

Analysis of the Kayak Forward Stroke According to Skill Level and Knee Flexion Angle

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Abstract

The purpose of this study was to investigate the differences between elite and novice kayak forward stroke motion. A total of 20 subjects participated; 10 elite university kayak players and 10 male university students. The experiment was performed indoors on a kayak-ergometer testing between varied knee flexion angles of 90°; 120°; 150°. During the three knee flexion conditions, the following were measured; stroke frequency, paddling amplitude, joint angle ROM for the knee flexion/extension and thorax and pelvis rotational ROM, and plantar foot pressure. The results show that rowing with 120° knee flexion angle showed had a higher stroke frequency and paddling amplitude than other knee flexion angles. There were significant differences at the thorax, pelvis rotation and knee flexion-extension ROM for each condition. There were significant differences for the foot pressure between the elite and novice. In conclusion, the skilled group used more rotation of their trunk and pelvis than the unskilled and the optimum angle for knee flexion was deemed to be 120°.

Keywords: *Kayak, Forward stroke, Kayak-ergometer, Skill level, Knee flexion angle*

1. Introduction

Kayaking is one of the most common water leisure sports and has been defined as an exercise where one sits comfortably upright in a boat with their legs parallel in front and their two hands hold a paddle perpendicular to the direction of boat motion [14, 18, 20]. It has been reported that to maintain speed and forward motion, the most important part of the driving force is to row not just with sheer force but with technique and skill [8]. Furthermore, for continuous strong rowing it is important to have a stable and an optimum body posture [5, 14]. Baudouin and Hawkins (2002) state that to develop an efficient rowing motion, both the biomechanics of the body of a rower, formation of the boat and their interaction between them, must be considered. Baudouin & Hawkins (2002) and Pendergast, Mollendorf, Zamparo, Termin, Bushnell, & Paschke (2005) have also examined the various ways to increase the drag caused by rowing. Jackson (1995) states that it is vital to maintain a high speed by reducing the resistance and drag of the boat while maximizing the propulsion of the paddle.

Many biomechanical studies carried out to investigate various aspects of rowing; analysis of elite athletes rowing motion in a competition such as the Olympic games [10, 11, 13], a study focusing on the ideal of an ideal stroke and paddle angle of the elite [16], as well as the

forces created by the body measured and compared with the use of strain gauges and plantar pressure sensors [2, 4, 5, 8, 9]. Limonta, Squadrone, Rodano, Marzegan, Veicsteinas, Merati, & Sacchi (2010) investigated the kinetic differences between the elite, intermediate and beginner kayak athletes. They demonstrate that the elite have longer paddling lengths and have a pattern of symmetry between the left to right.

Shephard (1987) and Caplan & Gardner (2005) both report that the force must be initially developed by the foot on the pedal and the saddle for rowing. Studies examining the causes of shoulder injuries have recorded electromyography during both kayak and rowing, especially in the muscles surrounding the shoulder joint, lower and upper back [6, 7, 17]. With this understanding of the interaction between the kayaker and the boat; correct posture, increase in efficient rowing, muscle activation levels, the reduction of injury may occur. Ultimately, through an analysis of both kinetics and kinematics is required to develop a scientifically based training program for both elite and novice kayakers. Thus, the purpose of this study is to investigate the paddling mechanism and its relationship between the distance between the paddle and seat by varying the knee flexion while performing a forward kayak stroke on an indoor ergometer by the elite and novice kayakers.

2. Method

2.1. Participants

Two groups participated in this study (Table 1). The elite group was made up of 10 elite athletes (height: 178.8 ± 4.4 cm; weight: 75.3 ± 7.8 kg; experience: 9.7 ± 0.9 years). An elite athlete was defined as an athlete that was registered as an elite player in the canoe federation during the current year. The novice group was defined as a group of male university students that never had any kayak or rowing experience. This group was made up of 10 (height: 175.5 ± 4.0 cm; weight: 68.0 ± 4.3 kg). The exclusion criteria was that of anyone who had experienced any musculoskeletal problems occurring in the last 6 months and or anyone that has received surgery that could affect the forward kayak stroke. Only after verbal explanation and signature of the consent forms the experiment commenced.

Table 1. Descriptives of the Subjects' Demographics

Group	Age(yrs)	Height (m)	Weight (kg)	Experience (yrs)
Expert	21.9 ± 0.9	1.78 ± 0.04	75.3 ± 7.8	9.7 ± 0.9
Novice	25.4 ± 2.3	1.75 ± 0.04	68.0 ± 4.6	none

2.2. Data collection & Analysis

The forward kayak stroke was performed on the indoor rowing kayak ergometer (Stroke 2 Max Ergo, Upington, South Africa) while the kinematic motion was captured (EVaRT 5.0, Motion Analysis, USA). 83 reflective markers were attached to both the subject and the ergometer while 10 infrared motion capture cameras (Eagle4, Motion Analysis, USA) at a sampling rate of 100 Hz captured the positional data. For the plantar pressure the Pedar X-system (Munich, Germany) was used to capture the pressure at a sampling rate of 100Hz and was placed inside the participant's shoe. The experimental set up is shown in Figure 1 below.

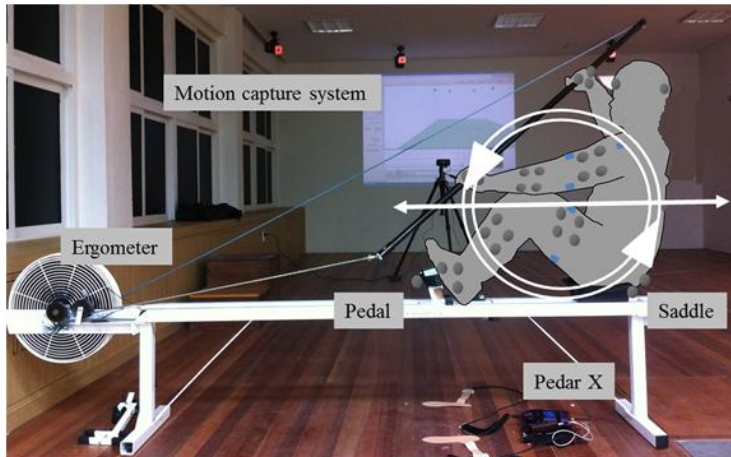


Figure 1. Experimental Equipment

2.3. Experimental Procedure

A warm up consisting of stretching and kayak specific exercises were performed after the participants were explained the procedure and signed the consent forms. As the beginners had never used an ergometer they were provided with additional training and practice times for a few minutes until they felt that they were comfortable to use the ergometer properly. When ready the participants had the reflective markers attached to the relevant joints and landmarks. Before the motion capture the 3 dimensional coordinates were calibrated by the using the L frame and the T wand for 60 seconds at a sampling rate of 100 frames/sec. After calibration, participants were then instructed to take off their shoes and the plantar pressure system was place inside (Figure 2).

The participants were then instructed how to perform the experiment at 3 different knee angles and after 30 seconds they had to perform the kayak forward stroke on the kayak ergometer (Figure 3). The order of the knee flexion condition was randomly ordered.



Figure 2. Experimental Procedure

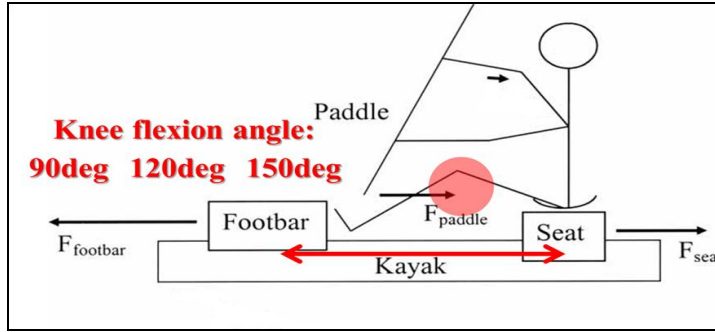


Figure 3. Description of Independent Variable

2.4. Data Analysis

The variables from the motion capture, i.e. thorax, pelvis and knee ankle joint angles and range of motions, were calculated by Visual 3D(C-motion inc, USA) while the maximum pressure, number of strokes, maximum pressure and forces were calculated by Matlab 2009 (Mathworks, Inc., USA). Prior to calculation of the kinematic variables a 4th order low pass Butterworth filter with a cut of frequency of 7 Hz was applied. For all of the variables calculated, the average of the three, 30 second trials was used for the analysis. Data from the left side was only included in the analysis.

2.4.1. Establishment of the Stroke Period: The period of one full stroke was defined as the period from the point where the left hand was out as far front is pulled back and then goes back out to the furthest frontal position (shown as in Figure 4 a to b to c).

2.4.2. Evaluation of the Kayak Forward Stroke Performance: The number of strokes during the period of 30 seconds and the length of the strokes was used to compare the performance of the kayak forward stroke motion between the elite and beginners. The stroke number was calculated per second and the stroke length was calculated as the distance from the left hand marker in the most anterior position to the left hand marker closed to the body (Figure 4).

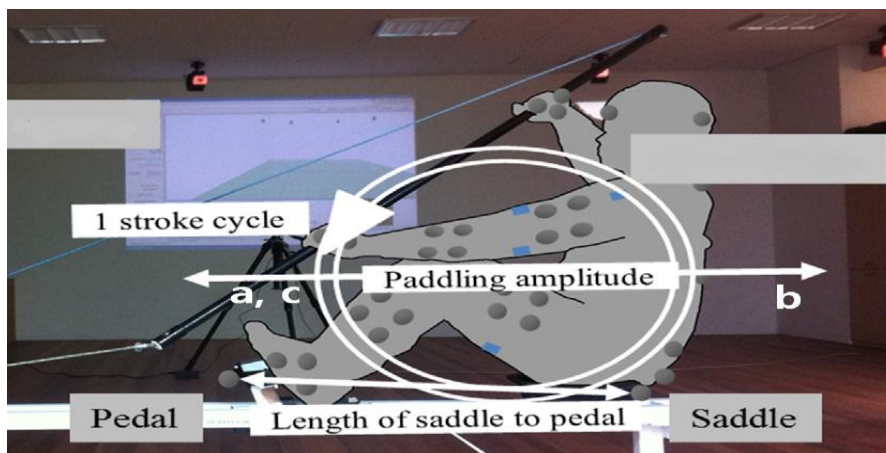


Figure 4. Stroke Cycle & Paddling Amplitude. a) Mid-sagittal Plane of the Left Hand as Far Front, b) Mid-sagittal Plane of the Left Hand as Close, c) Back to the Position on a

2.4.3. Kinematic Variables: The following kinematic variables were calculated; the range of the joint motion (ROM) for the knee, the rotational ROM angle in the horizontal plane of the thorax and pelvis.

2.4.4. Plantar Pressure Variables: The maximum plantar pressure variable was defined as the maximum pressure (kPa) of the left foot during one full paddle cycle (stroke period).

2.4. Statistical Analysis

SPSS version 18.0 was used to perform two way 2 (skill level condition) x 3 (knee flexion angle) repeated measures ANOVA with a significance level of 0.05 to investigate the differences between the groups according to the 3 knee flexion conditions. Post-hoc was carried out using Tukey criterion and a level of significance was set at 0.05.

3. Results

Table 2 and 3 display the descriptive statistics and results of the two way 2 (skill level condition) x 3 (knee flexion angle) repeated measures ANOVA was performed on the variables. There were main effects for the paddle amplitude, knee flexion ROM, thorax ROM and pelvis ROM. Post hoc analysis using the Tukey post hoc criterion was applied to investigate further significant differences.

Table 2. Descriptives and Post-hoc Results for the Maximum Pressure, Stroke Frequency and Paddle Amplitude

Knee Flexion(°)	Max Pressure (kpa)		Stroke frequency (stroke/s)		Paddle Amplitude (m)	
	Expert	Novice	Expert	Novice	Expert	Novice
90°	124.75±49.70	77.50±23.92	1.74±0.12	1.53±0.09	0.72±0.06	0.60±0.09
120°	117.50±29.23	65.75±25.66	1.74±0.15	1.49±0.12	0.76±0.06	0.65±0.09
150°	119.00±39.48	59.25±24.69	1.69±0.13	1.57±0.12	0.73±0.06	0.65±0.09
degree	p	0.26	0.29		0.034*	
	F	1.401	1.281		3.776	
within degree*group	p	0.707	<0.0001**		0.536	
	F	0.35	10.423		0.637	
post hoc	p	ns	Ns		0.042* ¹	
	F	18.946	13.514		9.418	
between	p	<0.0001**	0.002**		0.007**	
	F	18.946	13.514		9.418	

ns = not significant, i.e. above the level of significance

*p<.05; **p<.01; ***p<.001

¹ significantly different between 90 and 120

² significantly different between 90 and 150

³ significantly different between 150 and 120

Table 3. Descriptives and Post-hoc Results for the Knee Flexion ROM, Thorax ROM and Pelvis ROM

Knee Flexion		Knee Flexion ROM(°)		Thorax ROM(°)		Pelvis ROM(°)		
		Expert	Novice	Expert	Novice	Expert	Novice	
	90	15.96±7.89	4.98±1.58	82.59±6.93	51.09±8.35	21.48±6.09	5.76±2.79	
	120	29.16±7.91	9.87±6.81	87.89±7.89	54.54±6.94	22.92±6.07	5.72±2.33	
	150	24.78±6.07	9.90±5.45	81.74±7.54	54.79±9.38	16.46±4.74	5.10±2.13	
	degree	p	<0.0001**		0.003**		<0.0001**	
		F	32.063		6.967		16.293	
within	degree*group	p	0.005**		0.026*		<0.0001**	
		F	6.222		4.037		10.648	
between	post Hoc	p	<0.0001** ¹²		0.004** ¹ , 0.023* ³		0.003** ² , <0.0001** ³	
		F	36.824		88.671		67.486	

*p<.05; **p<.01; ***p<.001

¹ significantly different between 90 and 120

² significantly different between 90 and 150

³ significantly different between 150 and 120

4. Discussion

This study examines the effect of the knee flexion angle and the relationship of the distance between the saddle and paddle according to various skill level. Similar to the results shown in a previous study, different strategies are used at different knee angles and distances between the saddle and paddles [5]. To perform at a high level in kayaking competition it is important to be able to maintain the speed of the kayak with consistent and powerful stroke using your whole body [14, 16]. In this study the number of strokes per second and the length of the paddle stroke are investigate in an effort to quantify the performance of elite and beginners on an indoor kayak ergometer. Our results are similar to the findings of previous studies [14, 19] in that they highlight the effect that the knee flexion and distance between the peddle and saddle have on the stroke and changes in power.

Baudouin and Hawkins (2002) report the importance of the production of resistance by the length of the stroke (left and right) as well as the frequency of strokes during the contact between the paddle and the water. This study illustrates that with a change in distance as small as 10cm between the saddle and peddle, there is a substantial effect on the performance of the stroke length and frequency on the kayak ergometer. Furthermore, these results prove the need to understand the relationship between the distance between the saddle and paddle, as it is vital during both short and long distance kayak racing performance to use different paddling strategies.

Greene, et al., (2009) illustrated that there is a difference in the effectiveness of a rower according to the proportional size of their shank and their thigh while rowing on a kayak ergometer. When they investigated and compared high and low ratio of thigh to shank they observed differences in the rowing motion, especially expressed by the differences in the horizontal rotation of the trunk and the pelvis. Similarly in this study there were significant

differences observed between the rotation of the trunk and pelvis range of motions according to the groups. In addition from the mid-sagittal plane it was observed that there were significant differences at the joint ranges of motion and saddle to peddle distance, which were largest at the knee flexion angle of 120°.

The highest peak plantar pressures were recorded in order of the 90° knee flexion followed by the 120° and 150°. The elite kayakers are known for optimizing their use for the body by minimizing the loss of energy and by using the reaction force of the peddle to help create large thorax and pelvic rotations which increases the power efficiency and length of the stroke [9]. Although the highest peak plantar pressures were manifested at the knee flexion angle of 90°, this power didn't transfer to the horizontal plane in where the length of the peddle stroke and stroke efficiency are vital [13, 16].

5. Conclusion

In general, the expert groups used more knee flexion which helped them use more of their upper body (trunk and pelvis) to rotate more and thus generate more power(max pressure), higher stroke frequencies and longer paddle amplitudes. Similarly the subjects performed more efficiently at the knee angle condition of 120° by creating more movement and power. Future studies should investigate differences in the muscles used during the kayak forward motion stroke so as to be able to develop efficient training programs.

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