3-D KINEMATIC ANALYSIS OF CANOEING ON A SIMULATOR: DIFFERENCES BETWEEN ELITE, INTERMEDIATE AND NOVICE CANOISTS

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Using 3-D kinematic analysis, this paper identified kinematic variables that govern successful performance in canoeing on a simulator. The presence of side-to-side asymmetries in selected linear and angular variables was investigated. Elite, intermediate and novice canoeists participated. Similar to previously results for symmetrical cyclic sport activities like cross-country skiing, running and cycling, elite athletes evidenced higher movement amplitude and a more symmetric behavior compared with intermediate and novice paddlers. The less experienced athletes evidenced more accentuated saddle and pelvis movements in the frontal plane. Aerobic and anaerobic capacities and technical skills developed over years of training may explain the reported difference.

KEY WORDS: optoelectronic system, bilateral asymmetries, paddling, motor ability

INTRODUCTION: Simulators are widely used in biomechanic research and exercise testing because they can provide standardized procedures that are simple and inexpensive in a controlled environment. For kinematic data collection in particular, simulators offer a means of attaining a continuous action in a fixed experimental area. This allows the acquisition of a larger number of cycles per trial which increases the reliability of the kinematic variables. So far, few studies have investigated the kinematic characteristics of flatwater canoeing stroke. Sousa et al. (1996), utilizing a 2-D analysis, studied body segments kinematics in the sagittal plane with no kinematic data available for frontal and horizontal plane. By means of a 3-D kinematic analysis of elite, intermediate, and novice canoeists performing on a paddling simulator, the purpose of this paper was to identify the kinematic variables that govern successful performance in canoeing. In addition, the presence of side-to-side asymmetries in selected linear and angular variables was investigated by a simultaneous right and left analysis.

METHODS: A total of 15 male canoeists (5 elite, 4 intermediate and 6 novice) subjects, participated in this study. Mean values and standard deviations of certain physical characteristics and performance times are given in Table 1. Each subject performed on a specifically designed paddling simulator (Etindus Sport Department, France) which combines a highly realistic paddle feel (including a mobile carriage with side oscillation effects) with performance measurements.

Table 1 Physical Characteristics and Performance Times of the Subject Groups

	Mass (kg)	Height (cm)	Arm length (cm)	Trunk length (cm)	Age (yrs)	Performance times (1000 m)
Elite (n=5)	**84 ± 3**	**181 ± 3**	**58 ± 2**	**45 ± 2**	**25 ± 4**	**3' 50" ± 10"**
Intermediate (n=4)	**80 ± 4**	**183 ± 3**	**60 ± 2**	**47 ± 3**	**21 ± 3**	**4' 07" ± 8"**
Novice (n=6)	**78 ± 5**	**180 ± 5**	**58 ± 3**	**45 ± 3**	**23 ± 5**	**4' 55" ± 14"**
Total	**80 ± 4**	**181 ± 4**	**59 ± 2**	**46 ± 3**	**24 ± 6**	**4' 05" ± 22"**

After 30 minutes of standard warm up, each subject completed a 4 min paddling bout at increasing stroke frequency with the last minute performed at 95 rpm near their race pace. For each athlete, data for at least 20 stroke cycles were acquired during the last minute. Seventeen retroreflective hemispherical markers (12 mm in diameter) were placed on the following anatomical landmarks: acromions, epicondyles, ulnar styloid processes to mark the arms, posterior iliac superior spines and spinous process of C7, T10, L5 to reconstruct the pelvis and the trunk, centre of greater trochanters, lateral epicondyles, apex of lateral malleola to mark the lower limbs. In addition, two markers were placed on both sides of the saddle to capture its side to side movements in the frontal plane. At a sampling frequency of 100 Hz, the 3-D coordinates of each marker were estimated by an ELITE (B.T.S. srl, Milan, Italy) automatic motion analyzer by means of seven TV cameras to allow a complete 3-D analysis. Filtering of 3-D marker coordinates and computing of the derivatives were performed by using the algorithms based on an autoregressive model, fit to the signal, to evaluate the filter bandwidth and the extrapolation of the data. Next, the components of the coordinates of each marker were filtered by a linear phase FIR low-pass filter, with a proper cut-off frequency depending on the frequency content of the signal. Finally, the 3-D co-ordinates and the appropriate body segment parameters, stored in data files, were used as input for a specifically developed computer program. The program provided a unique array of graphic displays that allowed the user to instantly diagnose and treat asymmetry problems. The main menu has five options: 1) Enter data: after an automatic identification of the main stroke cycle events (push and pull phases), this routine normalizes the time over the stroke cycle. 2) Pre-elaboration: calculates internal joint rotation centers using markers co-ordinates and some measured anthropometric parameters. 3) Trajectories: plots and compares left right internal joint centers. 4) Angles: calculates relative and absolute joint angles and shows average angle patterns as a function of the stroke cycle. 5) Post elaboration: automatically identifies meaningful asymmetries computed for each variable as the percentage asymmetry index $ASY\% = [|right-left|/\min(left,right)]\cdot 100$ between the right and left side. Non parametric statistics were used to avoid the assumption of normal distribution of the underlying populations. Differences among the three subgroups were tested for significance using the Kruskall-Wallis one-way analysis of variance by ranks (unrelated samples), and the differences between the groups were localized by multiple comparisons ($p<0.05$).

RESULTS: Compared with the other two groups, the elite paddlers exhibited a significantly higher absolute and relative to arm length paddling amplitude (Table 2) despite having no significant difference in anthropometric dimensions (Table 1). The higher stroke amplitude of the elite paddlers was confirmed by analyzing the anterior-posterior displacement of the wrist joint centre in the sagittal plane (Figure 1) with elite and novice athletes characterized by the higher (83±3 cm) and lower values (67±4 cm), respectively. Similarly, angular motion at the elbows and knees in the sagittal plane and at the pelvis and trunk in the horizontal plane showed a tendency of decreasing values going from the more to the less experienced athletes (Table 3).

Table 2 Selected Biomechanical Parameters of the Paddling Action

		Elite	**Intermediate**	**Novice**
Paddling amplitude(cm)	Left	85	75	69
	Right	85*	77**	73
Paddling amplitude/ Arm length	Left	1.47	1.25	1.20
	Right	1.45*	1.28	1.25
Max saddle frontal angle (°)		2.5*	5.4	4.5
Min saddle frontal angle (°)		-4.8	-5.3	-8.1***
Saddle frontal ROM (°)		7.3*	10.7**	12.6

*Value significant different from intermediate and novice one. ** Value significant different from novice and elite one. *** Value significant different from elite and intermediate one.

Conversely, looking at the saddle (Figure 2 and Table 2 for the corresponding numerical values) and pelvis (Table 3) angular movements in the frontal plane the Elite and the Novice paddlers were characterized by the lower and higher range of motion, respectively. Examining some selected linear and angular variables (Table 3) generally the elite athletes demonstrated a more symmetric behaviour compared with intermediate and novice paddlers. This can be easily seen in Figure 1 where the average trajectory of the left and right wrist joint centre in the sagittal and horizontal plane for each subject group is displayed. In this figure, left and right trajectory patterns are displayed superimposed with respect to the simulator frame for better comparison.

Figure 1 Average trajectory of the left and right wrist joint centre in the sagittal and horizontal plane for each subject group (black = right, gray = left).

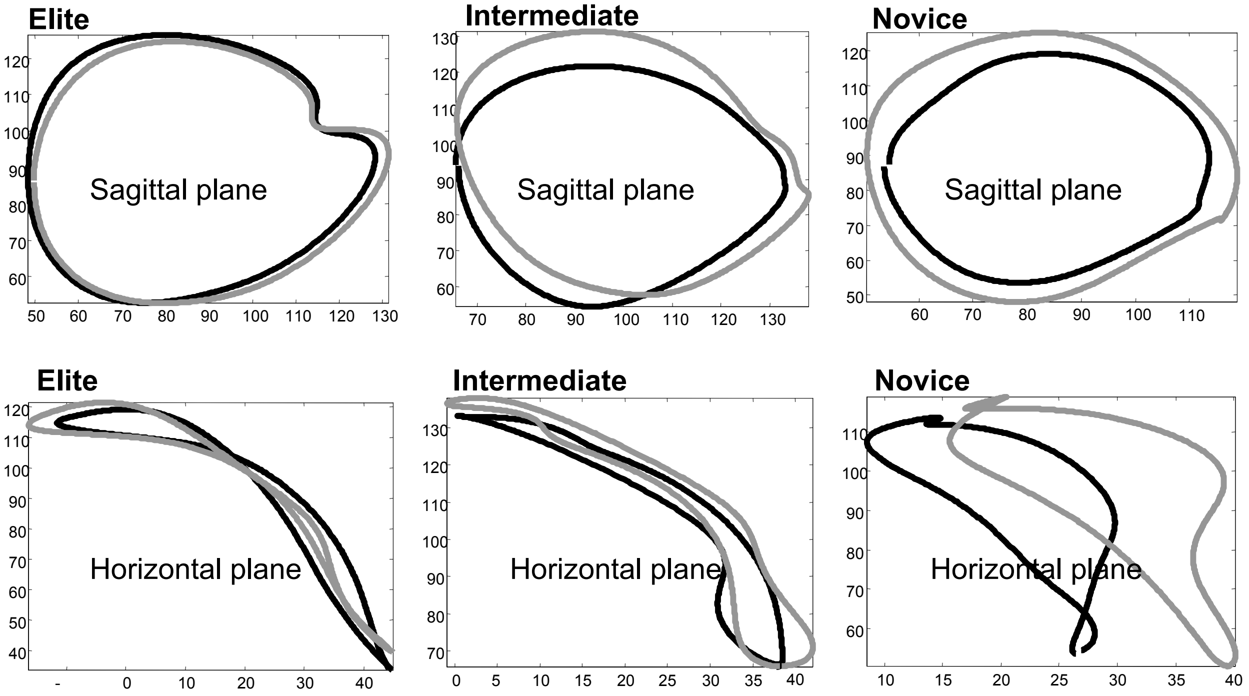
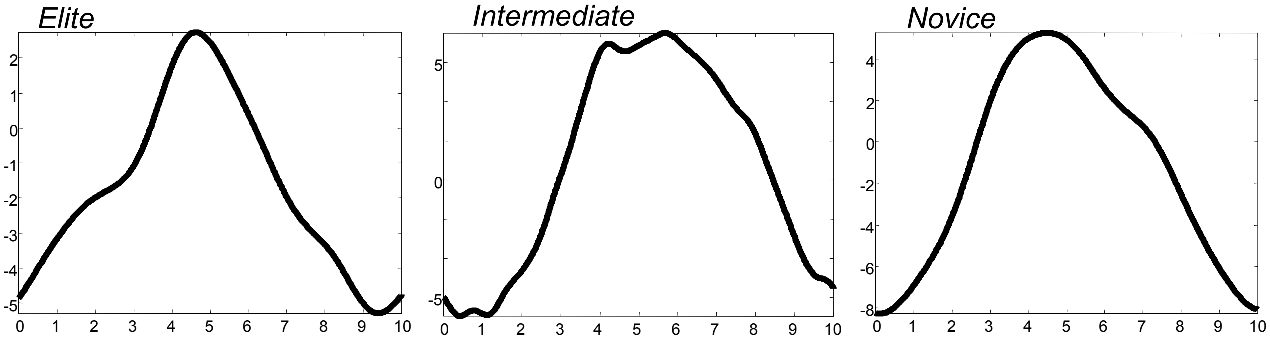


TABLE 3 Average Group Values for Selected Angular Variables

	Elite			Intermediate			Novice		
	Left (°)	**Right (°)**	**ASY %**	**Left (°)**	**Right (°)**	**ASY %**	**Left (°)**	**Right (°)**	**ASY %**
Sagittal plane									
Max elbow angle	136 (2)	138 (3)	1.5	137 (3)	120 (2)	14.2*	118 (3)	101 (4)	16.8*
Min elbow angle	25 (2)	28 (2)	12*	42 (3)	30 (2)	28.6*	50 (3)	37 (3)	35.1*
Elbow ROM	111 (3)	110 (3)	0.9	95 (3)	90 (3)	5.6*	68 (4)	64 (5)	6.3*
Max knee angle	175 (4)	176 (3)	0.6	172 (4)	170 (4)	1.2	168 (5)	167 (6)	0.6
Min knee angle	132 (4)	132 (5)	0	138 (5)	135 (5)	2.2	144 (7)	139 (8)	3.6*
Knee ROM	43 (5)	44 (4)	2.3	34 (6)	36 (5)	5.9*	24 (6)	27 (7)	12.5*
Frontal plane									
Max pelvis angle	1 (1)			5 (1)			9 (2)		
Min pelvis angle	-5 (1)			-2 (1)			0 (1)		
Pelvis ROM	6 (1)			7 (2)			9 (2)		
Horizontal plane									
Max pelvis angle	28 (2)			19 (5)			11 (4)		
Min pelvis angle	-20 (3)			-14 (4)			-7 (5)		
Pelvis ROM	48 (3)			33 (4)			18 (5)		
Trunk rotation	50 (5)			46 (4)			24 (5)		

*Significant asymmetries

Figure 2 Average angular movement of the saddle in the frontal plane for each subject Group.



DISCUSSION: The experimental protocol presented in this study allows identification and evaluation of significant differences in selected linear and angular kinematic variables among three groups of canoeists of different skill levels. The source factors of the documented difference among ability levels may only be speculated from the results of this study. Aerobic and anaerobic capacities as well as technical skills and mechanical efficiency developed over years of training may explain the reported differences.

The data shows a trend of decreasing amplitude of movement going from the more to the less experienced athletes with the joint ROM values significantly higher in the elite subject. This is similar to what was reported by Smith et al. (1996) in cross-country skiing and by Cavanagh et al. (1977) in running. Two factors can explain the reduced stroke amplitude in the less skilled subjects, 1) a reduced elbow flexion and 2) insufficient trunk and hip rotation. Likely, the reduced elbow flexion during the pull in the novice group was primarily a function of insufficient shoulder flexibility. When the shoulder are flexed less there is relatively little ROM available for the elbow to flex. Lack of strength in abdominal, lower back and upper leg muscles may explain the reduced ability to rotate the trunk and to keep the pelvis stable in the frontal plane. Trunk rotation is used primarily to increase the amplitude of the movement. In addition, trunk rotation stretches the abdomen and chest muscles which result in storage of elastic energy in the muscles and associated tissue. This storage energy may then partially assist the upper limbs during the next alternate rotation giving additional power to the following stroke.

Even if the presentation of the group data masks the individuality of each subject within the group and potentially washes out important intersubject differences most of the variables showed significant side to side asymmetries especially in the novice and intermediate group. The existence of significant kinematic asymmetries in a symmetrical activity like canoeing is similar to what was found for other symmetrical sports like running and cycling. As evidenced by Vagenas & Hoshizaki (1988) the systematic combination of structural and neuromuscular factors may be the source of bilateral differences frequently observed during the performance of symmetric physical activities.

REFERENCES:

Cavanagh, P.R., Pollock, M.L., & Landa, J. (1977). A biomechanical comparison of elite and good distance runners. In P. Milvey (Ed.), *The marathon: Physiological, medical, epidemiological, and psychological studies* (pp. 328-345). New York: New York Academy of Science.

Smith, G.A., Fewster, J.B., & Braudt, S.M. (1996). Double Poling Kinematics and Performance in Cross-Country Skiing. *Journal of Applied Biomechanics*, 12, 88-103.

Sousa, F., Oliveira, J., Goncalves J. (1996). Kinematic analysis of stroke cycle of an international athlete on canoeing-K1. In J. M.C.S. Abrantes (Ed.), *Proceedings of the XIV International Symposium of the Society of Biomechanics in Sports* (pp. 401-403). Lisboa: Edicões FMH.

Vagenas, G., & Hoshizaki, B. (1988). Evaluation of rearfoot asymmetries in running with worn and new running shoes. *International Journal of Sport Biomechanics*, 4, 220-230.