
# A new inertial measurement unit to collect running kinematics data outside of the lab


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## Introduction

The data collection process for sport biomechanics is often a very equipment intensive endeavor. Well equipped labs include multiple force platforms, a 3-D motion analysis system, treadmills (some with force-plates built in), and other specialized equipment. The use of this equipment is often limited to the lab. However with the continually improving state of sensor technology it is now possible to collect meaningful kinematic data with far less cost and, more importantly, in real world settings. Inertial measurement units (IMUs) are electronic devices that measure a body's velocity, orientation, and gravitational forces, using a combination of accelerometers, gyroscopes, and magnetometers. Accelerometers have long been used in biomechanics research to better understand impact and collision characteristics. In running research it is common practice to use an accelerometer strapped to the shank of a subject to record impact shock measurements while running in a variety of foot wear conditions and settings. In recent years custom fabricated IMUs have been used in gait labs (Greene et al, Sant' Anna and Wickstrom, Shih et al) and in the field (Strohrmann et al, Wixted et al). IMU's give the researcher an enhanced set of data over that acquired from a single accelerometer.

The runScribe IMU has the capability to collect research quality data in real world settings outside of the lab. It consists of a 3-D accelerometer, 3-D gyroscope, and 3-D magnetometer with an on-board microprocessor, 32MB of flash memory, 30+ hours of battery life from a replaceable CR2032 lithium battery, and wireless data sync via Bluetooth Smart (iOS). The unit weighs 8g and requires a 7g mounting clip. Motion data (pitch, roll, and yaw) can be collected at rates up to 200Hz; if used in the accelerometer only mode, data can be collected up to 1000Hz.

The objectives of this project are to introduce the runScribe sensor, describe and evaluate collected data in controlled conditions, and determine whether the data and calculated metrics show the expected relationships to known changes in running speed and are consistent with the literature. This is one of a series of tests that will be conducted to evaluate the runScribe sensor.

## Methods

### Subjects

- Ten subjects - 2 male, 8 female. All injury free
- Age range – 26 to 67 years
- All were experienced treadmill runners

### Testing Procedure

Each subject ran on a treadmill (Horizon Fitness CST4.5) at seven different speeds, which were separated by 0.25 min/mile and were unique to each subject. The middle of the seven speeds was set to each runner's comfortable long run pace and the other six determined from this speed. For example, if the subject reported that their average long run speed is 7.50 min/mile, their seven test speeds would be 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, and 8.25 min/mile. The testing sessions included the following:

- Two minutes at each speed with a break between
- Order of the runs randomized for each subject
- **90+ stride cycles** analyzed for each running speed
- Treadmill speed determined by an external source

### RunScribe Attachment and Configuration

**Figure 1**

The unit was temporarily attached to the heel of participants' shoe via a clip (figure 1). The sensor does not need exact alignment along the axes of the sagittal, transverse, or frontal planes as was necessary with others (Sabatini et al) because runScribe continually senses gravity to correct for the sensor orientation on the shoe. The runScribe unit was configured to collect motion data at 200Hz with an onboard low pass filter setting of 188Hz. The onboard motion processing unit (MPU) calculates the orientation (pitch, roll, and yaw) of the foot throughout the data collection period and stores the data to flash memory. Three dimensional accelerometer data were also collected and stored in flash memory for post processing.

### Data Processing

Scribe Labs Inc. has developed proprietary algorithms that detect foot strike and toe off, allowing time series data to be divided into segments corresponding to individual stride cycles. Cycle based metrics calculated for every stride include: ground contact time (CT), stride rate (SR), stride length (SL), pronation excursion (ProE), maximum pronation velocity (ProV), and peak accelerations in 3-D (PeakG-impact, braking, medio-lateral). These metrics are discussed here and a more complete list is given in Table 1. Scribe Labs Inc. analysis software provides a variety of visualization and analysis tools or the raw data can be exported for further analysis.

### Statistical Analysis

A mixed linear model (**SAS-University Edition**) was used to determine which of the response variables significantly correlate with known changes in running speed and to generate 95% confidence intervals for each subject.

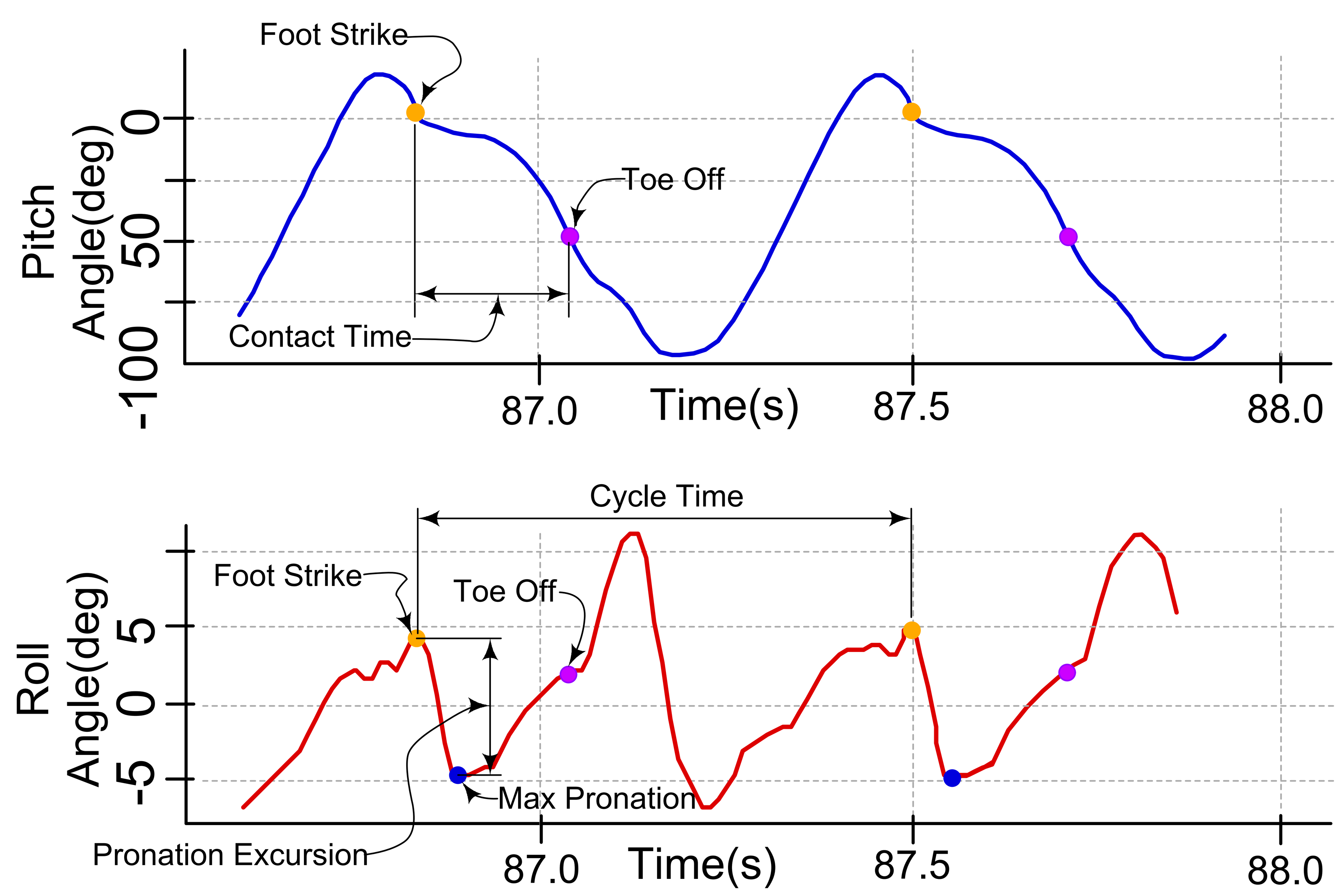


**Figure 2**: Example of raw angular displacement data of two stride cycles output by the runScribe IMU. Foot strike and toe off are indicated.

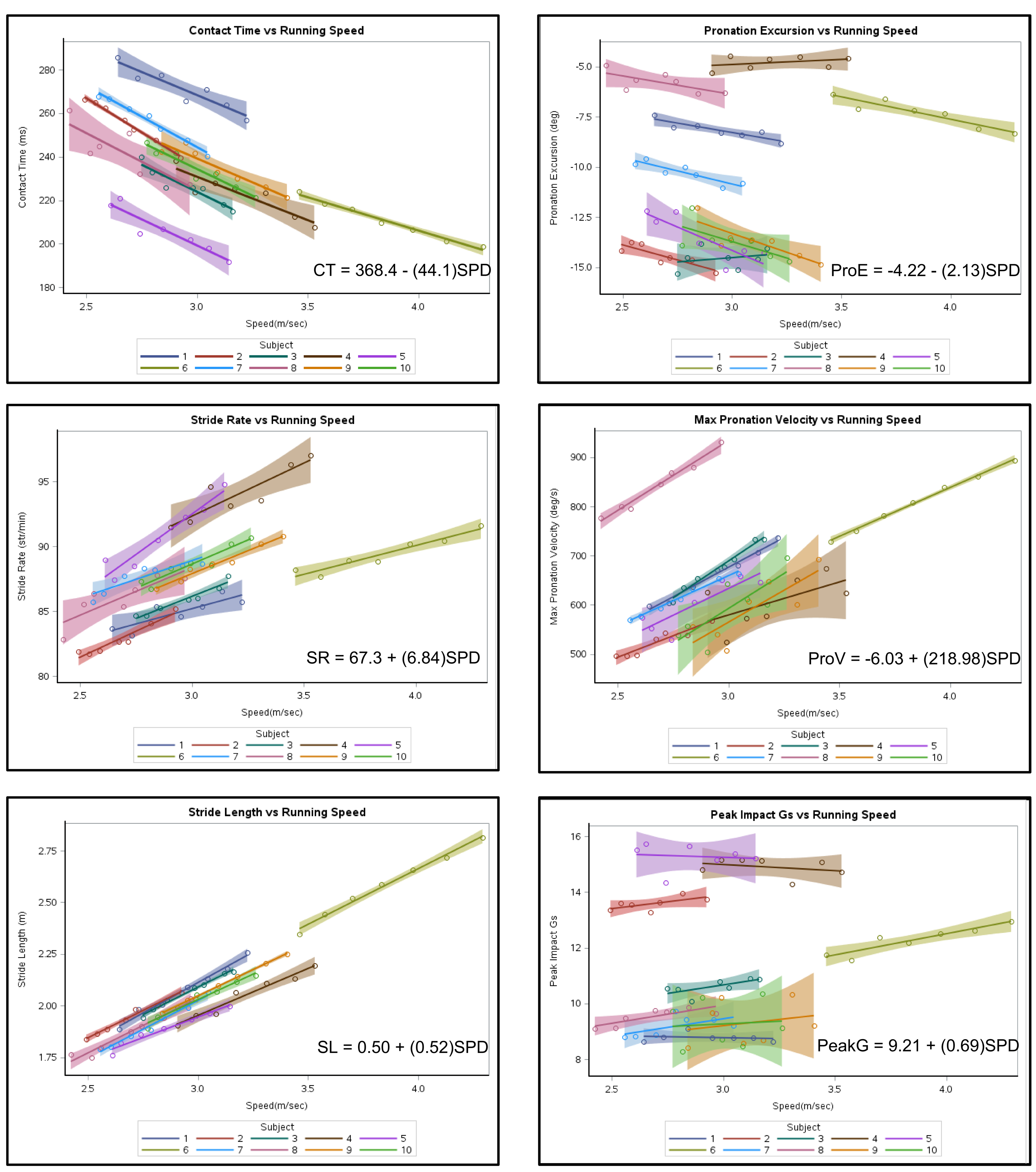


**Figure 3**: Plots of the regression lines for six calculated metrics, 95% confidence intervals for each subject, and average regression equations.

## Results

Table 1 includes the metrics calculated by the Scribe Labs FootSteps model. The majority of these metrics show a significant correlation with running speed (indicated by an asterisk *). Note that the first six metrics listed (CT, SR, SL, ProE, ProV, Peak Impact Gs) correspond to the plots in this poster; others are not included due to space limitations. Figure 2 illustrates two stride cycles of angular displacement data (pitch and roll) output by the runScribe IMU. Figure 3 consists of plots of six metrics calculated from the raw runScribe data. Each plot includes the linear regression for each subject and corresponding 95% confidence intervals.

| Metric | Slope (β) | Pr > F |
|---|---|---|
| Contact Time (ms) | -44.09 | *** |
| Stride Rate (str/min) | 6.84 | *** |
| Stride Length (m) | 0.52 | *** |
| Pronation Exursion (deg) | -2.13 | *** |
| Max Pron Vel (deg/s) | 218.98 | *** |
| Peak Gs - Y | 0.69 | * |
| Peak Gs – Z | 1.77 | *** |
| Peak Gs - X | 2.25 | *** |
| Time to Max Pron (ms) | -8.98 | *** |
| Cycle Time (ms) | -52.83 | *** |
| Pitch @ Max Pronation (deg) | 1.36 | NS |
| Pitch Excursion (deg) | 16.16 | *** |
| PitchMax to footflat (deg) | -3.82 | *** |
| footflat to PitchMin (deg) | -12.61 | *** |
| Pitch Excursion-1 (deg) | -1.37 | NS |
| Pitch Excursion-2 (deg) | -3.86 | *** |
| CT/cyctime | -0.038 | *** |

**Table 1:** List of metrics calculated by the Scribe Labs FootSteps Model

* = p<0.05
** = p<0.01
*** = p<0.001

## Discussion

As running speed increases, CT decreases (Munro, 1987). The data from runScribe showed this same relationship across all subjects. Furthermore, SR and SL are both positively related to changes in speed (Cavanagh) as runners utilize both metrics to alter their running speed. Enomoto et al nicely illustrates how runners use individual combinations of changes to SR and SL when altering running speeds however, the subjects in this study were very consistent in their SL changes in response to changes in speed but tended to vary in their SR response. The individual subject responses are possibly affected by the moderate intensity of the test speeds and it is likely their responses may differ as they get closer to max speed.

Information in the literature is somewhat mixed with regards to the relationship between running speed and ProE and ProV. In general, most studies show increases in pronation and pronation velocity with increasing running speed (Cavanagh, Nigg). The data from runScribe are consistent with these studies with 8 of the 10 subjects showing increasing ProE and all showing greater ProV with increasing running speed. It should be noted that runScribe measures eversion, or roll of the foot in the frontal plane and not the traditional pronation angle where both the rearfoot and leg angles are taken into account. This is an adequate representation of pronation given that, for an individual, the leg angle only changes one to two degrees during ground contact (Clarke et al 1984).

Tibial decelerations have been shown to increase with increased running speed. Particularly as runners get closer to maximum speed (Clarke et al, Mercer et al). Our data were in general agreement with those in the literature; seven of the ten subjects showed increases in Peak Impact Gs as the test speed increased. The test speeds in this project were slower than those in the cited studies which may account for the less dramatic increase in Peak Impact Gs with increasing speed. Also, in previous studies the sensor was located on the distal antero-medial tibia whereas in this study it was located on the heel of the shoe. This may have also accounted for some of the minor differences found between this and previous studies.

One interesting characteristic about these data is the inconsistent intra-subject variability evident in each plot. A number of authors have examined variability within individual gait patterns and there is some evidence that decreased variability could lead to increased risk of overuse injury (Hamill et al). These studies look primarily at coordinative variability between segments where these data illustrate end point temporal variability. However, it is possible in future studies to use multiple runScribe sensors in different locations to determine the relative timing of events to gain insight into the coordinative variability between segments.

In conclusion, the new runScribe IMU shows real promise as a tool to collect useful research quality data in real world settings. Future studies will investigate kinematic changes that occur as a result of different shoes, terrain, onset of fatigue, and gait retraining programs. These topics are not new to biomechanics research however, the availability of this new, light-weight, powerful sensor gives the researcher the ability to conduct investigations outside of the lab setting and gain new insight into these and other topics. Furthermore, a consumer grade product is also available that will provide the same information shown here however, the user will not have access to the raw data.

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