

A 6-COMPONENT PADDLE SENSOR TO ESTIMATE KAYAKER'S PERFORMANCE: PRELIMINARY RESULTS

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The purpose of this study was to measure the paddle shaft-hand interaction while an athlete paddled a kayak ergometer. The paddle shaft was specifically equipped with two 6-component force sensors to measure the contact force between the athlete's hands and the paddle shaft. In order to minimise the error of the data collected, this new instrumentation was specifically calibrated for this experience. Preliminary results suggested that this new instrumentation provided data of high interest to improve our knowledge of the propulsion and recovery phases while kayaking an ergometer. In the future, this innovative instrumentation could be used during on-water sessions.

KEY WORDS: 6-component force sensor; kayak; calibration; paddle interaction, ergometer.

INTRODUCTION: Kayaking is a cyclic sport which makes great demands on the upper part of the body for the propulsion of the boat. The measurement of forces generated by the hands on the paddle shaft is of first importance to better understand kayaking propulsion. The knowledge of these forces is important for both coaches and scientists to improve kayaking performance and to provide to the kayakers a feedback on their technique. Over the past years, few researchers have investigated the force applied on the paddle by the kayakers on ergometer or ecological conditions (Mimmi, et al., 2006; Begon, et al., 2009; Sturm, et al., 2010; Helmer, et al., 2011). These studies were mostly conducted using a single component sensor giving a partial view of the forces generated on the shaft by the hands. Thus, the objective of this paper was to set-up 6-component force sensors placed at the interface between the paddle shaft and the hands and to show preliminary results register using this innovative instrumentation.

METHODS: The first step was to design two 6-component force sensors to measure the interaction between the hands and the shaft of the paddle. Four main constraints have to be respected to design these sensors to be used by elite kayakers while paddling on an ergometer or on-water: mass, inertia with respect to the long axis of the sensor, dimension and nominal values. These two sensors (Figure 1) were specifically manufactured by Sensix (Poitiers, France). Tridimensional forces and moments generated on the handle were estimated by six Wheatstone bridges set up with gauges bonded on six beans. The mass of each sensor including the electronic was 430g; 90g for the test specimen and 150g for the handle. The mass of the sensor was distributed uniformly around the long axis of the sensor to limit the inertia. The maximal height and diameter for the test specimen were 27mm and 53mm, respectively. The maximal height and diameter for the handle were 130mm and 29mm, respectively. The nominal value of each sensor was 600N with a maximal force of 345N for each force component and 107Nm for each moment component. The second step was to design a specific paddle shaft for the integration of the two sensors at the level of the contact points with the hands using a computer aided design software (Figure 1A). This new shaft was composed by five tubes in carbon (Figure 1B) bonded with an epoxy two-component adhesive (Figure 1C). The main tube offered an external diameter of 25mm, smaller than the diameter usually used by kayakers, to allow the integration of the sensors. However, the mechanical properties were similar that those observed on the classical paddle shaft used in competition. This main tube was divided in his middle by a

device conventionally used in kayak providing translation along its long axis. Thus, this paddle shaft allowed a variation in length between 1340 to 1440mm. The positioning of the 6-component force sensors on the paddle shaft allowed a variation of the spacing between the two hands from 548 to 778mm. This spacing provided a wide range to fit the anthropometry of most kayakers. At the level of the hands, the diameter of the sensor tube was 29mm, similar to a classical paddle shaft.

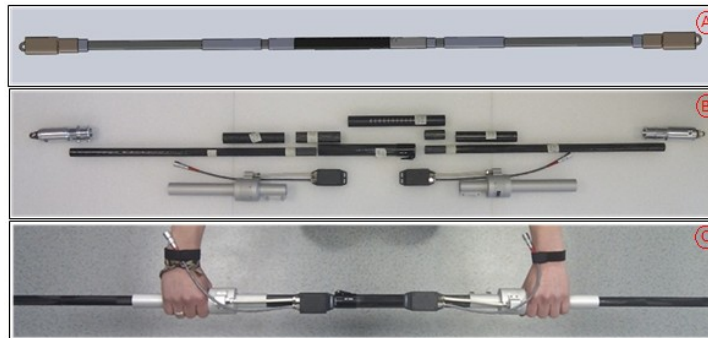


Figure 1: The paddle shaft equipped with the two sensors. Modeling of each component using a computer aided design software (A). View of each component (B). The paddle shaft assembled and equipped with the two 6-component sensors (C).

The third step was to develop a specific calibration method with the sensors placed on the shaft. This calibration method used standard weights (50N, 100N, 150N and 200N) in a specific set-up. These weights were applied on three different positions on the handle of the sensor (referred as P1, P2, P3 in Figure 2-A) to simulate the displacement of the centre of pressure and four orientations of the sensor (referred as to O1, O2, O3, O4 in Figure 2-B) to simulate the complex path of the shaft during the paddling cycle. This calibration method was designed to deform simultaneously the six strain gauges and to evaluate the sensor performances in both traction (T) and compression (C). To minimise the problems of coupling (linkage) between the paddle and the sensor, problem caused by the irregular surface of the paddle, a second order matrix calibration was generated from de data collected.

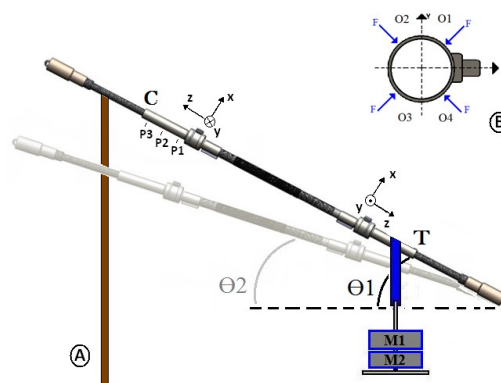


Figure 2: Experimental device to calibrate the sensors placed on the paddle shaft. Illustration of the three positions (A) and the four orientations (B) used during the specific calibration process.

An elite female kayaker (age: 22 years; mass: 56.7kg; height: 1.6m) volunteered to participate to this study. She performed a warm-up routine on the Poitiers-B kayak ergometer (Colloud, et al., 2010; Fohanno et al., 2014) until she was confident in kayaking with this new equipment. She was recorded during three 45-seconds tests at 60, 80 and 110 strokes per minute (spm), respectively (Figure 3). Each test included static, starting and steady paddling phases. Signals were recorded and synchronised in a tablet PC using a PCMCIA card.



Figure 3: The Poitiers-B kayak ergometer equipped with the instrumented paddle shaft paddled by the elite female kayaker.

RESULTS: The calibration method showed a difference between the reference values and the values estimated by these two sensors always lower than 10N regardless of the calibration weight. The relative errors were lower than 1.5% and 1% for the right and left sensors, respectively. The largest relative errors were less than 1.5%. They were observed in compression for the trial P1O1 for the two sensors. The lowest relative errors were obtained in traction during trials P2O3 and P3O2 for the right and left sensors, respectively.

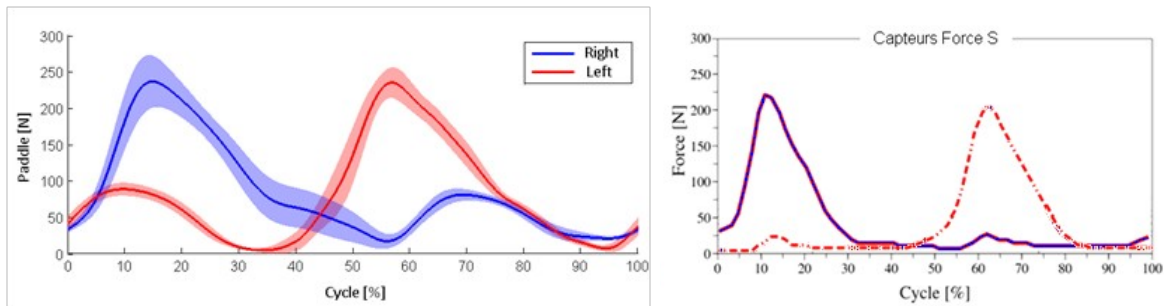


Figure 4: Mean curves of the force (norm) at 80 spm measured by the 6-component sensors with standard deviations (Left). Mean force measured at 84 spm by a mono-axial sensor reported by Begon, et al. (2009) (Right)

The forces were statistically averaged and time normalised to 100% of a kayaking cycle. The cycle begins with the entry of the right blade (Figure 3). During the propulsion phase, similar patterns and peak values were reported by previous studies (Begon, et al., 2009; Mimmi, et al., 2005) while kayakers paddling a kayak ergometer. The mean peak force increased of about 15% while the stroke rate increased from 60 spm to 110 spm. During the recovery phase, the force patterns showed some main differences. The upper limbs segments on the side of the propulsive blade (draw segments) were pulling on the shaft while those on the side of the aerial blade (thrust segments) were pushing the shaft. The mean peak force was similar $90\pm 5\text{N}$ whatever the stroke rate. As a result, the force generated by the thrust segments represented, on average, 35% of the force generated by the draw segments. Whatever the propulsion or aerial phases, the force generated on the shaft by the hand showed compression force and shear forces.

Table 1
Mean peak of the force (norm) measured by the sensors with standard deviations.

Stroke rate (spm)	Mean peak force (N)	
	Right	Left
60	224±15	225±19
80	248±15	237±15
110	258±33	263±13

DISCUSSION: The objective of this study was instrumented a paddle shaft in order to measure the force generated at the interface between the paddle shaft and the hands and to show preliminary results from this innovative instrumentation. The integration of two 6-component force sensor required a specific calibration procedure. This calibration method showed a low relative error in a static condition while it was associated with a second order matrix of calibration. The surface of the shaft was not regular enough to use a first order calibration matrix. The main disadvantage was that this calibration procedure has to be repeated if the force sensor is removed or even if one bolt is screwed harder. The consequence would be to modify the geometry of the force sensor and then, it would affect the calibration matrix.

These 6-component force sensors presented the advantage to show tridimensional forces during both propulsion and recovery phases. To our knowledge, shear forces generated during kayaking were not documented in the scientific literature, yet. Further investigation must be undertaken in the future to better understand how the handle force is generated and the link with kayaking performance. This instrumentation should be a main help to improve kayaking technique, to find factors that would minimise injuries, maximise the performance and evaluate new kayaking materials.

This instrumented paddle shaft was designed to be also used during on-water trials. To date, the main problem to solve is to measure the position and orientation of the paddle shaft during the whole kayaking cycle to be able to project the force vector in the global frame. The use of an Inertial Motion Unit could be a solution to access to these data. Hence, it would be interesting for further studies to know both accuracy and precision of this kind of device used during this specific application.

CONCLUSION: Two 6-component force sensors were designed and implemented on a paddle shaft to measure the force generated at the handle. A specific calibration procedure was developed to improve the force estimation. Tridimensional handle force was investigated when kayaking on an ergometer at different stroke rates. Our preliminary results suggested that this new instrumentation provided data of high interest to improve our knowledge of the propulsion and recovery phases while kayaking an ergometer.

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