KINEMATIC SYMMETRY IN ROWING: COMPARISON OF FIXED STRETCHER *VERSUS* FREE-FLOATING ERGOMETER

Floren Colloud[1, 2], Stéphane Champely[1], Pascal Bahuaud[3] and Laurence Chèze[2]
[1] CRIS, Université Claude Bernard, Lyon, France
[2] Laboratoire MECAL, Université Claude Bernard, Lyon, France
[3] Laboratoire LMSo, Institut National des Sciences Appliquées, Lyon, France

The purpose of this study was to examine kinematic symmetry of lower and upper limbs when using two kinds of rowing ergometers. Fifteen high-level rowers performed two 15-stroke tests at a race rate on two different Rowperfect rowing ergometers. One was fitted up with a fixed stretcher mechanism and the other with a free-floating stretcher mechanism. The tests were carried out in a randomised order. Flexion/extension angles were computed from trajectories of twenty-two markers collected by a motion analysis system. A functional data framework was realised to compare right *versus* left side angle function curves. These angle curves were validated by bibliographic data. High levels of symmetry were observed for angles of the lower and upper limbs regardless of the mechanism rowed. Shoulder and hip angles for the fixed and the free-floating conditions respectively, were the only exceptions in this regard. The rower's symmetry pointed out by this work allows one-side kinematical analysis of flexion/extension angles.

KEY WORDS: 2D kinematics, functional data analysis, rowing ergometry.

INTRODUCTION: Rowing an ergometer provides an indoor reasonable alternative to on-water rowing. Over time, rowing ergometers have evolved to reproduce load conditions of on-water rowing better. Nevertheless, all ergometers are built with a fixed stretcher mechanism. Lamb (1989) validated the use of fixed mechanism with on-water condition from kinematical parameters. However, the fixed stretcher seems not to take into account the on-water technical skill factor. On water, the displacement of the rower mass during recovery may have important negative effects on the boat motion whereas the displacement of the rower's mass along the central bar has no consequence on the performance recorded on a fixed ergometer. A new rowing ergometer (Rowperfect, Care, The Netherlands) has recently been designed with a free-floating stretcher mechanism to improve the simulation of on-water dynamic conditions. Colloud *et al.* (2001) showed significant dynamic differences between the two kinds of mechanisms during the rowing stroke. They observed a difference between forces developed by each lower limb on the stretcher. This asymmetry on the applied force appeared more important when the scullers were tested on the fixed mechanism. In contrast, Parkin *et al.* (2001) reported a symmetry of the rower's knee flexor and extensor strength during tests performed on an isokinetic dynamometer. From a fixed stretcher test at different stoke rates (14 to 30 beats·min^{-1}), Pudlo (1999) computed an important torque at L4/L5 level on the vertical axis which explains the low rotation of the rower's trunk. This result was confirmed by Parkin *et al.* (2001) who measured a difference in strength between the left and right extensors of the trunk. Although many authors (*e.g.* Lamb, 1989; Pudlo, 1999; Hawkins, 2000; Halliday *et al.*, 2001) have studied the kinematics of rowing an ergometer, no detailed data of right *versus* left joint angles are available in the literature. Lamb (1989) presented a vector loop model of the rower and displayed antero-posterior linear velocities during propulsion. Hawkins (2000) described a tool for motor learning and/or improving performance by feedback techniques using four electrogoniometers placed on the joints on one side of the rower's body (ankle, knee, hip and elbow), no angular data were presented. Pudlo (1999) and Halliday *et al.* (2001) computed three-dimensional kinematics of the whole of the rower's body, but they only reported the patterns of right joint curves. The objective of the present study is to analyse whether right *versus* left side joint angles are symmetric during ergometer sessions, and to determine if the type of mechanism rowed has an influence on the symmetry of the rower's motion.

METHODS: Fifteen high-level male rowers, whose training amounted to 8-12 sessions per week (age = 23.9 ± 3.2 years, height = 1.83 ± 0.06 m, body mass = 78.8 ± 7.5 kg) volunteered to participate in this study. The subjects completed the following rowing ergometer test schedule. After warming-up, they carried out a 15-stroke race rate test (35 beats·min^{-1}). In a randomised order, each rower performed twice, once on a Rowperfect rowing ergometer fitted with a free-floating stretcher mechanism, and once on a similar rowing ergometer with a fixed stretcher mechanism. A six-camera video-based motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) was used to collect kinematic data. Sixteen retro-reflective markers (diameter: 2 cm) were placed on the trunk, the right and left lower/upper limbs to model each rower as a chain of rigid segments linked by rotoïd joints (see Figure 1). The skin markers were glued over anatomical landmarks allowing to define respectively: the shanks, the thighs, the pelvis, the thorax, the upper arms and the arms. In addition, the handle and the stretcher of the rowing ergometer were also located by three markers.

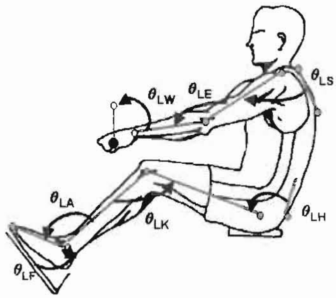

Figure 1. Positions of the skin markers on the left side of the rower and illustration of the left joint angles for foot (θ_{LF}), ankle (θ_{LA}), knee (θ_{LK}), hip (θ_{LH}), wrist (θ_{LW}), elbow (θ_{LE}) and shoulder (θ_{LS}).

The marker positions were collected for ten seconds (*i.e.* five successive strokes), at a sampling frequency of 60 Hz. To record a stabilised rowing gesture, the data collection began five strokes after the start of the test. An algorithm was developed to calculate the flexion/extension angles between each adjacent segment, respectively on right and left sides of the rower (see Figure 1). Each measurement was a regularly sampled curve. In statistics, this type of data is generally referred to as "functional data" (a synthesis is given by Ramsay & Silverman, 1997). A functional data framework intends to perform a complete and general analysis – here the comparison of two experimental conditions: right *versus* left side angles - directly in terms of function curves, instead of being analysed only in terms of characterised points (peaks, troughs, inflexion). Important pre-processing of each sampled curve was necessary due to the intra and inter-individual variations of the stroke duration: (*i*) The displacement of the handle provides a simple reference mark to clearly identify each rowing stroke (propulsion and recovery phases). This mark was also used for the sequencing of the angular variables. (*ii*) The cycles were normalised on the interval [0,1] to achieve direct superimposition. (*iii*) It was then possible to average these cycles to obtain a representative standardised cycle. n = 15 curves (average standardised cycles) on the right side: $r_i(t)$ and n = 15 curves on the left side: $l_i(t)$ were calculated, which represented the evolution of each angular variable during the two ergometer conditions. A first step consisted in computing the average curves. They were respectively defined by $\bar{r}(t)=\frac{1}{n}\sum_{i=1}^{n} r_i(t)$ and $\bar{l}(t)=\frac{1}{n}\sum_{i=1}^{n} l_i(t)$ for the data collected on right and left sides. Next, a distance (D) between these two average curves, called "observed distance" was computed by: $D(\bar{r},\bar{l})=\sqrt{\int_0^1 (\bar{r}(t)-\bar{l}(t))^2\,dt}$.

Thereafter, a randomisation test (*e.g.* Zerbe, 1979) was used to determine if a significant difference between right and left measurements could be observed. For each rower, right and left curves were randomly swapped, then two new average curves were computed and the distance between them, called "randomised distance", was calculated. The operation was reproduced a significant number of times (100) and the randomised distances were compared to the observed distances. The percentage (*P*) of randomised distances above the observed distance was calculated. For each measurement, a significant difference between the two ergometer conditions was observed when the p-value was below 5%.

RESULTS & DISCUSSION: Table 1 presents the range of motion of the whole set of quantities. The two-dimensional patterns are similar to those previously published by Pudlo (1999) and Halliday *et al.* (2001). The amplitudes documented here are comparable to Pudlo's data. The foot and wrist angles are not available in Pudlo's thesis. However, our data tend to show lower values than those of Halliday *et al.* (2001). In contrast, large difference were observed for foot and wrist angles. The fact that subjects rowed without shoes during our experimentation and the placement of markers on the hands in Halliday's study may have influenced the calculated amplitude. A poor difference (<3%) is shown between the two stretcher mechanism conditions for knee, shoulder and elbow angles. This difference is more important for the flexion/extension angle of the hip (<8%), foot (<14%), wrist (<20%), and ankle (<23%). It can be noticed that the higher percentages were calculated for the joints which present the smaller range of motion during the rowing cycle. When the symmetry of the range of motion was checked, the difference between right and left sides was usually below 2%. Furthermore, this percentage was always below 7% (*i.e.* shoulders, feet and ankles, angles when the fixed mechanism was rowed and feet angles when the free mechanism was rowed).

Table 1. Range of motion of flexion/extension angles (*n* = 15) for respectively the fixed (FM) and the free-floating mechanisms (FFM).

	Range (°)	
	FM	FFM
Right foot / stretcher	18.0	15.9
Left foot / strecher	17.3	16.7
Right ankle	47.7	54.9
Letf ankle	44.6	53.9
Right knee	109.4	112.2
Left knee	110.9	113.7
Right hip	79.1	75.9
Left hip	79.9	74.5
Right shoulder	102.7	100.0
Left shoulder	97.8	98.1
Right elbow	96.0	98.7
Left elbow	95.7	96.6
Right wrist	53.0	47.2
Left wrist	55.8	46.8

Table 2. Probability of difference between the right and left flexion/extension angles computed from the 100 randomised distances when subjects (*n* = 15) row respectively the fixed (FM) and the free-floating mechanisms (FFM).

	Probability	
	FM	FFM
Foot	.54	.07
Ankle	.48	28
Knee	.65	.32
Hip	.95	<.05
Shoulder	<.04	.19
Elbow	.21	.33
Wrist	.59	.49

Table 2 shows no statistical change in symmetry between right and left sides of the rowers regardless of the stretcher mechanisms rowed. Indeed, considering 100 randomised distances for each parameter, p-values were consistently above 5%. Shoulder and hip flexion/extension angles for the fixed and the free-floating conditions respectively, were the only exceptions in this regard. Indeed, from a 2D kinematical point of view, the upper and lower limb rotations realised by the rowers were symmetric. Moreover, this symmetry was not influenced by the ergometer mechanism rowed. Figure 2 illustrates the rower's symmetry on the knee angle curves collected during the two ergometer conditions. This close pattern between the two sides of the rower was also observed for the other parameters which appeared symmetric, regardless of the mechanism rowed. These results, obtained on a great number of subjects, suggest that as far as one plane kinematics is concerned, the analysis of one side is sufficient. For the two statically asymmetric variables (shoulder and hip for fixed and free-floating conditions, respectively), a poor difference between the curves and the ranges of motion was observed. Nevertheless, the functional data analysis allows to clearly identify that these quantities behaved in an asymmetric way. Hence, the shoulders' shapes collected from the right side mainly contrasted with those collected on the left side at the end of the propulsion and the beginning of the recovery. In contrast, the differences between the two hip joints could specifically be observed at the catch (end of recovery, beginning of propulsion) in free-floating conditions.

CONCLUSION: The results demonstrate a significant symmetry on the flexion/extension angles. This validates two-dimensional kinematic studies realised from one-side of the rower (*e.g.* Lamb, 1989; Hawkins, 2000). It suggests that rowers have symmetric movement although an asymmetric stretcher force production can be produced (Colloud *et al.*, 2001). However, this study should be complemented by three-dimensional analysis as Pudlo (1999) and Halliday *et al.* (2001) have demonstrated the significant out-of-plane movement of the rower's limbs. This work is a step towards a kinematic and forward dynamic study, whose objective is to improve the rower's movement from data collected on the two kinds of ergometers.

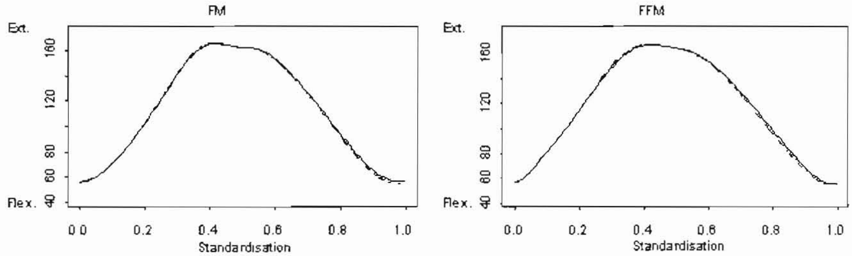

Figure 2. Illustration of the symmetry pattern from the knee angles obtained from the fixed (left) and free-floating conditions (right), in continuous line for the right side and in dotted lines for the left one.

REFERENCES:

Colloud, F., Bahuaud, P., Doriot, N., Champely, S., Monteil, K. M., & Chèze, L. (2001). Is force symmetry influenced by using a fixed *versus* a free-floating rowing ergometer mechanism? *Archives of Physiology and Biochemistry*, **109** (supplement), 65.

Halliday, S. E., Zavatsky, A. B., Andrews, B. J., & Hase, K. (2001). Kinematics of the upper and lower extremities in three-dimensions during ergometer rowing. In: R. Müller, H. Gerber, & A. Stacoff (Eds.), *Book of abstracts from the XVIIIth Congress of the International Society of Biomechanics, ETH Zürich,* 52.

Hawkins, D. (2000). A new instrumentation system for training rowers. *Journal of Biomechanics*, **33**, 241-245.

Lamb, D. H. (1989). A kinematic comparison of ergometer and on-water rowing. *American Journal of Sports Medicine*, **17**, 243-247.

Parkin, S., Nowicky, A. V., Rutherford, A. V., & McGregor, A. H. (2001). Do oarsmen have asymmetries in the strength of their back and leg. *Journal of Sports Sciences*, **19**, 521-526.

Pudlo, P. (1999). *Contribution to the analysis and optimisation of the rower's movement* (in French). Unpublished doctoral thesis, Université de Valenciennes et du Hainaut-Cambrésis.

Ramsay, J. O., & Silverman, B. W. (1997). *Functional data analysis*. Springer-Verlag.

Zerbe, G. O. (1979). Randomisation analysis of the completely randomised design extended to growth and response curves. *Journal of the American Statistical Association*, **74**, 215-221.