Correct Appliance of a Clubfoot Brace by using Pressure Sensors

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ABSTRACT
Most children who are born with clubfoot are treated with the Ponseti method. Part of this treatment involves wearing a brace for approximately 4 years. At the moment there are no feedback mechanisms for the parents to know whether they applied the brace correctly. This causes a lot of insecurity. This paper describes the research done to find out whether pressure sensors can be used to indicate correct appliance of a clubfoot brace. The research was conducted by applying pressure sensors in the braces of children with clubfeet. During the tests, different applications of the brace were measured with the sensors. These results were then compared in order to find out whether a range could be computed which indicated correct appliance. From the results can be concluded that the pressure sensors can be used to measure pressure within the brace. However, no range can be computed due to the many differences between eACH individual.

Author keywords
Clubfoot; Correct Appliance; Novel pressure sensors; Ponseti brace; Ponseti method; Pressure.

INTRODUCTION

Clubfoot is a birth deformity where one foot or both feet are rotated inwards and downwards.(Figure 1) It can be diagnosed during the 20 week ultrasound and is visible at birth. [8, 12] It causes no pain for the newborns. However the treatment of clubfoot should start immediately when diagnosed, since it can cause a series of problems when the child grows up. If the treatment is started in time those problems can be solved and affected children can lead a normal life.

Currently the most popular and effective treatment for clubfoot is the Ponseti Method. It was developed in the 1950s by Dr. Ignacio Ponseti. [11,13] The treatment combines manipulations, serial plaster cast immobilizations, achilles tenotomy and abduction orthosis. In 85% to 90% of the cases it produces a functional foot and only in few cases a corrective surgery is needed. [5,8]

Figure 1. A newborn with clubfeet
[Alvien Lee/Sinai Hospital, NPR, How Parents And The Internet Transformed Clubfoot Treatment]

The method consists of two phases: The treatment phase and the maintenance phase. In the treatment phase the deformity is corrected completely and during the maintenance phase the foot abduction orthosis, also known as the ponseti brace (see Figure 2), is used to prevent recurrence. In both phases attention to the details of the technique is essential as it has shown that treatment errors can lead to medically caused deformities, incomplete corrections and recurrences [12].

As stated before, the treatment should start as early as possible, ideally in the first week of life. In the treatment phase gentle manipulations are performed, which are followed by casting on a weekly basis. 5 to 6 casts are needed to fully correct the foot. The different aspects of the clubfoot are corrected simultaneously except for the equinus, which means that the upward bending motion of the ankle joint is limited. To correct this a percutaneous achilles tenotomy is done only. During this minimal invasive surgery the Achilles Tendon is completely cut through so when it heals, the child's foot can move upward. After this the last plaster cast is applied and worn for approximately 3 weeks. [11] When the maintenance phase begins the child must wear the ponseti brace with attached shoes. These have a 60°/70° outward rotation relative to the affected foot. The unaffected foot is set to a 30°/40° outward rotation. Furthermore there is a 15° bending of dorsiflexion, which means upwards, to keep the corrected foot in the same degree of abduction that was achieved in the last cast. [3]

According to a strict wearing protocol the brace is worn for 23 hours a day in the first 3 to 4 months. After this the brace only has to be worn during naps and at night for 2 – 5 years. [2] To prevent relapse wearing the brace is very important as failure to wear this brace shows to be associated with the recurrence of clubfoot. [2,11,12,15]

Figure 2. The Ponseti Brace

However research has shown that it is difficult for parents to comply with the strictness of wearing the brace.
We talked someone who is member of the board of the Dutch Clubfoot Association, one of the managers of their Facebook community and parent of a daughter with complex clubfeet, she told us that the parents see the brace as something negative. They think it hurts their child and are insecure about applying it. They might assume the brace is causing the child pain and when their child cries it often leads to removal of the brace. [9] As a result of frequent brace removal, the risk of the recurrence of clubfoot can increase. In addition to that, parents often do not know how to apply the brace correctly. Braces that are too loose can cause the feet to be able to move up and down causing redness and skin irritations. [1,9]

We had an expert interview with a researcher from the MMC Veldhoven. From this we got that for the Ponseti method to be successful the brace has to be worn frequently and in the correct way. If the brace is not worn correctly the chance of relapse is bigger and this means that the treatment phase of the ponseti method has to be done again. We learned from the orthopedic surgeon at MMC Veldhoven that the most important aspect of the brace is that it keeps the foot in the right position. Because of the brace the foot cannot move back and therefore the brace can make sure the foot takes the right position. Therefore, once again, it is stressed that the parents have to apply the brace frequently and in the correct way.

However at the moment there is no feedback for the person who is putting the brace on, so knowing whether the brace is applied correctly is difficult. When talking to parents we found out that parents are often insecure about how they have applied the brace. They fear that they are hurting their child when tightening the straps of the brace, or that they have applied the brace too loosely. Sometimes others have to apply the brace as well, like caretakers at a daycare for example. They do not have as much experience as the parents with the brace, and never got explanation from a professional on how to apply the brace. In addition to that, the one we talked to also stressed that everything that could make the appliance of the brace easier for the parents would be a good addition. The parents would care for feedback.

Unfortunately, not a lot of research has been conducted in this area. Only two existing papers focus on the measurement of the pressure in clubfoot braces. [6,16] These papers did not find any specific range in the data for when the brace is put on correctly. Furthermore they discussed the used sensors since those did not always give a clear data output.

Therefore the research question for our study is:
How can pressure sensors be used to indicate correct appliance of a clubfoot brace?
To help answer this research question, we developed two sub questions:

- Where and how should the sensors be placed in the clubfoot brace?
- Can a range be computed from the obtained data which indicates correct appliance of the brace?

RELATED WORK

Research has been done to measure whether the Ponseti Brace is worn long enough during the day. [14] The number of hours which the doctor advised the brace should be worn was compared to the number of hours the parents wrote down the brace was worn, this was compared again to the measured values of a temperature sensor in the brace. The parents did not know temperature sensors were placed in the brace which would measure the number of hours the brace was worn. It was kept from them to prevent them from influencing the results.

The results of the temperature sensors showed that the brace was worn approximately 8 hours per day whereas the parents wrote down that the brace was worn approximately 11,5 hours and the doctor had advised 12 hours. Children who wore the brace 8 hours or more had a good correction of the clubfoot. Children who wore the brace less than five hours a day needed a medical intervention. The biggest problem found in this research was that parents often leave the brace on for too few hours which causes the foot to not be corrected properly during the day.

Another research was done to measure the pressure of the Ponseti method on the foot in two different areas. [6] The Ponseti method applies forces on two sides of the foot: the medial side of the First Metatarsal (FM) and the lateral side of the Talar Neck (TN). In order to measure the forces a standard clubfoot model was used. The pressure point data was collected with the use of novel pressure sensors from the University of Twente [7] and an Arduino.

The pressure points of the clubfoot model were measured because little is known about the forces applied to the feet when using the ponseti method. This research tested the hypothesis that forces are lower during casting than during manipulation. This was true for TN but not for FM. This might be due to the difficulty of finding the right place to properly cast at the TN side. The padding also results in the pressure being spread over a larger area.

This research also used pressure sensors to measure the pressure points of the clubfoot brace to see if there is a difference between the casting period and the manipulation method. However it did not use the pressure sensors to measure whether the brace is applied correctly or not. Therefore this study provided input for us to focus our research on.

One other research project has been done to examine whether pressure in a clubfoot brace can be used to formulate correct appliance. [16] During this research the pressure of the feet were measured in a ponseti brace. The sensors were put at the following locations: Talar Neck, First Metatarsal and Heel Bone. The pressure sensors used for this experiment, are the FSR402. These are force-sensitive resistors, paper-thin with minor flexibility. It measures pressure from 0.2 Newton up to 20 Newton.

The brace, with the sensors in it, was put onto six children with the clubfoot condition for sixty seconds, three times with small breaks in between.

This research concluded that the sensors positioned at the Talar Neck and the First Metatarsal gave reliable data. However in order to obtain more reliable data, the research suggested to add a sensor at the back of the heel and use different sensors. The study did not obtain a range for correct appliance. It advised to do more research to obtain more clarity about the correct appliance of the brace. This paper was used as an inspiration source for our own research.

METHOD

Participants

We performed our research on three participants with clubfoot. The age of the participants varied from two to three year old children and they are all treated with the Ponseti method. The tests were done all over the Netherlands and not in a specific area. The participants were recruited with help of one of the managers of the Facebook community of the Dutch Clubfoot Association. We got permission to place a message in that Facebook community.

Sensors and sensor locations

In this research we have used the Novel Pressure Sensors from the University of Twente. During our tests we used two sets of sensors. The sensors are paired and a temperature sensor is also included. From left to right it's: Temperature sensor, Sensor B, Sensor A (see Figure 3). The sensors take 9 samples per second and when 60 samples are reached the data will be transferred to an SD card that saves all data. When the sensors are not needed anymore the battery has to be unplugged and the data can be exported to a computer. However the data has no unit, so this had to be converted by ourselves. [7]

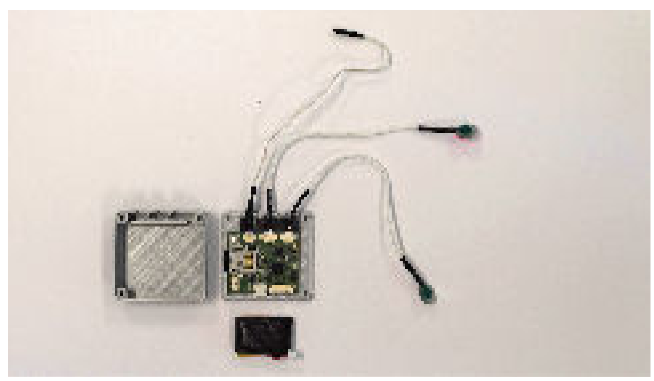


Figure 3. One set of the novel pressure sensors from the University of Twente

We used these sensors to find out if they can be used to indicate correct appliance of the brace. We placed the sensors in four different positions (see Figure 4).

Figure 4. The locations of the sensors

These positions were chosen, because they can give an indication whether the brace is worn correctly. In addition to that the orthopedic surgeon from MMC Veldhoven verified these places. If the pressure on the Talar Neck is very high and the pressure measured on the Heel Bone very low this indicates that the brace is not applied correctly. The foot should not move back up again into clubfoot position. The pressure on the Heel Bone should therefore be bigger than the pressure on the Talar Neck, because otherwise it indicates that the foot wants to move back into clubfoot position, which can cause relapse. Furthermore there should be pressure on the Achilles Tendon since this indicates that the heel of the foot is in contact with the back of the brace, which is needed for the brace to be effective. Lastly the First Metatarsal was chosen, because pressure at this location indicates that the brace is correcting the clubfoot in the right way since the foot has the tendency to move back inside into clubfoot position.

Materials

The sensors are fragile and can lead to pressure points on the participants skin if not covered up with a material to level the surface with the sensor. EVA foam was chosen since this is safe for children and is also used in toys for children. It is firm enough to protect the sensor, yet also soft enough to be comfortable for the child. To keep the foam with the sensor in place, we used duct tape. We chose duct tape, because nothing else sticks on the silicons of which the brace is made. Next to duct tape, masking tape was used to attach the cases to the bar of the brace (see Figure 6). These cases protect the PCB, SD card and the battery of the sensor.

During the test we used the participant's own Ponseti brace (see Figure 6). This way we were assured that the brace fitted the feet properly. In the brace we placed the four sensors on the four different locations mentioned before.

When connecting the battery and the SD card to the sensors, the sensors already start measuring. Therefore the results also show data of when we were placing the sensors in the brace. However, this data is not relevant to our research. For this reason it was essential to use a timer to be able to filter out the data that was collected outside of the relevant measurements. Next to this we also noted at which time the child moved excessively. This would allow for us to connect fluctuations in the graphs to the movement of the child. The form that was used to note these times can be found in Appendix A

Design

As mentioned above we placed the four sensors on the following locations: Achilles Tendon, First Metatarsal, Talar Neck and Heel Bone. We placed the sensors in the brace using EVA foam and duct tape. In figure 5 our design can be seen.

Figure 5. The Novel Pressure Sensors placed in the brace on the four selected placed with EVA foam and duct tape

Procedure

Before we started to place the sensors in the brace, we first introduced ourselves to the parents and gave them a consent form, which they could read and sign when we were placing the sensors in the brace. The consent forms can be found in Appendix B.

Before placing the sensors in the brace, we first had to turn the sensors on. After this we placed the sensors inside the brace together with the EVA foam and duct tape. When the sensors were in the brace, we used masking tape to attach the cases on the bar of the brace (see Figure 6). After everything was in place, we first informed the parents about the test and what they should do during the test. We first asked the parents to apply the brace correctly according to them, while the child is laying on their back. As soon as the brace is applied, we wrote down the start time of the test. Then we measured for two minutes. In these two minutes the child was laying down as still as possible. We chose to let the child lay down, because most of the children with clubfoot between two and three years old wear the brace when they are sleeping. This was a suggestions made by the orthopedic surgeon from MMC Veldhoven.

During the test notes were taken of the movement of the child and on the course of the experiment. Everything was noted on the form. After the first two minutes we asked the parents to loosen the straps of the brace by three holes. Then we measured again for two minutes. Subsequently, we asked the parents to take the brace off after which we removed the sensors from the brace and disconnected them. Lastly, we asked the parents the age, the shoe size and the weight of their child.

Figure 6. Child 1 laying on their back during the test

Data calibration

Because the values of the gathered data from the sensors have no unit, we had to calibrate the sensors. We calibrated all the sensors we had. These are the two sensors from set 2 and set 6 and one sensor from set 1. In the calibration we used light weights (6.5 grams, 13.1 grams, 19.6 grams, 26.2 grams) and heavier weights (19.5 grams, 38.9 grams, 58.3 grams, 77.7 grams). The setup of the calibrations can be seen in Figure 7. In the results section we will discuss what we got out of the calibrations.

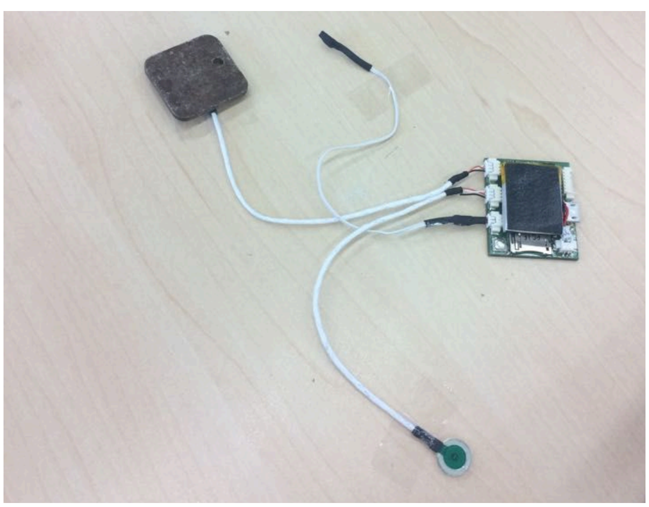


Figure 7. Setup of the calibration of the sensors

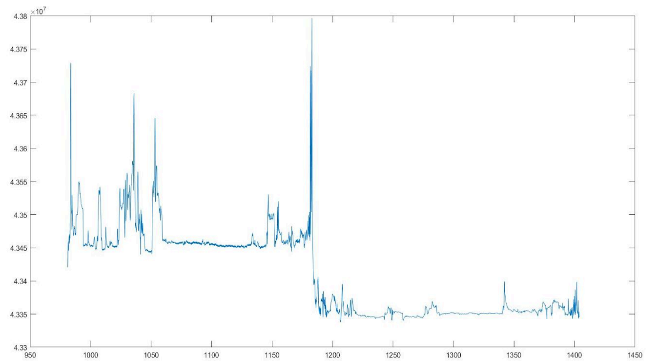
RESULTS

Formulas from calibration

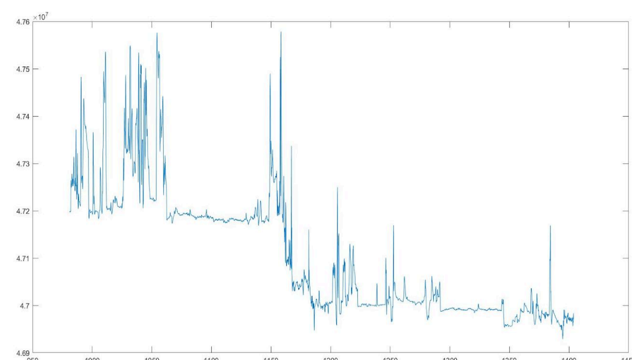
We plotted the data from the calibrations in Excel to make graphs. Within these graphs we plotted a trendline with the matching formulas. The goal was that we would be able to convert the outcome of the test (without an unit) to Newton with these formulas. However, we encountered some difficulties when doing this. This will be discussed in the Discussion section.

User test

In total three children participated in the research. All participants met our requirements of wearing a Ponseti brace and being between two and three years old. The data of one of the tests is shown in graph 1, 2 and 3.



Graph 1. Data of test 3, Pressure on Achilles tendon



Graph 2. Data of test 3, Pressure on the First Metatarsal

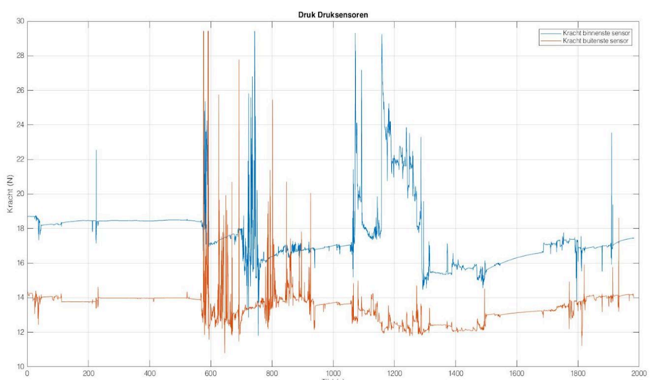
The data in Graph 1 shows what happened during the test. The first couple of peaks show when the child is moving a little bit in the brace. The next few peaks and the large peak in the middle are caused by the parent who is loosening the straps of the brace. After this high peak in the middle, one can see that the pressure drops. This is when the straps are loosened three holes. This shows that in the second part of the test the pressure is lower compared to the first part of the test.

The same can be said about graph 2. One can see that in both graphs the peaks occur around the same time during the test. They are not at the same height, but the time period matches. The other graphs can be found in Appendix C.

Matlab Script

We used a script that was made by a student from the University of Twente. This script made it possible to convert the data from our tests into Newton. It used our calibrations and data sets from the tests. In the script we had to indicate which weights belonged to which plateaus in the calibration. Using these weights, the script then converted the data sets from the tests into Newton, giving a figure with two graphs from both the sensors in there.

From these calculations we can concluded that in all the tests we did with set 2 of the novel pressure sensors, the pressure on the Heel Bone is higher than the pressure on the Achilles Tendon. In graph 3 the results from test 1, set 2 are shown.



Graph 3. Data from the script. The red line is the Achilles Tendon and the blue line is the Heel Bone

We can unfortunately not say whether the newton values are correct or not. We will discuss this in the discussion section. The other graphs from the script can be found in Appendix D.

DISCUSSION

Calibration of the sensors

When extracting the data of the sensors for the first time, we noticed that the values do not have units. Therefore the sensors had to be calibrated. The calibration has been done with several small weights. Weights of 6,5 grams and 19,5 grams were used. For calibration it is important to know the exact weight of the weights that are used. The scale we used to weigh the weights was accurate to 0.1 grams. This is not very accurate.

Next to this, the calibration was done manually. This means that the weights were placed on the sensor by hand each time. For this reason the calibration is more sensitive to a differentiation each time the sensor was calibrated. It was impossible to ensure that each calibration was conducted in the same way. It is also unsure whether 100% of the weight was transferred onto the sensor.

Formulas from calibration

During the analysis of the calibration, there was a big difference between the formulas we got from the graphs of the light weights compared to the heavier weights. Two example graphs can be found in appendix E. Therefore, we tried to combine the data of the two weights and formulated new graphs and formulas. However, the formulas we got out of this combination are not reliable, because the data points from the light and heavier weights most of the time did not lie not on the same line. One example graph can be found in appendix F. This makes it even harder to see if it is an exponential or linear function. Besides that, the zero values of the sensors deviated in such a way from the other points that the formulas were even less reliable. This deviation can be caused by a certain threshold the sensors may have. Still we tried to use all the formulas (from only the light weights, the heavier weights and the combination of light and heavier weights from an exponential ànd linear trendline) to convert the data of the tests to Newton. The results from this were that all of the answers had a negative value of Newton, which is practically not possible. With this information we went to D-search, where we talked to someone with a lot of experience in Matlab, because we thought that the trendline function of Excel was maybe too limited for these calculations or not accurate enough. This person confirmed that all the steps in our approach were correct, but we got the suggestion to not take the zero values into account, because it deviated too much from the rest of the data. As a result we extracted the zero values from all the points of the calibration. The light weights showed, in most of the cases, a more exponential function whereas the heavier weights showed, in most of the cases, a more linear function. Four example graphs can be found in appendix G. We used the formulas from the trendline again to convert the values to Newton. Unfortunately, the outcomes were still negative. A general explanation of how we calculated the Newton can be found in appendix H.

Our next step was to try and find the reason behind the negative values of Newton. We figured out that the values from the calibrations were much higher than the values from the tests. This resulted in the negative values of Newton of the tests. A possible explanation for this can be that when we calibrated, we did not use foam around the sensor, but we put a weight directly on the sensor. During the tests we used foam around the sensor in the brace. In the brace, the sensor is not on a completely flat surface and the feet of the children can contain a lot of tissue, which can result in weight not only being put on the pressure sensor itself, but also on the foam. A possible solution for this is to calibrate the sensors when the sensors are surrounded with foam or when they are surrounded with foam and placed inside the brace. This should be done directly before the actual test.

Temperature sensor ignored

During the tests, the temperature sensor was not placed inside the brace, and therefore no temperature values were measured. There were already 4 sensors placed inside the brace and the brace is not very big. Next to this we did not research what the ideal place would be to place the temperature sensor. This also because 4 sensors were used and there were only 2 temperature sensors. This would not allow us to place a temperature sensor at every pressure sensor. Since we did not collect any data on the temperature, we cannot say whether temperature inside the brace influences the pressure on the sensors, or the perceived pressure by the sensors.

Creating similar conditions

The research was conducted in two parts. In the first part of the test the brace was applied correctly according to the parent. In the second part of the test the brace was applied too loose according to the parent. It was crucial that for the rest the conditions would be exactly the same within the two tests. However, since we are working with young children who are very unpredictable, it is difficult to guarantee an equal condition amongst the two sessions. The same applies to the different children that were tested with. Not all children behaved in the same way. Some refused to lay down whereas others layed down very quietly.

No definition of 'correct appliance'

There was no definition of 'correct appliance' within this research. We had proposed to meet with an orthopedic surgeon who then could show us how to correctly apply the brace on a patient. By measuring during the application measurements we would have been able to define a correct application in values. However, we needed METC approval for this. The time was too limited for us to receive this approval. In our research we asked the parents to apply the brace correctly according to them. Their way of applying the brace might be different than the orthopedic surgeon might do. Also each parent might apply the brace differently. The parents are informed by the orthopedic surgeon to put the straps of the brace in certain holes until the next session, in which the doctor reviews his decision and adjusts it based on growth of the feet and healing of the condition. But these sessions sometimes take a year to follow up. Within a year a child's feet grow a lot. For this reason the parent might apply the brace differently than the surgeon might do.

Every foot is different

In order to be able to compare the data in the most reliable way you should have children with the same foot size and weight when comparing. A foot of size 5 will give a different pressure value than a foot of size 10. The same goes for weight. A heavier child will put more weight inside the brace, resulting in higher pressure values. In reality it is hard to resolve this, since there is a limited amount of children with clubfeet. The chance of finding 2 children that have the same foot size and weight is very slim. A foot of size 5 will give a different pressure value than a foot of size 10.

Range

A range was not defined within our research. This is due to multiple factors. Firstly as already discussed in this section, each foot is different. This makes it hard to find a range since data of two different sets of feet cannot conclude to a general range for feet inside a range of for example foot size 29 to 33. If a range were to be computed, this range would be personalized and applicable to this patient only. Furthermore since we did not know when the brace was applied correctly, only when it is too loose, we cannot define certain values that represent if a brace is applied correctly or not.

Matlab script

When using the script to convert the data into newton the zero values of the calibrations were for 5 out of 6 data sets higher than the points that were measured during the test. This means that when we converted the data set into Newton a lot of the data was filtered out. We could see some peaks that made it above the zero axis but not a lot. Therefore the script doesn't work with our calibrations and thus the newton values we got were only accurate for set 2 of test 1.

CONCLUSION

Overall we are able to say that the Novel Pressure Sensors from the University of Twente are sensitive enough to get an understanding of the pressure in a medical brace. When analysing the data, the small pressure differences can be visualized. We can clearly see when the child moved in the brace since the graphs show big pressure differences at those moments. This is something that force sensitive resistors were unable to do. Solely looking at the data the sensors are able to collect, these sensors would be competent enough for measuring pressure differences in braces.

Since the calibrations were vital in this research, these have to be done very accurate. It is important to do the calibrations in the same measurements as the tests, so the zero value of the calibrations is not higher than the ones from the tests. In addition to that the calibrations should be done when the EVA foam is already applied on top of the sensors. The pressure is divided in a different way when the EVA foam is on top, which means it gives different calibration values.

When looking at the script we can say that in all three tests we did with set 2 of the novel pressure sensors, the pressure on the Heel Bone is higher than the pressure on the Achilles Tendon. However the reason for this still remains unclear.

In the end we were not able to determine a range which indicates the correct appliance of the ponseti brace. Each child has a different age and weight and the severity of the deformity also varies which means that each foot is different. Determining a range would mean that the specific range should be personalized per child.
In addition to that the data that was collected from the sensors did not have a unit. Therefore we cannot conclude the value of the pressure that was put on the sensor to compute an (individual) range.

FUTURE WORK

Longer measurements

In our research we tested for 2 minutes, each round. One could argue that testing for more than 2 minutes is desirable. The children moved a lot during the tests, which is visible in the graphs. These data points cannot be used in the analysis of the data. When measuring for more than 2 minutes, more data points can be collected and therefore there could be more data points when the child does not move. In this way, there could be more data to use for the analysis.

Testing with the help of a orthopedic surgeon

In future research, testing should be done with the help of an orthopedic surgeon who is specialized in clubfoot. The data gathered during the tests with the doctor will function as a baseline of correct appliance. The data gathered during the tests with the parents can then be compared to the baseline to see if the parents are putting on the brace as the doctor or if there are big differences. In order to create a baseline of what is correct, the doctor has to put the brace on multiple times and in order to create a baseline for the parents, the parents also have to put on the brace multiple times. After this is done

Sensors

The sensors could be used for further research. However before using them an accurate calibration has to be done and a formula or script has to be written that can convert the data from the sensors into Newton. This is necessary to be able to say something about the pressure points.

Different methods to measure correct appliance

It could also be interesting to research which other methods could be used to measure correct appliance of the brace. One could for example look at measuring the pressure of the straps instead of in the brace.

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APPENDIX

Appendix A - Form used during the tests to verify the data deviations.

Kind: Leeftijd: Maat: Gewicht: Datum:

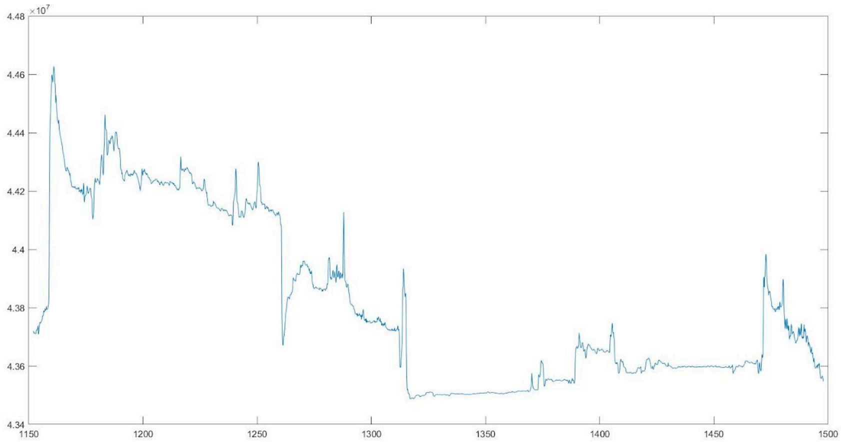
Begintijd	Eindtijd	Actie	Opmerkingen
		Sensoren aansluiten	
		Brace aandoen	
		Aantrekken gespen	
		Brace zit vast	
		Kind ligt in positie	
		Kind ligt stabiel	
		2 minuten testen	
		Ouder doet gespen losser	
		Brace zit ‘vast’	
		Kind ligt in positie	
		Kind ligt stabiel	
		2 minuten testen	
		Ouder doet gespen los	
		Ouder trekt brace uit	
		Brace is los	
		Einde test	
		Sensoren loskoppelen	

Appendix B - Consent forms

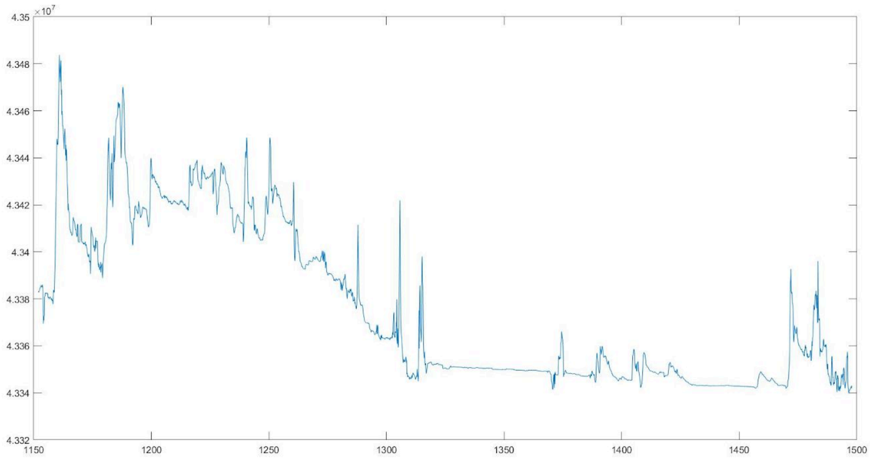
[This section is removed from the public version, so the participants stay anonymous.]

Appendix C - Graphs from Matlab

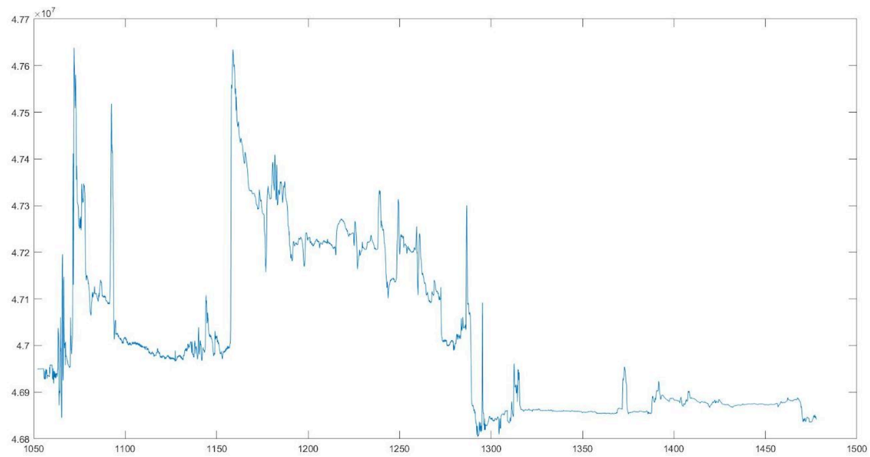
<u>Test 1</u>



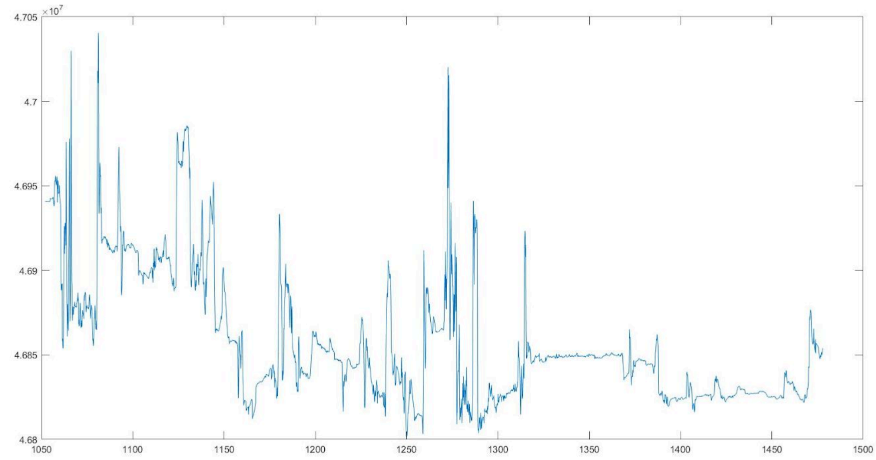
Set 2 - Sensor A (Heel Bone)



Set 2 - Sensor B (Achilles Tendon)

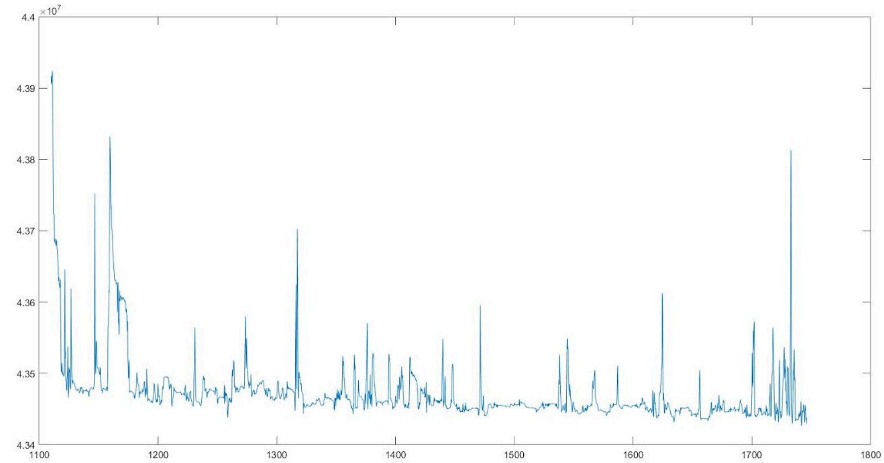


Set 6 - Sensor A (Talar Neck)

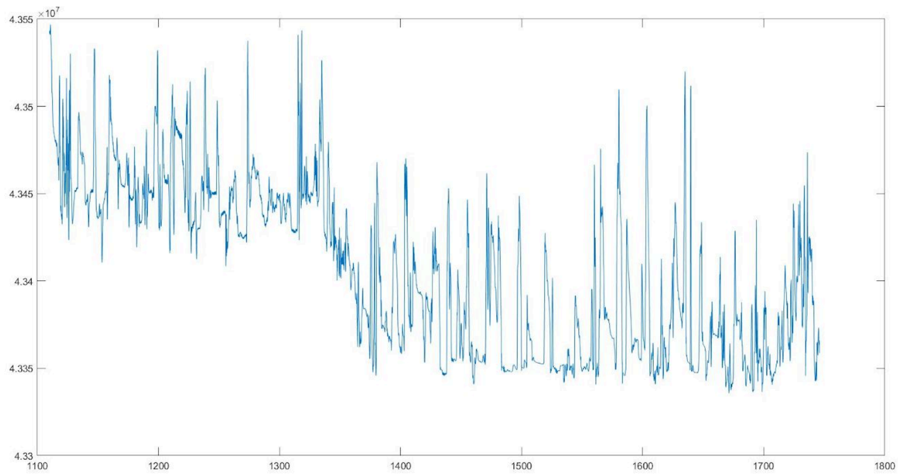


Set 6 - Sensor B (First Metatarsal)

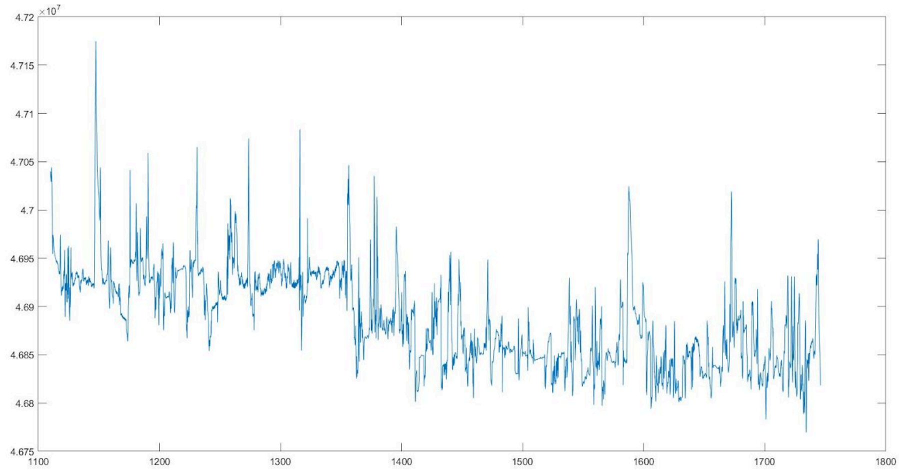
Test 2



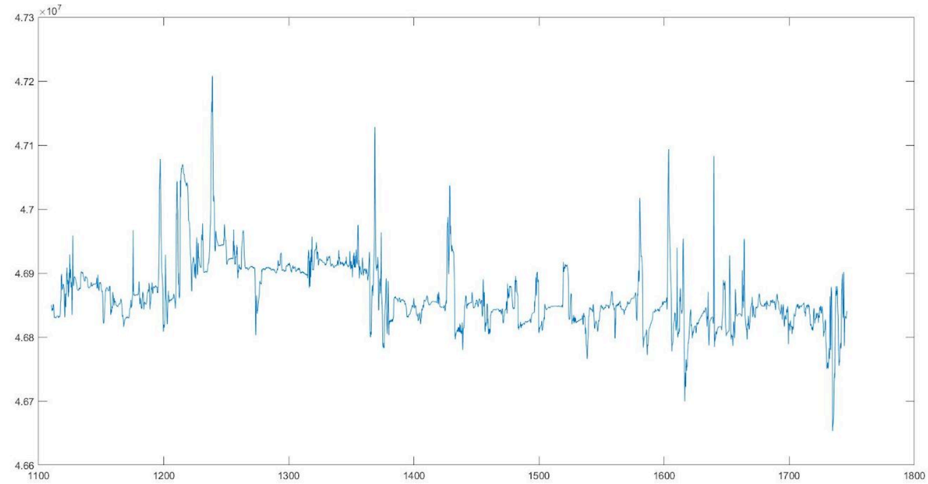
Set 2 - Sensor A (Heel Bone)



Set 2 - Sensor B (Achilles Tendon)

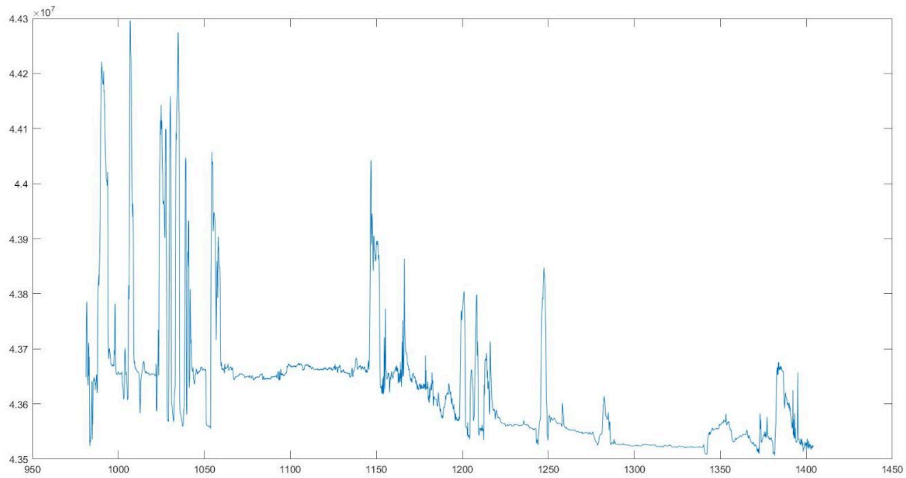


Set 6 - Sensor A (Talar Neck)

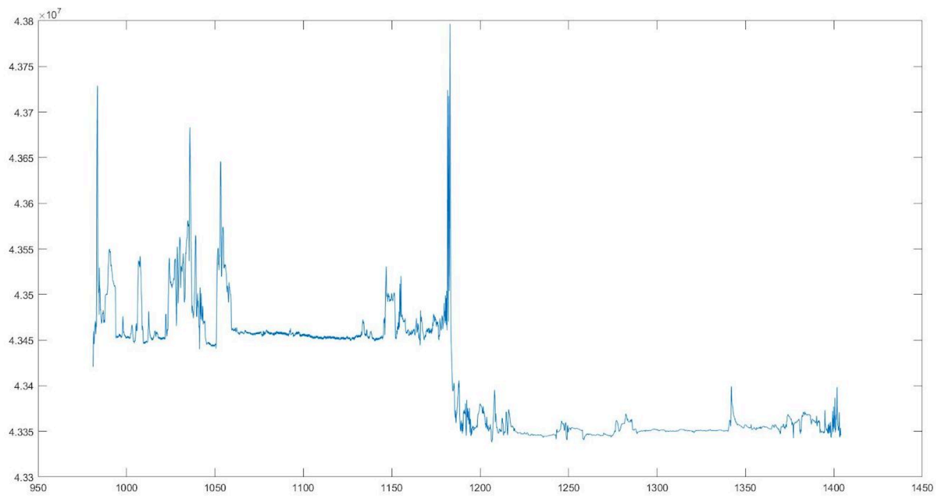


Set 6 - Sensor B (First Metatarsal)

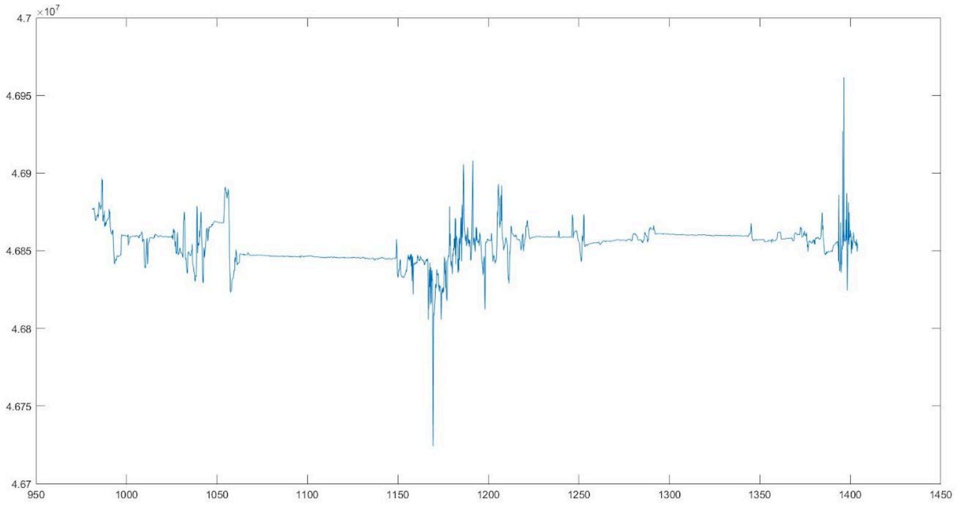
Test 3



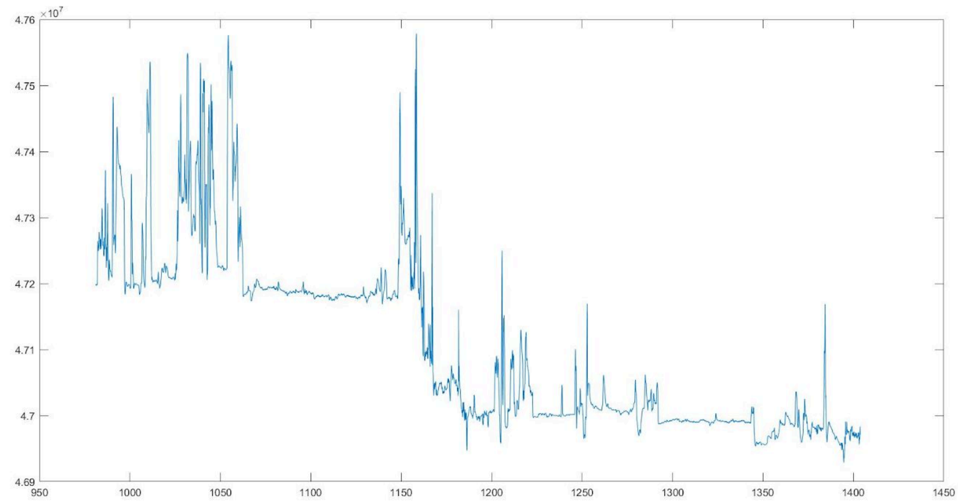
Set 2 - Sensor A (Heel Bone)



Set 2 - Sensor B (Achilles Tendon)

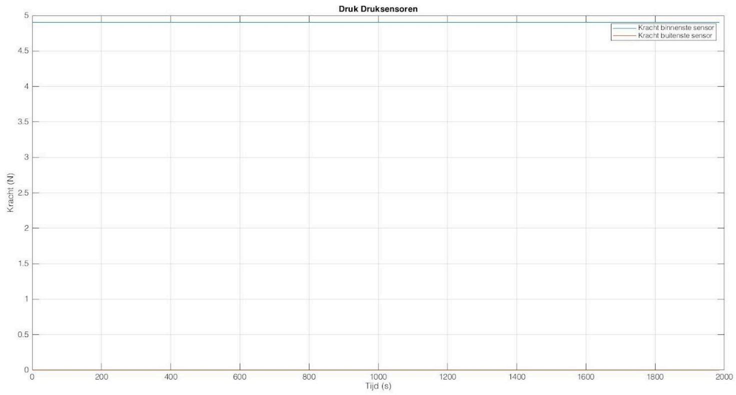


Set 6 - Sensor A (Talar Neck)

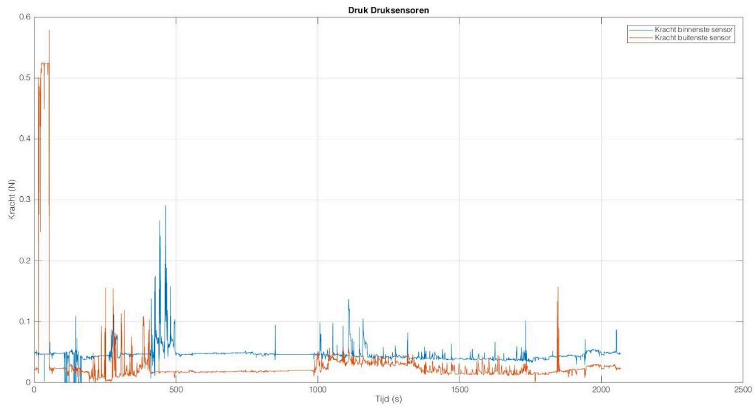


Set 6 - Sensor B (First Metatarsal)

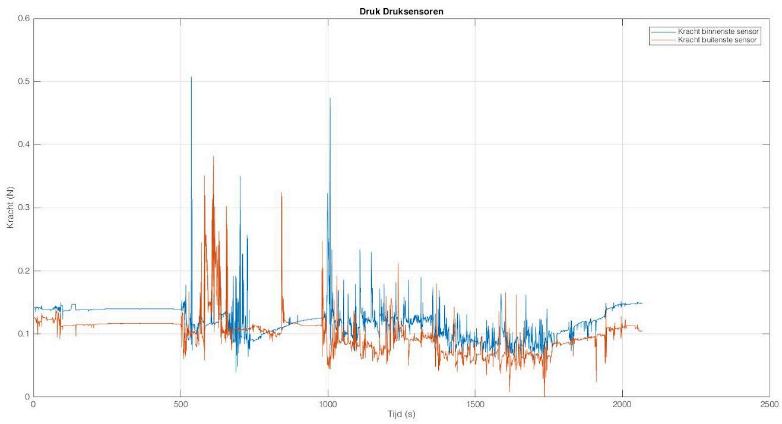
Appendix D - Graphs from script



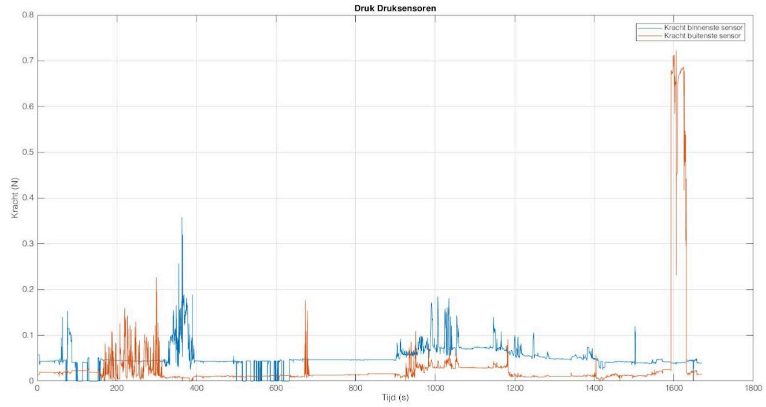
Test 1 - Set 6 - Blue line is the Talar Neck and red line is the First Metatarsal



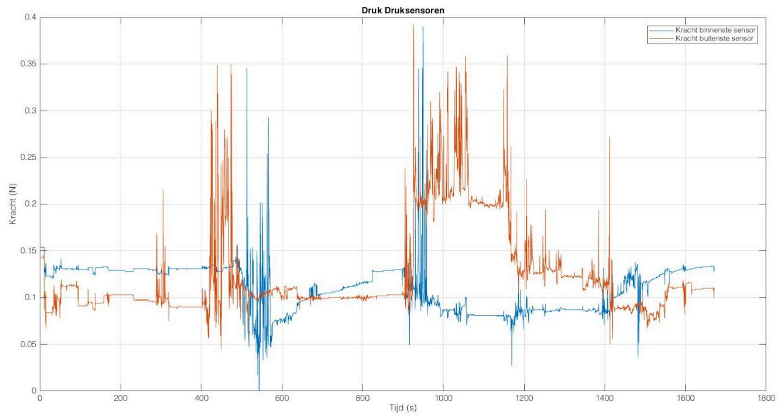
Test 2 - Set 2 - Blue line is the Heel Bone and the red line is the Achilles Tendon



Test 2 - Set 6 - Blue line is the Talar Neck the red line is the First Metatarsal

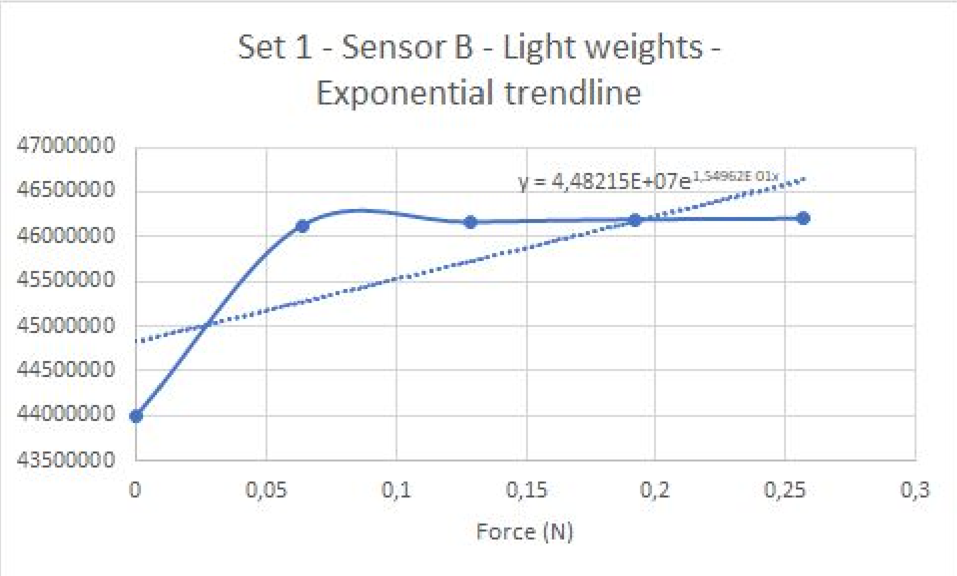


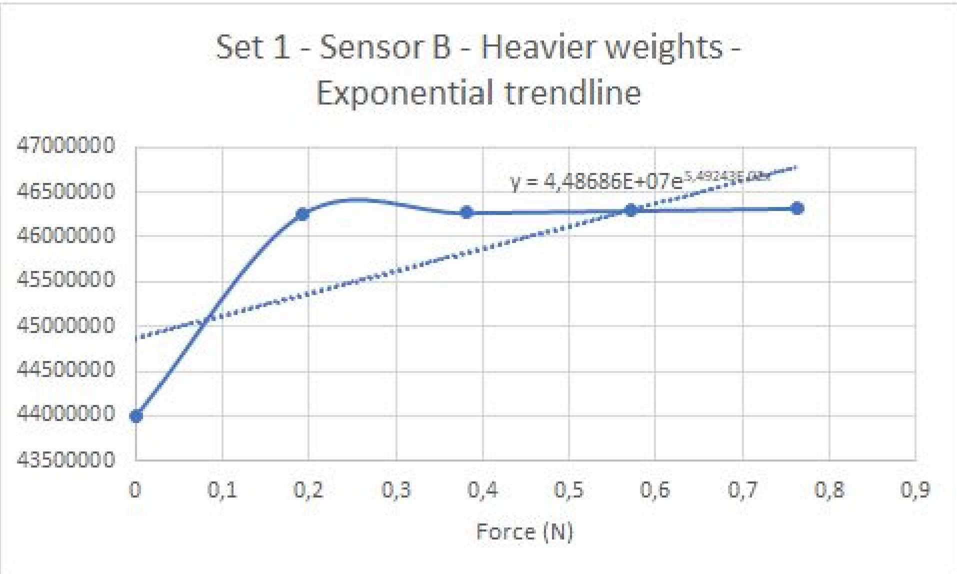
Test 3 - Set 2 - Blue line is the Heel Bone and the red line is the Achilles Tendon



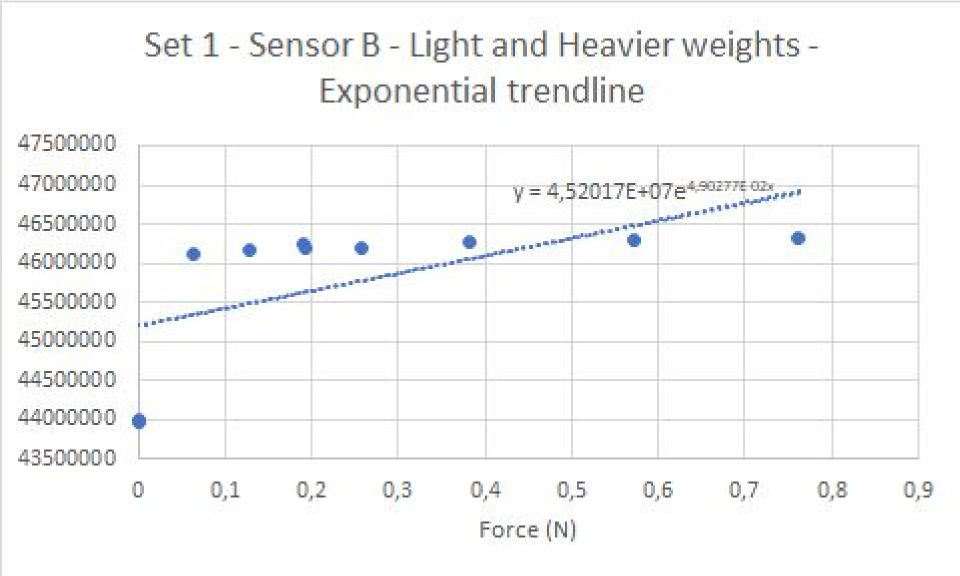
Test 3 - Set 6 - Blue line is the Talar Neck the red line is the First Metatarsal

Appendix E - Graphs from Excel (Light weights and Heavier weights with zero values)

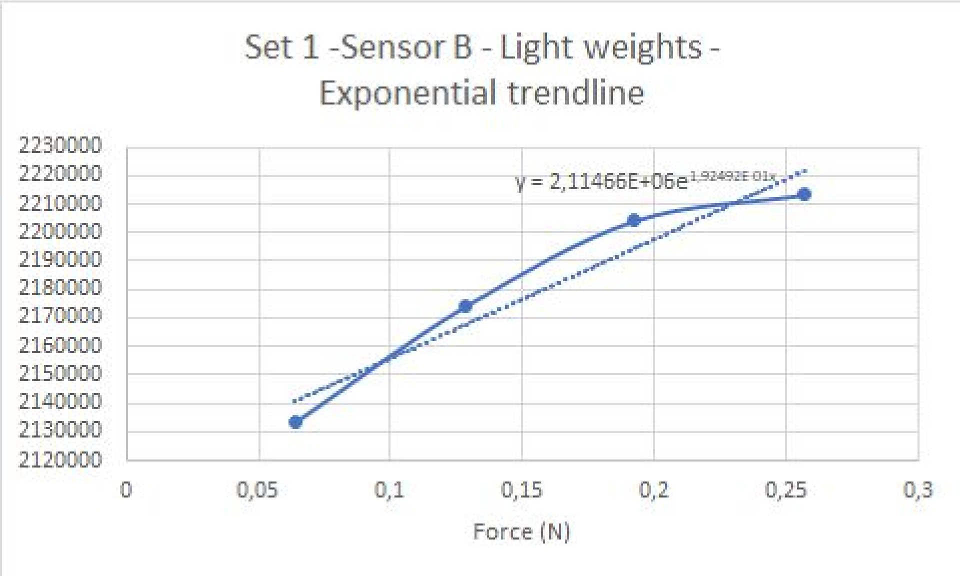


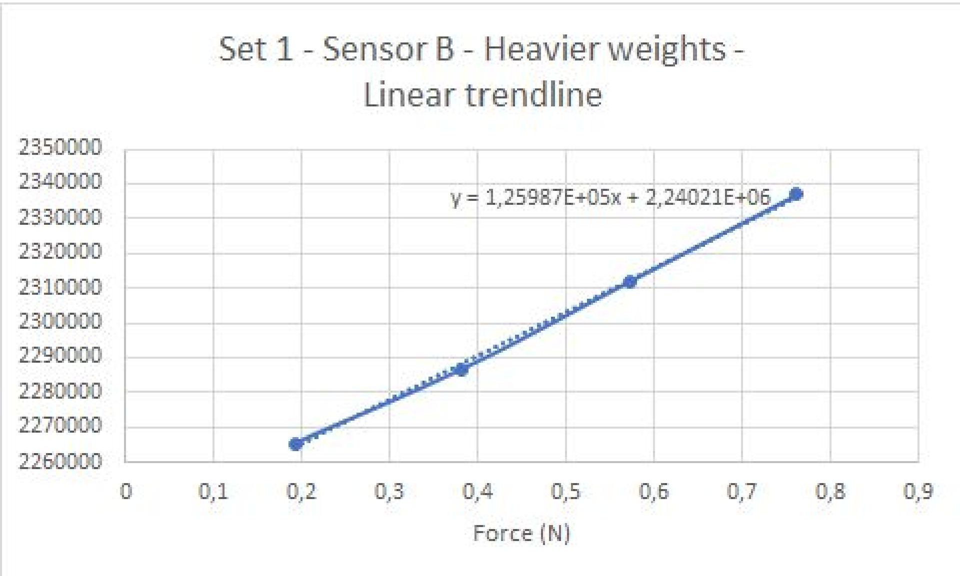


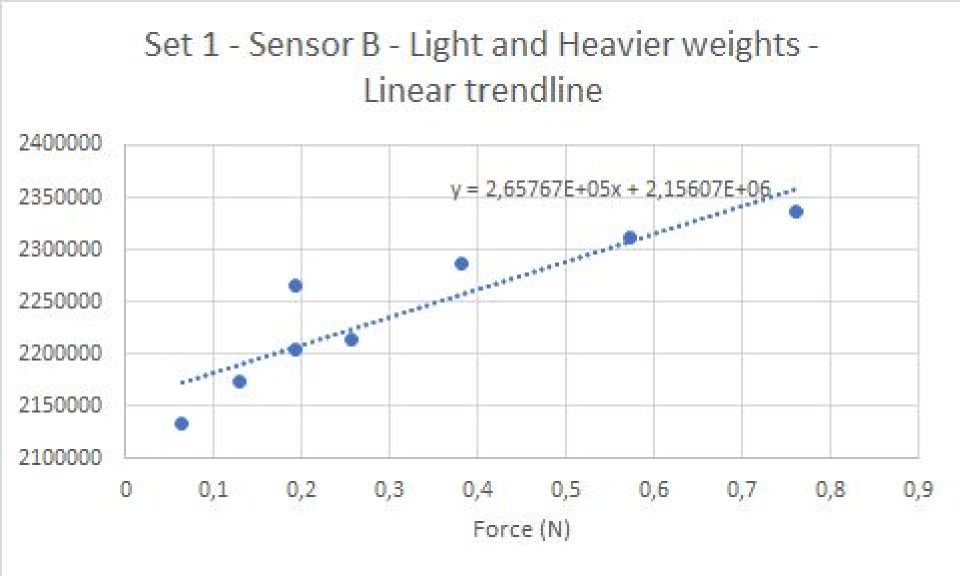
Appendix F - Graphs from Excel (Combination of Light and Heavier weights with zero values)

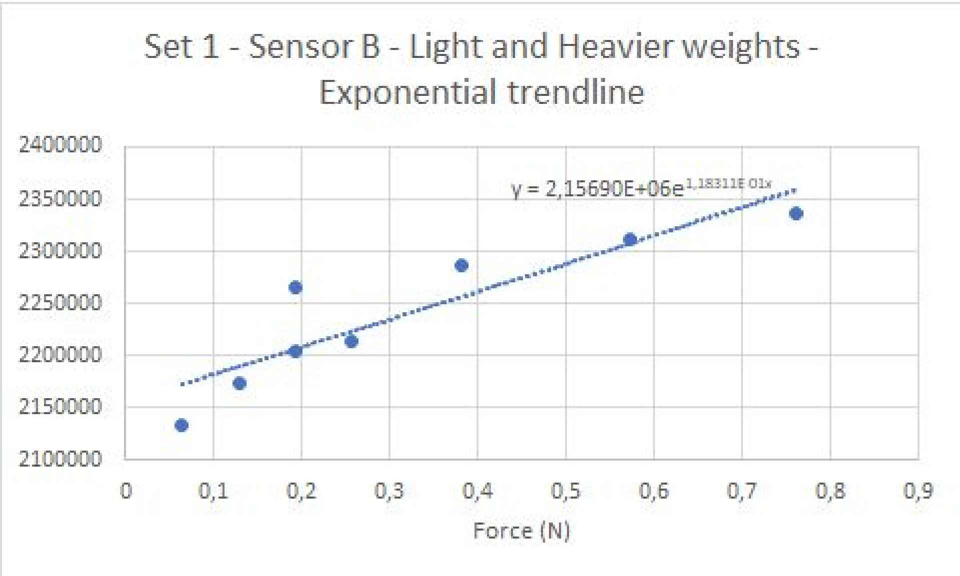


Appendix G - Graphs from Excel (Light weights, Heavier weights and Combination of Light and Heavier weights without zero values)






Set 1 - Sensor B - Light and Heavier weights -
Linear trendline
y = 2,65767E+05x + 2,15607E+06
2400000
2350000
2300000
2250000
2200000
2150000
2100000
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
Force (N)


Set 1 - Sensor B - Light and Heavier weights -
Exponential trendline
y = 2,15690E+06e
2400000
2350000
2300000
2250000
2200000
2150000
2100000
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
Force (N)

Appendix H - Calculations to Newton values

In general when we would convert a value of y to a value in Newton from a linear trendline we rewrote the linear trendline of the form $y=ax+b$ to $x=(y-b)/a$ and x would be a value in Newton then.

In general when we would convert a value of y to a value in Newton from an exponential trendline we rewrote the exponential trendline of the form $y=a*e^{(b*x)}$ to $x=(1/b)*\ln(y/a)$ and x would be a value in Newton then.