Power in Rowing

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Summary

As in other sports, rowing races are often decided within very small margins. Rowing performance can be quantified as the average boat velocity over a given race distance and is determined by a combination of rowers' physical power and rowing technique[1]. Rowers and coaches continuously search for opportunities and methods to improve performance. The work reported in this thesis aimed to contribute to this search by developing and evaluating tools for understanding and improving rowing performance.

To better understand rowing performance from a biomechanical point of view, the power balance for rowing [33, 89] was used. This balance provides insight into the relation between the physical capacities and intrapersonal movement coordination of rowers and their effect on rowing performance. More in particular, it follows from this balance that a rower's average power output and power losses associated with boat velocity fluctuations and the generation of propulsion are performance determining variables. Average power output is strongly related to metabolic energy consumption [37], and therefore an objective measure for the physical capacities of a rower. It thus forms and interesting variable to control training intensity and — in the long term — improve the physical capacity of a rower. Power losses are most certainly related to rowing technique and therewith potentially useful feedback variables for improving rowing technique.

To improve average power output and reduce power losses rowers require 'effective' feedback on these power variables. As stated in the introduction (**Chapter 1**), feedback on key variables can be qualified as effective as (1) the feedback variables can be determined accurately and (2) feedback on those variables enables athletes to adjust them [69]. To meet the first requirement, methods

[1] Rowing technique encompasses both *intra*personal movement coordination and, in the case of crew boats, *inter*personal movement coordination as well.

that allow for accurate estimations of the power variables were developed and evaluated (**Chapter 2-4, 7**). Subsequently, in the view of the second requirement, it was evaluated whether feedback on power variables enables rowers to adjust these variables (**Chapter 5-6**). To provide the feedback during training sessions and feedback studies, a custom-made feedback tool was developed (**Appendix**).

As regards power output, a new method to accurately determine this power variable was developed. As of yet, a rower's average power output was calculated by using oar forces and oar movements alone (e.g. [1–3, 6, 8, 9, 14, 17–19, 21, 22]), of which the calculation of the product of the moment around the oar and the oar angular velocity has been used the most (e.g. [1, 3, 6, 21]; referred to as the commonly used method). In **Chapter 2**, Newtonian mechanics was applied to demonstrate that this commonly used method is incomplete and therefore invalid. For a valid determination of a rower's average power output the average of the product of a rower's mass, the boat velocity, and the acceleration of a rower's centre of mass (CoM) need to be taken into account as well. The first two parameters can be measured rather accurately using one or two sensors, but this is not the case for the determination of the CoM acceleration. A validation study (**see Chapter 3**) showed that a rower's CoM acceleration can be accurately determined using inertial sensors measuring the acceleration of 13 body segments and Zatsiorsky's standard mass distribution model [5, 26].

Subsequently, in an on-water rowing experiment (**Chapter 4**), it was shown that the difference between average power output values determined using the commonly used method and the 'correct' method is substantial. When power output values are determined using the commonly used method, the values are underestimated by 12.3 % on average, with only marginal variations between rowers and rowing conditions such as the number of strokes min^{-1} (stroke rate). These results imply that the commonly used method needs to be corrected in order to provide accurate feedback on power output. An alternative would be to use the more encompassing measurement method introduced in **Chapter 2** and **3**, but this is less feasible in daily rowing practice.

An on-water feedback study was conducted to examine whether power output feedback enables rowers to adjust their power output (**Chapter 5**). Based on previous results from motor learning studies (e.g. [15, 16, 23, 25]), and the successful use of power output feedback in cycling, it was expected that rowers in single sculls (one man boats) were able to adjust their power output based on feedback on power output. However, it was uncertain whether the same would hold for rowers in crew boats since their movements are confined by the movements of other crew members. The results obtained confirmed that crew rowers can improve their compliance with power output feedback substantially when they receive additional feedback on power output compared to only traditional feedback, such as feedback on boat velocity and the number of strokes min^{-1}. This implies that feedback on power output can be used to control power output and thus training regimens aimed at improving physical capacities and rowing performance.

It can be appreciated from the power balance of rowing that average power output is not the sole determining factor of rowing performance. Performance also depends on power losses unrelated to average boat velocity. Although the power loss due to velocity fluctuations could already be determined with relative ease [33], it was uncertain whether feedback on this power loss enables rowers to reduce the loss. The results of a study involving audio-visual feedback on power losses resulting from velocity fluctuations (**Chapter 6**) suggested that, in general, this is not the case. Based on these results, it was concluded that this type of feedback is not useful to reduce power loss due to velocity fluctuations and thus improve rowing performance.

A larger portion (i.e. > 20 %; [2, 34, 36, 51]) of a rower's average power output is lost due to the generation of propulsion. Since this power loss could not be determined accurately at the start of this thesis, an alternative method has been developed to estimate this type of power loss more accurately (**Chapter 7**). The method in question consists of three pairs of strain gauges allowing for an accurate determination of local bending moments. A system of three associated moment equations allows for the determination of the water force component perpendicular to the blade and its point of application. The smaller but relevant parallel force component should in the future be determined with a different method. Additional research is required to examine whether rowers are able to reduce the power loss associated with the generation of propulsion when provided with feedback about this power loss.

In conclusion, this thesis aimed to develop and evaluate tools that contribute to the understanding and improvement of rowing performance. A mechanical analysis indicated that mechanical power output and power losses are important determinants of rowing performance. It was demonstrated that both variables can be determined rather accurately. Feedback on power loss due to velocity fluctuations however seemed to be ineffective, but rowers clearly benefited from feedback on average power output to control their power output. The most important implication of these findings for rowing practice is that the implementation of accurate online feedback about a rower's power output during training will help to control training intensity. In the long run, a better control of training intensity will likely help rowers to improve their physical capacities and rowing performance.