A predictive simulation framework for rowing: optimal control tracking of pelvic motion and lumbar load reduction

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Summary

Rowing requires full-body coordination, yet predictive simulation frameworks for the sport are scarce. We present a new rowing simulation model with the seat, footplate, and handle system. Pelvic motion data was used to set up an optimal control problem, track the movement, and reduce lumbar moments, a key factor in relieving back pain. Our results show that limiting upper limb movement produces patterns like natural rowing. The reduction lowered lumbar and hip moments, with a compensatory rise in shoulders, elbows, and knees. This study lays the ground for safer, more efficient, and custom rowing training.

Introduction

Rowing is challenging due to the full-body engagement of arms, trunk, and legs. While past studies have estimated joint kinematics and kinetics [1], predictive "what-if" simulations for rowing remain unresolved. Bridging this gap could enable optimised and safe training protocols that enhance performance, reduce injury risk and improve rehabilitation through biomechanical insights into movement efficiency and coordination [2]. This study aims to (1) introduce a novel predictive simulation framework for rowing and (2) track the pelvic translation during a stroke to predict the full-body movement while minimising lumbar loading.

Methods

We built a rowing simulation model (Fig. 1). The seat and footplate are modelled as rigid bodies, with the footplate fixed to the ground and the seat translating via a slider joint. The handle system (handle and support bar) is represented as cylinders connected by a prismatic joint to enable sliding. Kinematic constraints ensure proper toe-footplate contact and hand-handle coupling. We also included a cable-driven force between the handle and the support bar. Additionally, heel contact geometries simulate realistic footplate interactions during the stroke. Then, we collected pelvic translation through image processing and formulated an optimal control problem that tracks this movement during a complete rowing stroke. Recognising that lumbar pain is common in rowing [3], we augmented the cost function to minimise the lumbar moment (Eq. 1), addressing a key factor in reducing injury risk and enhancing training safety.

$$J = 1000\left(\int_t^{t_f}\left(x(t) - x_{ref}(t)\right)^2 dt\right) + \left(\int_t^{t_f}\sum_{c\in C} w_c |a_c(t)|\, dt\right) \quad (1)$$

$w_c = 1.0$ for lumbar and $= 0.1$ for other joints

Results and Discussion

After imposing upper limb constraints, we successfully tracked pelvic position regardless of whether lumbar activation minimisation was applied (Fig. 2(a)). These restrictions (e.g., limiting lumbar movement range and handlebar rotation) produced motion patterns that more closely resembled natural rowing, as confirmed by visual inspection. When the cost function emphasised reduced lumbar activation, we observed significant decreases in lumbar and hip moments, while most other moments remained similar (Fig. 2(b)). Compensation was achieved through increased shoulder adduction, elbow flexion, and knee flexion, effectively sustaining the rowing dynamics. These results suggest that alternative joint compensation could be key to reducing lumbar stress in rowing.

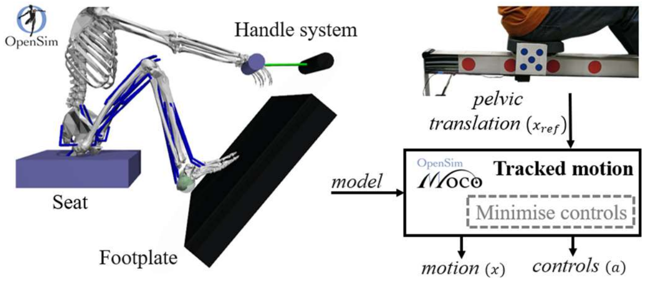

Figure 1: Rowing simulation model that tracks pelvic translation during rowing while minimising lumbar moments.

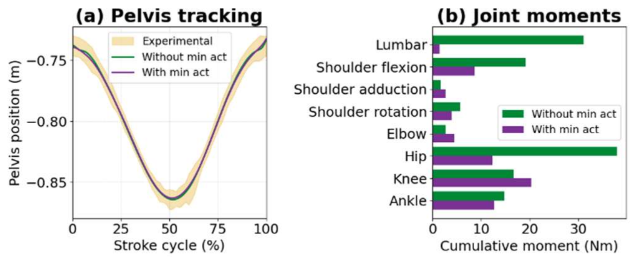

Figure 2: (a) Pelvic position during a stroke. (b) Cumulative joint moments with and without the minimisation of activations.

Conclusions

Our framework shows that refining full-body movement patterns via predictive simulation can lead to personalised training protocols in athletic and rehabilitation settings. Future research will integrate power output data with joint tracking to better understand energy transfer during rowing.

Acknowledgments

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References

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