CYCLIST'S PEDALING PARAMETERS USING KINEMATIC AND DYNAMIC MEASUREMENTS AND THE DISCRIMINATIVE VARIABLE ANALYSIS METHOD

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INTRODUCTION: This work deals with the pedaling study of the cyclist in a seated position. The aim of this paper is twofold. Firstly, a new kinematic and dynamic sensor was designed and built in order to measure the absolute angle of the pedal and the applied forces in the sagittal plane. A similar apparatus was designed by Boyd and Hull [1] to study pathomechanical knee injury; this equipment, having a pedal equipped with an embarked wrench sensor and an angular encoder, is too sophisticated for discriminating pedaling styles. Secondly, referring to a clinical approach in which many variables are observable, the discriminative variable analysis method using intra- and inter-class correlations followed by discriminant analysis is helpful for enhancing the relevant variables. In this approach, the data were obtained for cyclists from three different experience classes (3 cyclists per class).

Experimental apparatus and protocolus: The 360 degree resistive sensor indicates the relative angle β of the pedal through a tooth belt. The crank angle α is measured with 8 photoelectric cells triggered by a marker fixed on the crank (cf. Figure 1). In a previous work [2], this variable was recorded with a camera which proved difficult to use. Strain gauges attached to the pedals give the horizontal and tangential forces. This pedal is fixed on a laboratory-built bicycle with adjustable geometry (saddle and handle bar) and an electromagnetic brake which enables us to vary the applied power. The pedaling protocolus is characterized by the velocity rate (70tr/min or 100tr/min) and the applied power (140W, 180W or 280W). After a 10-minute warm-up time, each cyclist (A, B or C) pedals for 5 minutes at a given rate at a fixed power level. Corresponding data are recorded in a 5 second time span.

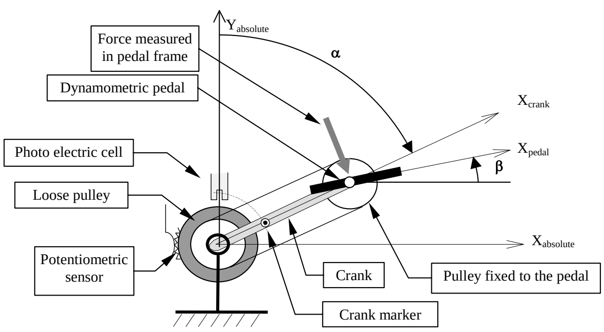

Figure 1: Experimental apparatus. *The photoelectric cell provides the evaluation of the angle α while the potentiometric sensor gives the angle β.*

The normal and tangential forces applied on the pedal are obtained by strain gauges glued on the pedal. The pedaling action is clockwise.

Discriminant variable analysis The data are composed of *n* observations measured by *p* variables. The various classes correspond to different values of an adjustable parameter, e.g., velocity or power classes.
The inter-class variance is defined as follows [3]:

$$\mathrm{var}(j) = \frac{1}{n}\sum_{k=1}^{g} n_k (\bar{x}_{kj} - \bar{x}_j)^2$$

while the intra-class variance is:

$$\mathrm{var}(j) = \frac{1}{n}\sum_{k=1}^{g}\sum_{i \in k} n_k (x_{ij} - \bar{x}_{kj})^2$$

i is the index of the *n* observations, *j* the index of the *p* variables and *k* the index of the *g* classes (the horizontal bar stands for the average).
When using discriminant factorial analysis, a discriminant linear combination of the variables is searched through the total covariance, the inter-class covariance and the intra-class covariance are defined as follows:

$$T = \mathrm{cov}(jj') = \frac{1}{n}\sum_{i=1}^{n}(x_{ij} - \bar{x}_j)(x_{ij'} - \bar{x}_{j'})$$

$$B = \mathrm{cov}_{\mathrm{inter}}(jj') = \frac{1}{n}\sum_{k=1}^{g}(x_{kj} - \bar{x}_j)(x_{kj'} - \bar{x}_{j'})$$

$$W = \mathrm{cov}_{\mathrm{intra}}(jj') = \frac{1}{n}\sum_{i=1}^{g}\sum_{i \in k}(x_{ij} - \bar{x}_{kj})(x_{ij'} - \bar{x}_{kj'})$$

Expressing the total covariance, we derive: $T = B + W$. Searching the direction *A* (of space R^p) leading to a better discrimination of classes is now equivalent to maximize the quadratic expression:

$$\frac{a^t B a}{a^t W a} \text{ with the equality constraint } a^t T a = 1$$

This can be solved with the aid of Lagrange multipliers and it is straightforward to show that *A* is the eigenvector of $T^{-1}B$. Hence the eigenvector corresponding to the highest eigenvalue gives the most discriminant direction or linear combination of the variables. An easily readable graphical representation is made with the first two normed eigenvalues (in a plane). In order to limit the number of variables, the variables are sorted, first thanks to intra- and inter-class analysis, and then factorial analysis is applied.

RESULTS AND DISCUSSION: Experiments in the laboratory were realized with 3 cyclists, A, B and C in a seated position. Two of them, B and C, were trained (5000 km/year) and the other, A, was an untrained biker (500 km/year). The velocity levels were indexed by 1 or 2 and the applied power by a, b and c. Hence the observation indexed as A2_b is relative to cyclist A at 100tr/min for a 180W applied power. The 132 variables of Table 1 are considered. The ones numbered

Variable names	Index
Amplitude and mean pedal angle β	1,2
Maximum and minimum pedal angle β	3,4
Mean, amplitude, maximum and minimum normal force	5 to 8
Mean, amplitude, maximum and minimum tangential force	9 to 12
Normal force sampled at a 15° step	13 to 36
Tangential force sampled at a 15° step	37 to 60
Absolute x force sampled at a 15° step	61 to 84
Absolute y force sampled at a 15° step	85 to 108
Pedal angle sampled at a 15° step	109 to 132

Table 1: Whole set of variables and corresponding indexes

from 1 to 12 are rather global, while for the others the interest is focused on the specific angular crank position.

a) Discrimination according to individuals. From the discrimination procedure, the following 11 variables were found (in a decreasing hierarchy): amplitude of the pedal angle, pedal angle (α) at 270°, 255°, 285° and 240°, horizontal component of the applied force at 150°, minimum angle of the pedal, vertical absolute component of the applied force at 285°, mean vertical force, absolute vertical force at 180° and vertical force at 180°. Among these variables, Figure 2 shows the plots of the main components for the first 6 variables. That cyclist A is untrained is clear from the points spread over a large area.

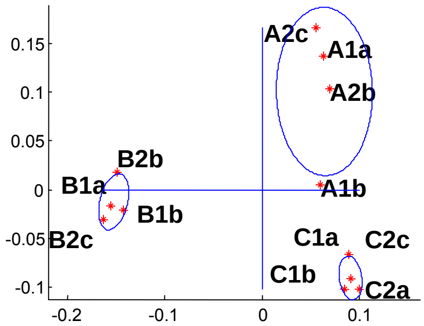

Figure 2: Factorial discrimination procedure for the cyclists

b) Discrimination according to velocity. The following 7 variables were considered (in a decreasing hierarchy): tangential force at 345°, absolute x force at 270°, pedal angle at 345°, absolute x force at 210° and 225°, pedal angle 360°, absolute at 255° and 240°. Using all these variable, Figure 3 is obtained. The dispersion areas are large, but nonetheless the velocities are identified which may be due to a limited number of cyclists. However, the importance of the absolute x force is noteworthy.

c) Discrimination according to power. The following 7 variables were considered (in a decreasing hierarchy): pedal angle, absolute y force, horizontal force amplitude, vertical force amplitude, absolute x force at 105°, pedal angle at 0° and 345°. For a weak power (a), the control leads to a larger area which can be explained in terms of a cyclist unaccustomed to such unusually low power.

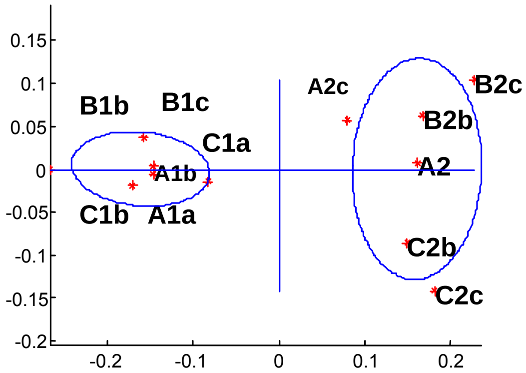

Figure 3: Factorial discrimination procedure for velocity

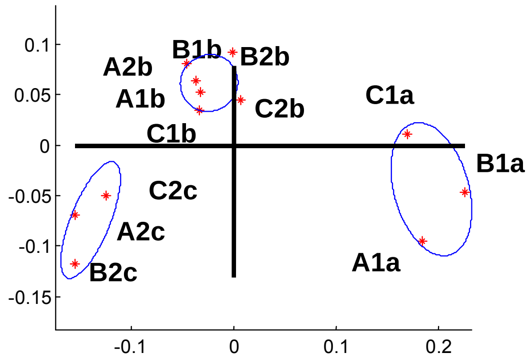

Figure 4: Factorial discrimination procedure for power

CONCLUSIONS: Using this new kinematic and dynamic sensor and the above reported discriminant method, the analysis with respect to the cyclist and to power was found to be relevant. The discriminant analysis according to the individual indicates its own practice level, whereas the analysis according to power seems to give evidence for repeatability in the pedaling action. Further work under progress will extend this procedure to a larger number of cyclists, and the discriminant analysis revealed to be an effective tool for exploiting the many data reported. Applications are being pursued in sports with an amateur team to improve training techniques.

REFERENCES:

[1] Boyd T., Hull, M., Wootten, D. (1996). An Improved Accuracy Six-Load Component Pedal Dynamometer for Cycling. *J. of Biomech.* **29**(8), 1105-1110.

[2] Deslandes, J. et al. (1996). Etude expérimentale du pédalage à l'aide de la force appliquée sur la pédale et de son orientation. *Arch. Phys. Bioch.* **104**, 614.

[3] Lebart, L., Morineau, A., Piron, M. (1995). Statistique exploratoire multidimensionnelle. Dunod.