

NEW 3D METHOD TO ESTIMATE THE CYCLING FRONTAL AREA DURING PEDALLING

Ventura Ferrer-Roca¹, Nicholas Vretos², Argyris Chatzifolis², Daniel Alvarez¹

¹Biomechanics Department, High Performance Sport Centre (CAR), Barcelona, Spain

²International Technologies Institute (ITI). The Centre for Research and Technology, Thessaloniki, Hellas (CEARTH)

Aerodynamic drag represents a high percentage of the resistive forces in cycling. The frontal area has been traditionally measured through 2D digitalization, which requires a capture and an analysis processes. In the present study, the 2D method has been compared with a new real time 3D method to measure the frontal area in three different cycling positions. High reliability (ICC>0.9) was found on both measurement methods. However there were differences between methods at the most aerodynamic positions. These differences might appear due to the capacity of the new method to measure the depth dimension, which supposes an improvement on the frontal area analysis. Furthermore, the new 3D method allows feedback of the frontal area in real time.

KEY WORDS: Aerodynamics, road cycling, mapping analysis, Kinect, real-time.

INTRODUCTION: Aerodynamics drag represents between 80-90% of the total resistive forces at 30-40 km·h⁻¹, depending on the equipment used by the cyclists (Garcia-Lopez et al., 2008). During road cycling, aerodynamic drag is directly proportional to the combined projected frontal area of the cyclist and bicycle, the drag coefficient, air density and the square of the velocity relative to the fluid. At the same mechanical power, the optimisation of the aerodynamic drag could be a determinant to improve the cyclist's performance. Considering that the rider's power is limited, it becomes important to modify the bicycle's dimensions and the cyclist's posture in accordance with the rules of the International Cycling Union (Garcia-Lopez et al, 2008). The projected frontal area represents the portion of a body which can be seen by an observer placed exactly in front of that body (Debraux, Grappe, Manolova and Bertucci, 2011). Different methods have been used to evaluate the projected frontal area in cycling but to date none has been able to measure the frontal area of the rider in real-time. Therefore, the purpose of this study was to test the validity and reliability of a new 3D method to estimate the frontal area in real-time during pedalling.

METHODS: Eleven UCI continental cyclists were tested (67.9 kg ± 5.2; 1.73 m ± 6.01). Frontal area in three different positions known as upright (UP), dropped (DP) and aerodynamic position (AP) were assessed through two different methods, 2D static digitalization (Figure 1) and a new 3D method based on the Kinect depth sensor. For the 2D analysis two pictures were taken from the cyclist on each of the three positions one with the cranks at 90° and the other at 180° with the camera placed at 5m of the rider (Heil, 2001). A calibration frame (1 X 1 m) was placed in the midpoint between the saddle and the handlebar and was recorded before each subject's data collection. The projected frontal area was measured by two different scientists using the same digitalisation protocol described in a previous study (Debraux, Bertucci, Manolova, Rogier and Londini, 2009). Furthermore, for the 3D method a Kinect depth sensor was placed in front of the cyclist located at 4m, measured from the back of the saddle. The cyclist was captured pedalling at 200 watts during 20 seconds in each of the three positions using a software developed for the present study (Cycling Coach, Experimedia, 2014) (Figure 2). This process was repeated twice in order to ensure the reliability of this method. Moreover, using the Kinect sensor, the pixels of the depth image encode the distance from the sensor. The Frontal area estimation is achieved by mapping the pixels to elementary areas, by using the Field Of View (FOV) parameters of the depth sensor and the distance encoded at the depth-pixels from it.

The Shapiro-Wilk test was applied to ensure normal distribution of all the analysed variables. Intraclass correlation coefficients were used to check the reliability of the 3D method (ICC 3.1) and the 2D method intra and inter-observer reliability (ICC3,1). Furthermore, concordance and consistence between methods were analysed as well (ICC 3.2). A two-way with-in subjects ANOVA was used to analyse the effect of both the assessment method and the cycling position on the frontal area. Bonferroni post-hoc test was used to establish mean differences. The statistical analysis was performed with the SPSS+ V.15.0 software (SPSS, Inc., Chicago, IL, USA). Statistical significance level was set at 0.05.

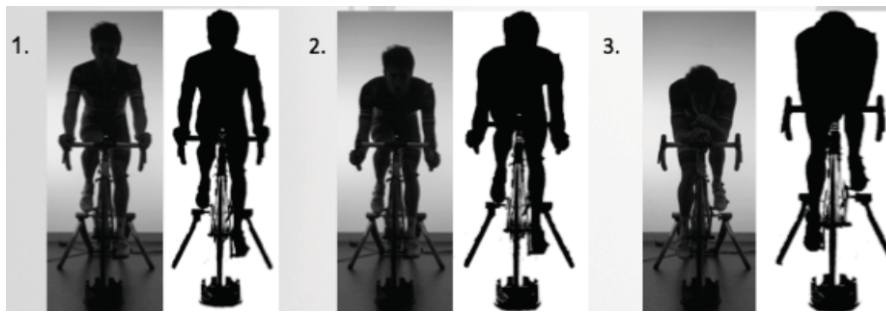


Figure 1. 2D digitalisation method. 1- Upright (UP); 2- Dropped (DP); 3- Aerodynamic position(AP)

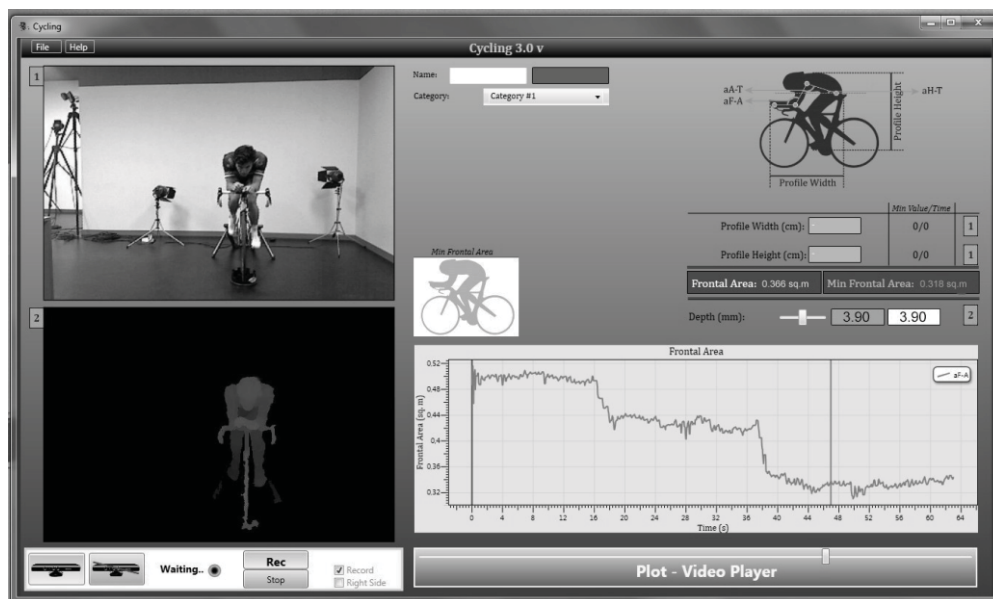


Figure 2. Determination of the frontal area with the new 3D method in real-time

RESULTS: The intraclass correlation index showed a high reliability test-retest of methods, the 2D digitalization and the 3D one, at the three cycling positions (ICC 3.1 > 0.9). A significant effect of riders' position on frontal area was found using the 3D method. The frontal area in the DP position was 0.029 m² lower than the one in the UP position (95% CI 0.015 to 0.043 m²; p<0.001). The AP position reduced the frontal area from the UP position by 0.106 m² (95% CI 0.084 to 0.128 m²; p<0.001).

Table1
Frontal area in the three analysed position

	3D method (m ²)	2D Method (m ²)
Upright	0.449	0.457
Dropped	0.420	0.436
Aerodynamic	0.343	0.393

There was a significant effect of cycling position on frontal area when measured through the 2D digitalization as well. The frontal area in the DP position was 0.020 m^2 lower than the one in the UP position (95% CI 0.009 to 0.032 m^2 ; $p < 0.05$). The AP position reduced the frontal area from the UP position by 0.064 m^2 (95% CI 0.046 to 0.082 m^2 ; $p < 0.05$).

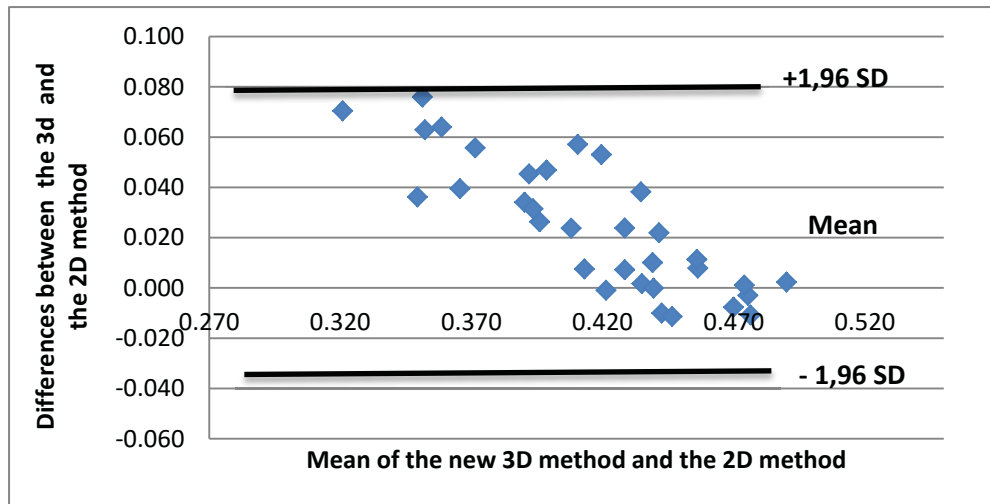


Figure 3. Bland-Altman plot of difference of the frontal area between 3D method and 2D method.

A high consistence was found when comparing both measurement methods with values over 0.8 on the ICC 3.1. However, there was a significant effect of measurement method on frontal area ($F=22.161$, $p < 0.05$). In fact, Bonferroni post-hoc analysis showed differences between methods on two cycling positions. A difference of 0.016 m^2 (95% CI 0.05 to 0.027 m^2) was found on the DP position while the difference on the AP position was 0.050 m^2 (95% CI 0.061 to 0.039 m^2 ; $p < 0.001$).

DISCUSSION: This is the first study that analysed the validity and reliability of a 3D method based on the Kinect depth sensor device in order to measure in real-time the cycling frontal area during pedalling in three fundamental positions. The main outcomes of the present study were: 1- to obtain a high and significant reliability of the frontal area using the new 3D method during pedalling; 2- To demonstrate that the new 3D method had high sensitivity in detecting changes in the cyclist's position.

The intraclass correlation index showed a high reliability test-retest of the new 3D method at the three cycling positions (ICC 3.1 > 0.9). These results are in agreement with finding from previous studies which used 2D digitalisation method to measure the projected frontal area in cycling (Debraux et al, 2009).

A significant effect of riders' position on frontal area was found using the 3D method. Previous studies analysed the frontal area of the riders during pedalling (Garcia-Lopez et al, 2008; Debraux et al, 2009). In the present study, two test positions correspond to two of the positions studied by the previous investigation (Debraux et al, 2009). For UP and AP position, the mean frontal area was different between the studies ($0.449 \pm 0.034 \text{ m}^2$ vs $0.525 \pm 0.01 \text{ m}^2$ and $0.343 \pm 0.031 \text{ m}^2$ vs 0.450 ± 0.04 , respectively). Probably these differences are given by the anthropometry of the subjects, heavier and taller in the previous study ($67.9 \text{ kg} \pm 5.2$; $1.73 \pm 6.01 \text{ m}$ vs $72.7 \pm 8.6 \text{ kg}$; $1.89 \pm 0.06 \text{ m}$ Kg).

In the present study, Bonferroni post-hoc analysis showed differences between methods on the DP and the AP cycling positions. Probably, the cause of these differences is that the 3D method takes into account the depth dimension, measuring the area of every part of the cyclists in its location. In contrast, the digitalisation method projected the frontal area on a

plane located in the midline between the saddle and the handlebar. The measured area might be influenced by antero-posterior translation of the centre of mass while the changes were made from upright to aerodynamic position.

This is the first study that analysed the frontal area in real-time during pedalling. Real-time feedback could help cyclists making connections between that feedback and their kinesthetic sense and proprioception information in order to create a proper link between the frontal area and the cyclist's perception. A follow-up of the present study should confirm that the real-time frontal area information is effective improving the position of the riders during time-trial stages.

The main limitation of the present study was that the three analysed positions were very different. Therefore, it would be expected to find differences between them. In order to apply this method in high performance riders, further studies should examine sensitivity in detecting minor changes in the cyclists' aerodynamic posture

CONCLUSION: The reliability of the new 3D method was high, similar to those shown in other digitalisation studies. This method demonstrated sensitivity to detect changes in the frontal area due to changes of the position of the riders (upright, dropped and aerodynamic position). The new 3D method allows giving feedback in real time avoiding the processing process helping in the correction of the rider's position during pedalling. The differences found between methods may be due to the projection of the frontal area with the 2D method, which can be affected by the movement of the centre of mass of the cyclists in different positions.

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