Performance and segmental velocity in Olympic and Traditional Rowing: an analysis in female rowers at different intensities

Rendimiento y velocidad segmentaria en remo olímpico y tradicional: un análisis en remeras a diferentes intensidades

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Abstract

Introduction: rowing power is one of the main factors that influences the increase in boat speed, and the increase in the speed of body segments enhances stroke velocity in Olympic Rowing.
Objective: the objective of this study is to analyze the relationship between the velocity of each segment and performance at different stroke rates, and to examine the differences between Traditional Rowing and Olympic Rowing.
Methodology: thirteen highly trained national-level female rowers performed sets at 18, 24, and 30 strokes per minute (spm) on rowing ergometers for both modalities. Video analysis was carried out using the Rower Up analysis system. Pearson's correlation coefficient was used to establish relationships between segment velocity and rowing performance. The magnitude of the correlation coefficient was interpreted as trivial (<0.1), small (0.1–0.3), moderate (0.3–0.5), strong (0.5–0.7), very strong (0.7–0.9), and almost perfect/perfect (0.9–1).
Results: Traditional Rowing shows significant correlations in the trunk at 18 spm (r=0.375; p<0.001), 24 spm (r=0.560; p<0.001) and at 30 spm (r=0.243; p=0.099). Arms show significant correlation at 18 spm (r=0.476; p<0.001) and at 24 spm (r=0.257; p=0.005). Olympic Rowing shows significant correlations in the legs at 18 spm (r=0.448; p<0.001), 24 spm (r=0.584; p<0.001) and at 30 spm (r=0.531; p<0.001). Arms show significant correlation at 30 spm (r=0.433; p<0.001).
Conclusions: the velocity of the legs in Olympic Rowing showed higher correlation than in Traditional Rowing at all intensities, whereas the velocity of the trunk showed the opposite, where the trunk never correlated with performance.

Keywords

fixed seat rowing; rowing biomechanics; kinetic; kinematic; power.

Resumen

Introducción: la potencia en el remo es uno de los principales factores que influye en el aumento de la velocidad de la embarcación, y el incremento en la velocidad de los segmentos corporales mejora la velocidad de la remada en el Remo Olímpico.
Objetivo: el objetivo de este estudio es analizar la relación entre la velocidad de cada segmento corporal y el rendimiento a diferentes frecuencias de remada, así como examinar las diferencias entre el Remo Tradicional y el Remo Olímpico.
Metodología: trece remeras altamente entrenadas a nivel nacional realizaron series a 18, 24 y 30 paladas por minuto (ppm) en remoergóemtros para ambas modalidades. Se llevó a cabo un análisis de video utilizando el sistema de análisis *Rower Up*. Se utilizó el coeficiente de correlación de Pearson para establecer relaciones entre la velocidad segmentaria y el rendimiento en el remo. La magnitud del coeficiente de correlación se interpretó como trivial (<0.1), pequeña (0.1–0.3), moderada (0.3–0.5), fuerte (0.5–0.7), muy fuerte (0.7–0.9) y casi perfecta/perfecta (0.9–1).
Resultados: el Remo Tradicional mostró correlaciones significativas en el tronco a 18 ppm (r=0.375; p<0.001), 24 ppm (r=0.560; p<0.001) y 30 ppm (r=0.243; p=0.099). Los brazos mostraron correlación significativa a 18 ppm (r=0.476; p<0.001) y a 24 ppm (r=0.257; p=0.005). El Remo Olímpico presentó correlaciones significativas en las piernas a 18 ppm (r=0.448; p<0.001), 24 ppm (r=0.584; p<0.001) y 30 ppm (r=0.531; p<0.001). Los brazos mostraron correlación significativa a 30 ppm (r=0.433; p<0.001).
Conclusiones: la velocidad de las piernas en el Remo Olímpico mostró una correlación más alta que en el Remo Tradicional en todas las intensidades, mientras que la velocidad del tronco presentó el comportamiento opuesto, ya que nunca se correlacionó con el rendimiento.

Palabras clave

remo de banco fijo; biomecánica de remo; cinética; cinemática; potencia.

Introduction

Kinematics and kinetics are the two main areas in the study of biomechanics. Kinematics examines the time-dependent, geometry-related aspects of motion, regardless of the forces causing that motion (Blazevich, 2013). In contrast, kinetics focuses on the forces that generate movement and the variables derived from them (Özkaya et al., 1999). Mechanical power, measured in watts, indicates the rate at which work is performed. It is calculated by dividing the work by the time to complete it. Additionally, power can be determined by multiplying the force exerted by the velocity (Rodriguez-Marroyo & Garcia-Lopez, 2015). Power is the main factor influencing the increase of boat velocity in rowing; therefore, biomechanical methods for improving rowing training are crucial (Kleshnev, 1998).

Biomechanical parameters influencing rowing performance were analyzed during water training. Various forces affect performance, including gravitational, buoyancy, drag, and propulsive forces. These forces can be categorized into two groups: propulsive forces, which act in the direction of movement, and resistance forces, which act in the opposite direction (Baudouin & Hawkins, 2002). Some factors depend on the rower, while others do not. Factors independent of the rower include weather conditions, paddle shape, and boat shape (Baudouin & Hawkins, 2002). In contrast, factors dependent on the rower include average and maximum force, power, stroke rate, and the impulse-per-stroke ratio (Kleshnev, 1998). The primary source of power generated by the rower comes from the legs (45%), followed by the trunk (32%), and the arms (23%). Additionally, it is known that the main points of force application are the footboard (47%) and the handle (53%) (Kleshnev, 2000). The stroke rate influences the distribution of forces acting on the boat and also affects the kinematics of the boat and blade, modifying aspects such as mechanical work (Hofmijster et al., 2007). Strength, catch angle flexibility, and higher stroke rates are key training variables (Holt et al., 2020).

Ergometers are devices that provide certain biomechanical parameters directly to the athlete and are used for training on land. There are two types: mechanical and electromagnetic braking ergometers. Both can measure the force exerted by the subjects and calculate the work and power developed using various formulas (Rodriguez-Marroyo & Garcia-Lopez, 2015). Specific rowing ergometer models are available for rowing training, and these models closely replicate the kinematic parameters of water rowing (Elliott et al., 2002; Lamb, 1989). The selection of the appropriate rowing ergometer is crucial. Some studies comparing different rowing ergometer models have found variations in biomechanical parameters, the repeatability of the rowing motion, stroke rate, and the angles of the catch and finish phases (Lu et al., 2023; Steer et al., 2006).

Rowing can be classified into two types of disciplines: Olympic Rowing and Traditional Rowing. The former is characterized by the use of a sliding seat mechanism that enables the rower to move along the boat’s longitudinal axis. In contrast, the latter employs a fixed seat, providing stable support to the rower’s ischial region throughout the stroke cycle (Penichet-Tomas et al., 2023). Traditional Rowing encompasses two primary boat modalities. The first is Trainera, a boat with a minimum weight requirement of 200 kg, manned by a crew of 13 rowers plus a coxswain, used in long-distance regattas (5556 m), which includes four lengths and three turning points, commonly referred to as tacks. The second modality is the Llaüt, a lighter boat with a minimum weight of 150 kilograms, crewed by 8 rowers and a coxswain, used in shorter-distance races (1400 m), also structured with four lengths and three tacks. The measurement of biomechanical parameters has led to numerous studies in both Traditional and Olympic Rowing. In Traditional Rowing competitions, differences are observed between the various race lengths. The third segment typically exhibits a lower average power compared to the others, with power increasing in the final segment (Lorenzo-Buceta et al., 2015). In 6-minute trials within Olympic Rowing, force, maximum velocity, and power remain stable after the peak force of the first stroke until the final 25 seconds, during which force and stroke rate increase (Hartmann et al., 1993). Biomechanical patterns of technique in Olympic Rowing have been analyzed to identify the most efficient rowing techniques. Early body extension has been found to reduce performance, while delaying the use of the body contributes to improved performance (Duchene et al., 2024; Ertel, 2018). Another factor that negatively affects performance is asymmetries in force application and inefficient force interactions (Buckeridge et al., 2015). Similar studies in Traditional Rowing have measured angulation and utilized accelerometry to analyze technique (Larrinaga-Garcia et al., 2023).

All of the above aspects are influenced by the athlete's sex. Men generally have greater muscle mass, body mass, and height compared to women, which allows them to generate more power in rowing. In contrast, women often demonstrate a better range of motion, which contributes to greater efficiency in the kinematics of the stroke (Li et al., 2020; McGregor et al., 2008). While rowing performance has been linked to various kinetic and kinematic factors, there is a lack of scientific evidence from studies that compare the behavior of different body segments and their differences across rowing modalities at increasing intensities. The aim of this study is to conduct a comparative analysis of the relationship between the velocity of each body segment and performance at varying stroke rates in both Olympic Rowing and Traditional Rowing.

Method

Participants

Thirteen highly trained female rowers participated in this study (McKay et al., 2022). The participants' characteristics, competing nationally in Llaüt, were 26.9 ± 5.1 years old, had a body mass of 60.6 ± 6.9 kg, a height of 166.7 ± 6.7 cm and an experience of 9.5 ± 4.7 years of rowing. None of the participants reported any injuries or were taking medication. All subjects were familiar with both Olympic and Traditional rowing techniques and were instructed to refrain from high-intensity physical activity for 24 hours prior to testing. Before participating, all participants reviewed and signed written informed consent form, confirming their understanding of the study's objectives and the intended exclusive scientific use of the collected data, in accordance with the guidelines of the World Medical Association (WMA). This study was approved by the Human Research Ethics Committee of the University of Alicante (IRB UA-2023-06-14_1).

Procedure

Participants initiated the protocol with a standardized 5-minute submaximal rowing warm-up, following procedures outlined by Gee et al. (2012) and Harat et al. (2020). The testing sequence involved three distinct intervals: 120 seconds at 18 strokes per minute (spm), 100 seconds at 24 spm, and 60 seconds at 30 spm, each separated by a 2-minute rest period. These intervals ensured participants completed at least 30 continuous strokes per set (Vieira et al., 2020).

Olympic rowing assessments were conducted using a Concept2 Model D ergometer (Morrisville, VT, USA) equipped with a PM5 monitor, which was calibrated to a drag factor of 110 (Li et al., 2021). For Traditional rowing evaluations, the same ergometer was adapted by immobilizing the seat and positioning participants' legs in a semi-flexed stance, adjusted individually to mimic the biomechanical demands of Traditional rowing. In this configuration, the drag factor was increased to 140 (Mujika et al., 2023; Penichet-Tomas et al., 2021). All procedures took place in a climate-controlled setting within the Motion Analysis Laboratory (0001P1006) at the University of Alicante, where ambient conditions were maintained at approximately 22°C with 60% relative humidity (Miras-Moreno et al., 2023).

Rowing sessions were recorded using a Sony DSC-RX100 IV high-speed camera (Sony Co., Ltd., Tokyo, Japan). The camera was mounted on a tripod 30 cm above the ground in the sagittal plane, carefully positioned to capture the full stroke cycle. Video resolution was set at 1280x720 pixels with a frame rate of 60 fps (Pueo et al., 2023). Data analysis was performed using RowerUp, an AI-powered tool designed for rowing technique analysis. This system employs a neural network to detect joint positions and ergometer or boat placement from video input. It combines traditional computer vision algorithms with post-processing techniques to evaluate human motion dynamics. Velocity analysis focused on the relative horizontal peak velocities of specific joints: the hip relative to the ankle for leg motion, the shoulder relative to the hip for trunk activity, and the wrist relative to the shoulder for arm movement. To calculate absolute velocities, the software applied a video scaling method that factored in average segmental body measurements.

Data analysis

Statistical analyses were performed using Jamovi version 2.3.28 (The Jamovi Project, 2022). Data are presented as the mean, standard deviation (SD). A Kolmogorov–Smirnov normality test indicated a normal distribution, so the statistical test applied was Pearson's correlation coefficient (r) to establish the relationships between segment speed and rowing performance. The magnitude of the correlation coefficient was interpreted as trivial (<0.1), small (0.1-0.3), moderate (0.3-0.5), strong (0.5-0.7), very strong (0.7-0.9), and almost perfect/perfect (0.9- 1.0) (Cohen, 1988). The level of significance was set to p<0.05.

Results

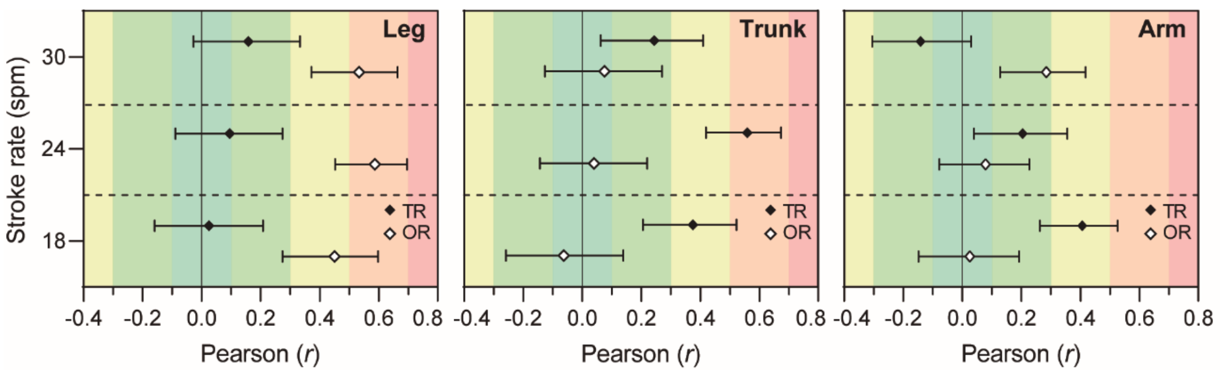
Traditional Rowing and Olympic Rowing show differences in segmental velocity with increasing stroke rate (Table 1). Legs velocity shows an increase of more than 0.15 m/s in Olympic Rowing, while in Traditional Rowing the increase does not exceed 0.10 m/s. Furthermore, legs velocity is always higher in Olympic Rowing at each stroke intensity. Trunk velocity has an increase between the lowest and highest intensity of more than 0.30 m/s. On the other hand, the velocity increase for this segment in Traditional Rowing is slightly higher than 0.30 m/s, but, although the increase is smaller, the trunk velocity at 18, 24 and 30 spm is higher in Traditional Rowing. Arms velocity shows the largest increase between both modalities. Traditional Rowing shows an increase of 0.30 m/s and Olympic Rowing shows an increase of over 0.40 m/s. In this segment, all velocities are higher in Olympic Rowing. Concerning the performance, it can be observed that Olympic Rowing outperforms Traditional Rowing with differences of more than 10 w at 18 spm, more than 35 w at 24 spm and more than 50 w at 30 spm.

Table 1. Mean values and standard deviation of segmental velocity and rowing performance at different stroke rates.

	Segment velocity (m/s)			Rowing performance (w)
	Leg	Trunk	Arms	
Traditional rowing				
18 spm	0.32 ± 0.05	1.24 ± 0.15	1.78 ± 0.13	117 ± 26.7
24 spm	0.36 ± 0.06	1.34 ± 0.15	1.93 ± 0.15	138 ± 19.4
30 spm	0.42 ± 0.05	1.46 ± 0.16	2.08 ± 0.15	171 ± 27.8
Olympic rowing				
18 spm	0.96 ± 0.12	0.96 ± 0.10	1.85 ± 0.16	130 ± 24.0
24 spm	1.07 ± 0.14	1.14 ± 0.10	2.07 ± 0.13	175 ± 27.4
30 spm	1.15 ± 0.15	1.34 ± 0.14	2.29 ± 0.14	226 ± 31.0

The correlation between segment velocities and performance (Figure 1) shows differences between Traditional Rowing and Olympic Rowing. The segments that correlate most with performance vary depending on the modality and stroke intensity. Traditional Rowing consistently shows a correlation with the trunk segment. At 18 spm, the correlation is moderate and statistically significant (r=0.375; p<0.001). At 24 spm, the correlation becomes strong with significant differences (r=0.560; p<0.001). At 30 spm, the correlation is weak and not statistically significant (r=0.243; p=0.099). The arms segment shows a moderate correlation with significant differences at 18 spm (r=0.476; p<0.001) but a low correlation with no significant differences at 24 spm (r=0.257; p=0.005). Traditional Rowing shows no significant correlations between leg velocity and performance.

Figure 1. Relationship between segmental velocity and performance in rowing at different stroke rates.



Olympic Rowing consistently shows a correlation with the leg segment. At 18 spm, the correlation is moderate and statistically significant (r=0.448; p<0.001). At 24 spm, the correlation is strong with significant differences (r=0.584; p<0.001). At 30 spm, the correlation remains strong, with significant differences observed (r=0.531; p<0.001). The arms segment shows a moderate correlation with significant differences at 30 spm (r=0.433; p<0.001). For the other intensities, the arms segment does not show any significant differences. The trunk segment shows no correlation with performance in this modality.

Discussion

This study examines the relationship between the velocity of each body segment and power. Olympic Rowing has shown higher power values than Traditional Rowing. Different studies have measured power in Traditional Rowing and Olympic Rowing. When comparing the watts generated in each modality, Olympic Rowing produces more power (Li et al., 2020; Lorenzo Buceta et al., 2015). The difference in power between Olympic Rowing and Traditional Rowing may be due to differences in rowing technique.

Our study shows that an increase in stroke rate results in higher segment velocities and greater generated power. Other studies measuring velocity have demonstrated that velocity can be a more critical factor than strength in maximal tests (Hartmann et al., 1993). Velocity can influence power output more significantly than strength with even minimal increases, making it a key element in performance (Rodriguez-Marroyo & Garcia-Lopez, 2015). These results show the importance of velocity in rowing performance.

Traditional Rowing demonstrates distinct velocities across segments. Trunk velocity is the only segment that consistently correlates with performance. The importance of the trunk in Traditional Rowing has been emphasized in numerous studies (González Aramendi, 2014; Penichet-Tomás et al., 2019), which highlight its role while reducing the significance of the leg segment. This result stems from the technical movement characteristics of Traditional Rowing, where leg velocity does not correlate with performance. The trunk is crucial not only for technical execution, but also for optimizing performance in Traditional Rowing.

In Olympic Rowing, leg velocity consistently correlates with performance. Prior studies have identified the leg segment as the primary driver in the stroke technique of this modality (Kleshnev, 2000). Other research emphasizes the importance of incorporating explosive strength and power training in Olympic Rowing (Penichet-Tomás & Pueo, 2017). The trunk does not correlate with performance in Olympic Rowing, which may be due to the relative immobility of the body and its dependence on leg movements. However, some studies have observed a slight increase in trunk range of motion (ROM) as stroke rate increases (Li et al., 2020). This increase in angulation may not translate to velocity gains, explaining the lack of performance correlation. Legs remain crucial in both technical execution and performance in Olympic Rowing. Remarkably, poor technique can result in lower performance, even if a segment does not correlate directly with outcomes (Buckeridge et al., 2015; Ertel, 2018).

When comparing both modalities, the trunk in Traditional Rowing consistently correlates with performance, although this correlation weakens at higher stroke rates. In contrast, in Olympic Rowing, the legs do not show a significant decline in their performance correlation. This may be due to the pelvic musculature's limitations in sustaining power and velocity at the same level as leg muscles. During strokes, trunk extension diminishes when flexor muscles are activated (Pollock et al., 2009). While the trunk does not correlate with Olympic Rowing performance, its movement remains important for maintaining technique, even if velocity gains are minimal.

The results obtained in this study refer to the segmental velocity on the rowing ergometer, and not to real rowing conditions. This lack of comparison limits the extrapolation of the results to real rowing practice and suggests the need for future research to validate the conclusions obtained on the ergometer through comparative studies with rowing in field conditions. Furthermore, it would be valuable to compare the force exerted by each segment and its relationship with performance. This study was conducted using a rowing machine, which measures only propulsive forces. Future studies could explore the propulsive and braking forces generated by each segment on water (Baudouin & Hawkins, 2002).

Conclusions

The present study shows biomechanical differences between Traditional Rowing and Olympic Rowing. The velocity of different segments influences performance in distinct ways, depending on the modality. In Traditional Rowing, trunk velocity is the primary factor impacting performance, while leg and arm velocities have less significance. In contrast, in Olympic Rowing, leg velocity has a greater impact on performance. These kinematic differences between the modalities also affect the power produced by the athlete. When the technical movement relies more on the legs, performance tends to be higher at any stroke rate. Therefore, analysing rowing performance requires focusing on leg velocity in Olympic Rowing and trunk velocity in Traditional Rowing.

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