A DYNAMOMETRIC METHOD FOR THE EVALUATION OF HIKING IN LASER BOATS

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This study aimed to develop a dynamometric method for the evaluation of hiking in Laser boats. The boat's and sailor's centres of mass, the hiking distance and the hiking moment were calculated from the ground reaction force, acquired by two force plates located under the boat hoof. Three sailors performed different hiking positions varying their hip and knee angles. Pearson's coefficient was used to verify the correlation between the measures obtained through the dynamometric method and a kinematic method. A very high correlation was observed between the methods (r=0.99) and the mean error was approximately 1% for both hiking distance and moment. Thus, the new method seems to be valid and efficient since it measured the variables in a fast and precise way, facilitating the analysis and assisting sailors and coaches on decision taking.

KEYWORDS: biomechanics, sailing, evaluation, performance.

INTRODUCTION: In order to counter balance the heel force exerted by the wind and increase the speed of the boat, the sailors need to increase the hiking moment by extending the body outside of the boat. In Laser class – which is one of the most popular classes of sailing – hiking is performed by hooking the feet under toestraps in the centre of the boat and suspending the rest of the body over the water (Vangelakoudi et al., 2007). Because of these characteristics, factors as the hiking moment (HM), the sailor's body weight and height, the hiking distance (HD), which is the horizontal distance of the sailor's centre of mass (CM) from the boat mid-line), the feet position and the knee and hip angles could be considered key performance indicators for Laser sailing (Mackie, 2003).
The measurement of HM and HD could help to better understand the mechanics of hiking and therefore to improve athletes' performance. These variables can be quantified through the use of kinematic systems (Putnam, 1979; Beillot et al., 1981; Maïsetti et al., 2002), when the Cartesian coordinates are obtained by video cameras in order to calculate the subjects' CM, the HD and thus the HM.
We believe a dynamometric system composed by force plates could be used as an alternative method for measuring the HM in a fast and precise way, since there is no need to use anatomical points of reference or to spend a long time digitizing and processing image files. Thus, this study aimed to develop a dynamometric method for the evaluation of hiking in Laser boats through the use of force plates, comparing the results with those obtained from a kinematic system.

METHODS: Three male Laser sailors, involved in regular training and national competitions, participated in this study. Subjects' mean±SD age, body mass and height were 21.0±0.8 years, 63.9±3.4 kg and 1.71±0.03 m.
Two force plates (dimensions of 500 mm x 500 mm x 200 mm, sensitivity of 2N, error lower than 1% and 60Hz of natural frequency) were used to measure the vertical and antero-posterior components of the ground reaction force (GRF), with a sample frequency of 600Hz. The acquisition system was completed by a 16 channels CIO-EXP-BRIDGE board and by the CIOD-DAS-16Jr A/D converter. Data were filtered (low-pass Butterworth with a cut-off frequency of 25 Hz) and processed using the SAD 32 3.0 software (Silva & Zaro, 1997). The force plates were positioned under the hoof of a Laser boat through the use of two supports

(Figure 1). The height of the supports was adjustable and the boat could be tilted to simulate racing situations.
Additionally to the force plates, a video camera (Peak HSC-180, 60 Hz) was used for a 2-D kinematic analysis using the software Peak Motus. The camera was positioned in front of the boat (at a distance of 3 m), perpendicularly to the sailor's sagittal plane. The following anatomical points of reference were used: temporomandibular joint, acromion, lateral epicondyle of the humerus, ulnar styloid process, greater trochanter of the femur, lateral epicondyle of the femur, lateral malleolus and fifth metatarsus.
The sailor's CM was calculated from video data through the use of the equations of the analytical method (Nigg & Herzog, 1999), based on the masses and the geometric and inertial properties of each segment of the model considered by Clauser et al. (1969).
Prior to the analysis with the sailors, the boat weight was measured using the force plates. The horizontal distance of the boat's CM to the origin of moment calculation was determined based on this measurement (Equation 1), instead of simply assuming the CM is located in the boat mid-line as done before in other studies (Maïsetti et al., 2002; Mackie, 2003; Tan et al., 2006). This distance was calculated in two different situations: (a) without inclination of the boat (α=0º); and (b) with an inclination of 9º, that was obtained by elevating the support over Plate B in 0.2 m (Figure 1). Afterwards, in each of these situations, the sailors performed three executions of hiking with variation of the hip angle (90º and 180º) and of the knee angle (160º and 180º), once these are values commonly used in previous studies (Marchetti et al., 1980; Maïsetti et al., 2002). Thus, considering the combination of the situations, 24 executions were analysed for each subject.

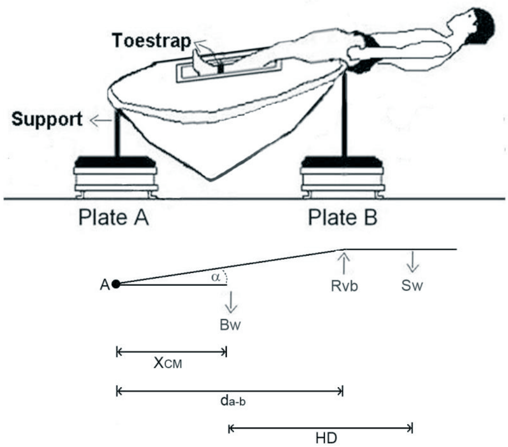

Figure 1: Hiking in one of the situations and force diagram used for analysis. A: origin for moment calculations; B_w: boat weight; α: angle of inclination; R_{vb}: vertical reaction in Plate B; S_w: sailor weight; X_{CM}: horizontal distance from the boat's CM to the origin; $d_{a\text{-}b}$: distance between Plate B and the origin; HD: hiking distance.

Based on the force diagram in Fig.1 and using a 3-DOF rigid body model ($\Sigma_{Fx}=0$, $\Sigma_{Fy}=0$ and $\Sigma M_A=0$, with point A as the origin for moment calculations), the horizontal distance from the boat's CM to the origin, HD and HM were calculated by equations 1, 2 and 3 respectively:

(1) Horizontal Distance from the Boat's Centre of Mass to the origin (X_{CM})

$$\sum M_A = 0$$

$$-\left(B_W \times X_{CM}\right)+\left(R_{vb} \times d_{a-b}\right)=0$$

$$X_{CM} = \frac{R_{vb} \times d_{a-b}}{B_W}$$

(2) Hiking Distance (HD)

$$\sum M_A = 0$$

$$-(B_W \times X_{CM}) + (R_{vb} \times d_{a-b}) - (S_W \times X_{CM}) - (S_W \times HD) = 0$$

$$HD = \frac{-(B_W \times X_{CM}) + (R_{vb} \times d_{a-b}) - (S_W \times X_{CM})}{S_W}$$

(3) Hiking Moment (HM)

$$HM = HD \times S_W$$

Descriptive statistics and Pearson's coefficient were used to analyse data. The "r" real meaning interpretation was calculated by the coefficient of determination and expressed as a percentage. The mean and maximum relative errors were calculated considering the results from the kinematic analysis as gold standards and were expressed in percentage. All the procedures were carried out using the SPSS 17.0 software.

RESULTS AND DISCUSSION: Table 1 shows the results of the measurements of the boat weight, distance between plates A and B and boat's CM in the different inclination angles.

Table 1
Boat weight, distance between Plates A and B and boat's CM in the different inclination angles
Mass and CG boat values

Boat weight (N)	608.2	
Distance between platforms (m)	1.27	
	Plain	Inclined
Inclination Angle (º)	0	9
Boat Centre of mass (m)	0.63	0.59

The dynamometric method suggested in this study made it possible to calculate the correct position of boat CM when inclined and plain, instead of assuming its position as being in the mid-line of the boat as done by other studies (Maïsetti et al., 2002; Mackie, 2003; Tan et al., 2006). Since HD depends on boat CM, a better localization of the boat CM will result in a more accurate value of HD and, consequently, in a more accurate value of the HM produced by the sailor. Table 2 shows the results of the calculation of HD and HM using the measurements provided by the kinematic and dynamometric analysis.

Table 2
Mean and standard deviation for hiking distance and hiking moment calculated through the kinematic and dynamometric methods

		Hiking Distance (m)		**Hiking Moment** (N.m)	
	n	Kinematics	Dynamometry	Kinematics	Dynamometry
Boat Plain	36	0.79 ± 0.10	0.79 ± 0.10	493 ± 61	497 ± 65
Boat inclined	36	0.80 ± 0.12	0.79 ± 0.11	501 ± 74	497 ± 67

Table 3 shows Pearson's correlation coefficient between the results of kinematic and dynamometric measurements and the relative error (mean and maximum).

Table 3
Pearson's correlation coefficient and relative error between methods

	r	r^2	Mean Error	Maximum Error
Hiking Distance	0.9929	98.58%	0.97%	2.27%
Hiking Moment	0.9941	98.82%	1.02%	1.60%

The values of HD and HM measured through the dynamometric and kinematic methods were strongly correlated. When compared to the kinematic method, the new method presented a mean error of approximately 1%, which can be considered low since the force plate itself present an error of 1%. In addition, the new method has shown to be a relatively fast and easy way of measuring HD and HM, since it does not requires a digitalizing process. A disadvantage of this new measurement is that it does not provide a description of the sailor's joint angles. However, Mackie (2003) affirmed that the joint angles during sailing are a less important factor than HD e HM, which have been considered the main indicative of a good performance (Maïsetti et al., 2002; Mackie, 2003; Tan et al., 2006).
It is important to highlight that this method does not take into account the real conditions of sailing, such as wind and waves, which probably would influence the strategy used by the sailor to control the boat (Bojsen-Møller & Bojsen-Møller, 1999).

CONCLUSION: A dynamometric method for the evaluation of hiking in Laser boats through the use of force plates was developed in this study and its results were compared to those obtained from a kinematic analysis. A very high correlation was observed between the methods and the mean error found is considered acceptable for both hiking distance and hiking moment. Therefore, the new method seems to be valid and efficient since it measured the variables in a fast and precise way, facilitating the analysis and assisting sailors and coaches on decision taking.

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