3D KINEMATIC COMPARISON BETWEEN ON-WATER AND ON ERGOMETER KAYAKING

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The purpose of this study is to propose a method for comparing on-water *versus* on ergometer kayaking. Two elite kayakers were filmed at 84 strokes per minute on an ergometer and in an indoor dock. Linear and angular time histories for the upper limbs were recorded and the kinematics repeatability on the ergometer and between the two environments was measured using a coefficient of multiple correlations (CMC). The kinematics were, on the whole, repeatable within ergometer cycles (CMC > 0.92) and between the on-water and on ergometer environments (CMC > 0.85), except for shoulders (CMC > 0.65). The main modifications concerned the motion of both shoulders in the frontal plane, these being explained by the specific resistance of the water and the kayakers' balance on water.

KEY WORDS: kinematics, kayak, in situ.

INTRODUCTION:

Ergometers are frequently used to simulate *in situ* locomotion because it offers a controlled and convenient environment for testing and training. The small filming area facilitates the use of static cameras and monitoring equipment. To ensure validity in locomotion research using ergometers, it is essential that the ergometer environment is as close to the *in situ* environment as possible. The difficulty in kayak paddling arises from an accurate on-water three-dimensional (3D) measurement (Sanders & Kendal, 1992). The investigation of the upper limbs 3D kinematics requires at least two calibrated cameras and a large filming area. In spite of these difficulties, some 3D descriptive analyses have been published (Kendal & Sanders, 1992). Few rigorous kinematic comparisons are available. By comparing the sagittal and rear views and, more precisely, posture and muscular masses, Dal Monte & Leonardi (1976) concluded that ergometers closely simulate the on-water technique. Campagna *et al.* (1982) analysed the path of the wrist, elbow and shoulder in the sagittal plane and showed a similar stroke pattern. The purpose of this study was to compare the 3D kinematics between on ergometer and on-water paddling.

METHOD:

A paddling ergometer was constructed using a flywheel and a frame on which a trolley (footrest and seat) moved back and forth (Figure 1A). The movement was recorded by a motion-analysis system at 50 Hz (six infrared cameras, Saga3^{RT}, Biogesta, France).
The on-water experiment was carried out in an indoor towing tank of 148 m long, 5 m wide and 3 m depth. The kayaker had enough distance (75 m), prior to entering the filming area, to stabilise his stroke rate and speed. Because of the experimental difficulties (uncontrolled lighting and its reflection on the water), a semi-automatic motion-analysis system was used. Five DV cameras (Saga3^{DV}, Biogesta, France; 50 Hz) were distributed between the two sides of the dock to record one full stroke (Figure 1B).
A stroke was defined as starting with the initial blade-water contact and continuing until blade-water contact was made on the opposite side. Each stroke was divided into three parts according to paddle immersion, shaft verticality and water-exit.
Two elite kayakers participated in this study. Because feet and pelvis were hidden by the kayak, markers were fixed on upper limb landmarks (directly on the skin for on ergometer experiment and on a wetsuit for the on-water experiments due to safety regulations) and defined eight body segments (scapular girdle, head, arms, forearms, hands). In relation to

body segment identification, the draw segments were defined as those closest to the water (bottom arm); whereas, the thrust segments were those away from the water (top arm) during the water contact phase of the stroke. Extra markers were placed on the trolley, the kayak and on the paddle.

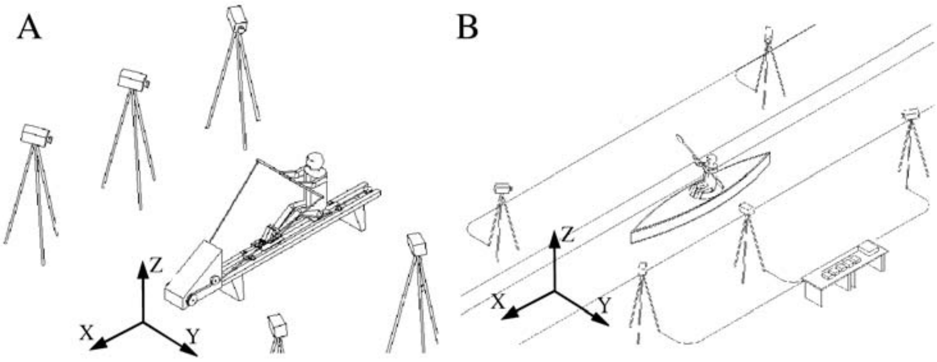

Figure 1: (A) The paddling ergometer (B) The kayak in the indoor towing tank

Kayakers followed a warm-up routine in order to get used to paddling in both environments. They were advised to paddle at a constant rhythm of 84 strokes per minute (spm) given by a metronome. Subjects completed one trial of 40 seconds on the ergometer and five trials on water. One trial per athlete was chosen, according to the position relative to the filming area and the actual stroke rate, and was fully analysed.
The kinematic comparison between the two environments was based on the measurement of within-stroke phase durations and on specific angular and linear time histories. Firstly, raw data were synchronized: (*i*) for temporal synchronisation, the first frame showing the right paddle entering the water was t_0 = 0 s and (*ii*) a local frame was defined for the trolley and the boat with the origin of both local systems being the mass centre of the upper limbs at t_0 = 0 s. On ergometer the relative height of the water was estimated by the mean height of the hip joints.
The phase durations were calculated as a percentage of the stroke. Since each paddle position was determined at ± ½ frame ± 0.01 s), the duration accuracy at 84 spm was 1% of the stroke. The kinematic variables were the time histories of the linear joint co-ordinates and that of the scapular girdle rotation. The path of the wrist, elbow and shoulder were analysed for the thrust and draw segments. The angular displacement of the scapular girdle in the horizontal plane completed the analysis.
Time-series waveforms were analysed by the coefficient of multiple correlation (CMC): the intra-subject repeatability of kinematic data was obtained from on-ergometer strokes and then from both conditions (mean on-ergometer stroke *versus* on-water stroke). CMC values of both subjects and of the three marker co-ordinates were grouped together in a mean value (± SD) that represented the reproducibility for each joint. A Wilcoxon test was employed to examine if there were any differences in the reproducibility within the ergometer environment and between the two conditions.

RESULTS:
The comparison between ergometer and on-water conditions was based on movement timing and on joint kinematics (Fig. 2). The first parameter was reproduced in the on-ergometer environment (Table 1). The aerial phase lasted about 40% of the stroke duration. The water phase was divided into 23% lasting from entry to the vertical position of the paddle and 37% from that point to its exit.
The CMCs (± SD) of on-ergometer kinematics were greater than 0.95 (Table 2), except for the thrust shoulder along the mediolateral axis in the case of the second subject (about 0.67). This poor correlation explained the high standard deviation for the thrust shoulder, despite the good mean CMC.

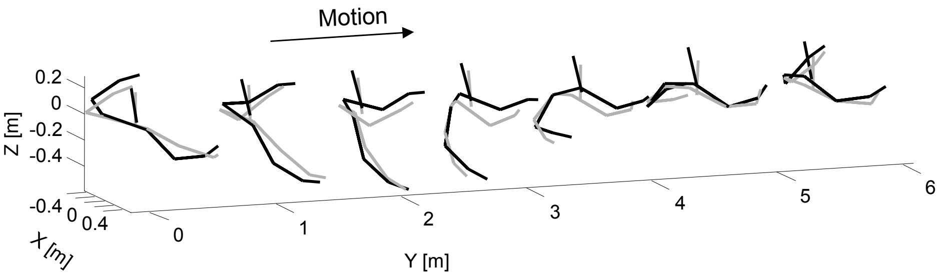

Figure 2: 3D positions of the upper limbs and the head during an on-water paddle stroke (grey line) and on ergometer paddle stroke (black line). This figure shows an exploded view of the movement with reference to the antero-posterior axis at 10 Hz.

Table 1: Relative duration as a percentage (± 1%) of the three parts of the right stroke, for the two subjects for both environments. Results of (A) Kendall & Sanders (1992) and (B) Plagenhoef (1979) are shown

	Subject 1		Subject 2		Literature	
Environments	On-water	Ergo.	On-water	Ergo.	(A)	(B)
Entry-Verticality	20	22	24	24		29
Verticality-Exit	37	37	37	36		44
Water phase	57	59	61	60	71.5	73
Aerial phase	43	41	39	40	28.5	26

Whatever variables were considered, the repeatability between the two conditions was significantly lower ($p < 0.01$) than within the on-ergometer cycles. The mean CMCs ranged from 0.47 to 0.95 and the mean CMCs for the path of both shoulders were less than 0.80. For both kayakers, significant differences were noted in the draw shoulder frontal plane and along the mediolateral axis for the thrust. However, the angular kinematics of the scapular girdle was not significantly different (CMC = 0.95).

Table 2: Mean CMC (± SD) within on-ergometer cycles and between on-ergometer and on-water trials

		Within ergometer	Ergometer *vs.* On-water
	Shoulder	0.97 (0.02)	0.66 (0.30)
Draw	Elbow	0.98 (0.02)	0.87 (0.13)
	Wrist	0.99 (0.01)	0.90 (0.11)
	Shoulder	0.92 (0.12)	0.76 (0.23)
Thrust	Elbow	0.98 (0.02)	0.86 (0.17)
	Wrist	0.98 (0.01)	0.91 (0.10)
Scapular	girdle	0.99	0.95

DISCUSSION AND IMPLICATIONS:

This paper presents a method for comparing the kayak paddling between on-water and on ergometer environments, and then ascertains if two elite kayakers could reproduce their kinematics on the ergometer. Timing and statistical analyses pointed to a low variability on the ergometer and an incomplete reproducibility between the ergometer and on-water conditions.

Firstly the lack of a water surface did not disturb the kayaking timing. The relative durations of the three phases differed from those quoted by Plagenhoef (1979) and Kendal & Sanders (1992) due to a difference in stroke rate and an evolution in technique. Over the past thirty years, the water phase duration has tended to decrease. The propulsive force depends on paddle velocity with respect to the water. Since race speed has increased, paddle velocity with respect to the boat should increase to maintain the force magnitude. As regards to joint kinematics, although scapular girdle rotation - as well as elbow and wrist trajectories - were similar, shoulder motion differed, the main differences being in the frontal plane for the draw shoulder and along the mediolateral axis for the thrust shoulder. Kayakers did not reproduce trunk roll on the ergometer. The CMC indicated the closeness of all joints along the anteroposterior axis, the direction of the main motion of the kayak.

There are at least three possible causes of between-conditions difference in kinematic data: *a)* error in the 3D-coordinates, *b)* experimental difficulties involved in the comparison, and *c)* variation in the pattern of motion. *(a)* On ergometer, the errors in the 3D-coordinate due to 3D reconstruction and skin movement artefacts are weak. Despite the extreme care taken in fixing the markers on the wetsuit, relative motion of the wetsuit with respect to landmarks are inevitable. Moreover in this environment, the marker of the right side were reconstructed with binocular triangulation, contrary to the markers of the left side and all markers on ergometer environment reconstructed with at least trinocular triangulation. However, it seems reasonable to assume that these errors have limited effect on the results. (*b)* Another explanation concerns the complexity involved in the movement comparison. Since only one stroke was analysed, expert kayakers who had automated their movements (Kendal & Sanders, 1992) were chosen. Furthermore, the spatiotemporal synchronisation between the two conditions was inaccurate because of the boat rocking and the low sampling frequency (50 Hz). (*c*) To that may be added a real movement difference due to kayaker's adaptation to a new environment. The lack of water modified the pattern of motion because, for example, the kayaker was not precariously balanced. A complete comparison will include a 3D anthropometrical model combined with a high speed kinematic and kinetic measurement for a population of kayakers.

Data from additional kayakers will be acquired to complete this present study. Using the technique developed by Colloud et al. (2008), numerous flatwater kayaking cycles will be acquired to improve the relevance of the analysis. This kinematics comparison is a part of a larger project which aims at improving kayaker’s movement and equipment design.

CONCLUSION:

In conclusion, the present study highlighted the feasibility of an accurate 3D kinematic analysis in flatwater kayak and then the comparison with an ergometer environment. Two expert kayakers reproduce their paddling patter of motion to a certain extent.

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