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Original scientific paper

Influence of the Position on the Bicycle on the Frontal Area in Road Cyclists

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ABSTRACT

The aims of the present study were to determine whether the estimations of the frontal area of the combined cyclist-bicycle (APCB) obtained with the Heil's non-logarithmic prediction equations (NPE) in the stem position (SP), brake hoods position (BHP) and drops position (DP) are comparable to the measured APCB with the computerized planimetry (CP) method, and to analyse with the CP method and the NPE the influence of the body position on the APCB. Nineteen participants competing in the Spanish Road Cycling First division took part in the study. The NPE overestimated the APCB in the BHP and in the DP compared with the measured APCB with the CP method (6.9% and 5.1%, respectively; $p<0.05$). Significant differences among the three positions were obtained with the CP method. The overestimation of the APCB with the NPE in the BHP and in the DP, and the less sensitivity of the NPE to show significant differences between the SP and DP suggest that the NPE are not appropriate to accurately predict the APCB.

Key words: *cycling, biomechanics, aerodynamic resistance*

Introduction

Several models based on physiological, anthropometric, and environmental parameters have been presented in the literature to estimate the resistive forces to overcome during a race[1–5]. The total resistive forces, when cycling on level ground at a constant velocity, are composed by the friction resistance, rolling resistance and aerodynamic resistance[6,7]. The friction resistance is produced in the bearings and in the chain drive system[3]. It can account for the 2–5% of the total resistive forces[3,8]. The rolling resistance is related to the combined weight of the bicycle and cyclist, tire pressure and road surface texture[3,8]. The aerodynamic resistance is determined by the drag coefficient, the frontal area of the combined cyclist-bicycle (APCB), the air density and the cycling velocity. This resistive force is the greatest force impeding the forward motion of the cyclist[3,7,9–12]: at cycling velocities greater than 30 $km \cdot h^{-1}$ roughly the 90% of the total resistive forces is due to the aerodynamic resistance[10,11], hence cyclist's energy is primarily expended to overcome this force[13]. Fox and McDonald[14] modelled the power to overcome the aerodynamic resistance by means of the following equation $Rd = 0.5 \times p \times APCB \times Cd \times v^2$, in which the aerodynamic resistance (Rd, N) is defined as the product of a constant (0.5), the air density (p, $kg \cdot m^3$), the projected frontal area of the combined cyclist-bicycle (APCB, m^2), the drag coefficient (Cd, dimensionless) and the velocity relative to the surface (v, $m \cdot s^{-1}$). It is common to measure the aerodynamic resistance and to infer from that data the drag area (APCB × Cd)[15], which is the lumped variable that must be ameliorated to reduce the aerodynamic resistance[16].

Since modifications of the APCB usually involve changes in the shape of the combined cyclist-bicycle, the APCB does not always vary independently of the drag coefficient, and hence the lumped variable (APCB × Cd) is often the variable of interest, rather than its components[15]. Therefore, to determine how shape modifications affect the drag coefficient, the APCB must be accurately measured[6,15,17,18].

Measurement methods of the APCB, such as the computerized planimetry (CP) method, the photographic weighing and the manual planimetry have been previously reported in the literature[6,15,19]: the CP method has shown high intra-class correlation coefficients (0.997) and accuracy and its results are similar to the photo-

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graphic weighing and to the manual planimetry[20–22]. Estimation methods to predict the area of the cyclists or the APCB are also found in the literature[19–21,23,24]. Some of them use a constant fraction of the predicted body surface area (BSA)[4,5,10,11,19,25,26]; these methods rely upon the assumption that the APCB is proportional to the body mass (BM) raised to the two thirds power. This assumption may lead to inaccurate estimations of the APCB when the BM of the participants falls out of the 60–80 kg range[20]. Another estimation method to predict the APCB is based on the participants' BM instead of on their BSA[21]; Heil came out with a regression equation to estimate the frontal area of the cyclists in a time trial position based on their BM[21]. In 2002, Heil presented non-logarithmic prediction equations (NPE), also based on the participants' BM, to estimate the APCB in different body positions; stem position (SP), brake hoods position (BHP) and drops position (DP)[20]. The advantages of the NPE method, in comparison to the CP method, are that it is a simpler and a time-saving technique, since only the BM of the cyclists is required. Nevertheless, the use of bicycles with different geometry in Heil's study[20], bring in the question of the accuracy of the NPE when bicycles with the same geometry are used.

To our knowledge no studies have compared the APCB predicted with the NPE with the results obtained with the CP method.

The aims of the present study are: 1) to determine whether the estimations of the APCB obtained with the NPE in the SP, BHP and DP are comparable to the measured APCB with the CP method, and 2) to analyse with the CP method and the NPE the influence of the body position on the APCB.

We hypothesized that the APCB predicted with the NPE in the SP, BHP and DP of an elite group of cyclists with bicycles with the same geometry was different to the APCB obtained with the CP method.

Materials and Methods

Nineteen elite male cyclists volunteered as participants for the present study. Participants provided written informed consent before the study. The human ethics committee at the University of the Basque Country (UPV/EHU) approved the protocol. The characteristics of the subjects are presented in Table 1. All of the participants, at the time of the study, competed in the Spanish road cycling first division and one of them placed third in the junior cycling world championship under-23 in 2008 and 2009.

TABLE 1
CHARACTERISTICS OF THE PARTICIPANTS

Variables	$\bar{X}$±SD	Range
Age (years)	20.6±1.62	18–22
Height (cm)	177.4±5.27	168–188
Mass (kg)	69.5±5.63	62–83
BSA (m^2)	1.86±0.08	1.70–2.04
CE (years)	2.21±1.31	1–5

The cyclists' BSA was calculated from the equation of DuBois and DuBois[29]. BSA – body surface area, CE – cycling experience

The APCB was determined with the NPE in the SP, BHP and DP:

1. SP: upright torso position with the hands placed near the stem of the handlebars.
2. BHP: partially bent-over torso position with the hands placed on the brake hoods.
3. DP: partially bent-over torso position with the hands placed on the drop portion of the handlebar and elbows fully extended.

The NPE for each of the body positions were:

$$\text{Equation 1 (SP): APCB} = 0.04038 \times \text{BM}^{0.594}$$

$$\text{Equation 2 (BHP): APCB} = 0.04324 \times \text{BM}^{0.594}$$

$$\text{Equation 3 (DP): APCB} = 0.04091 \times \text{BM}^{0.594}$$

Computerized planimetry

The participants were photographed on their bicycles (BH G5), which were supported by a stationary indoor trainer. The bicycles were levelled with the PosiMotion™ digital lever. The position of the camera (Casio Exilim F1) was similar to the position used by Heil[20]: it was set at 5.0 m in front of the participants and 1.1 m above the ground surface. The participants placed their right foot forward with the crank parallel to the ground (the crank at 90°, where the top dead centre is 0° and the left foot back, where the crank is at 270°) (Figure 1). They wore a tight jersey and cycling bib shorts and were told to look to the camera maintaining their leg and feet positions.

Four photographs of each participant were taken. The first photograph consisted of each cyclist holding a cali-

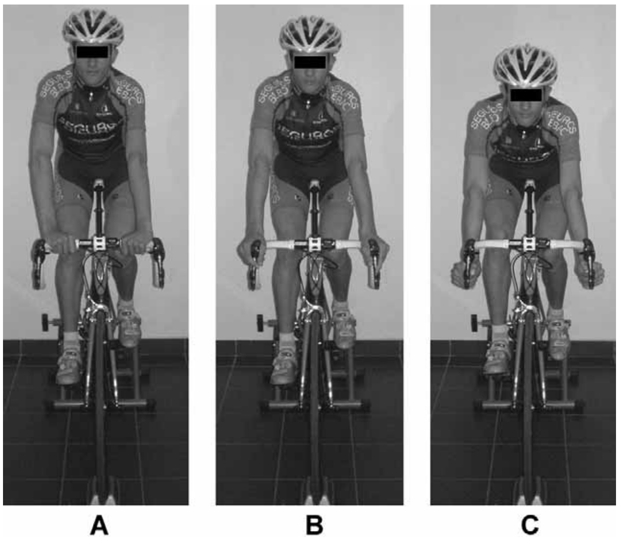
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Fig. 1. Sample photographs of a cyclist in the three different body positions: (A) – stem position, (B) – brake hoods position, and (C) – drops position.

bration squared frame of known area (0.5246 m^2) located midway between the hips and shoulders at the frontal plane. The other three photographs were taken with the cyclists at the SP, BHP and DP. The Adobe Photoshop CS software was used to extrude the calibration frame area and the APCB of each position. The extruded components consisted of any observable portion of the bicycle, such as the wheel spokes and the area between the legs and bicycle. The brake and the derailleur cables were not included[20]. The magnetic lasso tool with a 10 pixels width and an edge contrast of 99% was used for the extrusion. Every single pixel of the calibration frame and of the APCB was converted to the 0,0,0 RGB colour palette and counted with the histogram expanded view palette. The APCB in m^2 of each position was obtained dividing the product of the area of the calibration frame and the numbers of pixels of the APCB of each position by the number of pixels of the calibration frame.

Statistical analysis

For descriptive purposes the variables were reported as X±SD. The Shapiro-Wilk test was used to test the null hypothesis that the sample came from a normally distributed population. The inferential statistics Levene's test was conducted to assess the equality of variances. Paired sample t-tests were used to compare the APCB obtained with the CP method and with the NPE. Correlations between the APCB obtained with the NPE and the CP method were evaluated using Pearson's correlation coefficient. Repeated measures ANOVA were performed to examine the differences of the APCB obtained with the CP method and with the NPE among the three body positions. Post hoc comparisons were conducted with an alpha level ($p<0.05$) adjusted for multiple comparisons through a Bonferroni procedure. The Statistical Package for Social Sciences (SPSS, version 15.0) was used for the statistical analysis.

Results

Mean ± standard deviation (X±SD) values for the three body positions (SP, BHP and DP) are reported in Table 2.

The results show that the APCB values estimated with the NPE in the BHP and in the DP were significantly higher (6.9% and 5.1%, respectively; $p<0.05$) than the APCB measured with the CP method. Moreover, even though the BHP showed a positive correlation between the NPE and the CP method ($r=0.60$; $p<0.05$) (Figure 2), the DP did not show a correlation between the two methods ($r=0.29$; $p=0.21$) (Figure 3). On the other hand, no significant differences were found in the SP between the results obtained with the CP method and with the NPE. Furthermore, the SP showed a positive correlation between the NPE and the CP method ($r=0.52$; $p<0.05$) (Figure 4).

Regarding the influence of the body position on the APCB, significant differences were shown with the CP method between the SP and the DP (2.4%; $p<0.05$), between the SP and the BHP (–1.8%; $p<0.05$) and between the BHP and the DP (4.3%; $p<0.05$). On the other hand, even though significant differences were obtained between the SP and the BHP (–7.64%; $p<0.05$) and between the BHP and the DP (5.9%; $p<0.05$) when the NPE were used, no significant differences were shown between the SP and the DP. The biggest APCB with the CP method and with the NPE was obtained in the BHP. The smallest APCB with the CP method was obtained in the DP. On the contrary, with the NPE the APCB in the DP and in the BHP did not show significant differences and hence it can not be concluded which of these two positions showed the smallest value.

TABLE 2

FRONTAL AREA OF THE COMBINED CYCLIST-BICYCLE OBTAINED WITH THE COMPUTERIZED PLANIMETRY METHOD AND WITH THE NON-LOGARITHMIC PREDICTION EQUATIONS IN DIFFERENT BODY POSITIONS

Body position	CP (m^2)	NPE (m^2)
SP ($\overline{X}$±SD)	0.493±0.039^c	0.496±0.028^f
BHP ($\overline{X}$±SD)	0.502±0.039^a	0.537±0.029
DP ($\overline{X}$±SD)	0.481±0.039^{b,c,d}	0.507±0.024^f

SP – stem position, BHP – brake hoods positions, DP – drops positions, CP – computerized planimetry, NPE – non-logarithmic prediction equations, SP – stem position, BHP – brake hoods position, DP – drops position

[a] significantly ($p<0.05$) different from the BHP obtained with the NPE

[b] significantly ($p<0.05$) different from the DP obtained with the NPE

[c] significantly ($p<0.05$) different from the BHP obtained with the CP

[d] significantly ($p<0.05$) different from the SP obtained with the CP

[f] significantly ($p<0.05$) different from the BHP obtained with the NPE

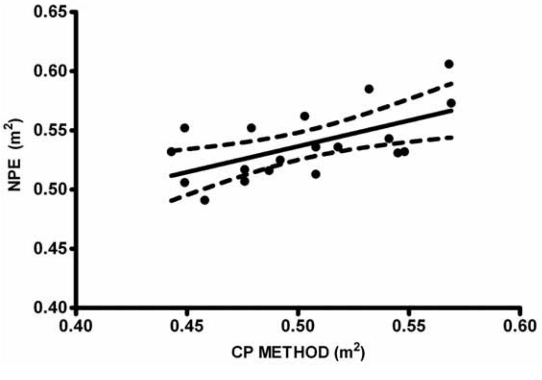

Fig. 2. Data illustrating the relationship of the APCB in the BHP between the NPE and the CP method. Linear regression is represented by a solid black line, ± 95 confidence intervals by dashed lines. There is a positive correlation between the two variables ($r=0.60$, $p<0.05$). The formula describing the relationship is $y=0.834x+0.055$; $R^2=0.363$. APCB – frontal area of the combined cyclist-bicycle, BHP – brake hoods position, NPE – non-logarithmic prediction equations, CP – computerized planimetry.

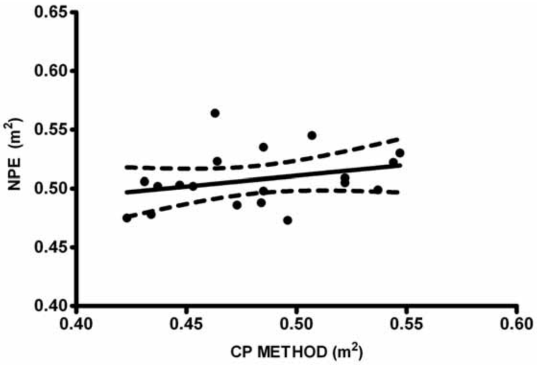

Fig. 3. Data illustrating the relationship of the APCB in the DP between the NPE and the CP method. Linear regression is represented by a solid black line, ± 95 confidence intervals by dashed lines. There is no correlation between the two variables ($r=0.29$, $p<0.21$). The formula describing the relationship is $y=0.488x+0.234$; $R^2=0.088$. APCB – frontal area of the combined cyclist-bicycle, DP – drops position, NPE – non-logarithmic prediction equations, CP – computerized planimetry.

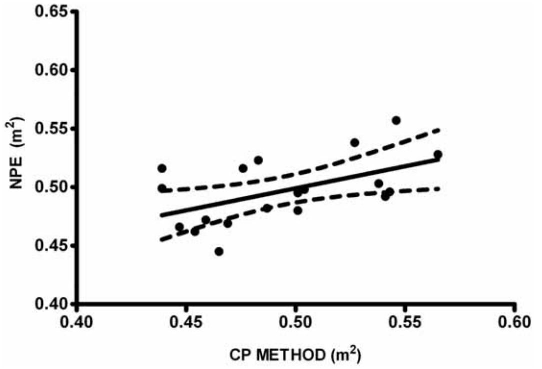

Fig.4. Data illustrating the relationship of the APCB in the SP between the NPE and the CP method. Linear regression is represented by a solid black line, ± 95 CI by dashed lines. There is a positive correlation between the two variables ($r=0.52$, $p<0.05$). The formula describing the relationship is $y=0.743x+0.2124$; $R^2=0.28$. APCB – frontal area of the combined cyclist-bicycle, SP – stem position, NPE – non-logarithmic prediction equations, CP – computerized planimetry.

Discussion

The calculation of the APCB with the NPE is a simple and a time-saving technique since only the participants' BM[20] is needed. On the contrary, the CP method is a time-consuming and a more complicate method to calculate the APCB: a photograph of the combined cyclist-bicycle must be taken and the APCB must be extruded with a digital imaging software. Nevertheless, the NPE might not be an appropriate method to predict the APCB when standardized bicycles are used, since bicycles with different geometry were used to calculate the NPE[20].

To our knowledge the present study is the first to compare the calculation of the APCB with the NPE, with the APCB obtained with the CP method using bicycles with the same geometry in the usually adopted body positions in mass-start races: the SP is mainly used when pulling up on the handlebars in hill terrain, the BHP when riding in level terrain and the DP is usually adopted at high velocities to minimise the aerodynamic resistance[27].

Since differences in bicycle geometry in Heil's study, particularly in seat-tube angle, might have biased the resulting BM exponent of the NPE closer to 0[20], a lower APCB than the obtained with the CP method was expected. Although there was a positive correlation of the APCB in the BHP between the NPE and the CP method (Figure 2), suggesting that higher frontal areas obtained with the NPE were associated with higher frontal areas obtained with the CP method, the significantly difference of the APCB in this position between the NPE and the CP (Table 2) suggests that the NPE might not be used to calculate the APCB in the BHP when bicycles with the same geometry are used. Moreover, the lack of correlation of the APCB in the DP between both methods (Figure 3) and the significant differences between them (Table 2) suggest that the NPE might not either be used to obtain the APCB in the DP.

Although the inclusion of the largest (95.7 kg) and of the smallest participant (62.7 kg) tended to increase the BM exponent, Heil pointed out that the difference between the results of the final NPE and the analysis without the outliers was not enough to warrant the exclusion of these subjects[20]. Nevertheless, the present results show that the increase of the BM exponent may have had an influence on the overestimation of the APCB in the BHP and in the DP.

The differences in the height of the participants between the Heil's study and the present study (182±5.1 cm *vs.* 177±6.4 cm, respectively) have not played a role in the results, since the height is not a significant contributor to the prediction of the APCB with the body position and BM already within the NPE[20].

In spite of the significant differences of the APCB in the BHP and in the DP, the estimated APCB with the NPE in the SP was similar to the APCB obtained with the CP method (Table 2). Moreover, a significant correlation was found between both methods in this position (Figure 4). These results suggests that the NPE, which is a simpler and a faster technique than the CP method, might be used to obtain the APCB with bicycles with the same geometry in the SP.

Due to the significant differences in the BHP and in the DP between both methods, it can not be concluded whether the similar APCB values in the SP with both methods are due to either the casualty or to the appropriateness of the use of the NPE in this body position to calculate the APCB. Future studies are required to address this issue.

The APCB value with the CP method in the SP is smaller than the value obtained by Debraux (0.533 m^2 *vs.* 0.493 m^2)[6]. Neuman[7] and Olive[28] reported higher values than the obtained with the CP method in the BHP (0.6

m^2 and 0.605 m^2, respectively *vs*. 0.502 m^2) and in the DP (0.5 m^2 and 0.563 m^2, respectively *vs*. 0.481 m^2). The differences in bicycle geometry, in body posture within each body position, and/or in the method of APCB calculation might have had an influence on the higher APCB obtained in other studies.

Regarding the influence of the body position on the APCB it has been observed that with either the NPE or the CP method the highest APCB was obtained in the BHP (Table 2): the wider placement of the hands in the BHP in comparison to the SP, and the increment of the trunk angle in comparison to the DP have played a role in the highest APCB in the BHP. The results from the CP method show that in the DP the APCB was significantly smaller than in the SP (Table 2). The trunk angle, when the hands were placed on the drops of the handlebars, was decremented helping the head and shoulder to become lower, decreasing the APCB.

Nevertheless, with the NPE there were no significant differences between the DP and the SP (Table 2). It was expected the smallest APCB in the DP, since this is the position that the riders adopt at high velocities to reduce the drag area diminishing their APCB[16]. Even though a specific NPE is established for each of the body positions[20], the lack of significant difference between the estimated DP and SP may be explained by the fact that the NPE method is not sensible enough to appreciate the APCB differences that are observed with the CP method.

Conclusion

The overestimation of the APCB in the BHP and in the DP with the NPE suggests that this technique might not be used to predict the APCB in these two body positions. On the contrary, the similar results of the APCB in the SP obtained with the NPE and with the CP method and the positive correlation between them imply that the NPE might be used to accurately obtain the APCB in this body position.

Regarding the differences among body positions, it was found that the biggest APCB was obtained with both methods in the BHP and the smallest APCB was obtained with the CP method in the DP. Nevertheless, the lack of significant differences of the APCB between the DP and the SP obtained with the NPE, suggests that this method is not sensible enough to appreciate the APCB differences that are observed with the CP method.

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UTJECAJ POLOŽAJA TIJELA VOZAČA NA PREDNJI DIO BICIKLA KOD ULIČNIH BICIKLISTA

SAŽETAK

Cilj ovog istraživanja bio je utvrditi jesu li procjene utjecaja na prednji dio bicikla dobivene formulom Heil nelogaritamskog predviđanja za tri različita položaja biciklista usporedive s vrijednostima dobivenim komjuteriziranom planimetrijskom metodom te analizirati uz pomoć obje metode utjecaj položaja tijela na prednji dio bicikla. Devetnaest natjecatelja španjolske prve biciklističke lige je sudjelovalo u istraživanju. Kompjuteriziranom planimetrijskom metodom utvrđene su značajne razlike s obzirom na položaj biciklista. Također je uvtrđeno da uspravni položaj biciklista na biciklu nije pogodan za procjenu utjecaja na prednji dio bicikla.