Experimentation Introducing Nextiles Force Plates, A Comparison Against Known Standards

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1 Introduction

For deployed infantry soldiers, the problem of having light sensors for critical diagnostic evaluation has a few solutions, but with the addition of this equipment, the existing sensors have to decrease in weight and setup time or it becomes unsustainable. For testing aspects of physical fitness either in field or at home, a force plate is a very useful tool that even high class athletes use to gauge metrics like jump height, balance, peak force output, fatigue, and more.

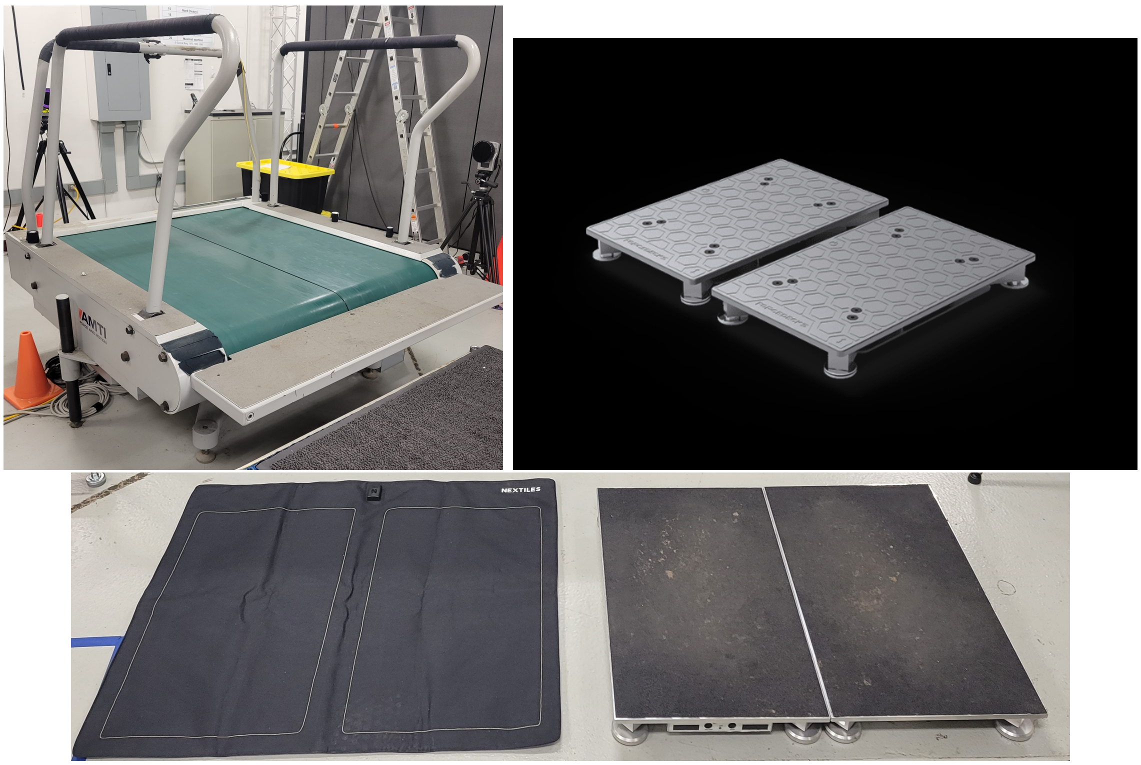

Figure 1: AMTI Golden Standard (top left), Vald Performance (top right) [3], Nextiles force sensor fabric (bottom left), and Hawkin Dynamics Force Plates (bottom right)

Common industry solutions include the AMTI force plate and mobile field versions like the Hawkin Dynamics Gen5 Wireless and Portable Force Plate, and the Vald Performance Force Decks. As seen in Figure 1, the AMTI sensor is a golden standard used for producing precision measurements in a lab environment, containing 3 axes force and moment measurements with optional peripherals like cameras to capture movement. It's a heavy plate sensor built into the floor at specific testing facilities. Each mobile option consist of two metal plates, one for each foot, and calculate a variety of metrics during different exercises. Currently these are known to produce useful results with enough precision and accuracy to be useful, while being light enough to pack in-field. However, since these are solid plates in multiple parts improvements to weight, flexibility, durability and setup time while maintaining data fidelity could available with newer products. The main purpose of this testing is to evaluate Nextiles sensors, using durable mats with sensors embedded into the fabric. If data fidelity, setup, and durability are comparable to the current standards, Nextiles may offer a lighter solution and be the next advancement in the technology to ease burden on deployed infantry soldiers.

Newer technology like what Nextiles offers is a solution to potentially complete the same job, outputting instantly generated analysis of a counter movement jump trial and other physiological tests, while being lighter, more durable, and much more easily stored. Instead of being two separate rigid sensors, like both the Vald Performance and the Hawkin Dynamics sensors are, Nextiles hardware comprise two strain-based force sensors sewn into durable fabric, making one piece that can roll up to store and will not damage with rough handling. To replace the existing older or heavier technology, there must be data that shows it can complete the same job and continue to provide the critical physiological metrics as the Hawkin Dynamics or other industry solutions. A comparison of the mentioned sensor's rated data output and physical footprint is shown in Table 1 below.

These sensors are used to replace multiple mechanical measurement devices, and as tested in this experimentation it is functioning as a vertical jump tester, the mechanical device shown in Figure 2. This is one function being replaced by electronic sensors, and is a common standard measurement that can yield many useful metrics. Many other exercises can be analyzed by Nextiles sensors, but because of its long standing usage this is a useful metric to compare between industry sensors. More sophisticated algorithms can produce measurements of the force distribution of the jump, jumping power, arresting force while landing, and strength increase over multiple sessions. If Nextiles sensors and algorithms can measure and calculate jump height results consistent within 1 or 0.5 inches of Hawkin Dynamics force plates, common resolutions of the mechanical vertical jump tester, or even if the measurements are internally consistent and follow similar trends to the Hawkin Dynamics Force Plate sensors, Nextiles will prove a valuable measurement tool for external mobile use.

Figure 2: This is a mechanical measurement device for the vertical jump height [5], one common device replaced by the force sensors in figure 1 and the metric examined in this experimentation.

Function	Gold Standard	Hawkin	Vald	Nextiles
volume ($cm\&m^3$)	$2m^3+$	72.4x61x7.6 .033564m^3	40x45x4.2 .007560m^3	.0011m^3
Weight	200kg +	19.5kg	10kg	1.08kg
Resolution/Precision	*0.7N	0.25N	0.15N	*0.2N
Measurement Error($\pm$ N)	*0.20N	0.1N	(?)	*8.06N
Force Plate Sections	1 Large	2	2	1
Maximum Load	?	$14kN$	19.5kN	3
Sample Rate (Hz)	2000	1000	1000	100
Measurement Axes	3 (6 deg of Freedom)	1	1	1
Statistic Calculation	×	✓	✓	✓
Local Saving/Operation	✓	✓	✓	×
Removable/Portable	×	✓	✓	✓

Table 1: Force Plate Feature and Hardware Comparison. The values for error and precision (marked by *) indicate these are calculated based on raw data, an explanation shown in section 3.1. [1] [2] [3] [4]

2 Materials and Methods

Between the tested sensors, the AMTI Golden Standard, Hawkin Dynamics force plates, and Nextiles force sensors, a control test is needed to measure several base readings. Control testing includes dropping known masses at a known height on the sensors to capture sample rate, noise, measurement error, and calculating the drop height, testing against a known response. The impulse response of a dropped mass is well documented, and while measuring humans there will be error created in weight shifting and movement, so a know response is a needed baseline. This will be on the ideal surface at no angle to ensure as much as possible measuring purely the sensor's response to the mass.

After the control test, the main human movement tested is the counter-movement jump. This is a jump starting and ending on the sensor, straight up in the air while maintaining hands on hips 3. Some sensors can determine jump heights from the force a subject's feet pushed off the ground with as well as other metrics that can be compared, while some like the Golden Standard just output the raw force vs. time data of each session. These can be compared visually with the known response a counter-movement jump produces, and after trials both the force-time plots and the output jump height values calculated by each sensor are compared.

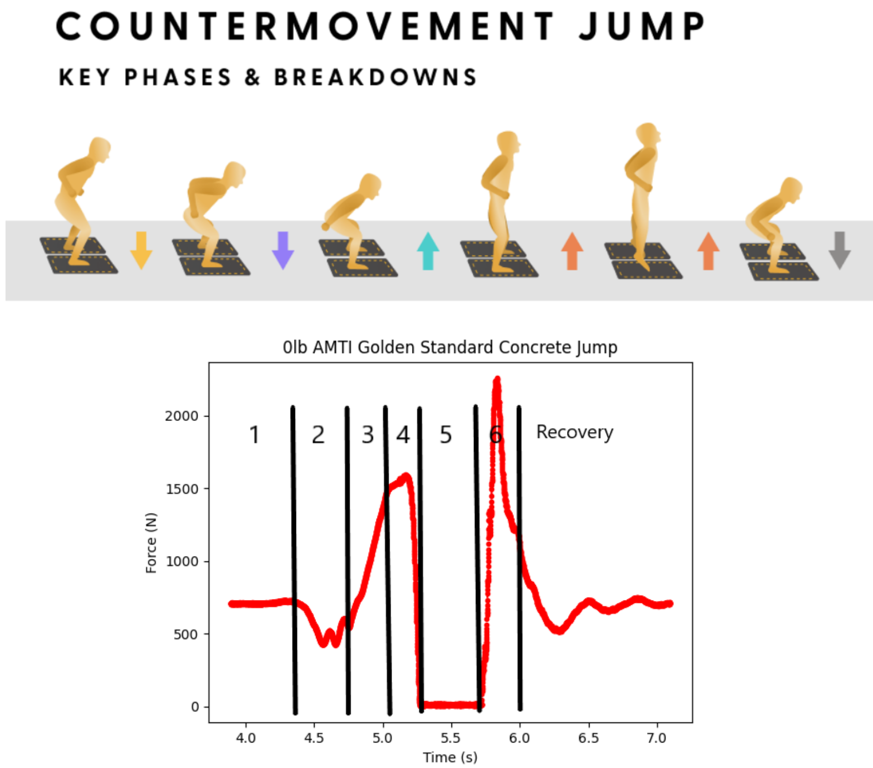

Figure 3: The Counter-Movement Jump consists of a stable jump starting with hands on the hips, and jumping with both feet leaving the ground and touching down at the same time. The plot above compares a sample jump on the AMTI force plate with this diagram, the stages being standing, wind-up, push-off, liftoff, airtime, landing, and recovery. More data can be taken from some stages, for example the push-off phase slope can show jumping power and response, landing and recovery can show the subject's balance and ability to regain equilibrium, etc.

Variations of this movement are conducted for each sensor first with different on-human masses, emulating a deployed solder carrying gear. The carried loads tested are 0lbs corresponding to no gear, 35lbs corresponding to an active fighting load, and 85lbs corresponding to a packed carry load. Vests are loaded with masses, as seen in figure 4, one with 35lbs and a second vest to wear on top, containing the 50lb difference.

Figure 4: Carried Load consisted of bars of lead strapped in V-max weight vests. Pictured: 85lbs carried load, bottom vest carrying 50lbs and top vest carrying 35lbs.

The surface on which the sensors are placed during the trials is also a variable. After all sensors are tested with all variations of carried load, the next surface have the same tests run on each of them, using the same masses and same sensors. Each test uses the same test subject. The tested surfaces will include flat concrete as the ideal scenario, rubber on an athletic track or covering a gym floor acting as an elastic surface, grass on a field to act as a comparison of in-field testing environments, gravel as a possible worst case shifting surface, and an angled or uneven surface. Each surface relates to both a possible environment for future use and testing believable failure modes. The AMTI Golden Standard can not be moved but can be electronically tilted, so will only be able to test flat and angled surfaces while the Nextiles and the Hawkin sensors test one Elastic, Grass and Gravel.

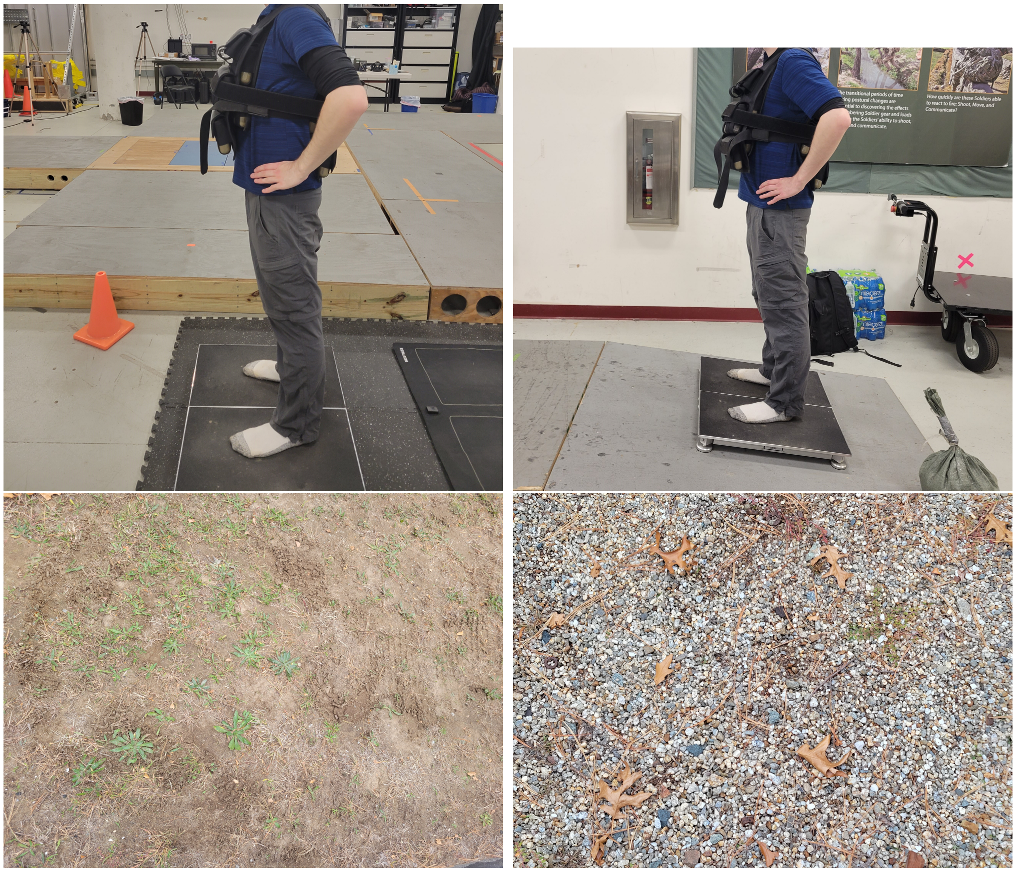

Figure 5: Each surface testes, with Figure 1 showing concrete, and the elastic, angled, grassy and gravel surfaces used for testing displayed here. The AMTI Golden Standard could not be tested on elestia, grass or gravel surfaces.

To reduce the chances of data outliers or strange results, 3 tests of each trial are conducted. In summary, the total tests will include 3 control tests for 4 sensor types, then 3 tests of counter-movement jump on each of 4 sensors on each of 5 surfaces. In total, this testing regiment will comprise 72 test trials each of 3 jumps.

Additionally, to directly compare data as closely as possible and since the Nextiles sensor is low profile fabric, several jump trials of 0lb, 35lb, and 85lb carry weight can be directly compared by stacking the Nextiles Mat on top of the Hawkin dynamics sensor and on the AMTI Golden Standard. This data should not be analyzed with the rest, as stacking sensors adds variables that would have to be tested and correlated, but looking at what data is read by the sensors and what results they produce is the most direct comparison of a single jump possible. Because one sensor then has an underlying surface being another sensor, adding a new variable, the different algorithms in use between Hawkin and Nextiles sensors may calculate different values. In the stacked testing a similar force-time curve was be output by each sensor.

2.1 Control Testing

Control tests for each testing platform consist of dropping a known mass from a known height. A sand bag weighting 15.7kg is dropped from 12 ± 0.5in (4.2%). The error in the drop height accounts for the lack of a precise test stand. The dropping height is measured with a ruler, one person holding the sand bag, and the other indicating raising or lowering of the bag to be within an acceptable range. Dropping masses give samples of sensor noise before and after the drops without the variability of a human standing on the sensor, and so it can calibrate or confirm calibration of each sensor. The impulse curve and physical relationships are well known for this measurement, and can be confirmed with these known forces to show baseline error incorporating sensor noise and time steps. Based on how accurate the control test calculations are for each sensor, the method of which the force sensors calculate jump height can be determined. If accurate, a similar impulse calculation can be used later on to calculate counter-movement jump height.

2.2 Comparative Tests and Variable Definition

Although many tests and metrics can be measured and contrasted with these sensors, the counter movement jump is very commonly used and jump height is one of the metrics these sensors were designed to produce, replacing larger mechanical devices and in-field. The main dependant variable will be jump height during the counter-movement jump, and testing variables include carry weight, the surface that the sensors are placed on, and the different force sensing platforms jumped on.

3 Results

3.1 Control Testing: Dropping Known Mass

This testing was also carried out in 3 trials per sensor, and allowed a comparison of initial setup and use of each sensor. It also confirmed that Nextiles force sensors have to have an internet connection to log any data, while Hawkin Dynamics force plates can store data to the app, provide some feedback instantly, and process it later. The AMTI Golden standard force plate is all operated and stored locally without cloud servers for processing, though is much more expert-oriented being lab based equipment. An in-depth breakdown of setup processes and differences is expounded on in section 4.5.

Using kinematic equations and the impulse-velocity relationship come together as seen in equation 2 (Appendix A) to give an estimation of the drop height. Because drop height is a controlled parameter but the impulse occurs within a very short time span, the calculation shows error caused primarily by sample rate and to a lesser extent sensor accuracy. After the impulse, the force sensor should read the normal force of the dropped mass, providing a reading of noise in the resulting values.

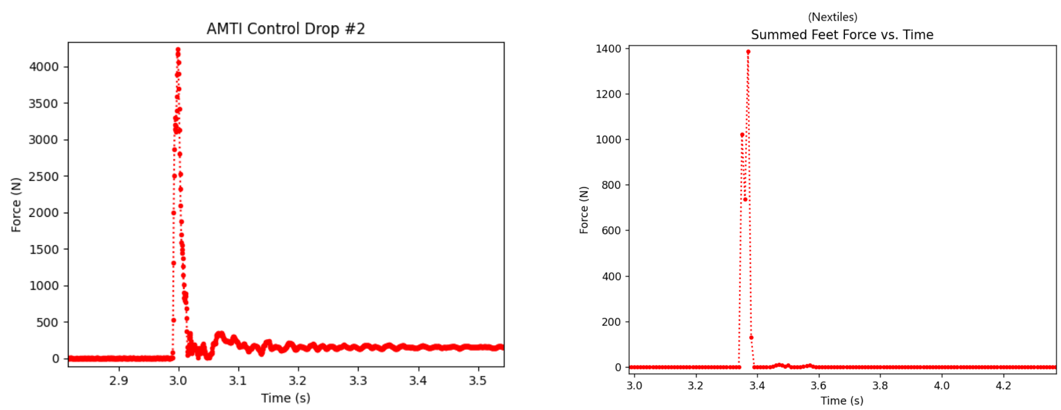

Figure 6: An example of the the expected data produced by the Golden Standard's dropped mass tests (left) compared to a Nextiles dropped mass test (right). The disparity in sampling rate is very evident here.

The AMTI Golden Standard produced relatively accurate results as seen below in Table 2, but using the same equations and attempting with many different data sample ranges, the Nextiles data could not output consistently accurate results. Out of 5 tests of dropping a mass on the Nextiles mats, only 2 tests output data usable for calculations, and the closest calculation was 22% below the known value. All of the AMTI Golden Standard control tests calculated fairly accurate results. This also reveals the method Nextiles must use to calculate counter-movement jump height, since this calculation does not have the accuracy needed at low time intervals. The three easiest ways to calculate jump height are using the impulse of the test subject pushing off the ground, the impulse of the test subject landing, and the time in air. The calculation for the time in air uses only kinematic equations. A counter-movement jump (assuming no air resistance) is symmetric in air with a point of zero velocity and the maximum height halfway through the air time. Equation 1 (Appendix A) shows the calculation, finding the falling distance in half the time the test subject spends in-air during the jump. Calculation B.1 in Appendix B shows an example calculation based on a counter-movement jump.

The average noise values of each sensor accounts for some error in measurements but does not include the variability of a human standing on a sensor. The AMTI maximum noise was on average less than $4N$ before being zeroed, and $0.20N$ afterwards. Nextiles was higher and doesn't have a way to zero, the average being about $6N$. The maximum noise values within those ranges was larger for the Nextiles mats, $20N$ vs $13N$ for Nextiles and the Golden Standard, respectively. Since this is orders of magnitude less than average standing and jumping forces, it is fairly negligible. It does give a comparison of base sensor error, and shows the main testing jump height error will be almost entirely human or post-processing based.

Function	Gold Standard	Nextiles
Control Tests Trials	3	5
Tests with Usable Data	3	2
Average Sensor Noise	0.20 N	6.2 N
Maximum Sensor Noise	13.25 N	20.0 N
Avg. Calculated Drop Height	12.85 in	21.09 in
Difference from Actual Value	6.9 %	75.8 %

Table 2: Control Test Outcome Overview, with the average drop height being 12 ± 0.5in.

From these tests, there are many ways to calculate error. The 'greatest possible' error method is half the minimum reading interval, but is less useful for sensors like Nextiles since measurements of strain are calculated and scaled for conversion to newtons. A more useful method would be the 'Absolute Error' method, deviation of the readings from the actual value. Nextiles engineers [6] have confirmed there is a drop off in accuracy at low and high weight values due to the nature of strain measurements. Taking a value of error at a low mass reading like the dropped mass will then produce a high value relative to the optimal range, which would be useful to compare against because it does not characterize only the most accurate range. Ideally, with much more data an error equation or table could be calculated based on applied mass, though Nextile's main use case would not require such metrics.

To calculate these values for the Golden Standard first, the absolute zero error would be the average difference from zero at no loading. After zeroing the scale, the average was +0.20N. The ansolute error after loading with 15.7kg (153.97N) during the dropped mass tests is calculated by subtracting the known actual value from the reading average. Over 12,000 data points the absolute error between the 3 dropped tests is 0.18N, even including the run with a larger noise reading before zeroing the scale. For Nextiles, the absolute zero error was 6.2N, and that increased with the addition of the mass to produce an absolute error of (+)8.07N. This value is an order of magnitude, almost two, above the error of the Golden standard.

Table 1 shows values comparing error and accuracy of the force sensors, with asterisks indicating calculated results. The control data was used to calculate these, error being the absolute error at low load, and the precision being based off the minimum difference of values seen in raw data. The AMTI Golden standard output values that were integer multiples of 0.69754N specifically, and using the Nextiles-supplied transformation function, the minimum difference being one strain-voltage unit at low load, created a 0.2N N difference after scaling.

3.2 Hawkin vs Nextiles Internally-Processed Data From Jump Trials

3.2.1 Platform and Carry Weight Tests

The data set averages were calculated several ways to eliminate other variables interfering with a measurement. Table 3 shows averaged jump heights corresponding to carry weights and to force plate type combining data from all surfaces. The next table, Table 4, compares more individually the effect of the sensor (Nextiles/Hawkins) and of the surface over all carried weight values.

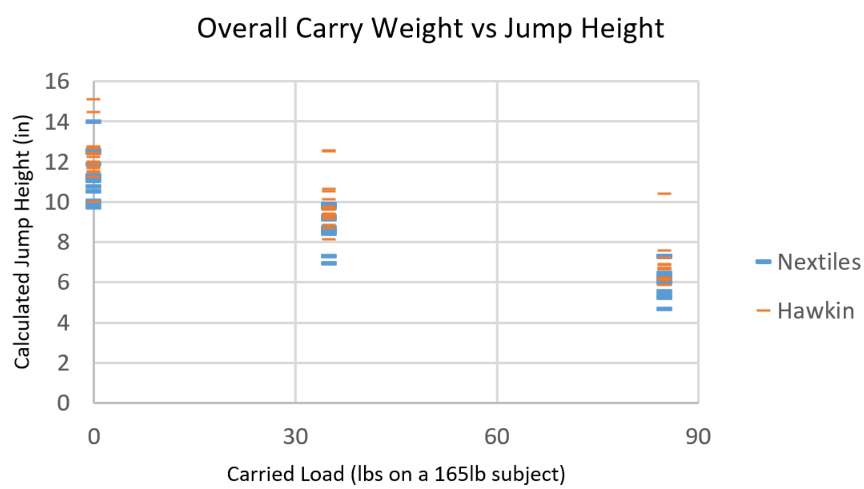

Figure 7: A visual of the sensor-calculated jump height information shown in Table 3, the top outliers being values from Hawkin Gravel tests.

Metric	Hawkin Avg	Nextiles Avg	% Difference	Inch Diff.
Test Variance	13.6%	9.6%	-	-
0lb Jump Height	12.26 (11.87)	11.32 (11.33)	-7.6% (-4.6)%	0.94(0.54)in
35lb Jump Height	9.87 (9.40)	8.86 (8.74)	-10.16% (-7.0)%	1.01(0.66)in
85lb Jump Height	6.81 (6.42)	6.13 (6.18)	-10.0% (-3.65)%	0.68(0.24)in

Table 3: Average Jump Heights and Test Variance (Parentheses contain overall values discluding the tests on Gravel to show the extent it skewed the data, see Surface Tests section)

Over 125 data points, the tests between the Nextiles produced results 9.3% lower than Hawkins in terms of jump height, this difference being slightly less (7.6%) at zero carried weight. The values in parenthesis in Table 3 indicate removal of gravel as a surface test in the average, since results were significantly different only for Hawkin sensors indicating a strong interaction for just that sensor. Without the gravel test, overall the weighted average difference is 5.2%, very similar to previous experimentation comparing Nextiles to Vald Performance force plates. Even with the gravel tests included this shows Nextiles is on average 0.88in lower than Hawkins values. On commonly used surfaces not including the gravel tests, this is even closer, only 0.48in lower. Use of an unpaired 2-sample t test shows the offset is not only evident in the averages or because of outliers, but with 98.25% confidence this offset is statistically significant. This does indicate that results are consistently offset between sensors, and that Nextiles is repeatably within the 0.5in - 1in guideline set early, based off common increments of a mechanical vertical high tester.

Additionally, the average percent variance of all Nextiles tests is 9.6% (that is, on average, tests were within 9.6% of the average). For Hawkin force plate tests, the average percent variance was higher, at 13.6%. This shows Nextiles as on average producing lower results, but being slightly more consistent. The average difference makes sense as a metric, but the jump height variance is included to show the consistency of jumping conditions, or how easy it is for the test subject to jump consistently. The jump height variance does not provide information on the sensors because human consistency is the largest source of error here. The variance is then useful to see how easily a surface or platform makes for a repeatable jump. Lower variance for Nextiles fabric force sensor could indicate that having a more comfortable surface directly on the ground gives more repeatable results, as opposed to a hard surface raised several inches from the ground on a myriad of surfaces.

3.2.2 Sensor Placement Surface Tests

Since the only trials on an ideal surface were the Concrete tests, it is important to compare values between surfaces to find these interactions previously untested by Nextiles engineers. Below, Table 4 shows the average jump heights and percent difference from these known good tests on a hard flat surface, as well as the variance of the tests to indicate how consistent the test subject could jump on the terrain and sensor combination.

	Hawkin		Nextiles		
Surface	Variance(%)	Concrete % Diff	Variance (%)	Concrete % Diff	% Diff N vs H
Concrete	2.37%	0	3.81%	0	-5.52%
12% Grade	1.07%	2.07%	1.57%	-9.29%	-11.34%
Elastic	1.64%	9.39%	6,99%	6.80%	-2.01%
Grass	3.24%	6.51%	2.56%	7.37%	-0.76%
Gravel	12.68%	32.26%	1.44%	1.57%	-23.18%

Table 4: Average Jump Heights (inches) on All Surfaces compared to Concrete (positive values indicate above the compared metric)

The surface tested with the highest percent difference between sensors was Gravel, with a sample size of 18 tests. Nextiles on average yielded jump heights 23.2% lower than Hawkins during the gravel tests, but Nextiles results both had a lower variance and a lower difference than tests on Concrete, whereas Hawkins had a variance of 12.6% and a significant difference from Concrete scores. There are a couple possible causes to this, either the surface altered the platform results differently depending on sensor, or the because of the subject being tested, the Hawkin force plates yielded slightly different values. It is to note that the test subject was fresh the second morning of testing using the Hawkins sensor on the Gravel due to the battery draining, while the others trials were over the course of one testing period. This gives credence to withholding gravel jump tests from bulk analysis (like the parenthetical values in Table 3), Hawkin force plates producing uniquely high variance paired with the highest jump height difference from the concrete tests.

The surface with the most agreement was interestingly the grass. The platforms differed by 0.76% this time, Nextiles and Hawkin sensors having an average percent variance of 2.5% and 3.2% respectively, also with a sample size of 18. This means the tests have high agreement within their platform and high agreement with each other. However, there could be some interference from the surface, since this differs from both the sensors' average difference and variance values and from concrete test results.

The calculated correlation coefficient for surface vs. jump height shows the strength of the relationship. A calculated 'r' value close to ±1.0 is a very strong correlation, usually associated with a linear or very low order polynomial relationship, and plotting the variables can often show if a curvilinear relationship exists and isn't detected by the correlation coefficient. A correlation could be detected by chance in a random sample, however based on the sample size we can calculate confidence levels of r; that is to say, in this sample size of 93 (not including laying the sensors on each other, as that may incorporate another variable), there's a 5% chance in a random sample the correlation coefficient would happen to be a maximum of ±0.205, indicating a 95% confidence. Therefore it is statistically significant if in this sample, an 'r' value larger than that is found. The r value would have to be even higher for a higher confidence, greater than ±0.267 for 1% at 93 tests (meaning 99% confidence), and even higher for lower sample sizes, etc.

Using the assigned values did produce a correlation coefficient of 0.210, having 95% confidence of a correlation between surface and output value. Removing carry weight as a variable yields r values showing more consistently significant correlations, meaning the relationship gains visible strength as the variables of interest are isolated.

Concrete Compared To:	12% Grade	Elastic	Grass	Gravel
Hawkin Confidence Interval:	<30%	95.13%	80%	99.6%
Nextiles Confidence Interval:	<30%	99.01%	98.5%	96.6%

Table 5: Paired t-tests showing confidence of a statistically significant difference in jump heights comparing Concrete to jump tests on another surface. Paired testing calculations are used because the carry weight is varying between tests but can be paired with similar weights on another surface, meaning the sample data is related by a common variable.

A t-test is another metric to compare two samples to determine if there is a statistically significant difference, though usually compares between two sample datasets and can't evaluate each different surface at once. For examples shown in in Table 5, using a paired t-test with 18 data points and a calculated t-stat of 1.76, this concurs with 95% confidence of a statistically significant difference between jumps on concrete and elastic surfaces. Between surfaces like grass vs concrete, the relationship is not as defined, being about 80% confident of a statistically significant difference. While a relationship has been confirmed showing differences in calculated results based on some jumping surfaces, characterizing the surface properties and how a difference is caused would need much more testing.

3.2.3 Stacked Sensor Testsing

Figure 8: An example of the Nextiles sensor stacked on top of the Hawkin Dynamics force plate for testing.

These stacked tests are the most direct jump tests possible, since the physical jumps are the same between sensors, the only difference being the hardware and software capturing and processing the data. Ideally, the results compared here should be a close as possible, but was limited to these testing trials because laying one sensor on another is adding an additional variable to the tests.

Carried Load	Hawkins	Nextiles	Difference
0 *lb*	10.76	9.74	1.02
0 *lb*	10.52	9,82	0.70
0 *lb*	10.93	9.87	1.06
0 *lb*	11.72	11.04	0.68
0 *lb*	11.99	9.91	2.07
0 *lb*	12.03	9.87	2.16
35 *lb*	9.24	8.97	0.26
35 *lb*	8.97	8.97	0
35 *lb*	9.98	8.08	1.90

Table 6: Stacked Sensor Test Jump Heights (inches) and their Differences. Average difference is 1.1in (9.87%)

Shown in Table 6, the tests with the Nextiles mat on top of the Hawkin plates produced an average percent difference showing Nextiles 9.8% lower, very close to the overall average difference. They were very consistent within each platform's dataset, less than 0.4% variance, and the differences themselves varied by 4.3%, with a dataset of 9 tests, 18 data points.

However, as noted earlier, they also differ from the average values of jump height on concrete even though they were ultimately on concrete. That is why the main testing did not include more stacked sensor arrays, as these should be considered separate since the sensors themselves would confound the other variables that the tests measure the relationship of. The side-by-side tests at 85lbs carried weight had time stamps that were very different, several minutes, whereas most of the other tests in this set had Nextiles and Hawkin time stamps at 7 seconds difference.The 85lb stacked tests are not included because of this. All this is too many words to say the stacked tests were very consistent, and so was their reading difference, bolstering the claim indicated by the overall platform jump height difference.

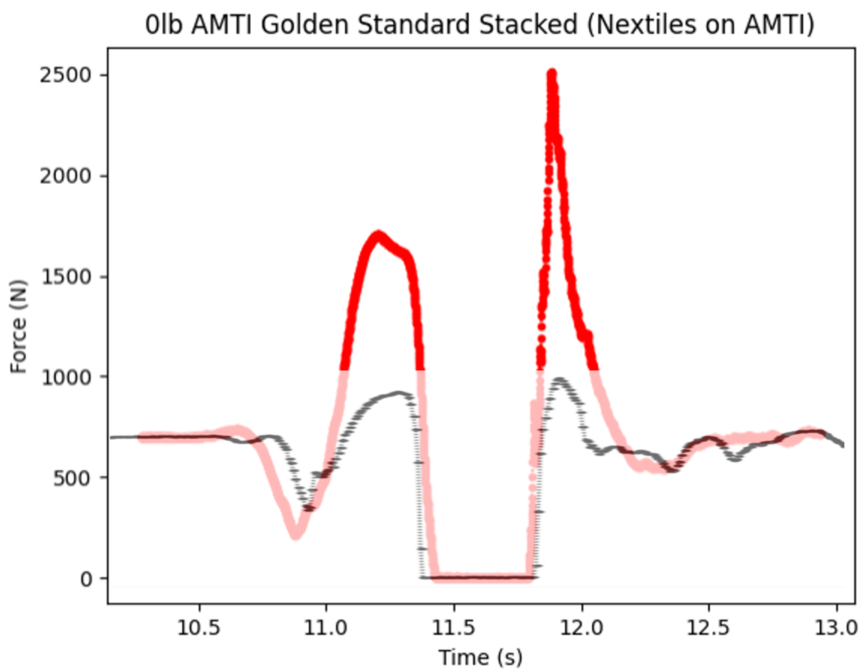

Figure 9: Overlay of Nextiles on Golden Sensor stacked tests with 0lb carried load, Nextiles (black) showing very similar characteristics, but with raw data scaling issues.

As seen in Figure 9, although force scaling was a pervasive issue with Nextiles Data, overlaying with similar time and force axis increments shows very similar shaping of the force-time readings. If there were more time, a better scaling function could be made to output force directly from Nextiles input, but for this experimentation it isn't critical, since it's mainly a comparison of calculated metric accuracy and general use.

3.3 Raw Data Captured

Reviewing the raw data output is useful both to see trends in the data captured and to compare availability and logistics of acquiring the data. For the AMTI Golden Standard, raw data is generated in separate files for each foot, and is output in newtons without having to scale. Hawkin also downloads force, but only for one jump at a time, though it does output newtons of each foot in the same file, making easier to use. Nextiles does not allow raw data download, but with help from Nextiles engineers and data scientists [6] raw data was procured for each test session as well as a scaling function that converts the output strain-voltage units into newtons.

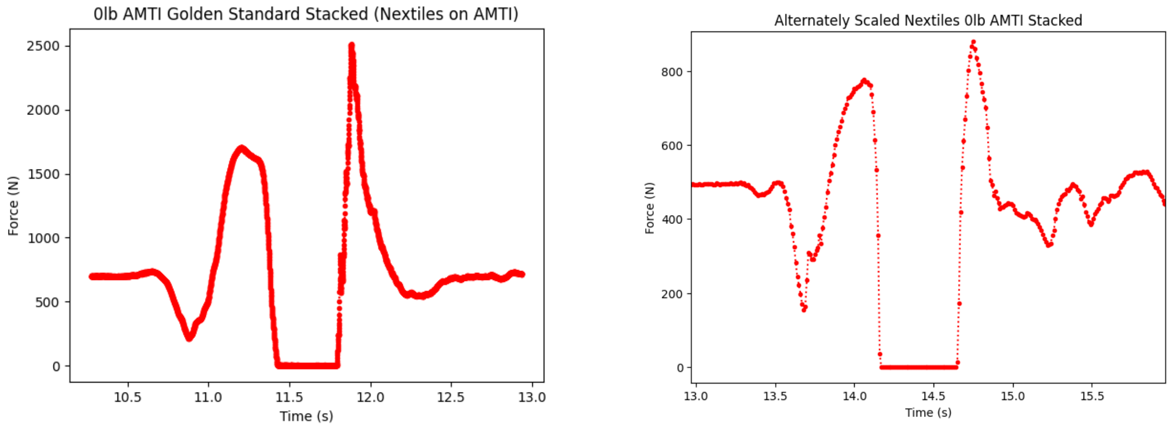

Figure 10: An example of Force/Time plots of 0lb Nextiles and Golden Standard tests. Originally, Nextiles provided a scaling function for the strain-voltage sensor readings. After testing this function, it was found to output three times the force values found by taking the average of the front tail of data and comparing it to the known standing normal force. This produced a self-found scaling factor around 0.1554. This is a constant instead of a function, so magnitudes of the impulses will be less accurate, but it seems more accurate than the scaling function provided.

Raw data provided from the force sensors was originally going to be used to create self-made algorithms to test height calculation based on time in air and off jump impulses and compare algorithms used between sensors, but Nextiles force scaling and Golden Standard force timing offsets between feet caused issue with using the impulse algorithms. The in-air jump height algorithm produced values found in Table 7 below, but due to complications in force scaling and last minute issues, consistent values for calculating jump height based on takeoff impulse and landing impulse were not able to be calculated.

Platform	0lb self	0lb Platform	35lb Self	35lb Platform
Nextiles	11.13in	11.33in	8.40in	8.74in
Hawkin	11.19in	11.32in	8.27in	9.40in
AMTI (GS)	11.11in	-	8.14in	-

Table 7: Calculated with the same basic self-made algorithm using a jump's air time to calculate Jump Height compared to the average platform-specific algorithm calculated values. All these are Concrete tests.

As load increased, it was expected that the impulse time increases, more force being exerted on the sensors over a larger time, and less air time and jump height resulting. The two plots in Figure 11 show that the maximum impulse magnitude does not increase considerably while the test subject is carrying an additional half their weight, but the impulse time span of takeoff and landing do proportionally. This biologically makes sense, as the body distributes more force over a longer time as evenly as possible instead of risking damage.

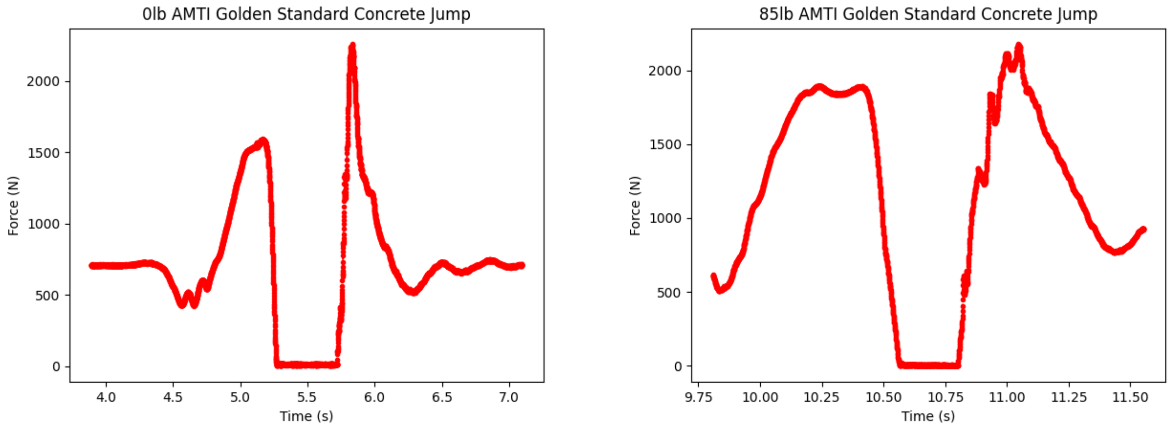

Figure 11: A visual examination of the affect on raw data characteristics of carrying more load during a counter movement jump.

Additionally, below is a comparison of Nextiles data on different surfaces, to visually contrast force output.

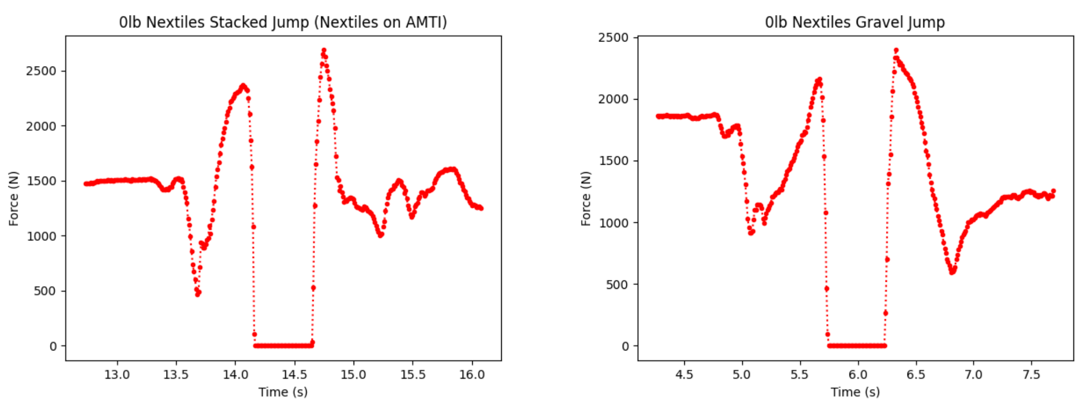

Figure 12: A visual examination of the affect on raw data characteristics of using alternate surfaces during a counter movement jump. Because this is scaled with Nextiles provided function, the force units show oddly varying standing load values, but the shapes are similar enough the be hard to tell apart. Hawkin did have one of the gravel tests show negative force, probably as the gravel shifted upon landing, though that raw data was only plotted within the Hawkin Application.

4 Discussion and Conclusions

4.1 Control Testing and Error Analysis

The control tests indicated a base level of noise within readings and the fidelity of data each sensor displayed. The AMTI Golden Standard held up very well, known relationships producing accurate results based off the force-time data output in only the Z axis to mimic the other sensors. This was expected to be accurate since it is a precise measurement device used for labs with a very high sample rate. Unfortunately Hawkin control raw data was not readily accessibly, but the comparison between Nextiles and the Golden Standard contrasts the data nicely.

Nextiles produced readings that have considerably more error than the Golden Standard, though the dropped mass measured is significantly below the force range the sensor is tuned for. Since human load is two orders of magnitude larger than Nextiles error, and the impulse readings 3 orders of magnitude greater than the error, this is still a relatively insignificant value. More error will be added by human force variation by standing still, let alone jumping multiple times. In summary, Nextile's error may be significantly higher than the Golden Standard, but is sufficiently insignificant for the required testing. The AMTI Golden Standard's level of accuracy is not needed for these measurements, and would be over-designed for in-field usage.

The sample rate of the Nextiles sensor is lower and noise is noticeably higher, and using the known relationships it was difficult to get an accurate calculation based off the impulse for control drop heights. This seems to indicate the main jump height calculation is done with the time in air, and this has been confirmed with the data scientists that developed the Nextiles technology [6]. While the data fidelity of the Nextiles sensor is lower than the Golden Standard as expected, the plots still show the common trends associated with a dropped mass. This indicates at low masses that the force readings should not be relied upon completely, though the jump tests prove how accurate it is with larger masses. This sensor uses strain gauges to produce sensor readings and then converts those readings into force measurements with a self-designed calibration curve, and according to the data scientists at Nextiles there is a high and low threshold where accuracy declines. This should be acknowledged while in use.

The decision to use the time in air for jump calculation was beneficial for Nextiles, since this is a very accurate calculation without needing higher data fidelity like the Hawkin or Golden Standard sensors. Calculating jump height via takeoff and landing impulse does allow for more statistics to be calculated, like readings for power and balance and relative leg strength, etc., but many of these statistics will not be used in field. Hawkin Dynamics generated over 60 statistics per jump, but more than often only jump height, symmetry and a couple others are used, in line with the data Nextiles generates.

4.2 Experimental Error Sources

It is important to recognize experimental bias and error though experimentation. A larger number of trials would have increased certainty on results, though time constraints did not allow this. Additionally, the test participant does not jump on sensors like these regularly for common training or exercise, potentially producing effects unseen in those regularly utilizing similar sensors. This could also mean later in the day, after much practice, the test subject was getting better at jumping to produce more consistent results, though that could have been mitigated by fatigue. Testing on Gravel with the Hawkin sensor without completing the Nextiles sensor at the same time also could have introduced error, as these were meant to be comparative but the Hawkin tests were done after resting and recovering. Additionally, a test stand for the control dropped mass testing would have reduced error and make the controls more consistent.

4.3 Platform-Calculated Metrics Analysis

This analysis is primarily based off of comparing outputs from the platform-specific-algorithms for jump height in inches, since this is the data that would be used in practice. The Golden standard did not produce jump height estimations, but raw data was collected and run through a separate in-air jump height analysis algorithm produced for this experimentation, shown in Table 7. Each sensor analyze their own raw data output and provided as many metrics as possible, and since these are the values easily and quickly available for use in the field, it is important that these agree. According to Nextiles, there has been previous testing showing about a 5% deviation in values Nextiles and Vald Performance force plates, but never before have variable carry weight and variable surfaces been tested. The main analysis is comparing average values of Nextiles generated and Hawking Dynamics generated jump height, sample data set variances, and determining if there is significant correlation between jumping surface and jump height values or variances. The platform-specific-algorithm calculated data for jump height can be seen at length in Appendix C.

4.3.1 Analyzing Platform and Carry Weight Effects

Although Nextiles does take in data of the participant's unloaded carry weight, even while carrying extra load the accuracy does not decrease. This is possibly because of their calculation method, using the in-air time to calculate the jump height. This is valuable information, since one account can be used by multiple people to get just those jump height values while retaining accuracy and reducing setup. However, viewing larger trends over time is only accurate if one participant were to use their account, and if their carried weight were constant over their tests to produce data that overall remains consistent.

Comparing between Hawkin and Nextile sensors, the average difference (not including the gravel trials) is within 5.1% (or 0.6in). This is close to one measurement increment for most mechanical vertical height testers, often 0.5in or 1in, and this offset is consistent. Assuming Hawkin jump heights are accurate, this means that Nextiles measurements can be consistently compared with the mechanical device and with the Hawkin sensors with the knowledge of this offset. Previous tests with Nextiles and Vald force plates yielded similar results, Nextiles producing results about 5% lower, supporting this fairly consistent relationship.

Even comparing the jump height data produced by a third-party algorithm designed for this experimentation, the raw data produced values of jump heights differing between platforms within 0.1in (Table 7). This demonstrates that each sensor is capable of producing the required statistics and does produce results that can be compared with an offset, with variation in analysis algorithms that produces this offset.

4.3.2 Analyzing Surface Effects

This experimentation is the first testing of Nextiles equipment with both multiple carried loads and multiple surfaces. Seeing a consistent and logical relationship of increased carry causing deceasing jump height is the expected result, but the effect of multiple surfaces of varying stability and properties is difficult to quantify and analyze. Over the five surfaces observed in this experimentation, concrete, an angled surface, an elastic surface, a grassy surface, and a shifting surface, multiple effects were observed in both calculated jump heights using the platform-specific algorithms and in the force responses produced by the counter movement jump trials. The surface used as an ideal surface was concrete, being hard and flat, stable, and close to what the sensors were presumably tested upon. This was compared to each other surface trial, and each surface trial used to show the differences and similarities between Hawkin and Nextile jump height values, showing similar variations in almost all surface trials.

The trials on a 12% grade incline (equating to 7^o) displayed low-variance data indicating it was not difficult for the test participant to jump consistently, though the sensors did not output similar data as calculated by their individual jump height algorithms. At a 7^o incline, there is some force component acting in another axis that will not be sensed by the z-axis force sensors. This reduction in overall force reading is insignificant ($\sin 83^o = 99.25\%$ of perfectly vertical readings) and the data was scaled to correct for this angle, but the results still show a large difference between sensors. It could indicate that because Nextiles functions with strain readings, there is some interference with out-of-axis readings. More testing would have to be done to this effect, but avoiding using Nextiles sensors on heavily angled surfaces is advised.

The elastic surface caused each sensor to calculate a jump height slightly higher than concrete's trials. This logically makes sense, the jump using the elastic surface like a spring to jump more efficiently analogous to the effect of a slight trampoline, but also causing a slightly higher variance in the Nextiles tests. The force-time diagrams for each platform displayed the normal characteristics (fig 13), with variation mainly in the relative minimum in force before takeoff and the duration of the impulse upon landing.

Table 5 shows the likelihood that these results indicate a statistically significant difference, instead of randomly producing a difference. Normally when T tests are used, a threshold of this confidence is used to accept or remove a variable as being significant, often being around 5% error (95% confidence). If this were used, the angled surface would be thrown out as significant, and the Hawkin testing on grass as well. While this analysis is meant for use with data sets under 30 values, more data can clearly show if these relationships hold, and potentially quantify them.

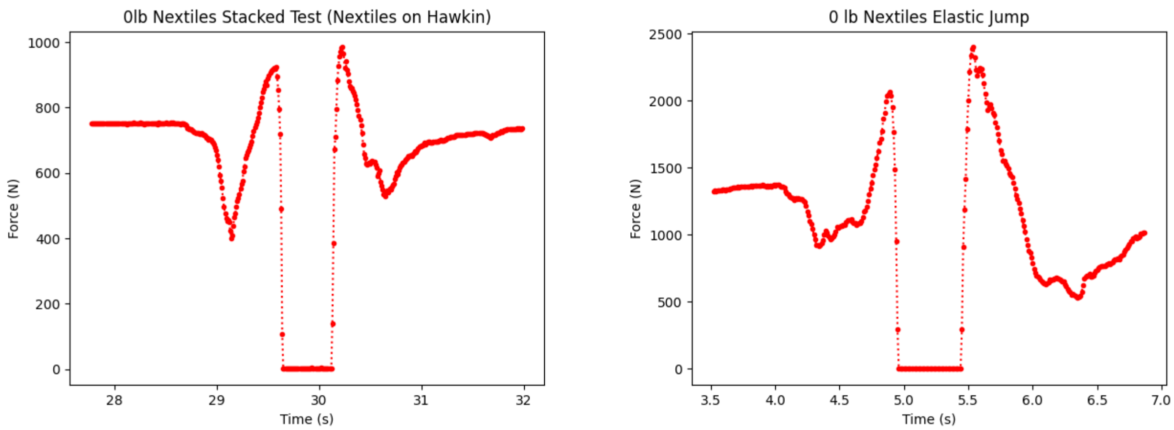

Figure 13: A visual examination of the affect on raw data characteristics of jumping on a hard surface vs an elastic surface.

Grass, or grass covered by thin fabric, is a common surface in field tents where many sensors would be used by soldiers deployed or on training excursions. Both sensors produced very similar values slightly above the concrete tests, indicating this surface affects each sensor the same way and produce comparable results, as is desired. Even though the values are 7% above expected readings seen at more ideal conditions, being off by the same amount means Nextiles compares well with what is currently being actively used in industry. Both sensors also had low variances showing ease of repeatability for the test participant. The results may change after rains and depending on soil conditions, mud possibly absorbing force while deforming during the jumps. On a damp, flat, and sparsely grassed dirt surface shown in Figure 5, these tests indicate that test results will read slightly above the expected values.

The gravel trial yielded significantly different results between sensors. Having an unpredictable and shifting surface logically would not be an ideal test site, but this confirms both its inadequacy and how it impacted the sensors uniquely. Nextiles tests, consisting of a piece of fabric causing the test participant to be jumping directly from ground contact, produced results very similar to the concrete tests. The Hawkin force plate is a pair of plates removed several inches vertically from the jumping surface and in contact only at the feet at the corners of the plates and yielded values over 30% greater than expected. The following is one possible explanation for the test differences, though it would need more testing to confidently confirm. On gravel, Hawkin sensor's flat metal feet would contact the gravel at relatively few places, concentrate force, and cause more gravel to shift and throw off the test data as well as introducing some instability that reduces the jump repeatability for the test participant. The Nextiles flexible form factor causes more surface area to come in contact with the gravel spreading out force more effectively to reduce shifting, possibly explaining the repeatable tests more consistent with the values produced on ideal conditions.

4.3.3 Stacked Sensor Tests

Stacked sensor tests produced sensor-calculated counter-movement jump height results with a fairly consistent difference, an average of 1.1in. This just over the accuracy desired to compare with a mechanical vertical height tester, but since stacking sensors adds variables to confound this comparison, this is not the basis which it should be judged on. The force-time plots of stacked tests agree in terms of timing and major trends as seen in Figure 14, with the main visible difference being in the sample rate and magnitude due to scaling issues. They each resulted in clean jumps with few unexpected perturbations and showing similar air times.

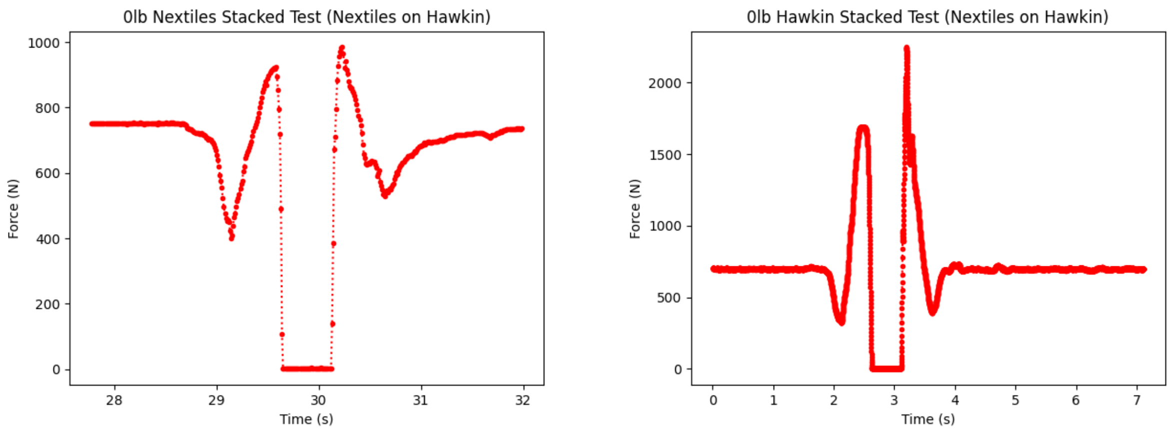

Figure 14: A visual examination of raw data from tests of Nextiles stacked on top of Hawkin Dynamics force plates. Again, the unit scaling with Nextiles is with respect to the known standing normal force with no carried load, so impulse extreme values may be less accurate.

Overall this shows general agreement of the sensors, and like the jump height comparison done by a third party algorithm it shows a slight bias based on their calculation methods that produces the consistent difference in calculated metrics.

4.4 Raw Data Analysis

Raw data analysis in Table 7 confirms the sensors are all accurate enough to produce the same values for a given jump on an ideal surface, but the algorithms are tuned differently and cause or exacerbate an offset. This tabulated comparison of jump height that is based off air time is basically the same method Nextiles and Hawkin use while calculating their jump height values, but not tailored to any specific platform or data type so they can be viewed under the same lens. Comparing the Golden standard in these tests is also useful, since it is the most accurate sensor but does not have any algorithms to calculate metrics like jump height.

This inspection in Table 7 shows how similar data each sensor produces, and how on a near ideal surface it is primarily their different algorithms that cause the calculated metrics to differ. Even with the large differences in data fidelity, this is a useful method of calculating jump height. Hawkin data also shows a larger difference between its platform-specific algorithm's jump height calculation and the basic algorithm made for this experimentation, whereas Nextiles has only slightly higher values. The main difference is probably based on tuning the algorithm to their sensor, and specific towards each platform's different sample rate, sensor accuracy and empirical testing.

This offset is consistent, and also within or equal to one increment on mechanical measurements of the same statistic. Overall this shows that Nextiles is usable and internally self-consistant, and also reliably comparable to Hawkin sensors if a half inch offset is included.

4.5 Setup Procedure Comparison

Even with large differences in the form factor of each sensor, for wide use setup should be sufficiently simple that little to no documentation is needed, and be concluded quickly. Otherwise equipment will be used less or avoided, or easier-to-use solutions will easily overshadow these force plate standards.

For Nextiles sensor setup, the mat must be charged with USB-C, turned on with a long press until a haptic vibration is felt, and then connected to an IOS device via bluetooth when in the Nextiles Application. The setup can be done without reading any documentation, though there are setup guides available. The app has 5 main screens of obvious use along the bottom, and either the second or the third option allows a device (an arm-hanging or mat Nextiles sensor) to be connected in a fairly straightforward way. Starting a test session without looking at documentation took a little while to find, but it's the bottom middle button option, the Nextiles logo, as long as a sensor is connected.

Hawkin Dynamic's force plates setup it fairly similar, though more of a hassle because of the bulk of the sensors. Each plate must be charged, then placed down next to each other centered on the participant's feet, since each sensor measures one leg. Next a cord must connect the sensors, on-sensor controls turn the sensors on, and then tare the scales before pairing with the application. The application needs to be started, and paired with the sensors next. While this connection functionality can be fast it usually needed to be repeated, turning everything off and back on again and re-zeroing the scales before connection.

The Golden Standard force plate is a comparatively massive and much more precise sensor, and needed trained professionals to start it up, connect it to the main interface, then to the computers, then start the slightly dated software and operate it. The AMTI force plate calculated force and moments on 6 degrees of freedom with the ability to connect cameras and track movement. The software can also show a myriad of different metrics, plots and connections, and does require training to used at all. Since it is more of a measurement device, there are no calculated metrics produced by the accompanying software. This is very infeasible for regular casual measurements, but again since it is a measurement device it would not be used in the field anyways. That's why lighter and easier-to-use sensors like Vald, Hawkin Dynamics and Nextiles exist.

4.6 Overall Nextiles Comparison

For a sensor that is designed to see in-field use by non-professionals, fast and easy setup and test procedure is a huge necessity. In this facet, Nextiles scores better than both Hawkin Dynamics and Vald force plates. Nextiles also takes the lead in storage, water-resistance (being able to be exposed to water for several hours before risk of damage), and durability. Applications between sensors show the Nextiles app as easier to do multiple trials with, seeing as the Hawkin's app only allows one jump at a time. Nextiles does not need to be consistently zeroed, and is as easy or easier to use compared to Hawkins. They both have

Figure 15: The on-sensor interface of the Hawkin Dynamics Force Sensors (top), and the relatively bulky travel case for the Hawkins Force Plates.

systems to label or describe the trials taken, though Nextiles is lacking the ability to log tests without internet connection. This is a desirable function.

Comparing the results between any sensor and the surface it is placed on has shown significant variability both in read and calculated results, force-time curve characteristics, and in how easy it is for a test subject to jump consistently. Hawkin and Nextiles sensors confirm that while many surfaces can be used, a flat and hard one is ideal. With the data collected, there is at now precedent as to how the surface alters results, though is difficult to mitigate across all in-field sensors. The data has shown that Nextiles is slightly more consistent in these regards, which is good to know, but primarily the sensors should still be used on a flat, hard, non-shifting surface as much as possible.

All sensors tested have repeatedly shown the predictable result of adding a carried load onto the test subject decreasing jump height by a consistent relationship. A function could be generated to predict this, though would be specific to the individual being tested. Although Nextiles is the only sensor to have an input field for the subject's unburdened weight, all sensors produced results consistent with the expected result and following the same trend. While each sensor would have a upper and lower threshold for ideal sensor accuracy, adding weight to the participant minimally impacted the differences shown between sensors and universally impacted how consistent the test subject could jump. Nextiles held up well and did not deviate from this relationship.

Other factors like how subject fatigue may impact jump height and other statistics as well, and optimal surfaces will definitely produce a cleaner data set. Shifting surfaces did visibly impact raw data trends and calculated metrics, but results did vary on adverse terrain based on what platform was used, Nextiles producing results agreeing slightly more with the ideal conditions, possibly because of its low-lying and conforming geometry. The main solution is either ensure consistent jumping conditions if they can't be ideal, and/or software compensation. If the applications associated with these platforms do provide metrics on improvement over time, they could feasibly capture how ideal the environment is during a jump trial since it would help accuracy and confidence of calculated improvement metrics.

As to whether Nextiles measures up to Hawkins on data accuracy overall, the jump height values are close and consistently offset where they can be statistically compared. Nextiles yields on average 0.48in lower calculated estimates than Hawkin Dynamics sensors, and Nextiles handles adverse surfaces possibly better than Hawkins judging by the gravel test consistency and values.

5 References

[1] "Fabric Force Plate." Nextiles Website, Nextiles Inc., 2023, www.nextiles.com/fabric-force-plate.

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[4] Dr. Ramsay, John. Interviews. Conducted by Roderick Landreth. Weekly Meetings September to November 2023.

[5] Vertical jump challenger. BSN Sports. (n.d.). https://www.bsnsports.com/vertical-jump-challenger

[6] Dr. Sun, George. Interview. Conducted by Roderick Landreth. Weekly Meetings September to November 2023.

Appendix A Equations

Calculating Jump Height from Air Time with kinematic equations:

$$
\begin{aligned}
\Delta x &= V_i t + \frac{1}{2}at^2 \Big|_{t=\frac{1}{2}t_{air}}^{V_i=0} \\
\Delta H &= \frac{1}{2}g(\frac{1}{2}t_{air})^2 \\
\Delta H &= \frac{g\Delta t_{air}^2}{8}
\end{aligned} \tag{1}
$$

Where g is the acceleration due to gravity ($9.807 m/s^2$), t_{air} is the time spent in air during the jump, velocity will be zero, $V_i = 0$, halfway through the jump at the maximum height, and ΔH is the jump height, calculated here through time falling.

Calculating Jump Height from Impulse using kinematic equations and impulse relationships:

$$
\begin{aligned}
V^2 &= V_o^2 + 2a\Delta x \Big|_{\Delta V=\sqrt{2a\Delta x}}^{V_o=0} \\
F_{eff}\Delta t &= m\Delta V \\
\frac{F_{eff}\Delta t}{m} = \Delta V = \sqrt{2a\Delta x} \quad &\Rightarrow \quad \Delta x = \frac{F_{eff}^2\Delta t^2}{2gm^2}
\end{aligned} \tag{2}
$$

Where F_{eff} is the average force (minus the weight of the dropped mass) within the impulse time period, g is the acceleration due to gravity ($9.807 m/s^2$), $\Delta t, m$ is the mass taken as an average of the data points after the impulse drop reaches steady state minus the average noise of the sensor readings, V_o is Zero because the mass is dropped from rest, V is the velocity of the mass as it hits the force sensor and so it equal to ΔV, and Δx is the drop height.

Appendix B Sample Calculations

B.1 Air Time Jump Height Calculation

Choosing a set of raw data to use for example jump height calculations:

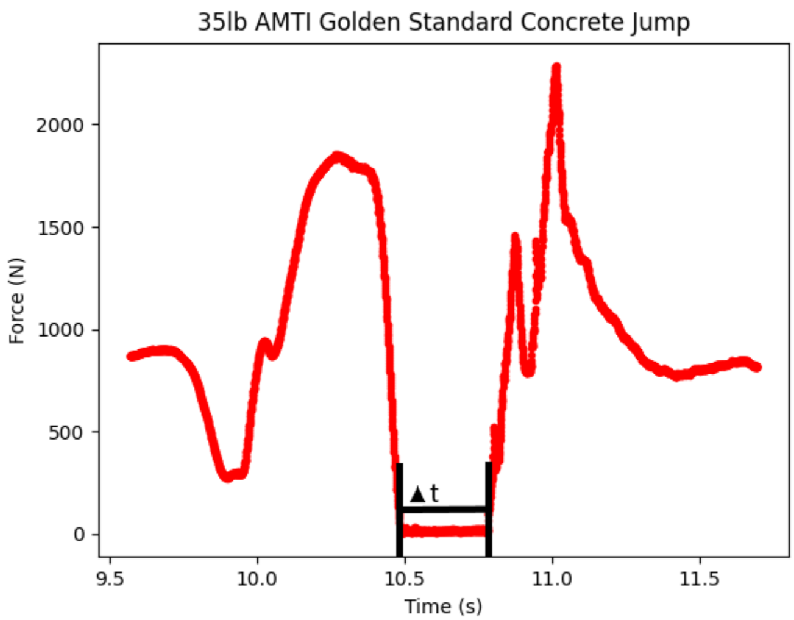

Figure 16: Estimating the jump duration at around $0.35s$.

$$\Delta H = \frac{g\Delta t_{air}^2}{8}$$

$$\Delta H = \frac{9.807 * 0.35^2}{8} = 5.9in$$

This is a slightly low estimation, possibly due to individual feet having a time offset when they left the ground, causing the summed force (as its plotted) to have a smaller amount of time at zero and lowing the apparent time in air.

B.2 Impulse-Based Jump Height Calculation

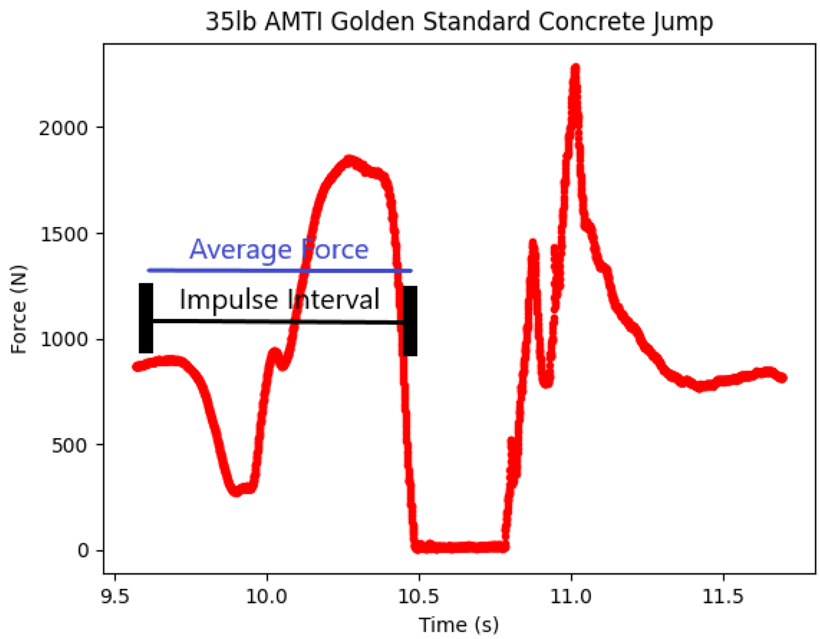

Figure 17: Estimating the impulse duration averaging to around $1100N$ over a duration of $0.8s$, with a standing normal force carrying 35lbs is $\frac{160lbs+35lbs}{2.204} = 88.48kg$, or $867.7N$.

$$\Delta x = \frac{F_{eff}^2 \Delta t^2}{2gm^2}$$

$$\Delta x = \frac{(1100N - 867.7N)^2 * (0.8)^2}{2 * 9.807 * 88.48^2} = 0.208m = 8.2in$$

This examples is an example estimation of jump height with 35lbs carried weight, fairly close to the average jump height of 9.07in for an estimation.

Appendix C Platform-Calculated Data

Testing Device	Surface	Carried Weight (lbs)	Jump Height (in.)
Hawkin	grass	0	12.37401614
Hawkin	grass	0	11.52362242
Hawkin	grass	0	12.71653584
Hawkin	grass	35	9.708661728
Hawkin	grass	35	8.141732544
Hawkin	grass	35	9.740157792
Hawkin	grass	85	6.12204744
Hawkin	grass	85	6.885826992
Hawkin	grass	85	6.6929136
Hawkin	gravel	85	10.3858271
Hawkin	gravel	85	7.228346688
Hawkin	gravel	85	7.5787404
Hawkin	gravel	35	10.64960664
Hawkin	gravel	35	12.55511851
Hawkin	gravel	35	12.51181142
Hawkin	gravel	0	15.09055166
Hawkin	gravel	0	14.46063038
Hawkin	gravel	0	12.6456697
Hawkin	elastic	85	6.637795488
Hawkin	elastic	85	6.834645888
Hawkin	elastic	85	6.216535632
Hawkin	elastic	35	9.38976408
Hawkin	elastic	35	10.10629954
Hawkin	elastic	35	10.50787435
Hawkin	elastic	0	11.7125988
Hawkin	elastic	0	12.75984293
Hawkin	elastic	0	11.85433109
Hawkin	12% grade	35	9.535433376
Hawkin	12% grade	35	9.090551472
Hawkin	12% grade	35	8.606299488
Hawkin	12% grade	85	6.145669488
Hawkin	12% grade	85	6.035433264
Hawkin	12% grade	85	5.803149792
Hawkin	12% grade	0	12.34252008
Hawkin	12% grade	0	11.88976416
Hawkin	12% grade	0	11.38582714

Table 8: Calculated Data Part 1

Testing Device	Surface	Carried Weight (lbs)	Jump Height (in.)
Hawkin	concrete	85	6.681102576
Hawkin	concrete	85	6.208661616
Hawkin	concrete	85	6.645669504
Hawkin	nextile	85	6.444882096
Hawkin	nextile	85	6.488189184
Hawkin	nextile	85	6.330708864
Hawkin	nextile	35	9.984252288
Hawkin	nextile	35	8.968504224
Hawkin	nextile	35	9.236220768
Hawkin	nextile	0	12.03149645
Hawkin	nextile	0	11.98818936
Hawkin	nextile	0	11.71653581
Hawkin	nextile NZ	0	10.92913421
Hawkin	nextile NZ	0	10.52362238
Hawkin	nextile NZ	0	10.76377987
Hawkin	concrete	0	11.65354368
Hawkin	concrete	0	12.37007914
Hawkin	concrete	0	12.24015787
Hawkin	concrete	35	9.377953056
Hawkin	concrete	35	8.830708944
Hawkin	concrete	35	9.736220784
Hawkin	concrete	35	9.275590848
Hawkin	concrete	0	11.21653579
Hawkin	concrete	0	9.996063312
Nextiles	concrete	0	11.12832
Nextiles	concrete	0	11.12832
Nextiles	concrete	0	9.7373283
Nextiles	concrete	35	7.3088043
Nextiles	concrete	35	6.9378603
Nextiles	concrete	35	8.3988387
Nextiles	hawkin NZ	0	9.7373283
Nextiles	hawkin NZ	0	9.8242683
Nextiles	hawkin NZ	0	9.8678832
Nextiles	GS NZ	0	10.3093452
Nextiles	GS NZ	0	8.4391692
Nextiles	GS NZ	0	11.5023552
Nextiles	GS	0	10.3987968
Nextiles	GS	0	11.0820003
Nextiles	GS	0	11.1747363

Table 9: Calculated Data Part 2

Testing Device	Surface	Carried Weight (lbs)	Jump Height (in.)
Nextiles	hawkin	0	11.0357772
Nextiles	hawkin	0	9.9115947
Nextiles	hawkin	0	9.8678832
Nextiles	hawkin	35	8.9722563
Nextiles	hawkin	35	8.9722563
Nextiles	hawkin	35	8.0796723
Nextiles	GS	35	8.4391692
Nextiles	GS	35	8.5607403
Nextiles	GS	35	8.52012
Nextiles	hawkin	85	6.1903212
Nextiles	hawkin	85	6.25968
Nextiles	12% grade	0	10.4436675
Nextiles	12% grade	0	11.1747363
Nextiles	12% grade	0	9.8242683
Nextiles	12% grade	35	8.4795963
Nextiles	12% grade	35	8.52012
Nextiles	12% grade	35	8.52012
Nextiles	12% grade	85	4.6117323
Nextiles	12% grade	85	5.1963072
Nextiles	12% grade	85	5.2917963
Nextiles	elastic	0	10.0433088
Nextiles	elastic	0	11.0357772
Nextiles	elastic	0	13.9801452
Nextiles	elastic	0	12.56283
Nextiles	elastic	0	11.12832
Nextiles	elastic	0	12.4154667
Nextiles	elastic	35	9.8678832
Nextiles	elastic	35	8.7241875
Nextiles	elastic	35	8.52012
Nextiles	elastic	85	6.25968
Nextiles	elastic	85	7.2338427
Nextiles	elastic	85	7.3088043
Nextiles	grass	0	11.2678587
Nextiles	grass	0	11.3145648
Nextiles	grass	0	12.56283
Nextiles	grass	35	9.8678832
Nextiles	grass	35	9.8242683
Nextiles	grass	35	9.6940032
Nextiles	grass	85	6.4347675

Table 10: Calculated Data Part 3

Testing Device	Surface	Carried Weight (lbs)	Jump Height (in.)
Nextiles	grass	85	5.9506083
Nextiles	grass	85	7.2712752
Nextiles	gravel	85	5.5506843
Nextiles	gravel	85	6.2945043
Nextiles	gravel	85	6.0870075
Nextiles	gravel	35	9.2660652
Nextiles	gravel	35	9.78075
Nextiles	gravel	35	9.1395675
Nextiles	gravel	0	11.2678587
Nextiles	gravel	0	11.8825728
Nextiles	gravel	0	10.7604672

Table 11: Calculated Data Part 4

Appendix D Additional Pictures

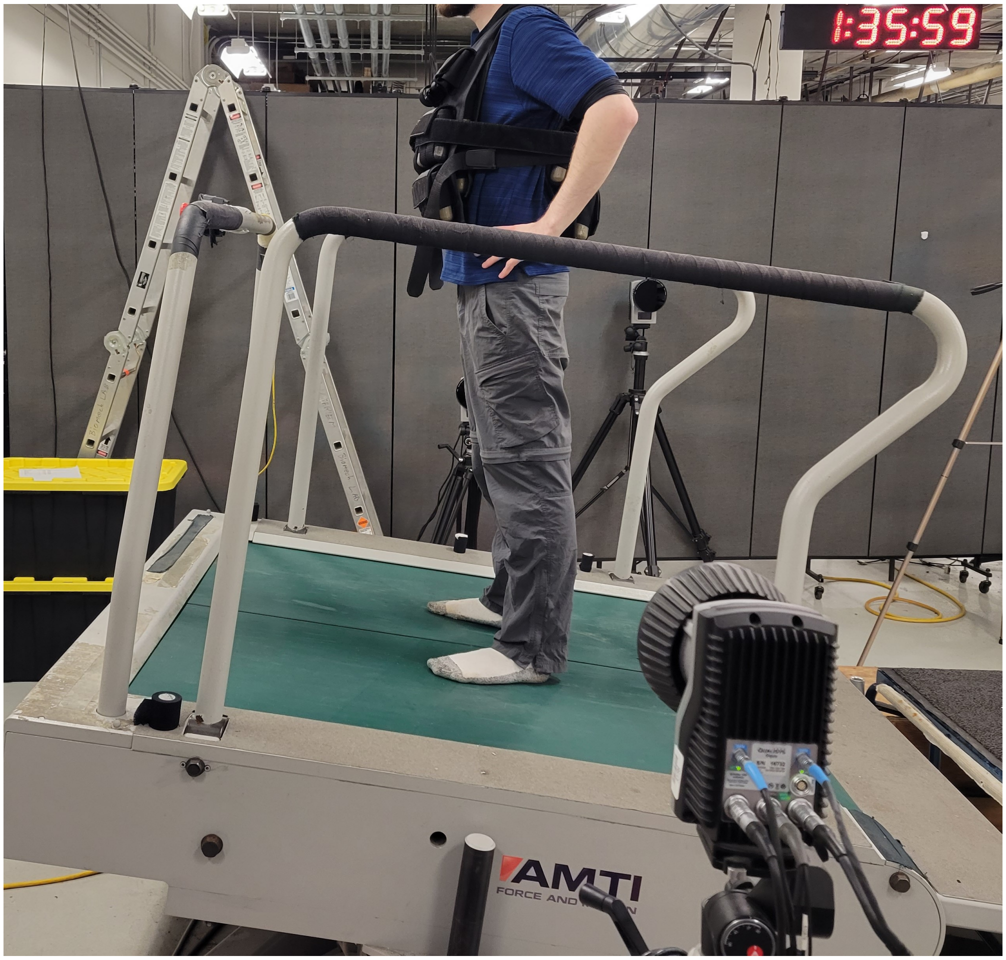

Figure 18: AMTI Golden Standard angled at a 12% grade, equivalent to 7^o

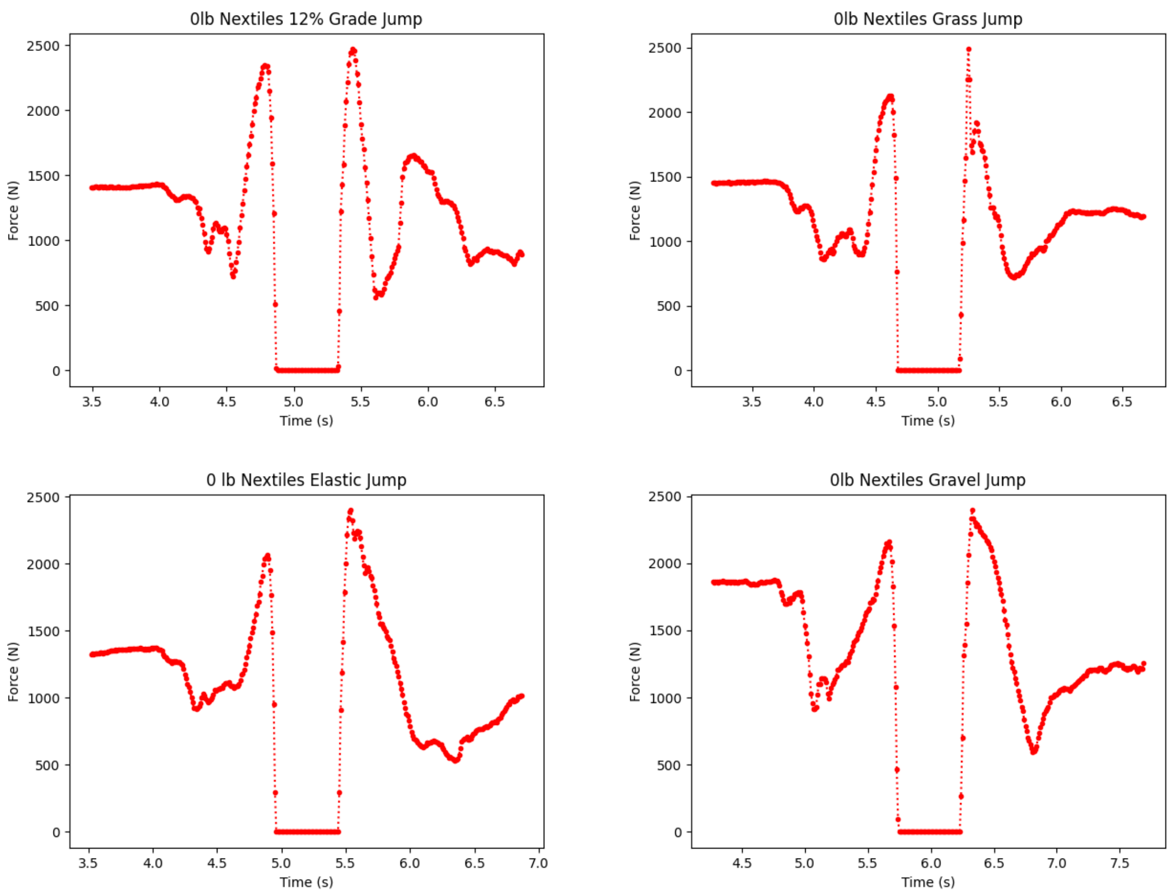

Figure 19: Nextiles All Surfaces at 0lbs carried load.

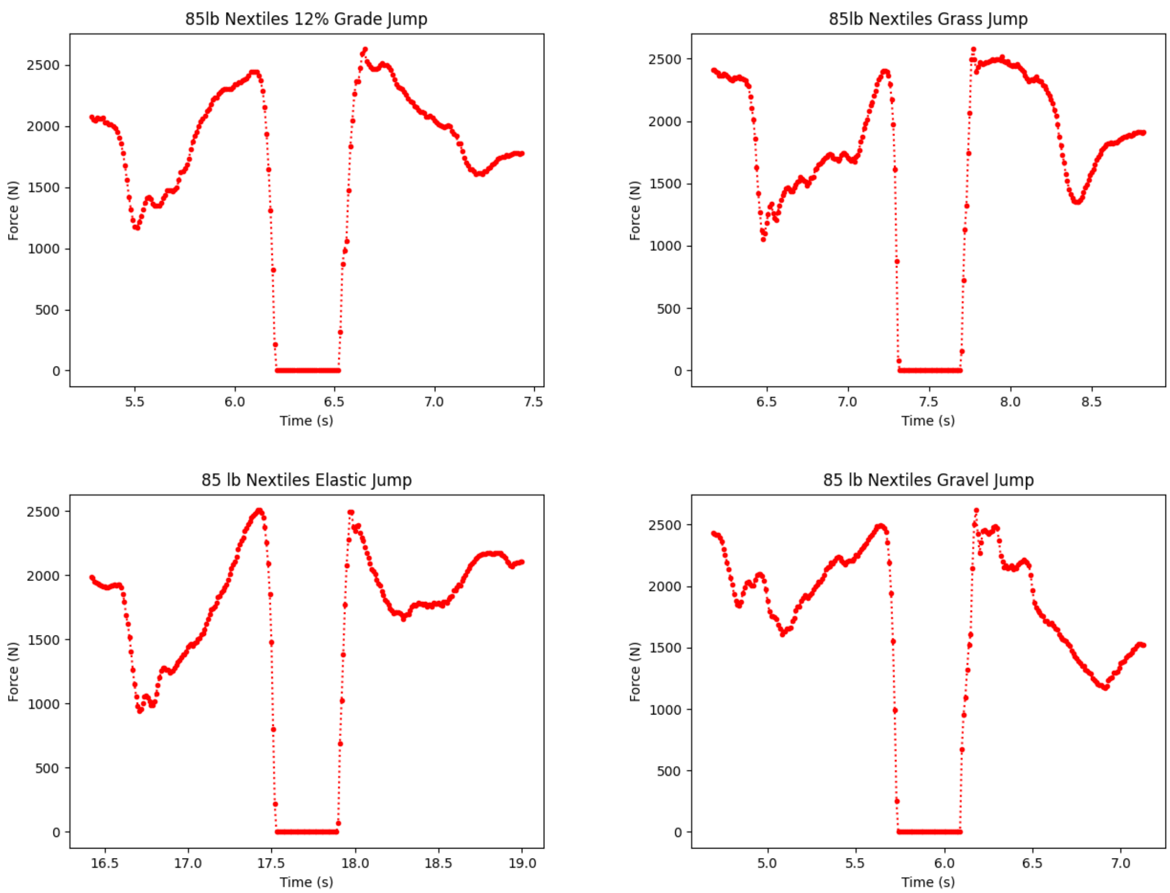

Figure 20: Nextiles All Surfaces at 85lbs carried load.