A Data-Driven Approach to Running Gait Assessment Using Inertial Measurement Units

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Background: Running is an extremely common exercise, both recreationally and competitively. Combined with clinical assessment, technology-driven biomechanical gait analysis can be used to examine markers of performance and injury risk in runners.

Indications: The indication is to provide clinicians and sports science researchers a framework for using inertial measurement units (IMU) for data-driven, quantitative gait assessments.

Technique Description: This video details practical application of IMU use in biomechanical gait assessments. Details on participant and equipment setup, in-session protocols, and selection of gait variables are included.

Results: Following collection of demographic and anthropometric outcomes, IMUs should be placed on rigid segments of the lower extremity, sacrum, and trunk. In our model, we place IMUs on the foot, shank, thigh, sacrum, and lower thoracic spine. Following static anatomical calibration, running gait biomechanics are evaluated at multiple speeds using IMUs, 2-dimensional high-speed video cameras, and an instrumented treadmill. The high-speed video and IMU data are analyzed together at various parts of the gait cycle, including foot strike, mid-stance, toe-off, and flight. Many kinematic and kinetic variables (ie, unilateral discrete joint angles, joint excursions, joint moments, spatiotemporal outcomes, etc) can be selected for analysis, ideally via a collaboration between the sports science, athletic, and sports medicine teams. A collaborative approach should also be used to determine how this information will be used to alter training programs or influence injury risk in the running athlete.

Discussion/Conclusion: This report details how to use a data-driven approach to evaluate running gait biomechanics using IMU technology. This framework for gait analysis is most applicable, and effective, when the team of researchers works in conjunction with coaches, sport scientists, and athletes. Utilizing this framework, training can be adapted based on the objective and clinical assessment to reduce injury risk and improve performance in the gait assessment.

Keywords: inertial measurement units; running; athlete; biomechanics; kinematic; kinetic

VIDEO TRANSCRIPT

In this video, we will be demonstrating the athlete gait assessment protocol used in the Michigan Performance Research Lab at the University of Michigan. We will explain the background information on this type of assessment, walk through the process of the assessment as well as the assessment report, and finally go over the clinical applications of the assessment.

There are no relevant disclosures to this presentation.

Running is an extremely common exercise, both recreationally and competitively. Running gait assessments are traditionally performed with the use of clinical observation skills and biomechanical technology. Gait assessments are used to examine markers of performance and injury risk in runners and other athletes. Gait assessments are used by runners, clinicians, coaches, and anyone else involved in athlete health, performance, and injury treatment and prevention.

Injuries among running athletes are common and hinder athletic performance. Prevalent injuries include patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome, Achilles tendinopathy, plantar fasciitis,

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stress fractures, and muscle strains. Running biomechanics play a key role in both athletic performance and injury development. Because of this relationship, there is potential to predict running injury risk based on biomechanical and anthropometric profiles of runners. Joint angle asymmetries, ground reaction force data, and gait patterns can be analyzed together to assess injury risk and development. Running gait assessments can be performed with the use of instrumented treadmills, 3-dimensional (3D) motion capture systems, inertial measurement units (also called IMUs), and 2-dimensional videos with clinician observation. In a clinical setting, where 3D motion capture systems are impractical, using IMUs can provide clinicians with objective, quantifiable outcomes to be paired with their clinical observations, allowing them to quantify gait asymmetries or underlying impairments that may be otherwise missed. The objective of this video is to provide a systematic framework for a clinical-based IMU and video-based assessment for runners.

Gait biomechanics is the analytical study of lower limb musculoskeletal structural capability and function. Gait biomechanics includes kinetics—the forces, power, and energy dynamically affecting movement—and kinematics—the visual motion analysis without regard to external forces or energy. To assess gait biomechanics, IMUs, paired with processing software, measure acceleration and orientation via accelerometer and gyroscope technology to determine kinematic variables. Instrumented treadmills or embedded force plates can be used in combination with IMUs to also assess kinetics.

The gait analysis begins by welcoming the subject; taking the athlete's weight, height, foot, and shoe size; and acquiring posture photos. Posture photos are taken facing each direction for analysis to better understand postural asymmetries that may influence running biomechanics. The anthropometric measurements are helpful for clinical analysis.

In our lab, we use the Noraxon (Scottsdale, Arizona) IMU sensor system. We have designed our protocol in accordance with best evidence guidelines to place IMUs midway on the shank, laterally just below the head of the fibula, avoiding muscle. The thigh sensors are placed midway, laterally over the iliotibial (IT) band, and avoiding the quadriceps muscles. An additional sensor is placed on the pelvis above the sacrum and in line with the iliac crest. The final sensor is placed on the lower thoracic spine approximately 2 to 3 inches above the bottom of the ribcage.

To minimize potential measurement error and increase data reliability, it is important to standardize IMU placement across participants and ensure sensors are properly calibrated for each trial, per manufacturer guidelines. In addition, error can be reduced by appropriately securing the sensors with elastic stretch tape to avoid IMU movement, or drift, during the running trial; our lab has found that a base layer of pre-wrap and cover of stretch tape, such as Sher Light, reduce IMU drift.

Once the sensors are secured on the athlete and calibrated, the athlete begins the first of 2 running trials. It is optimal to assess running gait biomechanics at multiple speeds, which are agreed upon by the coaching staff and the athlete. Our protocol currently uses one trial at a self-determined easy pace and a second trial at an increased pace, closer to aerobic threshold.

Two-dimensional high-speed video cameras are set up to record the athlete during the trials. One camera is set up for a sagittal view and another is set up for a posterior view.

Mid-trial kinematic and kinetic outcomes are measured to ensure that the athlete has acclimated to the treadmill and the pace and is running with their normal mechanics.

The high-speed video and IMU data can be analyzed together to provide a holistic representation of the runner's biomechanical profile. There are many commercially available and research-grade IMU sensors that can be used in a clinical setting, and it would be up to the clinician to evaluate the best model and software that would fit their needs.

As seen here, the IMU processing software creates a kinematic skeletal model and a force plate map and collects joint angle data in real time. The lower half skeletal model is monitored to examine visual gait kinematics and ensure proper IMU function. The instrumented treadmill collects ground reaction forces to provide weight distribution mapping. The joint angle measurements are analyzed to identify joint asymmetries for the clinical gait analysis report.

The data are then processed to create a report that can be presented to the athlete, along with their medical and coaching staff. The report begins with the athlete's anthropometric profile.

The first measurements analyzed in this report are spatiotemporal variables. These variables are calculated by the time spent on and off the treadmill based on the data from the force plate. These variables include contact time, stride time, step time, flight time, stride length, step length, and step width. The average of each variable over the entire trial is calculated for each foot, as well as the bilateral differences. Practically significant bilateral differences are highlighted in blue, as denoted by strong effect sizes of greater than 0.8.

It is important to note that we determine practically significant bilateral differences by calculating Cohen's d effect size, as shown on the screen. Cohen's d effect sizes can be calculated by taking the difference in the gait outcome between the limbs and dividing by the pooled standard deviation. Effect sizes can help to evaluate the strength, or magnitude, of asymmetries observed.

The kinematic portion of our analysis is broken down into the 4 stages of running gait: initial contact, midstance, toe-off, and flight. For each stage, the unilateral averages of the kinematic angles are calculated. The kinematic variables are selected by the sports science and clinical teams and may vary across the gait. Relevant kinematic variables include angles and motions of involved joints. Once again, bilateral differences are calculated, and practically significant differences are highlighted in blue.

The same process is done for knee, hip, lumbar, and pelvic range of motion through the entire gait cycle.

Finally, the report includes kinetic data in the form of foot pressure distribution and vertical force distribution data from the force plates on the instrumented treadmill. From these data, ground reaction force variables and bilateral differences are once again calculated.

It is up to the discretion of the coaching and medical staff, as well as the athlete, to determine how training should be curated based on the report. The findings from the report can be applied to training to modify and monitor asymmetries, with the goal of decreasing injury risk and improving performance. This technique has been previously published as a way to address running gait asymmetries in runners. This framework for gait analysis leads to greater effectiveness and efficiency in returning or bringing athletes to higher optimum performance.

This concludes our video on a data-driven approach to kinematic running gait assessment using IMUs.

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