A Study On The Rowing Stroke Curve

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***Abstract*—This study explores the relationship between stroke force curves, pulse rates, and performance metrics using data collected from personal rowing sessions on an RP3 ergometer supplemented by a Garmin HRM-Dual chest strap heart rate monitor. By analyzing force curves during UT2 and AT workouts, this research aims to identify key characteristics of efficient strokes and develop a model for an ideal stroke curve. This study's findings provide insights into optimizing rowing technique for improved performance.**

I. Introduction

Rowing is a sport that heavily relies on the efficiency of each stroke. Understanding the dynamics of stroke force curves can provide rowers with valuable feedback on their technique. This study uses personal workout data collected from an RP3 ergometer to analyze stroke force curves during UT2 (steady-state) and AT (anaerobic threshold) workouts. The objective is to determine the characteristics of an ideal stroke curve and how it correlates with other performance metrics such as power output and stroke length.

II. Methodology

A. Data Collection

The data analyzed in this study was collected from the author's personal rowing sessions on an RP3 ergometer and a Garmin HRM-Dual chest strap heart monitor. The dataset includes stroke-by-stroke metrics such as peak force, stroke length, energy sum, pulse rate, stroke rate, and curve data representing the force applied throughout each stroke. Workouts were classified into UT2 and AT categories based on pulse rates and stroke rates with UT2 generally being a lower-intensity, lower rate, longer-duration workout and AT being comparatively shorter and higher-intensity.

B. Data Cleaning and Preprocessing

The data was cleaned by removing outliers using Z-score normalization, focusing on the energy sum (or area of the force curve), curve standard deviation, and time to peak force. This method helps to identify any strokes taken during a rest interval or a stroke that has been taken incorrectly. The data was further filtered to remove any strokes with missing or zero values, ensuring the accuracy of the subsequent analysis. The curve data, which was initially in string format, was converted into numerical arrays for easier processing.

C. Calculation of Combined Curve Scores

Two formulas were developed to calculate a combined curve score for each stroke, tailored to the workout type and keeping in mind its interchangeability with a workout on an actual boat on the water:

1) AT Workouts:

$$\begin{aligned}\text{Combined Curve Score} = &\left(\frac{F}{F_{\text{max}}}\right) \times 0.2 \\ &+ \left(\frac{A}{A_{\text{max}}}\right) \times 0.2 \quad + \left(\frac{D}{D_{\text{max}}}\right) \times 0.1 \\ &+ \left(\frac{P}{P_{\text{max}}}\right) \times 0.3 \quad + \left(\frac{SL}{SL_{\text{max}}}\right) \times 0.2\end{aligned} \tag{1}$$

This formula takes into account the Peak Force F, Energy Sum A, Distance per stroke D, Power output P, and Stroke Length SL with the weights corresponding to the importance of each in a high-intensity AT workout done on the water in an actual boat. While the importance of the Energy Sum and Power output are obvious, the Stroke length has a lower importance in comparison as the rower tends to shorten up the stroke in a higher intensity workout to accommodate for a higher rate and the distance per stroke has the least importance as it is also affected by the momentum carried forward by the previous stroke.

2) UT2 Workouts:

$$\begin{aligned}\text{Combined Curve Score} = &\left(\frac{F}{F_{\text{max}}}\right) \times 0.1 \\ &+ \left(\frac{A}{A_{\text{max}}}\right) \times 0.4 \quad + \left(\frac{SL}{SL_{\text{max}}}\right) \times 0.5\end{aligned} \tag{2}$$

This formula takes a more balanced approach and does not take into account or gives lesser importance to the metrics that are more power or distance covered focused such as power output, distance per stroke and peak force. The metrics covered are Peak Force F, Energy Sum A, and Stroke Length SL. Since the UT2 workouts focuses mostly on maintaining a certain level of perceived effort the formula should focus solely on the size and length of the curve making sure that the rower is as long on the stroke as possible but at the same time as efficient as possible on every stroke.

D. Identification of Ideal Stroke Curves

Using the combined curve scores, the stroke with the highest score was identified for both UT2 and AT workouts. These strokes were then plotted to visualize their force curves. A cubic Hermite spline was used to generate a model of an ideal stroke curve, which was compared to the real stroke curves identified.

III. Results

A. Visualization of Stroke Curves

The force curves for the ideal strokes in UT2 and AT workouts were plotted alongside a model curve generated

using cubic Hermite splines. The model curve aimed to capture the general shape of an efficient stroke, with a rapid rise to peak force followed by a more gradual decline, as seen in the figure below:

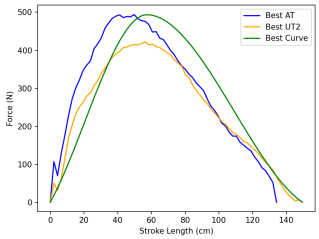

Fig. 1. Best AT and UT2 Curves taken from workouts and Best Stroke curve calculated using workout data

B. Analysis of Combined Curve Scores

The time series of combined curve scores for AT and UT2 workouts was plotted to visualize the consistency and performance trends over time. It was observed that strokes with higher combined curve scores typically corresponded to better overall performance in terms of pulse, stroke length, and estimated 500m time as it corresponds to better form.

C. Relationship between Curve Scores and other metrics in AT Workouts

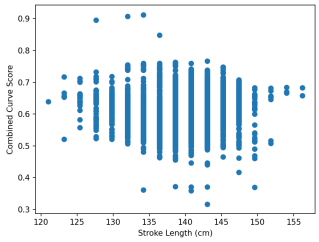

Fig. 2. Stroke Length plotted against Curve Scores

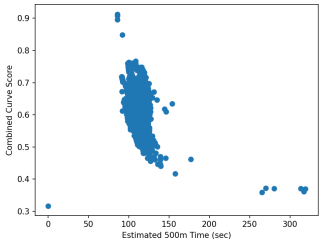

Fig. 3. Estimated 500m Time plotted against Curve Scores

The analysis reveals distinct relationships between the combined curve score and three variables: stroke length, estimated 500m time, and power.

1) Stroke Length vs. AT Combined Curve Score: (Figure 1): The scatter plot shows that stroke lengths between 135 and 150 cm generally correspond to higher combined curve scores (above 0.7). This range could be considered optimal for achieving efficient strokes during AT workouts.

2) Estimated 500m Time vs. AT Combined Curve Score: (Figure 2): The data suggests that as the estimated 500m time decreases (indicating faster pace), the combined curve score tends to increase. However, significant variability exists, especially at slower paces, which might reflect variations in technique under different pacing conditions.

D. Relationship between Curve Scores and other metrics in UT2 Workouts

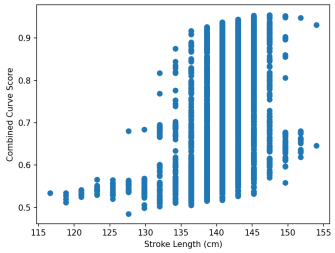

Fig. 4. Stroke Length plotted against Curve Scores

1) Stroke Length vs. UT2 Combined Curve Score: The data suggests that increasing the stroke length up to a certain point (around 140-145 cm) leads to better performance (higher combined curve scores). Beyond that, the benefit plateaus, and performance does not improve significantly or could decrease slightly as the user may not be able to take a proper stroke.

IV. Discussion

The analysis reveals that strokes with a higher combined curve score, particularly in AT workouts, tend to have a steeper rise to peak force and a longer, more controlled decline. This characteristic was reflected in the modeled ideal stroke curve (Figure 3), suggesting that maximizing force early in the stroke and maintaining control during the recovery phase is crucial for optimal performance.

In contrast, UT2 workouts, which focus more on endurance, showed that strokes with a longer, smoother force application, albeit with lower peak forces, tended to score higher. This highlights the different physiological demands of UT2 and AT workouts and the need for different stroke characteristics.

In terms of practical applications, I could have made the formula for the scores more strict with respect to aspects of a stroke that will increase speed but since we want to find the best stroke

V. Future Work

- Real-time feedback systems could be developed to help rowers adjust their technique mid-session based on live curve analysis.
- To conduct the study using data from rowers of different ages, weights and heights and not just the author them self.

VI. Conclusion

This study provides a comprehensive analysis of stroke force curves using data from personal rowing sessions. The identification of ideal stroke curves in both UT2 and AT workouts offers valuable insights into optimizing rowing technique in a way where it can be applied to water sessions. The results indicate that maximizing the combined curve score can lead to improved performance metrics, and the proposed model curve could serve as a benchmark for training and technique refinement.