Asymmetrical Force Sensor for Rowing Biomechanics

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Rowing is a highly demanding exercise that commonly leads to lower back and hip injuries, particularly among female athletes. Bilateral asymmetry of force output through the legs has been observed to significantly influence lumbar-pelvic kinematics and pelvic twisting, which could be causal factors for lumbar spine injury. These injuries arise due to repetitive asymmetrical force output exerted by the lower extremities during the rowing motion, causing misalignment of the hips thereby inducing stress on the lumbar spine. Currently, coaching staff and athletic trainers at the University of Wisconsin-Madison primarily rely on qualitative, visual analysis of athlete performance during ergometer training to identify and correct asymmetrical movements. However, such qualitative assessments are subjective and inadequate for precisely identifying biomechanical imbalances that can lead to injury.

The client, Dr. Jill Thein-Nissenbaum, has tasked the team with creating a force plate system that can collect biomechanical data from rowers' lower extremities and display it to a rower in real-time as biofeedback. Existing commercial solutions such as force platforms and instrumented rowing ergometers are often cost-prohibitive, too complex to integrate into training environments, and lack real-time quantitative feedback capabilities. These limitations prevent widespread adoption, leaving a gap in accessible and affordable technology.

The team's previous design measured asymmetry indirectly using a rotating plate and angular encoder. This design consisted of a rotating footplate and an angular encoder that correlated the degree of rotation of the footplate with the force difference applied. Though this design effectively identified asymmetry, only capturing force difference, rather than absolute force from each leg, limited the applications of the data collected from the device. This prototype's thickness also caused rowers to alter their form during data collection. Based on these issues, the team decided to create a lower-profile design that can measure applied normal load while protecting load cells from the effects of off-axis and shear loading. The force plate consists of four uniaxial compression load cells housed between two aluminum plates. The bottom plate is mounted to the ergometer footplate base, while the rower rows on the top plate. The top and bottom plates are connected by two shoulder screws passing through sleeve bearings press-fit into the bottom plate, reducing friction as the top plate translates in the normal loading direction. Ball-bearing tipped set screws in the top plate transfer force to the load cells, while compression springs on the shoulder screws preload the load cells by pushing the plates together, allowing measurement of both tension and compression.

Validation and reliability testing of the device consisted of calibration and dynamic compression testing using the MTS Criterion, and in-person trials with UW Rowers. After calibration, the device was loaded with the MTS at three locations under normal and shear loads to demonstrate its accuracy. Reliability testing was performed with 27 rowers of varying sex and weight class who rowed on the device at their steady-state pace. This data was analyzed to reveal metrics like peak force per leg, asymmetry index, power, and impulse.

This design provides the client with clinically relevant data that can be used to treat injury. Force profiles and their derived metrics can be correlated with rower demographic information to reveal rowers at higher risk of force asymmetry so they can be trained and cleared from injury effectively. The biofeedback from the device will also allow these high-risk rowers to adapt their technique and row symmetrically, thereby reducing their risk for injury.

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