise intensity was then set at 55% of PVO2max for the measurement of GEpre. Participants then rested for 3-minutes before commencing the self-paced 20-minute time-trial test. After completion of the time-trial, participants rested for 3 minutes (100 W), to allow VO2 and RER to drop below the level at 55% of PVO2max. Participants then commenced the post-GE test with exercise intensity set to 55% of PVO2max for 10 minutes. Exercise intensity (55% of PVO2max) for the GE tests were selected to ensure the participants were able to exercise with an RER <1.0 at all TA positions. Two post-GE tests were performed to check if GE remains constant over time. Participants were allowed to freely select a cadence at their first pre-GE test, which then had to be used across all other GE tests at each visit, as cadence has been shown to affect GE (Lucia et al. 2004; Lepers et al. 2001).

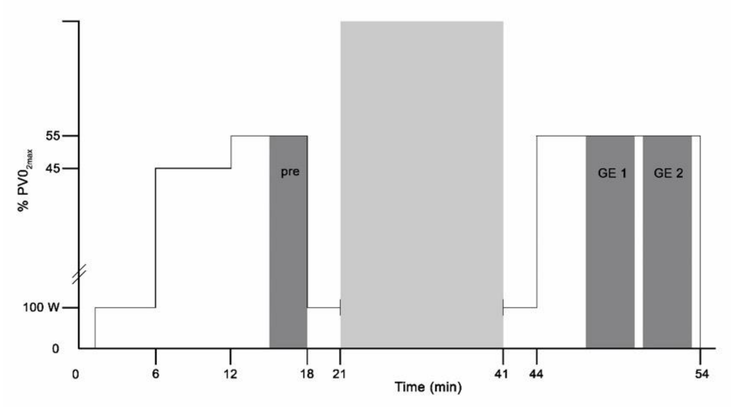


Figure 2. Experimental protocol of the GE and time-trial test (adapted from Noordhof et al. 2015). Mean respiratory values will be determined over the dark shaded areas (pre-time-trial 15:00 to 18:00 [GEpre], post-time-trial 3:00–6:00 [GEpost1] and 6:30–9:30 [GEpost2]). The light shaded area represents the 20-minute time-trial.

Blood lactates (B[La]) were collected using a fingertip capillary blood sample, prior to exercise commencing and 3 minutes post time-trial. Blood samples were analysed using a Biosen C-Line (EKF Diagnostic, London, UK) and then safely disposed of in accordance with the Human Tissue Act. RPE measurements were taken at the end of each 5-min throughout the time-trial, using the Borg 6–20 scale (Borg, 1998). PO and HR were continuously recorded throughout all parts of the protocol.

Study design

Gross efficiency during the pre time-trial submaximal bout was calculated over the final 3 minutes of the 55% of PVO2max step (GEpre) using average values of V̇O2 and RER. Average values for V̇O2 and RER from minutes 3:00 to 6:00 (GEpost1) and 6:30 to 9:30 (GEpost2) were used to calculate GE during the post time-trial submaximal bout (restriction that mean RER is ≤ 1.00 and V̇O2 is in steady state). Steady state was accepted if the difference in V̇O2 between minutes 3:00 to 4:00 and 5:00 to 6:00 (or 6:30 to 7:30 and 8:30 to 9:30) expressed relatively to the mean V̇O2 over the corresponding 3 minutes was ≤ 5%.

Gross efficiency was calculated using the following equation, GE % = (Work accomplished/ Energy expenditure) x 100 (Gaesser and Brooks, 1975). In order to establish the 'Work accomplished', the mean power recorded during the same period as the respiratory collection was converted into kcal.min-1 via the following equation: 'Work accomplished' (kcal.min-1) = Power (W) x 0.01433. Energy expenditure was calculated using the average V̇O2 and RER from the 3-minute collection periods. The calorific equivalent of O2 was then determined from the data of Peronnet & Massicotte, (1991): 'Energy expenditure' (kcal.min-1) = V̇O2 (L.min-1) x kcal.L-1 of O2.

The 20-min time-trial was split into four 5-min quarters for analyses, with PO, HR, V̇O2, pulmonary ventilation (V̇E) and breathing frequency (Bf) averaged over each quarter.

Statistical analyses

Data are presented as individual values or mean ± SD (unless specified otherwise). Statistical analyses were conducted using IBM SPSS Statistics 26 (IBM, Armonk, New York, USA). Visual inspection of Q-Q plots and Shapiro-Wilks statistics were used to check whether data were normally distributed. Two separate two-way repeated measures analysis of variance with Bonferroni post hoc comparisons 1) three TA (0o, 12o, 24o) X time (GEpre, GEpost1, GEpost2) and 2) three TA (0o, 12o, 24o) X four time-trial quarters (0-5min, 5-10min, 10-15min, 15-20min) were used to determine between and within condition effects for all dependent variables. Partial eta squared ($\eta p2$) were computed as effect size estimates and were defined as small ($\eta p2$ = .01), medium ($\eta p2$ = .06), and large ($\eta p2$ = .14; Lakens, 2013). Pearson's correlation coefficient was used to assess the relationship between time-trial PO and GE measured pre time-trial. The significance level was set at P = < 0.05 in all cases.

3. Results

Participant characteristics and data collected from the maximal incremental exercise tests are presented in table 1.

Table 1: Participant characteristics and maximal incremental exercise test results

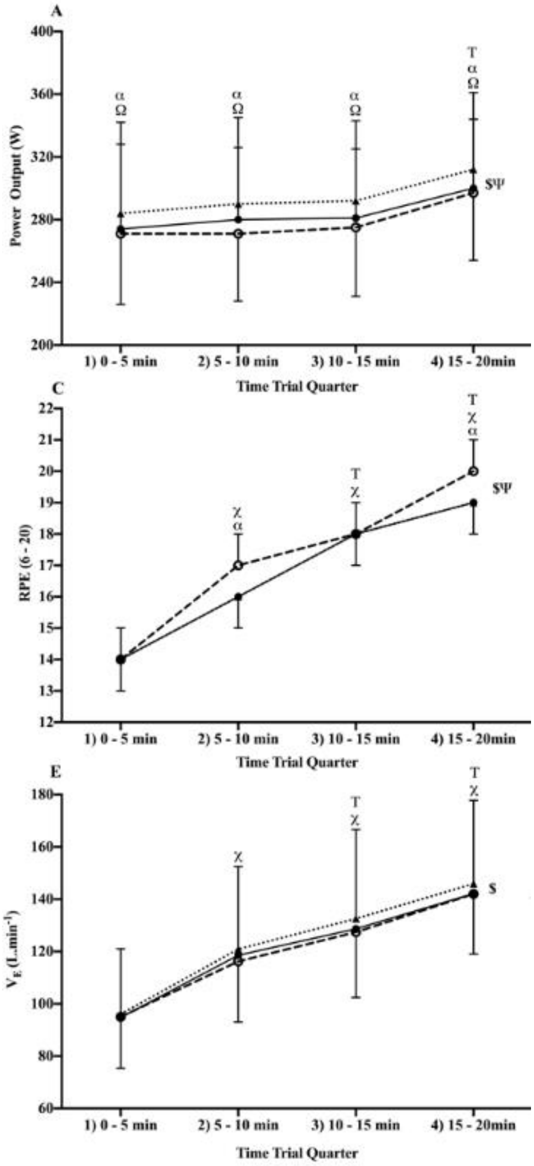
Age (years)	31 ± 10
Height (cm)	175.3 ± 6.2
Body mass (kg)	68.7 ± 7.4
Preferred TA (degrees)	12.7 ± 6.4
Time to exhaustion (s)	940 ± 148
$\dot{V}O_{2max}$ ($L.min^{-1}$)	4.7 ± 0.7
Relative $\dot{V}O_{2max}$ ($ml.kg.min^{-1}$)	68.6 ± 10.2
$P\dot{V}O_{2max}$ (W)	392 ± 49
45% $P\dot{V}O_{2max}$ (W)	177 ± 22
55% $P\dot{V}O_{2max}$ (W)	216 ± 27
Relative $P\dot{V}O_{2max}$ ($W.kg^{-1}$)	5.8 ± 0.8
HR_{max} (bpm)	187 ± 8
RPE	19.8 ± 0.5

Values are Mean ± SD. Abbreviations: TA, Torso angle; $\dot{V}O_{2max}$, maximal oxygen consumption; $P\dot{V}O_{2max}$, power at maximal pulmonary oxygen uptake; HR_{max}, maximal minute heart rate; RPE, rating of perceived exertion.

Time-trial results

Statistics and effect-size estimations from the ANOVA for each variable measured during the time-trial are shown in Table 2. No interactions were found between TA and time-trial quarter for PO, HR, RPE, $\dot{V}E$ and Bf. However, interactions effects were found between TA and time-trial quarter for $\dot{V}O2$. There was a main effect of TA for PO (Figure 3A), RPE (Figure 3C) and $\dot{V}O2$ (Figure 3D), but not for HR (Figure 3B), $\dot{V}E$ (Figure 3E) and Bf (Figure 3F). There was a main effect of time-trial quarter for PO, HR, RPE, VO2, VE and Bf.

There was no difference in B[La] at the end of the time-trial between TA (F = 0.44; P = 0.65; ηp2 = 0.04).



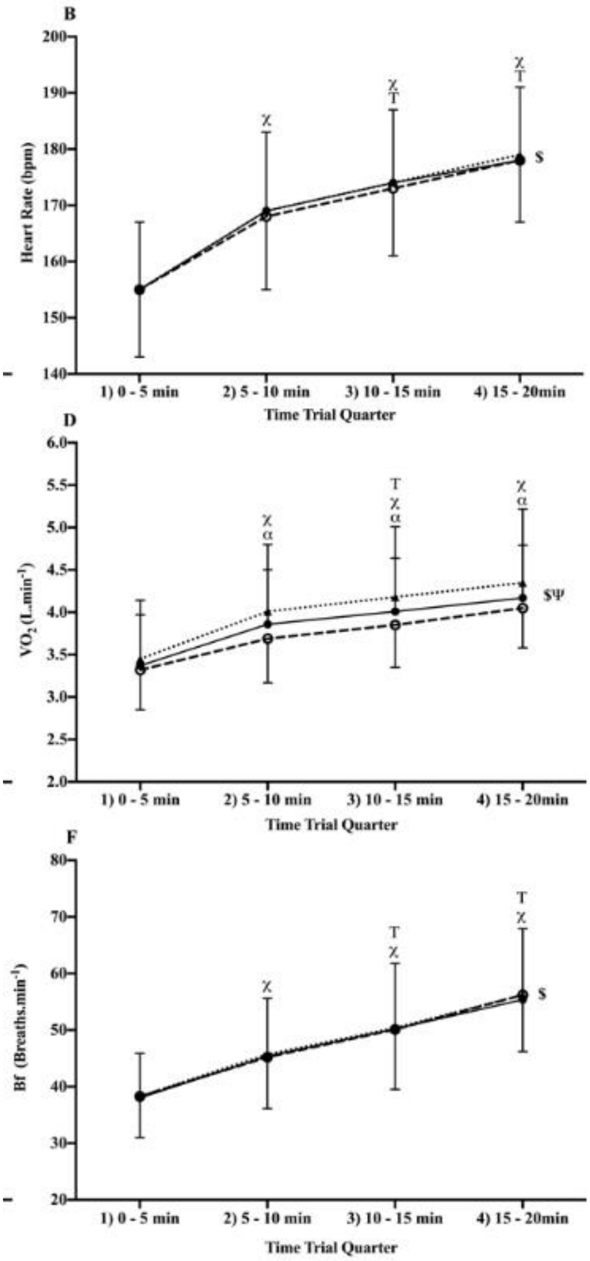


Figure 3. (A) Mean PO, (B) mean HR, (C) mean RPE, (D) mean VO2, (E) mean VE, (F) mean Bf. Data are displayed per time-trial quarter as mean □ SD, with 0o TA (Open circles), 12o TA (Closed circles) and 24o TA (Closed triangles). X Significant difference from 1st quarter. T Significant difference from previous quarter. α Significant difference between 24o & 0o TA. Ω Significant difference between 24o & 12o TA. Ψ Main effect of TA (all P < 0.05). $ Main effect of time-trial quarter (all P < 0.001).

Gross efficiency results

There was no interaction between TA and time of GE measure (F = 1.10; P = 0.37; ηp2 = 0.09; Figure 4A), suggesting that the change in GE across the time points was not different between TA. However, there was a main effect of TA on GE, with GEpre being significantly lower at the 0o TA (21.77 ± 1.01%), when compared to the 24o TA (22.57 ± 1.11%; P = 0.039; Figure 4A). There was no difference in GEpre between 0o and 12o (21.77 ± 1.01% vs. 22.10 ± 0.73%; P = 0.745) and 12o and 24o (22.10 ± 0.73% vs. 22.57 ± 1.11%; P = 0.417; Figure 4A). There was a main effect of time on GE (F = 63.48; P = < 0.001; ηp2 = 0.85), with GE significantly lower post time-trial when compared to pre time-trial for all TA (Figure 4A).

Combined data from all TA revealed a significant weak positive correlation between GE and mean time-trial PO (R = 0.337; R2 = 0.114; P = 0.044; Figure 4B).

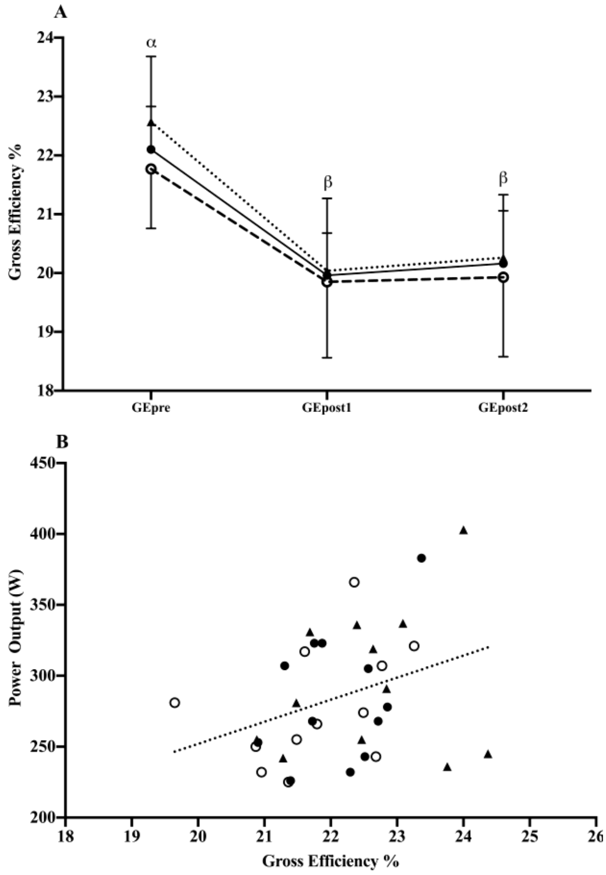


Figure 4. (A) Gross efficiency at different TA pre and post time-trial (data displayed as mean ± SD), (B) Correlation between GEpre

and mean time-trial PO. 0o TA (Open circles), 12o TA (Closed circles) and 24o TA (Closed triangles). β Significant difference from GEpre (P < 0.001). α Significant difference between 24o and 0o TA (P < 0.05).

of physiological performance when lowering

Table 2 Statistics and effect-size estimations from the ANOVA for each variable measured during the time-trial

	Main effect of TA			Main effect of time-trial quarter			Interaction (TA X time-trial quarter)		
Variable	*F*	*P*	η_p^2	*F*	*P*	η_p^2	*F*	*P*	η_p^2
PO	12.37	<0.001*	0.53	9.12	<0.001*	0.45	0.84	0.55	0.07
HR	0.07	0.94	0.01	0.97	<0.001*	0.89	0.87	0.52	0.07
RPE	5.73	0.01*	0.34	212.96	<0.001*	0.95	1.08	0.38	0.09
$\dot{V}O_2$	4.55	0.02*	0.29	41.91	<0.001*	0.79	2.44	0.03*	0.18
V_E	1.11	0.35	0.09	59.76	<0.001*	0.85	0.64	0.69	0.06
Bf	0.14	0.87	0.01	72.49	<0.001*	0.87	0.28	0.95	0.03

Abbreviations: PO, power output; HR, heart rate; RPE, rating of perceived exertion; $\dot{V}O_2$, pulmonary oxygen uptake; V_E, pulmonary ventilation; Bf, breathing frequency. *Statistical significance.

4. Discussion

Time-trial performance findings

The first aim of this study was to determine the effects of different TAs (while systematically controlling the AP) on a 20-min laboratory time-trial performance. The main finding was that lowering TA resulted in reductions in mean time-trial PO, for a similar physiological, metabolic and perceptual load (Figure 3). These findings complement previous research demonstrating the impairment to performance when lowering TA (Ashe et al. 2003; Evangelisti et al. 1995; Fintelman et al. 2015, 2016; Gnehm et al. 1997; Jobson et al. 2008; Peveler et al. 2005), while providing new evidence that reductions in time-trial performance can also be observed with much smaller changes in TA. Current findings contrast with a large body of research which failed to show impairments TA (Berry et al. 1994; Duke et al. 2014; Dorel et al. 2009; Egana et al. 2006; Franke et al. 1994; Grappe et al. 1998; Hubenig et al. 2011; Heil et al. 1997; Origenes et al. 1993; Welbergen & Clijsen, 1990). This discrepancy is likely the result of the heterogeneity in the cycling positions adopted across these studies, in addition to the use of large TA (> 10o) which do not impose the same restrictions found at small TA.

The decrease in mean time-trial PO between the 0o and 24o TA were comparable to the results of Jobson et al. (2008), in which an UP was compared with an AP in a laboratory time-trial. Although there was an increase in mean time-trial PO associated with larger TA, there was no difference in mean time-trial HR (Figure 3B). The similar HR for a lower exercise intensity would suggest an increased strain on the cardiovascular system at lower TA. As would be expected the 0o TA increased the participants RPE (Figure 3C). The lower TA would likely affect the comfort of the cyclists, primarily due to the increased pressure on shoulder gridle, neck and arms

(Gnehm et al. 1997). Any reduction in comfort would result in participants reporting a higher RPE relative to the PO produced.

Based on the current evidence, it could be concluded that increasing the TA is a good strategy when setting up a time-trial position. However, such a conclusion over-simplifies the optimisation of the time-trial position, primarily because it does not account for the importance of aerodynamic drag (Crouch et al. 2017; Candau et al. 1999; Kyle & Burke, 1984). While the current study did not measure frontal area, a study using an identical method to prescribe position observed a significant 14% reduction in frontal area between the 24o and 0o TA (Fintelman et al. 2015). In accordance, several studies using wind tunnel technology have also reported similar reductions in frontal area by lowering TA, resulting in meaningful decreases in aerodynamic drag (Chabroux et al. 2012; Gracia-Lopez et al. 2008; Underwood et al. 2011). Therefore, there is a clear aerodynamic advantage to adopting a lower TA when setting up a time-trial position.

As the aerodynamic power savings of each TA were not calculated in the current study, it is not possible to precisely establish whether the observed PO losses were outweighed by the aerodynamic gains. In conjunction with previous evidence, the data of the current study provides further confirmation of the trade-off known to exist between physiological losses and aerodynamic gains (Fintelman et al. 2014, 2015). The model used by Fintelman et al. (2014) found the optimal time-trial TA to be a function of frontal area, rider physiology, cycling speed, cycling duration and course profile. The authors also suggested that at speeds above 46 km/h the aerodynamic power savings of a low TA outweighed the physiological losses, while at slower speeds or in variable conditions (hilly course topography, strong winds) the optimal TA maybe more upright. It is evident that the optimisation of the AP is highly individualised and should therefore be informed by individual aerodynamic and physiological testing, while accounting for the demands of the event (Fintelman et al. 2014; Underwood et al. 2011).

Gross efficiency findings

The second aim of the study was to investigate GE during submaximal exercise before and after a 20-minute time-trial performed at different TAs (while systematically controlling the AP). Data from the current study shows a significant decrease in GE following self-paced time-trial exercise (Figure 4A). It was hypothesised that a lower TA (0o) would result in a greater decrease in GE during the time-trial, when compared to larger TAs (12o and 24o). However, there was no significant effect of TA on the decrease in GE during the time-trial (Figure 4A). While not significant, the largest reduction in GE was observed after the time-trial performed at the 24o TA. This is likely explained by the higher time-trial PO (Figure 3A), which would logically require greater physiological adjustments, thus the greater decrease in GE.

Current findings are in accordance with previous studies which have shown that GE decreases during cycling exercise (Hopker et al. 2016; Mulder et al. 2015; Noordhof et al. 2015; Passfield & Doust, 2000). Moreover, it seems that GE declines during both submaximal (Hopker et al. 2016; Krustrup et al. 2003; Passfield & Doust, 2000) and maximal exercise (Asan Grasaas et al. 2014; Bangsbo et al. 2001; de Koning et al. 2012, 2013; Mulder et al. 2015; Noordhof et al. 2015), regardless of the exercise modality and exercise protocol. While the aforementioned studies have shown GE declines during exercise, this study has been the first to show that TA does not affect the decrease in GE observed during self-paced time-trials.

Gross efficiency measured pre time-trial was significantly higher at the 24o TA, when compared to a 0o TA (Figure 4A). Thus, supporting the findings of Fintelman et al. (2015), who also reported GE to be significantly higher at the 24o TA, when compared to TAs ranging from 0o to 16o. While in another recent study, GE was again found to be significantly reduced at 0o and 8o TA when compared to the 16o TA (Fintelman et al. 2016). The reduction in GE observed at the 0o TA pre time-trial would account for nearly 63 seconds over a 40-km time-trial (Moseley & Jeukendrup, 2001). On the other hand, the projected frontal area is estimated to be reduced by 14% when lowering TA from 24o to 0o (Fintelman et al. 2015). As frontal area has been found to be a reliable estimate of aerodynamic drag (Debraux et al. 2011), it could be suggested that the aerodynamic advantage outweighed the metabolic cost of the low TA (0o).

Lower TA positions may not be optimal for all cyclists, due to the interindividual variability in the relationship between aerodynamic savings and losses in efficiency when changing TA position. Moreover, time-trial performance lead to a decrease in GE, which effectively nullified the significant difference in pre time-trial GE found between the 24o and 0o TAs (Figure 4A). As a result, any potential performance benefits from a higher GE at the 24o TA were lost during the time-trial. As current findings are only based on 20-minute time-trial performance, it is not possible to establish whether the same levelling of GE would occur over longer time-trials at lower relative intensities.

An analysis of several studies found the variation in GE could explain around 30% of the variation in time-trial PO (Jobson et al. 2012). In the current study the variation in GE could only explain 11% of the variation in time-trial PO, far lower than previously reported (Figure 4B). This is likely due to use of several TA positions which affected each participants physiological and time-trial performance to different extents. As such, it is difficult to completely elucidate the effect of GE on time-trial PO. None-the-less, current findings further highlight the importance of GE in determining time-trial performance PO. Time-trial cyclists may therefore take efficiency into account when optimising their position. Maximising GE is especially important when competing at slower speeds over long duration events (> 2 hours) when energy savings from a higher GE become increasingly important and aerodynamic drag less dominant (Fintelman et al. 2014).

The current study followed the same methodological approach to prescribing cycling positions as Fintelman et al. (2015, 2016), by changing TA while systematically controlling for the AP. Therefore, it can be reported almost unequivocally, that lowering TA while adopting the AP impairs physiological performance during submaximal exercise.

5. Conclusion.

The current research has shown that GE decreases during time-trial exercise, while lower TAs do not result in a greater the decrease in GE. Furthermore, it was found that lowering TA results in a reduction in physiological and metabolic performance at submaximal and time-trial intensity, with the greatest reductions in performance seen at the 0o TA. However, the physiological and PO losses observed in the current study would likely be offset by the aerodynamic savings of a field-based time-trial performance. For competitive time-trial cyclists there exists a trade-off between aerodynamic gains and physiological losses; a trade-off dependent on the physiology of the individual and the demands of the event (cycling speed, cycling duration and course profile). Therefore, to achieve the optimal AP the individual must undergo aerodynamic and physiological testing.

Conflicts of Interest

The author declares no conflict of interest.

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