



Department of
Biomedical Engineering
UNIVERSITY OF WISCONSIN-MADISON

Asymmetrical Force Sensor for Rowing Biomechanics

BME 402

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Overview

- Problem Statement
- Product Design Specifications
- Project Impact
- Current Design
- Semester Goals
 - Design Improvements
 - Testing
- Product Delivery Considerations
- Acknowledgements
- References



Figure 1. UW-Madison rowing team. [1]

The Clients



Figure 2.

Tricia De Souza
UW Athletic Trainer
[2]



Figure 3.

Jill Thein-Nissenbaum
UW Athletics Physical Therapist
[3]



Figure 4.

David Bell
Professor | Department of
Kinesiology
[4]

Problem Statement

- Rowing athletes, particularly women, are susceptible to lower back or hip injuries
 - Asymmetric weight distributions on each leg while rowing
- Current methods
 - Visual analysis from coaches and PT staff
 - Fully qualitative data looking for potential injury risks
- Sensor system to collect biomechanical data from rowers' lower extremities
 - Capture force output during time of use in the ergometer
- User-friendly interface
 - Assess lower extremity asymmetry
 - Improve performance and safeguarding against injuries

Background



Figure 5. Rowing Phases. [5]



Figure 6. Ergometer [6]

- When rowing, most force is exerted by the leg [7]
- Most of the year is spent on indoor training and using the ergometer
- Majority of rowers face injuries while using the ergometer rather in the boat

Competing Designs

- BioRow 2D Stretcher [8]
 - Load cells utilize strain gauges
 - Senses horizontal and vertical force components
 - Two load cells per foot
 - Too expensive, no interactive display
- Bertec Force Plate [9]
 - Load cells on each corner
 - Collects forces in all three directions
 - Designed for gait, balance, and performance analysis
 - Too large and expensive

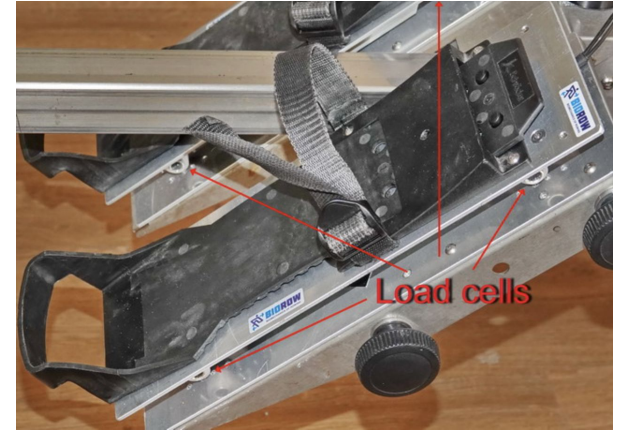


Figure 7. BioRow 2D Stretcher. [7]



Figure 8. Bertec Force Plate. [8]

Product Design Specifications

Force Sensor/Footplate

- Compatible with RowErg
- Margin of error $< 5\%$ [5]
- Adjustable to foot size
- No technique impedance

Display/User Interface

- 24 Hz frame rate [6]
- Mounted at 1.1 m height
- Clear indication of asymmetry
- Data storage



Figure 5. Foot stretcher on Concept2 RowErg. [7]



Figure 6. Concept2 RowErg. [8]

Project Impact

Competing designs

- BioRow 2D Stretcher - 2 strain gauge load cells per foot
- Bertec Force Plate - 4 triaxial load cells
- Not compatible with current models, too expensive, indirect data collection

Impact

- Identifies rowing force patterns
- Guides training and injury prevention
- Supports recovery and long-term health

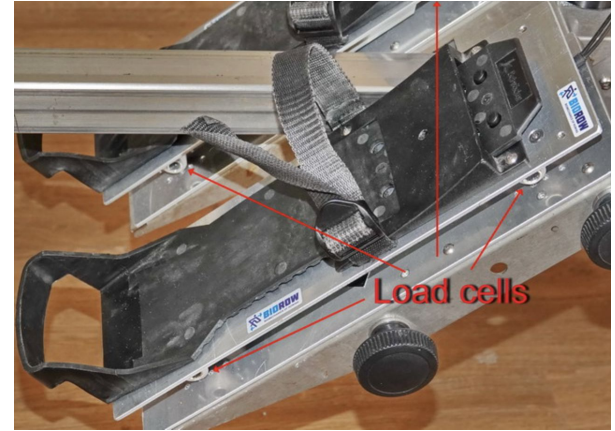


Figure 7. BioRow 2D Stretcher. [9]



Figure 8. Bertec Force Plate. [10]

Design Components

- Two force-sensing footplates over foot stretchers
- Visual feedback
- Instrumentation

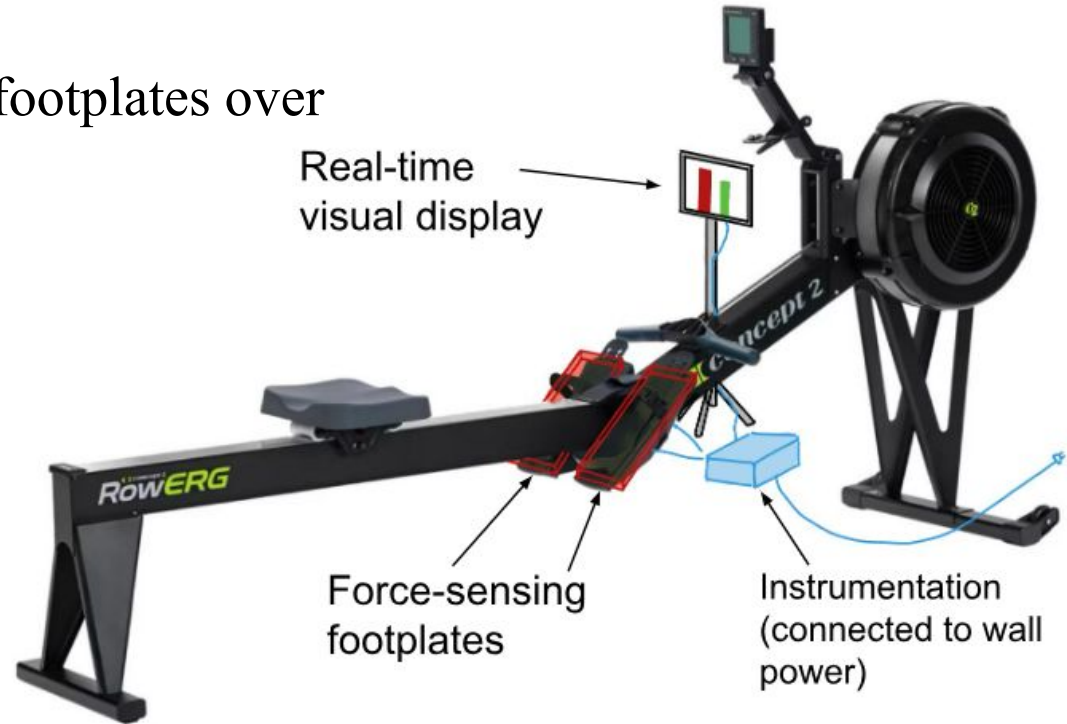


Figure 9. Sketch of Comprehensive Design with Concept 2 RowErg. [8]

Current Design



Figure 10. Side view of prototype when rowing.



Figure 11. Assembled prototype on ergometer.

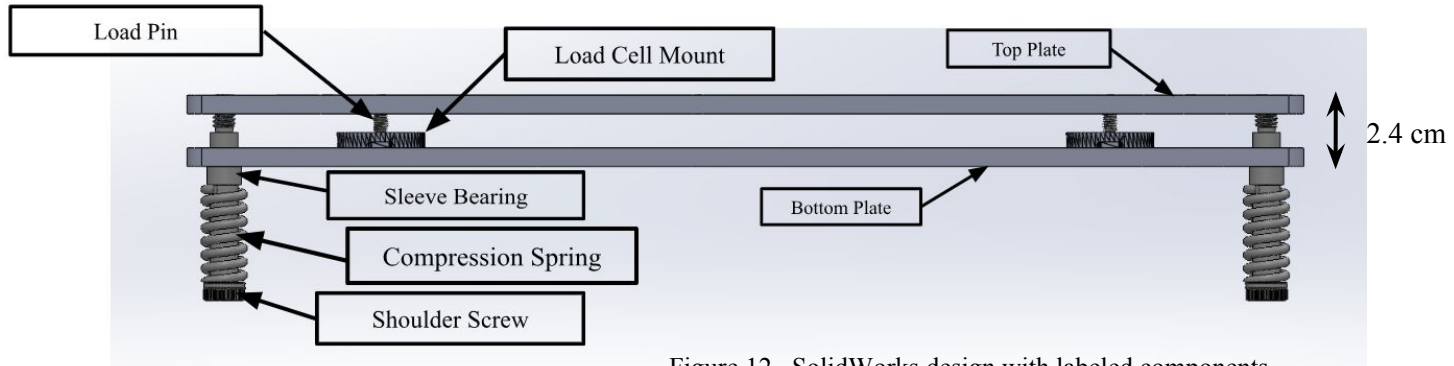


Figure 12. SolidWorks design with labeled components.

Current Design

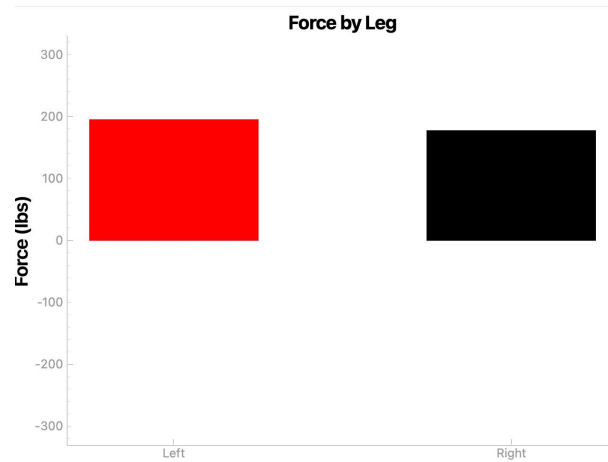


Figure 13. GUI for rower display.

- 4 GUIs to pick from
- Can be displayed on a laptop, TV, or tablet

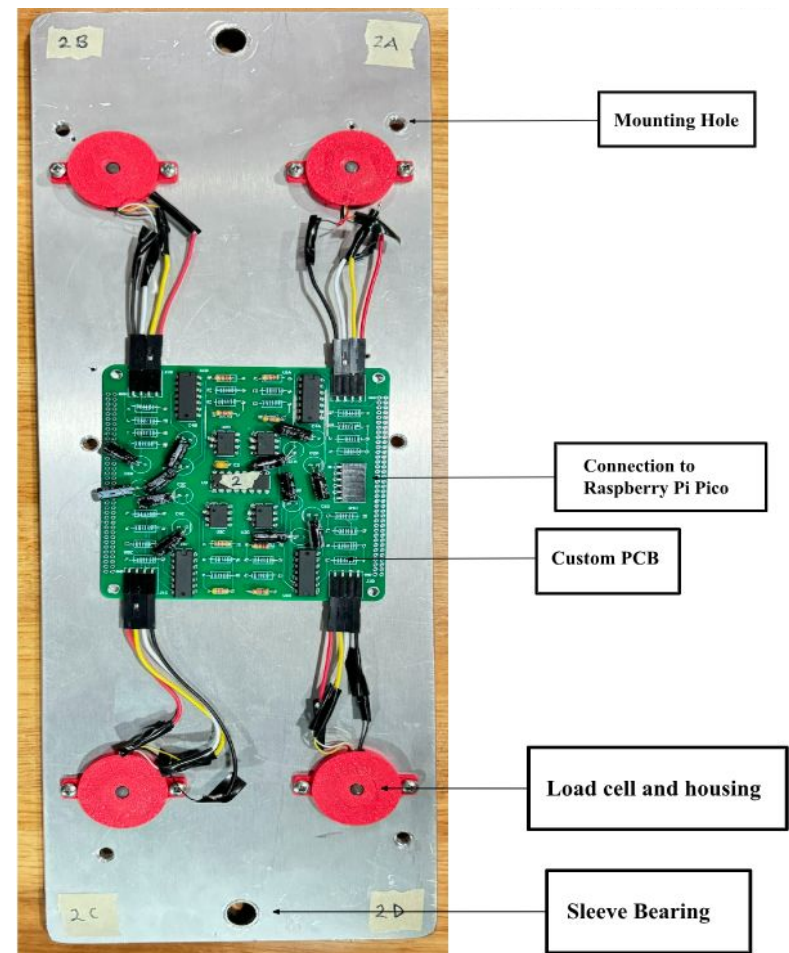


Figure 14. Top view of bottom foot plate labeled components.

Current Design

Previous Testing

- Calibrated load cells with MTS
- Used point load system with various weights to test the accuracy of our readings
 - Within %3 error - meets PDS requirement
- Loaded various spots on the plate
- Tested shear loading with a pulley system

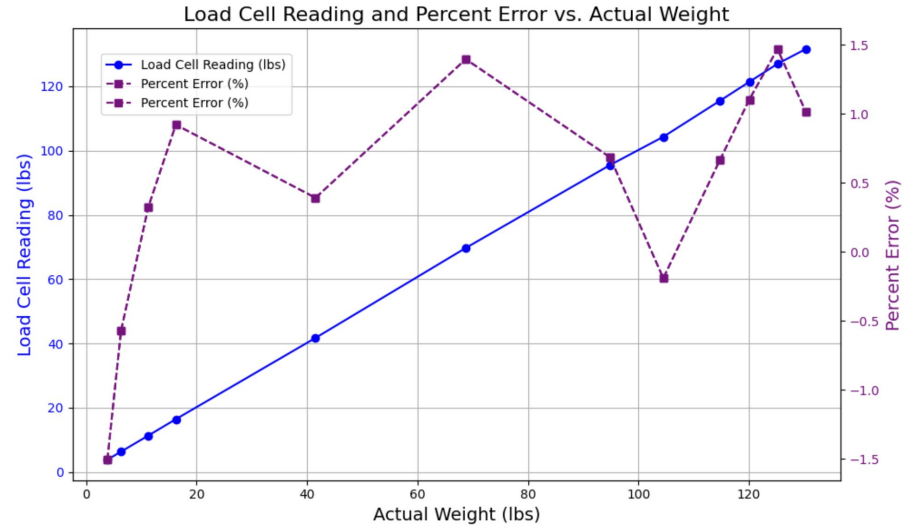


Figure 15. Load cell reading and percent error vs actual weight loaded at center of force plate.

Design Improvements - Electrical

Improved load cell PCB

- Through hole -> SMD components
- 2 layer board -> 4 layer board
- Improved grounding technique
- Molex picoblade board-wire connectors

New PCB to integrate the pico

- 4 layer board
- Socket headers for pico

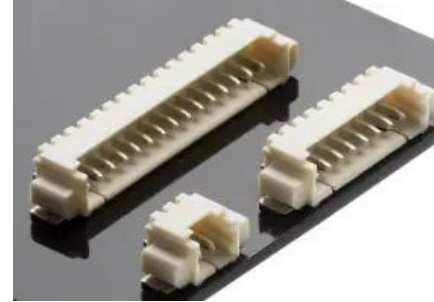


Figure 16. Molex PicoBlade board receptacles. [11]

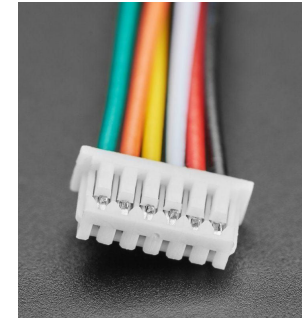


Figure 17. Molex PicoBlade wire connectors. [12]

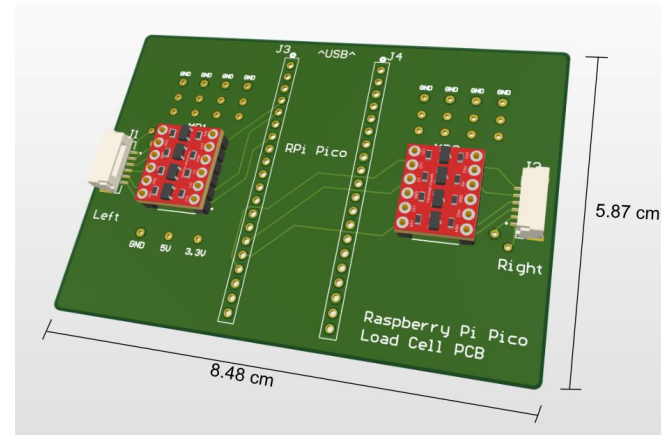


Figure 18. Custom PCB design for pico integration board.

Design Improvements - Software

- Improved error handling
- Option to save raw data to a csv
- Maybe: display immediate results to rowers

Design Improvements - Mechanical

3D Printed PCB Housings

- Load cell PCBs between foot plates
- Pico integration PCB - clip on to erg

Maybe: Ball point set screws

- Reduce friction between screw and load cell
- ~\$6.00 each x 8 = \$48.00



Figure 19. JW Winco Set Screw with Full Ball Point. [13]

Test Design - MTS

Materials

- Custom compression platen
- Custom footplate mount

Methods

- Static Loading
 - Load between 0 - 900 N in 12 increments
 - Ramp to 75 N, hold for 10 sec, ramp to 150 N, hold for 10 sec, ...
- Dynamic Loading
 - Load between 0-900 N in varying frequencies and amplitudes
 - Amplitudes: 300 N, 600 N, 900 N
 - Frequencies: 0.25 Hz, 0.4 Hz, 0.6 Hz

Test Design - Rowers

Participants

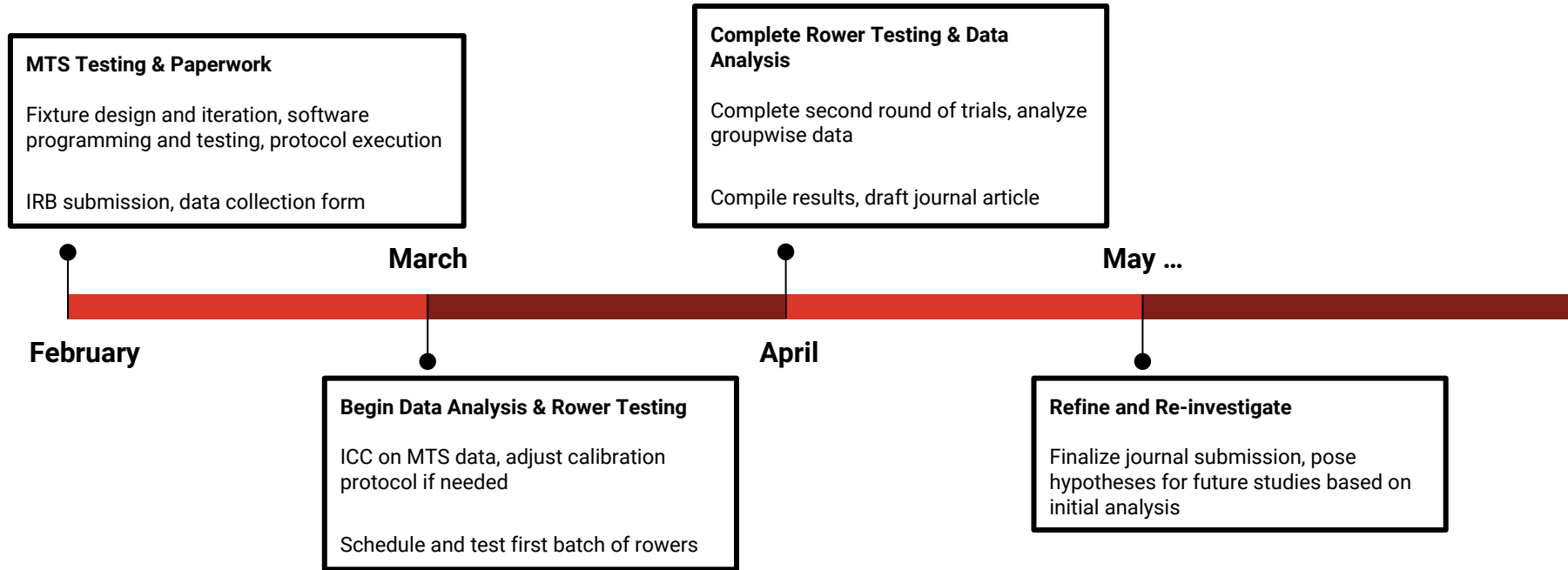
- 60 collegiate rowers from men's and women's crew team
- Varying experience levels, injury histories, height, weight

Methods [14]

- Standard warm up
- Row 2000 m (~ 5-8 min) at steady state (22-24 strokes/min)
- Rest 2 min
- Row 2000 m

Repeat after 3-5 days with rowers who displayed consistency between trials.

Testing Timeline



Product Delivery Considerations

Assembly Instructions

- Provide detailed instructions to ensure easy set-up
- Provide labeled pictures

Software Packaging

- Color-coded wiring instructions to clarify assembly instructions
- Designing case for simple storage and less setup confusion

Project Budget

Description	Item #	Specs	Price	Qty	Item Total
Alloy Steel Sleeve Shoulder Screw	91259A632	3/8" Shoulder Diameter	\$2.86	4	\$11.44
PTFE Sleeve Bearing Shell	60695K2	3/8" OD 0.5" Length	\$2.44	4	\$9.76
TI Connectivity Compression Load Cells	824-FX292X-100A0100L	100lb Operating Force	\$28.43	8	\$227.44
12 BIT MCP3008 ADC	MCP3208-CI/P-ND	12 Bit IC ADC	\$4.97	2	\$9.94
TLV274IN	296-14379-5-ND	Op Amp 4 Circuit	\$1.06	10	\$10.58
1K Ohm Resistors	RNF14FTD1K00	1k ohm resistors	\$0.03	100	\$3.15
Raspberry Pi Pico H	2648-SC0917-ND	microcontroller	\$5	1	\$5.00
Stainless Steel Flat-Tip Set Screws (Pack of 25)	94355A337	10-32 0.5" Long	\$5	1	\$5.41
Aluminum Footplates	6061 T651	12x16x.25	\$31	2	\$61.16
Custom Printed Circuit Boards		95x95mm (5 copies)	\$10.61	1	\$10.61
Compression Spring	9657K374	124 max load, 1.75" L	from last year	12	

Total prototype cost: \$354.59

Remaining budget: \approx \$545.00

Potential future costs: New set screws (\$48); Additional full assembly (\$354.59); Backup load cells(\$28.43 ea.)

GUI + Display

- GUI
 - Rowers/coaches choose preferred graphic
 - Absolute Force vs. Force Difference
 - Line Graph vs. Bar Graph
- Display
 - Laptop
 - Can be hooked up to TV/Tablet

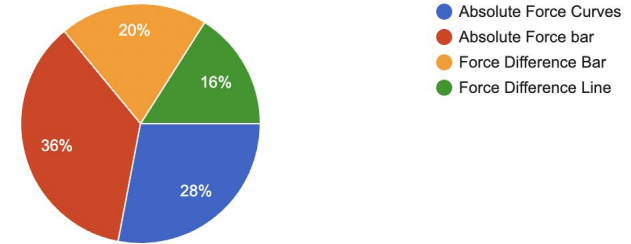
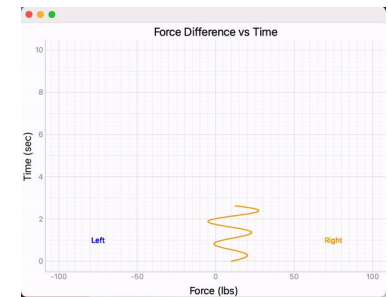
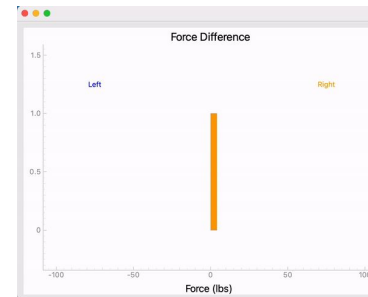
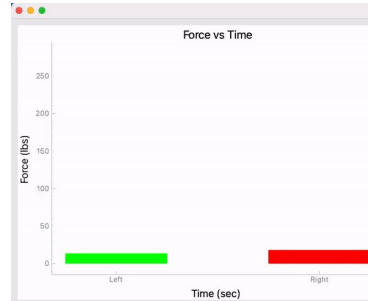
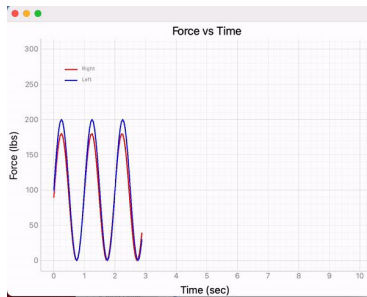


Figure 16. Pie chart of preferred GUIs based on survey response.



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- Ms. Tricia De Souza
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- Ms. Sarah Navin
- Dr. David Appleyard
- Dr. Kreg Gruben
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References

- [1] “Badgers announce 2019-20 women’s rowing roster,” Wisconsin Badgers. Accessed: Oct. 05, 2023. [Online]. Available: <https://uwbadgers.com/news/2019/9/20/badgers-announce-2019-20-womens-rowing-roster.aspx>
- [2] “Tricia De Souza | Men’s Rowing Coach | Wisconsin Badgers.” Accessed: Oct. 05, 2023. [Online]. Available: <https://uwbadgers.com/sports/mens-rowing/roster/coaches/tricia-de-souza/731>
- [3] Walworth, “Jill Thein-Nissenbaum, PT, MPT, ATC, DSc, SCS Selected for National Athletic Trainers’ Association Title IX Panel - UW Family Medicine,” UW Family Medicine & Community Health. Accessed: Oct. 05, 2023. [Online]. Available: <https://www.fammed.wisc.edu/jill-thein-nissenbaum-selected-for-national-athletic-trainers-association-title-ix-panel/>
- [4]“(17) Sarah Navin | LinkedIn.” Accessed: Oct. 05, 2023. [Online]. Available: <https://www.linkedin.com/in/sarah-navin-915862179/>
- [5]S, Arumugam, et al. “Rowing Injuries in Elite Athletes: A Review of Incidence with Risk Factors and the Role of Biomechanics in Its Management.” *Indian Journal of Orthopaedics*, vol. 54, no. 3, Jan. 2020. pubmed.ncbi.nlm.nih.gov, <https://doi.org/10.1007/s43465-020-00044-3>
- [6] “Black Concept 2 RowErg Rower - PM5 - Model D.” Accessed: Oct. 04, 2024. [Online]. Available: <https://www.roguefitness.com/black-concept-2-rowerg-rower-pm5-black>
- [7] S. Arumugam, P. Ayyadurai, S. Perumal, G. Janani, S. Dhillon, and K. A. Thiagarajan, “Rowing Injuries in Elite Athletes: A Review of Incidence with Risk Factors and the Role of Biomechanics in Its Management,” *Indian J Orthop*, vol. 54, no. 3, pp. 246–255, Jan. 2020, doi: 10.1007/s43465-020-00044-3.
- [8] “2D_Stretcher,” Biorow. https://biorow.com/index.php?route=product/product&path=61_115&product_id=109 (accessed Sep. 21, 2023).
- [9] “Force Plates,” Bertec. <https://www.bertec.com/products/force-plates> (accessed Sep. 13, 2023).
- [10] Q. Liu, Y. Dai, M. Li, B. Yao, Y. Xin and J. Zhang, "Real-time processing of force sensor signals based on LSTM-RNN," 2022 IEEE International Conference on Robotics and Biomimetics (ROBIO), Jinghong, China, 2022, pp. 167-171, doi: 10.1109/ROBIO55434.2022.10011703
- [11] S. Allison, Y. Fujii, and L. M. Wilcox, “Effects of Motion Picture Frame Rate on Material and Texture Appearance,” *IEEE Transactions on Broadcasting*, vol. 67, no. 2, pp. 360–371, Jun. 2021, doi: 10.1109/TBC.2020.3028276.
- [12] “RowErg,” Concept2. Accessed: Oct. 05, 2023. [Online]. Available: <https://www.concept2.com/indoor-rowers/concept2-rowerg>

References

- [1] “Badgers announce 2019-20 women’s rowing roster,” Wisconsin Badgers. Accessed: Oct. 05, 2023. [Online]. Available: <https://uwbadgers.com/news/2019/9/20/badgers-announce-2019-20-womens-rowing-roster.aspx>
- [2] “Tricia De Souza | Men’s Rowing Coach | Wisconsin Badgers.” Accessed: Oct. 05, 2023. [Online]. Available: <https://uwbadgers.com/sports/mens-rowing/roster/coaches/tricia-de-souza/731>
- [3] Walworth, “Jill Thein-Nissenbaum, PT, MPT, ATC, DSc, SCS Selected for National Athletic Trainers’ Association Title IX Panel - UW Family Medicine,” UW Family Medicine & Community Health. Accessed: Oct. 05, 2023. [Online]. Available: <https://www.fammed.wisc.edu/jill-thein-nissenbaum-selected-for-national-athletic-trainers-association-title-ix-panel/>
- [4] “Bell, David,” Kinesiology. Accessed: Feb. 06, 2025. [Online]. Available: <https://kinesiology.education.wisc.edu/fac-staff/bell-david/>
- [5] Q. Liu, Y. Dai, M. Li, B. Yao, Y. Xin and J. Zhang, "Real-time processing of force sensor signals based on LSTM-RNN," 2022 IEEE International Conference on Robotics and Biomimetics (ROBIO), Jinghong, China, 2022, pp. 167-171, doi: 10.1109/ROBIO55434.2022.10011703
- [6] S. Allison, Y. Fujii, and L. M. Wilcox, “Effects of Motion Picture Frame Rate on Material and Texture Appearance,” IEEE Transactions on Broadcasting, vol. 67, no. 2, pp. 360–371, Jun. 2021, doi: 10.1109/TBC.2020.3028276.
- [7] “Concept2 RowErg Review: Even The Best Have Flaws,” Treadmill Review Guru. Accessed: Feb. 06, 2025. [Online]. Available: <https://www.treadmillreviewguru.com/concept2-rowerg-review/>
- [8] “RowErg,” Concept2. Accessed: Oct. 05, 2023. [Online]. Available: <https://www.concept2.com/indoor-rowers/concept2-rowerg>
- [9] “2D_Stretcher,” Biorow. https://biorow.com/index.php?route=product/product&path=61_115&product_id=109 (accessed Sep. 21, 2023).
- [10] “Force Plates,” Bertec. <https://www.bertec.com/products/force-plates> (accessed Sep. 13, 2023).
- [11] “PicoBlade Standard Connectors.” Accessed: Feb. 05, 2025. [Online]. Available: <https://www.mouser.com/molex-picoblade>
- [12] “1.25mm Pitch 8-pin Cable Matching Pair - 10cm long (Molex PicoBlade Compatible),” The Pi Hut. Accessed: Feb. 05, 2025. [Online]. Available: <https://thepihut.com/products/1-25mm-pitch-8-pin-cable-matching-pair-10-cm-long-molex-picoblade-compatible>
- [13] “Socket Set Screws GN 605,” JW Winco Standard Parts. Accessed: Feb. 05, 2025. [Online]. Available: <https://www.jwwinco.com/en-us/products/3.2-Mounting-positioning-levelling-with-screws-clamping-and-supporting-elements/Swing-bolts-Shoulder-screws-Thrust-bolts/GN-605-Steel-Socket-Set-Screws-With-Full-Flat-and-Serrated-Ball-Point-Ends>
- [14] G. K. Barratt, C. Bellenger, E. Y. Robertson, J. Lane, and R. G. Crowther, “Validation of Plantar Pressure and Reaction Force Measured by Moticon Pressure Sensor Insoles on a Concept2 Rowing Ergometer,” *Sensors (Basel)*, vol. 21, no. 7, p. 2418, Apr. 2021, doi: [10.3390/s21072418](https://doi.org/10.3390/s21072418).



Questions?