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Developing and applying a tri-axial accelerometer sensor for measuring real time kayak cadence

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Abstract

Cadence measurements are commonly used in sport to give athletes and coaches live and delayed information about the frequency of a repetitive movement. Lisa Carrington won gold at the 2012 London Olympics with a cadence of 70 double strokes per minute in the women's K1 200 Canoe Sprint, while Mahe Drysdale won gold in the Men's Single Sculls rowing final with an average cadence of about 35 strokes per minute. These numbers, while interesting, provide important feedback to the athlete about whether they are performing within the cadence range that is most efficient and will provide them with the greatest performance. In cycling, pedalling at low cadences, 60rpm vs. 100rpm, reduces gross and physiological efficiency [1] while too higher cadence [2] causes suboptimal muscular coordination. Non-optimal cadences may also be linked with injury. For example, in rowing [3], high cadence may change pelvic motion, leading to low back pain symptoms. A tri-axial accelerometer was programed within an electronic circuit to compare kayak paddles movements against set acceleration criteria indicating the completion of a stroke. Upon identifying a stroke, this information was used to calculate the frequency of completed strokes per minute. This frequency information was then transmitted via ANT+™ protocol, received and displayed on an ANT+ ™ compatible device (e.g. Garmin's Forerunner or Edge GPS watches). A case study demonstrating the application of this technology to kayak performance training was observed. The coach set distances for athletes to train over, with varying cadence requirements while aiming to maintain the kayak's speed. The rationale for this type of cadence based training was that by fixing cadence and asking the athlete to manipulate speed, improvements in stroke length and technique were required.

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Keywords: Cadence; kayak; Vaaka; accelerometer; feedback

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1. Introduction

Cadence measurements are commonly used in sport (e.g. cycling, running, rowing and swimming) to give athletes and coaches live and delayed information about the frequency of a repetitive movement. Changes in cadence can optimize or deteriorate gross and physiological efficiency [1]. When performing a sport within the ideal cadence, athletes tend to move in an optimal manner; while performing with high or low cadence, may lead to suboptimal technique, resulting in poor muscle recruitment and force production, and consequently poor performance. Therefore, performing at the optimal cadence is crucial for athletes.

Cadence has been extensively researched in sports like cycling, and it has been used for determining the gross efficiency and/or economy in that sport [1]. For example, some studies have reported that changes in cadence leads to improved economy (i.e. lower oxygen uptake) [4, 5]. Pedaling at low cadences (e.g. 60rpm) was shown to reduce gross and physiological efficiency, when compared to 100 rpm [1]. On the other hand, excessively higher cadence may lead to suboptimal muscular coordination, impacting on athlete's performance [2]. Measuring cadence can provide valuable information for athletes and coaches to improve performance.

Suboptimal cadences can also impact in musculoskeletal injuries. In rowing, high cadence was shown to change pelvic movement pattern, and that could, theoretically, be the cause of lower back pain complaints in rowers [3]. Similarly, a recent review reported relative low stroke rate to be associated with high load per stroke, and that could lead to rib stress fractures [6]. This review also reported that a stroke rate of 24 resulted in decreased stress on the lumbar spine, when compared to a stroke rate of 18, 20 or 22 [6]. Therefore, injuries may be prevented by controlling load and stroke rate.

At the 2012 London Olympics, Lisa Carrington won gold with a cadence of 70 double strokes per minute in the women's K1 200 Canoe Sprint, while Mahe Drysdale won gold in the Men's Single Sculls rowing final with an average cadence of about 35 strokes per minute. These two cadences were crucial factors as many of their opponents had lower cadences meaning they needed a longer stroke length to maintain the same speed.

These numbers, while interesting, provide important feedback to athletes and coaches about whether they are performing within the cadence range that is most efficient. While cadence devices are commonly used for training purposes in sports like cycling, running, rowing and swimming, there has been no equivalent device developed for kayaking. Most commercialised cadence devices utilise magnetic switch technology mounted to a bike pedal or sliding seat on a rowing skiff and this technology is unsuitable for kayaking. The movement of a kayak stroke does not always pass close enough to the boat for magnetic switch sensor to be effective. Accelerometers however have started to appear in swimming watches or running shoe pods and provide acceleration information which can be interpreted for movement characteristic that indicate a cycle has occurred. This type of technology lends itself to the motion of a kayak paddle providing a starting point for designing a new kayak cadence device. It also could be applied to many cyclical motions in various sports for measuring cadence including, canoe paddling and horse racing. The aim of this study is to describe the development and application of a tri-axial accelerometer sensor for measuring real time kayak cadence.

2. Methods

This is a technical report on the development of a tri-axial accelerometer sensor for measuring real time kayak cadence, with a case-study report illustrating its use during a kayak training session.

2.1 Development of a tri-axial accelerometer sensor for measuring real time kayak cadence

The Vaaka™ kayak cadence sensor is an electronic sensory device which has 3 components: a plastic housing, AAA 1.5v battery and an electronic circuit containing a sensor, microprocessor and transmission chip.

The plastic housing was constructed using steel tool injection mounding where hot plastic was squirted into a steel mold. Three types of plastic were used: hard wearing for the top, transparent acrylic for the base and silicon for the strap which connected it to the paddle (Figure 1). When assembled these component were rated to IP67 dust and waterproofing standard [7] which was deemed necessary for its use in salt and freshwater.

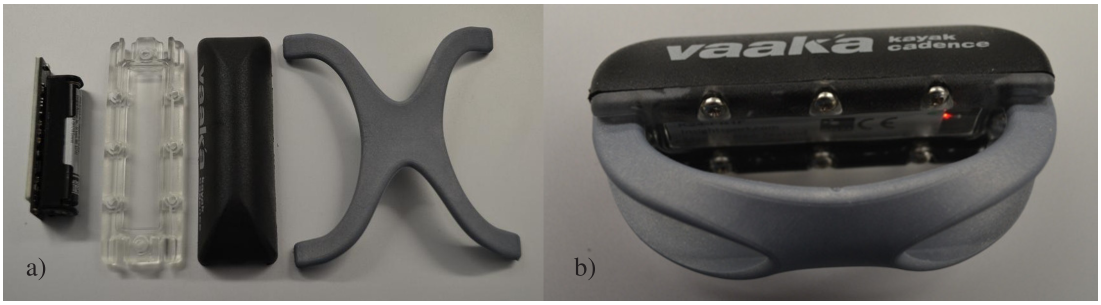

Fig. 1. a) Four pre-assembly cadence sensor components: electronics and battery, transparent acrylic bottom, hard wearing top and silicon strap; b) Assembled parts ready for attachment to paddle.

Within this housing, there was a battery powered electronic circuit containing: a tri-axial accelerometer, ANT+ transmission chip and a microprocessor which controls the various elements of the sensor. The microprocessor also detected motion and switched the device on and off automatically, negating the need for an external switch. Within the microprocessor interpretation of the accelerometers data also occurred and a calculation of cadence was determined.

Upon identifying cadence information, an output of strokes per minute was sent to the ANT+™ chip. This was then transmitted via ANT+ ™ protocol and received by an ANT+ ™ compatible device, e.g. Garmin's Forerunner™ or Edge GPS™ watches. To enable the information to be displayed in both real-time as well as recorded for download after training, the receiving device was set to an ANT+ ™ cadence or speed and cadence setting. The receiving device captured and stores all information while the Vaaka™ sensor did not store any information. The whole device was powered by a single AAA 1.5v battery capable of running the device for an estimated 1 year before being replaced.

The sensor was attached to the kayak paddle via the silicon strap close to the paddles center point, between the paddler's hands. This reduced peripheral mass making the paddle more economical to move and kept it close to the receiving device

Fig. 2. Cadence sensor attached to kayak paddle ready for calculating and transmitting cadence information to a compatible device.

2.1. Application of a tri-axial accelerometer sensor for measuring real time kayak cadence

In order to gather real data and assess the output obtained from this device, the instrument was used during a VO2 max kayak training session. X athletes took part in this pilot case study. The coach set three repetitions of 250m sprint with 1:1 work to rest ratio, followed by three repetitions of 500m sprint with 1:1work to rest ratio, then finally three repetitions of 1000m sprints with 1:1 work rest ratio for the observed athlete. This was a total training session distance of 12 km's including warm up and warm down.

The association between cadence and heart rate as well as cadence and speed was assessed by calculating the Pearson correlation coefficient, with an alpha set at 0.05. Moderate associations were found for "cadence and heart rate" ($r = 0.44$, 95% confidence interval = 0.42 to 0.46, and p-value = 0.00), and "cadence and speed" ($r = 0.55$, 95% confidence interval = 0.53 to 0.57, and p-value = 0.00).

The coach informed the athlete that they should maintain a cadence of 45 double strokes per minute (DSPM) for all of the efforts with a recovery cadence of 30-35 DSPM. The coach rated this session as hard and this particular athlete was unable to maintain the target cadence of 45DSPM as observed in Figure 3. This information helped the coach to identify the need to focus future training on their aerobic capacity. This session was used as part of a training programme prior to a national sprint kayak event.

It was observed that cadence and heart rate response were closely related to each other, as expressed by the Pearson correlation coefficient. This suggests that the target cadence increased physiological demands on the athlete. This could, therefore, inform the coach and athlete about possible training intensity zones using cadence alone in future training sessions.

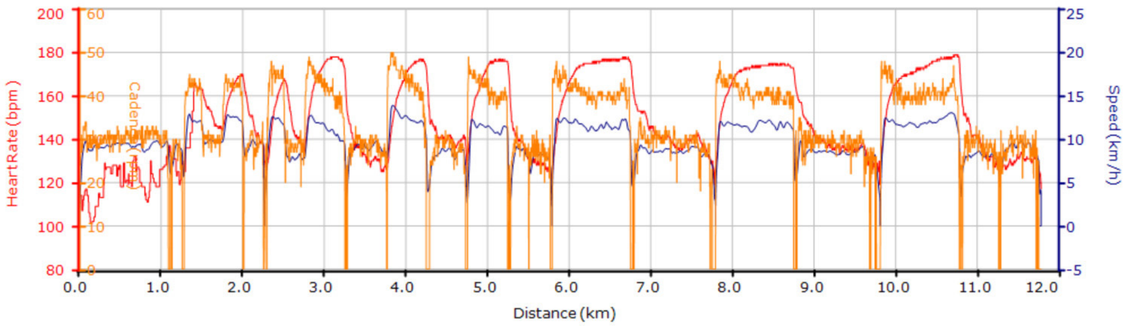

Fig. 3. Captured training session data (distance, cadence, heart rate and speed) from a Garmin Forerunner™ watch, viewed in Garmin Training Centre™ software, post training session.

3. Conclusion

The development of a device that can evaluate movement [8] and transmit real-time data is not novel [9], however a device that processes the specific movements of a kayak paddle stroke prior to transmission is. Although simple in appearance, this device provides information to athletes and coaches during as well as after training, using movement detection methods which have not been employed in kayaking in the past. Many of the cadence training strategies employed in other sport such as cycling & rowing can now be implemented in kayaking.

With moderate associations between cadence and heart rate ($r = 0.44$), as well as cadence and speed ($r = 0.55$) identified, this paper provides insight into the relationship that cadence has with other performance parameters. This in itself requires further investigation. With the addition of set training zones programmed into signal receiving device, similar to that used in heart rate watches, athletes could receive auditory cues if their cadence varied from a desired zone.

A limitation of this device is an inability to store session data locally, rather the user requires a receiving device like certain models of Garmin™ or Suunto™ watches which can receive ANT+ transmission signals. Secondly this device may not detect cadence if the athlete has an unusual technique, not fitting the acceleration criterion within the microprocessor.

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