Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

KINEMATICS IN ELITE KAYAKERS WHILE PADDLING A SLIDING ERGOMETER EQUIPPED WITH STANDARD AND SWIVEL SEATS

Vincent Fohanno, Floren Colloud, Khalil Ben Mansour and Patrick Lacouture

Institut Pprime UPR 3346, CNRS – Université de Poitiers – ENSMA,
Département génie mécanique et systèmes complexes, Poitiers, France

This study investigated the effects of two seat designs (standard versus swivel seats) at two paces (training and race paces) on the main kinematics parameters involved in kayaking performance. Eight elite athletes performed two trials at an incremental stroke rate. Sixteen markers were recorded by a motion capture system. Angular (trunk) and linear (blade tips) kinematics were calculated during aquatic phase. A Wilcoxon signed-rank test was carried out to compare seat conditions. Results indicated a significant increase of pelvis and thorax rotations associated with both greater mediolateral displacements and velocities of the blade tips at both paces. However, complex interactions may limit these positive effects. While paddling on-water, the performance in competition was not improved significantly with the introduction of the swivel seat.

KEY WORDS: flatwater kayaking, performance, equipment.

INTRODUCTION: In flatwater kayaking, the final ranking is determined by the time taken to complete a race distance (500 m and 1000 m at the Olympics). Hence, the mean velocity of the *athlete-paddle-kayak* system (S_{apk}) is the external mechanical factor of on-water performance. The change in velocity of S_{apk} depends on both its mass and the four forces acting on this system: gravitational, buoyancy, total resistance due to aerodynamic and hydrodynamic drag, and blade force (e.g. Begon, Colloud & Lacouture, 2009). The anteroposterior component of the blade force represents the propulsive force. Its magnitude depends on blade shape, blade orientation, and the velocity of the submerged part of the blade. To create a propulsive force, this velocity must be superior to the S_{apk} velocity in a global coordinate system with corresponding vectors in opposite directions.

Over the past twenty years, the introduction of the wing blade significantly improved performance by generating a propulsive force composed by both drag and lift forces (Michael, Smith & Rooney, 2009). To generate and properly use a lift force, the blade motion must be more laterally oriented than observed with conventional (flat) blades. It was shown that the propulsive efficiency was increased when using lift forces, explaining a large part of the performance improvement (Jackson, Locke and Brown, 1992). Thus, the effort required to propel the S_{apk} is assumed less important and more economical using the wing blade.

Michael, Smith & Rooney (2009) reported that this lateral movement observed when paddling with a wing blade is the consequence of a larger torso rotation coupled with a larger knee extension (i.e. larger lower limb pedalling movement). It was suggested that torso rotation was used as a physiologically economical solution to move the wing blade laterally because larger muscles are solicited than during the extension of both shoulders and upper limbs. Recently, Begon, Colloud & Sardain (2010) simulated a 1000 m kayaking race performed on the Poitiers-A kayak ergometer. They showed an important increase of the energy expenditure when the pelvis was fixed, i.e. the knees were kept extended. Moreover, this study outlined the need to increase the pelvis rotation using the lower limbs to improve the performance (i.e. the blade velocity).

Several different types of seats are currently available. They mainly differ from each other by the height of the backside and by the design of mechanisms that facilitate the pelvis rotation (e.g. swivel seat). Michael, Smith & Rooney (2010) reported that paddling an ergometer equipped with a swivel seat over a two-minute all-out race led to a significantly greater mean power output compared to paddling with a standard seat. They concluded that physiological responses are not sufficient and a biomechanical approach could provide a complete representation of how the swivel seat affects performance at race pace, i.e. a stroke rate superior to 100 strokes per minute (spm) (Szanto, 2004). To our knowledge, athletes and coaches cannot choose a seat from objective criteria as no comparative analyses have yet been carried out in term of biomechanical parameters. Moreover, since performance in flatwater kayaking is mainly due to the kayaker's aerobic capacities (about 70-75% for a 500 m race, Bishop, 2000), training sessions mainly include long distances covered at a low stroke rate. As a result, it seems crucial to have an objective biomechanical quantification of the paddling movement using a swivel seat at training pace.

The purpose of the present study is to investigate the effects of two seat designs (i.e. standard vs. swivel seats) at two different stroke rates (training and competition stroke rates) on the main kinematics parameters involved in kayaking performance.

METHODS: After giving their informed consent in accordance with local ethical procedures, eight elite athletes (three females and five males) volunteered to take part in the study (age: 19.9 ± 2.4 years, height: 1.81 ± 0.10 m, body mass: 75.0 ± 9.9 kg). After a warm up session, the participants performed two 45 seconds tests in a random order, one on a standard seat and one on a swivel seat, on the Poitiers-B kayak ergometer. Each test was performed at an incremental stroke rate dictated by an electronic metronome (60-110 spm) to assess the influence of the seat design at both training and competition stroke rates. The Poitiers-B kayak ergometer has been recently developed to improve the reproduction of on-water dynamics (Colloud et al., 2010). This ergometer offers the possibility to easily change the seat set-up. The standard seat is the commonly equipped seat on flatwater kayak. The swivel seat has a higher back as well as an added pivot under the seat. This pivot allows a rotation along a vertical axis to facilitate the rotation of the pelvis. This also has the effect of increasing the trajectory of the blade during the propulsion. Sixteen reflective markers were used to collect the 3D coordinates of the ergometer paddle (4 markers), trolley (4 markers), pelvis (right and left EIAS and EIPS) and thorax (C7, D3, Manubrium and Xiphoid). The trajectories were recorded using a 10-camera motion capture system sampled at 250 Hz (T40, Vicon-Oxford, UK). The gaps in the trajectories caused by occlusions were filled in by spline interpolation. As the trolley can move back and forth, all the trajectories were expressed in a frame embedded to the trolley to be able to compare the performance of each participant.

To accurately identify aerial and propulsive phases of each cycle, both virtual waterline and virtual blade tips were set for each participant from measurements done with their kayak (K1) and paddles used in flatwater kayaking competitions. The personalised distances between the waterline and the seat were measured on-water during a static trial. These were used during the ergometer tests in a frame embedded to the trolley as the virtual waterlines. The situation of the virtual blade tips during the kayaking tests for each participant was computed using the length of their paddle and the four markers placed on the ergometer paddle.

Angular parameters were calculated for each participant during aquatic phase: amplitudes of the internal/external rotation of the pelvis, thorax and thorax with respect to (*wrt*) the pelvis. Angles were calculated using the Cardan sequence following the recommendations of the International Society of Biomechanics (Wu et al., 2005). The internal/external rotation corresponded to the third (and last rotation) of the Cardan sequence. Moreover, displacements and mean velocities of the virtual blade tips were computed along the anteroposterior and mediolateral axes of the trolley frame. Eight consecutive cycles were selected for both 60-80 and 90-110 spm intervals to analyse the calculated parameters at training and competition paces, respectively. For each variable, the hypothesis of normal distribution was rejected (Shapiro-Wilk test). A Wilcoxon signed-rank test was carried out to compare seat conditions at training and competition stroke rates. A significant difference was found when the p-value was below 0.05.

RESULTS: The mean amplitudes of the internal/external rotation (table 1) were all statistically different for each stroke rate ($p < 0.05$). On one hand, concerning the pelvis and thorax rotations, the amplitudes were superior for the swivel seat condition whatever the stroke rates. On the other hand, lower mean rotation amplitudes of the thorax *wrt* the pelvis were observed for the swivel seat condition.

Table 1
Internal/external rotations for seat conditions and stroke rates (mean ± standard deviation)

Stroke rate (spm)	60-80		90-110	
Seat type	Standard	Swivel	Standard	Swivel
Pelvis (°)	24.6 ± 7.3	35.1 ± 8.9*	29.9 ± 6.5	39.3 ± 7.4*
Thorax (°)	66.5 ± 9.9	73.9 ± 11.3*	76.9 ± 9.4	81.3 ± 9.6*
Thorax *wrt* Pelvis (°)	35.9 ± 3.6	32.8 ± 5.2*	40.5 ± 5.8	36.1 ± 6.5*

An asterisk (*) indicates a significant difference between seat conditions at the corresponding stroke rate

As the time duration could have a direct influence on the calculation of the blade-tip parameters, a statistical analysis on the aquatic phase duration was performed. No significant difference was found between seat conditions at training ($p = 0.5$) and competition ($p = 0.4$) stroke rates. Mean displacements and velocities of the blade tips (table 2) were significantly greater for the swivel seat condition along the lateral axis for each stroke rate ($p < 0.05$). Although the tendency was the same for these parameters along the anteroposterior axis, no statistical difference was found whatever the considered stroke rate.

Table 2
Displacements and velocities of the virtual blade-tips for seat conditions and stroke rates (mean ± standard deviation)

Stroke rate (spm)	60-80		90-110	
Seat type	Standard	Swivel	Standard	Swivel
Anteroposterior displacement (m)	1.89 ± 0.07	1.92 ± 0.06	1.83 ± 0.08	1.85 ± 0.08
Mediolateral displacement (m)	0.58 ± 0.08	0.64 ± 0.11*	0.56 ± 0.09	0.61 ± 0.10*
Anteroposterior velocity ($m \cdot s^{-1}$)	3.70 ± 0.36	3.76 ± 0.38	5.02 ± 0.40	5.06 ± 0.47
Mediolateral velocity ($m \cdot s^{-1}$)	1.13 ± 0.16	1.25 ± 0.21*	1.52 ± 0.16	1.66 ± 0.21*

An asterisk (*) indicates a significant difference between seat conditions at the corresponding stroke rate

DISCUSSION: The objective of the present study was to assess the effects of the kayak seat design on key kinematic parameters involved in the performance at training and competition paces. Our results indicated that participants used the additional degree of freedom to increase their internal/external rotation amplitudes for both pelvis and thorax segments (see table 1). However, lower internal/external rotation amplitudes of the thorax *wrt* the pelvis were reported for the swivel condition. Hence, the larger rotation of the thorax was a consequence of the larger pelvis rotation. Larger displacements, but not significant for the anteroposterior axis, of the virtual blade tips were observed with the swivel seat. In other words, the swivel seat promotes the pelvis rotation associated with a stabilisation of the trunk that results in better performance. Our results may be related to the findings of Michael, Smith & Rooney (2010) who showed an increase of the performance (i.e. power output) with similar physiological responses (e.g. oxygen consumption, blood lactate concentration, heart rate) between both seat conditions. In their survey article, Michael, Smith & Rooney (2009) suggested that the greater solicitation of the trunk muscle groups instead of those of the upper limbs may be an economical solution from a physiological point of view to move the blade tips laterally when paddling a wing blade. One of the effects observed during the swivel seat condition was the larger lateral movement of the blade tips. Hence, our results may be also interpreted in terms of energy minimisation. Lower limb pedalling movements may be less demanding than the rotation of the thorax *wrt* the pelvis that involves numerous short muscles of the trunk.

The second observation of the present study was the increase of the mediolateral blade tip velocity with the swivel seat whatever the stroke rate (table 2). While using the wing blade, this increase should lead to a greater production of lift forces that contribute to the forward propulsion of the kayak (Jackson, Locke and Brown, 1992). Consequently, the performance would be improved since the anteroposterior component of the velocity remained unchanged. Although Michael, Smith & Rooney (2010) focused on the physiological responses to the use of a swivel seat in comparison with a standard seat at race pace, they reported a greater mean power output when paddling a swivel seat. Our results confirmed their findings since the calculation of the power output on an ergometer is function of the flywheel velocity that is dependent of the blade tip velocity. Moreover, results were similar between 60-80 and 90-110 spm indicating that the benefits of the swivel seat design and the segments coordination are preserved at training stroke rates. This result is important from a coaching point of view. As for rowing, the main part of training sessions is performed at low stroke rates to develop aerobic capacities (Szanto, 2004).

Although the anteroposterior velocity was slightly greater with the swivel seat, no statistical differences were found. These findings did not confirm the differences observed in the simulation study of Begon, Colloud & Sardain (2010) where the anteroposterior velocity was significantly decreased when the pelvis rotation was suppressed. The pelvis was not kept fixed in our study for the standard seat condition. This feature could explain the non-significant results obtained between both seat conditions. The experiments were conducted on an ergometer to measure easily and accurately the 3D kinematics of the participants. Although the Poitiers-B kayak ergometer is an evolution of the one used in our previous studies that reproduced accurately on-water mechanical conditions (Begon & Colloud, 2007), further specific analysis is required to investigate the effects of seat designs during on-water kayaking. Indeed, there is currently no evidence that a swivel seat significantly improves on-water performance. Complex interactions may limit the benefits showed in this study.

CONCLUSION: This study showed the effects of the swivel seat design on the kinematics while kayaking on an ergometer. Pelvis and thorax rotation amplitudes were increased and led to greater mediolateral displacements and velocities of the blade tips. Hence, a greater performance would be expected since the anteroposterior velocities remained unchanged. Further research is necessary in ecological conditions to investigate the mechanical effects of the swivel seat on performance.

REFERENCES:

Begon, M., & Colloud, F. (2007). A kayak ergometer using a sliding trolley to reproduce accurate on-water mechanical conditions. *Journal of Biomechanics, 40,* S439.

Begon, M., Colloud, F., & Lacouture, P. (2009). Measurement of contact forces on a kayak ergometer with a sliding footrest-seat complex. *Sports Engineering, 11,* 67-73.

Begon, M., Colloud, F., & Sardain, P. (2010). Lower limb contribution in kayak performance: modelling, simulation and analysis. *Multibody System Dynamics, 23,* 387-400.

Bishop, D (2000). Physiological predictors of flat-water kayak peformance in women. *European Journal of Applied Physiology,82*, 91-97.

Colloud, F., Brichet, R., Durand, F., Munoz, F., & Lacouture, P. (2010). Improvements in the design of a kayak ergometer using a sliding footrest-seat complex. *Procedia Engineering, 2*, 3465.

Jackson, P.S., Locke, N., & Brown, P. (1992). The hydrodynamics of paddle propulsion. In *Proccedings of the 11th Australasian Fluid Mechanics Conference,* pp. 1197-1200.

Michael, J.S., Smith, R., & Rooney, K (2009). Determinants of kayak paddling. *Sports Biomechanics, 8,* 167–179.

Michael, J.S., Smith, R., & Rooney K. (2010). Physiological responses to kayaking with a swivel seat. *International Journal of Sports Medicine, 31,* 555-560.

Szanto, C. (2004). *Racing canoeing*. International Canoe Federation.

Wu, G., van der Helm, F.C.T., Veeger, H.E.J., et al. (2005). ISB recommendation on definition of joint coordinate systems of various joints for the reporting of human joint motion–Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics 38*, 981–992.

Acknowledgements

V. Fohanno was supported by a grant from the Ministère de la recherche et de l’enseignement supérieur (France). The financial support of Région Poitou-Charentes (France) and European Union (CPER 2007-2013) is gratefully acknowledged. We thank O. Boukpetit and A. Richard (Fédération française de canoë-kayak), F. Durand (CAIPS, CREPS Poitou-Charentes) and the athletes for their contributions in the study.