Asymmetrical Force Sensor for Rowing Biomechanics

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Abstract and Problem Statement

Elite rowers that engage in a high volume of training can suffer from injuries pertaining to the lumbar spine [1]. Perfecting technique and maintaining proper form in the full body movement rowing sport is essential to preventing such injuries and improving performance overall [2]. The UW women's rowing team has tasked the team with creating a force sensing system to measure real-time biomechanical data in order to determine the presence of any lower extremity asymmetries. Existing products often involve expensive and highly advanced equipment [3]. In creating the design, achieving an affordable solution and maintaining an appropriate level of accuracy that doesn't disrupt users' rowing technique was considered. The final design consists of a footplate that rotates when uneven force is applied through the feet. Data was collected using rowers on the UW Rowing Team and analyzed using Kinovea to reveal that rowers apply more force to their oarside foot.

Motivation

- Many members of the University of Wisconsin Women's Rowing team have been dealing with lower back pain and other injuries, potentially due to asymmetric force output while rowing.
- Many rowers experience back injuries due to various reasons: consistently exerting force when the back is flexed, repetition of the rowing movement, and failure to properly adapt to the size of the ergometer or boat [4].
- Current methods do not involve a way to quantitatively assess asymmetry in rowers or correlate it with other risk factors.
- With this device, the athletic training staff hopes to be able to interpret differences in symmetry of a rower's force output, fix athletes' form, identify and reduce the risk of lower back injury, and make quantitative judgements on return from injury.

Background

- The rowing motion can be modeled as a deadlift with the athlete pushing their feet off the footplate and pushing their oar against the water.
- Rowers typically only hold an oar on one side in an asymmetric "sweep rowing" position.
- This asymmetric loading causes rowers to rotate or overcompensate on one leg.
- There are four phases of rowing:
  - Catch, Drive, Finish, Recovery

Figure 1. Phases of the rowing stroke [5].

Design Criteria

- Must be compatible with Concept2 RowErg specifications
  - Footplate dimensions: 13.3 cm x 30.7 cm
- Must not impede natural rowing motion
- Must have an easily interpretable real-time biofeedback display
  - Frame rate > 24 Hz, delay < 0.5 s, font size > 10 mm [6, 7, 8]
- Life in service of at least 6800 hours
- Asymmetry in force measured within a margin of error of 5%

Final Design

- The coupler secures the angular encoder and shaft together to ensure identical rotation
  - Fabricated out of aluminum rod using the lathe and mill
- Wood encoder holder secures the base of the encoder to the bottom plate

Figure 2. Angular encoder mount and coupling

- Seat height extender bolts directly between the seat and RowErg to securely add height to the rower
- Fabricated with band saw and hand drill

Figure 3. Front view of top plate bolted to flex foot and foot plate

Figure 4. Seat Mount

- Top plate bolts directly to the shaft mounts and is where the rower interfaces with the FlexFoot
- Top and bottom plates were fabricated out of wood using water jet
- Bottom plate bolts directly to the RowErg and is the base for the shaft configuration and springs
  - Holes were made using drill press
  - Aluminum spring mounts were made using the lathe
  - Mounted shaft supports between bearings connect the bottom to the top plate

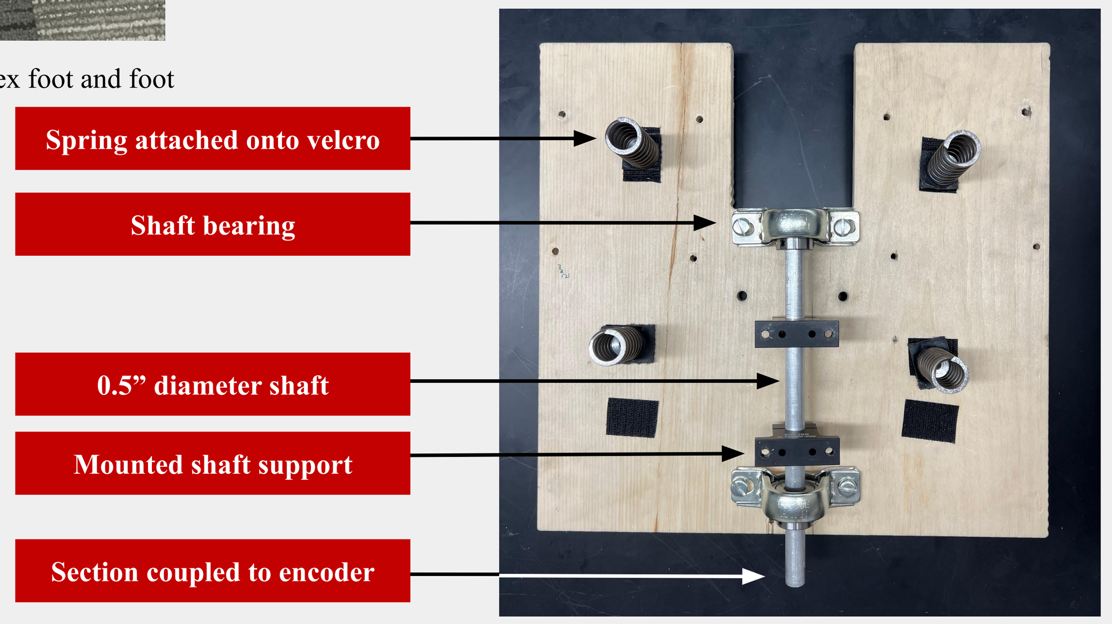


Figure 5. Bottom plate with various components

Testing

- Testing was conducted in the tank at the UW Boathouse.
- Test subjects were in-season healthy rowers from different weight classes:
  - A female lightweight student rower
  - A female openweight student rower
  - A female openweight Olympic rower
  - A male student rower
- Subjects were asked to row at steady state for thirty seconds on two different configurations of the device:
  - Stiff springs at both the metatarsophalangeal (MTP) joint and heel
  - Compliant springs at the MTP joint; stiff springs at the heel
- Data of each trial was collected by recording a side view of the top plate.
  - Qualitative feedback on rower comfort and technique was also obtained.

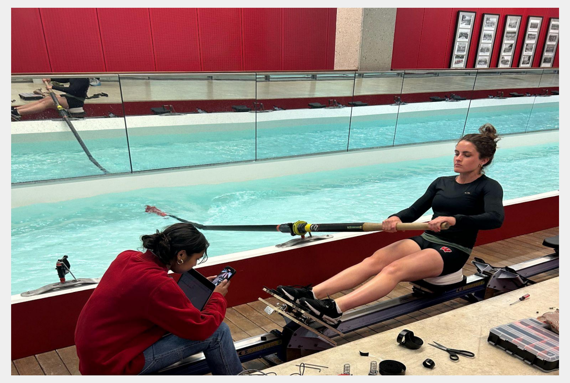


Figure 12. Data collection from rower

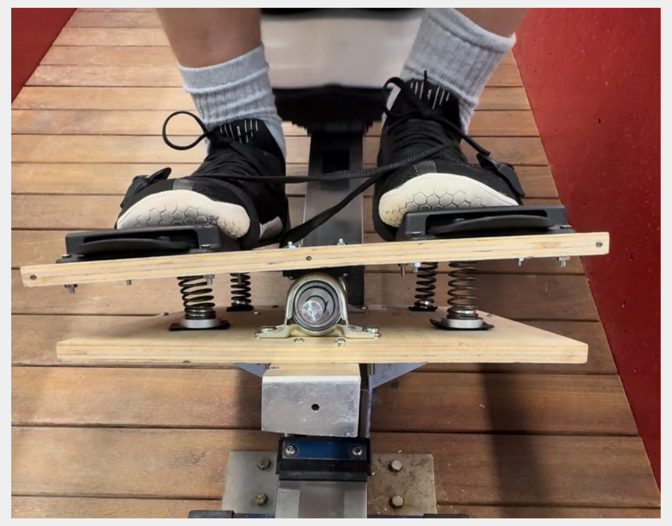
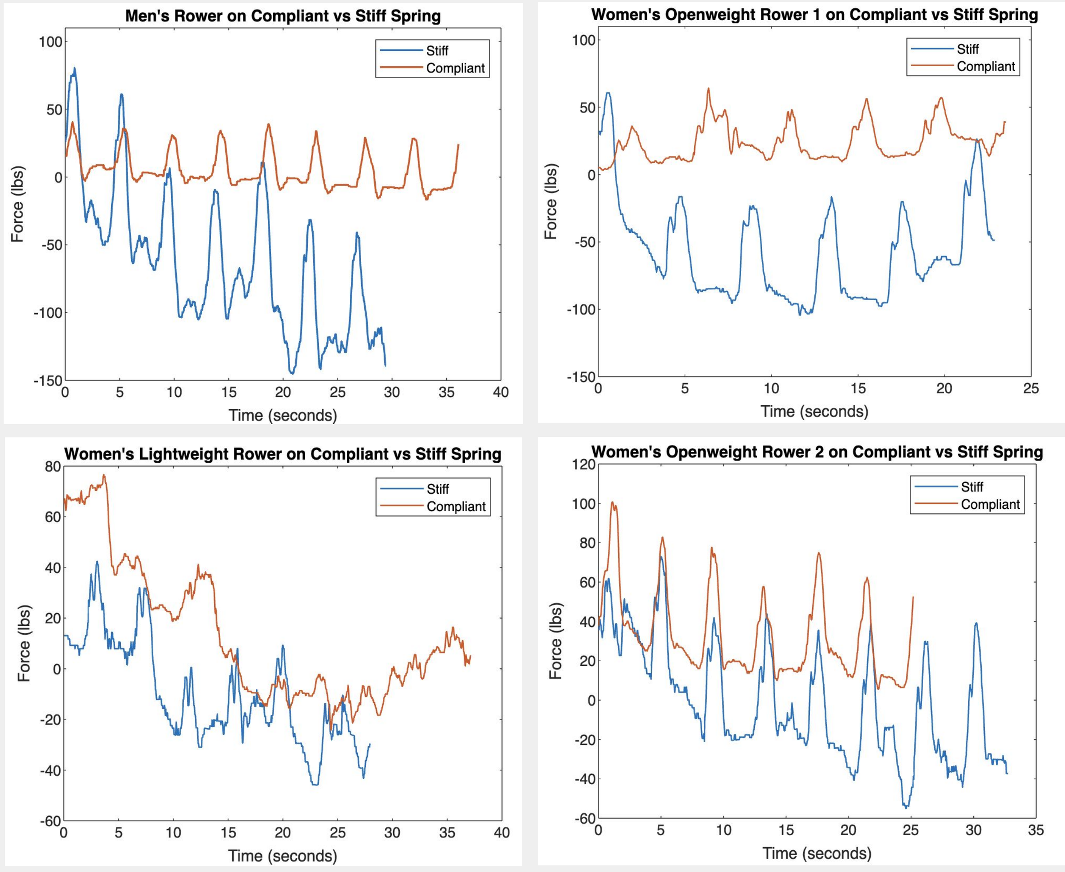


Figure 13. Men's rower on pivot design

Results and Discussion



Figures 6, 7: Force vs Time graphs for the Men's rower on stiff and compliant spring (top left), Women's Openweight rower 1 (top right)
Figures 8, 9: Force vs Time graphs for the Women's Lightweight rower (bottom left), Women's Openweight rower 2 (bottom right)

Table 1. P-values of Stiff and Compliant Springs

Athlete	P-Value
Men's Rower	0.1879
Openweight 1	0.0052
Openweight 2	0.0045
Lightweight	0.6006

Data Analysis and Interpretation

- Video data collected during in-person testing was analyzed using Kinovea.
  - The angle of tilt with respect to the horizontal was measured.
- A calibration curve was created by measuring tilt angle using known weights.
  - This curve was used to calculate force difference outputted by each rower.
- A two -sample test was performed on peak force difference for each rower on the stiff and compliant springs to determine significance in difference between device configurations.
  - The data reveal that for openweight rowers, there is a significant difference in measured asymmetry on the compliant and stiff springs.
- Average peak force difference was also plotted against weight to investigate whether weight is a determining factor in asymmetrical force output.

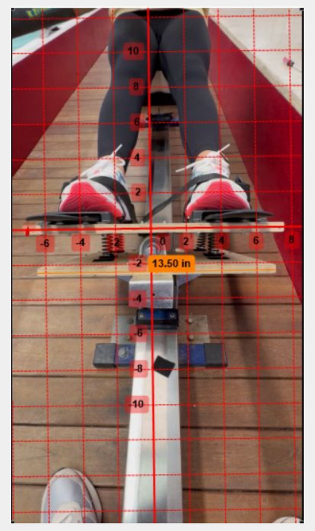


Figure 11. Kinovea Image

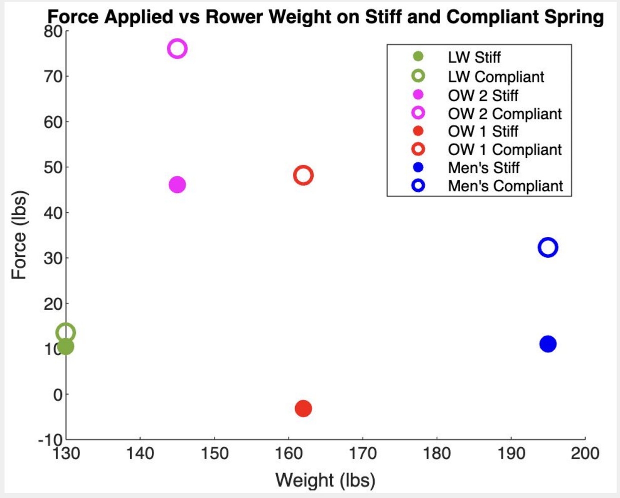


Figure 10. Force Applied vs Rower Weight graph on stiff and compliant spring

Sources of Error

- Data was collected using a handheld iPhone camera, which allowed for some shaking and variation in viewing angle between videos.
- Angles were manually drawn on and measured in Kinovea and were subject to human error and inconsistencies.
- Due to the raised footplate design, many rowers noted that their flexion at the hip and knee were not identical to their typical form.

Future Work

- Integrate angular encoder and user interface with mechanical device
- Incorporate load cells to measure direct force rather than force difference
- Complete validation testing with a larger range of rowers
- Correlate angle/force data with other patient metrics to determine risk factors for asymmetry.

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