VALIDATION STUDY

XSENSOR's Intelligent Insoles Sensor Validation

Validation study demonstrating the long-term calibration stability of XSENSOR's Intelligent Insole pressure sensors.

DOC-03-00031 R00

XSENSOR Intelligent Dynamic Sensing

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Revision History

- **Rev 00:** November 12, 2025 - First Release

Introduction

A long-term evaluation was conducted to confirm the **accuracy and repeatability** of the Intelligent Insole pressure sensors used to measure plantar pressure during gait and standing. The sensors were each subjected to **200,000 cycles of controlled loading and of flexing,** representing approximately **three years of normal clinical*** **or equivalent use.** Measurements were taken at regular verification intervals and compared against calibrated reference loads across a range of pressure levels. Results demonstrated that the sensors maintained **measurement accuracy within 3.2% of full-scale error** and **repeatability of 3.4%**, with no significant drift observed over the test duration. These findings confirm the long-term calibration stability of the pressure measurement system. Based on the results, routine recalibration is not required within three years of normal clinical use, ensuring confidence in consistent, high-quality data for clinical and equivalent plantar pressure measurement applications.

* **Normal Clinical Use:** Under estimated normal clinical use conditions, the sensors are employed during **walking tests** conducted **five days per week for three years**, with **five sessions per day** and **60 test steps per session**, resulting in approximately **200,000 sensor cycles** over the duration of use.

Equipment

Sensor Array

The sensors used for this study were the HX210:11.31.M (size 9) insole sensors. The sensors have 11 columns and 31 rows, comprising an array of 235 individual sensing elements (sensels). The sensing elements depend on insole size; for a size 9, they are 8 mm squares. The sensors are integrated into an insole designed to be placed inside a shoe. X4 electronics energize two rows at a time, energizing half of the sensor at once. When completed, the next two rows are energized, and the process repeats until the entire sensor has been scanned. Each sensor is calibrated from 1–128 psi and can record up to 160 frames per second – 235 individual pressure values 160 times per second.

Two insole pairs were tested: S0188 and S0201.

Shoe Bending Machine

The shoe-bending machine consisted of a rigid steel frame supporting a motorized bending mechanism. The shoe was secured with adjustable clamps that accommodate all sizes. The bending actuator consisted of a servo motor connected to a pivoting arm that flexed the metatarsal region of a shoe. The bending angle was set to 70°, and the machine operated at 150 RPM, with the rotation controlled via a programmable controller to allow variable cycle counts. The insole sensor was placed inside the shoe with the clamps directly pressing on the heel and toe ends of the sensor. The electronics (sensor pack, SPK) and cord were zip-tied to the nearest stress point to relieve strain and prevent disconnections. All sessions were recorded using XSENSOR Lab (XLab) software at a sampling rate of 1 Hz.

Instron

The Instron® testing machine (Instron 8872 Servohydraulic Fatigue Testing System) was equipped with a heel indenter attachment to apply cyclical loading to insole sensors. The insole was secured down with tape to maintain consistent positioning and prevent lateral movement during testing. The heel indenter consisted of a cylindrical stainless-steel rod with a hemispherical plastic tip of 2.5 inches in diameter to mimic heel contact. The load was applied sinusoidally with a minimum force of 0.04 kN and an amplitude of 0.42482 kN at 1 Hz for a total of 200,000 cycles. A shoe insole was placed under the insole sensor to minimize friction, with a 1-inch-thick silicone block under the heel. The force and displacement data were recorded using the Instron WaveMatrix™ software at a sampling rate of 10 Hz. The setup enabled real-time monitoring of load and sensor response using XLab.

Air Chamber

The air chamber consisted of a single inflatable bladder positioned above a rigid plastic support plate to apply uniform pressure across the insole sensor. The insole was placed beneath the bladder to ensure consistent alignment. A National Instruments® Data Acquisition (NI® DAQ) control system regulated pressure between 1–128 psi, enabling precise, repeatable pressure application during each validation session. Real-time data was recorded in XLab. Sensors were re-validated before, during, and after both bending and loading tests to compare pressure responses.

Data Collection & Processing

Baseline measurements were collected during the certified calibration process (1–128 psi). An additional validation was performed immediately after calibration in the air chamber using XLab's built-in air script calibration protocol, which recorded both pressure images and raw values in real time. For each validation session, the calibration files were overlaid with the raw data to calculate measured pressures in psi.

The primary objectives of this validation study were to quantify:

- Accuracy, defined as the percent full-scale (%FS) error between applied and measured pressures.
- Repeatability, defined as the two-standard-deviation spread of repeated measurements, normalized to full scale.
- Durability, assessed by tracking changes in accuracy and repeatability across 200,000 loading or bending cycles.

Collection Protocol:

1. **Baseline Validation:** All sensors were calibrated (1–128 psi) and validated in the air chamber before mechanical testing.
2. **Bend Test:** Sensors subjected to 200,000 flex cycles inside the bending machine. Validations performed before and after testing.
3. **Cyclic Loading Test:** Sensors subjected to 200,000 heel-loading cycles using the Instron machine. Validations performed at varying cycle intervals.
4. **Data Logging:** At each validation interval, measured pressures and standard deviations were manually logged into Microsoft Excel for further analysis.

Analysis Methods

To evaluate performance, all validation data from overlapping cycle numbers across the four sensors were averaged together to create a single representative dataset. This combined dataset was then used for all subsequent calculations.

For each validation cycle, accuracy was calculated as the %FS error using the averaged measured pressures for that specific cycle:

$$\%\, FS\ Error = \frac{Measured\ Pressure - Applied\ Pressure}{Max\ Applied\ Pressure} \text{ x } 100\%$$

For the load test, the %FS error values were then averaged across all applied pressures to yield a single accuracy value for that validation cycle.

Repeatability was calculated across all validation cycles at each individual applied pressure interval. For each pressure, the standard deviation of the averaged measured pressures across all cycles was used to compute repeatability as:

$$Repeatability = \frac{2\sigma}{128} \text{ x } 100\%$$

where **σ** is the standard deviation of the averaged measured pressures across all four sensors. The factor of 2 corresponds to a 95% confidence level. This approach yields one repeatability value per applied pressure, reflecting the sensor’s consistency across the entire test duration.

Results

The measured pressures averaged across all four insole sensors were used to evaluate accuracy following 200,000 bending cycles.

The figure below presents the average %FS error across the applied pressure range of 1–128 psi.

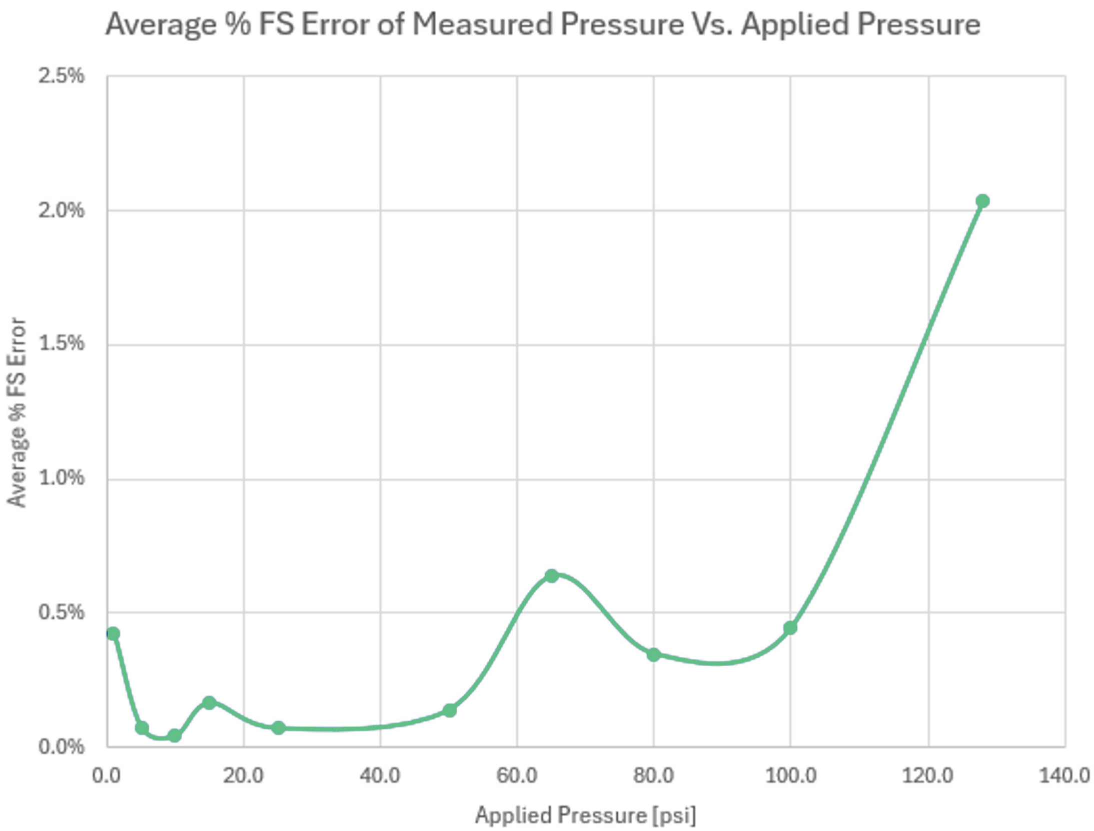

Figure Above: % Full-Scale Error vs. Applied Pressure, Averaged Across Four (4) Sensors

The results show that the average %FS error remained below ±5% across the entire pressure range, confirming that the insole sensors maintain accuracy within XSENSOR's stated specification even after extensive bending. This demonstrates strong mechanical resilience and minimal degradation in sensing performance after repeated flexing.

Load Test:

Accuracy

The figure below illustrates the average %FS error across all four sensors. Each data point represents the mean %FS error across all applied pressures at the corresponding cycle count.

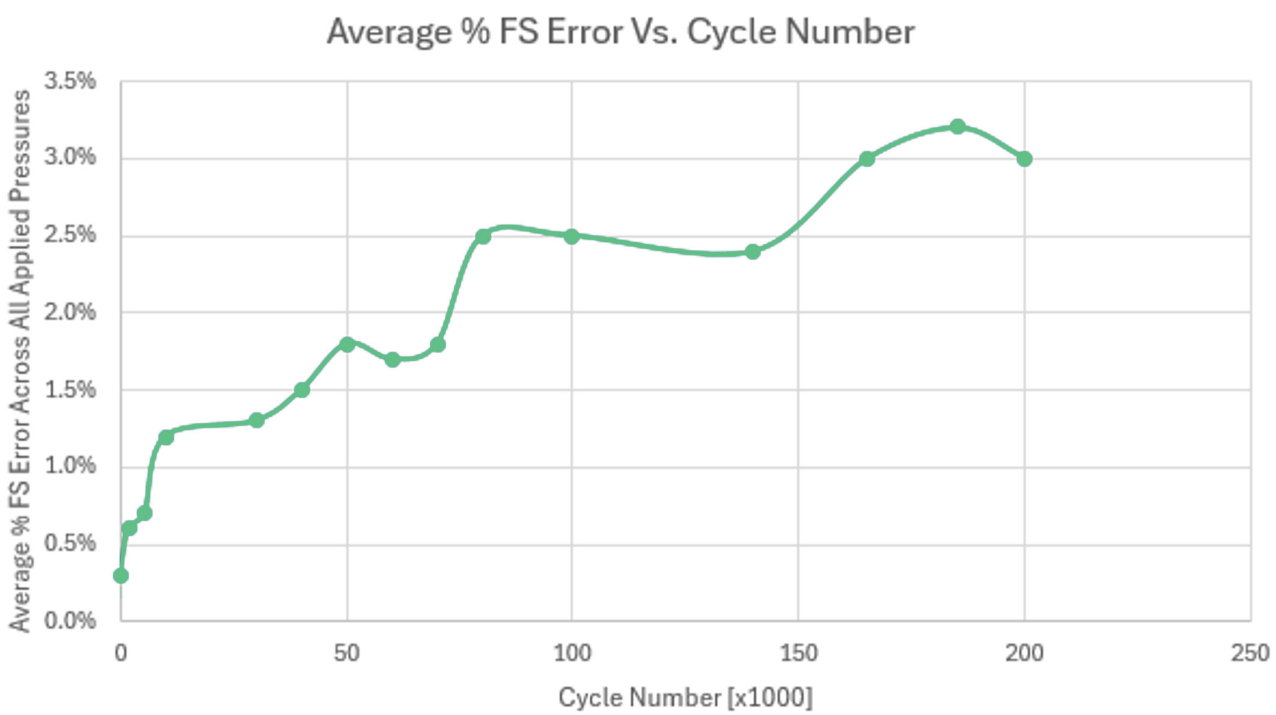

Figure Above: Cycle-by-Cycle Average % Full-Scale Error Across All Four (4) Sensors

Across the full test duration of 200,000 loading cycles, the mean accuracy remained consistently within ±5% full-scale, with a maximum average %FS error of 3.2%. This confirms that the sensors maintain stable performance and precise response characteristics even after prolonged cyclic loading.

RESULTS

The figure below shows the average repeatability error across all applied pressures after 200,000 loading cycles.

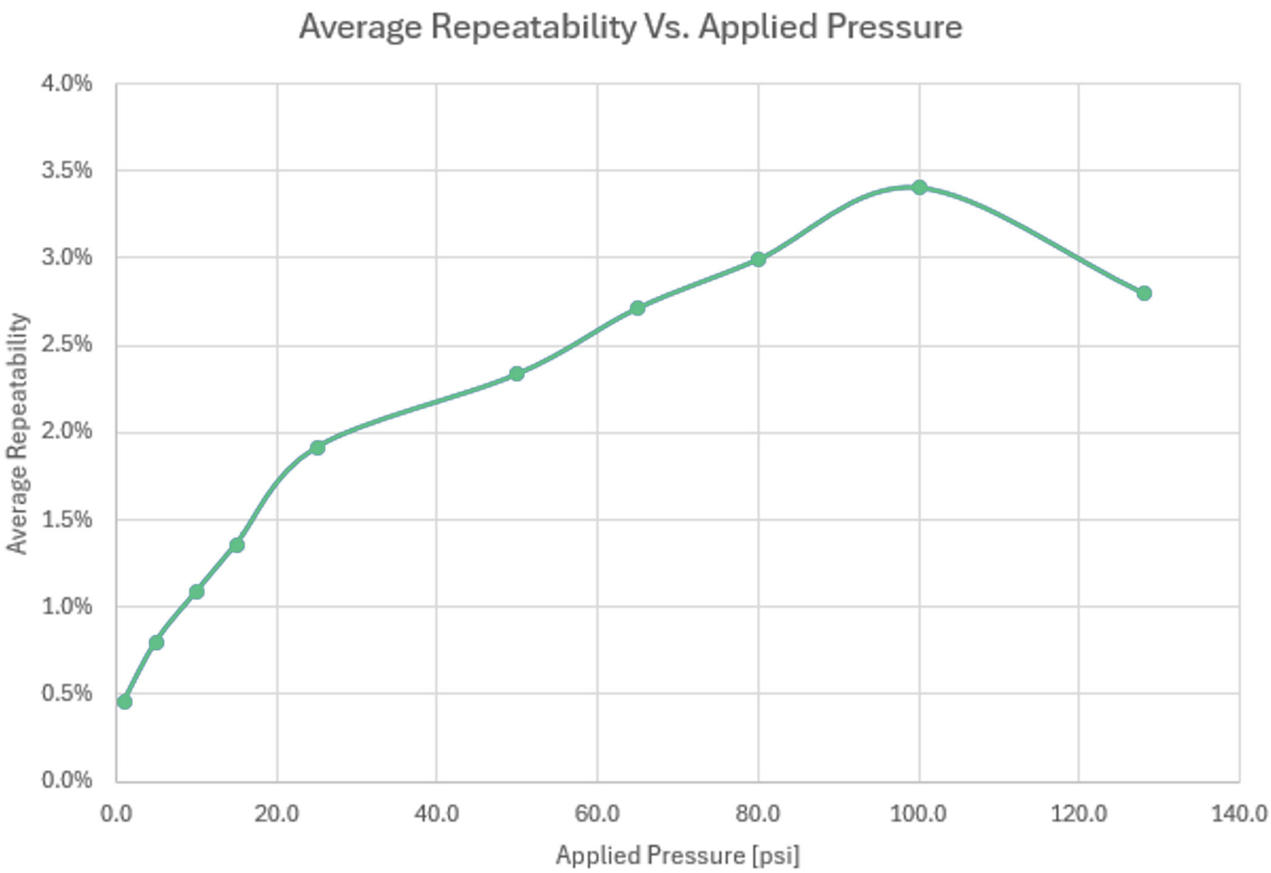

Figure Above: Average Repeatability Error for All Applied Pressures Across 200,000 Loading Cycles

The maximum average repeatability error, expressed as ±2σ/128 (k = 2, 95% confidence), was 3.4% at an applied pressure of 100 psi. Throughout testing, repeatability remained below ±5% full-scale, indicating stable and consistent measurements under repeated mechanical stress. These findings verify the long-term reliability of XSENSOR insole sensors for continuous loading applications.

Discussion

The results demonstrate that XSENSOR's Intelligent Insole sensors maintain consistent performance after extensive mechanical cycling. Both bending and loading tests confirmed that accuracy and repeatability remained within ±5% full-scale, indicating minimal drift and high measurement stability. These findings verify that the sensors can withstand long-term, clinical use with no significant performance degradation.

Implications

These results indicate that insole sensors provide reliable pressure measurements under repeated use. Accuracy is maintained across the tested conditions, supporting the use of these sensors in clinical, research, and footwear applications where precise data is critical. End-users can expect consistent performance under normal operating conditions.

Limitations

This study used a **small sample of four sensors,** and the mechanical bending protocol simulated conditions more aggressive than those in typical real-world use. Environmental factors such as exposure to significant shear loading, excessive dirt, moisture, or perspiration were not included in this evaluation and may influence long-term sensor performance under extended field conditions.

Conclusions

XSENSOR's Intelligent Insole sensors maintain specified accuracy and repeatability after prolonged cyclic loading, remaining within the stated ±5% full-scale specification. Accuracy remained under 3.2% full-scale and repeatability stayed below 3.4% full-scale across the full pressure range up to 128 psi over 200,000 cycles, confirming the sensors' calibration stability for clinical, research, and footwear performance testing applications. Based on these results, **routine recalibration is not required for 3 years of normal clinical use,** ensuring consistent and dependable data quality throughout the sensor's expected service life.

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