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Original Article

Time Trial positioning in elite cyclists - exploring the physiological effects of adapting to a lower torso position

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Abstract: Lowering of the upper body to optimize cycling time trial (TT) performance is a balance between the aerodynamic advantage related to a lower frontal area and prospective detrimental physiological effects associated with a reduction of the hip-torso angle. To explore this in elite athletes and across positions relevant for competitive cyclists, we analysed racing positions for world championships [WC] top-10 finishers and 10 national elite TT-cyclists. Subsequently, laboratory studies were completed to evaluate effects on exercise economy, muscle oxygenation and perceived exertion for the national TT-group for their habitual position and compared to standard (4-12-20˚) torso angles. Hence, covering the racing position observed for top-10 WC finishers (positioned from 4-12˚) and the national elite (range 8-18˚). Oxygen calorimetry and near-infrared spectroscopy revealed that there was no difference in overall energy expenditure, delta exercise efficiency or muscle oxygenation across the investigated range of positions. However, rating of perceived exertion was significantly elevated for the lowest position (4˚ torso angle) compared to the rider's habitual position. This lets us conclude that elite TT-cyclists can acutely adopt to a very low upper body position without compromising exercise economy or muscle oxygenation and some WC-level TT riders have adopted this low (4˚) racing position. However, the elevated perception of exertion with an acute reduction of the torso-hip angle indicates that it presumably requires specific training in the position or factors not related to exercise economy and muscle oxygenation determine if a rider in practice can perform in the very low position.

Keywords: *exercise economy; torso angle; time trial; cycling*

1. Introduction

In cycling the aerodynamic resistance as determined by the rider (and bikes) frontal area (A) and the coefficient of drag (Cd) is a parameter of major importance for outdoor cycling performance (Debraux et al., 2009, 2011; Heil, 2001). In addition to the technological development of aerodynamic equipment and clothing, the cyclist's position on the bike is indeed a major determinant for the combined CdA. Particularly, in the process of optimising time trial (TT) performance, it is therefore attractive to lower the upper body to reduce the CdA and hence the power output required to sustain a given pace or increase speed for a given power output. The drawback may be that the aerodynamic benefits from lowering the upper body are outweighed by the reported detrimental effects on exercise economy and the ability to maintain power output when the hip-torso angle is compromised (Faulkner & Jobling, 2021; Fintelman et al., 2014; Fintelman, Sterling, et al., 2015; Grappe et al., 1998). The reported impairments in exercise efficiency following a graduate reduction in the hip-torso angle from 24˚ to 0˚ (Faulkner & Jobling, 2021;

Fintelman et al., 2014; Fintelman, Sterling, et al., 2015; Grappe et al., 1998) are in stark contrast to observations from elite TT, where riders appear to adopt a torso position much lower than optimal in terms of exercise efficiency. However, findings from previous studies in less trained subjects may not apply for the highly adapted athlete and it remains unknown if elite TT riders can adopt a very low racing position without compromising exercise economy and the ability to produce power. Therefore, the aim of the present study was to investigate the variation of the torso angles among elite TT-cyclists and secondly, to investigate the effect of a gradual reduction of the torso angle on physiological performance parameters among national elite TT-cyclists.

2. Materials and Methods

To the above aims we first analysed racing positions for the top-10 world championships [WC] TT finishers (age: 26 ± 4 years, height: 184 ± 9 cm, body mass: 75.1 ± 6 kg), and 10 national elite TT riders (age: 23 ± 3 years, height: 190 ± 7 cm, body mass: 76.5 ± 7 kg). Subsequently, laboratory tests on the national group were completed to evaluate effects on exercise economy, muscle oxygenation and perceived exertion for their normal TT-position, 4˚, 12˚ and 20˚ torso-horizontal angles (covering the range of racing positions observed). The participants provided their written informed consent and the study was performed in accordance with the declaration of Helsinki ("World Medical Association Declaration of Helsinki", 2013 as approved by the ethics committee of the Capital Region of Denmark (H-4-2012-FSP)).

The analysis of the riders' habitual racing positions was performed in an image analysis software (ImageJ, National Institutes of Health, USA) (see Figure 1) from a photo of the riders in a sagittal plane with the leg at the bottom of the pedal stroke (180˚). The torso angle was evaluated by a horizontal line (i.e. the line between the two-wheels axels) and a line between the anatomical landmark of trochanter major and processus acromion (see Figure 1).

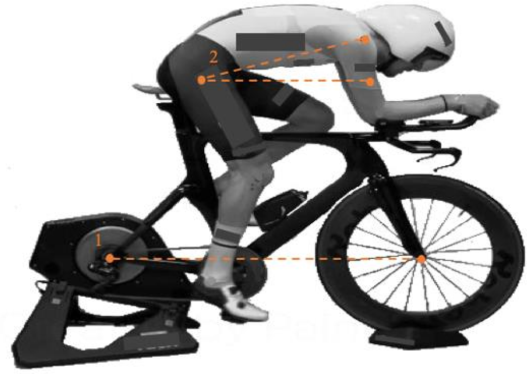


Figure 1. Representative rider in his habitual [normal] TT position and illustration of the determination of torso angle (˚defines as a horizontal line (1) [between the two-wheel axels] and a line (2) [between the anatomical landmarks of trochanter major and processus acromion]).

The participant's normal TT bike was measured and replicated on a modified test bike (LC6 I, Monark, Vangsbo, Sweden), with similar saddle height, setback, reach (saddle tip to the end of extensions), and arm position (distance between the arm wrist and angulation). A goniometer (Lafayette Instrument Co, Lafayette, USA) and an image in sagittal plan (analysed in an image software (ImageJ, National Institutes of Health, USA)) were then used to determine the test bike set-up for the different torso angles.

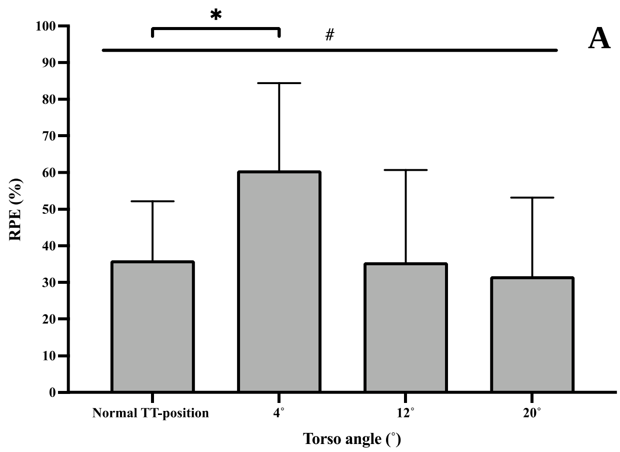
The laboratory test started with 15 min warm-up followed by three submaximal exercise bouts (100, 200 and 300 watt for n = 7 and 150, 250, 350 watt for n = 3; allowing for the highest possible workload without compromising the ability to maintain steady state at all three levels), which was completed for each torso position in randomised order (with 15 min rest between each positions tested) at a fixed cadence (constant during and across trials) similar to their reported TT cadence and with 100 watts between the three submaximal workloads (with the highest load corresponding to 315 watts equal to 87% of their best TT performance).

Total energy expenditure, gross- and delta efficiency (i.e. the slope of the regression line between the delta increase in external power output divided by the delta increase in total energy expenditure) was calculated for each position from steady-state oxygen uptake (VO_2) and respiratory exchange ratio (RER) (indirect calorimetry; (Garby & Astrup, 1987; Péronnet & Massicotte, 1991)). Muscle oxygen saturation of vastus lateralis (**SmO_2**) was evaluated with a near-infrared spectrophotometry sleeve (Graspor, Graspor Aps, Viby J, Denmark) and the participants provided a rating of perceived exertion (RPE) (Borg, 1970; Casey et al., 2015) immediately after the last workload of each torso angle tested.

Statistical analysis was performed by using GraphPad Prism version 9.3.1 (La Jolla, CA, USA). The Shapiro-Wilk test was performed to test for normality and distributions. One-way repeated measures ANOVA of variances were used to determine the effect of the torso angle on variables. If a significant main effect was observed, a Bonferroni post hoc analysis was conducted. Simple linear regression was calculated to evaluate the linear relationship between Δ changes in torso angle and Δ changes in RPE, total ventilation (VE), VO_2 and breath frequency (BF). Data are presented as mean (± standard deviation (SD)) and the accepted significant level was set to $P < 0.05$ unless otherwise stated. The dataset was cleaned for outliers and data points were excluded if they exceeded ± 2 SD of the mean. To determine the required sample size (N), a sample size calculation was performed with a power (β) = 80% and α = 0.05 on data from pilot-trials.

3. Results

Torso-horizontal angle for top-10 WC finishers ranged from 4-12° with an 8.2° average, while the national elite TT racing positions were in the range from 8-18° with an 12.6° average. For the lowest observed and lab-investigated position (4° torso-angle), RPE was significantly aggravated compared to the more upright 12° and 20° positions and higher than scores for riders' normal TT-positions (see Figure 2.A).



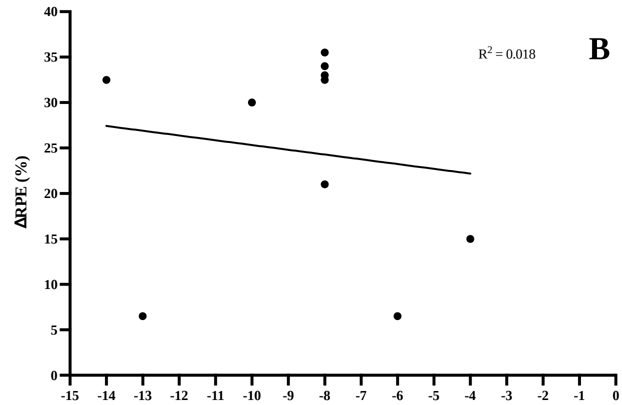


Figure 2. (A) Rating of perceived exertion (RPE: % of maximal effort) at the highest evaluated workload. Data are mean (bars + SD) for n = 10 national elite cyclists in their normal (habitual race) TT-position and the fixed positions with 4, 12 and 20° torso angles. # main effect of torso angle ($p < 0.05$). *significantly higher than the normal TT-position ($p < 0.0001$). **(B)** Data are the individually (ΔRPE) changes in rating of perceived exertion plotted against the individual Δ change (lowering) in torso angle from the riders normal (habitual race) TT-position to the (4°) evaluated for the 10 national elite TT-cyclists (at 300 or 350 watts).

However, there was no difference in overall total energy expenditure, gross efficiency, delta efficiency or measures of SmO_2 at the highest sub-maximal insentient with steady-state oxygen uptake across the investigated range of positions (see Table 1). Likewise, no main effect of torso angle on VE, VO_2, VT and RER (see Table 2) at any torso angle compared to the participants' normal TT-position was observed. However, BF was lower at 20° torso-angle compared to the participants' normal TT-position (P = 0.043 – see Table 2).

Table 1. Total energy expenditure (J/s), gross efficiency (%), delta efficiency (%) and muscle oxygenation saturation (SmO_2) at highest evaluated workload. Data present mean (and SD) for n = 10 in the normal TT (habitual race) position and the fixed positions with 4, 12 and 20° torso angle.

	Normal TT-position	4°	12°	20°
Total energy expenditure (J/s)	1410 (194)	1393 (218)	1399 (196)	1402 (172)
Gross efficiency (%)	22.1 (2.6)	22.4 (2.0)	22.8 (2.2)	22.4 (1.7)
Delta efficiency (%)	28.4 (3.7)	29.1 (4.9)	29.4 (4.6)	28.4 (3.5)
SmO_2 (%)	39.8 (8.0)	39.8 (7.9)	38.8 (6.8)	40.2 (10.9)

Table 2. Oxygen consumption (VO_2 [$L \cdot min^{-1}$]), Total ventilation (VE [$L \cdot min^{-1}$]), tidal volume (VT [L]), breath frequency (BF [per min]) and respiratory exchange ratio (RER [VCO_2/VO_2]) at highest evaluated workload. Data present mean (SD) for n = 10 in the normal TT (habitual race) position and the fixed positions with 4, 12 and 20° torso angle. *Significant different from the normal TT-position ($p < 0.05$).

	Normal TT-position	4°	12°	20°
VO_2 ($L \cdot min^{-1}$)	4.11 (0.58)	3.98 (0.73)	4.03 (0.59)	3.91 (0.72)
VE ($L \cdot min^{-1}$)	120.1 (21.9)	115.2 (22.9)	117.3 (20.3)	112.9 (21.3)
VT (L)	3.33 (0.44)	3.48 (0.58)	3.23 (0.53)	3.42 (0.37)
BF (per min)	37.0 (5.8)	33.3 (5.6)	36.8 (5.1)	32.9 (5.5)*
RER (VCO_2/VO_2)	0.93 (0.05)	0.92 (0.05)	0.93 (0.03)	0.93 (0.05)

There was no correlation (r = -0.14, R^2 = 0.02 - See Figure 2.B) between Δ changes in RPE and Δ changes in torso angle between the lowest tested torso angle (4°) and the normal TT-position. Furthermore, no correlation between Δ changes in torso angle and Δ changes in VE (r = -0.09, $R^2 = < 0.01$), VO_2 (r = -0.07, $R^2 = < 0.01$) and BF (r = 0.04, $R^2 = < 0.01$) was observed.

4. Discussion

The main findings from the explorative part of the study were identification of low torso angle for all top-10 WC finishers (mean of 8.2°; with all riders positioned below 12° and two out of three podium finishers positioned as low as 4°), while torso-horizontal angles in the national elite group ranged from 8-18°. The reported torso angles both provide a benchmark for international elite TT-cyclists and define the relevant positions to investigate in the laboratory tests. The second intervening part of the study revealed that acute lowering of the torso from the rider's habitual position to the lowest (4° torso-angle) did not compromise any measures of exercise efficiency or muscle oxygenation. However, compared to the rider's habitual position as well as the standard more upright 12° and 20° it elicited higher RPE for all participants.

In recent years, the balance between aerodynamic advantages and the physiological disadvantages of lowering the upper body has been investigated. When adopting a very low racing position (reducing torso angle) the physiological response to this change could be influenced by several factors (Blocken et al., 2018; Fintelman, Hemida, et al., 2015; Oggiano et al., 2008; Polanco et al., 2020).

Findings from the present study demonstrate no effect of a reduction in torso position on exercise economy (i.e. total energy expenditure, gross- and delta efficiency). This is in contrast to previous findings, which have demonstrated a decrease in gross efficiency that resulted in higher energy expenditure and hence also higher total ventilation at a given workload, when the torso angle was reduced (Fennell et al., 2020; Fintelman et al., 2016; Fintelman, Sterling, et al., 2015). In the present study, we observed a lower BF in the 20˚ position compared to the participant's normal position, but with similar BF response at 20 and 4˚ position, where the tidal volume was similar to all other tested position indicating that breathing depth was not compromised by lowering of the torso. The lower BF at 20˚ could be attributed to a tendency for lower total ventilation in this position, however, neither VE nor VT was significantly different across the tested torso angle and this is in accordance with previous observations (Dorel et al., 2008; Fintelman et al., 2016; Ghasemi et al., 2022; Grappe et al., 1998; Origenes et al., 1993).

Reducing the torso angle (adapting a more forward bend upper body [i.e. inducing axial compression or/and hip hyperflexion]), could potentially affect the blood flow to the working muscles in the lower limb by partial occlusion of the iliac- or femoral artery (Arnold et al., 2022; Lim et al., 2009; Mughal et al., 2011; Poulson et al., 2018). An explanation for this may be that an individually anatomical difference can occur in how the iliac- and femoral artery branches and their location related to the surrounding muscles (Ciftcioğlu et al., 2009; Lim et al., 2009). Nevertheless, findings from the present study did not demonstrate any changes in SmO_2 at submaximal exercise intensity, when reducing the torso angle, which is a sufficient measurement of blood flow to the lower limb. However, in some cases, the above explanation/phenomena only occur at maximal exercise intensities (Lim et al., 2009) and therefore, it cannot be excluded that elite TT-cyclists would experience a similar drop in blood flow at maximal exercise intensity based on the present study.

The increased RPE, reported by the participants for the lowest of the investigated torso angle indicates, that change to the torso angle potentially influences fatigue and may affect the ability to produce/sustain power in the 4˚ position. Furthermore, an explanation for the higher RPE score for the lowest laboratory investigated torso angle, is potentially caused by the sudden changes in position, which cause an unfamiliar activation of the neck- or upper body muscles (Gnehm et al., 1997) and previous findings have shown that changes in the torso angle affecting RPE and comfort (Peveler et al., 2005; Priego Quesada et al., 2017). However, findings from the present study have shown no correlation between individual Δ changes in torso angle (4˚ torso angle and normal TT-position) and Δ changes in RPE, VE, VO_2 and BF. This suggests that there is no indication for those riders with a larger reduction in torso angle also have a large increase in the above-mentioned variables. In addition, it must be considered that a more forward bended upper body required an increased anteriorly rotated pelvis to adopt a lower torso position which can be affected/limited by hamstring flexibility (Holliday & Swart, 2021), which for some individuals may be a limitation for their potential in lowering their upper body and therefore score a higher RPE. Nevertheless, it is often said that - what you are training, is what you are good at, - i.e. the torso angle you are training in is often where you are performing best (Jeukendrup & Martin, 2001; Peveler et al., 2005). This may explain why a higher RPE is reported when a new/more aggressive torso angle is adopted that is not adequate to the rider's normal TT-position, on the other hand, it must be kept in mind that an RPE score is a measurement of somatic stress and an individually arbitrary measurement (Borg, 1970).

It should be noted that evaluation of the torso-position for the top-10 WC finisher was based on images without the possibility to use palpation to verify the exact marking of the anatomical landmarks of trochanter major and processus acromion. Although, checked in duplicate and verified by measures/comparison with assessment in the national group the analysis may potentially provide a small over-or underestimation for some of top-10 WC finishers.

Findings from this study indicate that other (individual/not accounted for) factors may affect the ability to adapt to a low torso angle, and therefore future research should try to elucidate the effect of trainability of the position and potentially blood flow restrictions on the lower limb when reducing the torso angle.

5. Practical Applications

Translation of findings from lab testing to ecological settings should always consider the limitations that e.g. are related to the difference between a stationary test bike setup and outdoor cycling where movements and rotations in the frontal plane could affect cycling economy as well as influence CdA. Hence, a lower torso position may not per se reduce CdA and maintained efficiency is of cause on the premise that the rider is able to maintain similar level of stability. Effects of an intervention (change in torso position) should therefore be tested in real settings for the individual rider. However, our reported observations from top-10 WC finishers demonstrate that elite TT riders are adopting and can perform very well in the low position indicating that our lab findings are transferable to ecological settings. In this context we emphasize that the ability of the individual athlete to adopt a TT-position that both accommodates the aerodynamic advantages of a low position and accounts for the potential physiological disadvantages is a complex task. It is important to understand the impact of the environment, external and internal factors that have an impact on the position and thereby the performance. However, the present findings with no impairment in exercise economy or muscle oxygenation for the lowest and most aerodynamic attractive position indicate that elite cyclists can adopt a low and most likely more attractive aerodynamic position at submaximal intensities. The higher RPE reported when riders are exposed to an acute lowering of the torso angle (from habitual to 4°) indicates that it may require position-specific training and further adaptation before it may translate into a potential performance advantage. It is also possible that individual variation in anthropometry and flexibility limits how low a rider may go and even with adequate adaptation it is likely that disadvantages such as compression of the iliac artery may restrict the ability to produce power and provoke fatigue or lower limb symptoms (Arnold et al., 2022; Holliday & Swart, 2021; Lim et al., 2009; Mughal et al., 2011; Poulson et al., 2018; Veraldi et al., 2015). However, based on the present observation a low racing position in elite TT can be applied without compromising the performance at submaximal intensities.

6. Conclusion

The present observations let us conclude that elite time trial cyclists may adopt a very low (and aerodynamic attractive) position without compromising exercise economy or muscle oxygen delivery. However, the elevated exertion expressed when the torso position was acutely lowered to 4° (i.e. reduced in comparison to the habitual racing position for the national level TT riders) indicate that training in the position is required. Alternatively, that factors not accounted for in the present study determine if a rider is able to adopt the low TT position that was observed for two of the WC-podium finishers.

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