Individual Performance Optimization of Elite Cyclists

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Abstract: The present work focuses on individual posture optimization with the aim to individually reduce the drag and increase the power output on six elite cylists. In order to be able to quantify the changes in drag, power output and VO2max, wind tunnel tests combined with power output and oxygen intake measurements were carried out on each of the athletes tested. Drag measurements were performed in the large scale wind tunnel at NTNU at a constant wind speed of 14.2m/s using a AMTI high frequency force plate. Simultaneously with the drag measurements, the volume of oxygen intake and the power output generated by the athletes during the test in different positions were acquired respectively with a Metamax II portable analyzer from Cortex Biophysic and a Tacx Bushido cycling rig. The main results show that lowering the handlebar while raising the seat in order to obtain a smaller frontal area and a straighter back, lowers the aerodynamic drag but will possibly affect the volume of oxygen intake. The handlebar repositioning leaded to similar results and it might then be questionable whether it is worth reducing the air resistance if the athlete does not sit as comfortably. In most cases a lower handlebar positioning and a narrower set up of the handlebar resulted in a considerable drag reduction without compromising the volume of oxygen intake. Being the present work a preliminary test, no statistical results are presented but as an overall conclusion, it can be pointed out the need to couple drag force measurements with oxygen intake and power production measurements in order to have a clearer picture of the effectiveness of the wind tunnel testing.

1 INTRODUCTION

The aerodynamic drag is the main opposing force that cyclists need to overcome with their generated power and it counts as 90% ((De Groot et al., 1995, Di Prampero, 2000, Oggiano et al., 2008)) of the total forces acting against the athletes motion, leading to the fact that even small reductions could then lead to a large improvement in terms of performances.

(Debraux et al., 2012) gives a clear overview of the parameters that affect the drag on cyclists and on the existing methods and theories used to measure it, minimize it and reduce it, with particular focus on frontal area direct and indirect measurements and on frontal area reduction. In his review Debraux also lists the different methods of assessment of aerodynamic drag used by different authors dividing them in wind tunnel tests, linear regression analysis models, traction resistance measurement methods and deceleration methods. The author also points at pros and cons of each measuring method. However, most methods and tests often focus only on drag (or frontal area) reduction by modifying and adjusting the athletes position on the bike, often discarding or neglecting the side effects that a postural change might induce in terms of biomechanical and physiological effectiveness.

A number of authors (Atkinson et al., 2007, Broker et al., 1999, Di Prampero, 2000, Heil et al., 2001, Olds, 1998, Olds, 2001, Olds et al., 1995, Padilla et al., 2000) on the other hand tried to create mathematical models in order to be able to estimate the power output generated by the athlete depending on its posture and on the power required to overcome the drag and the other resistive forces. These models often use the posture as input, modeling the frontal area and the drag and successively assuming the needed power output.

The present study aims to individually optimize cyclists performances by simultaneously measuring oxygen intake, aerodynamic drag and power output generated in a wind tunnel test. All the adjustments on the cyclists posture were done keeping the athletes posture within the parameters stated in the UCI regulations (UCI, 2012).

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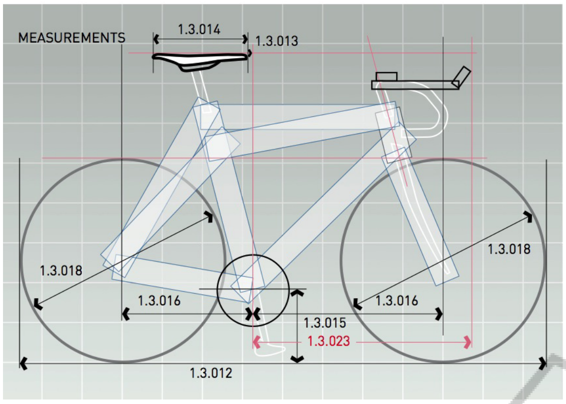

Figure 1: Bike measurements by UCI regulations (UCI, 2012).

The test was conducted in the large industrial wind tunnel at NTNU in Trondheim. During the test, six athletes from the Norwegian Cycling Federation (NCF) were tested, of which five were from the Under-23s and one from the Paralympics team. Physiological data about the athletes were previously collected.

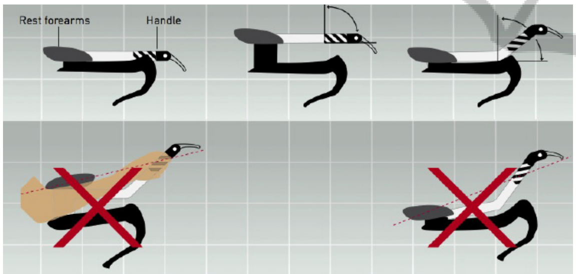

Figure 2: Possible modifications to the handlebar by UCI regulations (UCI, 2012).

2 EXPERIMENTAL SETUP

The large industrial wind tunnel at NTNU in Trondheim was used for the test. The tunnel has a test section which is 12.5 m long, 2.7 m wide and 1.8 m high, and it is able to reach a maximum wind speed up to 30 m/s. During the test, the speed was set at a constant value 14.2m/s. The test section is equipped with an AMTI BM600400HF force plate which is able to measure forces in 6 directions (3 forces and 3 moments on the 3 axes). The forces were acquired using an in-house made Labview program.

The power output generated by the cyclists during the test was acquired with a fully wireless Tacx Bushido trainer (REF). The Bushido trainer was modified and welded to a steel plate and bolted to the force balance. The front wheel was equipped with an electric motor to add rotation at the correct speed. The whole unit was under the wind tunnel floor to avoid disturbances on the flow field.

The Volume of Oxygen intake (VO2max) was measured using a Metamax II portable metabolic analyzer 3.9 (Cortex biophysics GmbH,Leipzig, Germany), previously evaluated by (Medbø et al., 2008) The analyzer has built-in sensors to measure O2 and CO2 , barometer and thermometer, and it measures the flow of exhaled air using a turbine flow meter placed in the breathing mask. The instrument was calibrated against ambient air and gas of known concentration of O2 (16%) and CO2 (4%) the morning before testing. The concentration of O2 and CO2 in the room were measured before each athlete started its respective session. The analyzer was mounted under the wind tunnel floor to avoid flow disturbances.

3 METHODS

Six athletes with different ages and body characteristics were chosen for the test (table 1). The test was carried out on the NTNU wind tunnel with a constant wind speed of 14.2m/s. During the test, 5minutes samples at 1000Hz were acquired and the mean values for V02max, Power Output generated and drag force were acquired.

Being this test an individual test focused on improving the posture of each of the athlete more than in finding general conclusions, each athlete was asked to assume their regular time trial posture and their natural posture was successively modified within the UCI rules trying to reduce the frontal area and straighten their back without compromising the comfort. Small adjustments were then individually suggested for each athlete in order to be able to reduce the drag and possibly increase the power output and the VO2 intake. Only a limited number of adjustments were tried for each athlete and they were obtained adjusting the width and height of the handlebar and the height of the seat.

The adjustments used were chosen for each athlete basing the choice on a qualitative analysis of the reference posture:

a) Vertical adjustment of the handlebar: lowering the handlebar leads to a frontal area reduction but it also leads to a lower efficiency due to a more compressed posture. Raising the handlebar has the opposite effect.
b) Horizontal adjustment of the seat: directly influences the "seat tube angle" (STA). Larger

Table 1: Participants and adjustments.

		Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
Age		21	38	23	21	20	18
Weight	[kg]	71	71	69	78	79	76
Height	[cm]	185	179	185	183	194	193,5
Resting heart rate	[bpm]	42	41-46	39	–	45	45
Maximum heart rate	[bpm]	204	189	202	196	190	203
Adjustments							
		a high **b** forward **c** high + **e** tight	a high b forward	a high c high e tight	a lower c low + a high e tight	a low e tight c low + b forward	a high c high e wide

STAs have been proven to give an increase in power outputs and a reduction in drag (Ettema and Lorås, 2009).

c) Vertical adjustment of the seat: it directly influences the back of the athletes. It is know that a flatter back can help lower the drag, but can provide lower efficiency.

d) Horizontal adjustment of the handlebar in the longitudinal direction. It directly affects the back posture of the cyclist. If the handlebar is pushed forward, the shoulders are lower and thus the frontal area can be reduced. Opposite effects can be found when the handlebar is adjusted in the opposite direction.

e) Horizontal adjustment of the handlebar in the cross-flow direction (adjusting distance between the brackets): increasing the distance between the arms leads to lower drag.

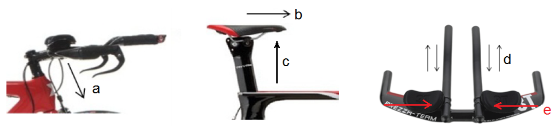

Figure 3: Type of adjustments made to handlebar and seat.

Not all the adjustments were used for the six athletes but only individual adjustments based on comfort response and qualitative analysis of the reference posture were made (Table 1).

4 RESULTS

The adjustments are summarized in figure 4 where the increase or decrease of drag, VO2max and power generated are presented in percentage in a columns plot.

Adjustment a - The vertical handlebar adjustment was tested on all athletes, lowering or raising it depending on the reference posture of the participant. The results relative to this adjustment seem to consistently prove that lowering the handlebar results in lower drag while raising it produces an increase in drag. At the same time, lowering the handlebar increases the VO2 consumption while raising it leads to a lower VO2 consumption. The link between power output generation and handlebar adjustment does not show consistent results but it seems the adjustment seems to differently affect each participant.

Adjustment b - Moving the seat forward (adjustment b) did not affect the athletes drag but it created a noticeable fall in VO2 consumption. A large increase on power output was also noticed for participant 1 while this didn't happen for participant 2. During the test it was however noticed that participant 1 was more comfortable and stable in holding this position than participant 2 and this might explain the difference.

Adjustment c - Raising the seat showed in general induce a flatter back on the athletes, making this change beneficial both in terms of drag reduction but also in term of power production. However, there is a maximum limit for the seat high and some athletes already had their seats set to the maximum. Raising the seat over this limit leads to lower efficiency and lower power production.

Adjustment d – Moving the handlebar forward proved to have an effect on drag reduction and power production. However, this adjustment was performed only for participant 1 in combination with the seat raising.

Adjustment e - Narrowing the handlebar leads to narrower arms and generate a smaller frontal area but this adjustment resulted to be somehow less comfortable for the riders. No increase in power production was noticed.

Some combinations of adjustments were also performed following the athletes inputs and resulted in large increases in power production and

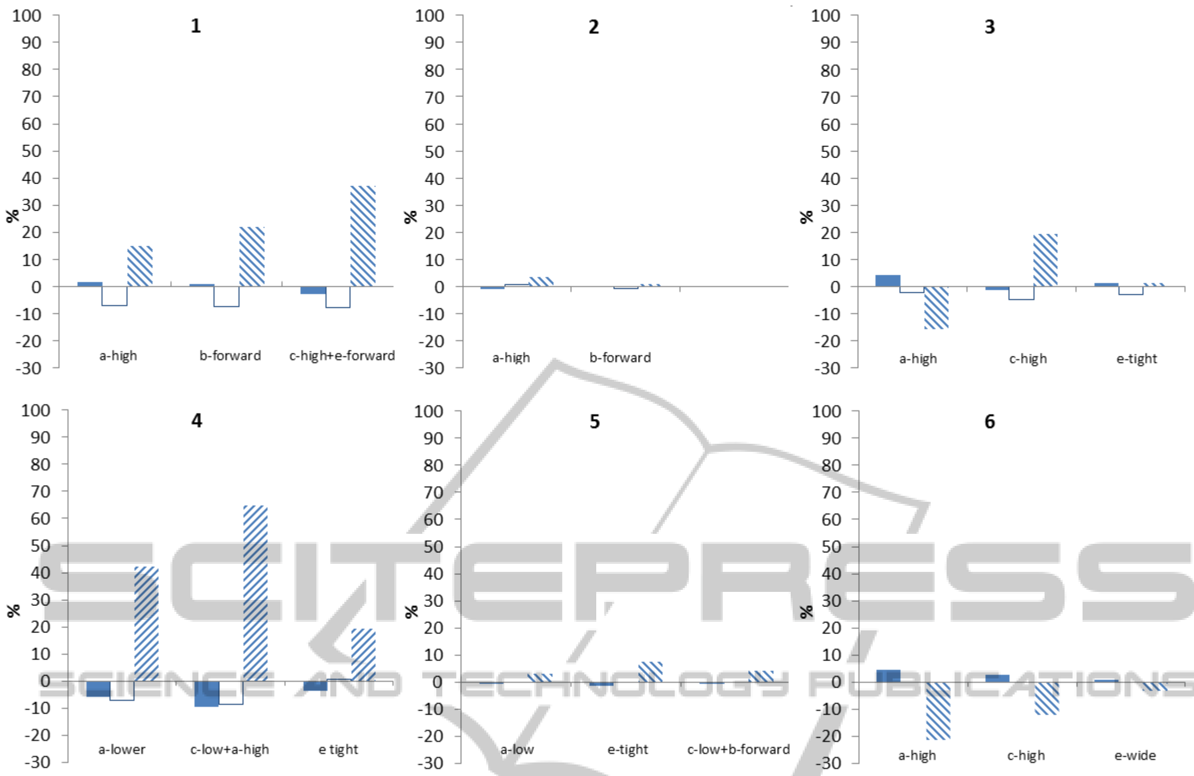

Figure 4: Individual results for the 6 participants. The first column (■ solid blue filling) represents the drag change in percentage with respect to the reference posture, the second column (□solid white filling) represents the change in percentage of VO2 consumption with respect to the reference posture and the third column (◪blue oblique lines filling) represents the power output change in percentage with respect to the reference posture.

reductions in drag. The combination c_high+d_ forward for participant 1and the combination c_low+a_high for participant 4 proved that in some cases small individual adjustments are able to dramatically improve the performances.

As an overall comment, all the athletes except for participant 6 were able to reduce their VO2 consumption, increase their power output and reduce their drag with small adjustments to their reference position. If the drag reduction plays a large role at higher speeds, the VO2 reduction has a great impact on the riders performances at lower speeds where the aerodynamic drag is negligible and the riders can use less oxygen .

5 CONCLUSIONS

Six athletes were tested in the NTNU wind tunnel laboratory and their performances were analyzed measuring simultaneously the drag, the VO2 consumption and the power output generated.

It was impossible to complete a full matrix of adjustments to the athletes' positions but, even with small adjustments, simultaneous gains in terms of VO2 reduction, drag reduction and power output increase were noticed.

The results show that individual adjustments can lead to large improvements in terms of performances and but they are too variable and too individual to be able to draw general conclusions thus a deeper analysis with a larger number of participants should be carried out in order to be able to generalize the results.

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