Original Article

Discriminant analysis of the speciality of elite cyclists

ANA B. PEINADO[1], PEDRO J. BENITO[1], VÍCTOR DÍAZ[1,2], CORAL GONZÁLEZ[3], AUGUSTO G. ZAPICO[4], MARÍA ÁLVAREZ[2], NICOLA MAFFULLI[5], FRANCISCO J. CALDERÓN[1]

[1]Departamento de Salud y Rendimiento Humano, Facultad de Ciencias de la Actividad Física y del Deporte – INEF, Universidad Politécnica de Madrid, Spain

[2]Institute of Veterinary Physiology, Vetsuisse Faculty and Zürich Center for Integrative Human Physiology (ZIHP), University of Zürich, Switzerland

[3]Departamento de Métodos de Investigación y Diagnóstico en Educación, Facultad de Educación. Universidad Complutense de Madrid, Spain

[4]Departamento de Expresión Musical y Corporal, Facultad de Educación, Universidad Complutense de Madrid, Spain

[5]Centre for Sports and Exercise Medicine, Queen Mary University of London, Barts and The London School of Medicine and Dentistry, England

ABSTRACT

Peinado AB, Benito PJ, Díaz V, González C, Zapico AG, Álvarez M, Maffulli N, Calderón FJ. Discriminant analysis of the speciality of elite cyclists. *J. Hum. Sport Exerc.* Vol. 6, No. 3, pp. 480-489, 2011. The different demands of competition coupled with the morphological and physiological characteristics of cyclists have led to the appearance of cycling specialities. The aims of this study were to determine the differences in the anthropometric and physiological features in road cyclists with different specialities, and to develop a multivariate model to classify these specialities and predict which speciality may be appropriate to a given cyclist. Twenty male, elite amateur cyclists were classified by their trainers as either flat terrain riders, hill climbers, or all-terrain riders. Anthropometric and cardiorespiratory studies were then undertaken. The results were analysed by MANOVA and two discriminant tests. Most differences between the speciality groups were of an anthropometric nature. The only cardiorespiratory variable that differed significantly ($p<0.05$) was maximum oxygen consumption with respect to body weight (VO_{2max}/kg). The first discriminant test classified 100% of the cyclists within their true speciality; the second, which took into account only anthropometric variables, correctly classified 75%. The first discriminant model allows the likely speciality of still non-elite cyclists to be predicted from a small number of variables, and may therefore help in their specific training. **Key words**: PHYSIOLOGICAL CHARACTERISTICS, CYCLING, SPECIALISTS, TRAINING.

Corresponding author. Facultad de Ciencias de la Actividad Física y del Deporte INEF. Martín Fierro, 7. 28040 Madrid. Spain.
E-mail: anabelen.peinado@upm.es
Submitted for publication September 2010.
Accepted for publication September 2011.
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.4100/jhse.2011.63.01

INTRODUCTION

Road cycling is a resistance sport that makes very great energy demands (Faria et al., 1989; Lucia et al., 1998; Padilla et al., 1999; Rodriguez-Marroyo et al., 2003), the result of the need to maintain high intensity exercise over many kilometers (Burke, 2000; Lucia et al., 1998; Rodriguez-Marroyo et al., 2003). A number of studies have investigated the physiological profile of professional cyclists with respect to their morphological characteristics and their team role in competitions (Lucia et al., 2000; Padilla et al., 1999; Sallet et al., 2006). In general, these studies suggest that performance in cycling is related not only to the ability to meet the physiological demands made, but to anthropometric characteristics; the morphological profile of a cyclist has an influence on the resistance exerted against forward movement. Some studies have suggested that morphology influences the team role played by cyclists in competitions (Impellizzeri et al., 2008; Padilla et al., 1999; Padilla et al., 2001). Certainly, road cyclists face a wide variety of terrains and competitive situations, given the different competition formats that now exist. A recent study provided information regarding the performance profiles required in three types of Tour de France stage: flat terrain, mountain and high mountain (Vogt et al., 2007).

The combination of competition demands plus the different morphological and physiological characteristics of cyclists has led to the development of specialities within the sport (Mujika & Padilla, 2001; Padilla et al., 1999): flat terrain riding, the specialists of which stand out and control the flat stages of races (Mujika & Padilla, 2001; Padilla et al., 1999; Sallet et al., 2006); hill climbing (Mujika & Padilla, 2001; Padilla et al., 1999; Sallet et al., 2006); all-terrain riding, the specialists who perform well in all kinds of stage – these are usually team leaders (Mujika & Padilla, 2001; Sallet et al., 2006); sprinting, in which the aim is to win fast, flat stages in which a large number of cyclists finish close together (Mujika & Padilla, 2001; Padilla et al., 1999; Sallet et al., 2006); and time trial racing in individual stages (Mujika & Padilla, 2001; Padilla et al., 1999).

The opinions of the trainer, team director, or of individual cyclists themselves are used to classify riders within these five specialist categories (Lucia et al., 2000; Mujika & Padilla, 2001; Padilla et al., 1999). The main differences between different specialists are anthropometric. Hill climbers tend to be shorter and lighter, flat terrain and time trialists are usually taller and heavier (Lucia et al., 2001; Lucia et al., 2000; Padilla et al., 1999; Sallet et al., 2006), and hill climbers show the highest maximum load attained (W_{max}) and maximum oxygen consumption (VO_{2max}) values (Lucia et al., 2000; Mujika & Padilla, 2001; Padilla et al., 1999; Sallet et al., 2006).

It is important to know to what degree different variables are able to discriminate between different cycling specialities in order to better detect talented athletes and to orientate training of elite cyclists towards specific goals. Discriminant analysis has commonly been used for this purpose in other sports (Leone & Lariviere, 1998; Reilly et al., 2000), e.g., in rowing (Smith & Spinks, 1995), athletics (Pollock et al., 1980), swimming and basketball (Sampaio et al., 2006). It has also been used to classify children and adolescents as apt for different sports according to their characteristics (Leone & Lariviere, 1998; Leone et al., 2002), and as part of models for identifying and selecting sport talents (Leone & Lariviere, 1998; Reilly et al., 2000).

The aim of the present work was to determine the physiological and anthropometric differences between different types of cycling specialist, and to develop a multivariate model that can classify and predict the speciality to which emerging cyclists might be best suited.

MATERIAL AND METHODS

The study participants were 20 male, elite amateur cyclists (sub-23). These were classified in terms of their speciality (i.e., in terms of the roles they played in their teams) by their two trainers (members of the *Real Federación Española de Ciclismo;* the Royal Spanish Cycling Federation). These particular cyclists fell into the specialities of flat terrain rider, hill climber, or all-terrain rider. When there was any doubt regarding their assignment (which was the case in <10% of the sample) a third trainer was asked to provide an opinion.

All cyclists were informed verbally and in writing of the characteristics of the tests they would undergo, their aim, and any associated risks. All gave their written consent to be included in agreement with the requirements of the Declaration of Helsinki Declaration and the World Medical Association for research involving human subjects. The study was approved by the ethics committee of the *Universidad Politécnica de Madrid*.

Nine anthropometric and 14 cardiorespiratory variables were recorded for each subject during a single visit to the laboratory. All were recorded by the same person. The anthropometric measures were: body weight, height, six skin fold thickness (triceps, subscapular, abdominal, suprailiac, thigh and calf), three diameters (femur bicondylar, radius biepicondylar, and radius bistyloid), and three circumferences (contracted arm, thigh and calf). All measurements were taken following a standardised procedure (Lohman et al., 1991). The data recorded were used to calculate some of the anthropometric variables (see table 1): muscular mass, bone mass, residual mass, percentage fat, relative weight, and body mass index (BMI) (Carter & Heath, 1990; De Rose & Guimaraes, 1980).

The cardiorespiratory variables were measured during a spirometric test and an incremental exercise test. Both tests were carried out with a Jaeger Oxycon Pro® gas analyser (Erich Jaeger, Germany). Standard procedures for spirometry (Quanjer et al., 1993) were followed. The incremental exercise test was performed using a Jaeger ER 800® cycloergometer (Erich Jaeger, Germany) adjusted so that each subject could assume his normal riding posture. After spending one full minute sitting still on the saddle, the subjects warmed up for 3 min at a load of 50 W. This load was then gradually increased (in a continuous manner) by 25 $W \cdot min^{-1}$ while the subject maintained a pedalling rate of 70-90 rpm (Lucia et al., 1999; Lucia et al., 2000; Lucia et al., 2006). All subjects continued pedalling at this rate until they could no longer do so. The criteria of Basset and Boulay (2000) were used to confirm that the test had been undertaken at the maximum level of exercise possible. Gas exchange was monitored continuously during the incremental exercise test using a Jaeger Oxycon Pro® gas analyser (Erich Jaeger, Germany). The gas analyzer has been previously validated for such use (Carter & Jeukendrup, 2002; Foss & Hallen, 2005; Rietjens et al., 2001), and was calibrated before and after each test according to the manufacturer's instructions. Fifteen second means were determined for use in later analysis. VO_{2max}, maximum carbon dioxide production (VCO_{2max}), maximum ventilation (V_{Emax}), maximum heart rate (HR_{max}) and W_{max} were measured. The ventilatory thresholds (VT_1 and VT_2) were determined following the method described previously (Davis, 1985; Gaskill et al., 2001). At the end of the test, 25 µl of capillary blood were collected from the fingertip and the lactate concentration at maximum load ($[La^-]_{max}$) was determined using a YSI 1500® Sport Analyser (Yellow Spring Instruments Co., Ohio, USA).

Multivariate analysis of variance (MANOVA) was used to detect significant differences between specialities. When these were detected a *post hoc* Scheffé analysis was performed. Two discriminant analysis (AD) (enter independent variables together) were used to determine which variables best distinguished between the different specialities and to seek an equation that would predict the speciality to which a cyclist might be best suited. In the first (AD1), all 23 variables recorded were included, while in the second (AD2) only the nine anthropometric variables were included. All calculations were performed using SPSS v.13 software for Windows® (SPSS, Chicago, IL). Significance was set at α<0.05.

RESULTS

Tables 1 and 2 show the means and standard deviations (SD) of the anthropometric and cardiorespiratory variables recorded for each speciality, as well as the results of the MANOVA test. The latter showed no significant differences between the three specialities (Wilks' Lambda=0.006, F=0.703, p=0.745), although some differences between the anthropometric and cardiorespiratory variables were seen in univariate analysis (Tables 1 and 2).

Table 1. *Anthropometric variables. Values are means ± SD.*

	Flat terrain riders	Hill climbers	All-terrain riders
Age	19.22 ± 1,39	21.00 ± 1,41	**21.50 ± 2.07** [a]
Body weight (kg)	71.8 ± 5.5	**58.8 ± 5.7** [a]	**68.8 ± 4.5** [b]
Height (cm)	179.7 ± 4.8	**169.9 ± 6.8** [a]	174.6 ± 3.2
Percentage fat	8.22 ± 0.66	**7.05 ± 0.76** [a]	7.85 ± 0.57
Muscular mass (kg)	36.64 ± 3.16	**30.20 ± 2.83** [a]	**35.26 ± 2.29** [b]
Bone mass (kg)	11,97 ± 1,15	**10,29 ± 1,17** [a]	11,55 ± 1,05
Residual mass (kg)	17.31 ± 1.33	**14.18 ± 1.39** [a]	**16.58 ± 1.09** [b]
Relative weight (%)	92.35 ± 3.13	86.58 ± 7.35	**94.55 ± 3.09** [b]
BMI (kg/m^2)	22.21 ± 0.81	**20.38 ± 1.68** [a]	**22.55 ± 0.82** [b]

Note: [a] Significantly different compared to flat terrain riders (p<0.05). [b] Significantly different compared to hill climbers (p<0.05). BMI: body mass index.

The body weight, muscular mass, residual mass and BMI of the flat terrain and all-terrain riders were significantly greater than those of the hill climbers (Table 1). The only cardiorespiratory variable to differ significantly was the maximum oxygen consumption relative to body weight (VO_{2max}/kg), which was significantly greater among the hill climbers (Table 2).

Table 2. *Cardiorespiratory variables. Values are means ± SD.*

	Flat terrain riders	Hill climbers	All-terrain riders
FVC (%)	120.5 ± 8.1	112.9 ± 14.8	117.5 ± 10.9
HR_{max} (beats·min^{-1})	198 ± 9	196 ± 8	198 ± 9
W_{max} (W)	477 ± 47	421 ± 50	461 ± 41
W_{rel} (W·kg^{-1})	6.65 ± 0.52	7.15 ± 0.30	6.69 ± 0.24
VO_{2max} (mL·min^{-1})	5286 ± 435	4818 ± 530	5308 ± 639
VO_{2max}/kg (mL·min^{-1}·kg^{-1})	73.74 ± 5.09	**81.88 ± 3.58** [a]	76.98 ± 5.25
VO_{2max}/kg mus (mL·min^{-1}·kg^{-1}mus)	144.67 ± 10.97	159.54 ± 9.39	150.35 ± 12.33
V_{Emax} (L·min^{-1})	183.3 ± 11.8	167.8 ± 15.1	183 ± 23
VCO_{2max} (mL·min^{-1})	5442 ± 543	5161 ± 639	5858 ± 745
VO_2 VT_1 (%)	64.2 ± 7	66.2 ± 5.4	60.2 ± 4.0
VO_2 VT_2 (%)	84.2 ± 6	84.4 ± 8.4	85.7 ± 5.7
HR VT_1 (beats·min^{-1})	161 ± 12	165 ± 6	155 ± 13
HR VT_2 (beats·min^{-1})	183 ± 10	185 ± 5	188 ± 10
$[La^-]_{max}$ (mmol·L^{-1})	9.58 ± 3.23	10.09 ± 0.95	9.18 ± 1.31

Note: [a] Significantly different compared to flat terrain riders (p<0.05). [b] Significantly different compared to hill climbers (p<0.05). FVC: forced vital capacity; HR_{max}: maximum heart rate; W_{max}: maximum load; W_{rel}; maximum load relative to body weight; VO_{2max}: maximum oxygen consumption; VO_{2max}/kg: maximum oxygen consumption relative to body weight; VO_{2max}/kg mus: maximum oxygen consumption relative to muscular mass; V_{Emax}: maximum ventilation; VCO_{2max}: maximum carbon dioxide production; VO_2 VT_1: percentage of the maximum oxygen consumption corresponding to the ventilatory threshold 1; VO_2 VT_2: percentage of the maximum oxygen consumption corresponding to the ventilatory threshold 2; HR VT_1: heart rate at the ventilatory threshold 1; HR VT_2: heart rate at the ventilatory threshold 2; $[La^-]_{max}$: maximum lactate concentration.

AD1 initially involved all 23 variables recorded, or which 10 were eliminated by the procedure during the analysis. Table 3 shows the standardised coefficients obtained for each variable in the two discriminant equations (DF) provided by the model. According to these equations the most important variables in DF1 (p<0.05; Table 3) for predicting the speciality of a cyclist are relative weight, percentage of the maximum oxygen consumption corresponding to the ventilatory threshold 1 (VO_2 VT_1), V_{Emax}, body weight, forced vital capacity (FVC) and height. AD1 successfully classified all our subjects (100%) into their true speciality group (Figure 1). Equation 1, which is obtained from the non-standardised coefficients or non-typified weightings for DF1 (p<0.05), provides the discriminating score for each subject:

SPECIALITY = 9.215 + 1.457 * Age + 1.039 * Body weight – 0.702 * Height + 0.572 * Percentage fat + 0.992 * Muscular mass – 1.667 * Relative weight + 0.417 * FVC – 0.195 * HR_{max} - 0.013 * W_{max} + 1.134 * VO_2 VT_1 – 0.532 * VO_2 VT_2 – 0.077 * VO_{2max}/kg mus + 0.035 * V_{Emax} + 0.515 * $[La^-]_{max}$.

Equation 1. *Discriminating equation for AD1. VO_2 VT_2: percentage of the maximum oxygen consumption corresponding to the ventilatory threshold 2; VO_{2max}/kg mus: maximum oxygen consumption relative to muscular mass.*

Table 3. *Standardised coefficients of the canonical discriminating equations obtained.*

	DF1	DF2
Relative weight	-7.483	-0.467
VO_2 VT_1	6.696	1.845
V_{Emax}	5.815	1.904
Body weight	5.518	-1.604
FVC	4.528	-0.029
Height	-3.479	2.178
VO_2 VT_2	-3.499	-0.933
Muscular mass	2.825	-1.904
Age	2.373	-0.026
HR_{max}	-1.769	-1.153
$[La^-]_{max}$	1.222	0.264
VO_{2max}/kg mus	-0.846	-0.124
W_{max}	-0.600	1.593
Percentage fat	0.379	-1.302

Note: DF1: Wilks' Lambda =0.006 (χ^2=51.2; p=0.009); DF2: Wilks' Lambda =0.148 (χ^2=19; p=0.162).

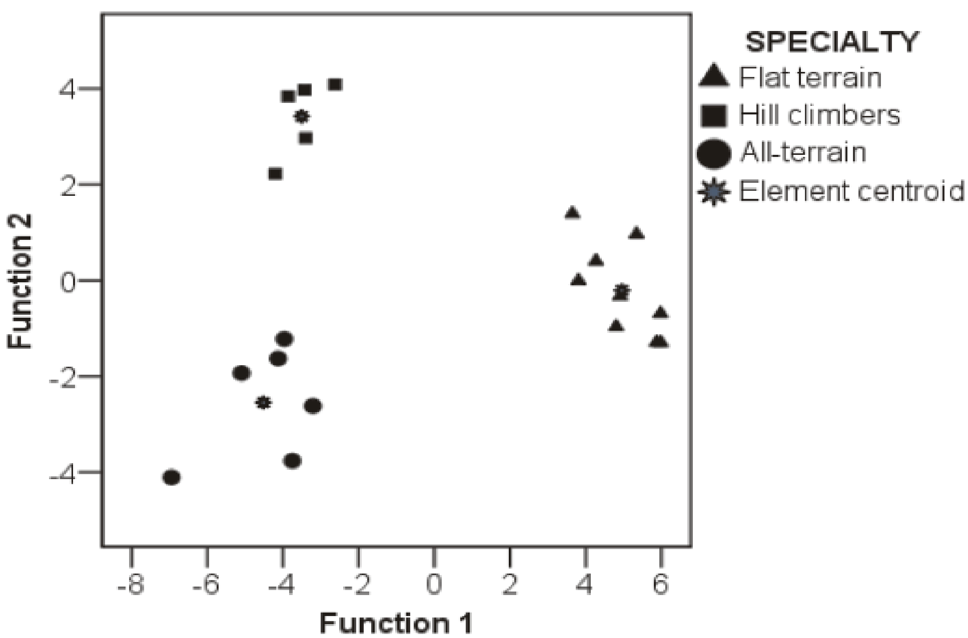

Figure 1. *Dispersion diagram for AD1. Elements centroid: Flat terrain riders (4.957, -0.203); hill climbers (-3.503, 3.419); all-terrain riders (-4.516, -2.545).*

AD2 only took into account the nine anthropometric variables, of which the procedure discounted four. Table 4 shows the standardised coefficients for each of the five variables finally included; body weight, height and BMI showed the most discriminating power. Of the two DFs obtained, only the first was significant (p<0.05) (Table 4). On the whole, AD2 was able to correctly classify 75% of the subjects; 80% of the hill climbers were correctly classified, but only 66.7% of the all-terrain riders. Figure 2 shows the distribution of the groups. The non-standardised coefficients for DF3 (p<0.05) allowed the following discriminating equation to be developed:

SPECIALITY= 56.024 + 0.418 * Body weight – 0.445 * Height + 1.468 * Percentage fat + 0.565 * Muscular mass – 1.696 * BMI.

Equation 2. *Discriminating equation for AD2.*

Table 4. *Standardised coefficients of the canonical discriminating equations obtained.*

	DF3	DF4
Body weight	2.219	-2.993
Height	-2.206	2.594
BMI	-1.834	3.894
Muscular mass	1.609	-1.867
Percentage fat	0.973	-0.179

Note: DF1: Wilks' Lambda =0.237 (χ^2=21.62; p=0.017); DF2: Wilks' Lambda =0.731 (χ^2=4.69; p=0.320).

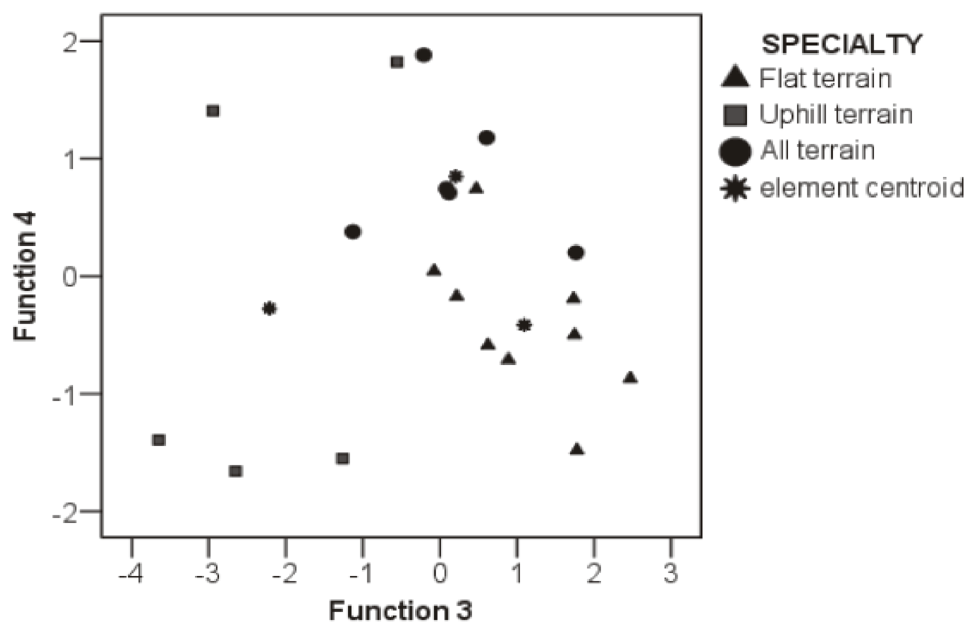

Figure 2. *Dispersion diagram for AD2. Elements centroid: Flat terrain riders (1.094, -0.414); hill climbers (-2.214, -0.274); all-terrain riders (0.205, 0.849).*

DISCUSSION

The most important results of this study are the equations that allow the classification of cyclists within a speciality group. The solution of these equations requires the measurement of anthropometric and cardiorespiratory variables, or of anthropometric variables only. Although discriminant analysis has been used in other sports, in cycling the studies published so far have only examined the differences between specialists (Impellizzeri et al., 2008; Lucia et al., 2000; Lucia et al., 1998; Sallet et al., 2006). The results of the present work therefore could provide useful information regarding the orientation of training and the selection of talented cyclists. However, the sample size should be increased to validate and improve the model.

Tables 1 and 2 show the characteristics of the flat terrain riders to be similar to those of the all-terrain riders, and those of the hill climbers to be different to either. Similar findings have been reported in other studies (Mujika & Padilla, 2001; Padilla et al., 1999; Sallet et al., 2006). The anthropometric variables were those that showed most differences. For example, the flat terrain riders were taller and heavier and had a higher percentage fat mass and muscular mass than the hill climbers. Similarly, the hill climbers were lighter and had a smaller muscular mass than the all-terrain riders. Other authors have reported similar findings, suggesting a lighter body weight to be an advantage in mountain stages due to gravity influence (Lucia et al., 2000; Mujika & Padilla, 2001; Padilla et al., 1999; Sallet et al., 2006). The all-terrain riders were significantly older than the other riders. This may be explained in that these riders were team leaders; these positions tend to be held by more experienced and therefore older cyclists (Sallet et al., 2006).

The only cardiorespiratory variable to show any significant differences was VO_{2max}/kg, which was greatest among the hill climbers (81.88 ± 3.58 $mL \cdot min^{-1} \cdot kg^{-1}$). The VO_{2max}, however, was similar in all groups. The same has been reported in other studies which indicate the importance of expressing this variable relative to body weight (Lucia et al., 2000; Mujika & Padilla, 2001; Padilla et al., 1999; Sallet et al., 2006). Hill climbers are also reported to be able to cope with significantly greater relative loads (Padilla et al., 1999), although in the present work no significant differences were seen. A high W_{rel} and high VO_{2max}/kg are requisites of hill climbers, since their energy demands and the aerodynamic resistance they face are greater (Lucia et al., 2001).

The present discriminant models suggest that it is possible to predict the speciality that a cyclist might best be able to develop. AD1 correctly classified all of the present subjects. Some of the variables that showed no significant differences between the three speciality groups in the MANOVA had high discriminating power in this model. AD2 involved only anthropometric variables, among which the greater part of the differences between the specialists were found; such anthropometric differences between specialists have also been reported in other sports (Leone et al., 2002). This model correctly classified an overall 75% of the subjects (80% of the hill climbers). The level of correct classification achieved in other sports when using this method has been similar (Leone & Lariviere, 1998; Leone et al., 2002; Smith & Spinks, 1995), e.g., 85.9% in classifying the position of basketball players (Leone et al., 2002; Sampaio et al., 2006).

CONCLUSIONS

We present a model that could be used to predict the speciality of a cyclist from a number of anthropometric and physiological variables. This could be employed to orientate the training of cyclists towards a speciality, but could also be of use in improving performance in deficit areas. Further studies are required to construct models that include sprinters and time trialists.

REFERENCES

1. BASSET FA, BOULAY MR. Specificity of treadmill and cycle ergometer tests in triathletes, runners and cyclists. *Eur J Appl Physiol.* 2000; 81(3):214-21. doi:10.1007/s004210050033 [Back to text]
2. BURKE ER. Physiology of cycling. In: WEJ GARRET, DT KINKERDALL (Eds.). *Exercise and Sport Science* (pp. 759 - 770). Philadelphia: Lippincott Williams & Wilkins; 2000. [Abstract] [Back to text]
3. CARTER J, JEUKENDRUP AE. Validity and reliability of three commercially available breath-by-breath respiratory systems. *Eur J Appl Physiol.* 2002; 86(5):435-41. doi:10.1007/s00421-001-0572-2 [Back to text]
4. CARTER L, HEATH B. *Somatotyping. Development and applications*. Cambridge: University Press; 1990. [Abstract] [Back to text]
5. DAVIS JA. Anaerobic threshold: review of the concept and directions for future research. *Med Sci Sports Exerc.* 1985; 17(1):6-21. [Abstract] [Back to text]
6. DE ROSE EH, GUIMARAES AC. A model for optimization of somatotype in young athletes. In: M OSTYN, G BUENEN, J SIMONS (Eds.). *Kinanthropometry II*. Baltimore: University Park Press; 1980. [Back to text]
7. FARIA IE, FARIA EW, ROBERTS S, YOSHIMURA D. Comparison of physical and physiological characteristics in elite young and mature cyclists. *Res Q Exerc Sport.* 1989; 60(4):388-95. [Back to text]
8. FOSS O, HALLEN J. Validity and stability of a computerized metabolic system with mixing chamber. *Int J Sports Med.* 2005; 26(7):569-75. doi:10.1055/s-2004-821317 [Back to text]
9. GASKILL SE, RUBY BC, WALKER AJ, SANCHEZ OA, SERFASS RC, LEON AS. Validity and reliability of combining three methods to determine ventilatory threshold. *Med Sci Sports Exerc.* 2001; 33(11):1841-8. [Full Text] [Back to text]
10. IMPELLIZZERI FM, EBERT T, SASSI A, MENASPA P, RAMPININI E, MARTIN DT. Level ground and uphill cycling ability in elite female mountain bikers and road cyclists. *Eur J Appl Physiol.* 2008; 102(3):335-41. doi:10.1007/s00421-007-0590-9 [Back to text]
11. LEONE M, LARIVIERE G. Caractéristiques anthropométriques et biomotrices d´adolescents athlètes élites de disciplines sportives différentes. *Science and Sports.* 1998; 13:26-33. doi:10.1016/S0765-1597(97)82989-9 [Back to text]
12. LEONE M, LARIVIERE G, COMTOIS AS. Discriminant analysis of anthropometric and biomotor variables among elite adolescent female athletes in four sports. *J Sports Sci.* 2002; 20(6):443-9. doi:10.1080/02640410252925116 [Back to text]
13. LOHMAN TG, ROCHE AF, MARTORELL R. *Anthropometric standardization reference manual*. Champaign, Illinois: Human Kinetics; 1991. [Back to text]
14. LUCIA A, CARVAJAL A, CALDERON FJ, ALFONSO A, CHICHARRO JL. Breathing pattern in highly competitive cyclists during incremental exercise. *Eur J Appl Physiol Occup Physiol.* 1999; 79(6):512-21. doi:10.1007/s004210050546 [Back to text]
15. LUCIA A, HOYOS J, CHICHARRO JL. Physiology of professional road cycling. *Sports Med.* 2001; 31(5):325-37. [Abstract] [Back to text]
16. LUCIA A, JOYOS H, CHICHARRO JL. Physiological response to professional road cycling: climbers vs. time trialists. *Int J Sports Med.* 2000; 21(7):505-12. doi:10.1055/s-2000-7420 [Back to text]
17. LUCIA A, PARDO J, DURANTEZ A, HOYOS J, CHICHARRO JL. Physiological differences between professional and elite road cyclists. *Int J Sports Med.* 1998; 19(5):342-8. doi:10.1055/s-2007-971928 [Back to text]

18. LUCIA A, RABADAN M, HOYOS J, HERNANDEZ-CAPILLA M, PEREZ M, SAN JUAN AF, ET AL. Frequency of the VO2max plateau phenomenon in world-class cyclists. *Int J Sports Med.* 2006; 27(12):984-92. doi:10.1055/s-2006-923833 [Back to text]
19. MUJIKA I, PADILLA S. Physiological and performance characteristics of male professional road cyclists. *Sports Med.* 2001; 31(7):479-87. [Abstract] [Back to text]
20. PADILLA S, MUJIKA I, CUESTA G, GOIRIENA JJ. Level ground and uphill cycling ability in professional road cycling. *Med Sci Sports Exerc.* 1999; 31(6):878-85. [Abstract] [Back to text]
21. PADILLA S, MUJIKA I, ORBANANOS J, SANTISTEBAN J, ANGULO F, JOSE GOIRIENA J. Exercise intensity and load during mass-start stage races in professional road cycling. *Med Sci Sports Exerc.* 2001; 33(5):796-802. [Full Text] [Back to text]
22. POLLOCK ML, JACKSON AS, PATE RR. Discriminant analysis of physiological differences between good and elite distance runners. *Res Q Exerc Sport.* 1980; 51(3):521-32. [Abstract] [Back to text]
23. QUANJER PH, TAMMELING GJ, COTES JE, PEDERSEN OF, PESLIN R, YERNAULT JC. Lung volumes and forced ventilatory flows. Report Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. Official Statement of the European Respiratory Society. *Eur Respir J Suppl.* 1993; 16:5-40. [Back to text]
24. REILLY T, WILLIAMS AM, NEVILL A, FRANKS A. A multidisciplinary approach to talent identification in soccer. *J Sports Sci.* 2000; 18(9):695-702. doi:10.1080/02640410050120078 [Back to text]
25. RIETJENS GJ, KUIPERS H, KESTER AD, KEIZER HA. Validation of a computerized metabolic measurement system (Oxycon-Pro) during low and high intensity exercise. *Int J Sports Med.* 2001; 22(4):291-4. doi:10.1055/s-2001-14342 [Back to text]
26. RODRIGUEZ-MARROYO JA, GARCIA-LOPEZ J, AVILA C, JIMENEZ F, CORDOVA A, VILLA VICENTE JG. Intensity of exercise according to topography in professional cyclists. *Med Sci Sports Exerc.* 2003; 35(7):1209-15. [Abstract] [Back to text]
27. SALLET P, MATHIEU R, FENECH G, BAVEREL G. Physiological differences of elite and professional road cyclists related to competition level and rider specialization. *J Sports Med Phys Fitness.* 2006; 46(3):361-5. [Abstract] [Back to text]
28. SAMPAIO J, JANEIRA M, IBÁÑEZ S, LORENZO A. Discriminant analysis of game-related statistics between basketball guards, forwards and centres in three professional leagues. *Eur J Sport Sci.* 2006; 6(3) 173-8. doi:10.1080/17461390600676200 [Back to text]
29. SMITH RM, SPINKS WL. Discriminant analysis of biomechanical differences between novice, good and elite rowers. *J Sports Sci.* 1995; 13(5):377-85. doi:10.1080/02640419508732253 [Back to text]
30. VOGT S, SCHUMACHER YO, ROECKER K, DICKHUTH HH, SCHOBERER U, SCHMID A, ET AL. Power Output during the Tour de France. *Int J Sports Med.* 2007; 28(9):756-61. doi:10.1055/s-2007-964982 [Back to text]

