IS THE VELOCITY PERTURBATION METHOD SUITABLE FOR THE CALCULATION OF THE USEFUL MECHANICAL POWER OUTPUT OF SPRINT KAYAKERS IN OUTDOOR CONDITIONS?

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This study assessed whether the Useful Mechanical Power Output (P_{MO}) estimated using the Velocity Perturbation Method (VPM) would be a valid biomechanical measure of performance enhancement in sprint kayaking that would not be affected by changes in environmental conditions. Twelve national-age K1 sprint kayakers performed twelve trials each of 60m maximal effort sprints within two separate sessions, six of which were conducted while towing a hydrodynamic object of known resistance. The opposing wind condition in each trial was recorded and classified as either mild or strong. The sprint velocities at towing-free and towing conditions under similar wind velocities and the resistance of the hydrodynamic object were matched to estimate the P_{MO}. Non-significant differences in P_{MO} between mild and strong wind conditions were observed. However, the typical error of P_{MO} in both wind conditions were larger than 26% of the mean values, which hindered the ability of the P_{MO} to detect the smallest worthwhile enhancement that would be valuable for high-performance kayak sprinting.

KEYWORDS: sprint kayak, K1, active drag, useful mechanical power output

INTRODUCTION: Sprint kayaking takes place in an open environment with varying wind and current conditions. Variation in these weather conditions from session to session (training or competition) hinders the use of direct biomechanical measures (e.g., velocity, power output at the blades and shaft) as indicators of performance enhancement. The ideal biomechanical model to assess performance in kayaking should consider the impact of the environmental conditions, particularly at the aero- and hydrodynamic resistive (drag) forces.
One prospective alternative is the Velocity Perturbation Method (VPM), a model developed in swimming to estimate the active drag (F_D) at maximum swimming velocity and the useful mechanical power output (P_{MO}) required to overcome the drag (Kolmogorov & Duplishcheva, 1992). First, this model assumes that the athlete delivers a constant P_{MO} at maximum effort. Since the P_{MO} is the product of F_D and the maximum velocity, an increase in drag caused by towing a hydrodynamic object of known resistance would lead to a proportional decrease in the recorded velocity. Therefore, the VPM allows the F_D and thus the P_{MO} to be estimated using as predictors the recorded velocities at two maximum effort trials, one of which towing a hydrodynamic object, along with the resistance created by the object.
Unlike in swimming, the aerial resistive force in sprinting canoeing is not negligible. However, the equation of resistive force (Kolmogorov & Duplishcheva, 1992) applies to air and water fluids. Even when air and water resistances are considered, the resulting VPM equation remains unaltered, assuming the towing-free and towing trials are held in the same environmental conditions. Consider (i) each testing session (i.e., one towing-free and one towing trial) is held under constant environmental conditions, whereas these conditions vary across different sessions, and (ii) the VPM assumption that the athlete delivers a constant P_{MO} at maximum effort. Therefore, we hypothesised that the P_{MO} of sprint kayakers would not differ between sessions at different environmental conditions without the influence of training-related adaptations. This study aimed to assess whether the VPM was suitable to monitor performance in K1 sprint kayaking without being affected by environmental conditions. Since the estimated P_{MO} should be sufficiently reliable to detect the smallest worthwhile performance

enhancements, it was further hypothesised that the P_{MO} was an intra-session measure with adequate reliability for assessing performance enhancement.

METHODS: Twelve age-group, national-qualifiers and injury-free sprint kayak athletes (six male and six female, 15.2 ± 0.16 years) volunteered in the study. They attended two sessions within one week, in each of which performing six trials of 60-m maximum K1 sprint efforts in a flat-water river stream, with a build-up start before the start line. Five minutes were allowed between trials for a full recovery. The average trial velocity was computed with two synchronised video cameras (50 Hz), one at the start and the other at the end line. Three of the six trials were sprinted while towing a hydrodynamic object, whose resistance was obtained as a function of constant towing velocity (Figure 1). This function was computed experimentally when the object was towed at constant velocities between 1 m/s and 6 m/s while recording the tension in the towing cable with a dynamometer (Etekcity) with a resolution of 0.1 N.

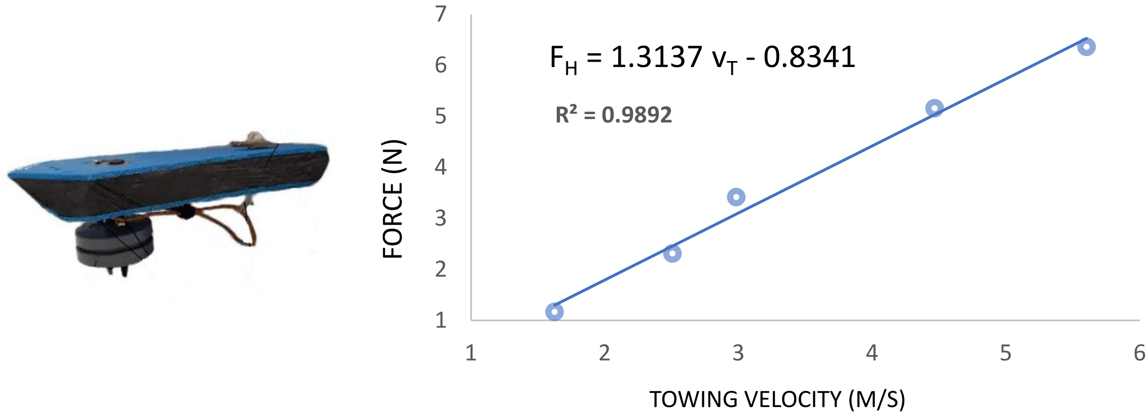

Figure 1: Hydrodynamic object (left) and experimental data used to create the model that predicts the resistance of the hydrodynamic object as a function of the towing velocity (right).

Opposing headwind speeds (with a deviation no greater than 20º from the direction of boat travel) were recorded at the start and finish lines before each trial using a wireless weather station anemometer (Paegdooy) with a resolution of 0.03 m/s. These wind velocities were classified as either mild (1.8 ± 0.3 m/s) or strong (2.9 ± 0.3 m/s) using k-means clustering.
For the calculation of F_D and P_{MO}, each towing-free trial was paired with a towing trial of the same participant and wind classification, ensuring that the average wind speed of the two trials did not differ by more than 0.2 m/s. These criteria were followed to estimate as many P_{MO} values as possible for each participant and wind condition since variation in these conditions were observed within a single session. The recorded velocities of the two trials and their respective object resistance were used as predictors (Kolmogorov & Duplishcheva, 1992):

$$F_D = \frac{F_H \cdot v_T \cdot v_F^2}{v_F^3 - v_T^3} \quad \text{Eq. 1}$$

$$P_{MO} = F_D \cdot v_F \quad \text{Eq. 2}$$

Where F_D is the combined resistance from the water and the air, v_F is the towing-free velocity, and F_H is the added resistive force of the hydrodynamic object as a function of the average towing velocity (v_T).
Before comparing the P_{MO} values estimated for each participant at mild and strong wind conditions, all P_{MO} values were normalised by the mean of the respective participant's mild-wind P_{MO} to account for differences in performance between participants. The number of paired comparisons for each participant was capped by the lowest number of P_{MO} computed in each condition. For instance, if there were four valid mild-wind P_{MO} and eight strong-wind P_{MO} data for a given participant, the four strong-wind P_{MO} with the highest wind velocity recorded were selected for the comparison. Alternatively, when less strong-wind data was available, the mild-wind P_{MO} with the lowest wind velocities recorded were selected. Since only eleven paired comparisons met these criteria, the normalised P_{MO} values estimated for each participant at mild and strong wind conditions were compared using the Wilcoxon Signed Rank Test (α =

0.05). For the reliability assessment, first, each P_{MO} value was normalised by the mean of the respective participant and condition data. Then, the within-subject standard deviation (Hopkins, 2000) was computed in each condition.

RESULTS: The Wilcoxon test showed a non-significant ($p = 0.29$) difference between the normalised P_{MO} computed at mild (1.02 ± 0.15) and strong (0.93 ± 0.76) wind conditions (Fig 2). The typical error of the P_{MO} at mild ($n = 112$) and strong ($n = 124$) conditions were 26.1% and 26.7% of the respective means.

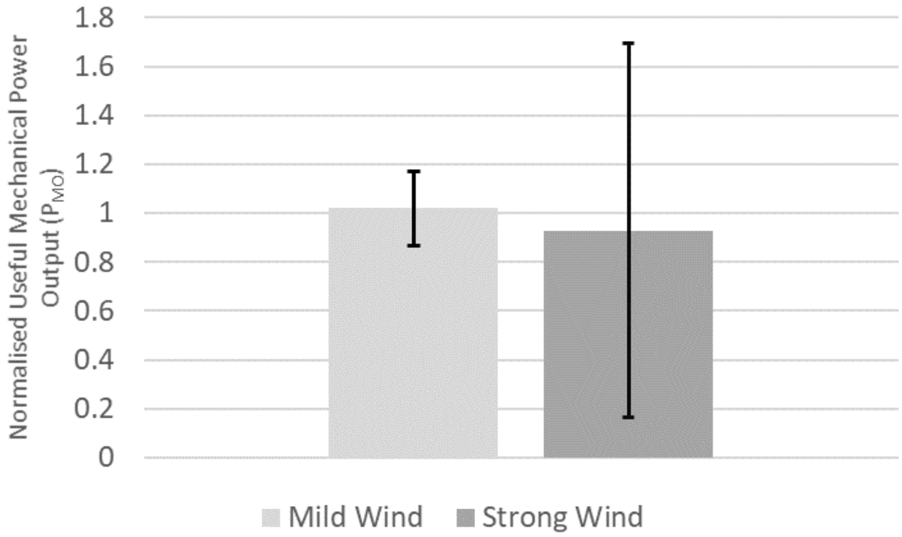

Figure 2: Comparison between the Useful Mechanical Power Output (P_{MO}) normalised by means of the respective participant's Mild Wind (error bars refer to the standard deviation).

DISCUSSION: The specific goals of the present study were twofold. First, it aimed to verify whether P_{MO} would not differ across sessions of different environmental conditions. Such consistency would suggest the feasibility of the P_{MO} to track the performance of K1 sprint kayakers without being influenced by the environment. No significant differences were encountered; however, this result needs to be interpreted with caution since the statistics were influenced by using just eleven comparisons and the large standard deviation of the strong wind distribution. In fact, the large standard deviation of the latter was caused by the small number of pairwise comparisons. Some athletes had as many as just two valid mild-wind P_{MO} values, which hindered the calculation of the mean value used to normalise the strong-wind data. Other athletes also had as many as two valid strong-wind P_{MO} data, which also rendered the central tendency and variability of this condition data inadequate. Therefore, a larger number of pairwise comparisons between the mild- and strong-wind data would have been required for an appropriate statistical inference about this first hypothesis testing.

The small cohort was caused by ensuring that only towing-free and towing velocities from trials with wind velocities not different by more than 0.2 m/s would be matched to compute the participant-specific P_{MO}. This velocity difference was anecdotally selected based on the maximum difference between wind velocities (0.2 m/s) observed at the start and end lines. The consistency in wind velocities between the two trials was important to validate the mathematical model of the VPM, ensuring that the resistance of the hydrodynamic body was the only source of additional drag. Greater control over the environment (e.g., measuring current velocity and the water/air temperature) would result in more restringing conditions and thus a lower number of mild- and strong-wind P_{MO} data to be compared. Moreover, from a practical perspective in the training environment, more environmental variables to control would render the testing session more cumbersome for athletes and coaches, and thus the usefulness of this test for the practitioners would be questionable.

As means to have a larger number of pairwise comparisons between the mild- and strong-wind data available for an appropriate statistical inference about the first hypothesis, two alternatives

could have been adopted. First, allowing larger differences in wind speed between towing-free and towing trials to be accounted for, and (ii) using a larger number of participants and trials per participant. However, none of them would have positively impacted the second specific goal of the study, which was testing the reliability of the P_{MO} estimated via VPM. Less control over the environmental influence between the towing-free and towing conditions would have led to more potentially neglected causes of augmented or reduced drag, thus increasing the typical error of the P_{MO}. In the current format, already large typical errors of more than 26% of both mild- and strong-wind means were encountered, which hinders the potential of the P_{MO} to detect the smallest worthwhile performance enhancement. Therefore, the conundrum is that changes in the criteria for wind difference between the two trials would either yield more data with lower reliability or less data with higher reliability for statistical inference when comparing the P_{MO} at mild or strong wind conditions.
Nevertheless, it seems more plausible that the main source for the large typical errors was that the fundamental assumption, i.e., the constant P_{MO} at maximum efforts, may not have been met. This fundamental assumption is also adopted by the Assisted Towing Method (ATM), another model to estimate F_D and P_{MO} in swimming. The ATM shares the same principles of the VPM, except that an assisted towing trial to generate more velocity is used instead of a resisted towing trial. Hazrati et al. (2018) assessed the uncertainty of the estimated F_D using the ATM when the P_{MO} for the towing-free and the assisted towing are not assumed as equal. The authors showed that a power change of 7.5% between the two trials would yield about 30% error in the estimated F_D. The resemblance between VPM and ATM makes it feasible that similar scenarios would be observed for the VPM. Some of the explanations for potential differences in P_{MO} between the towing-free and the towing trials are levels of expertise of the athletes involved and learning effects during the experimental setup. Specifically, to sprinting kayak, it could be argued that the P_{MO} is also affected by the ability of the athlete to maximise propulsion while maintaining balance on the K1, mainly when dealing with sudden and punctual changes in the surrounding conditions (e.g., choppy waves or wind gusts). Indeed, some participants showed very similar or even faster trial times with the hydrodynamic objects compared to the respective towing-free trial at the same wind speed, respectively rendering unrealistically high or even negative values for the P_{MO}, which were then discarded for further analyses. Therefore, even if more participants and trials were included to help assess the first hypothesis, the reliability of the P_{MO} estimated using the VPM would unlikely be improved. Thus, the proposed method did not meet the goal of detecting the smallest worthwhile improvement in P_{MO} for sprinting kayakers.

CONCLUSION: A larger number of pairwise comparisons between the mild- and strong-wind data would have been required to test the hypothesis that the P_{MO} estimated using the VPM for K1 sprinting kayak would not be affected by environmental conditions. Nevertheless, the reliability of the estimated P_{MO} was not sufficient to detect the smallest worthwhile performance enhancement of the sprint kayakers, and thus it is unlikely useful for coaches and athletes in training environments.

REFERENCES

Hazrati, P., Sinclair, P. J., Spratford, W., Ferdinands, R. E., & Mason, B. R. (2018). Contribution of uncertainty in estimation of active drag using assisted towing method in front crawl swimming. *Journal of Sports Sciences*, *36*(1), 7-13.

Hopkins, W. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*(1), 1-15.

Kolmogorov, S., & Duplishcheva, O. (1992). Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. *Journal of Biomechanics*, *25*(3), 311-318.

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