10.61186/aassjournal.1473 Video summary on YouTube Infographic summary on LinkedIn

Ann Appl Sport Sci 13(1): e1473, 2025.
e-ISSN: 2322-4479; p-ISSN: 2476-4981

ORIGINAL ARTICLE

The Analysis of the Force Profile of Men's Lightweight Coxless Four Athletes in Indonesia

[1]Dede Rohmat Nurjaya*, [2]Agus Rusdiana, [3]Angga M. Syahid

[1]Sports Coaching Education Program, Faculty of Sports and Health Education, Universitas Pendidikan Indonesia, Bandung, Indonesia.
[2]Sports Science Program, Faculty of Sports and Health Education, Universitas Pendidikan Indonesia, Bandung, Indonesia.
[3]Physical Sports Coaching Program, Faculty of Sports and Health Education, Universitas Pendidikan Indonesia, Bandung, Indonesia.
***. Corresponding Author: Dede Rohmat Nurjaya**; **E-mail:** Dede-rohmat-n@upi.edu

Submitted October 21, 2024;
Accepted January 25, 2025.

CrossMark

KEYWORDS
Rowing,
Powerline,
Elite Rower.

ABSTRACT

Background. Analyzing force characteristics generated during rowing is a crucial determinant of success among elite rowers. **Objectives.** This study analyzed the synchronization of force in the performance of elite Men's Lightweight Coxless Four (LM4-) athletes in Indonesia. **Methods.** A descriptive and quantitative method was adopted, engaging four male rowing athletes from the Indonesian national team with an average age, height, and weight of 22 ± 1 years, 180 ± 2.5 cm, and 70 ± 0.5 kg, respectively. Furthermore, mean and standard deviation were calculated as initial data for further analysis on the normality (Chi-square method), homogeneity (Levene's test method), and bivariate correlation test with sig <0.01. The PowerLine instrumentation system introduced by Peachinnovation was synchronized with 3 Panasonic Handycam HC-V100 Full HD cameras for video recording purposes. **Results.** The results showed that the p-value of the catch angle against the effective angle is 0.566, and the p-value of the finish angle against the finish angle is -0.761, indicating the presence of variations in the magnitude of force generated by four rowers with the same force graph shape. The study offered a thorough scientific examination of oarlock force concerning the angle and timing of rowing in the boat. This clarification enhanced the understanding of previous examinations on the force's effectiveness concerning rowing angle and time. A total of 4 observed rowers were synchronized, and the results showed variations in force magnitudes concerning time and angle while the graph shape remained constant. **Conclusion.** The rowing method of the four athletes was harmonious, but the collective effectiveness was not uniform.

INTRODUCTION

Rowing is a highly intricate sport where on-water performance depends on technical proficiency and physiological work capacity (1-3). Among the technical aspects, the concepts of oar angle and the application of force are of particular significance and are fundamental contributors to propulsive work (4, 5). In this context, the oar plays a crucial role in effectively transmitting the force generated by the rower to the blade (6), thereby influencing the entire rowing mechanism. This dynamic interaction between the rower's movements, dictated by joint moments, and the oar handle is further shaped by the frictional force between the blade and water (7).

Rowing strokes follow a cyclical pattern, comprising the drive (propulsive) and recovery (non-propulsive) phases. Based on observations, variations in boat velocity occur during each stroke. In a study conducted by (8), maximum velocity is achieved at the start of the recovery phase, while the minimum was registered during the catch phase. These fluctuations are fundamentally a consequence of the interplay of pushing and pulling forces operating within the entire boat system, which includes rower, boat, and oar, as elucidated by (9). According to previous studies, rowing strength is the singular source of propulsion, playing a significant role in overall performance (7). Consequently, the importance of rowing strength lies in analyzing the coordination to shape the force profile, as it constitutes a performance element that is challenging to attain solely through physical improvements (10, 11).

Previous studies have established that collecting force data on rowing boats is important due to the acknowledged disparities between force profiles on water and ergometers (12). The integration of contemporary boat instrumentation systems (13), such as PowerLine, combined with synchronized video data, facilitates the comprehensive analysis of the force profile on water (14). Following the results of previous examinations, this method effectively served the purpose of presenting the critical attributes of an effective force profile. Studies on rowing performance using the force analysis approach in Indonesia remain limited. The country is trying to improve rower performance through a high-tech digital tool approach. Therefore, this study aimed to investigate the synchronization of force in the performance of Indonesia's Men's Lightweight Coxless Four (LM4-) rowing team. The results are intended to contribute valuable insight and foster innovation in the force analysis of rowing teams in developing countries such as Indonesia.

MATERIALS AND METHODS

Method. A descriptive and quantitative method was adopted to systematically and accurately describe facts about specific symptoms that are the center of attention.

Participants. The sample used included four male rowing athletes from the Indonesian National Team, with an average age, height, and weight of 22 ± 1 years, 180 ± 2.5 cm, and 70 ± 0.5 kg, respectively. Purposive sampling was used to ensure that participants met the specific study criteria. All participants provided written consent and were confirmed not injured. Before the test, technical explanations related to the implementation procedures were provided comprehensively. These athletes specialized in Men's Lightweight Coxless Four (LM4-) and had achieved a third-place finish at the 2017 World Rowing Championship U-23, held in Plovdiv, Bulgaria. Only male athletes with expertise in swift boat events were included in the study.

Instrument. The study used the PowerLine instrumentation system introduced by Peachinnovation (14), synchronized with 3 Panasonic Handycam HC-V100 Full HD cameras for video recording purposes. A total of 4 powerline sensors were installed on each rower's oarlock.

Statistical Analysis. Statistical analysis was conducted using SPSS version 22.0 application software (SPSS Inc., Chicago, IL). Furthermore, mean and standard deviation were calculated as initial data for further analysis on the normality (Chi-square method), homogeneity (Levene's test method), and bivariate correlation test with sig <0.01.

Data Analysis. The PowerLine system incorporated various sensors for measuring force, angle, boat velocity, and boat acceleration during rowing activities. The parameters under analysis included catch angle, finish angle, effective angle, and the average oarlock force over % time and angle. Figure 1 shows a detailed explanation of force calculations performed using the PowerLine device.

The variables are measured using a powerline tool installed on the boat's oarlock at an angle that produces the force (F gate and F gate-ax) shown in Figure 1.

Procedure. A single team participating in the Men's Lightweight Coxless Four (LM4-) category was equipped with the PowerLine™ system to record pin force and oar angle data at a rate of 50 Hz for calibration on the powerline. Furthermore, athletes were instructed to complete a warm-up on rowing a boat covering approximately 4 kilometers, incorporating a minimum of 20 familiarization strokes at the intended race rate. During this warm-up phase, adjustments were made to the horizontal foot-stretcher position to achieve seat catch angles of 70 ± 1 degrees, and the data were relayed to a laptop in the coach boat for calibration on the powerline. Subsequently, athletes were directed to execute 20 strokes on rowing a boat, each being performed at a different rate of stroke/minute (R20, R24, R28, R32). A 10-minute rest interval was separated for each trial to minimize fatigue and ensure consistent performance.

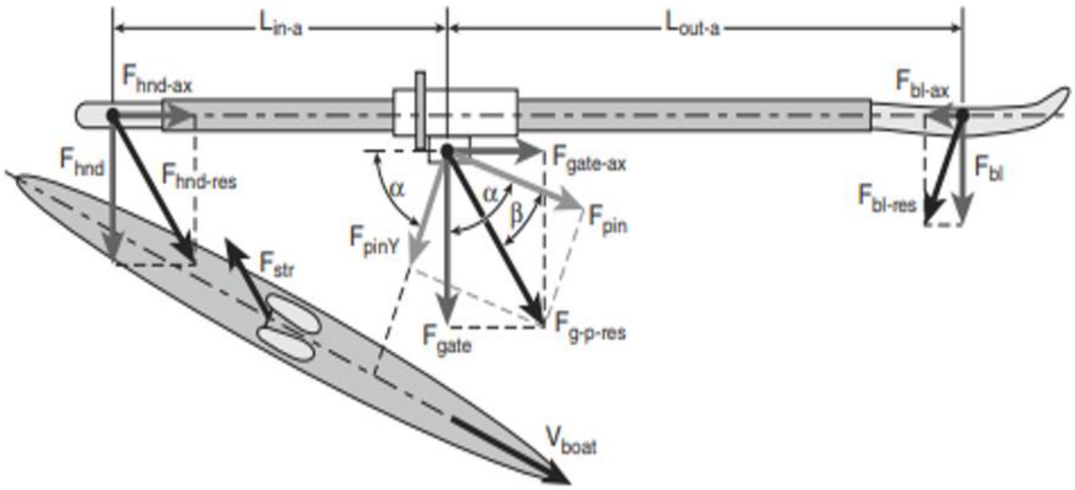

Figure 1. Schematics of force measurement in rowing (15).

RESULTS

Table 1 shows the average of the catch and finish angles, standard deviation, and significance value, defining effective rowing angles during paddling. These measurements were collected from each athlete across five different stroke speeds/minute (R20, R24, R28, R32, and Rmax).

The p-value of the finish angle is -0.761, which explains that the larger the degree, the less effective it is during paddling. The p-value of the catch angle is 0.566, which shows that the bigger the ideal angle (Table 2), the better the effective angle during paddling.

Each crew consisted of rowers with diverse body types, physical capabilities, strengths, and rowing methods, which gave rise to distinctive movement patterns and disparities in force profile. This diversity presents the critical need for a deeper comprehension of the propulsion mechanisms specific to various boat classes and the integration of efficacious force profiles. In this context, using the oarlock force average-angle curve has proved to be a valuable tool for comparing different stroke rates, offering a visual representation of the work accomplished per stroke, as emphasized by a previous study (16). Figure 2 shows the four athletes' average force generated with respect to the rowing angle.

Table 1. Catch Angle, Finish Angle, and Effective Angle when paddling.

	Mean ± SD	P-Value
Catch angle (◦)	52.63 ± 2.82	0.566**
Finish Angle (◦)	35.05 ± 0.99	-0.761**
Effective angle (◦)	72.09 ± 3.50	1

**: Significant at P<0.01

Table 2. Rower stroke's oar angle.

Criteria	Unit	Target	Measurement				Difference			
			1	2	3	4	1	2	3	4
Net Drive Time	sec	0.67	0.60	0.68	0.61	0.59	-0.07	+0.01	-0.06	-0.08
Catch Angle	deg	-52	-50.9	-56.3	-51.9	-51.4	-1.1	+4.3	-0.1	-0.6
Finish Angle	deg	34.0	34.7	33.9	35.6	36.1	+0.7	-0.1	+1.6	+2.1
Total Angle	deg	86.0	85.6	90.2	87.6	87.5	-4.5	+0.1	-2.5	-2.6
Catch Slip	deg	9.0	5.90	4.00	4.00	5.30	-7.2	-9.1	-9.1	-7.8
Finish Slip	deg	9.0	8.80	9.10	12.3	13.1	-5.5	-5.2	-2	-1.2

The "front-loaded" design, shown in Figure 2, situated the peak force ahead of the perpendicular position of the oarlock, leading to a significant, consistent power curve. This design diminished fluctuations in boat velocity and enhanced comprehensive efficiency. It is important to acknowledge that the concept has been supported by previous studies (15, 16). Analysis of the force profile produced showed that rower no.1, represented by the blue curve, achieved the most efficient performance, as the stroke peak corresponded with the perpendicular position of the blade. Meanwhile, no.3 and no.4 had relatively minor peak forces compared to no.1. Rower no.2, represented by the red curve, showed an inefficient stroke profile, signifying that the peak force occurred correctly before the blade reached the perpendicular position. This discrepancy in the position of the peak force in the stroke may be attributed to the greater reliance on lifting force to initiate the motion, a more efficient method of propelling the boat than lifting over a stalled blade (16). Previous studies have recommended the adjustment of the body positions in order to commensurate force output with the strength of specific body segments (17) and reduce the strain on the arms (18) to address these inefficiencies in rowing methods.

Following the front-loaded design, additional data comprised the oarlock force average - % time, as shown in Figure 3. This profile represents force concerning temporal scales, with time presented on the y-axis (19) or as a percentage of time after tempo normalization (9). Therefore, these graphical representations may be denoted as force-time or percentage-force profiles.

Figure 3 shows the temporal evolution of force during both the drive and recovery phases. Rower no.1, represented by the blue line on the graph, had the highest peak force and a significantly large impulse area. However, the others generated smaller peak forces, with no.2 experiencing a significant decline during the drive phase. It is important to acknowledge that all rowers produced identical force profiles at the recovery phase, showing a commendable synchronization.

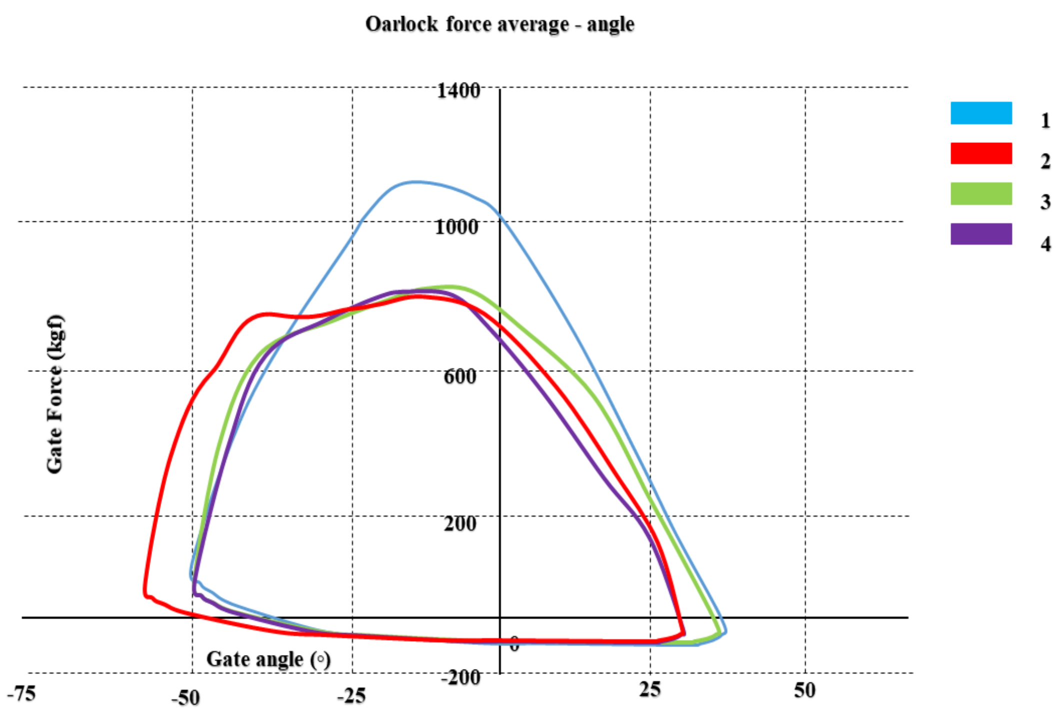

Figure 2. Oarlock force average – angle at coxless four.

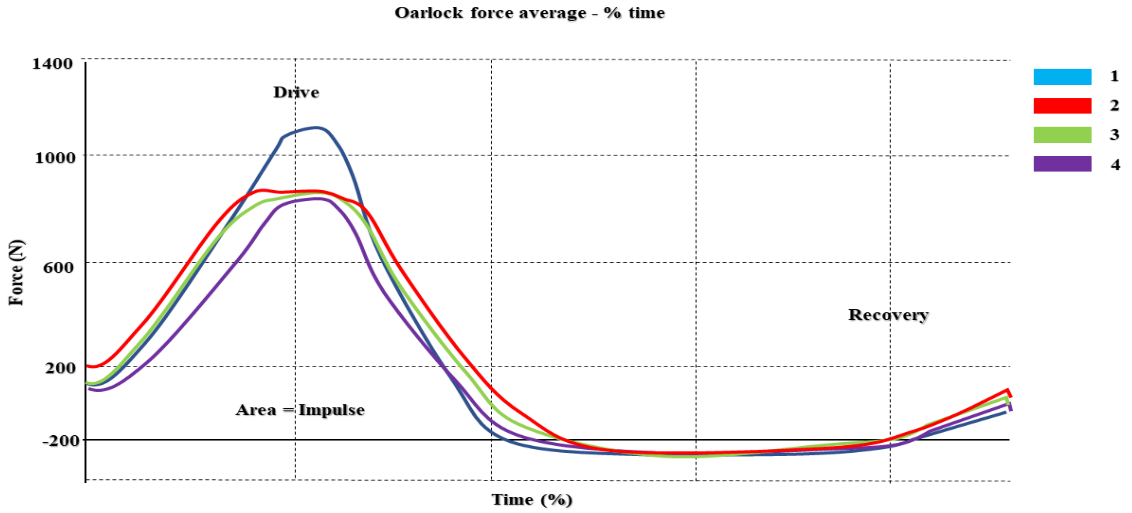

Figure 3. Relative Force over Time.

DISCUSSION

The variances observed in the oarlock force profile were attributed to the differences between the angles generated by rowers during strokes, as detailed in Table 2. The force-time profile served as a valuable tool for observing crucial temporal parameters associated with force production, including stroke rate and the ratio of time allocated to the propulsive phase relative to the recovery phase (11). This profile also enables the assessment of disparities in the magnitude of force application and the time required to attain the maximum level. Additionally, the force-time function aids in examining the impulse generated by rowers during each stroke cycle. Following this, the strength-time graph, a potential tool for monitoring training intensity, served as an exercise load indicator (20). Using the percentage force profile further enhanced the analysis by correlating force application with the stroke profile, enabling the coordination of key events within the stroke cycle. As a result, this correspondence permits the qualitative observation and comparison of force application characteristics related to magnitude during the primary phases of the stroke cycle.

The red line in Table 2 signifies values that require improvement to meet the predefined target. Meanwhile, the blue values show that the targets have already been achieved. Further information on the angle calculation system and the targets of rowers is provided in Figure 4.

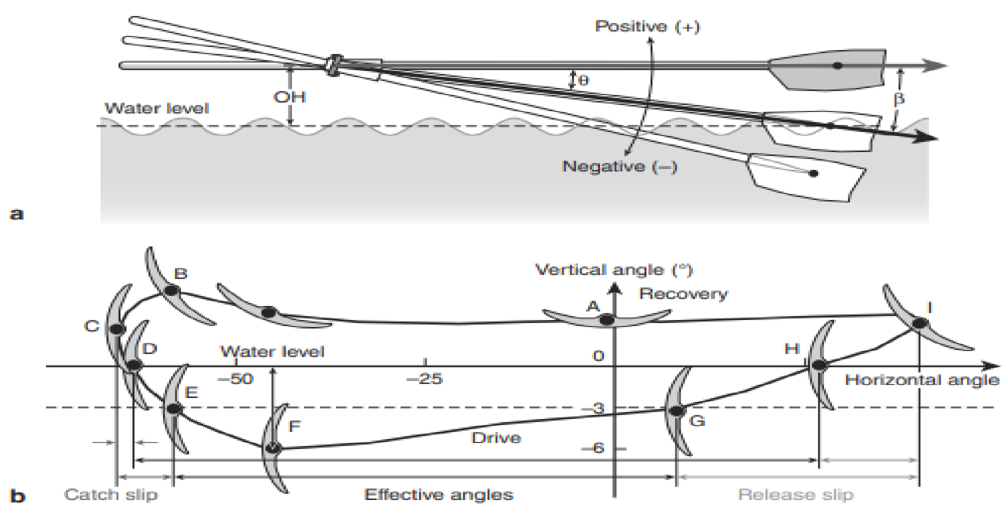

Figure 4. Vertical Oar Angle. a) reference system of the vertical oar angle; b) criteria of the trajectory of the blade's center (21).

For practical purposes, it was assumed that the oar's vertical angle (θ) was set to zero at water level, precisely in the middle of the blade. Furthermore, the position of the oar was designated above and below the water surface in the positive and negative directions, respectively. The reference system used for measuring the vertical angle is shown in Figure 4. In this context, β, which represents the angle between the oar at 0 degrees and the horizontal plane, was contingent on the outboard length and the height (OH) of the gate above the water level. This height fell within the range of 22 to 26 cm, leading to common angle values of 9° to 10° in sculling and 6° to 7° in rowing. Several factors (22-24), such as the weight suspension of the rower during the drive and variations in the roll and pitch of the hull, have been observed to influence the height of the gate above the water. The variation can modify the vertical oar angle in sculling and rowing by up to 1.7° and 1.2°, respectively, with an amplitude of up to 5 cm during the stroke cycle. This flaw can be addressed by measuring the hull's pitch, roll, or three-dimensional acceleration.

The trajectory of the blade concerning the water level was plotted using the reference system described in Figure 4. In the recovery phase, the stroke cycle was discovered to start at point A, where the oar was perpendicular to the boat in the horizontal plane. At this stage, θ measures 2.4° ± 0.8° (mean ± SD) and remained consistent for both rowing and sculling. Subsequently, the blade was raised to facilitate squaring, and θ reached the maximum at point B, achieving 4.9° ± 1.2° in sculling and 4.1° ± 1.2° in rowing. It is also important to acknowledge that the blade initiated a descent, moving approximately 2° to 4° horizontally toward the bow direction before altering the course at point C. The catch angle, which was discovered at this location, corresponded to the horizontal oar angle, with the bottom edge of the blade nearly at a +3° water level. The following are ways to define catch slips:

1. The first definition occurred between catch points C and D, where the blade's center intersected the water surface. At this juncture, the boat-rower system can start a forward movement as the depth of the blade in the water becomes sufficient to generate propulsive power that surpasses drag.

2. The second definition occurred between catch points C and E, where the entire blade was fully submerged, offering complete propulsive force. In this context, the angle may vary depending on the outboard and blade width. For practical purposes, the criterion at 3° was established in this study, ensuring that all dimensions adequately covered the blade.

At point F, the blade attained minimum θ, corresponding to the maximum depth in the water. This angle measures 7.2° ± 1.3° in sculling and -5.7° ± 1.2° in rowing. Following catch slips, another set of components to observe in this study are the release slips, which can be delineated by either starting from point G at -3 ° θ or H at 0° θ, with both ending at point I (the finishing angle).

CONCLUSION

In conclusion, this study offered a comprehensive scientific examination of oarlock force concerning angle and time during rowing in a boat. The results provided a further understanding of the force's effectiveness, explicitly concerning angle and time during rowing, building upon previous studies. The synchronized rowing strokes of 4 observed rowers in Men's Lightweight Coxless Four (LM4-) led to variations in force graph magnitudes concerning time and angle, while the entire graph shape remained consistent. This observation showed that the rowing method of athletes was harmonious, but the collective effectiveness was not uniform. The scope of this study was limited to the number of light-class sweep competitions for male rowers. Therefore, further investigations should explore other boat numbers, such as sculling or another gender in rowing sports.

APPLICABLE REMARKS

- Analyzing rowing methods, focusing on force efficiency and effectiveness in elite athletes, is essential.
- Providing technical skills to athletes through training Exercises that support the efficacy of biomechanical principles.
- The results of this study should be provided to the relevant Federations and the Olympic Committee.

ACKNOWLEDGMENTS

The authors thank the Universitas Pendidikan Indonesia and the Indonesian Rowing and Canoeing Association (PB.PODSI).

AUTHORS' CONTRIBUTIONS

Study concept and design: Dede Rohmat Nurjaya. Acquisition of data: Agus Rusdiana. Analysis and interpretation of data: Angga M. Syahid. Drafting the manuscript: Dede Rohmat Nurjaya. Critical revision of the manuscript for important intellectual content: Agus Rusdiana. Statistical analysis: Angga M. Syahid. Administrative, technical, and material support: Dede Rohmat Nurjaya. Study supervision: Dede Rohmat Nurjaya.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this study.

FINANCIAL DISCLOSURE

There are no financial interests related to the material in the manuscript.

FUNDING/SUPPORT

This study was self-funded by the authors.

ETHICAL CONSIDERATION

As the present study engaged human participants for the survey method, the authors obtained informed consent from all the participants.

ROLE OF THE SPONSOR

Since this study was self-funded, no funding organizations had a role in the design and conduct, collection, management, and analysis of the data or the manuscript's preparation, review, and approval.

ARTIFICIAL INTELLIGENCE (AI) USE

The present study's authors did not use artificial intelligence-based software to adjust brightness, contrast, or color balance or apply AI-assisted imaging methods to interpret the underlying data.

REFERENCES

1. Huang CJ. Strength and Power Determinants of Rowing Performance. Article in Journal of Exercise Physiology Online [Internet]. 2007. Available from: https://www.researchgate.net/publication/269037399.
2. Legge N, Watsford M, O'Meara D, Slattery K. "A feeling for run and rhythm": coaches' perspectives of performance, talent, and progression in rowing. Journal of Sport Science. 2023;41(10):927–36. [doi:10.1080/02640414.2023.2249752] [PMid:37609886]
3. Barrett RS, Manning JM. Relationships Between Rigging Setup, Anthropometry, Physical Capacity, Rowing Kinematics and Rowing Performance. Sport Biomechanics. 2004;3:221–35. [doi:10.1080/14763140408522842] [PMid:15552582]
4. Warmenhoven J, Cobley S, Draper C, Smith R. Over 50 Years of Researching Force Profiles in Rowing: What Do We Know? Sports Medicine. 2018 Dec 1;48(12):2703–14. [doi:10.1007/s40279-018-0992-3] [PMid:30298480]
5. Legge N, Draper C, Slattery K, O'Meara D, Watsford M. On-water Rowing Biomechanical Assessment: A Systematic Scoping Review. Sports Med Open. 2024 Dec 1;10(1):1–0. [doi:10.1186/s40798-024-00760-2] [PMid:39331267]
6. Hill H. Dynamics of coordination within elite rowing crews: Evidence from force pattern analysis. J Sports Sci. 2002;20(2):101–17. [doi:10.1080/026404102317200819] [PMid:11811567]
7. Baudouin A. A biomechanical review of factors affecting rowing performance. Br J Sports Med [Internet]. 2014 Dec;36:396–402. [doi:10.1136/bjsm.36.6.396] [PMid:12453833]
8. Kleshnev V. Boat acceleration, temporal structure of the stroke cycle, and effectiveness in rowing. Proc Inst Mech Eng P J Sport Eng Technol. 2010 Mar 1;224(1):63–74. [doi:10.1243/17543371JSET40]
9. Smith RM, Loschner C. Biomechanics feedback for rowing. J Sports Sci. 2002 Oct;20(10):783–91. [doi:10.1080/026404102320675639] [PMid:12363295]
10. Anderson R, Harrison A, Lyons GM. Rowing: Accelerometry based feedback can it improve movement consistency and performance in rowing? Sports Biomech. 2005 Jul 1;4(2):179–95. [doi:10.1080/14763140508522862] [PMid:16138656]

11. Doyle MM, Lyttle A, Elliott B. Comparison of force-related performance indicators between heavyweight and lightweight rowers. Sports Biomech. 2010 Sep;9(3):178–92. [doi:10.1080/14763141.2010.511678] [PMid:21162363]
12. Li CF, Ho WH, Lin HM. Strength Curve Characteristics Of Rowing Performance From The Water And The Land. J Biomech. 2007 Jan;40:297. [doi:10.1016/S0021-9290(07)70758-3]
13. Worsey MTO, Espinosa HG, Shepherd JB, Thiel D V. A systematic review of performance analysis in rowing using inertial sensors. Electronics (Switzerland). 2019 Nov 1;8(11). [doi:10.3390/electronics8111304]
14. Hume P, Nolte V, Coker J. Validity of the Powerline boat instrumentation system. In: ISBS-Conference Proceedings [Internet]. Limerick; 2009. Available from: https://www.researchgate.net/publication/283517531.
15. Kleshnev V. Biomechanics of Rowing. In: Nolte V, editor. Rowing Science. Human Kinetics, Inc.; 2024. p. 105–21.
16. nolte volker. Introduction to the Biomechanics of Rowing. In FISA Coaching Development Programme Course- Level III; 2020. p. 83–8.
17. kleshnev V. Rowing Biomechanics Newsletter. Biorow [Internet]. 2001. Available from: www.sportscoach-sci.com.
18. Kleshnev V. Rowing Biomechanics Newsletter. Biorow. 2002.
19. Roth W, Schwanitz ?, Pas P. Force-Time Characteristics of the Rowing Stroke and Corresponding Physiological Muscle Adaptations. J Sports Med. 1993;14:32–534. [doi:10.1055/s-2007-1021221] [PMid:8262705]
20. Hofmijster MJ, Landman EH, Smith RM, Van Soest AJK. Effect of stroke rate on the distribution of net mechanical power in rowing. J Sports Sci. 2007 February 15;25(4):403–11. [doi:10.1080/02640410600718046] [PMid:17365527]
21. Nolte V. Rowing Faster. 2nd ed. V.Nolte, editor. Human Kinetics; 2011. [doi:10.5040/9781718219397]
22. Findlay M, Turnock SR. Mechanics of a rowing stroke: Surge speed variations of a single scull. Proc Inst Mech Eng P J Sport Eng Technol. 2010 Mar 1;224(1):89–100. [doi:10.1243/17543371JSET49]
23. Held S, Siebert T, Donath L. Changes in mechanical power output in rowing by varying stroke rate and gearing. Eur J Sport Sci. 2020 March 15;20(3):357–65. [doi:10.1080/17461391.2019.1628308] [PMid:31232195]
24. Warmenhoven J, Cobley S, Draper C, Harrison A, Bargary N, Smith R. How gender and boat-side affect shape characteristics of force–angle profiles in single sculling: Insights from functional data analysis. J Sci Med Sport. 2018 May 1;21(5):533–7. [doi:10.1016/j.jsams.2017.08.010] [PMid:28958487]