WEARABLES BIOMECHANICS SUMMER SCHOOL 2025

SFU RUN LAB

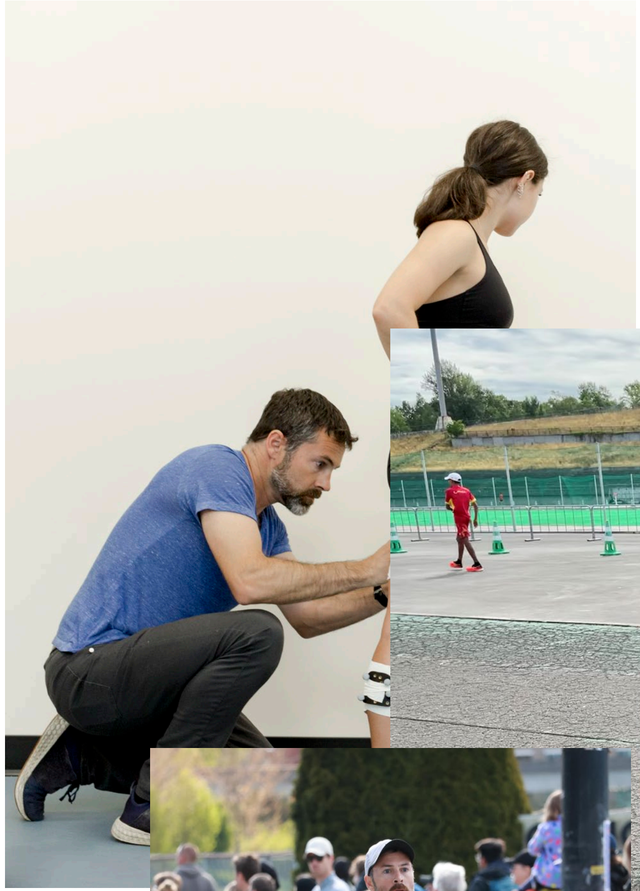
RUNNING BIOMECHANICS BEYOND THE LAB

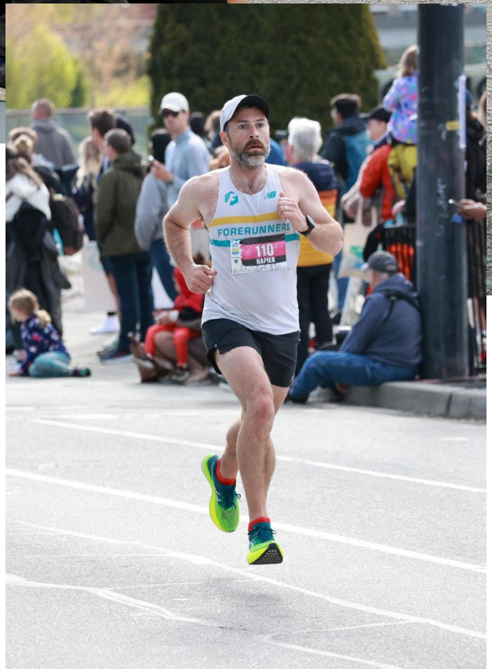
Chris Napier, PT, PhD
Assistant Professor
Biomedical Physiology & Kinesiology
Simon Fraser University

SFU RUN LAB

WHO AM I?

- Assistant Professor, Department of Biomedical Physiology & Kinesiology, Simon Fraser University
- Director, SFU Run Lab
- Sport Physiotherapist (Athletics Canada/Restore Physiotherapy)
- Runner





OBJECTIVES

SFU RUN LAB

- **Differentiate** between the strengths and limitations of traditional lab-based running biomechanics and field-based wearable technology approaches.
- **Identify** the key technologies suitable for real-world running biomechanics studies, and articulate the advantages and limitations of each.
- **Understand** the logistical challenges and opportunities of conducting biomechanics research in authentic running environments.
- **Discuss** how real-world data collection can enhance the understanding, prevention, and management of running-related injuries.
- **Describe** practical examples of field-based biomechanics studies and interpret their implications for performance enhancement and injury prevention.

MOTIVATION & RATIONALE

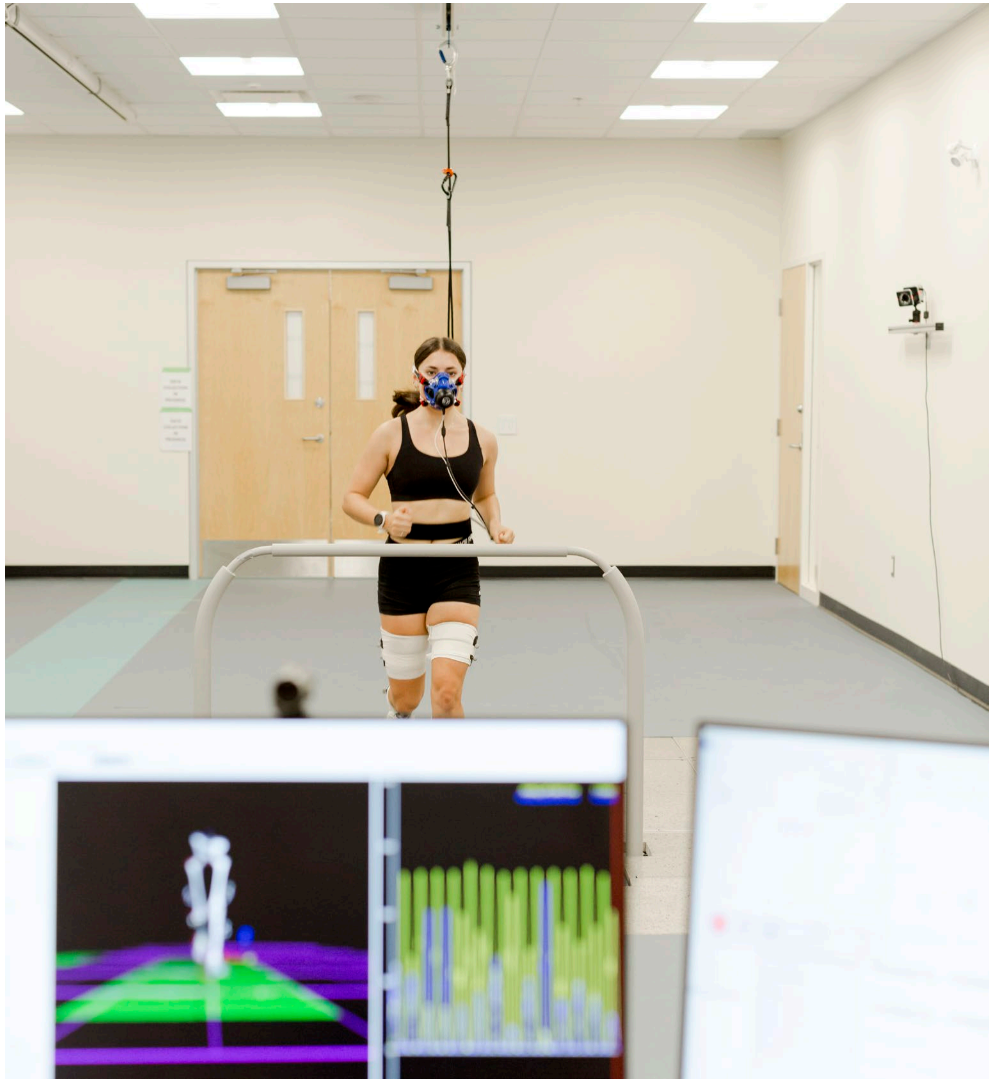
WHY GO BEYOND THE LAB?

Lab-based studies are:

- Accurate
- Controlled
- Repeatable

But:

- Do not reflect reality
- Generalization of findings is limited



MOTIVATION & RATIONALE

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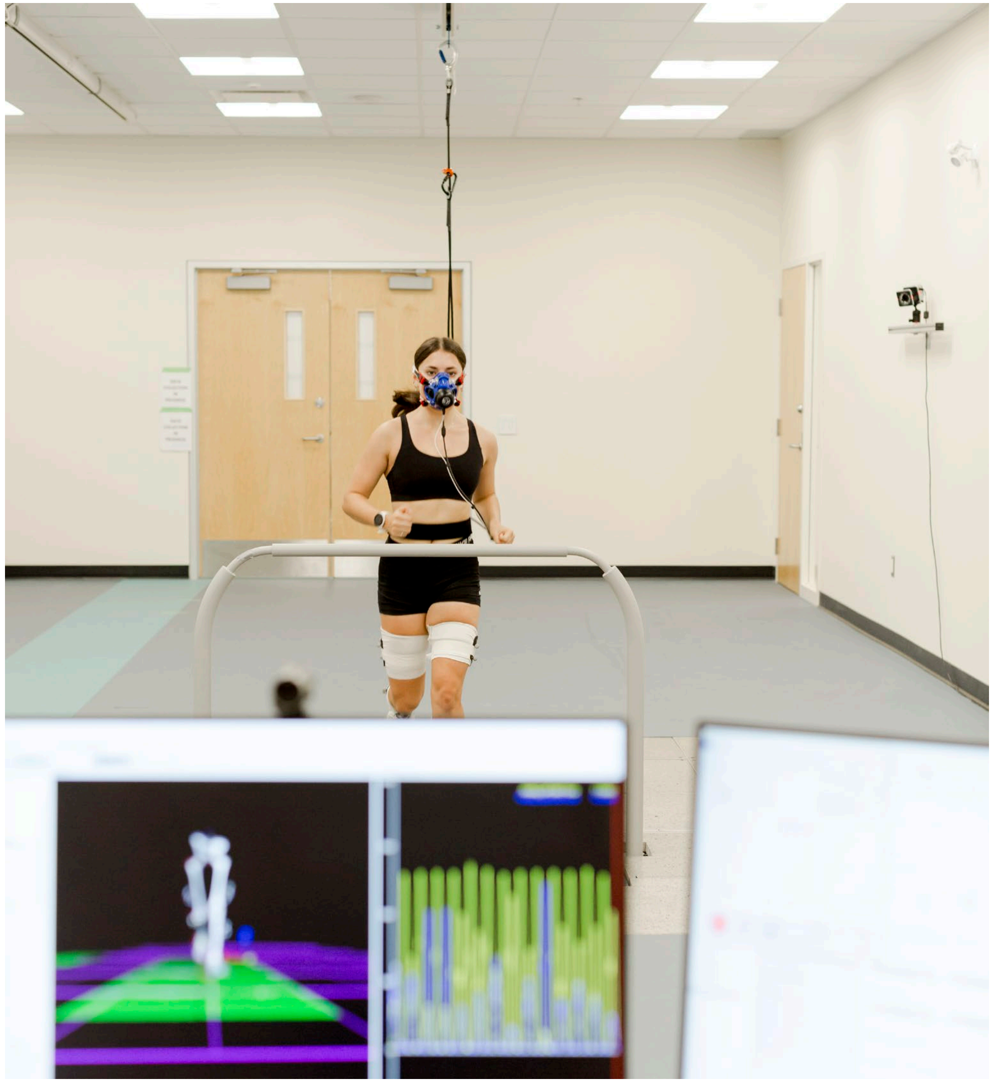
CONSTRAINTS & LIMITATIONS

- Marker-based motion capture
- Level ground
- Treadmill /1-2 force plates
- Cross-sectional
- Don’t resemble a typical training session or race
- Limited to smaller participant numbers



WEARABLES FOR RUNNING ANALYSIS

SFU RUN LAB

WEARABLES FOR RUNNING ANALYSIS

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- Over 75% of runners use wearables
  - Distance, pace
  - Biomechanics
- GPS Smartwatches, shoe/foot pods
- Smart garments/shoes
- Rings, patches, etc.
- Paired with apps and social media

WEARABLES FOR RUNNING ANALYSIS

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RESEARCH OPPORTUNITIES

Changes in biomechanics due to:

- Fatigue
- Training responses
- Injury
- Surface

Effects of biomechanics and training load on injury

WEARABLES FOR RUNNING ANALYSIS

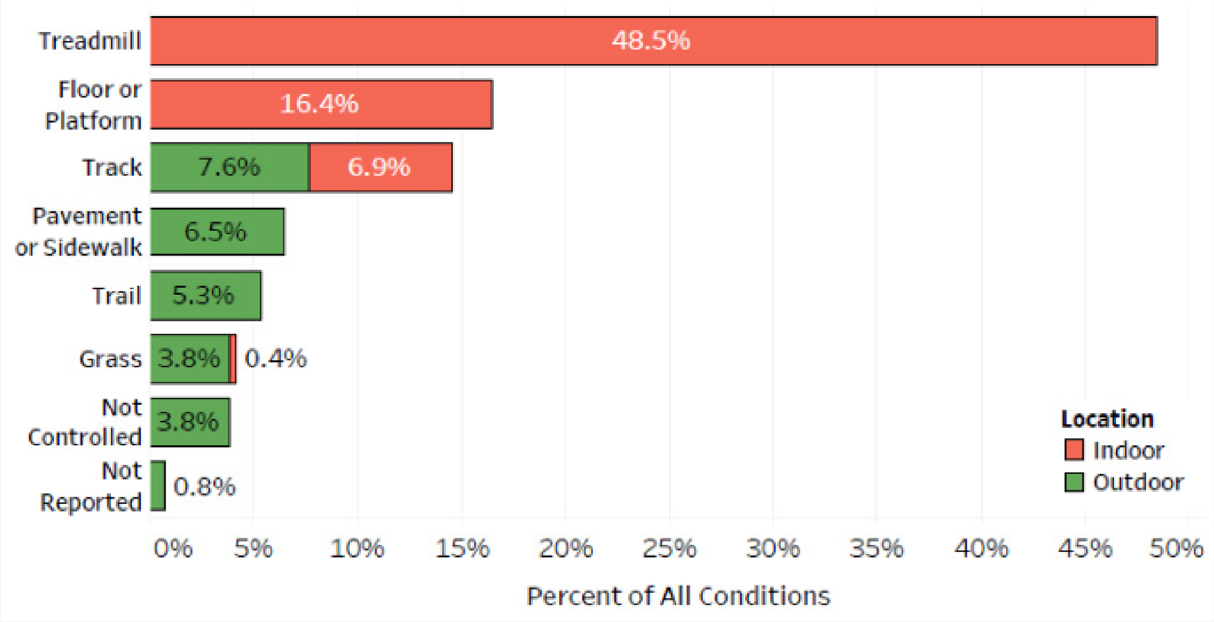
SFU RUN LAB

Open Access | Systematic Review

Is This the Real Life, or Is This Just Laboratory? A Scoping Review of IMU-Based Running Gait Analysis

by Lauren C. Benson [1,2,*], Anu M. Räisänen [1,3], Christian A. Clermont [1,4] and Reed Ferber [1,5,6]

Figure 3. The percent of all conditions (262 across 231 studies) by running surface and location (indoor, outdoor).



Benson et al 2022

WEARABLES FOR RUNNING ANALYSIS

SFU RUN LAB

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4.1. Running Environments

Laboratory-based conditions are controlled and are often different from typical running conditions, as most runners complete their runs outdoors [243]. Additionally, loads vary with each stride and a runner's load capacity changes throughout a running session [244], suggesting that assigning the same estimated load to each stride is not a suitable approximation for the cumulative load in a running session. Therefore, it is important to monitor running in actual real-world conditions, including over long distances. Yet, despite the portability of IMUs [6,7], one of the main findings of this review is that running biomechanics are mainly recorded with IMUs indoors, on a treadmill, at prescribed speeds, and over small distances. Furthermore, the majority of studies that investigated running in artificial environments have been published recently; there has not been a trend away from laboratory-based conditions over time. It is unclear why researchers are using IMUs to record running, but still have participants running in the laboratory, at controlled speeds, on treadmills and/or over short distances. If the purpose of these devices is to capture real-world running, we suggest that the research in this area should move out of the lab to less controlled environments.

Benson et al 2022

WEARABLES FOR RUNNING ANALYSIS

SFU RUN LAB

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Several of the included studies compared running quality between surfaces, and the findings underscore the need to observe runners in their actual running environment. More unstable surfaces lead to less regularity and greater variability during running [5,142], and the variance in outdoor data cannot be explained by indoor measures [31,95]. Moreover, it is likely that not all metrics differ between the running conditions [245]. For example, there was no difference in running power on a track compared to a treadmill [166]. Among the four studies that compared tibial acceleration between treadmill and outdoor running, the acceleration magnitude was either lower [241], greater [31,95], or not different [84,241] in outdoor conditions compared to on the treadmill, but in only one case did the outdoor conditions represent an uncontrolled running environment [95]. We suggest that rather than estimating what it is like to run outdoors, it would be helpful to use IMUs during actual training runs, over longer distances and on surfaces that represent real-world running.

Benson et al 2022

WEARABLES FOR RUNNING ANALYSIS

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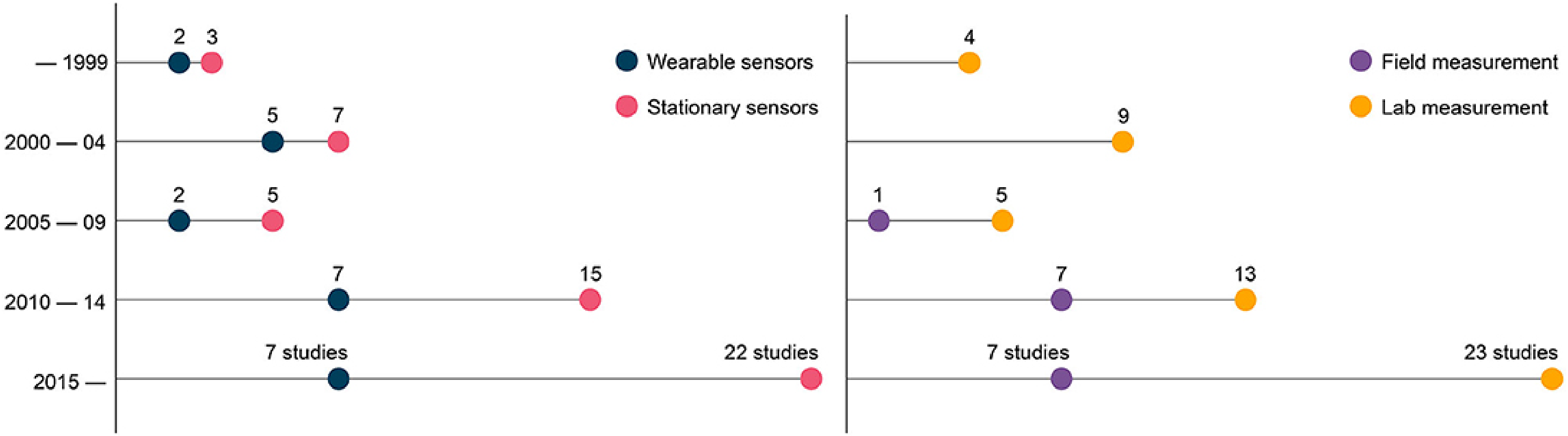
Biomechanical Response of the Lower Extremity to Running-Induced Acute Fatigue: A Systematic Review

SYSTEMATIC REVIEW article
Front. Physiol., 26 August 2021
Sec. Exercise Physiology
Volume 12 - 2021 | https://doi.org/10.3389/fphys.2021.646042



Apte et al 2021

WEARABLES FOR RUNNING ANALYSIS

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Finally, this systematic review allows us to highlight the current gaps in literature regarding sport-induced fatigue. One of the main findings is the lack of field studies with continuous measurements, conducted during the actual run. As seen in the results (Section Nature of Measurement Environment), stationary measurement systems represent 76.5% of sensors used, significantly more than wearables; and the ratio between stationary vs. wearable motion sensor has not changed over time (Figure 4). The main reason is that studies performed in-laboratory allow for highly controlled environmental conditions and are generally easier to perform. However, the recent burgeoning market of wearables, miniaturization of sensors, and development of advanced algorithms (Camomilla et al., 2018) have given researchers the capability to collect and analyze continuous data during sporting activates with good accuracy and precision.

Apte et al 2021

WEARABLES FOR RUNNING ANALYSIS

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"Current literature highlights a lack of studies with continuous measurement of biomechanical parameters during actual running activities, pointing towards an opportunity for future research using wearable sensor technologies."

Apte et al 2021

FIELD-BASED BIOMECHANICAL STUDIES

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- Longitudinal, continuous monitoring
- Natural surfaces, grades
- Follow through standardized training / self-directed training / racing
- Ability to study large sample sizes
- Potential to solve complex problems
- Big data / AI

TECHNOLOGY OVERVIEW

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STATIONARY SYSTEMS

- Markerless motion capture

WEARABLE SYSTEMS

- Inertial Measurement Units
- Strain sensors

TECHNOLOGY OVERVIEW

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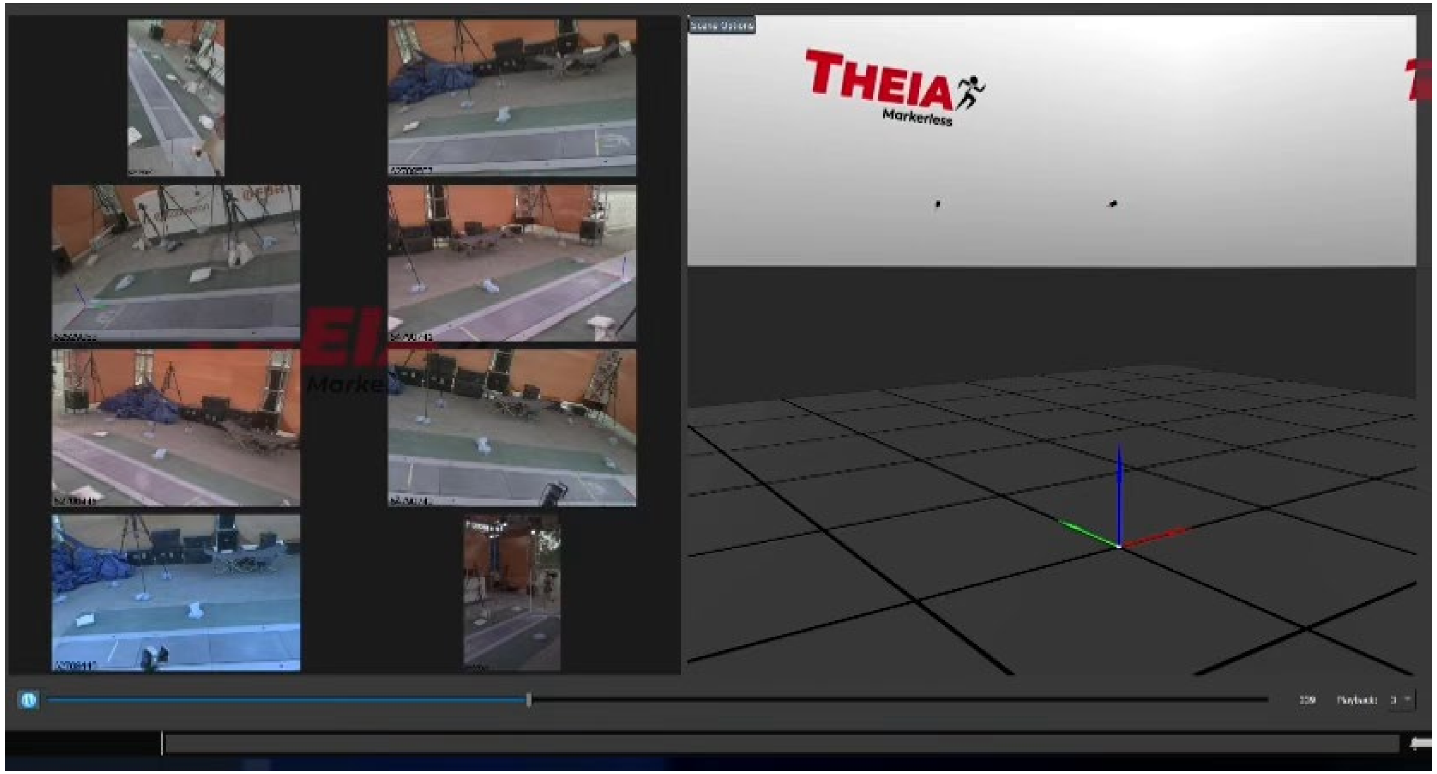
MARKERLESS MOTION CAPTURE

- Works in diverse, real-world environments
- Tracks multiple subjects simultaneously
- No specialized clothing or markers required
- Minimal participant setup (reduced burden on subjects)



- Scalable and efficient for large participant numbers
- Less intrusive, allowing more natural movement patterns

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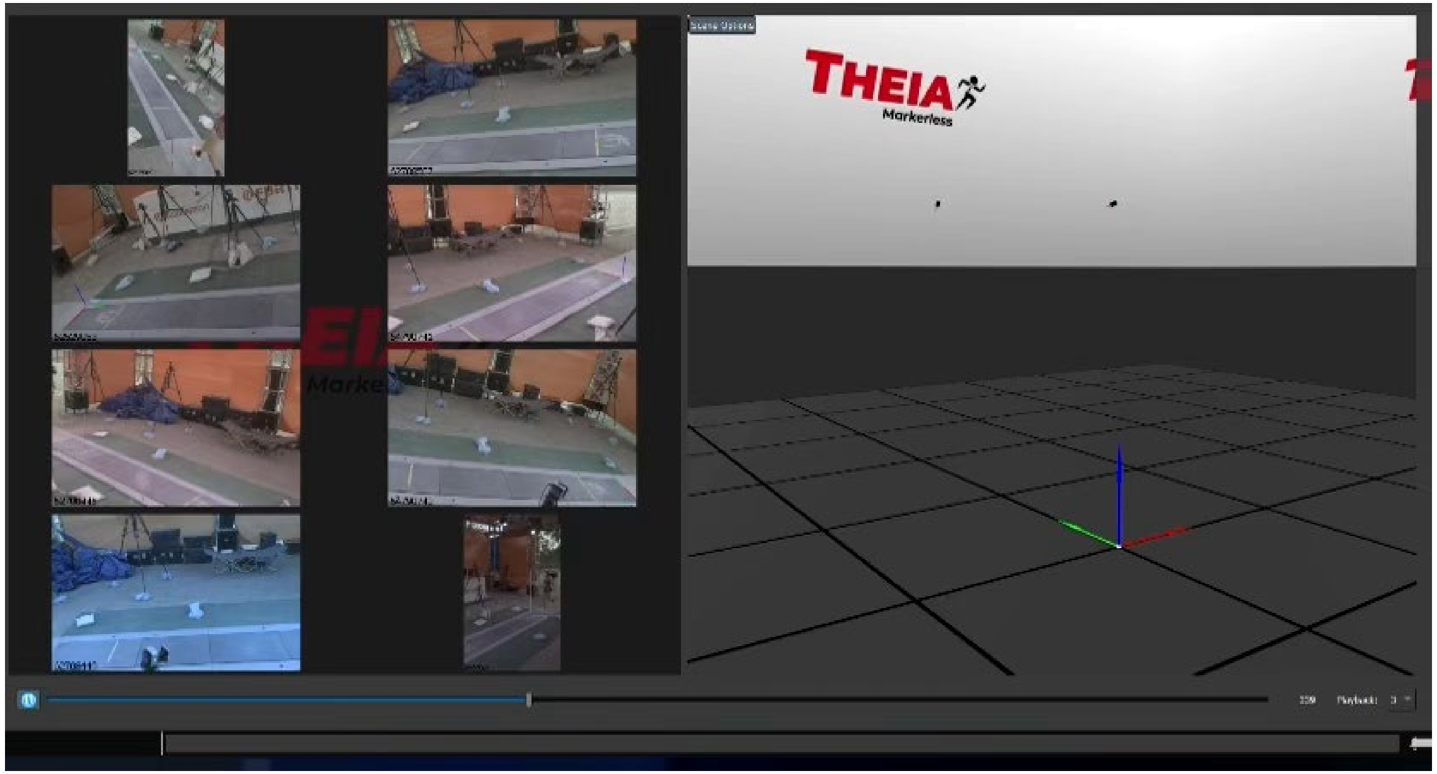
TECHNOLOGY OVERVIEW

MARKERLESS MOTION CAPTURE

- Requires consistent, controlled lighting
- ↓ accuracy outside sagittal plane
- ↓ accuracy with increased distance or occlusion
- Processing algorithms are computationally demanding
- Generates vast amounts of data
- Requires calibration procedures and proper camera placement



TECHNOLOGY OVERVIEW

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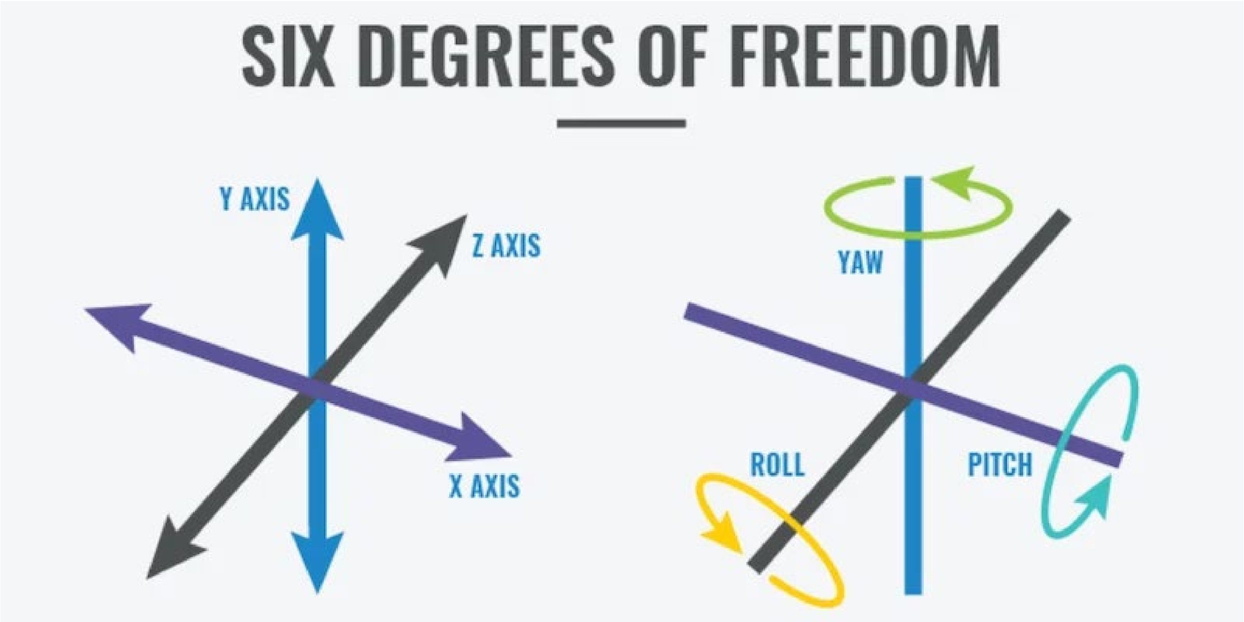
INERTIAL MEASUREMENT UNITS (IMUS)

- Lightweight, small, unobtrusive, and portable
- Suitable for unrestricted real-world movement
- High sampling rates provide detailed temporal data



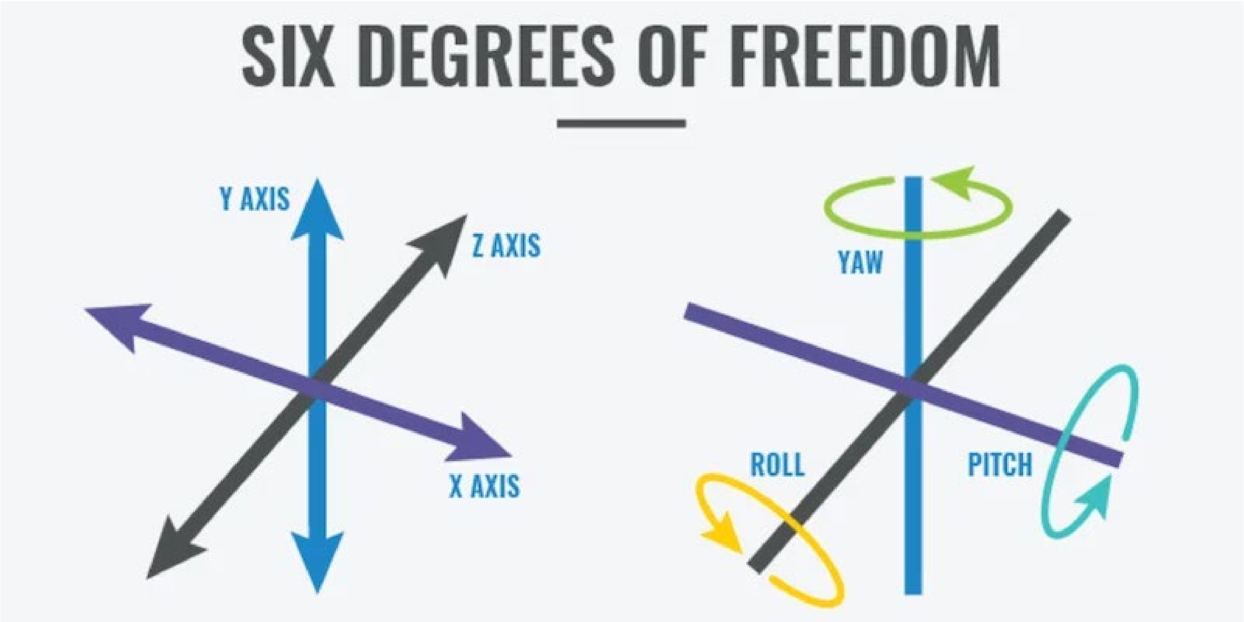
- Relatively cost-effective and easy to deploy at scale
- Not limited by lighting conditions or line-of-sight issues
- Effective for measuring accelerations, angular velocities, and orientation in multiple planes

TECHNOLOGY OVERVIEW

SFU RUN LAB

INERTIAL MEASUREMENT UNITS (IMUS)

- Susceptible to sensor drift and cumulative error over time
- Requires careful calibration and orientation procedures
- Orientation estimation is prone to errors, especially during dynamic movements



- Data processing complexity (sensor fusion and drift correction algorithms needed)
- Potential discomfort or movement artifacts if attachment is insecure
- Placement and secure fixation on body segments is critical

TECHNOLOGY OVERVIEW

SFU RUN LAB

STRAIN SENSORS

- Directly measure tissue deformation and joint angles
- Good sensitivity to subtle changes and movement patterns
- Suitable for measuring localized strains (e.g., muscle, tendon deformation)
- Highly flexible, conforming comfortably to the body, allowing natural motion
- Minimal interference with athlete’s performance
- Can be integrated seamlessly into clothing or wearable textiles

Open Access | Article

Lower Body Kinematics Monitoring in Running Using Fabric-Based Wearable Sensors and Deep Convolutional Neural Networks

by Mohsen Gholami, Ahmad Rezaei, Tyler J. Cuthbert, Christopher Napier and Carlo Menon *

Menrva Research Group, Schools of Mechatronic Systems Engineering & Engineering Science, Simon Fraser University, Metro Vancouver, BC V5A 1S6, Canada

* Author to whom correspondence should be addressed.

Sensors **2019**, *19*(23), 5325; https://doi.org/10.3390/s19235325

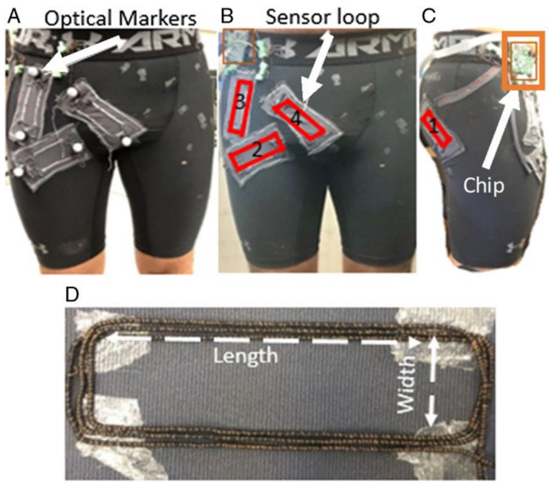
ADVANCED INTELLIGENT SYSTEMS Open Access

Full Paper | Open Access

Textile-Based Inductive Soft Strain Sensors for Fast Frequency Movement and Their Application in Wearable Devices Measuring Multiaxial Hip Joint Angles during Running

Mohammad Tavassolian, Tyler J. Cuthbert, Christopher Napier, JingYang Peng, Carlo Menon

First published: 28 January 2020 | https://doi.org/10.1002/aisy.201900165



TECHNOLOGY OVERVIEW

STRAIN SENSORS

- Limited durability & potential for degradation over prolonged use
- Sensor calibration can be challenging & may require frequent recalibration
- Susceptible to signal noise from sweat, temperature changes, or sensor slippage
- Data interpretation may require advanced signal processing methods and validation
- Limited capability in capturing complex, multi-plane or multi-segment motions without multiple sensors

Open Access | Article

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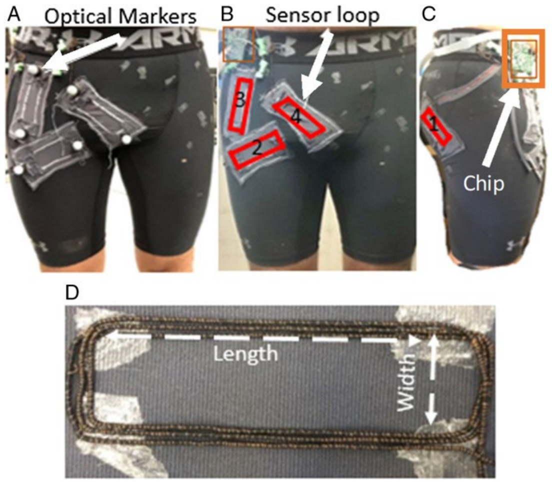

TECHNOLOGY INTEGRATION

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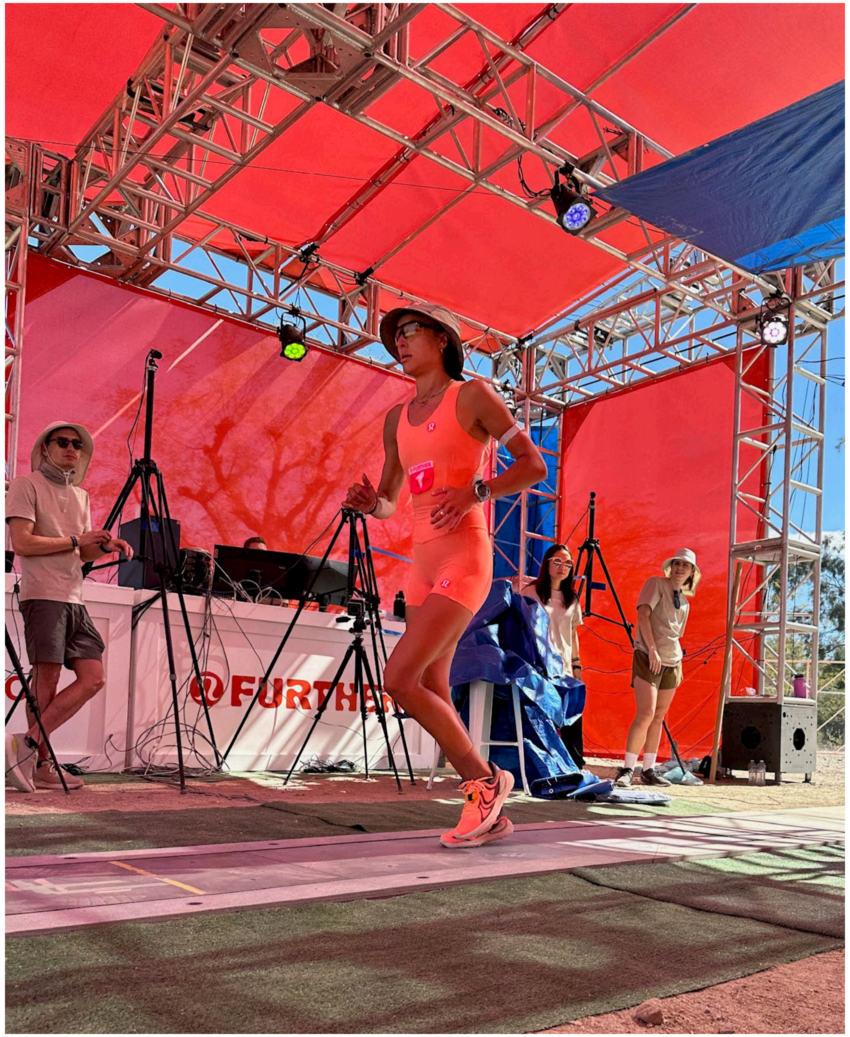
- Improve Movement Analysis
- Address Limitations
- Expand Field-Based Research Capability

Enhanced Accuracy and Ecological Validity



PRACTICAL TIPS FOR FIELD-BASED STUDIES

SFU RUN LAB

LOGISTICAL CONSIDERATIONS

- Plan detailed timelines and contingency options (e.g., weather, cancellations)
- Ensure equipment portability, power supply, backup hardware, and storage solutions
- Develop clear, standardized setup and calibration procedures

PRACTICAL TIPS FOR FIELD-BASED STUDIES

SFU RUN LAB

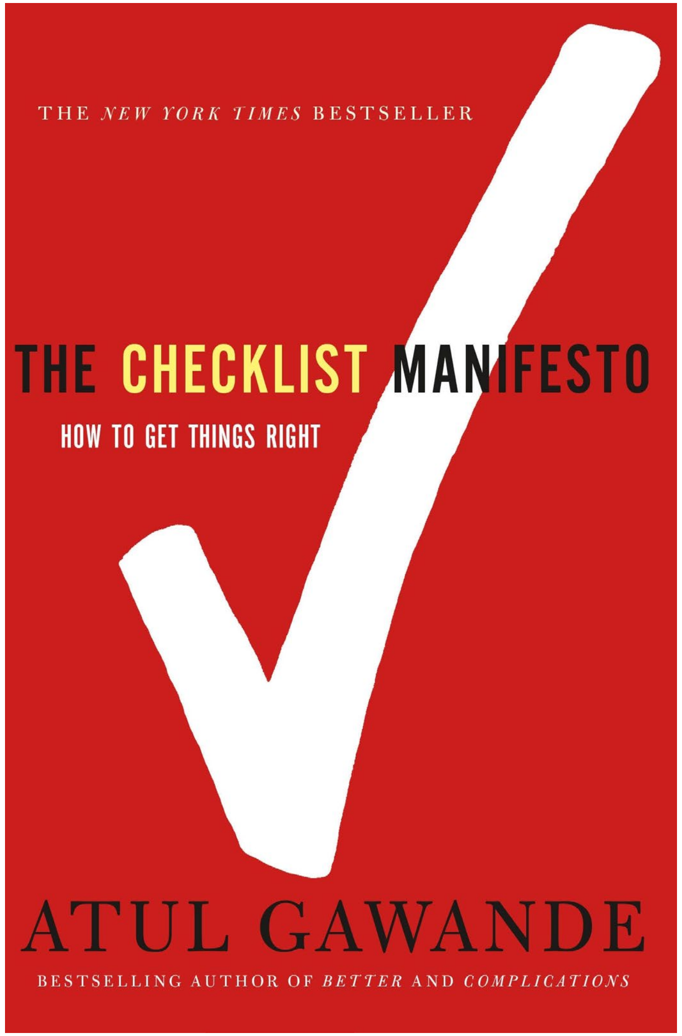
PARTICIPANT ADHERENCE

- Provide clear instructions and training sessions for wearable devices
- Maintain regular, supportive communication with participants
- Minimize participant burden (quick setup, comfortable equipment, minimal interference)

PRACTICAL TIPS FOR FIELD-BASED STUDIES

DATA MANAGEMENT STRATEGIES

- Plan efficient data workflows (e.g., automated backups, naming conventions)
- Use cloud storage solutions or portable storage devices to secure large datasets
- Establish clear protocols for data organization, version control, and privacy protection



PRACTICAL TIPS FOR FIELD-BASED STUDIES

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ENSURING DATA QUALITY IN UNCONTROLLED ENVIRONMENTS

- Regular device calibration & equipment checks during data collection
- Implement data verification protocols (frequent spot-checking, real-time monitoring)
- Collect contextual data (e.g., environmental conditions, terrain, fatigue levels) to explain variability in biomechanical data
- Plan for redundancy (e.g., extra sensors or complementary measurement systems)

PRACTICAL TIPS FOR FIELD-BASED STUDIES

SFU RUN LAB

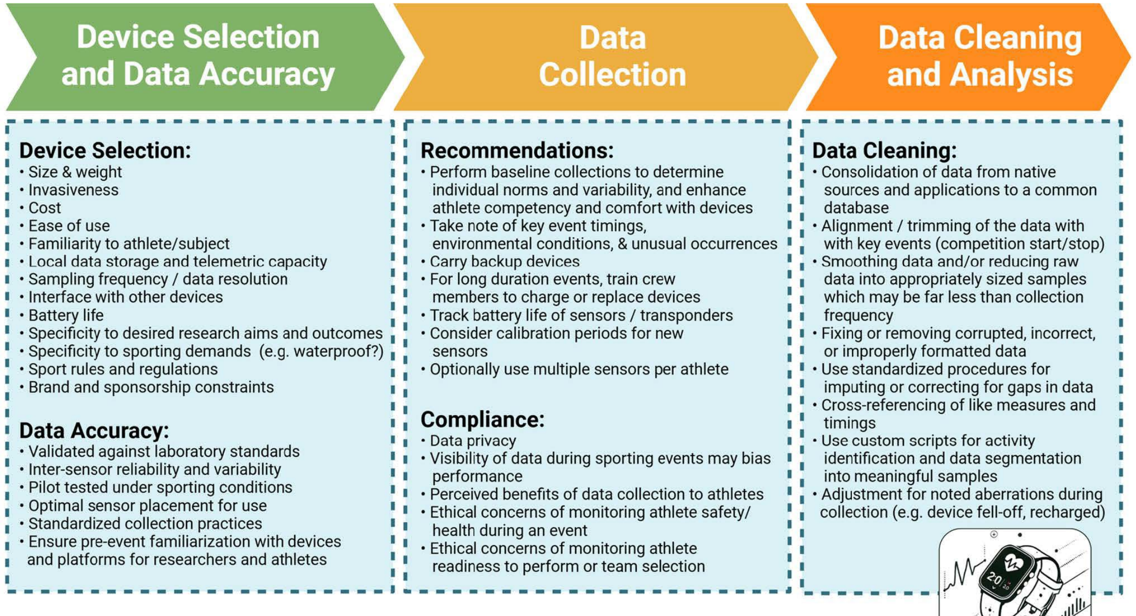
Sports Medicine
https://doi.org/10.1007/s40279-025-02227-0

REVIEW ARTICLE

Check for updates

Integrative Field-Based Health and Performance Research: A Narrative Review on Experimental Methods and Logistics to Conduct Competition and Training Camp Studies in Athletes

Trent Stellingwerff[1,2,3] · Louise M. Burke[4] · Hannah G. Caldwell[5,6] · Robert J. Gathercole[7] · Chris J. McNeil[5] · Christopher Napier[8] · Sarah A. Purcell[5,9] · Susan Boegman[1] · Elizabeth Johnson[1] · Sharleen D. Hoar[1] · Alexandra M. Coates[8] · Erica V. Bennett[3] · Alannah K. A. McKay[4] · Ida. A. Heikura[1,2] · Michael J. Joyner[10] · Jamie F. Burr[11]



5 Field-Based Motion-Capture Considerations

Technological advances have made it feasible to capture high-quality field-based biomechanical data without the use of reflective markers. Markerless motion capture (MMC) provides high-fidelity data in complex or restrictive environments using advanced computer vision and machine learning algorithms to track joint movements directly from high-resolution video footage [81, 82]. This allows researchers to study athletes in their natural environments, with minimal disruption. Although MMC expands the scope and ecological validity of biomechanical research into field-based settings, there are several logistical and technical challenges that must be addressed to ensure accurate and reliable data capture.

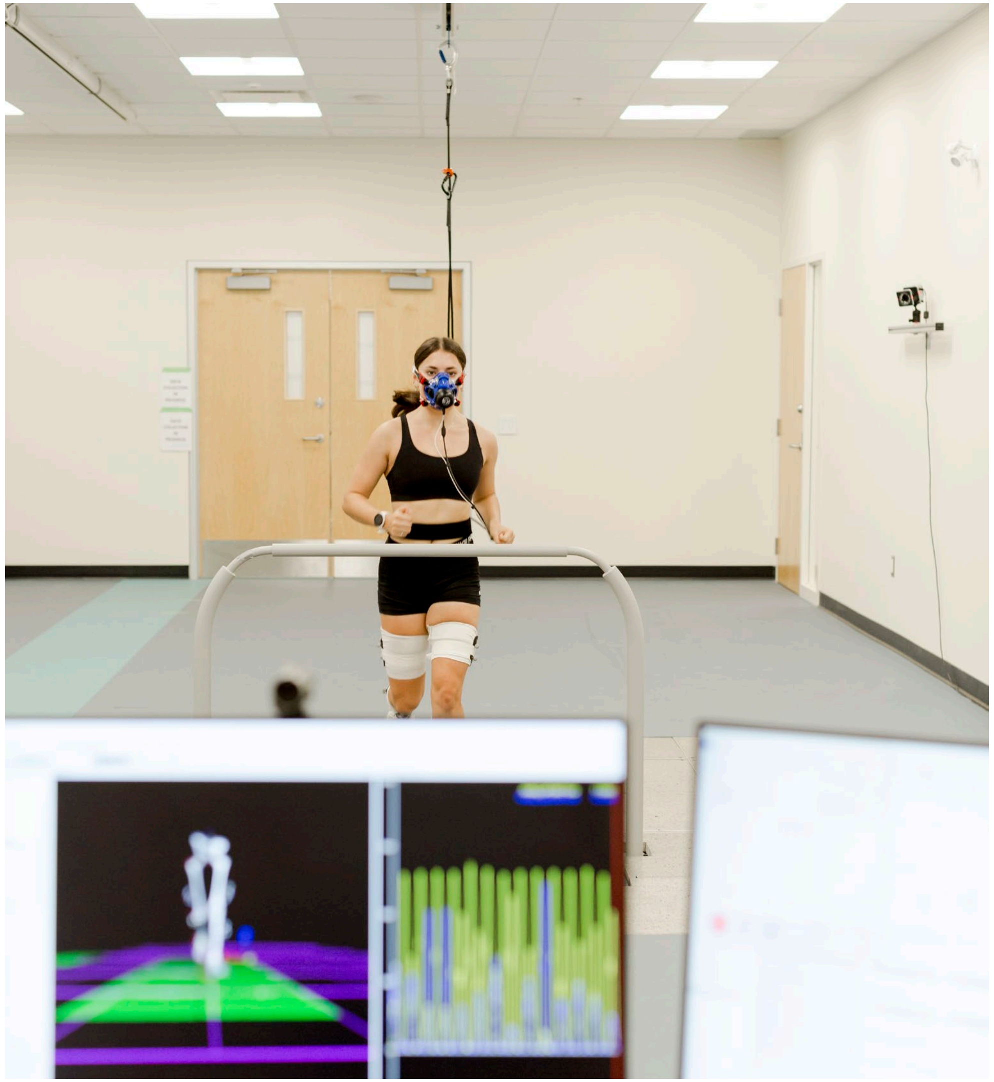
In summary, we strongly recommend piloting all systems/methods prior to actual data collection. With meticulous planning, researchers can improve the reliability and applicability of the data collected. Accordingly, MMC can be a powerful tool for enhancing the understanding of athletic performance, ultimately contributing deeper insights into how athletes perform in their natural field-based environment.

Stellingwerff et al *Sports Med* (2025)

EXAMPLES FROM THE SFU RUN LAB

SFU RUN LAB

- Lululemon FURTHER event 2024
- Canadian 10,000 m Championships 2024
- Running Online Injury Prevention Feasibility Study



LULULEMON FURTHER EVENT

SFU RUN LAB

The event:

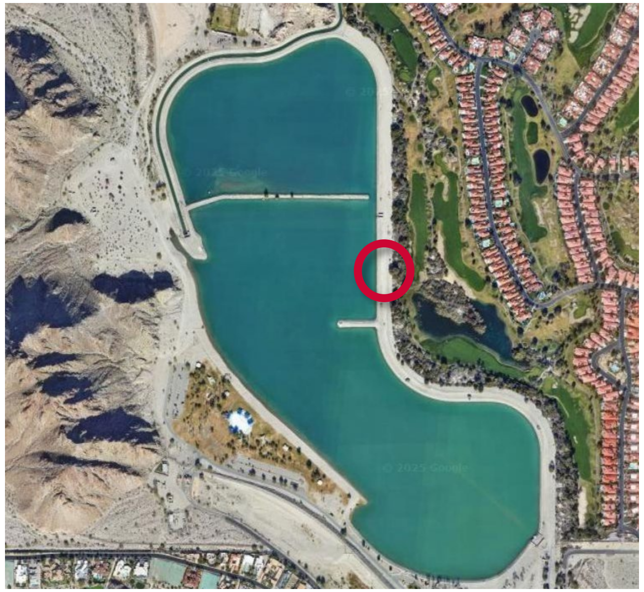
- 10 women
- 6 days (144 hours)
- 2.5 mi / 4 km loop

Overarching goal:

- To determine the effect of both acute and chronic fatigue on running biomechanics during a 6-day UER event

LULULEMON FURTHER EVENT

SFU RUN LAB



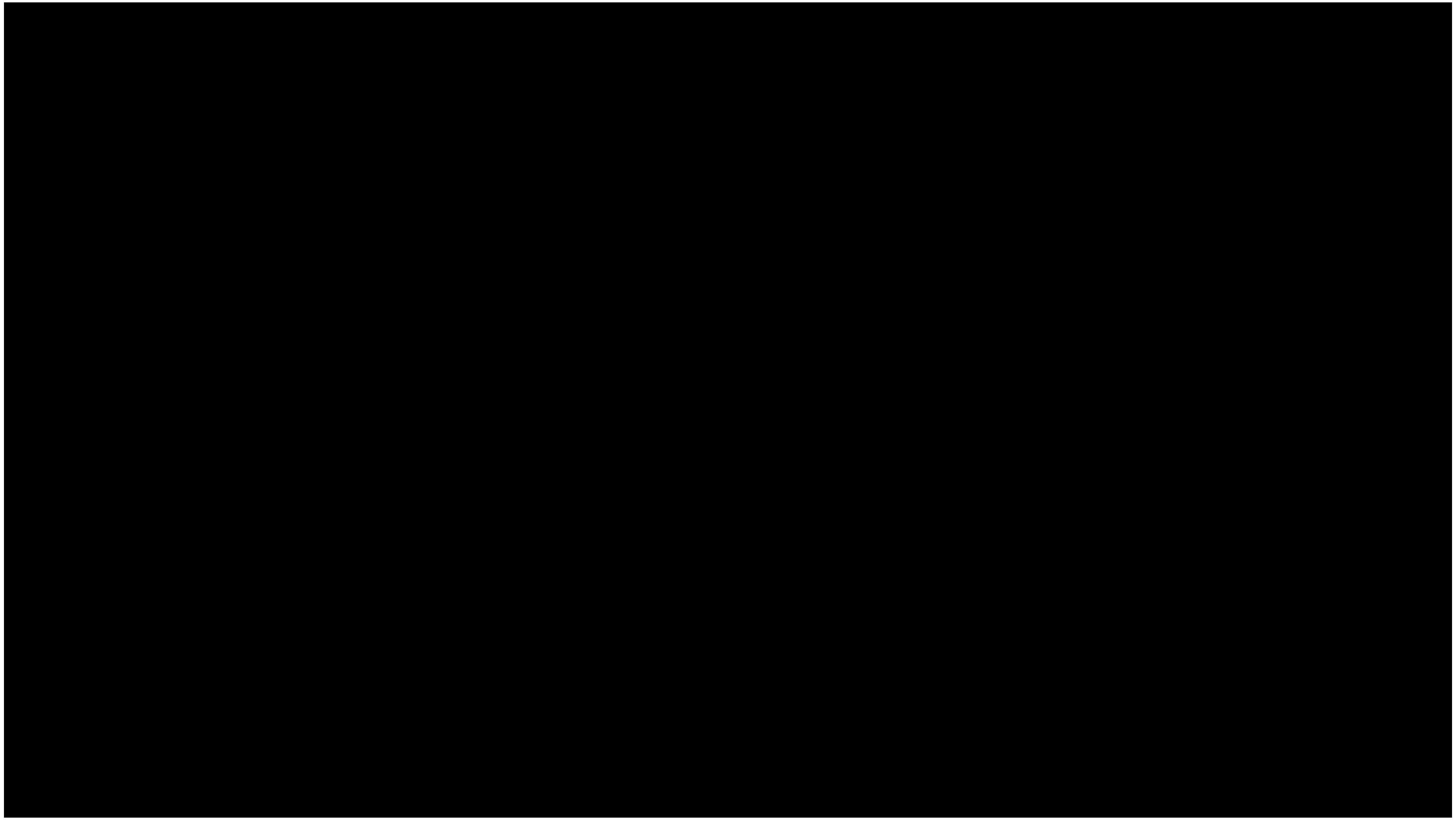
LULULEMON FURTHER EVENT

SFU RUN LAB

LULULEMON FURTHER EVENT

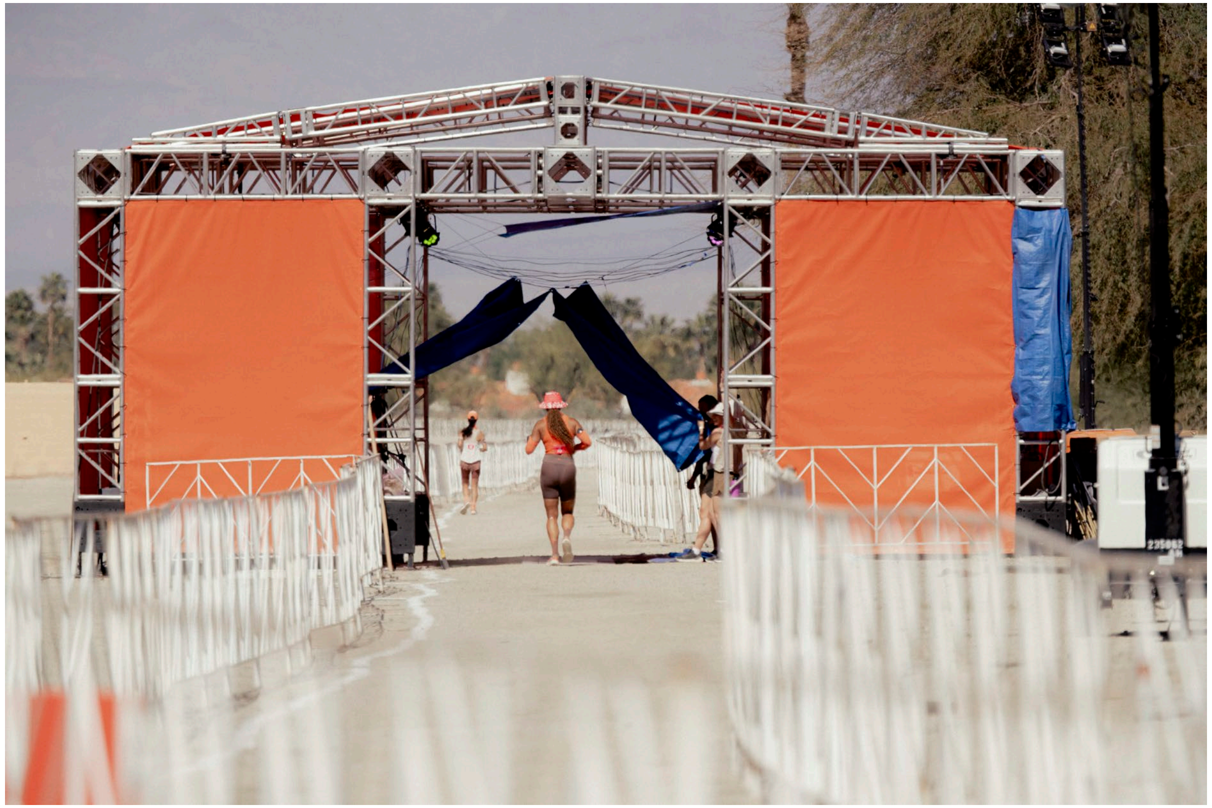
SFU RUN LAB

And then…

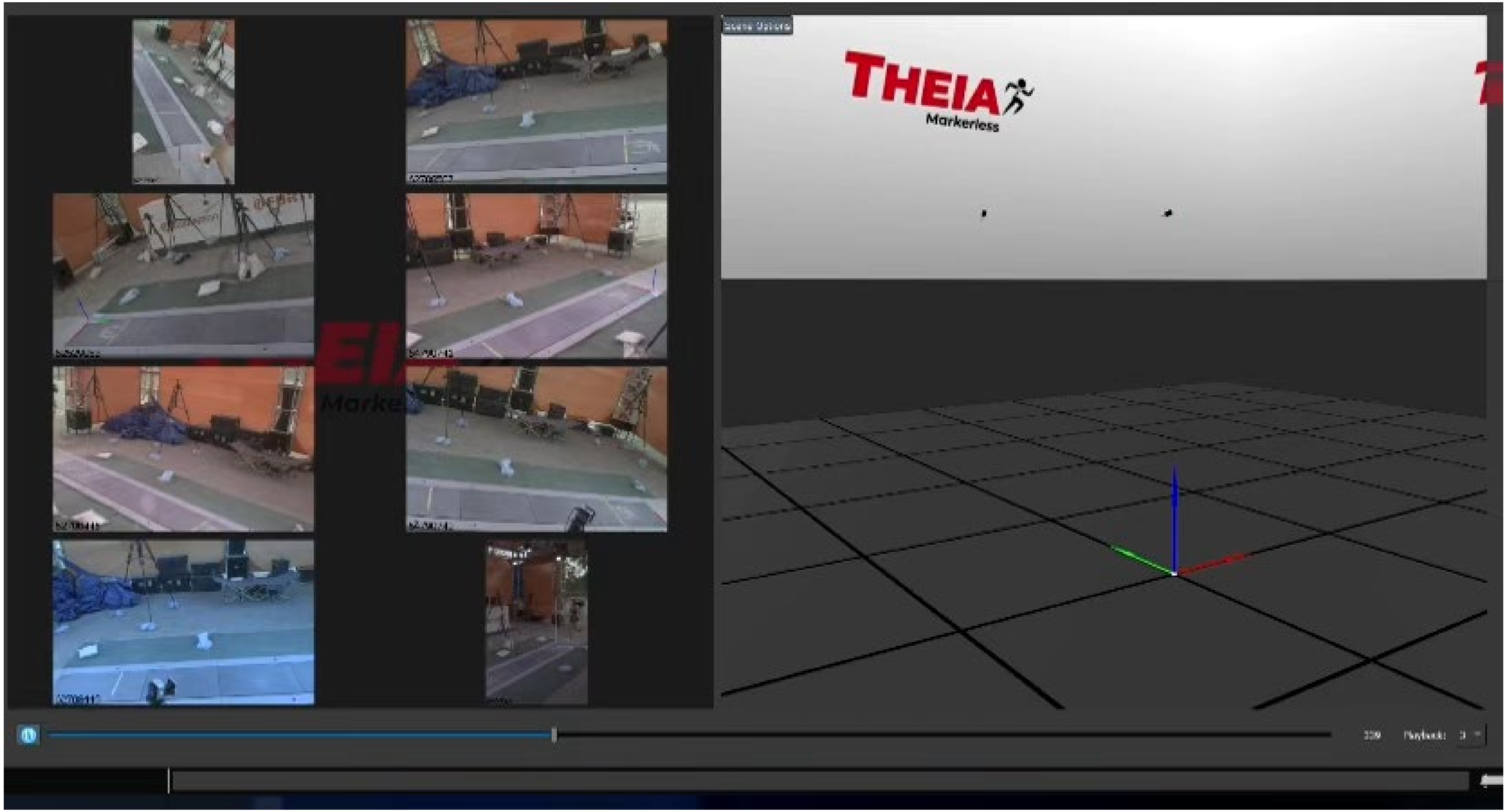


LULULEMON FURTHER EVENT

SFU RUN LAB



LULULEMON FURTHER EVENT



LULULEMON FURTHER EVENT

INERTIAL MEASUREMENT UNITS

- 6-axis IMU
- +/-32G, 500 Hz sampling rate
- 8+ hour battery life
- Time-synchronized
- Small and lightweight (5 g)

Plantiga Technologies, Vancouver, Canada

LULULEMON FURTHER EVENT

SFU RUN LAB

INERTIAL MEASUREMENT UNITS

- 6-axis IMU
- +/-32G, 500 Hz sampling rate
- 8+ hour battery life
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- Small and lightweight (5 g)

Plantiga Technologies, Vancouver, Canada

LULULEMON FURTHER EVENT

Markerless Motion Capture

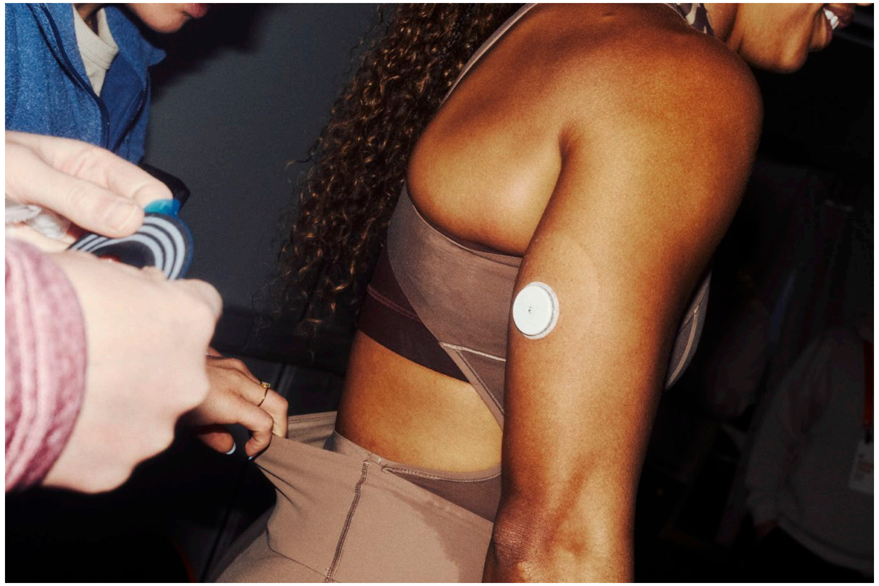
- Lighting/shadows (calibration)
- Heat
- Rain/Wind (2nd windstorm on Day 1 evening)

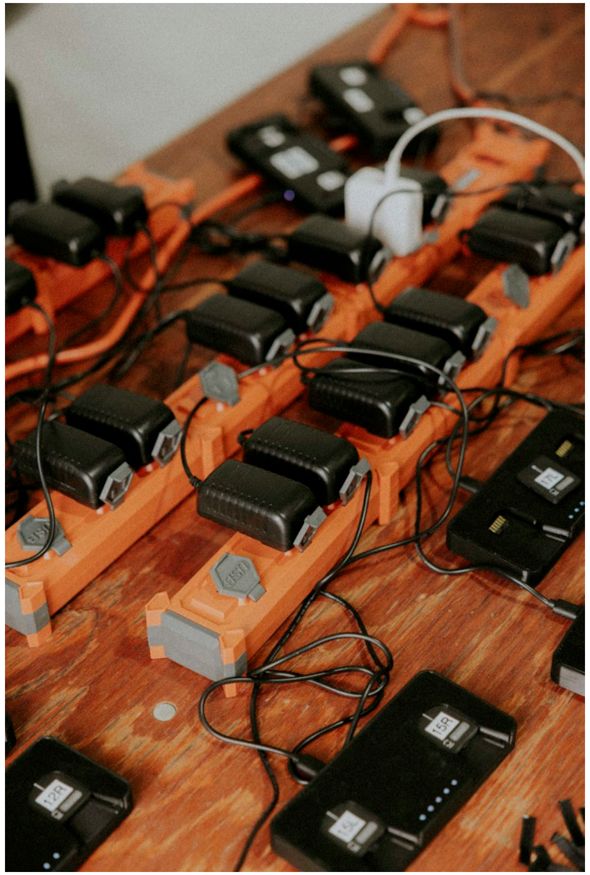
LULULEMON FURTHER EVENT

SFU RUN LAB

Inertial Measurement Units

- Fixation
- Power/Battery, Wifi
- Lost/missing sensors





CANADIAN 10,000 M CHAMPIONSHIPS

SFU RUN LAB

- Markerless Motion Capture
- Camera configurations
- Obscurement
- Heat
- Changing lighting
- Data storage
- Cable management

RUNNING ONLINE INJURY PREVENTION FEASIBILITY STUDY

- 60 women
- In-shoe IMUs (n = 30)
- Training load monitoring (Strava)
- Menstrual cycle monitoring
- Training Intervention

SUMMARY & CONCLUSIONS

SFU RUN LAB

Real-world Biomechanics

- Provides ecological validity, greater participant numbers, and long-term insights beyond traditional lab settings.

Advanced Wearable Technologies

- Markerless motion capture, IMUs, and strain sensors each offer unique strengths for capturing real-world running data; integration enhances overall measurement accuracy and insight.

Overcoming Challenges

- Careful consideration of data quality, logistics, participant adherence, and field protocols are essential for successful real-world biomechanics studies.

Big Data & AI Opportunities

- Integration of wearable tech with AI-driven analysis allows for enhanced injury prediction, personalized training interventions, and deeper insights into biomechanics of running performance.

Impact on Injury Prevention & Performance

- Field-based studies provide direct, actionable insights applicable to athletes, coaches, clinicians, and researchers, bridging the gap between biomechanics research and practical application.

Industry Partners

MYNORMATIVE

plantiga

GARMIN™

lululemon athletica

ARC'TERYX

HETTAS

Grant Funding

Michael Smith Health Research BC

NSERC CRSNG

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QUESTIONS?

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