



Biomechanical differences in recovery, drive, and finish phases between injured and non-injured rowing athletes



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ABSTRACT

Background: The prevalence of injuries among rowing athletes, as determined by previous analyses, provided a key foundation for this study. This study aimed to analyze differences in rowing kinematics during each phase of the rowing stroke (catch, drive, and finish) between rowing athletes with a history of injury and those without.

Methods: The study utilized the quantitative descriptive method with a causal-comparative design. Participants were selected based on the criteria, including active rowing athletes at the national training camp preparing for the 2025 SEA Games, undergoing routine training, and physically capable of completing a 100-meter ergometer test. Athletes who had incomplete injury history, were undergoing rigorous rehabilitation, or had any acute injuries or pain that limited movement during data collection were excluded. The final samples were 21 Indonesian National Team rowers. This rowing kinematics was evaluated using Kinovea software with two-dimensional video records of athletes who performed the rowing actions on an ergometer in training without assistance.

Results: The analysis did not show a significant difference between the two groups, but the descriptive analysis showed differences in the average angles for both groups during each phase.

Conclusion: The results of this study suggest that even non-statistically significant kinematic changes may have treatment implications. It highlights the need for a thorough biomechanical assessment, technique-specific rehabilitation and regular monitoring of movement quality as important elements of injury prevention and performance enhancement in competitive rowing.

Keywords: 2D motion analysis, catch phase, drive phase, ergometer, finish phase, injury, kinematics, Kinovea, rowing.

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INTRODUCTION

Rowing may appear to be a low-impact activity, but it is actually quite injury prone. This is because it involves repetitive, high-intensity motions that need significant strength, endurance, and coordination. Rowers are more likely to sustain injuries due to poor technique or straining too hard on their joints and muscles.¹ Injuries to the lower back are most common, accounting for around 53% of cases. This makes sense, as the sport's great range of motion and repeated pounding on the lumbar area mount up quickly.² Knees follow at roughly 14%, frequently due to unequal stresses around the patellofemoral joint during the forceful push-off phase. Rib and chest injuries account for around 10% of all injuries, and are usually caused

by skimping on rest, increasing training intensity, overloading, or abruptly shifting pressure patterns.³

Rowing technique is divided into three connected phases: catch, drive, and finish. Rowers who do this incorrectly frequently exhibit crooked joint angles and imprecise coordination between the knees, hips, and trunk. Over time, this not only reduces performance but also increases mechanical stress on the muscles and joints.² Typical slip-ups during the recovery (catch) phase include excessive knee flexion, loss of trunk control, and getting the arms and legs out of sync. One major red flag is too much bend in the lower back—it increases compressive and shear pressures on the spine, increasing the risk of chronic lower back ailments.⁴ Rowers with previous injuries may compensate with restricted

movement or off-kilter trunk placement, which might disrupt subsequent phases.⁵

During the drive phase of rowing, sitting in a suboptimal recovery position can shift the workload away from your legs and straight onto your lower back. The main culprits are using your arms too early and distributing force unevenly across your body. These common technical slip-ups build up repetitive mechanical stress, paving the way for overuse injuries. The main culprits are using your arms too early and delivering force unevenly across your body. These common technical errors cause repetitive mechanical stress, which leads to overuse injuries.⁶ Overextending your upper body, pulling primarily with your arms, and hanging on to the oar for too long all disrupt the smooth power transfer from your legs to the blade during

the final phase. This increases tension on your back, shoulders, and ribs. Athletes who have previously experienced injuries generally exhibit greater variety in their upper body and hip movements, it's as if their body is adapting to avoid pain, but this results in less effective strokes overall.⁷

Certainly, there has been a lot of research on rowing biomechanics, but nobody considered the phase-by-phase kinematic differences with regard to injuries until now. This study is a follow-up of previous work by examining the modifications of rowing movements during the three main phases in injured and unaffected athletes. The technique, viewing the rowing stroke as a single continuous chain of motion, helps to highlight how minor technical flaws can accumulate, increasing joint stress and the risk of injury.^{2,8}

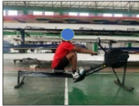
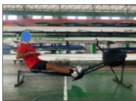
Kinematic analysis gives a full picture of joint angles, angular velocities, stroke length and body locations during the rowing cycle.^{9,10} Following an injury, athletes often employ compensatory movements that alter these important parameters.¹¹ While these changes may protect them in the short term, they usually develop unproductive habits and increase the likelihood of re-injury.¹² Therefore, this study discusses rowing kinematics in injured and uninjured rowers, focusing on differences during the three critical phases: recovery, drive and finishing.

METHODS

The research was conducted on April 28-29, 2026 at the National Rowing Athlete Dormitory Situ Cipanunjang, Pangalengan, Bandung, West Java. The purpose of this research is to find out the difference of rowing kinematic by observing movement on ergometer without interference. The present study assessed the angles of the joints during the recovery, stroke, and finish phases of athletes with and without injury history by two-dimensional video recording. This research used a descriptive quantitative method with a causal-comparative research design.

This study included 21 rowing competitors from the national training camp who were chosen via total sampling due to the limited population size. The participants were active athletes at

Table 1. Kinematic angle variables

Kinematics variables		Angle range	
Phase	Angle	Minimum (o)	Maximum (o)
Recovery (Catch) 	Shin	85	94
	Hip	19	35
	Knee	40	57
	Trunk	105	119
Mid Drive 	Shin	48	127
	Hip	96	117
	Knee	126	161
Finish 	Trunk	62	79
	Shin	48	127
	Hip	71	101
	Knee	104	155
	Trunk	73	96

the national training center who were preparing for the 2025 Southeast Asian Games and were training on a regular basis during data collection. Inclusion criteria for the athletes included having sustained an injury or never sustained an injury throughout their careers, therefore being able to divide the athletes into injured and uninjured groups. Participants were required to consent to participate, complete a structured injury-history questionnaire via Google Forms and be physically able to complete a 100 m rowing test on an ergometer.

Subjects not completing the injury history form and not giving written agreement to be respondents were eliminated. We also omitted athletes in severe rehabilitation who were unable to participate in regular training sessions. We also excluded participants with acute injuries or painful conditions that might impede movement during data collection, as these circumstances can affect kinematic measurements.

This study utilized an injury history questionnaire and a 100-meter rowing kinematic test on a Concept ergometer. The kinematic assessment was conducted using two-dimensional video observation and evaluated with Kinovea software. The instruments were validated by comparing observed kinematic angles to ideal ranges published in previous investigations by Sugiharto et al. and Barrett and Manning¹³ as shown in [Table 1](#). This study examined the effect of previous

injury on the angles of the shin, knee, hip and trunk at different stages of the rowing stroke. We also compared movement patterns of injured and uninjured rowers to determine technique flaws that may increase risk of injury.

RESULTS

The participants were generally young individuals aged 18 to 25, with 3 to 10 years of rowing experience between them. Over 60% had experienced at least one training injury. Hot areas were shoulders, waist, lower back, hamstrings and knees. There were only four rowers in the injury free group, one man and three women. The injured group consisted of 17 rowers, the majority of whom were males (15). Their injuries included three shoulders, seven lower backs, four lumbar areas and one hamstring. Both women in the group had knee concerns. Their complaints were three shoulders, seven lower backs, four lumbar areas and one hamstring. Both women in the group had knee problems. The injury-free group contained just four rowers: one male and three females.

Rowers sometimes blame their injuries on over-training, bad rowing technique and too much time on the machines. These challenges often lead to poor performance, diminished movement and flexibility, rowing pain and unstable balance. This is clearly demonstrated in Figures 1-3 from our kinematic study using the Kinovea software that shows how the angles of the

Table 2. Mean results of the kinematic analysis of joint angles across rowing technique phases

Injuries	Recovery (Catch) Phase				Mid Drive Phase				Finish Phase			
	Shin(o)	Knee(o)	Hip(o)	Trunk(o)	Shin(o)	Knee(o)	Hip(o)	Trunk(o)	Shin(o)	Knee(o)	Hip(o)	Trunk(o)
Shoulder	64	52	28	120	114	150	110	73	121	161	125	56
Hip	61	48	28	119	113	146	109	72	120	163	132	56
Lower back	63	51	28	121	114	149	108	73	122	165	131	57
Hamstring	64	54	27	120	109	142	103	76	123	166	136	53
Knee	61	47	26	121	114	148	103	77	122	165	135	55
No injury	71	65	29	118	115	146	94	78	121	166	134	56

joints change in the different phases of a rowing stroke.

By using Kinovea for 2D kinematic analysis, we found that the angles of the shins, knees, hips and trunk were significantly different in the three major phases of the rowing stroke: the recovery/catch, mid-drive and the finish. Rowers with previous injuries showed significantly different movement patterns than rowers without injuries. During the recovery phase (catch) these athletes often overreached with their arms, and their trunks were flexed forward much more than what is typically recommended. They also showed increased ankle flexion, which resulted in smaller knee angles. Overall, these patterns point to an uneven force distribution that is probably a compensatory process to cope with residual discomfort or decreased range of motion.

In the mid-drive phase of rowing, mistakes in the sequence of movement are easily detected. Some athletes begin to bend the arms too early, before they finish their leg drive and trunk extension. These errors lead to a decrease in the efficiency of power transfer and an increase in the mechanical stress on the shoulders, lower back and knees. In the final phase, athletes with injuries often demonstrate excessive leg extension, excessive wobble of the upper body and hand placement higher than optimal at the end of the stroke. Some athletes begin to bend their arms prematurely, before their leg drive and trunk extension are complete. These inaccuracies lead to a decrease in the efficiency of power transfer and increase in the mechanical stress on the shoulders, lower back and knees. In the final phase, athletes with injuries generally exhibit overextension of the legs, excessive

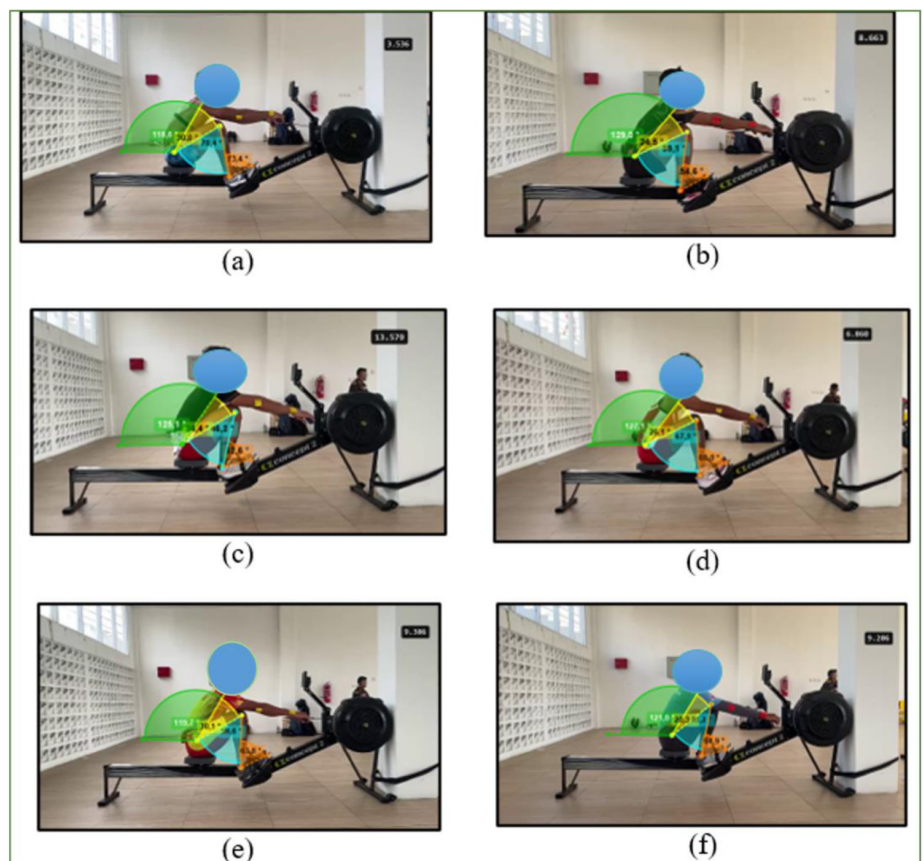


Figure 1. Results of the kinematic analysis of the rowing stroke during the recovery (catch) phase in athletes with and without injuries: (a) no injury, (b) shoulder injury, (c) waist injury, (d) lower back injury, (e) hamstring injury, (f) knee injury.

wobbling of the upper body, and placement of the hands higher than optimal at the end of the stroke. All of this increases joint stress and reduces the overall efficiency of the row. **Table 2** provides a detailed breakdown of kinematic angles across rowing phases, comparing participants with and without injury history.

DISCUSSION

The kinematic analysis of rowing motion suggests that previous injuries influence

how athletes move through each phase of the stroke, even if not all differences are statistically significant. During the recuperation phase, we observed athletes overreaching with their arms, their trunk angles reached 129° and 127°, much above the optimal 119° indicated by Barrett and Manning. This type of deviation most likely increases strain on the deltoids and lats, and if it occurs repeatedly, it has the potential to exacerbate existing injuries.^{13,14}

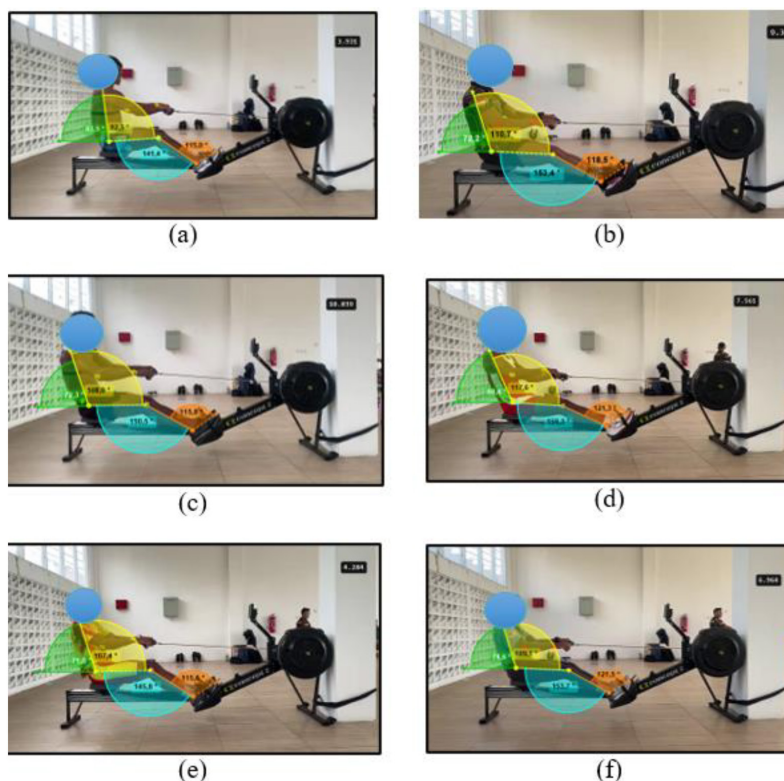


Figure 2. Results of the kinematic analysis of the rowing stroke during the mid-drive phase in athletes with and without injuries: (a) no injury, (b) shoulder injury, (c) waist injury, (d) lower back injury, (e) hamstring injury, (f) knee injury.

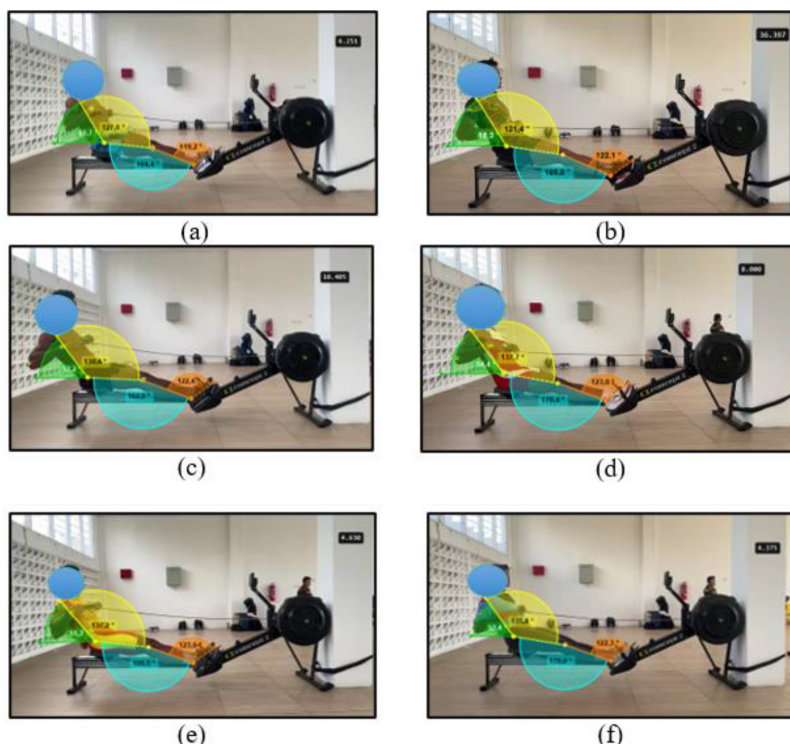


Figure 3. Results of the kinematic analysis of the rowing stroke during the finish phase in athletes with and without injuries: (a) no injury, (b) shoulder injury, (c) waist injury, (d) lower back injury, (e) hamstring injury, (f) knee injury.

Athletes with previous lower back and knee problems had excessive ankle flexion—their tibial angle reached 78° , much below the required 85° minimum. This led their foot to partially lift out of the shoe, requiring them to rely more on their quads and lower back muscles. These workarounds are most likely the result of pain avoidance, which disrupts movement patterns and impairs force transfer throughout the body. If individuals continue to practice these patterns during long training sessions with high reps and heavy loads, muscle fatigue may increase, increasing the likelihood of re-injury in those previous places.^{15,16}

This study found that injured athletes frequently begin pulling with their arms too soon in the drive phase, the key power-generating element of the rowing stroke. They start the jump before they finish the leg drive and upper-body swing. This disorganized process breaks up the smooth flow of energy from the legs to the torso and out to the arms. This creates more mechanical stress on the shoulders, back, and lower-body muscles. Such errors often happen without the athletes realizing it, and often stem from the repetitive nature of training without sufficient technical changes, particularly when they are trying hard to row faster.¹⁷ This is consistent with prior research: early arm flexion is a core error that wastes power and increases the risk of injury. Even elite rowers like Cameron Buchan display this in biomechanical breakdowns: by keeping their arms straight until their legs have finished their work, they improve energy transfer and better distribute the load.¹⁸

In the tail end of the rowing cycle, injured athletes display some distinct changes in their movement patterns. For instance, they often hyperextend their knees beyond the optimal range of 126° to 161° , leading to a disruption in quadriceps activation and placing extra stress on the knee joint.^{19,20} Their upper body angle is also decreased to 51° to 58° (below the ideal 62° to 79°), indicating an excessive backward tilting and increased strain on the lower back muscles, in particular the latissimus dorsi and erector spinae.^{21,22}

Athletes with a history of hamstring injuries tend to swing their arms excessively, beyond the epigastric region.

This excessive movement leads to a decrease in movement efficiency and increases mechanical stress on the lower back. It is a frequent compensatory behavior that appears after a hamstring injury. These results highlight the importance of coordinated and strong movements in the late part of rowing. In fact, the activity requires the perfect coordination of the lower limbs, the trunk and the upper body.^{23,24}

In general, our data indicate that injured athletes significantly modify their joint angles during the catch phase of the stroke. These angles tend to be smaller or bigger in specific joints, indicating variations in how they begin their swim stroke, both in their initial setup and the mechanics of that first pull. This could even affect their resting posture while swimming. During the propulsion phase, we observed more variability in their movements, particularly in the hip and trunk angles. It appears that injured athletes are using compensatory strategies to keep going. During the terminal phase, they frequently end up in altered postures, notably at the knee and hip joints.^{25,26}

Although the kinematic angle changes between injured and unaffected athletes appear little at first glance, even minor deviations from the ideal can disrupt rowing performance and alter how stress is distributed across muscles and joints.^{27,28} If an injury goes untreated, athletes frequently resort to compensatory motions to avoid pain, which disrupts their core biomechanics and reduces movement precision. Over time, as these skewed patterns become chronic, all of the repetitive high-load effort increases muscle fatigue and exacerbates existing problems.^{22,29}

Therefore, it is recommended to adopt a conservative rehabilitation approach, which includes adequate rest, cold therapy, correction of muscle imbalances, improvement of joint stability, and refinement of movement techniques.³⁰ Furthermore, technical corrections through kinematic video analysis have proven to be an effective strategy for injury prevention and performance optimization, as they allow for continuous monitoring of movement patterns and support athlete development while minimizing the risk of re-injury.³¹

Study limitations should be recognized when interpreting the findings of this study. The relatively small population and limited sample may not be sufficient for the entire range of kinematic variability of rowing athletes to be fully demonstrated with regard to overall sample size. Another limitation of this study was the small sample size that results in the inability to make statistical inferences between the injured groups and injury-free groups. Second, this cross-sectional study design meant that measurements were taken at a single point in time, failing to analyze the kinematic changes prior and immediately after injury onset and longitudinal changes in rowing technique over time. Thirdly, data was collected primarily through a two-dimensional (2D) motion analysis, which inherently limits the ability to capture the full three-dimensional shape of human movement, potentially overlooking out-of-plane motions important to insight into injury mechanisms. Finally, since data collection was conducted on an ergometer, the movements observed on rowing are not necessarily adequate to simulate the biomechanical requirements of rowing on water, since the ergometer environment presents a difference in the balance, resistance and dynamics of motion from those found in real boats.

CONCLUSION

The current study found no significant differences in the kinematics of rowing during the recovery, middle and final phases between athletes with and without a history of injury, although small differences were seen in joint angles. This suggests that athletes who have recovered from injuries are still able to master their skill with adequate rest and specific training. It is important to maintain a strong posture and smooth, coordinated motions through the rowing stroke, as even small errors in joint angles can accumulate over time and increase risk of injury. This is why it is critical to identify those off mechanics early.

ETHICAL CONSIDERATIONS

This study has been approved by the Research Ethics Committee of the Indonesia University of Education (No. 34/

UN40.K/PT.01.01/2025). All participants have provided written consent.

CONFLICT OF INTEREST

The entire research process was conducted independently, and there were no conflicts of interest with the parties involved in this study.

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AUTHOR CONTRIBUTIONS

AFF contributed to concept development, study design, data collection and analysis, and manuscript writing and review; RNR contributed to literature search, experimental studies, data collection, and manuscript editing and review; DRN contributed to concept development, literature search, data collection, and drafting and reviewing the manuscript; PP contributed to concept development, study design, literature search, data analysis, and drafting and reviewing the manuscript. CL contributed to data analysis, and drafting and reviewing the manuscript.

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