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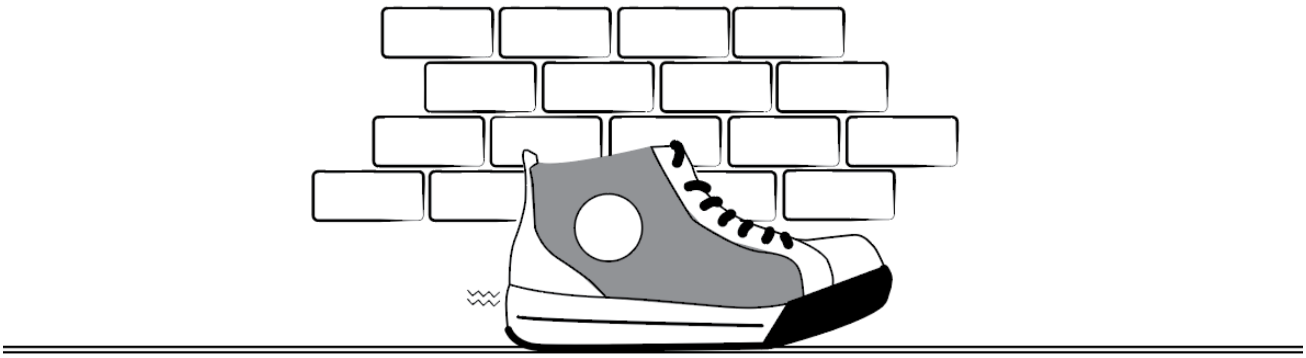
The smart safety Shoe.

A new type of safety shoe that helps prevent lower back problems and opens the door to a new era of preventive safety footwear.

-- Master thesis –- Mohamed Fayed --



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- In the loving memory of my father -

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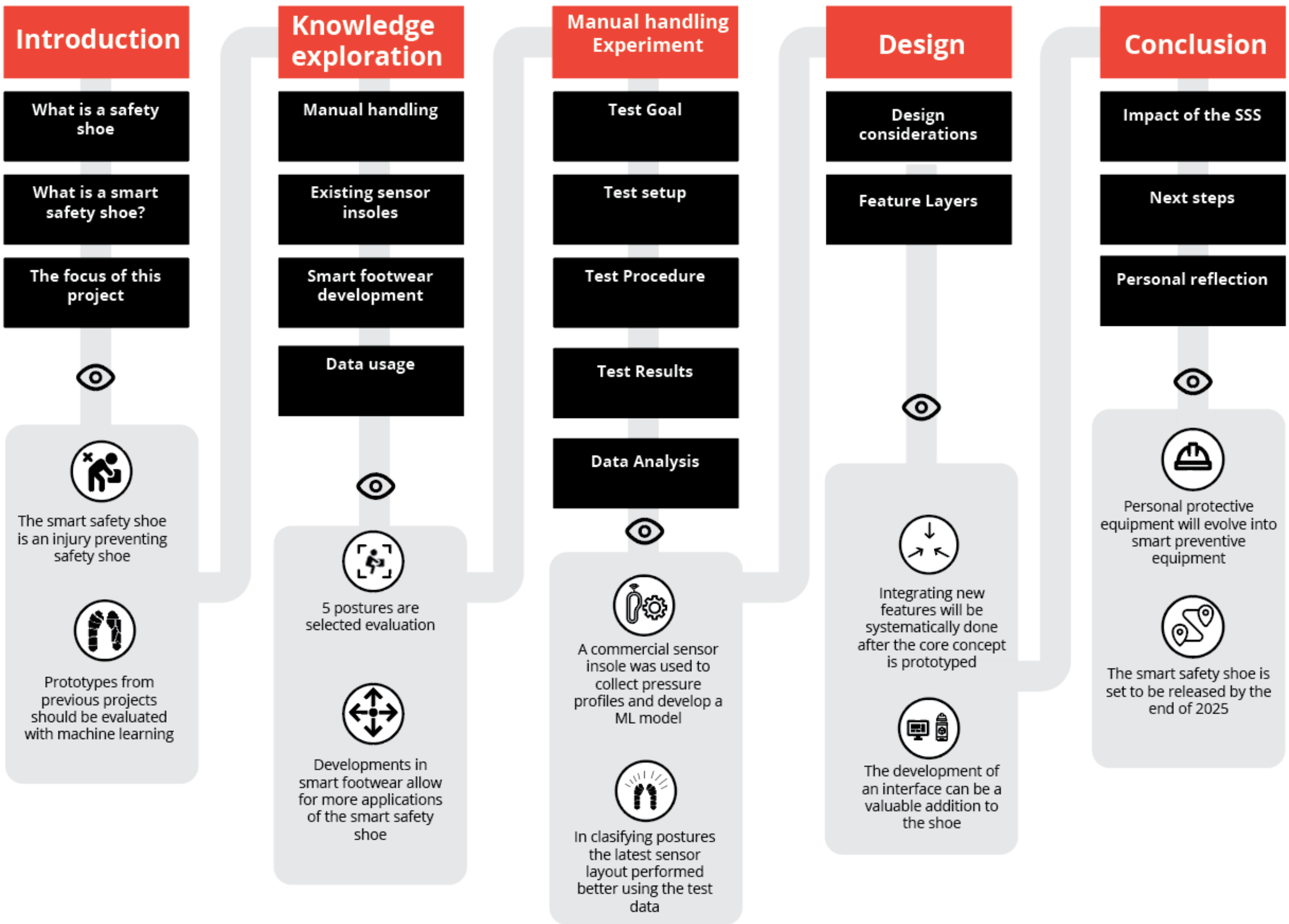
Summary

The smart safety shoe is a concept safety shoe that has been in development as a collaboration between Allshoes safety footwear and TU Delft since 2020. Previous work on the shoe consisted of 2 graduation projects and a student course which resulted in the current concept of an injury preventing safety shoe focused on preventing lower back pain in the logistics sector. The shoe works by using pressure sensors and machine learning to detect unhealthy postures while its wearer has to lift various objects as part of their job (manual handling).
This project focused on further developing the concept of the smart safety shoe and evaluating the prototypes from the last two projects. Previous projects provided two different pressure sensor layouts which are evaluated using a high-end pressure sensing insole.
A manual handling experiment was set up and performed on 16 different participants from a lab and a warehouse. During testing participants were instructed to perform manual handling while holding 5 different postures. It was possible to train a machine learning model using the various pressure profiles gathered from the experiment. Using this model, the two sensor layouts from the previous projects were evaluated for their ability to detect the 5 predetermined postures. It was found that the latest layout outperformed the previous one and was therefore selected for further development of the smart safety shoe.
The integration of various other sensors and actuators was evaluated, and the core functions of the shoe were defined with an indication towards future improvements of the smart safety shoe.
The shoe has now been publicly presented by Allshoes and the goal is to have the product on the market by the end of 2025. In order for this to happen further prototyping is needed to create an improved machine learning model based on the selected sensor layout. The shoe shows promising responses from current safety shoe clients. When finally launched it will be part of a new type of protective equipment focused on prevention.



01: Introduction

Introducing the concept of the smart safety shoe

This chapter provides a basic understanding of safety shoes and the various requirements attached to them. This is followed by a definition of smart safety shoes (SSS). Prior projects regarding the SSS are highlighted and the focus of this project is described using a program of requirements and Identified knowledge gaps.

Chapters

- What is a safety shoe?
- What is a smart safety shoe?
- The focus of this project?

01.1 What is a safety shoe?

Figure 1: Images of safety footwear used in different industries.

Safety footwear is a very specific but large market to design for. Most people in the world need some kind of footwear in their daily lives. And many of these people are required to wear safety shoes as part of their job. They are typically required for people who work in industries where there is a risk of injury from falling objects, electrical hazards, sharp objects, or slippery surfaces. These are industries like construction, manufacturing, warehousing, logistics, oil and gas, mining, transportation, commercial kitchens and public services like police, firemen, hospital staff, ambulance workers, and trash collectors.

In the Netherlands, the amount of people who work in such areas are over 9 million (CBS, 2022). These different industries have varying working conditions that generate a demand for variety in safety footwear.

In the Netherlands this demand is being fulfilled by companies like Allshoes. Allshoes is a company that specializes in safety footwear. An impression of the various types of shoes they offer is given in Figure 2. The company sells a variety of safety shoe brands, some of which are their own brands which they design and develop for in-house.

Figure 2 selection of different safety shoes from the assortment of Allshoes

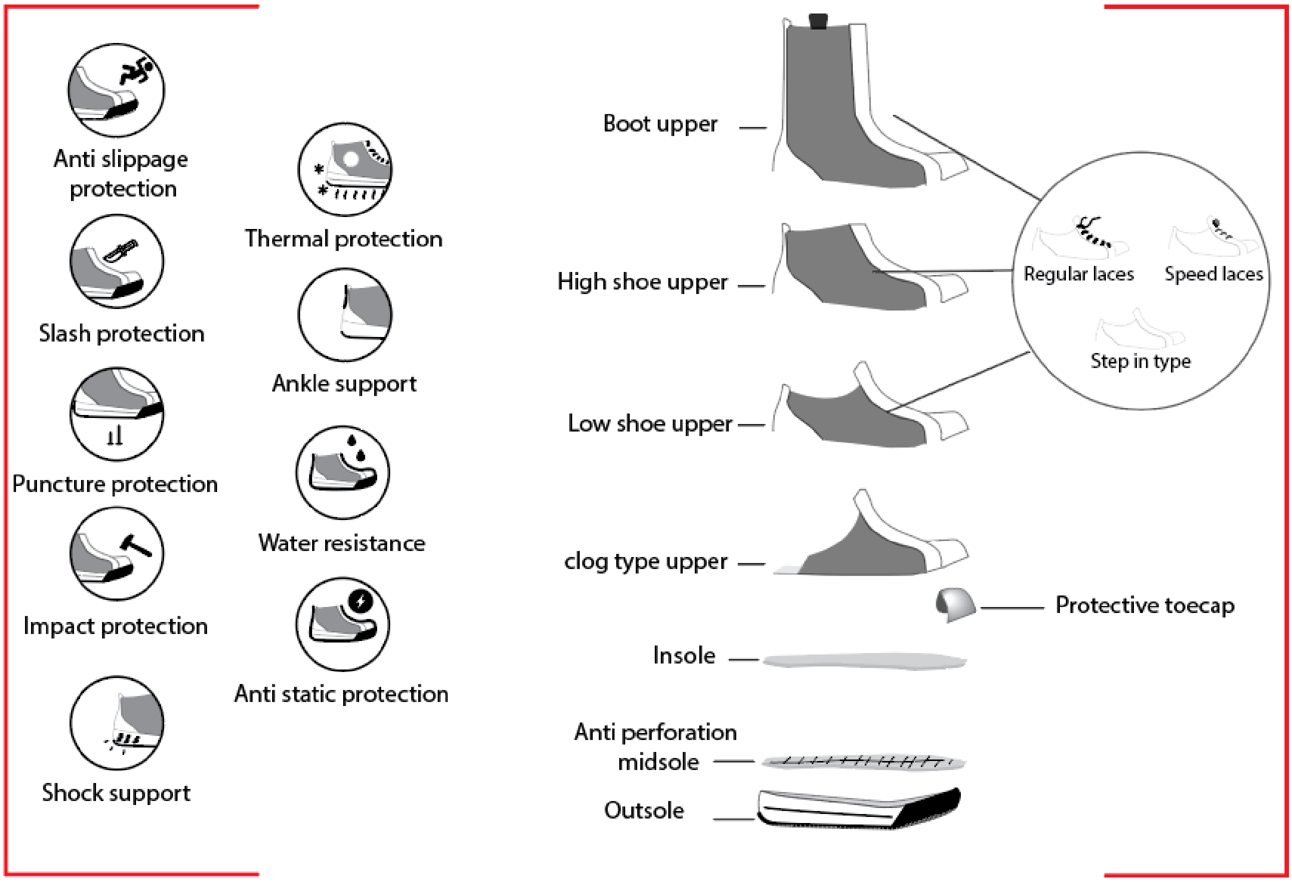


Figure 3: a simplified overview of the various components that make up a safety shoe and the possible features.

Designing for safety shoes

Although each safety shoe differs per brand and industry, they also share components to provide standardized protection. Figure 3 gives an overview of the various components that make up a safety shoe. When designing a new safety shoe there are two main parts that can be reconsidered. These are the upper part of the shoe, and its sole. Different variations of these parts can lead to different features to the safety shoe. A selection of these features shown in the figure is discussed below.

Impact protection

The most common requirement for safety shoes is to provide impact protection to the wearer. This translates to an either metal or plastic reinforced toecap embedded into the shoe. All types of impact protection must be able to withstand at least an impact of 200 joules. This is equivalent of 20 kg's dropped from 1 meter onto the toe.

Slip protection.

Safety shoes need to provide enough grip to prevent people from slipping. Especially for people Working in wet environments. Therefore, an anti-slippage profile with a grove pattern on the outsole is often required.

Anti perforation & slash protection

Safety shoes provide protection against sharp objects entering the shoe by adding metal or aramid (e.g., Kevlar) midsoles to the shoe. This will prevent injuries from accidentally stepping on sharp objects such as nails. In some cases, the upper is also made from reinforced materials.

Thermal protection

Safety shoes are often worn in environments where extreme temperatures occur. To keep the user comfortable, the shoes should be able to isolate heat or provide breathability depending in the circumstances.

Anti-static protection

In some environments like manufacturing plants, sensitive electronics are being used and developed. These electronics can be vulnerable to electrostatic discharge (ESD). Therefore, some safety shoes will require ESD protection.

Water resistance & water tightness

Safety shoes can be water resistant or watertight. water resistance, meaning that no moisture will enter the shoe through the upper a predetermined amount of time while complete water tightness will always keep your feet dry.

Shock protection & extra support

As workers are required to be on their feet for prolonged hours, some safety shoes provide extra cushioning materials to prevent lower back pain.

Lastly, safety footwear falls under a European standard known as EN ISO 20345. This standard provides a basis for companies to create their own designs and even innovate. According to the standard, safety shoes are classified in different classes ranging from SB, basic safety to S7. Each class specifies the type of design, their requirements and even materials that must be used in the shoes. (Table 1). Before a new shoe can be released on the market it has to conform to one of these standards.

SB	Basic safety shoe which must have a steel or plastic toe that can withstand an impact of 200 joule
S1	Adds requirement for antistatic protection and a shock absorbing heel to SB
S1P	Adds requirement for steel or Kevlar midsole to S1
S2	Adds water resistant requirement to S1
S3	Adds anti slippage profile to the outsole as requirement to S1
S4	Only Applies to boots, specifies materials as PU, rubber, or plastic and are watertight.
S5	Only Applies to boots, adds midsole and anti-slippage requirement to S3
S6	Applies to safety shoes without anti perforation protection,
S7	Adds complete watertightness to the requirements of S3

Table 1: different safety classes

01.2 What is a smart safety shoe?

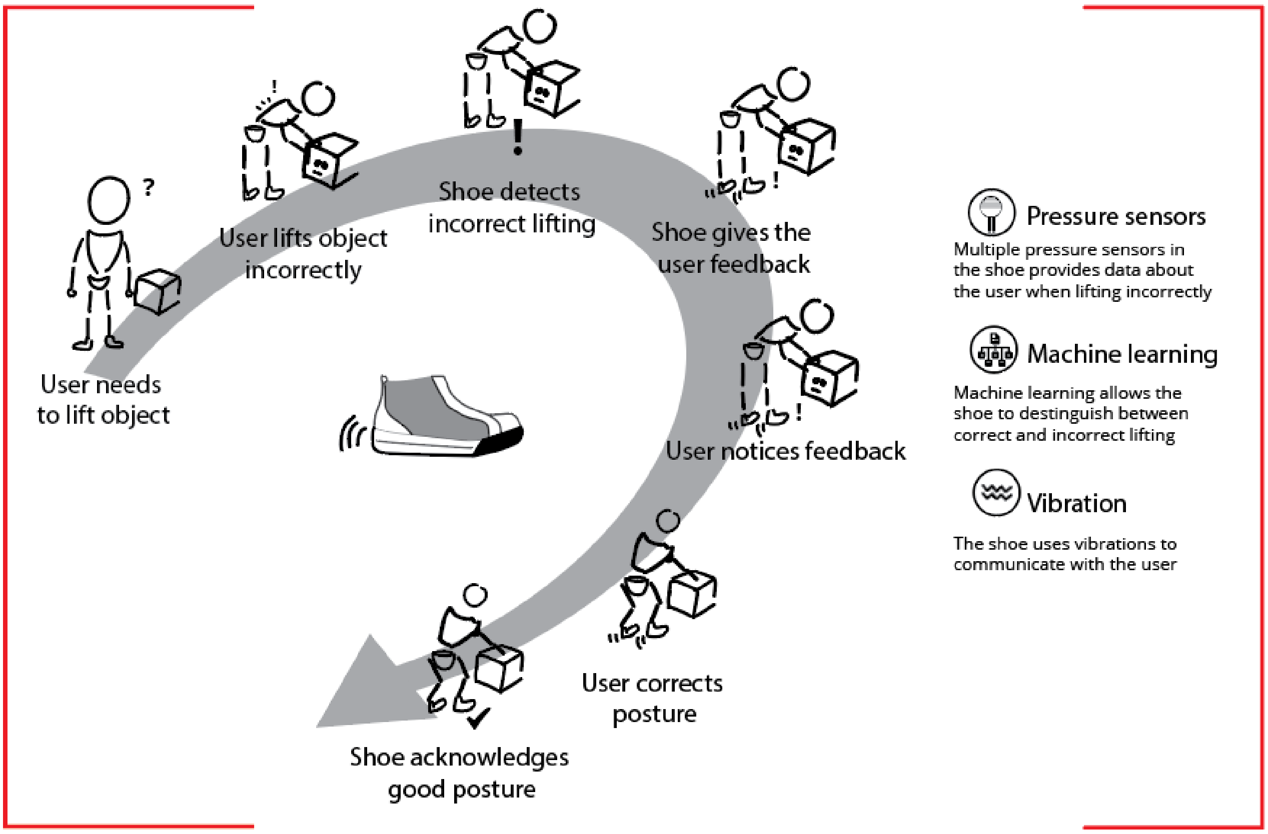


Figure 4 core functionality of the smart safety shoe

In its current definition, the smart safety shoe is a safety shoe that detects and corrects the posture of its wearer. This is enabled by using pressure sensors, machine learning, and vibrational feedback (Figure 4). Because the shoe provides real-time feedback to its wearer to encourage a healthier posture, it ultimately reduces the risk of lower back pain for workers. This concept originated in 2020. Allshoes created a design assignment to turn a regular safety shoe, which they framed as a shoe that only offers passive protection against safety hazards, into a shoe that provides active protection. This started an ongoing collaboration with TU Delft. 3 projects have since been conducted to define and test the smart safety shoe. Figure 5 gives an overview of the results that have been achieved during these projects.

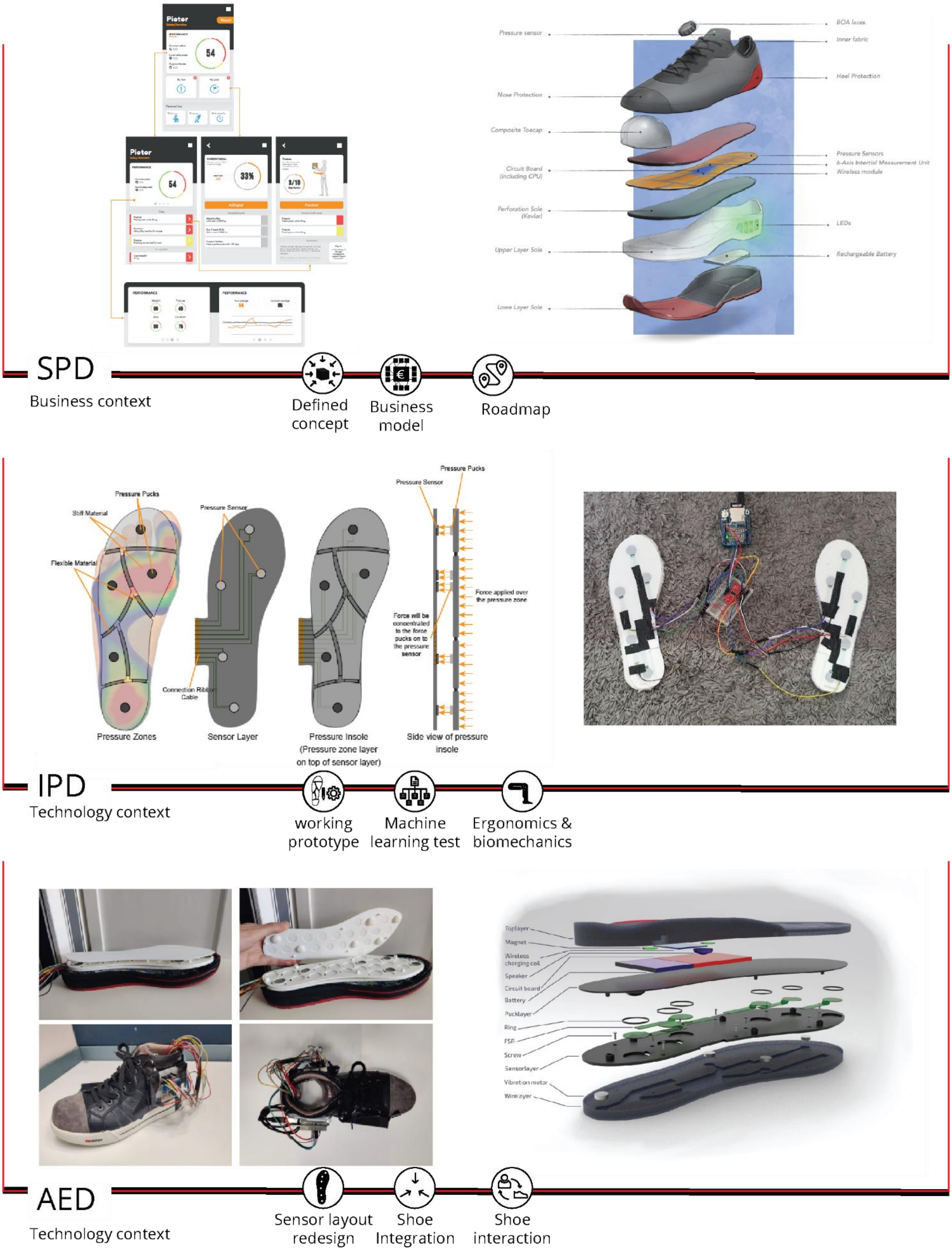


Figure 5: overview of results from previous projects on the smart safety shoe

Concept definition and business context (SPD project)
Strategic product design (SPD) Is one of the three masters' studies given at faculty of industrial design in Delft. The study focusses on the business context of product design. During this first project (van den berg, 2020), the current definition of a smart safety shoe has been defined. The goal of the smart safety shoe was to create a shoe that aids in preventing lower back pain. This was achieved by analyzing the existing market, considering the needs of the involved stakeholders, and researching existing technological capabilities. A roadmap was produced of which the first item for a follow up project was to create a physical prototype of the shoe.

Technology and prototyping (IPD project)
Integrated product design (IPD) is also a master's study from the faculty of industrial design. Its focus lies on conceptualization and embodiment design. This was the second graduation project done on the smart safety shoe. During this project (zhang,2021), the concept from (Van den berg 2020 was further developed regarding its technological feasibility. A physical prototype was produced using a custom insole with pressure sensors. Zhang managed to test the insole on himself and use the sensor data to make a machine learning model which was able to accurately differentiate between 3 harmful postures. The next steps for a follow up project were to try and validate this result for multiple users and further integrate the sensors in a safety shoe as well as the actuators that signal a detected posture to the user.

Technology and prototyping 2.0 (AED project)
Advanced embodiment design (AED) is a course given in the IPD master's program which teaches students about the different aspects of embodiment design. During this course a group of 6 students built on the concept from the previous projects and focused on integrating the required electronics into a safety shoe. Through prototyping the group explored interactive elements with vibrations and sounds, and a new layout for the pressure sensors was created. Next steps included further considering how to integrate all elements into a safety shoe as well as testing how the sensors would perform on multiple users for machine learning classification.

01.3 The focus of this project

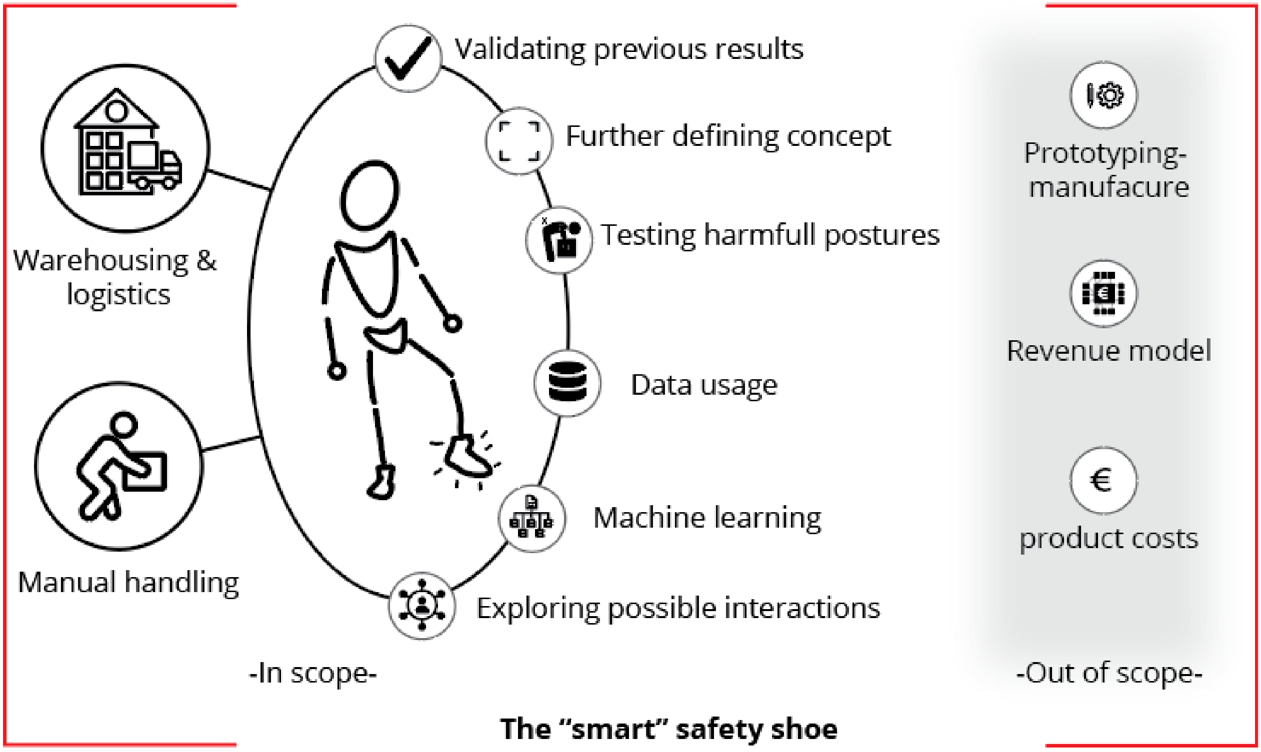


Figure 6 schematic view of several focus points in this project

The focus of this project lies in further defining and validating the smart safety shoe. Currently, the shoe is intended for the warehousing and logistics industry, The target group is for its workers who have to repeatedly lift objects as part of their job. The proof of concept provided from previous work still needs to be tested on multiple people, specifically the use of machine learning as a posture classification technique. Because machine learning requires a lot of data, the responsible use and collection of this data is further evaluated. Furthermore, the exact functionality of the smart safety shoe is explored and considered.
Some elements of the shoe are disregarded to reduce the scope of this project to a manageable size. Creating a fully functioning prototype and reevaluating its costs and revenue model are important steps which should be part of a follow-up project.

A "smart" product.
"Smart" products can be seen as products that combine the use of sensors and actuators with algorithms, and other technologies to collect and analyze data. They often communicate with other devices as part of an ecosystem of products. As a result, smart products are supposed to be more efficient, convenient, and user-friendly than their traditional "dumb" counterparts. When designing a smart product, it is important to keep its purpose in mind. Especially when regular versions of such products exist, the added benefit for improving it with "smart" technology should be clear and meaningful to avoid the risk of the product becoming a gimmick or an unnecessary luxury. For the smart safety shoe this means that it should not just exist because the technology allows it to, but because it genuinely contributes to a real-world problem.

Product requirements list

To further illustrate the concept of the smart safety shoe (SSS) and demonstrate what aspects of the shoe need to be considered, a list of requirements was made using wishes from Allshoes, results from the previous projects and a checklist from the delft design guide (van Boeijen, 2014). They have been sorted into external requirements, which are requirements that involve and affect external parties. Technical requirements, which are requirements that consider the technology involved in the shoe. And experience requirements, which are focused on benefits for the user.

External requirements

- The SSS should adhere to the current NEN ISO safety standards of safety shoes
- The SSS should adhere to the data protection requirements of the European GDPR.
- The SSS must allow for integration with current workplace protocols
- Producing The SSS should be possible with as little change as possible to the existing production of safety shoes.

Technical requirements

- The SSS can detect predefined postures of multiple wearers with considerable accuracy (at least 90%).
- The electronic components in the SSS need to be able to withstand environmental conditions inside (safety) shoes.
  (Body temperature, moisture, weight/force, static electricity etc.)
- The number of sensors needed to detect a posture needs to be optimized to minimize costs and complexity,
- The SSS should be able to process the sensor data locally.
- The battery life of the SSS should be long enough for a working shift of 8 hours,
- The SSS should allow for the replacement or charging of its battery.
- In producing the SSS, an effort must be made to promote sustainability of the product itself.
  (Durability, repairability, recyclability)
- The SSS should be provided as a standalone solution, its core functionality is fully integrated into the shoe.
- Posture detection has to work offline without the need for connection to other equipment.

Experience requirements

- Beyond the core functionality of the SSS, its potential for more functionalities should be communicated to users
- The presence of electronic components in the SSS must not compromise the comfort of the shoe.
- The SSS users should not feel uncomfortable in being monitored while wearing the shoe,
- The wearer Should feel supported and looked after when the shoe gives feedback about lifting postures.
- The feedback given by the SSS must always be noticeable by the wearer.
- The weight of the SSS must be optimized to prevent it from becoming heavy and burdensome equipment
- Continuous usage of the SSS should result in improved posture for a user.
- Compared to regular safety shoes, the SSS should reduce the number of injuries a user can get.

Knowledge gap

Which postures should the SSS be able to detect?
In order to build on the concept, the most relevant postures that can be detected need to be reconsidered. Both ergonomics and feasibility should be factors in this decision.

What can be learned from existing insoles and smart footwear?
The pressure sensing functionality of the smart safety shoe has been inspired by existing pressure sensing insoles. By analyzing examples of these insoles and their design, knowledge can be gained for the implementation of the SSS.

What is the best pressure Sensor layout?
From the last two projects, the pressure sensors in the smart safety shoe have been presented in two different layouts. The question remains which of the two layouts will perform better in their intended purpose of machine learning classification.

How to derive postures from sensor readings?
Machine learning is the overarching technology used to detect postures. In order to design for this functionality, A better understanding of the process and type of machine learning Is needed.

Which data is relevant?
The usefulness and relevance of other data needs to be evaluated. Besides data from its pressure sensors, what other data is required for the SSS to function as it is supposed to? And what data could be considered as well?

How to process data?
The large amount of data involved with the smart safety shoe requires the right processes and protocols to be set up. The safest, most efficient, effective, but also responsible and ethical way to process the data need to be evaluated.

02: Knowledge exploration

Obtaining knowledge surrounding smart and interactive footwear.

This chapter provides a knowledge exploration to obtain a better understanding of manual handling, the existing uses and design pressure sensors in footwear. And the use of data that this footwear can potentially collect.

Chapters

- Manual handling
- Existing sensor insoles
- Smart footwear development
- Data usage

02.1 Manual handling

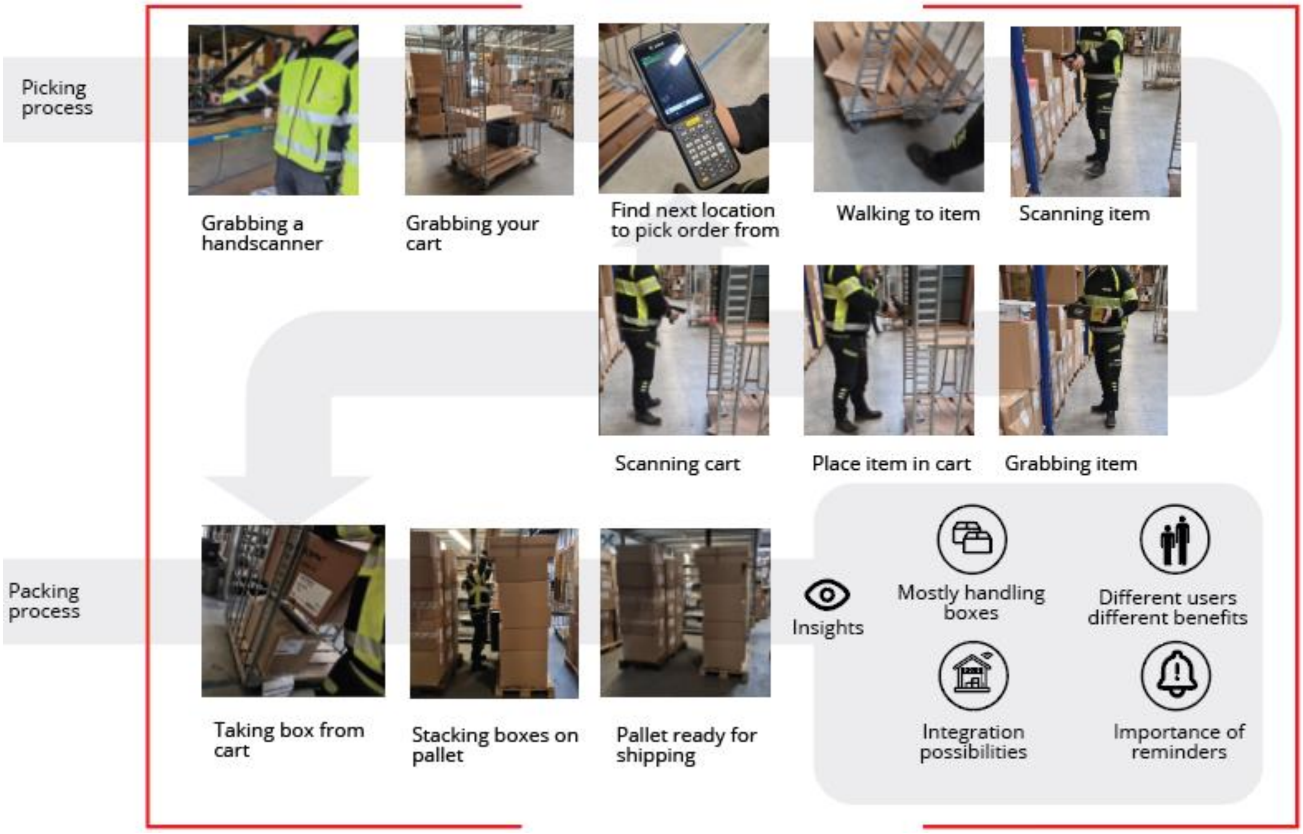


Figure 7: processes in the Allshoes warehouse where lifting occurs.

Warehouse processes

In the Netherlands, work related Lower back problems are most common in the warehousing and construction sector (NEA,2019). These jobs often require manual materials handling (MMH). This describes the process of routinely moving and handling objects by carrying, holding, lifting, pulling, pushing, and stooping. (CDC, 2022).
If done incorrectly and repeatedly, workers will develop lower back pain over time.
In a visit to the Allshoes warehouse, two specific processes are further looked at for manual handling. These are the picking process, and the packing process (Figure 7). During the Picking process, a worker is tasked with gathering specific items that are part of a customer's order. Order picking is often the most labor-intensive job in a warehouse (Romaine, 2022). Workers are required to move around the warehouse, pick orders from the various shelves and put them onto a cart. The cart can be motorized, but sometimes it is pushed manually.
In the packing process, the orders that have been picked are sorted and packed for delivery. In the case of large shipments, workers are required to stack the boxes on top of each other onto pallets. Using a forklift, these pallets will then be loaded onto a truck and shipped out.

Insights

There are a few insights that should be considered when designing a possible intervention from the smart safety shoe. First of all, being physically strong and tall is a benefit as they sometimes pick boxes from high places. Secondly, many employees understand the importance of correct manual handling, but they also admit that it is not often on their mind when they are working, they would have to be reminded about this from their team leader. Even though communication between workers is mostly verbal, tools like the hand scanners used in the picking process are connected Via Wi-Fi throughout the whole warehouse which demonstrates some possibility for a smart product to be integrated into their work.

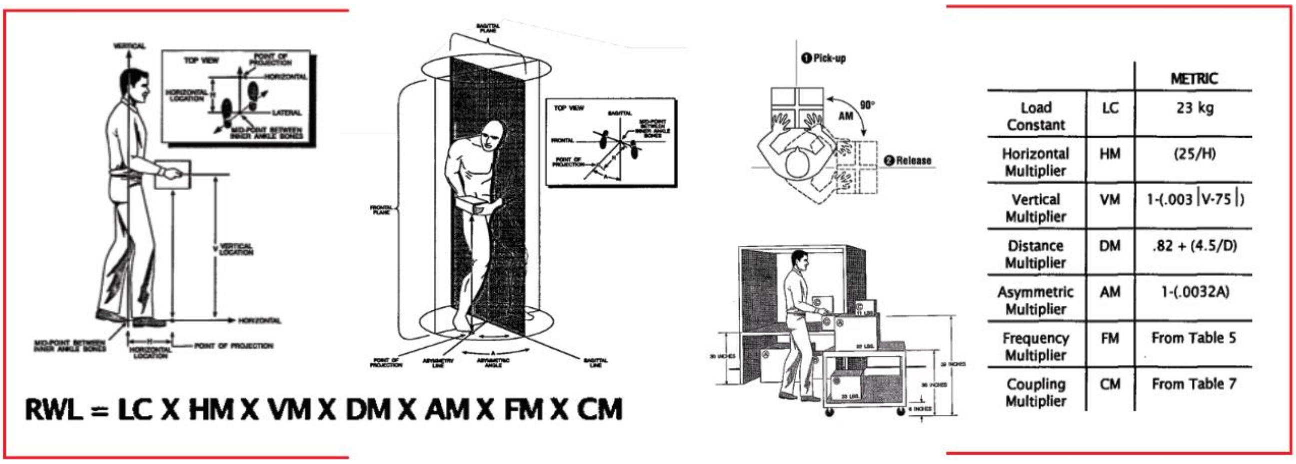


Figure 8: NIOSH formula for the recommended weight limit is calculated by looking at conditions of a task.

NIOSH equation

The National Institute for Occupational Safety and Health (NIOSH) provides guidelines for correct lifting. A common method Is to make use of their recommended weight limit. (Waters et al.1994). The recommended weight limit (RWL) is described as a formula which can be calculated using the conditions of a specific task that a worker needs to perform (figure 8). The formula starts with a load constant (LC) which has a starting value of 23. This represents a maximum weight that can be lifted of 23 kg under perfect conditions. Perfect conditions are achieved when all multipliers are set to 1. Depending on the specific task a worker has to perform, the multiplier value can decrease which also decreases the recommended weight limit. In the warehouse, workers will usually not be lifting under perfect circumstances. A simple example is the face that carboard boxes have no handles which reduces the coupling multiplier depending further on the size of the box. When considering the other multipliers, a more realistic weight limit will be around 10 to 15 kg.

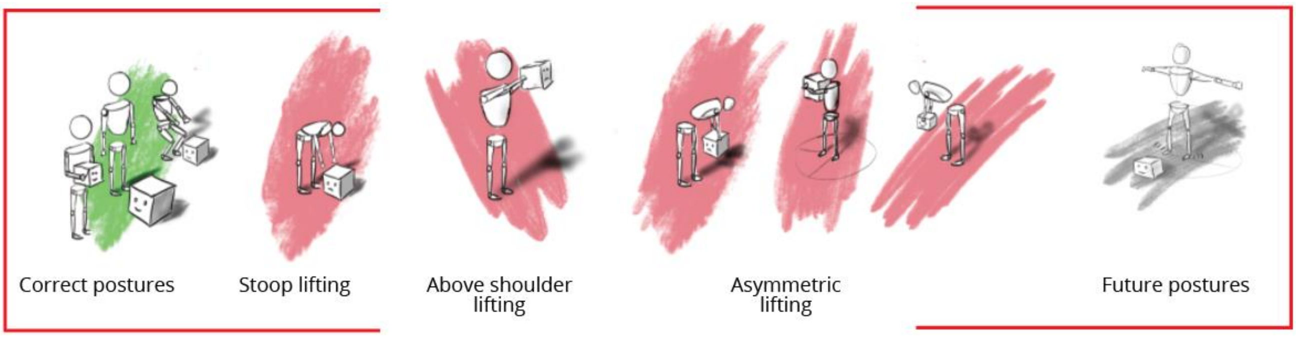


Figure 9: overview of postures to be detected by the SSS.

Different poses to be detected.

In a previous project, (zhang,2021) was able to distinguish between stoop lifting, above shoulder lifting and asymmetric lifting using machine learning. These postures were found to be harmful in a warehouse. More postures could be defined, but detecting the most harmful ones should be considered part of the core functionality of the shoe. In order to distinguish between the harmful and good postures, the shoe needs to be able to detect a correct posture too. Figure 9 highlights these different postures

02.2 Existing sensor insoles

Different uses for pressure sensing insoles

The smart safety shoe integrates pressure sensors into safety shoes, but the use of pressure sensors inside footwear is not unheard of. Pressure sensors have been applied to other types of footwear and turned into commercial products as removable insoles. Figure 10 gives an overview of these products. It reveals that the insoles are used in two main sectors. Some are intended for medical research and diagnostics, while others are used as an analysis tool in the sports industry. Specific uses of these insoles are further highlighted in figure 11.

All the insoles are used to measure plantar pressure distribution, this is a term used to describe the pressure as a result of the force that your feet exert on the ground. By studying plantar pressure (Pedobarography), insights can be gained about a subject's health. It can be studied statically, allowing the detection of uneven and abnormal pressure patterns and the design of custom footwear to correct unhealthy stances (orthotics). But often the sensors are combined with inertial measurement units, enabling a dynamic study of plantar pressure distribution. This is known as gait analysis, which concerns the study of human locomotion. Specifically, during walking and running. Gait analysis allows for even more insights to be gained about a subject's health and enables applications like creating custom treatment plans for rehabilitation and performance optimization in sports.

The insoles are available for varying prices depending on their technical specifications, target group, included software, and accessories. Products that are relatively cheaper like the Nurvv running insoles can be bought for 200 euros (Nurvv,2016), while the xsensor insoles start at around 10.000 euros (xsensor demo,2023). During a demo of these insoles, it was explained that their high price was partially due to the included software, but other aspects like the number of sensors, need for calibration, and durability all influence the price.

Other insoles with relevant features for the smart safety shoe are the Feetme insoles which incorporate wireless charging. The neurogait insoles also provide a wireless charging dock, the company claims that their insoles can provide insights into human gait using just 4 pressure sensors (SALTED, 2021). Lastly the open go insoles (moticon,2023) which are powered by a coin cell battery. Battery life is claimed to be 8 to 15 hours.

Insights for the smart safety shoe

For the smart safety shoe, elements of gait analysis could be considered to gain insights into the wellbeing of workers. If this is done, privacy sensitive information is collected which has to be considered against the risks involved.

Even though all insoles come with their own custom software solution, software developed for the smart safety shoe should be adjusted for warehouse workers and possibly managers to incorporate the different postures.

Most of the insoles are intended as temporary tools to gain insights about a user's health and performance. They can be reused across different shoes and different users. The smart safety shoe, however, is intended for daily use, for a single person.

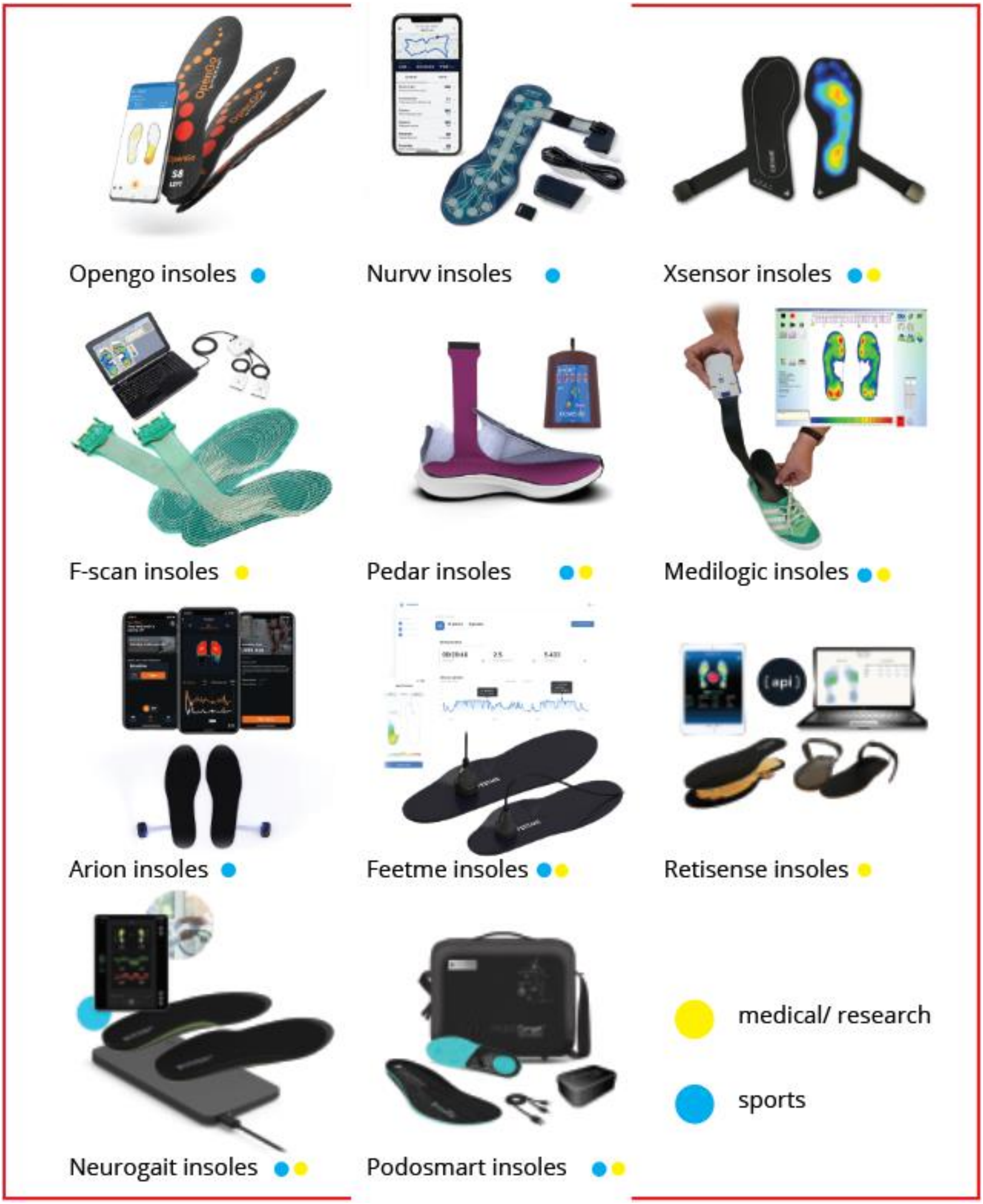


Figure 10: different commercial insoles and their uses.

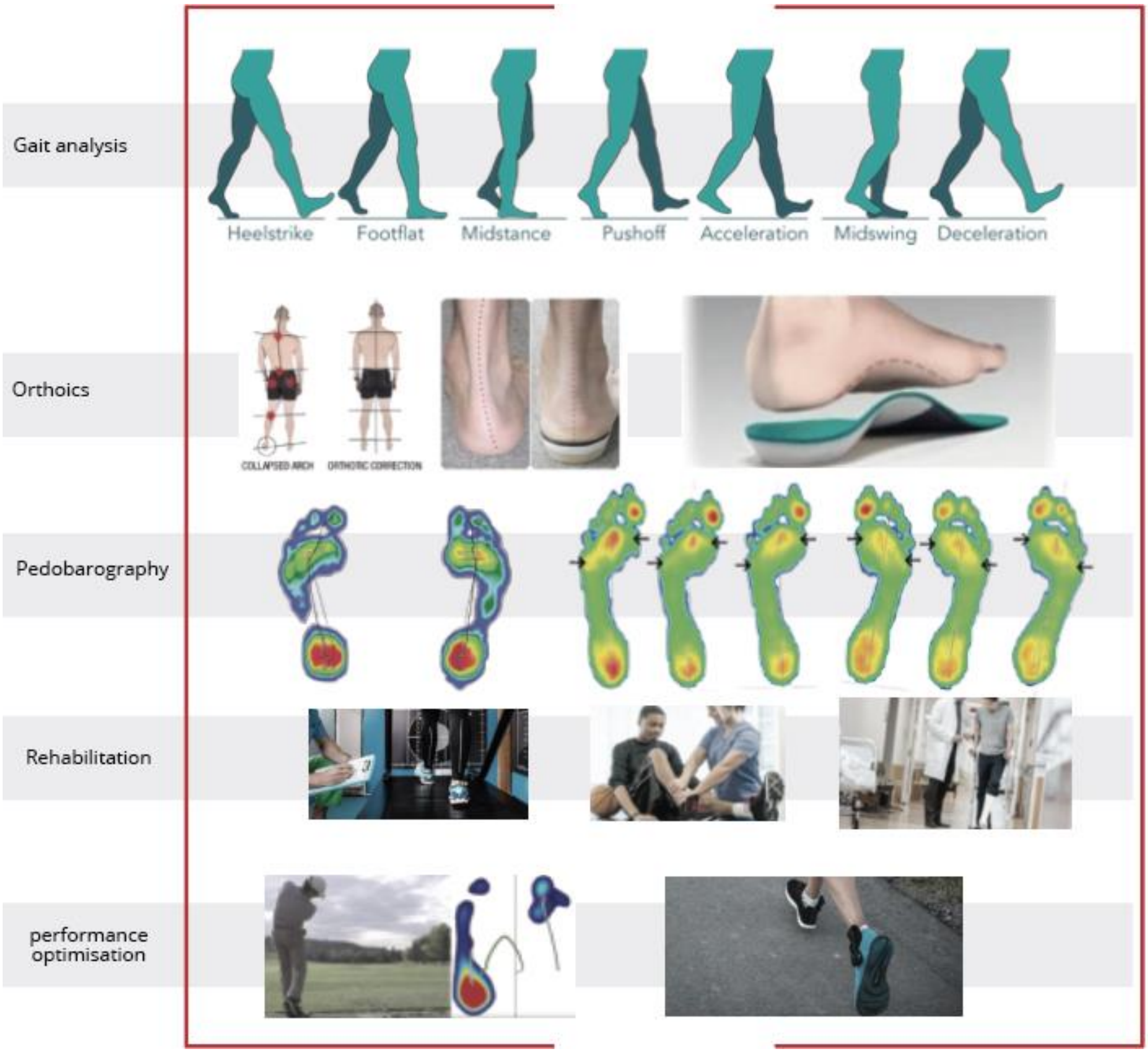


Figure 11: specific uses for different pressure sensing insoles.

02.3 smart footwear development

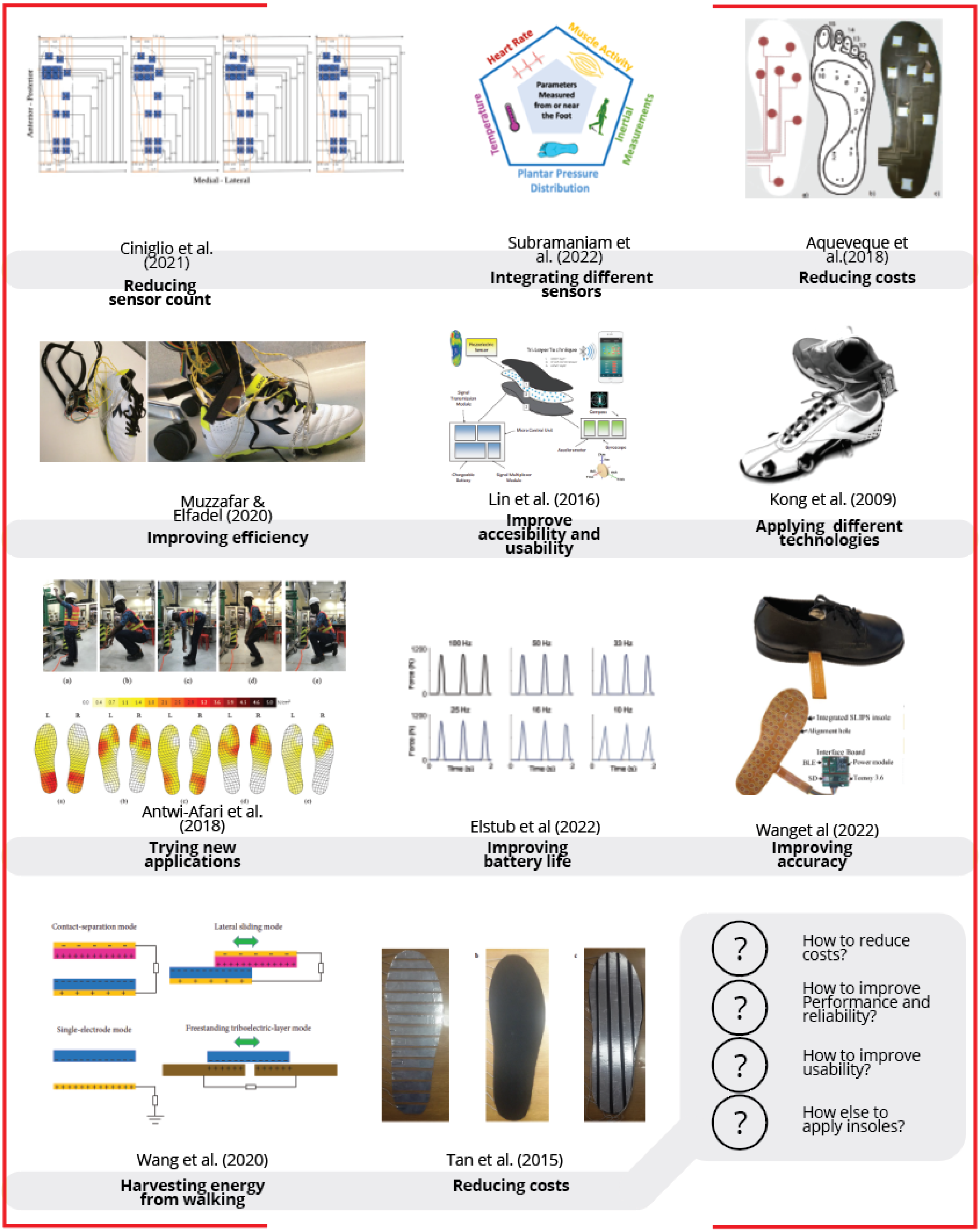


Figure 12: Overview of different studies on developing Sensorized footwear.

An analysis of various studies focused on the development of smart insoles reveals a few common goals (figure 12). Firstly, high costs are a limitation when it comes to implementing smart insoles in everyday lives. Strategies for cost reduction are decreasing the amount of sensors, using different types of sensors, and reducing processing power. Some of these strategies will also result in increased battery life which further enables the implementation of these insoles in different areas. With reduced costs, however, compromises are sometimes made to the quality of the sensors which affect the insights that can be gained from them. The most common and cheapest pressure sensors are so called force sensing resistors (FSRs). These sensors have been used on early prototypes of the smart safety shoe due to their price and availability. Initial tests proved that these sensors would suffice, but to improve durability other types of pressure sensors could still be considered.

All sensor insoles are paired with a software solution to make sense of the raw data stream coming from the sensors. An interface is commonly provided which plots the pressure readouts onto a graph or heatmap. These types of data visualization tools still require human interpretation to gain insights about the wearer.
With the use of machine learning, acquiring some of these insights can be automated, this is one of the core principles of the smart safety shoe.

02.4 Data usage and processing

There are many ways in which smart footwear can be used to gain insights from its wearers. These insights should be considered privacy sensitive and should therefore be handled with care.

Considering the GDPR

Nowadays the use of any kind of smart device carries privacy risks that should be closely considered when designing its ecosystem and setting up a data architecture. The European general data protection regulation (GDPR) has a few requirements *(GDPR.com, 2019)* that can have an impact on the design. Discussed Below are articles from the GDPR that could be relevant for the design of the smart safety shoe.

Article 12 (transparency and communication):
The way that data is processed for the smart safety shoe must be explained in clear and plain language.
Article 13 (during data collection):
Now of data collection, several information needs to be communicated to the wearer of the shoe. This includes what data is being collected as well as contact information.
Article 15 (right of access):
People wearing the shoe have the right to access the data that is being collected about them. Even though it is part of the concept of the smart safety shoe to provide the wearer with an overview of their lifting behavior devised from the data about their foot pressure.
Article 18 (Right to erasure):
Also known as the right to be forgotten. This means that people wearing the shoe or who have worn the shoes have the right to have the data it has gathered about them deleted.
Article 18 (right to restrict processing):
A little less extreme than completely erasing data. The people whose data is being processed should also have the right to restrict some of their data. In the future the smart safety shoe could be capable of more than just detecting and correcting bad postures. Workers should have the ability to opt out of extra features.

Other considerations

Companies are often encouraged to practice data minimization. This means that they should try to collect the least amount of personal data possible. When they collect only what is necessary for a product to function, they reduce the potential for abuse as well as the risks associated with a data breach. While the GDPR provides a set of rules to ensure the general protection of data, the customers' experiences, and attitudes towards a particular product or service should always be evaluated.

02.5 Key insights

Posture detection

Currently many lifting postures are being evaluated on a visual basis, it's good to have more quantifiable tools that can speed up the process. In this project 5 types of postures are further evaluated; these include harmful and correct postures.

Using Insoles as a prototyping and development tool

While existing insoles are too expensive to use directly in the smart safety shoe, they can be used in its development process. An accurate insole will provide valuable information to validate the different postures that the shoe should be able to detect.

Responsible data use

Guidelines from the GDPR can be seen in a checklist for the design of the data structure of the smart safety shoe. But the actual attitude towards the shoe should still be monitored to make sure the shoe will be well received.

Possibility for expansion

The different variations and applications of Sensorized insoles indicate how the smart safety shoe could be further applied as the first of its kind for safety footwear. The continuous development of new insoles proves that there is a growing interest and demand in smart footwear.

03: Manual handling experiment

Finding a relationship between posture & pressure pattern

This chapter contains the documentation of an experiment with a pair of pressure sensor insoles. The test was performed to get insights into the pressure patterns of people performing predetermined lifting postures. The goal was to select a sensor layout from the previous smart safety shoe projects and gain knowledge regarding the use of pressure sensing insoles. The data from the test is analyzed using a program called orange, Using the tree machine learning algorithm both layouts were evaluated, and the better performing layout was selected.

Chapters

- Test goal
- Test setup & procedure
- Test results
- Data analysis
- Discussion
- Key insights

03.1 Test goal

It was determined that the layout of the pressure sensors in the smart safety shoe had to be selected. This test represents the approach to achieve this goal. It involves a commercial set of pressure sensing insoles. The goal is to collect plantar pressure distribution profiles of the 5 types of postures which the smart safety shoe needs to be able to detect. The data gathered for each profile will help determine which sensor layout works best for classifying the different postures using machine learning.
The insoles used in this test have a total of 230 sensors per foot. Currently the smart safety shoe is meant to work with 6 pressure sensors. The 2 potential layouts for the sensor locations developed in the previous projects are shown in figure 13. Having this reduced number of sensors means that they must be placed at the right locations inside the shoe to accurately perform posture detection.

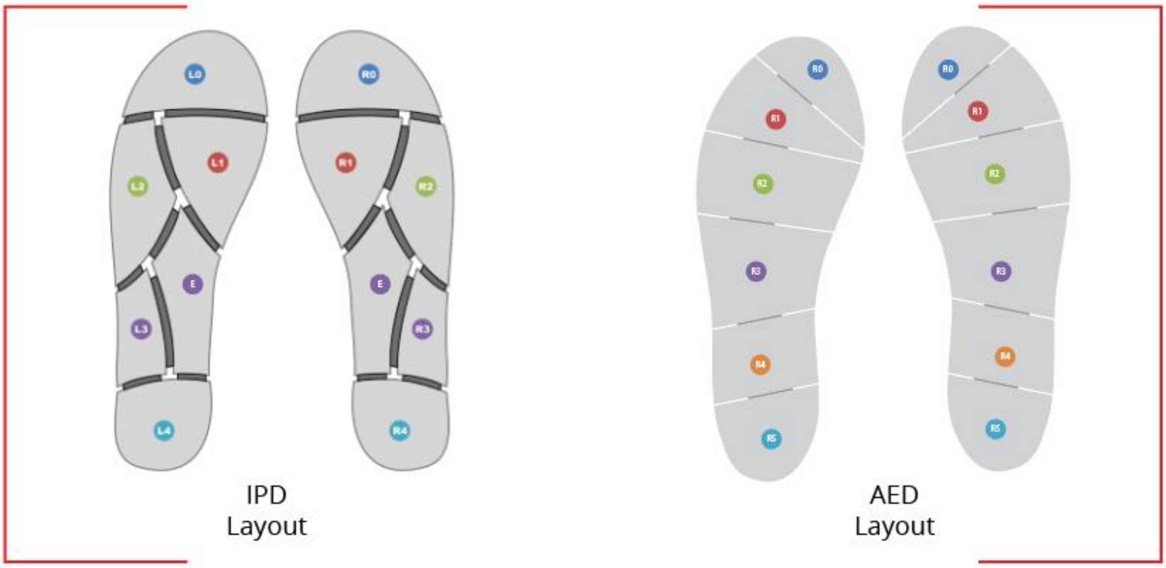


Figure 13 : 2 layouts of sensor locations from previous project on the SSS

Research questions

1. What do the pressure profiles of participants performing the predetermined poses look like?
2. Where on the foot appear pressure spikes when performing the different poses?
3. How well would the existing sensor layouts of the smart safety shoe be able to detect the 5 different poses using machine learning?
4. How well are the insoles able to detect different loads.
5. Which elements of the xsensor insoles and its software can be used for the design of the smart safety shoe?

03.2 Test setup & procedure

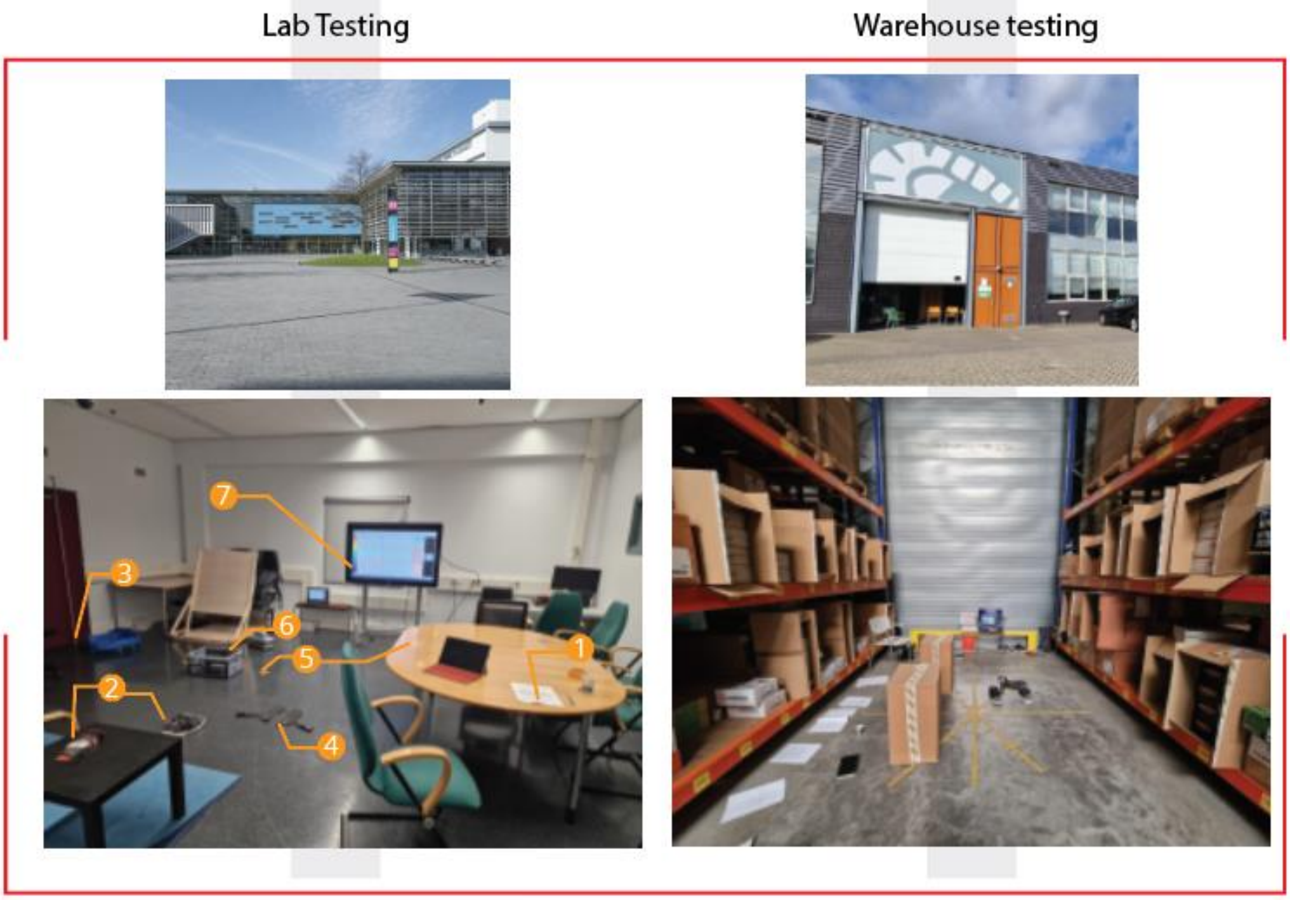


Figure 14: two test locations: the IDE HCD Lab in Delft (left) and the Allshoes Warehouse in Alkmaar (right)

Testing took place in two locations over the course of 1 week. Initial tests were performed in a laboratory environment with mostly students as participants. The test was then replicated in the Allshoes warehouse with warehouse employees as participants because they are the actual target group of the smart safety shoe. Figure 14 shows the setup of the test with the most relevant elements. For consistent results the test setup in the warehouse was kept the same as the test in the Lab. The numbered elements are as follows:

1) **Consent form:** Participants were first introduced to the test and given time to sign the consent form.
2) **Safety shoes & socks:** Safety shoes were provided along with a new pair of socks to minimize the effect of different shoes on sensor readings and eliminate hygiene issues.
3) **Measurement tools:** Measurements of each participant's length, weight and foot size were taken.
4) **Xsensor insoles:** Sensor insoles were put on after participants had tried on the shoes to check if there were any noticeable differences with the insoles.
5) **Taped markings:** To keep the lifting consistent for each participant the ground and table were marked with tape.
6) **Crate & weights:** A crate with weights of 1kg, 5kg, and 10kg was used for each posture.
7) **Software display:** The xsensor software visualizing plantar pressure was deliberately put on a display for participants to help them better understand the test.

About the insoles

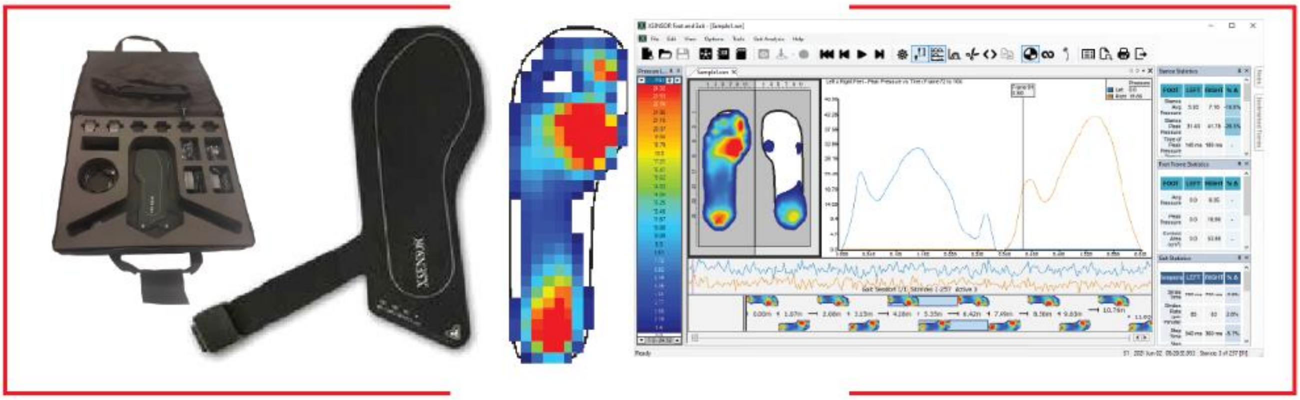


Figure 15 xsensor insoles and the software that comes with it.

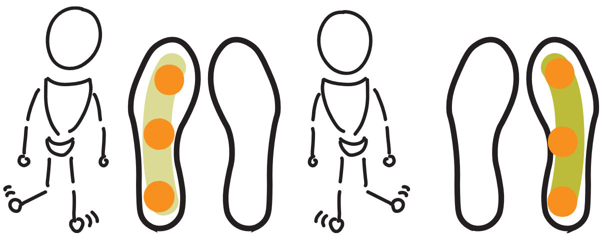
The Xsensor insoles used in this test can be used to visualize and quantify plantar pressure distribution due to its high resolution of pressure sensors. Each foot has a total of 230 piezoelectric pressure sensors called sensels (Pro Foot & Gait user manual, 2022). The pressure sensors are integrated into the footbed while a ribbon cable connects to an enclosure which houses the battery, processing unit and wireless communication module. Other elements in the enclosure are a charging port, storage card slot for offline data readings and an inertial measurement unit (IMU) that can be used for gait analysis. This enclosure is clipped to the side of the shoe. The insoles are often used to improve sports performance or help in walking rehabilitation. But they are also used in footwear design to optimize the shape of a shoe and provide enough support where pressure spikes occur. To accommodate this a custom foot and gait analysis software is included (figure 15). The software makes it easy to visualize the data coming from the insoles and provides a set of tools to perform analysis.
In this test, only pressure sensor readings are used, it was chosen not to make use of the IMU sensor as only static readings are used for classification. A direct Bluetooth connection with the sensors was used to allow for the visualization of plantar pressure during the test.

Procedure

During the test, participants were instructed to perform 5 different poses. They were first demonstrated before participants were asked to perform it themselves a total of two times. This was then repeated for a 1kg, 5kg and 10 kg configuration of the crate. Different weights were used to be able to test if the insoles could differentiate between them.
While the goal was to get readings of unhealthy postures, it was still important to stay within the recommended weight limit describe by NIOSH (waters et al. 1994). Therefore, a maximum of 10 kg has been used to stay within the weight limit. This was also ensured by using a crate with handles which eliminated the effect of a coupling modifier. Each participant performed the postures in the same order.

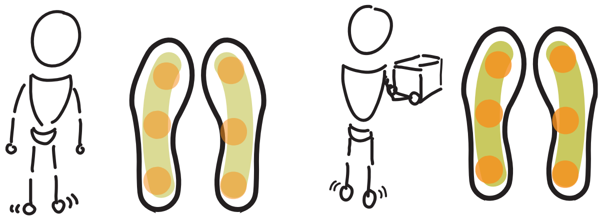
Sensor check/Calibration

The participant is asked to lift one foot up to check if se sensors are correctly placed and their shoes are not tied too tight. Their plantar pressure is expected to be zero for each foot that is held up. If this is not the case a zero-load calibration can be done.



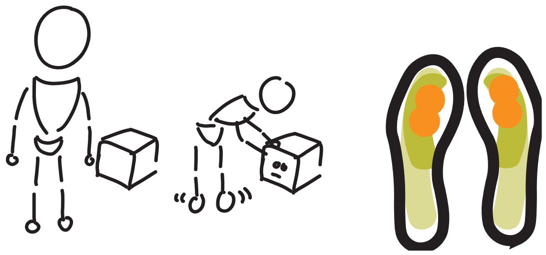
Standing still

The participant is asked to stand still without any load and while holding a load the correct way,
Their plantar pressure should be equally distributed over their feet.



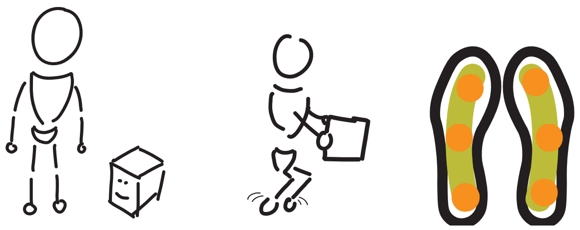
Stoop lifting

The Participant is asked to lift the crate incorrectly by bending over and picking up the box. Their plantar pressure is expected to be concentrated near their toes.



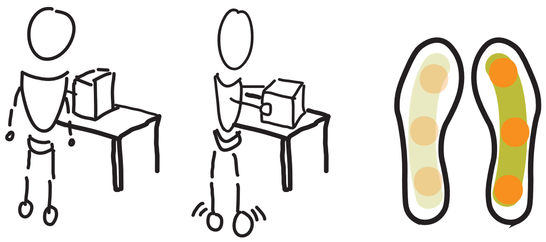
Correct lifting

The participant is asked to lift a box correctly by crouching and lifting the box while standing up. Their plantar pressure is expected to be more equally distributed along the whole foot but less than fully standing with the weight.



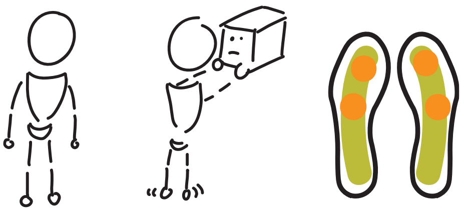
Asymmetric lifting

The participant is asked to lift a box incorrectly by moving it between two points on a table only being allowed to rotate their body without moving their feet. Their plantar pressure is expected to be unevenly distributed per foot.



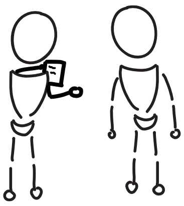
Above shoulder lifting.

Participant is asked to lift a box incorrectly by holding it above their shoulders. Their plantar pressure is expected to be more concentrated near their toes.



End of test/ evaluation

Participant is given the opportunity to further try out the insoles, the test is concluded with questions for participant regarding their experience of the test.



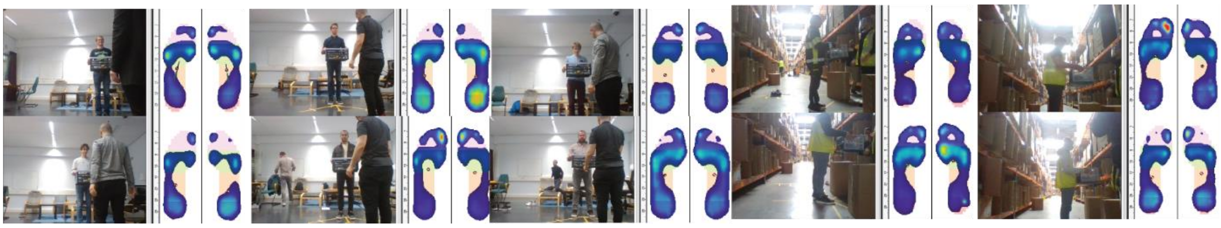
(The full script of the test that has been used is included in *appendix B)*

03.3 Test results

Visual analysis of the pressure profiles

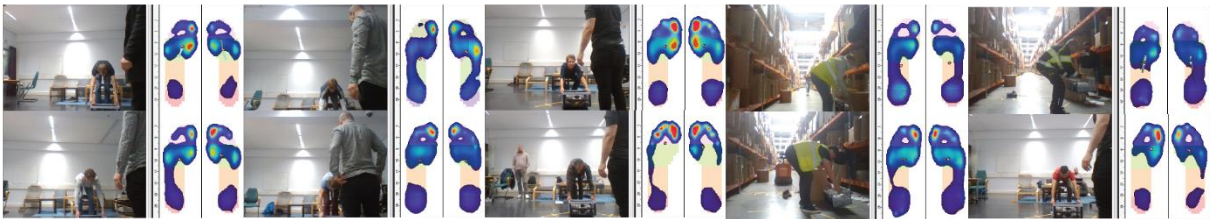
The following profiles are snapshots taken from participants performing the instructed postures with a 10 kg weight.

Standing still



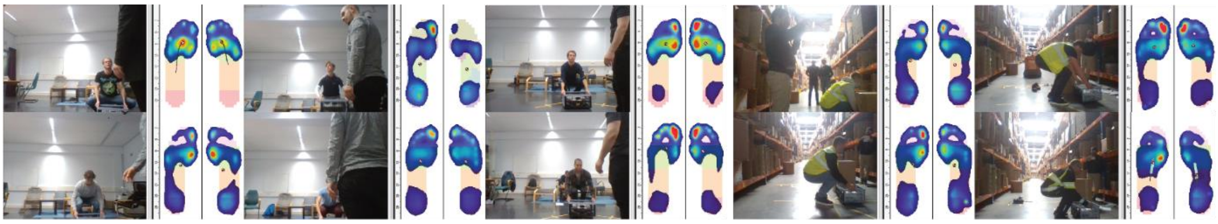
The pressure patterns of participants standing still while holding a weight clearly show an evenly distributed pressure profile over the whole foot. The center of pressure is slightly forward due to the participants holding a weight in their hands. The contact area between a participant's foot and the sensor footbed differs per participant. This can be explained by the different foot sizes, a participant's weight, and the flatness of their feet.

Stoop lifting



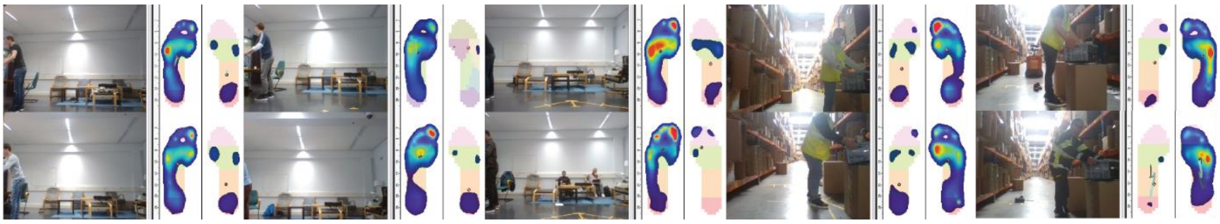
During stoop lifting, participants lean forward to pick up the crate, their weight should therefore be concentrated near their toes. This can clearly be seen in the pressure patterns from the test. However, there is a difference in the exact position of these concentrations. While most participants lean largely on their biggest toe, for some the pressure is more spread out over the area of their forefoot. The contact area near the heel is also preserved, although the pressure in this area is relatively low, the fact that it can still be registered could help in defining the posture for classification.

Correct lifting



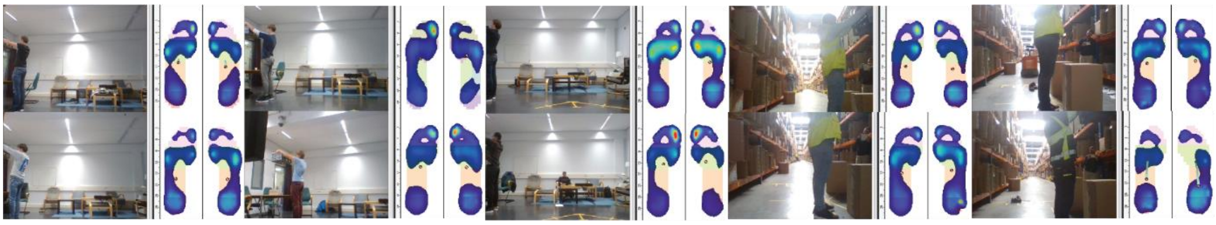
The pressure profiles of participants performing correct lifting seem harder to differentiate between the other profiles than expected. As some participants lifted the crate, the exact direction was not perfectly vertical. This resulted in varying pressure distributions. Furthermore, even though all participants received the same instructions and a demonstration, some participants still preferred to lift while only their toes touched the ground while others had full contact with the ground. This demonstrates the complexity of human behavior while lifting.

Asymmetric lifting



Pressure profiles from asymmetric lifting are easy to identify due to the fact that most of the bodyweight is resting on a single foot. Some pressure is still registered in the non-load bearing foot, this can be explained by small variations from participants performing the posture as well as the fit of the insoles inside their shoes.

Above shoulder lifting



Upon first sight, the profiles from above shoulder lifting look similar to those of the standing still posture. I expected the pressure to be more concentrated near the toes but instead most profiles show a more evenly distributed load. It's important to mention that while participants moved the load above their shoulders for a brief moment this expectation was met, however, to be able to keep their balance most participants would correct for this by moving their head back resulting in an evenly distributed load.

Layout selection

A visual analysis of each of the profiles provides some insight into how these postures can be detected. At first glance it seems like asymmetric lifting and stoop lifting are easiest to detect. However, visually it is very difficult to decide which of the two layouts (AED and IPD) would be most suitable to detect the postures. As a next step, both layouts will be tested for their performance using machine learning. This is further described in the next chapter section regarding data analysis.

03.4 data analysis

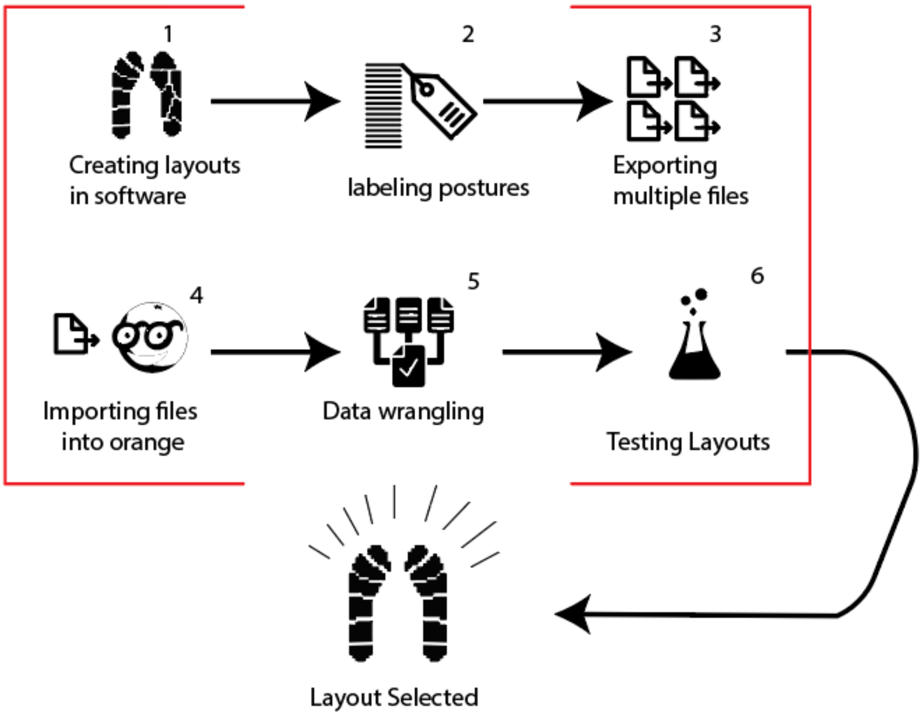


Figure 16 overview of activities in data analysis

Creating layouts in software

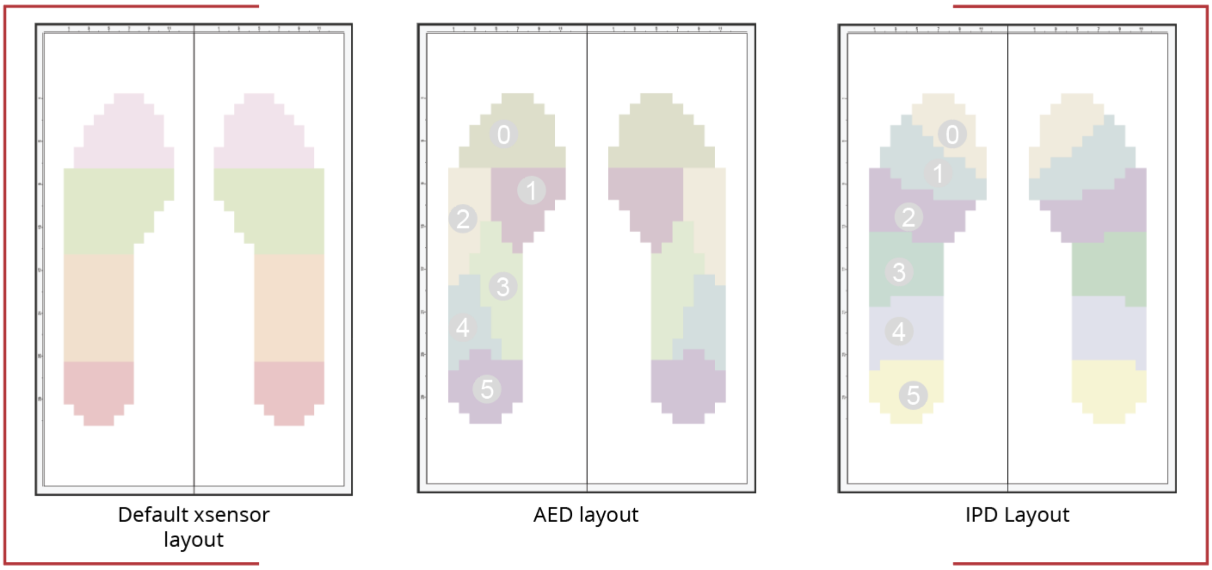


Figure 17: step 1: two layouts from the previous projects were created within the xsensor software.

The first step in the data analysis process was to recreate the different layouts from the previous projects (figure 17). This had to be done within the xsensor software. The software comes with a default layout that defines 4 different regions in the foot. These are the toe region, metatarsal region, midfoot region, and heel region.
All 230 individual sensors are distributed among these regions. In the software the regions are customized and extra regions are added to resemble the layouts from the last two projects on the smart safety shoe. Both layouts have 6 different regions.

Labeling and exporting files

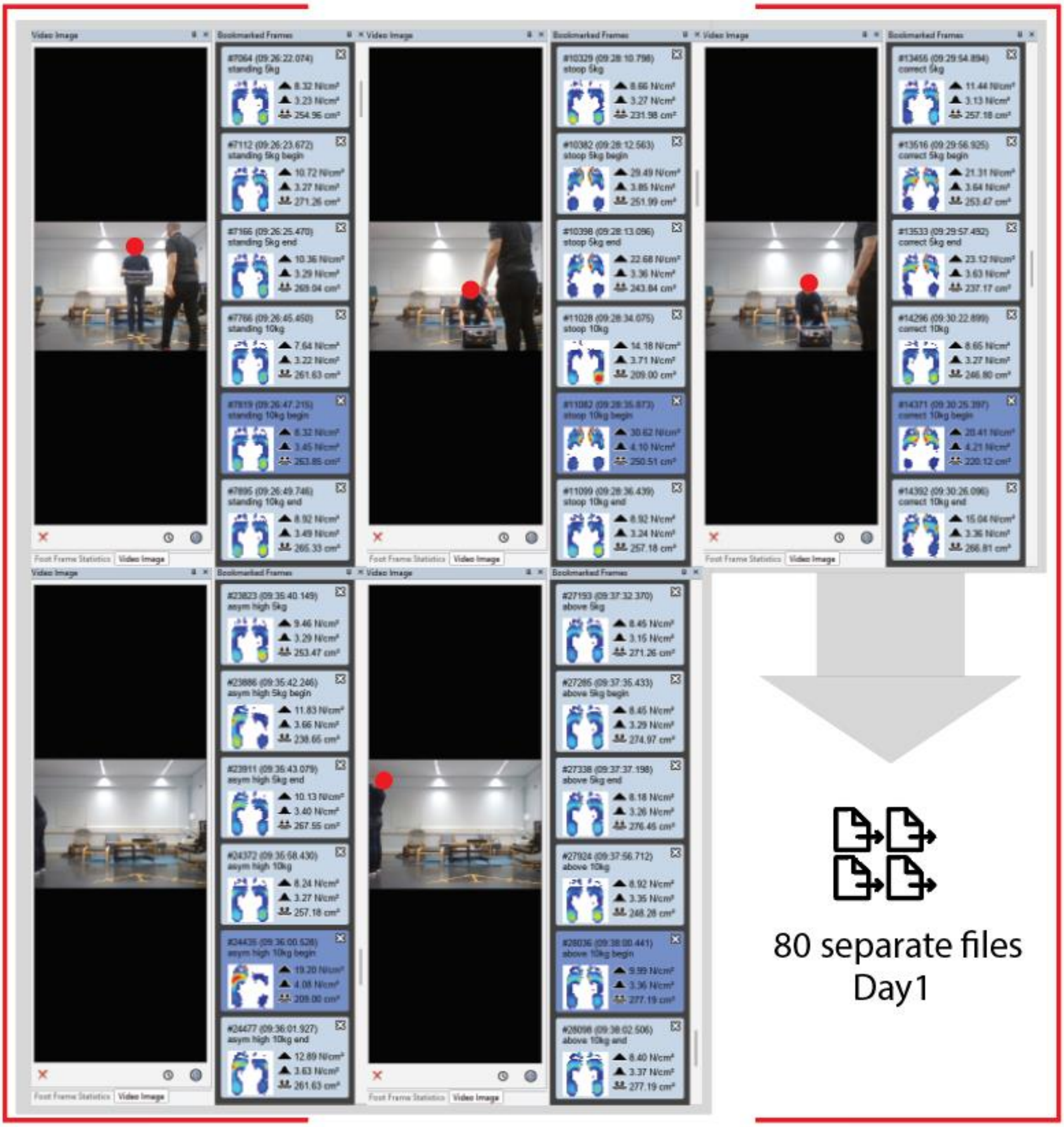


Figure 18: every posture is labeled manually with a begin and end bookmark in the xsensor software.

The next step is to manually label every posture within the software. Figure 18 shows how each posture is bookmarked with a begin and end tag. Using these bookmarks, the exact timeframes in which a participant performs a posture is selected and individually exported. This process is then repeated for every participant, posture, and layout. for the first 4 participants, this resulted in 80 different data files.

Data import and data wrangling

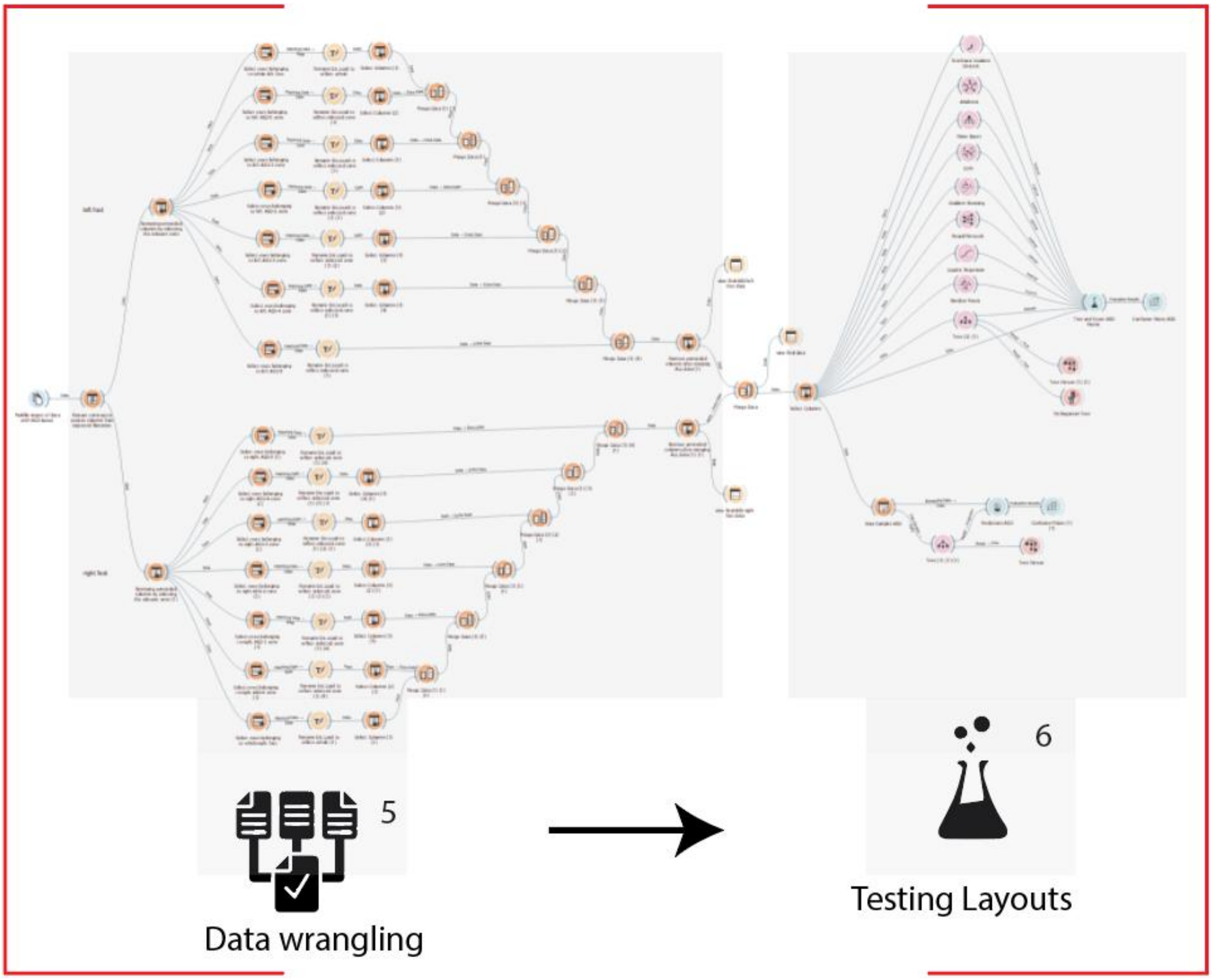


Figure 19: complete orange workflow

Orange is an open-source machine learning and data visualization tool. With the help of Wilfred van der Vegte the workflow was set up to import the data and prepare it for testing with machine learning. The workflow can be divided into two parts. The first is called data wrangling. This simply means that the data is converted to a different format which can be used to test and score the layouts for classification. This is done in the next and last step of the data analysis.

Testing and selecting layout.

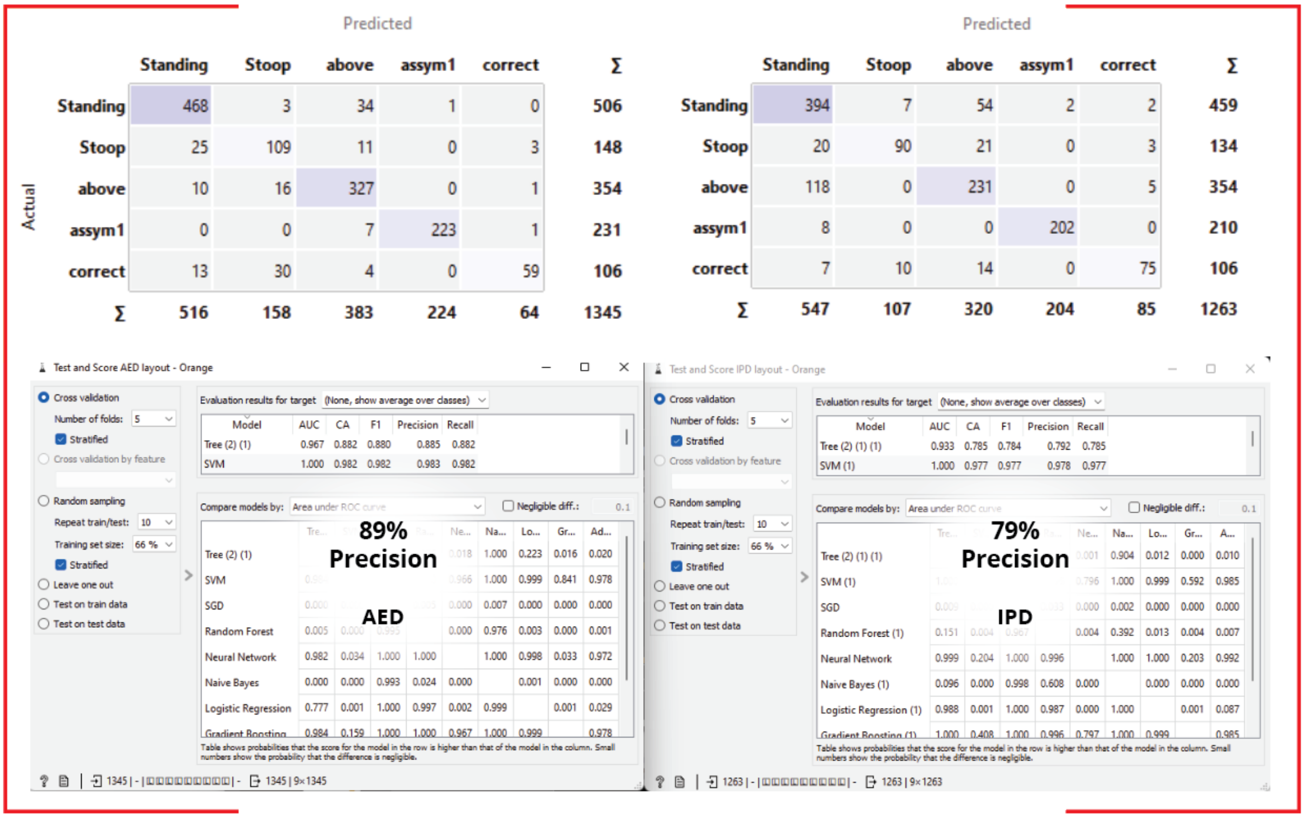


Figure 20: results from the test and score widget from orange and the confusion matrix for both layouts.

The specific type of machine learning that applies here is called supervised machine learning. This means that the data used to train the model has been labeled beforehand. (Machine learning lecture 1, 2023). It will allow the shoe to classify uncategorized data from the sensors into predefined classes, these classes represent different postures that can be detected. In orange a selection of the data from the manual handling test is used to train the model and then the remaining data runs through it to see how accurate it is able to classify different postures. Figure 20 shows the results of this. Several classification algorithms were tried but it was chosen to use the tree algorithm because of its simplicity and explainability. The results show that the AED layout is more precise in classification than the IPD layout (89% vs 79%). Another way to evaluate their performance is to use the confusion matrix shown above in figure 20. This shows the number of misclassifications for each posture. If the models were 100 % accurate, all fields except the ones in the middle would show 0. For both layouts the matrices show which postures are harder to detect. An interesting insight here is that the IPD layout has trouble differentiating between standing and above shoulder lifting with 118 misclassifications, while the AED layout does this significantly better with only 10 misclassifications.

03.5 Insights & discussion

Data sample limitations and biases

The test had a total of 16 participants since only a size 43 xsensor insole was available for testing. Because of this, participants were also mostly male as in general men tend to have larger feet than women. In future tests it would be meaningful to aim for more participants from a more diverse group of people. This should also make machine learning more reliable as the model will include different types of people.

The Inertial measurement unit of the insoles was not used during testing as only static postures are considered. For future tests, and when the functionality of the smart safety shoe is extended to dynamic posture recognition. Inertial measurements would have to be included as well to determine how they can aid in the preventive goal of the smart safety shoe.

Usability and technical issues

While the xsensor insoles are an industry standard in gait analysis and research. They were far from perfect for application in this project. Some complications with the insoles themselves and the software arose during and after the test. For example, the part of the insoles that had to be clipped to the safety shoe kept falling off which interrupted the test several times, this had to be fixed with tape. Other interruptions during the test were due to Bluetooth connection failing or taking a long time to connect.

In some cases, the software showed unusual spikes in certain areas of participants' feet. This could be due to the sensor not laying completely flat inside the shoe or something being stuck underneath it, it was accounted for using a zero-load calibration, but the question remains whether this affected the accuracy of the measurements. initial tests showed that the insoles were not very accurate in estimating the weight of a participant.

Lastly, the fact that each session had to be manually bookmarked to highlight the specific posture needed for the data analysis slowed down the process significantly, but also made the data more susceptible to human error on my part. If a faster and more reliable workflow is developed to bookmark and export data from the insoles software more tests could be performed on multiple layouts.

People are not perfect.

The insoles were able to detect small amounts of movements. For example, some people when they bend over to pick up the crate are more inclined to lean on their right or left leg, some participants moved and adjusted their foot orientation to prepare for lifting. Even though the test was controlled, which meant that they were instructed to keep their feet on a designated spot. It was unavoidable to completely prevent people from moving their feet slightly. This is natural behavior which the smart safety shoe should also be able to account for when it is deployed in a real warehouse and actual workers are making use of it.

Experience of the test

After the tests in both locations no volunteer reported discomfort while wearing the insoles and performing the instructed lifting postures. As part of the evaluation participants were asked questions about how they would consider the smart safety shoe as a concept, specifically about the fact that the shoe will be able to detect their posture and provide corrective feedback when necessary. The goal was to get qualitative insights about how the smart safety shoe is perceived after participants had experienced wearing a shoe with similar capabilities simulated with the xsensor insoles. Overall participants showed positive reactions to the functionality of the concept. When pressed with questions about possible negative aspects of the concept like a privacy issue with being constantly monitored, it is interesting to note that participants in the lab acknowledged that the shoe could negatively impact their work, while warehouse employees showed an overall excitement towards the concept.

Selected layout

This manual handling experiment demonstrates how a high-end pressure sensing insole can be used to develop a low-cost solution for application in the smart safety shoe. The goal of this test is to see which of the two layouts scored best, but a future study could be focused on further reducing the number of sensors while retaining accuracy and functionality. Although the accuracy was less than the results from (Zhang, 2021), the fact that this test included data from multiple people also had an impact. While machine learning was used in the process it should be kept in mind that the actual machine learning model that will be running on the shoe should be derived from its own sensors.

04: Design

Iterating on the smart safety shoe

This chapter describes the design steps taken to get to the current concept of the smart safety shoe. Several design explorations were made and discussed. The shoe is ultimately presented as a minimum viable product with an extra layer of improvements and added functionality for future iterations.

Contents

- Design considerations
- Feature layers

04.1 Design considerations

Shoe model

Figure 21: overview of selected redbrick safety footwear, model used for the SSS is shown at the bottom.

Figure 21 shows an overview of several redbrick safety shoes sold by Allshoes. The current model that will be used for the smart safety shoe is shown below them. Allshoes intends to launch the smart safety shoe for their own brand of redbrick safety shoes. While the shoe should be considered as a new type of safety shoe, it will still be sold as a safety shoe, and it will still have to adhere to the current standards of safety shoes. Therefore, a good starting point for its design is the existing safety shoes. As a first generation of the smart safety shoe, it was chosen to use a variation of an existing Redbrick safety sneaker. Similar design elements are kept with a slight change in materials.

Added components and electronics.

The intention with the current model of the smart safety shoe is to retrofit the components that give the shoe its functionality. The benefit here is that existing infrastructure and manufacturing can be reused while a small prototyping team can add the necessary components. This will suffice for small batch numbers but for future versions it should be considered to create a new design that incorporates all components in manufacturing process. The different considerations for what these components are and how to integrate them are discussed below.

Sensors and actuators

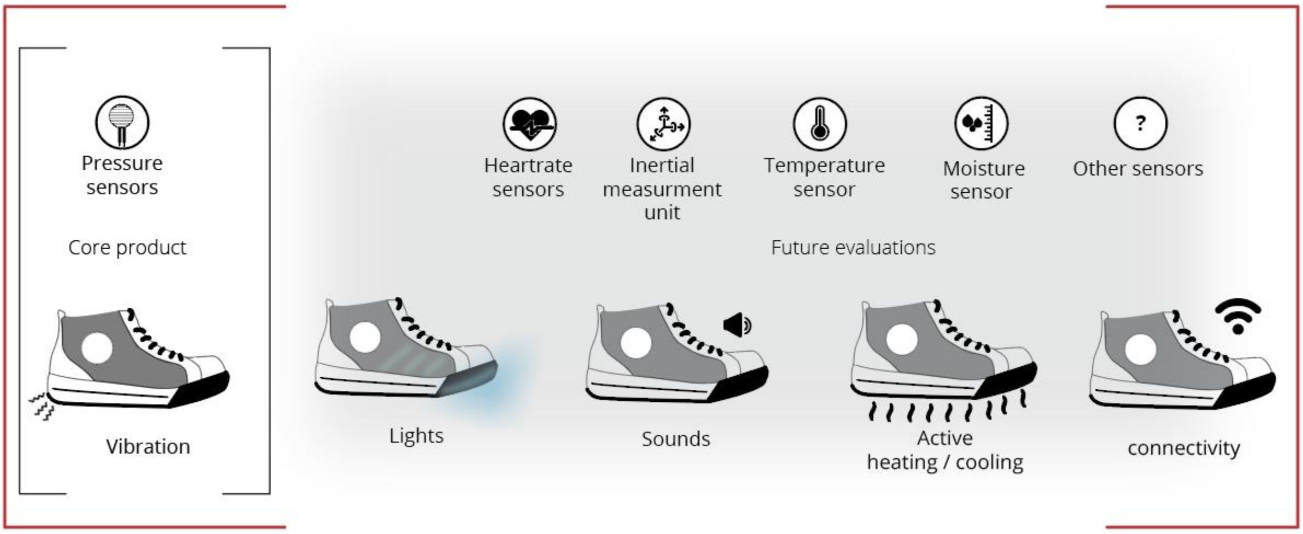


Figure 22: overview of the types of sensors and actuators that are considered for the shoe.

Figure 22 gives an overview of sensors and actuators that can be considered in the smart safety shoe. They are based on different examples of smart footwear explored in chapter 2. Pressure sensors Stay part of the core concept of the smart safety shoe because it has been evaluated and tested in previous projects. It was however chosen to only include vibration feedback as actuator for the shoe. Other actuators are considered to be valuable but need further evaluation.   For similar reasons other sensors are left out of the core product as well.

component integration

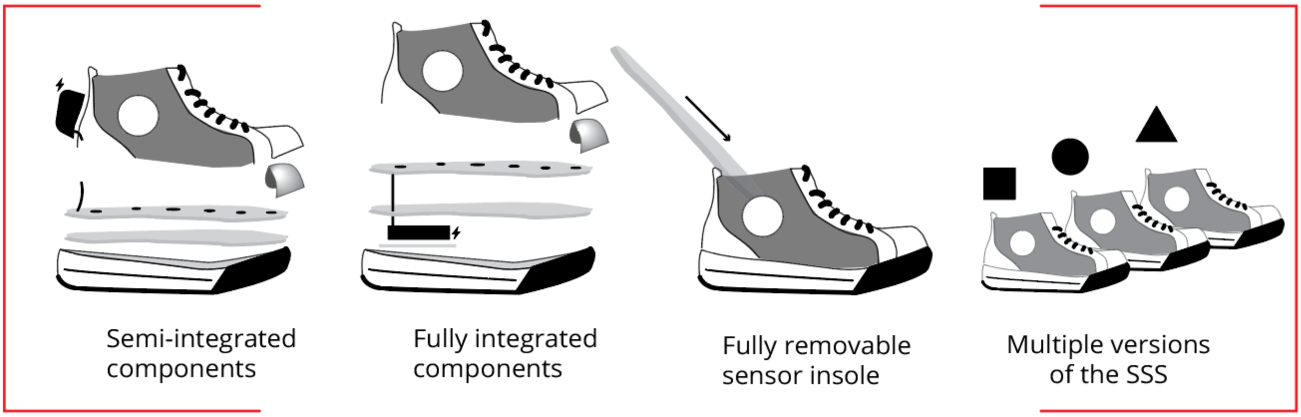


Figure 23 considerations regarding the integration of components into the shoe

Integrating the necessary components into the smart safety shoe can be done in 4 ways (figure 19). Firstly, all components could be integrated into the insole. This solution is similar to the existing sensor insoles made for sports and medical analysis discussed in chapter 02.2. It would mean that the insoles are interchangeable between

shoes and also requires little changes to be made to the design of the shoes themselves. However, this insole-based system changes the concept of a smart safety shoe into that of smart safety insole. While it has clear benefits, it lies beyond the scope of this project.
A semi-integrated approach could be considered instead. This approach provides several opportunities. If there are complications with fitting all components into the shoe, a decision could be made to only integrate key components. The other components can then be attached separately in their own enclosure. This essentially gives the shoe a modular feature, allowing companies to customize the smart safety shoe according to their wishes in a specific working environment. This semi-integrated modular design also allows for repairability as broken modules could be replaced. An attachment system for these modules would still have to be considered and developed. The xsensor insoles from the test in chapter 3 use metal clips for example. But more elegant and user-friendly attachment solutions should be considered using, for example, magnets, snap-fits, or the existing shoelaces.
Another strategy is to create a fully integrated smart safety shoe. It would seem desirable to include all possible components into the shoe without the need for external modules. This may not always be possible. The shoe could become too complicated and prone to failure. When the shoe has too many features. Its development will also take considerably longer. ways to prevent this is to go back to a semi-integrated modular approach, or simply create different versions of the smart safety shoe.

Charging / power

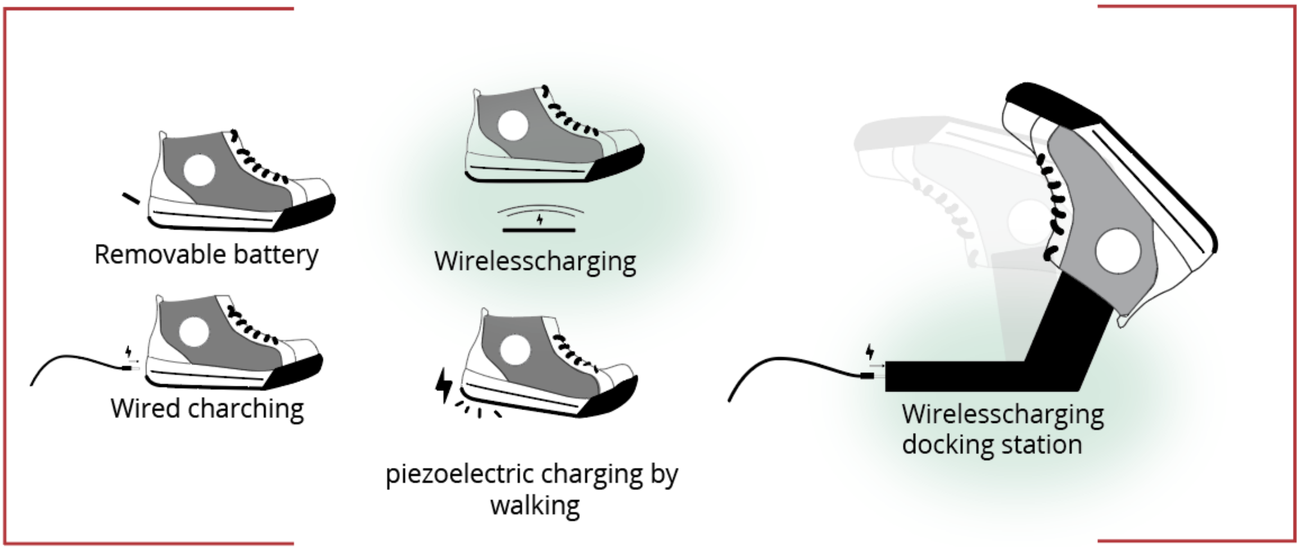


Figure 24 charging solutions for a fully integrated smart safety shoe.

To power the shoes a few possibilities are considered. They are shown in figure 24. Compared to the last concept from the AED course It was chosen to keep making use of wireless charging due to the fact that this allows for easier water resistance, a common requirement for safety shoes. An interesting challenge would be to try and include all the features as they show benefits in different industries. But as discussed integrating too many features will further complicate the product. A better solution would be to create multiple versions here.

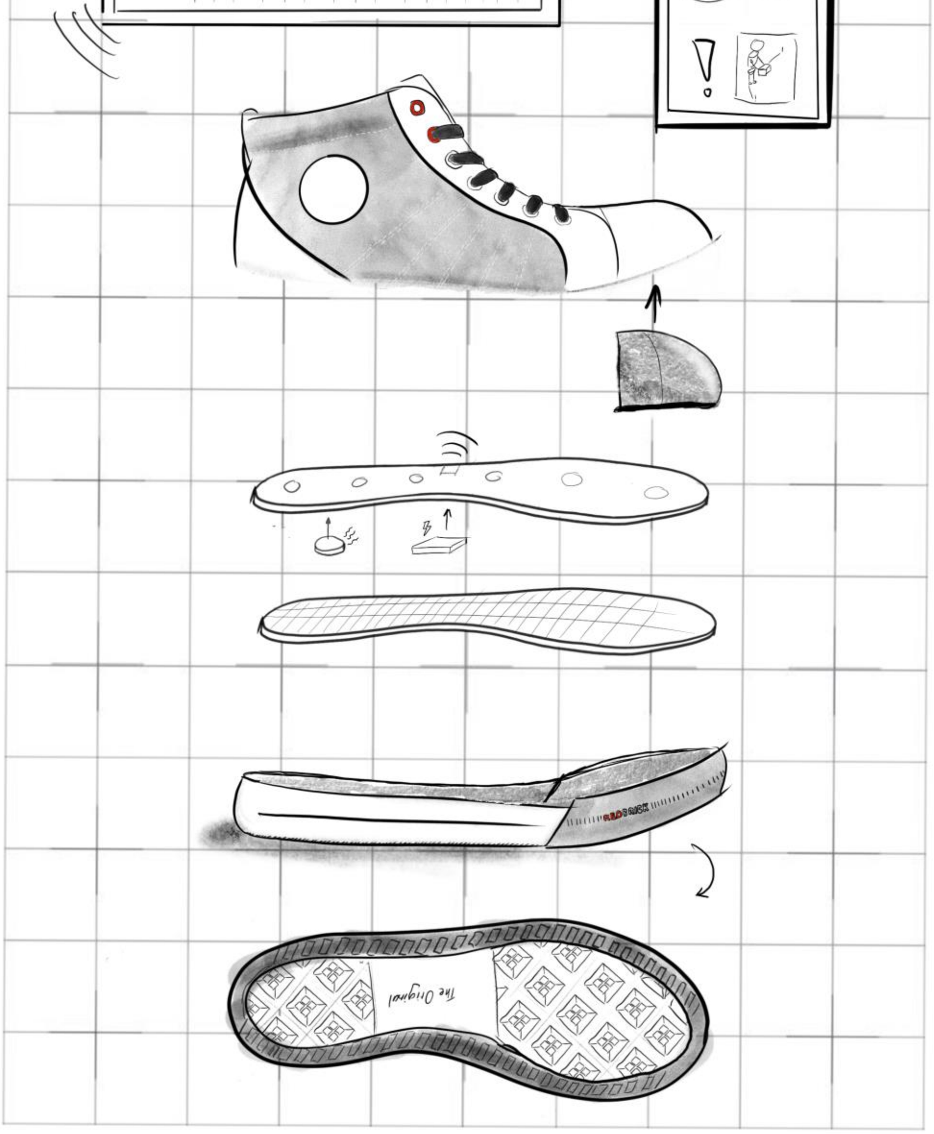


Figure 25 initial concept sketch of the smart safety shoe communicating with two interfaces.

Interface scenarios

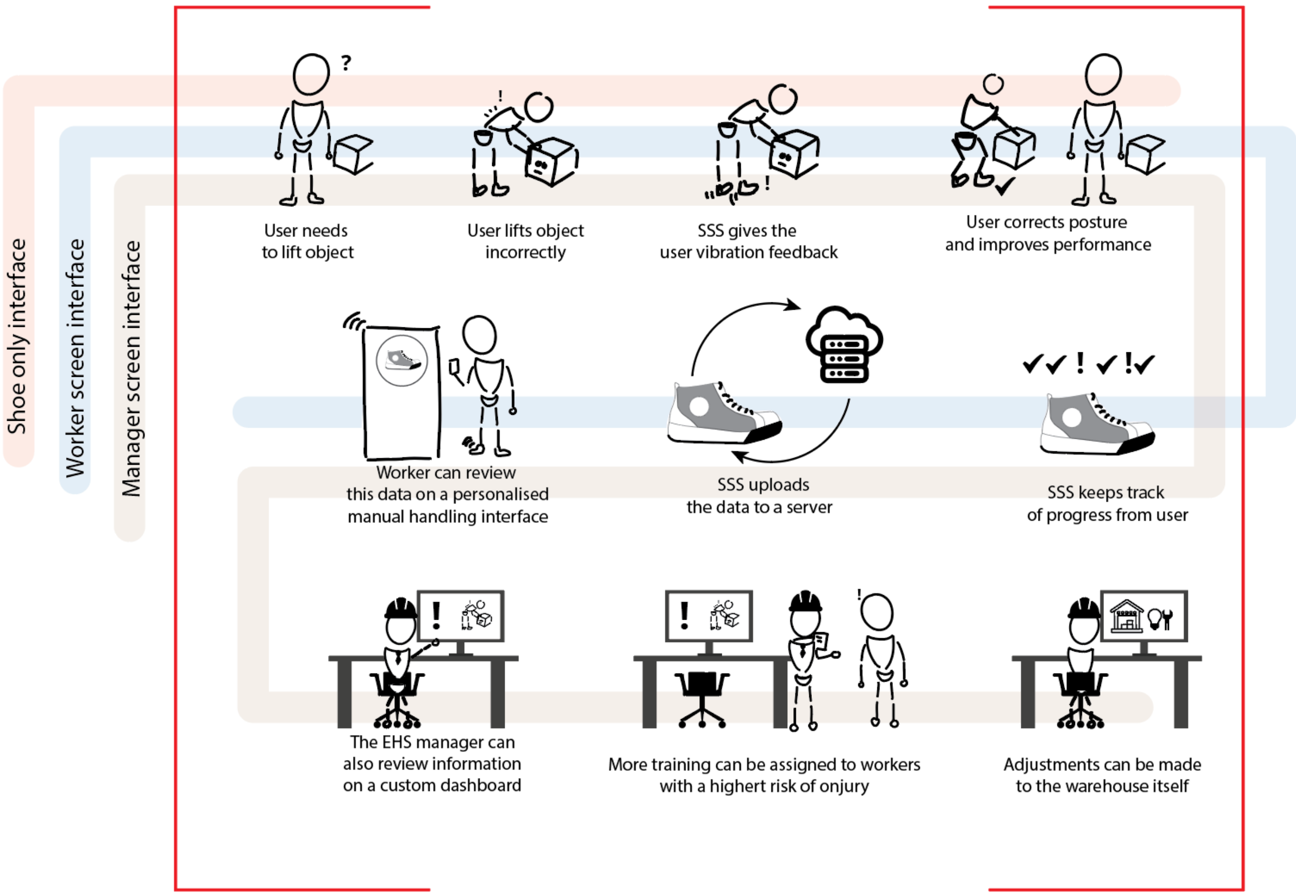


Figure 26: where the different user interfaces fit in

The smart safety shoe can be combined with a user interface to extend its functionality and increase usability. Three scenarios have been developed that highlight how such a user interface could work. The different scenarios are composed in such a way that they can complete each other. In a future project, these interfaces should be further developed and evaluated individually.

04.2 Feature layers

Figure 27: final set of requirement and desired features of the smart safety shoe

Figure 27 Shows how the smart safety shoe is envisioned in two different layers of functionality. The first layer can be seen as a base model of the smart safety shoe. It has the most important features integrated and works as a standalone safety shoe. I consider this a minimum viable product which is a version of the product that can be built, tested, and learned from with a minimum amount of effort and the least amount of development time (Ries, 2011). after this first layer has been developed up to a point where it can be released, development of second layer should begin.

05: Conclusion

Presenting final thoughts on the smart safety shoe

This chapter concludes the project on the smart safety shoe,
A perspective is given on the potential impact of the shoe. A projection towards its future is discussed and finally a personal reflection highlights the lessons learned and achieved goals during the project.

Contents

- Impact of the smart safety shoe
- Future of the smart safety shoe
- Personal reflection

05.1 The impact of the smart safety shoe

To Consider the potential impact of a smart safety shoe when its available on the market it's important to view how safety shoes are currently meant to improve workplace safety. The purpose of a safety shoe is to protect its wearer against various hazards in a work environment. They are what is known as personal protective equipment (PPE). Within risk management, the national institute of occupational health and safety (NIOSH) considers PPE as the last line of defense in ensuring workplace safety (CDC, 2023). This is shown in their hierarchy of controls, which is a framework for controlling risks in the workplace environment (see figure 28).

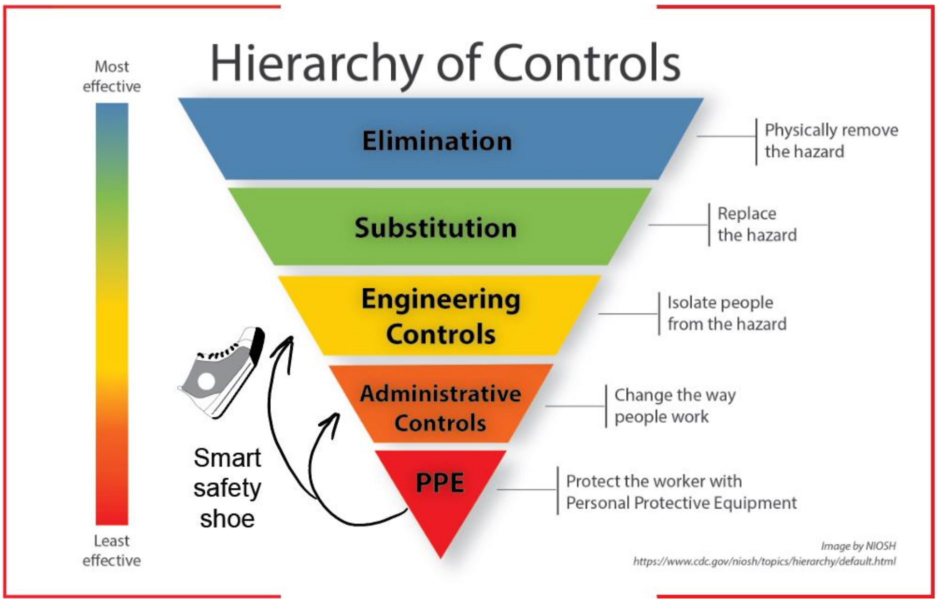


Figure 28: PPE in the hierarchie of controls by NIOSH PPE could become more effective with smart safety shoes.

The framework highlights how There are more effective ways of reducing risk of injury other than with PPE. A best-case scenario would be to completely remove any hazard from the workplace (elimination). This is however not always possible due to time or cost constraints. Removing hazards as a solution to eliminate risk might require a complete overhaul of a workplace, or a complete change in the way people work. Because of this, companies often turn to less effective measures that bring the overall risks down to an acceptable level. We acknowledge the fact that some workplaces are just unsafe. Using PPE, we do our best to provide protection for these workers, but it will never be as effective as not having those people work there at all.
While we keep improving on PPE such as with the improved mechanical properties of safety shoes highlighted in the latest revision of their European standards (Nen,2022). With the smart safety shoe, we are not just making conventional improvements to PPE. Smart safety shoes add a new way of ensuring the safety of their wearer by providing real-time feedback. The shoes allow for new interactions with their wearer. They improve on the purpose of a safety shoe, which is to prevent injury to workers, with the added ability to prevent long-term injuries that develop over time. When considering this in the hierarchy of controls framework, it can be argued that smart safety shoes would not just be considered PPE. They allow for more control over the risks of injury in a workplace. This translates to administrative control, meaning that the shoes can be used to create better work practices, and even engineering control, meaning that the shoes themselves are engineered to prevent accidents.
By using this kind of "smart PPE", we increase its effectiveness in creating a safe working environment.

05.2 Next steps

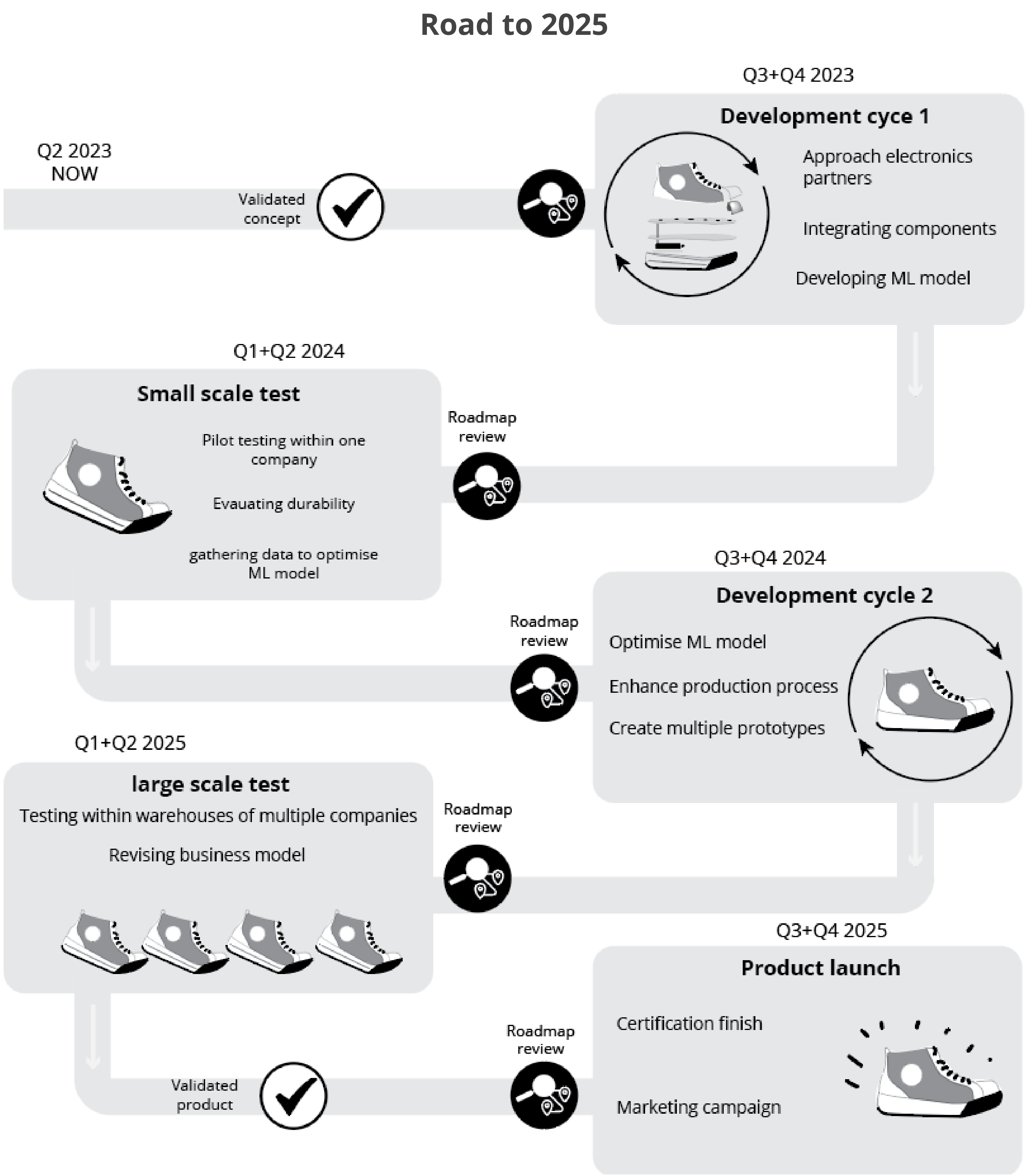


Figure 29: a highlight of main steps towards the planned release in the end of 2025

The smart safety shoe is expected to launch at the end of 2025. The steps that need to be taken in order to reach this goal are highlighted in figure 29. After each two quarters, a roadmap review is placed to reassess the process of the project. Because the milestones and processes are estimates it is important to frequently revisit them and consider whether they are realistic against the circumstances at the moment of review.
The current project proved that it is possible to create a machine learning model to classify poses from multiple users. Because this was done with an external sensor insole, the next step is to integrate the necessary components of the core product into the shoe. This will be done in development cycle 1. During this cycle a machine learning model should be developed using the actual sensors in the shoe. The model will be tested in the next phase, which is a small-scale test. This test evaluates the developed product on the accuracy of its model and the durability of the shoe. The insights from this test will be used in the second development cycle. Next to the classification model, improvements should also be made to the production of the shoe itself. During this cycle. This is because in the next phase the shoes will be tested at multiple companies in their warehouses. To fully validate the product, it's important that feedback is gathered about how different people will use the product and how the product will perform in different environments. Furthermore, because multiple clients are involved, the business model can also be reevaluated. After this, the last phase will be to launch the product. This means that the smart safety shoe is officially offered as a product to clients.

Production adjustments

Currently, production is outsourced AMF shoes in Portugal, this is a manufacturer that only has experience in creating regular safety shoes, so a third party needs to be involved for the integration of electronic components. The shoe can have many independent systems that would have to be validated separately. Integrating these systems could pose a further challenge.

Changes in the market and safety standards

In 2022, the ISO norm received an update which added safety levels S6 and S7 to better specify the types of shoes on the market *(ISO,2022)*. These norms are often implemented as a reaction to innovation and trends on the market. As the safety shoe industry keeps innovating, more possible applications for the smart safety shoe can appear as well, perhaps even a new norm would be produced to regulate smart PPE/ footwear.

Improving on posture recognition

Since the first concept of the smart safety shoe was foreseen, it was foreseen that we should start small with the most harmful postures and expand from there. This is still the strategy. The final machine learning model that the

User acceptance

The smart safety shoe was introduced by Allshoes during their very first sustainability event (figure 30). It has caught the attention of their suppliers. While the concept is generally met with excitement. The actual acceptance of the final product can only be evaluated when the shoe is produced.

Figure 30: presentation stand during the Allshoes sustainability event.

05.3 Personal reflection

This project was a great test of my project management capabilities. Through guidance and a lot of trial and error I have managed to learn a lot about planning, time management and decision making. During the project I found myself spending a lot of time on smaller tasks that seemed less relevant. This often left me feeling like I made little progress. I eventually got a better grasp of the time with a system where I would spend a predetermined chunk of time and go on to the next task. Setting smaller goals and deadlines has been an important tool for me in finishing the project.

Testing with the xsensor insoles was a fun and exciting challenge. Especially since it all had to happen within the timeframe of one week. I would also like to thank Jan and Tiago Machado from AMF Shoes for making the time to attend parts of the experiment. I have learned a lot about the importance of collaboration with experiments like these.

Throughout the project I have gone through many tools to help me achieve the goals I wanted, this sometimes felt like a project by itself. During the data analysis for example there were several repetitive tasks that had to be performed. After this for a while I realized that there were things I could automate. Because I lacked certain skills for this I had dived into the world of macros and learned a lot about software automation in general. This is a skill that will benefit me further and I am thankful for learning it.

Lastly, I have always had a big interest in new technologies applied to new, out of the box concepts, I often envision my future self-working on designs that could be game changers, and possibly even disruptive. The smart safety shoe checked a lot of those boxes for me. I was often very excited about the potential of the shoe, and this made it an enjoyable project for me. However, I also realized how important it is to narrow down a concept to something manageable and essential. In that aspect this project has been a well-received reality check and a good starting point for an exciting career into the world of design.

06: References

International Organization for Standardization. (2021). Personal protective equipment — Safety footwear (ISO Standard No. 20345:2021). https://www.iso.org/standard/73222.html

van den Berg, S. (2020). Smart safety shoes: The next step in preventing occupational incidents. Tudelft.nl. https://repository.tudelft.nl/islandora/object/uuid%3A2d39a75c-005a-42ef-bc6d-90bb1bd02361?collection=education

Zhang, Y. (2021). Smart safety shoe of the future: Detecting risks of low back pain. Tudelft.nl. https://repository.tudelft.nl/islandora/object/uuid%3A95906b6a-67c9-421f-b222-f628f54a6099?collection=education

Advanced embodiment design report (2022), (document can be requested from course organizers)

van Boeijen, A., Daalhuizen, J., Zijlstra, J., & van der Schoor, R. (2013). Delft Design Guide: Design strategies and methods. BIS Publishers.

(2019, April). Nationale Enquête Arbeidsomstandigheden 2018. https://www.cbs.nl/-/media/_ pdf/2019/15/nea2018-methodologisch-rapport-gecorrigeerde-versie.pdf

Thomas R. Waters, Vern Putz-Anderson, & Arun Garg. (1994). Applications Manual For the Revised NIOSH Lifting Equation. Centers for Disease Control & Prevention. https://wonder.cdc.gov/wonder/prevguid/p0000427/p0000427.asp

Romaine, E. (2022, January 25). How to Solve a Warehouse's 3 Largest Labor Consuming Applications. Conveyor. https://www.conveyco.com/blog/warehouse-labor-consuming-applications/#:~:text=1.,of%20a%20warehouse's%20total%20labor .

OpenGo Sensor Insoles - Wireless pressure, force & motion sensing. (2023). Moticon. https://moticon.com/opengo/sensor-insoles

Smart Insoles for Running Running Tracker App | NURVV Run. (2016). NURVV Run; NURVV RUN (UK). https://www.nurvv.com/en-gb/products/nurvv-run-insoles-trackers/

XSENSOR | De leider in Intelligente Dynamische Sensing. (2023). Xsensor.com. https://nl.xsensor.com/

Footwear pressure distribution measurement- pedar| novel.de. (2023, January 20). Novel.de. https://www.novel.de/products/pedar/

F-Scan System | In-Shoe Pressure Measurement Foot Function Gait Analysis System | Tekscan. (2016). Tekscan.com. https://www.tekscan.com/products-solutions/systems/f-scan-system

medilogic WLAN insole - medilogic. (2019, August 23). Medilogic. https://medilogic.com/en/medilogic-wlan-insole/

ReTiSense | Stridalyzer Sensor Insoles – Sensor Insoles for Gait Research, Physiotherapy, Runners and Rehab. (2023). Retisense.com. https://www.retisense.com/

Homepage - FeetMe. (2023, February 16). FeetMe. https://feetmehealth.com/

Quantified patients' gait and running analysis. (2023). Digitsole. https://www.podosmart.tech/en

ARION. (2023, January 30). ARION. https://www.arion.run/

SALTED. (2021). Salted.ltd. https://www.salted.ltd/eng/main/index.html

Ciniglio, A., Guiotto, A., Spolaor, F., & Sawacha, Z. (2021). The design and simulation of a 16-sensors plantar pressure insole layout for different applications: From sports to clinics, a pilot study. *Sensors*, *21*(4). https://doi.org/10.3390/s21041450

Muzaffar, S., & Elfadel, I. M. (2020). Shoe-integrated, force sensor design for continuous body weight monitoring. *Sensors (Switzerland)*, *20*(12). https://doi.org/10.3390/s20123339

Antwi-Afari, M. F., Li, H., Seo, J. O., & Wong, A. Y. L. (2018). Automated detection and classification of construction workers' loss of balance events using wearable insole pressure sensors. *Automation in Construction*, *96*. https://doi.org/10.1016/j.autcon.2018.09.010

Aqueveque, P., Osorio, R., Pastene, F., Saavedra, F., & Pino, E. (2018). Capacitive Sensors Array for Plantar Pressure Measurement Insole fabricated with Flexible PCB. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, *2018-July*. https://doi.org/10.1109/EMBC.2018.8513383

Elstub, L. J., Grohowski, L. M., Wolf, D. N., Owen, M. K., Noehren, B., & Zelik, K. E. (2022). Effect of pressure insole sampling frequency on insole-measured peak force accuracy during running. J Biomech, 145, 111387. https://doi.org/10.1016/j.jbiomech.2022.111387

Antwi-Afari, M. F., Li, H., Yu, Y., & Kong, L. (2018). Wearable insole pressure system for automated detection and classification of awkward working postures in construction workers. *Automation in Construction*, *96*. https://doi.org/10.1016/j.autcon.2018.10.004

Kong, K., & Tomizuka, M. (2009). A gait monitoring system based on air pressure sensors embedded in a shoe. *IEEE/ASME Transactions on Mechatronics*, *14*(3). https://doi.org/10.1109/TMECH.2008.2008803

Lin, F., Wang, A., Zhuang, Y., Tomita, M. R., & Xu, W. (2016). Smart Insole: A Wearable Sensor Device for Unobtrusive Gait Monitoring in Daily Life. *IEEE Transactions on Industrial Informatics*, *12*(6). https://doi.org/10.1109/TII.2016.2585643

Subramaniam, S., Majumder, S., Faisal, A. I., & Jamal Deen, M. (2022). Insole-Based Systems for Health Monitoring: Current Solutions and Research Challenges. In *Sensors* (Vol. 22, Issue 2). https://doi.org/10.3390/s22020438

Wang, L., Jones, D., Jones, A., Chapman, G. J., Siddle, H. J., Russell, D., Alazmani, A., & Culmer, P. R. (2022). A Portable Insole System to Simultaneously Measure Plantar Pressure and Shear Stress. IEEE Sensors Journal, 22(9). https://doi.org/10.1109/JSEN.2022.3162713

Zou, Y., Libanori, A., Xu, J., Nashalian, A., & Chen, J. (2020). Triboelectric Nanogenerator Enabled Smart Shoes for Wearable Electricity Generation. Research, 2020. https://doi.org/10.34133/2020/7158953

Tan, A. M., Fuss, F. K., Weizman, Y., Woudstra, Y., & Troynikov, O. (2015). Design of Low-Cost Smart Insole for Real Time Measurement of Plantar Pressure. Procedia Technology, 20. https://doi.org/10.1016/j.protcy.2015.07.020

van der Vegte, machine learning lecture slides (2023)

A guide to GDPR data privacy requirements - GDPR.eu. (2019, February 22). GDPR.eu. https://gdpr.eu/data-privacy/

Pro Foot & Gait user manual (2022), XSENSOR Technology Corporation.

Hierarchy of Controls. (2023). CDC.gov. https://www.cdc.gov/niosh/topics/hierarchy/default.html

Nieuwe normen voor werk- en veiligheidsschoenen: beter maar ingewikkelder. (2022). NEN; NEN. https://www.nen.nl/nieuws/pbm-persoonlijke-beschermingsmiddelen/interview-nieuwe-normen-voor-werk--en-veiligheidsschoenen-beter-maar-ingewikkelder/

Ries, E. (2011). The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses.

07: Glossary

Safety shoe: A type of footwear that is sometimes required to be worn in industries to protect workers from the hazards of the environment.
Smart safety shoe (SSS): A concept safety shoe that detects unhealthy lifting postures and warns the wearer about this.
Manual materials handling (MMH) : The process of routinely moving and handling objects by carrying, holding, lifting, pulling, pushing, and stooping
Gait analysis: the systematic study of human motion during walking or running.
Pedobarography: the study of pressure between the foot and its supporting pressure
Pressure: a specific force applied over a specific area
Plantar pressure: the pressure your feet exert on the ground.
GDPR: European general data protection regulation
Edge machine learning: A term used to describe how complex, pre-trained machine learning models can be exported and run on portable devices with less computing power.
data minimization: a general principle to reduce the amount of personal data that is collected from users.
Supervised machine learning: A type of machine
Minimum viable product (MVP): A version of the product that can be built, tested, and learned from with a minimum amount of effort and the least amount of development time.

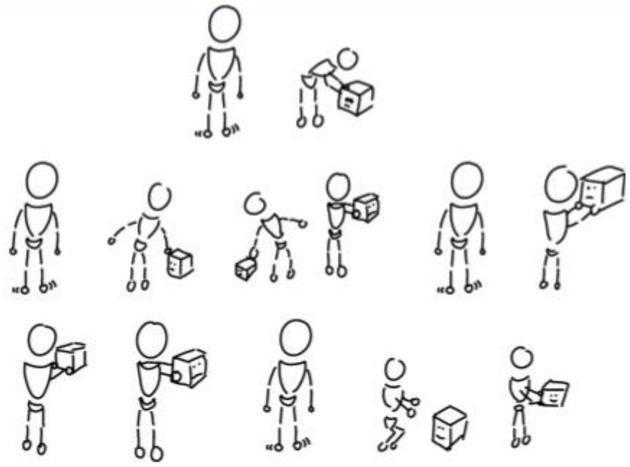
08: Appendix

A: **Manual handling test poster & recruitment survey**

FIELDLAB UPPS

Allshoes safety footwear

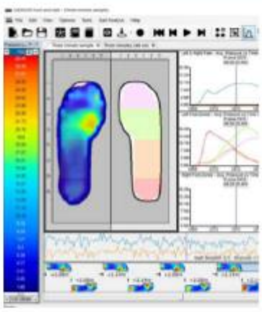
Participants needed for:



Manual handling test

We are looking for people with **shoe size 42, 43 or 44** to perform tests with a sensor insole. Participating will take about 40 minutes. You will be compensated for your time with a present and a bol.com gift card

When: 24 and 25 oktober, multiple time slots throughout the day
Where: Enter room second floor HCD department



Interested? Want to know more? Scan the Qr code to fill in the form
For any questions you can contact Mohamed Fayed
m.m.h.fayed@student.tudelft.nl

Manual handling test, interest form

thank you for your interest in the manual handling test.
in collaboration with Allshoes safety shoes we are developing a smart safety shoe.
this shoe will be able to detect various unhealthy lifting poses that can lead to lower back pain if done repeatedly over a long time.
in this test you will be asked to perform a series of poses under close supervision and with minimal weights.

Log in bij Google om je voortgang op te slaan. Meer informatie

*Vereist

to be able to safely perform this test it is important that you are physically healthy and have had no previous complications with regards to lower back pain *

○ in the past 12 months I have had no issues with lower back pain

During test you are required to wear a safety shoe. A new pair of socks will be provided for you.

what shoe size do you normally wear?

- ◯ size 42
- ◯ size 43
- ◯ size 44

tests will take place in week 43 on both Monday 24th of October and Tuesday 25th of October

when would you prefer to participate?

Datum Tijd

mm/dd/yyyy :

how can we contact you?
leave your email address or phone number and you will be contacted to confirm the time and participation.

Jouw antwoord

if you have any questions leave it here

Jouw antwoord

B: xsensor test script

Participant ID:
Scheduled time:
Actual start time:

Preparation of room	Welcome & intro	Measurements & shoe fitting	Performing lifting	Final evaluation

The test lab is prepared and checked before the participant enters.

- Are the cameras working?
- Do the insoles work?
- Are the socks and gift cards in place?
- Are the weights placed on the initial spot?

Preparation of room	Welcome & intro	Measurements & shoe fitting	Performing lifting	Final evaluation

The participant is welcomed and thanked for being present and wanting to take part in this study.
The participant is being offered something to drink.

The cameras in the room are pointed out and the participant is asked for permission to turn on the recording. It is explained that the recording will only be used to aid in the documentation of the test and if the participant does not wish their recording to be used in a presentation or report they can say that.

- Has the participant given permission to turn on the cameras?
- Are the cameras recording?

The consent form is being pointed out; the researcher gives the following introduction verbally:

English	Dutch
“This test is part of my graduation project called “the smart safety shoe”. The project is done in collaboration between the TU Delft and Allshoes which is a company specialised in safety shoes. The purpose of this study is to collect data about the pressure that your feet exert on the ground while lifting an object. This is called plantar pressure. During this test you will be asked to perform a series of lifting procedures that are unconventional and not advised for people who lift objects as part of their job. You will therefore only be asked to lift for a maximum of 2 times per procedure and with a weight of up to 10 kg. If you are experiencing any discomfort during the test, it is important that you speak up. we can stop at any time”.	“Deze test maakt onderdeel uit van mijn afstudeerproject genaamd " de slimme veiligheidsschoen" het project is een samenwerking tussen de Tu delft en het bedrijf Allshoes. Dit is een bedrijf dat zich specialiseert in werkschoenen. Het doel van deze test is om data te verzamelen over de druk die je voeten uitoefenen op de grond tijdens het tillen, dit wordt plantar pressure genoemd. Tijdens deze test ga ik je vragen om een aantal tilhoudingen te verrichten waaronder enkele houdingen die niet aanbevolen zijn voor mensen die in hun dagelijkse werk moeten tillen. Je gaat daarom bij deze test met een maximaal gewicht van 10 kilo tillen en dit doe je ook maximaal 2 keer per houding. Als je tijdens de test ergens last van hebt is het belangrijk dat je dit laat weten. We kunnen op elk moment stoppen om even te rusten. ”

The participant is given time to sign the consent form, meanwhile the researcher connects the insoles with the laptop and performs a zero-load calibration in the software.

- Is the consent form signed?

Preparation of room	Welcome & intro	Measurements & shoe fitting	Performing lifting	Final evaluation

The participant is asked to put on the provided work socks.
The participant is asked to step on the scale while their weight is measured.
The participant is asked to stand against the wall while their length is measured.
The participant is asked to put each foot on a piece of paper to draw its circumference.
The participant is asked whether they are aware of any irregularities in their foot (flat foot, hole foot, walking irregularities)
The participant is asked to put the shoes on and give feedback of how it fits without the xsensor insoles.
-how does it fit? Any irregularities?

____

____

The participant is asked to take of the shoes and the xsensor insoles are inserted into the shoe.

-how does it fit? Do the insoles make it different?

____

____

Preparation of room	Welcome & intro	Measurements & shoe fitting	Performing lifting	Final evaluation

Standing	please stand still and count to 3 while holding the box		
	1 kg	5 kg	10 kg
own lifting	please lift the crate according to how you would lift it yourself		
	5kg		
Stoop lifting	walk up to the box, bend over slowly and pick it up, then count to 3 and put it down		

	1 kg	5 kg	10 kg
correct lifting	bend through knees and pick up weight		
	1 kg	5 kg	10 kg
low Asymmetric lifting	please move the weight from this point on the floor to the other point on the floor in one single slow and steady motion. as you move the weight keep your feet pointing straight and		
	1 kg	5 kg	10 kg
high Asymmetric lifting	please move the weight from point A of the table to point B on the table in one single slow and steady motion.		
	1 kg	5 kg	10 kg
Above shoulder lifting	please lift the box from the table and hold it above your shoulder for 3 seconds		
	1 kg	5 kg	10 kg
walking	please pick up the weight and walk with it to the other side of the table		
	1 kg	5 kg	10 kg

Preparation of room	Welcome & intro	Measurements & shoe fitting	Performing lifting	Final evaluation

- how did it go?

____

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- The shoes will be used to help you correct your posture while lifting, how does that make you feel?

____

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would you have any privacy concerns wearing such a shoe?

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How would you prefer to be corrected if you are lifting incorrectly?

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Is there anything you would like to add that felt relevant in this experience?

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____

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C: Consent forms for testing

Consent form participation in smart safety shoe research test

This test is part of a research study called “ The smart safety shoe”. This study is being done by Mohamed Fayed, a graduate student, from the TU Delft as part of a Design for interaction masters Graduation project. The project is done in collaboration with Allshoes BV which is a company specialised in safety shoes.
The purpose of this study is to collect data about the pressure that your feet exert on the ground while lifting an object. This is called plantar pressure.
During this test you will be asked to perform a series of lifting procedures that are unconventional and not advised for people who lift objects as part of their job. You will only be asked to lift for a limited amount of times with a weight of up to 10 kg. If you are experiencing any discomfort during the test, it is important that you speak up. You can also stop at any time.
During the test you will wear a safety shoe with a sensor insole that can measure your plantar pressure. A new pair of socks will be provided for you to put on.
The test will be filmed. If the footage is used in publications or presentations you will always be anonymised.

PLEASE TICK THE APPROPRIATE BOXES	Yes	no
1. I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: - Putting on safety shoes with smart insoles that can measure and visualise my plantar pressure - Performing a series of lifting procedures - Answering questions about how I experienced the test	☐	☐
4. I understand that I will be compensated for my participation by a 25 eur gift card and a pair of socks	☐	☐

5. I understand that taking part in the study involves the risk of physical discomfort by lifting incorrectly. This risk will be mitigated by allowing me to stop at any time and only lift when I am comfortable doing so. I will be given proper instructions before I am asked to lift anything.	☐	☐
6. I understand that taking part in the study also involves collecting specific personally identifiable information and associated personally identifiable research data with the potential risk of my identity being revealed	☐	☐
7. I understand that steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach. Identifiable data will be stored offline or in a non public secure storage drive. This data will not be shared with anyone before it is anonymised.	☐	☐
8. I understand that the (identifiable) personal data I provide will be destroyed within 3 months after this project ends in february 2023.	☐	☐
9. I understand that after the research study the Anonymised information I provide will be used for further research and development regarding new safety shoes.	☐	☐
10. I agree that my responses, views or other input can be quoted anonymously in research outputs	☐	☐
11. I give permission for the anonymised data that I provide to be archived in Tu delft repository so it can be used for future research and learning.	☐	☐

________________________ ________________________ ________

Name of participant **Signature** **Date**

______________________ ________________ ________

Researcher name **Signature** **Date**

For further information you can contact:

Mohamed Fayed
0611190200
m.m.h.fayed@student.tudelft.nl

Participant ID: ………

Toestemmingsverklaring participantbg

Ik neem vrijwillig deel aan dit onderzoek.

Ik erken dat ik vooraf voldoende informatie en uitleg heb gekregen over dit onderzoek en al mijn vragen zijn naar voldoening beantwoord. Ik heb de tijd gekregen die ik nodig had om in te stemmen met de deelname. Op elk moment kan ik vragen stellen met betrekking tot het onderzoek.

Mij is bekend dat dit onderzoek bestaat uit:

1. Het testen van een veiligheidsshoen met een binnenzool die drukmetingen kan doen
2. Het uitvoeren van tilhandelingen
3. Het antwoorden van vragen over mijn ervaring met tillen

Ik ben mij ervan bewust dat tijdens het onderzoek gegevens worden verzameld in de vorm van bijvoorbeeld aantekeningen, foto's, video's en/of geluidsopnames. Ik geef toestemming voor het verzamelen van deze gegevens en het maken van geluidsopnames, foto's en video opnames tijdens het onderzoek. Gegevens zullen geanonimiseerd worden verwerkt en geanalyseerd (zonder naam of andere identificeerbare informatie). Deze gegevens zijn alleen voor het onderzoeksteam en hun TU Delft begeleiders beschikbaar.

De foto's, video's en/of geluidsopnames zullen worden gebruikt ter ondersteuning van het analyseren van verzamelde gegevens. Video opnames en foto's kunnen tevens worden gebruikt ter illustratie van onderzoeksbevindingen in publicaties en presentaties over het project.

Ik geef toestemming voor het gebruik van foto's en video opnames van mijn deelname: *)*

- ☐ waarin ik <u>herkenbaar</u> ben voor publicaties en presentaties over het project.
- ☐ waarin ik <u>niet herkenbaar</u> ben voor publicaties en presentaties over het project.
- ☐ <u>enkel voor data analyse doeleinden</u> en niet voor publicaties en presentaties over het project.

Ik geef toestemming om gegevens nog maximaal 5 jaar na afloop van dit onderzoek te bewaren en te gebruiken voor onderwijs- en onderzoeksdoeleinden.

Ik erken dat er geen financiële compensatie gegeven wordt voor deelname aan het onderzoek.

Met mijn handtekening bevestig ik dat ik de informatie over het onderzoek heb gelezen en dat ik de aard van mijn deelname heb begrepen. Ik begrijp dat ik mijn deelname aan het onderzoek op elk moment kan intrekken of kan stoppen. Ik begrijp dat ik niet verplicht ben om vragen te beantwoorden die ik niet wil beantwoorden en dat ik dit kan aangeven bij het onderzoeksteam.

De onderzoekers nemen de geldende COVID-19 richtlijnen in acht. Als deelnemer aan dit onderzoek zal ik de COVID-19 maatregelen respecteren en de aanwijzingen van de onderzoekers opvolgen.

Een kopie van deze toestemmingsverklaring zal aan mij worden gegeven.

______________________	______________________
Achternaam	Voornaam
___ / ___ / 2022	______________________
Datum (dd/mm/jjjj)	Handtekening

D: Project brief

Procedural Checks - IDE Master Graduation

TUDelft

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Anton Jellema   date 15 - 09 - 2022   signature

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 33 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

NO missing 1st year master courses are:

name C. van der Bunt   date 27 - 09 - 2022   signature C. van der Bunt Digitally signed by C. van der Bunt Date: 2022.09.27 12:10:28 +02'00'

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED   NOT APPROVED

Procedure: ★ APPROVED   NOT APPROVED

comments

name Monique von Morgen   date 04 - 10 - 2022   signature

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30   Page 2 of 7

Initials & Name MMH Fayed 5935   Student number 4460057

Title of Project smart safety shoe

Personal Project Brief - IDE Master Graduation

TUDelft

smart safety shoe

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 01 - 09 - 2022

13 - 02 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The smart safety shoe is a concept that has been developed in a series of graduation (SPD and IPD) and group projects (AED) for Allshoes.

In this follow-up project, Allshoes is entering a collaboration with the fieldlab UPPS from TU Delft. Allshoes is a company that provides safety shoes for work environments like warehouses where regular shoes do not provide enough protection or support to prevent injuries.
The smart safety shoe takes this prevention a step further because it has the ability to detect certain poses that can cause health issues such as lower back pain due to lifting. This is possible because their insoles are equipped with force sensitive resistors (FSR) that give an indication of the amount of force applied to specific regions in the shoe (see image 1). When the data from these sensors are analysed, it can be compared to the data from a series of known unhealthy lifting postures and then used to identify when someone is not lifting correctly. In addition the shoe can provide a signal to its wearer as a warning via sound or vibration making the shoe interactive . Machine learning is used to make sense of the raw data coming from the sensors. This concept is still under development and has reached a point where certain experience aspects of the shoe can be further considered. Specifically the actual use and implementation in a warehouse needs to be further worked out.
Currently Allshoes intends to develop the smart safety for their own brand of safety shoes called Redbrick which is being produced in Portugal by a factory called AMFshoes. The final form of the shoe is not yet fully defined. Decisions like what exact sensors, actuators and energy source need to be used will be reevaluated in this project. This means that electronics experts from the TUDelft need to be consulted as well as the factory in Portugal for advice on feasibility.
With the added functionality of the shoe, it's important to consider how it fits the context of use in the warehouse and how it could be easily understood by warehouse workers.
Another important aspect to the shoe is the data which it captures from employees. This can potentially be privacy sensitive and therefore needs to have a clear policy for what the data will be used for and how its processed.

Lastly, with the added components in the shoe, price could be a limitation that should also be considered. Allshoes sells safety shoes to individuals who buy their own gear, but also to businesses. A reasonable price or business model for the specific use in warehouses needs to be set up.
Smart insoles already exist for the purpose of research in sports and rehabilitation (image 2). These insoles are too expensive for mass produced safety shoes and would be overqualified for the purpose of detecting predetermined poses. They could however be used in the development of the shoe as a reference for cheaper and less sensors used in the smart safety shoe.

1)Zhang, Y. (2021). Smart safety shoe of the future: Detecting risks of low back pain. TU Delft.
2)document can be found on request to AED organisers

space available for images / figures on next page

introduction (continued): space for images

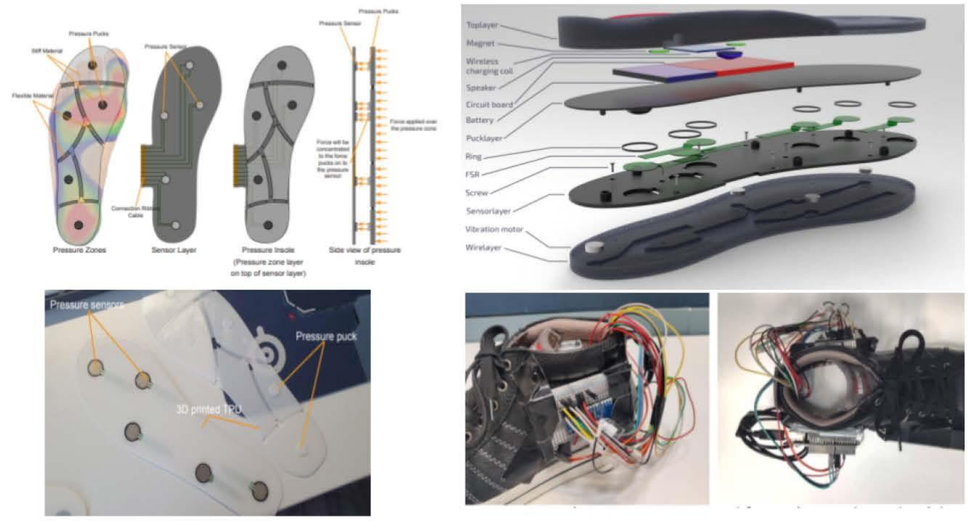


image / figure 1: Smart insole designs & prototypes from previous graduation project (left) and AED course(right)

image / figure 2: existing smart insoles could be used to determine the right sensor layout for the smart safety shoe.

Initials & Name MMH Fayed 5935 Student number 4460057

Title of Project smart safety shoe

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The scope of this project concerns further developing the smart safety shoe starting from the results of previous projects within Allshoes. This means that the solution space is focused on developing the safety shoe for use in warehouses, initially warning its wearer directly when they are in an unhealthy pose, and helping to improve workplace safety in the long term through data analysis.

Currently there is a need to get more sensor data to enhance the posture detecting capabilities of the shoe. The pressure patterns for predetermined unhealthy postures should be determined with detailed measurements. Possibly using the high-end insoles with plantar pressure sensors already on the market as a reference. This will then be used to improve the sensor layout of the smart safety shoe, making posture detection more reliable.

Having a fully finished design ready to ship may not be feasible in the scope of this project. The focus should be on validating the current design

Currently the sensor bed in the shoe is the only input for its interface. Its output has been considered in the form of actuators on the shoe itself. But there is also a need to test an interface that gives a more detailed overview of a workers performance. This can be presented to both the workers themselves but also to warehouse managers or those responsible for the safety of the employees. Such an interface will need to be evaluated with end users.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The smart safety shoe already has a proof of concept. With it I will perform measurements with multiple users to gather and analyse data about pressure distribution in the shoe. if needed I will reconsider the layout and the design, and use the test results to develop classification models about unhealthy postures in a warehouse

I expect to design a user interface for the shoe that should help the user in assuming the right posture while lifting. and guide users to lift weights in a proper way.
Data generated by the shoe should also be made available to people responsible for safety in the warehouse such as managers or health departments without violating privacy rules and regulations.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

working on a smart product
When I read about the smart safety shoe I was intrigued with the idea that a shoe could do more than just support your feet by actively helping you understand when you are lifting something in an unhealthy way. I realised that the project would involve designing the right interface for such a new idea, which also needs to be evaluated.
During my masters I followed the course Usability and Experience Evaluation and Redesign (UXAD) and had a positive experience in designing an innovative new interface and setting up tests to evaluate it. In this project I expect similar activities would have to be performed but on a larger scale. This is a challenge I would love to take on and become more confident in as in the future I would like to keep working on interfaces of new smart products.

health and wellbeing
The smart safety shoe has the potential to prevent musculoskeletal injuries in warehouses. To me this health aspect of the project is a motivation to see the project to its end.

prototyping
To make a prototype of the shoe I need to integrate several components into its sole and create a working user interface. This should be a nice challenge as I have always been someone who likes to tinker and understand how products work. In this project I suspect my skills will be put to the test as It will involve electronics, arduino and possibly 3d printing. Because I am working with a company that designs their own shoes I also hope to learn more about how the shoe will be made.

project management
In this project I have the opportunity to work closely with Allshoes at their office and coordinate my efforts with relevant stakeholders such as their factory in Portugal and the technical experts available at the TU delft. This makes a good opportunity for me to develop my skills in project management which I would personally like to improve upon.

I have previously had the unfortunate experience of working on a graduation project without success, this was partly due to an inability to communicate with the relevant stakeholders leaving me with little input and too many uncertainties to continue. With this new project I hope that the ability to work directly at a company will minimise the risk of this happening again.

Lastly, current work on the smart safety shoe project has had more of a technical nature because most efforts came from the IPD masters, the focus was on feasibility and figuring things out for production. While I do have the relevant technical background from my industrial design bachelors. I also aim to apply the knowledge and experience from my specialisation into interaction design. This also means that to work on aspects of the shoe that might be too technical or production specific I will have to consult the right experts and not try to do everything myself. I believe this is an important trait to have to be able to stay on schedule.

FINAL COMMENTS

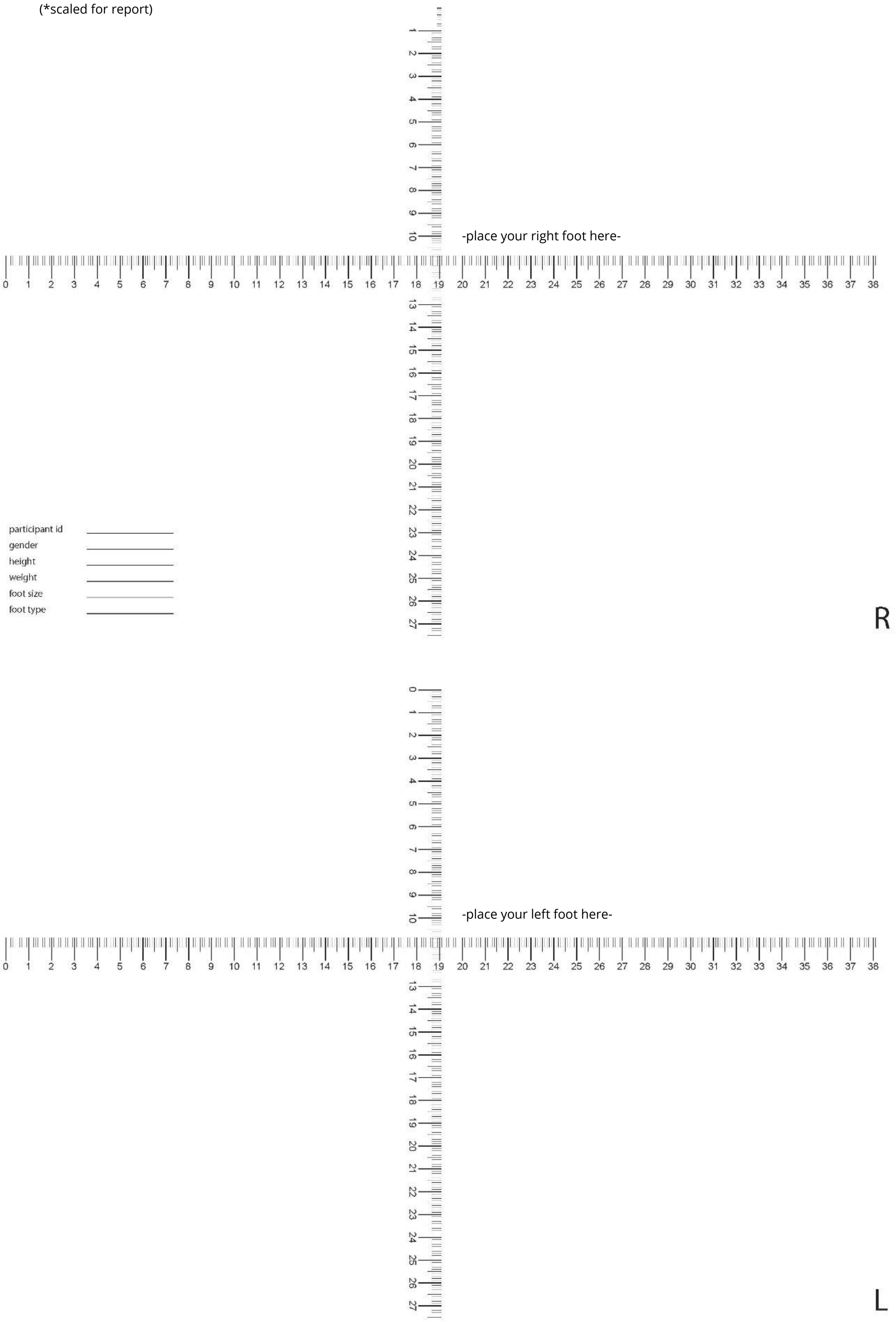
In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name MMH Fayed 5935 Student number 4460057

Title of Project smart safety shoe

E: Foot measurement tool for test

(*scaled for report)



F: Project assignments

Graduation Opportunity

Develop the Smart Safety Shoe of the Future!

Part 2

SMART SAFETY SHOE

Our story

The Netherlands excels at logistics, construction and transport. These industries are growing fast! A huge number of people work in these sectors. Working in warehouses, on constructions sites or with heavy equipment involves risks. Safety shoes are required in many workplaces and 1.5 million pairs of safety shoes are sold in The Netherlands each year, with Allshoes Safety Footwear as market leader. With own brands such as Redbrick and Mr. Miles and exclusive distribution rights for Grisport and Vismo, our company owes its success to our courageous decision to introduce revolutionary safety footwear that reflects the latest fashion and sports trends into a conventional market.

Our aim

Despite many measures to prevent accidents at work, 60 people are killed and 2,300 seriously injured every year. Safety shoes only protect the feet and only provide protection when an incident occurs. In other words, safety shoes currently play a static role. To help prevent manual handling injuries, such as back problems, we want to contribute in proactive incident prevention. Our goal? To create a "smart" safety shoe that detects and alerts the wearer to danger in high-risk situations. In cooperation with TU Delft and a SPD graduation student, research was conducted regarding this topic. A strategic concept has already been developed in which a smart safety shoe measures the leading and lagging indicators with regard to manual handling. This shoe can then give feedback by sending the measured data to relevant parties in order to eliminate the causes of manual handling incidents. It was strongly suggested that machine learning and/or AI offer predictive capabilities with strong potential, but concrete deployment of these technologies needs further elaboration.

Your task? Make the concept of "smart shoe" concrete.

On behalf of Allshoes Safety Footwear, we challenge you to further develop the smart safety shoe that will reduce the number of injuries caused by manual handling. It is your task to follow up on the current strategic concept; build tangible prototypes, test them and finally end up with an innovative smart safety shoe with the aim of bringing it to the market. You will continue to develop the current idea including the technology behind it.

Who are we looking for?

Are you the one who wants to bring the smart safety shoe to life and who wants to drive change with us? Then you are the person we are looking for! We are looking for an IPD graduation student who is able to develop an idea into a tangible prototype. You are willing to explore the potential of machine learning, AI, IoT and related cutting-edge technologies, and meaningfully incorporate these into your design. You do not hesitate to ask for information or assistance: during the project our colleagues will be there to offer helpful insights and advice.

What do we offer?

You can make use of a great workplace at the heart of safety-shoe land in our brand-new office in Amsterdam. However, it is also possible to work remotely. You will have access to our large network of manufacturers to gain all the information needed. There will be a budget available for you to develop your idea into a prototype. Our organization is informal and we have short lines of communication. You will receive an internship allowance and your travel expenses will be reimbursed.

Will you be the one to develop the Smart Safety Shoe?

If you're interested, please contact Jan.Arts@allshoes.eu

Wilfred van der Vegte from the Knowledge & Intelligence Design section is the envisaged chair for this graduation project. He can offer support on machine learning and related technologies. He also chaired the foregoing SPD assignment and is available for additional info: w.f.vandervegte@tudelft.nl

Allshoes safety footwear

Graduation Opportunity

Develop the Smart Safety Shoe of the future!

Our story

The Netherlands excels at logistics, construction and transport and these industries are growing fast! A huge number of people work in these sectors and working in warehouses, on construction sites and/or with heavy equipment involves risks. Since safety is crucial, we are investigating ways to minimise the risk and consequences of injury. Safety shoes are required in many workplaces and 1.5 million pairs of safety shoes are sold in the Netherlands each year, with Allshoes Benelux BV as market leader. Our company owes its success to our courageous decision to introduce revolutionary safety footwear that reflects the latest fashion and sports trends into a conventional market.

Our aim

Despite many measures to prevent accidents at work, 60 people are killed and 2,300 seriously injured every year. Safety shoes only protect the feet and only provide protection when an incident occurs. In other words, safety shoes currently play a static role. Allshoes Benelux BV wants to change this. We want safety footwear to make the transition from offering static protection to providing proactive protection. And we want to research how to do this with TU Delft. Our goal? To create a 'smart' safety shoe that detects and alerts the wearer to danger in high-risk situations.

Your task? Develop a Smart Safety Shoe

On behalf of Allshoes Benelux BV, we challenge you to develop a smart safety shoe that will increase safety at work. We imagine this will involve the use of sensors. Maybe to alert the wearer to potential hazards, such as a dangerous edge when working at height, or to navigate safely past traffic, or to detect tiredness and calculate breaks based on personal algorithms and walking routes. Of course, you may have other ideas! If you accept our challenge, there's one thing you need to bear in mind: the safety shoe must meet circular economy requirements.

Who are we looking for?

Do you want to create innovations that will drive change and maybe even save lives? Then you are the person we're looking for!
You are inquisitive, have the drive to achieve real innovation in our market segment and are able to develop an idea into a tangible prototype using applied market-oriented solutions. You do not hesitate to ask for information or assistance: during the project our colleagues will be there to offer helpful insights and advice.

What do we offer?

We offer a great workplace at the heart of safety-shoe land at our office in Amsterdam. You will have access to a large network of manufacturers and a budget to develop your idea into a prototype with the aim of marketing it!
Our organisation is informal, we have short lines of communication and celebrate success as a collective achievement. You will receive an graduation allowance and your travel expenses will be reimbursed.

Will you be the one to develop the Smart Safety Shoe?

If you're interested, please contact Jan.Arts@allshoes.eu

Allshoes Benelux

GRADUATION OPPORTUNITY ALLSHOES

All Shoes and Fieldlab UPPS and hopefully you will create a "smart" safety shoe that detects and alerts the wearer to danger in high-risk situations.

In an SPD graduation project at TU Delft, a strategic concept was developed in which a smart safety shoe measures the leading and lagging indicators with regard to manual handling. Following this concept, an IPD graduation project resulted in a tangible prototype equipped with pressure sensors in its insole. With this prototype, it was shown in a small-scale experiment that it was possible to deploy machine learning in order to detect several harmful postures in one subject. Detecting such postures can open up the way to support the prevention of work-related disorders in the long run. This graduation opportunity is the third and closing part of the Safety Shoe triptych as we are in the final stage of the project.

What will be your task? In this final stage we want to validate our current knowledge and findings by putting it into practice by scaling up the experimental testing of the principles behind the Smart Safety Shoe. It will be your responsibility to design and conduct experiments with multiple subjects in realistic situations and analyze the resulting sensor data, deep-diving into possible implementations of machine learning and/or AI. Furthermore, you will explore possible user interfaces that help end-users to improve the way they handle materials (e.g., through a tactile alert, or using a smartphone app), all whilst seriously taking GDPR measures into account. By conducting all these steps, our ultimate goal is to bring the Smart Safety Shoe to market. Are you up for this challenge?!

Who are we looking for? Are you the one who wants to bring the Smart Safety Shoe to life and who wants to drive change with us? Then you are the person we are looking for! We are looking for an IDP student (or possibly a DFI student) who is able to successfully perform the research steps described above, all whilst taking the user perspective into consideration. You are willing to explore the potential of machine learning, AI, and related cutting-edge technologies, and meaningfully incorporate these into your research and design. You do not hesitate to ask for information or assistance: during the project, our colleagues will be there to offer helpful insights and advice.

What do we offer? During this graduation, you can make use of a great workplace at the heart of the land of safety shoes in our brand-new office in Amsterdam, whereas it is also possible for you to work remotely. Allshoes has an informal organizational culture and has short lines of communication. There will be a budget available for you to conduct your research, a graduation allowance, and your travel expenses will be reimbursed. Lastly, the Safety Shoe project is conducted in association with the TUDelft Fieldlab Upps. Following up on the previous graduation project, a supervisory team has already been put in place for this project. Wilfred van der Vegte from the Knowledge & Intelligence Design section is the envisaged chair, and Anton Jellema from the section Applied Ergonomics and Design and Fieldlab UPPS is the envisaged mentor. They can offer support on machine learning and related technologies on one hand, and ergonomics, user research, and user interaction on the other. Will you be the one finalizing the last stage in the development of the Smart Safety Shoe?

Please contact Jan.Arts@allshoes.eu

G: NIOSH Multiplier tables for RWL calculation

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤ 1 Hour		>1 but ≤ 2 Hours		>2 but ≤ 8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Vertical Multiplier

V	VM	V	VM
in		cm	
0	.78	0	.78
5	.81	10	.81
10	.85	20	.84
15	.89	30	.87
20	.93	40	.90
25	.96	50	.93
30	1.00	60	.96
35	.96	70	.99
40	.93	80	.99
45	.89	90	.96
50	.85	100	.93
55	.81	110	.90
60	.78	120	.87
65	.74	130	.84
70	.70	140	.81
>70	.00	150	.78
		160	.75
		170	.72
		175	.70
		>175	.00

Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Horizontal Multiplier

H	HM	H	HM
in		cm	
≤10	1.00	≤25	1.00
11	.91	28	.89
12	.83	30	.83
13	.77	32	.78
14	.71	34	.74
15	.67	36	.69
16	.63	38	.66
17	.59	40	.63
18	.56	42	.60
19	.53	44	.57
20	.50	46	.54
21	.48	48	.52
22	.46	50	.50
23	.44	52	.48
24	.42	54	.46
25	.40	56	.45
>25	.00	58	.43
		60	.42
		63	.40
		>63	.00

Distance Multiplier

D	DM	D	DM
in		cm	
≤10	1.00	≤25	1.00
15	.94	40	.93
20	.91	55	.90
25	.89	70	.88
30	.88	85	.87
35	.87	100	.87
40	.87	115	.86
45	.86	130	.86
50	.86	145	.85
55	.85	160	.85
60	.85	175	.85
70	.85	>175	.00
>70	.00		

Asymmetric Multiplier

A	AM
deg	
0	1.00
15	.95
30	.90
45	.86
60	.81
75	.76
90	.71
105	.66
120	.62
135	.57
>135	.00

RWL = LC X HM X VM X DM X AM X FM X CM

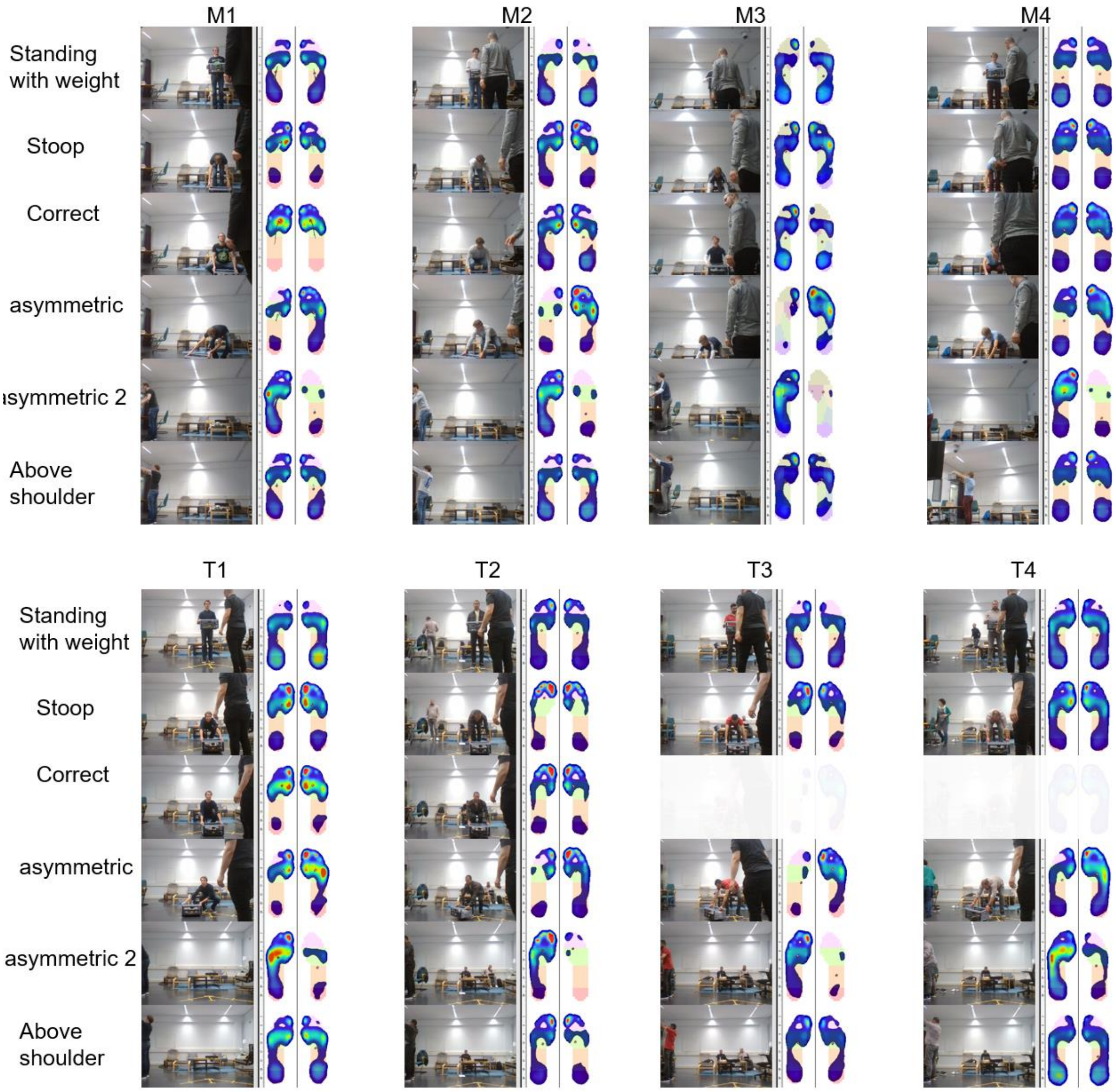
H: inspiration

Aesthetic footwear elements shaped like pressure sensors. (Form follows function)

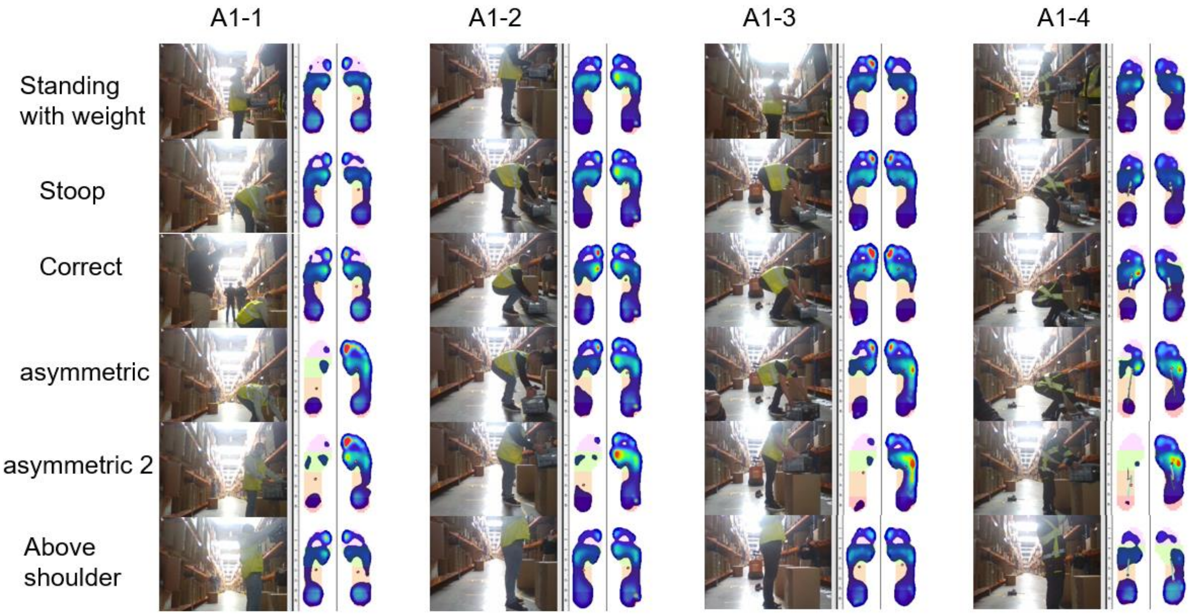
Modular safety shoe products

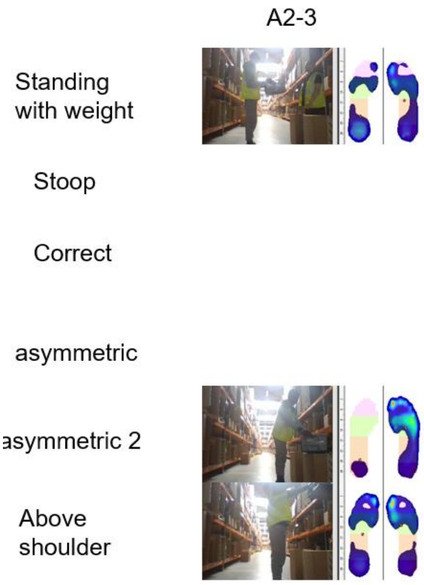
I: Test data

	participant id	weight	length	foot size	gender
Delft day 1	lab-1-1	64	1.8	42	male
	lab-1-2	74	1.86	42	male
	lab-1-3	67	1.83	43	male
	lab-1-4	70	1.83	43	male
Delft day 2	lab-2-1	77	1.83	43	male
	lab-2-2	75	1.83	44	male
	lab-2-3	76	1.83	42	female
	lab-2-4	61	1.68	43	male
	lab-2-5	114	189	45	male
Alkmaar day 1	alk-1-1	67	176	42	male
	alk-1-2	92	188	44	male
	alk-1-3	105	177	44	male
	alk-1-4	76	173	42	male
Alkmaar day 2	alk-2-1	77	185	44	male
	alk-2-2	81	180	45	male
	alk-2-3	73	185	45	male
total 16 participants 15 male 1 female					



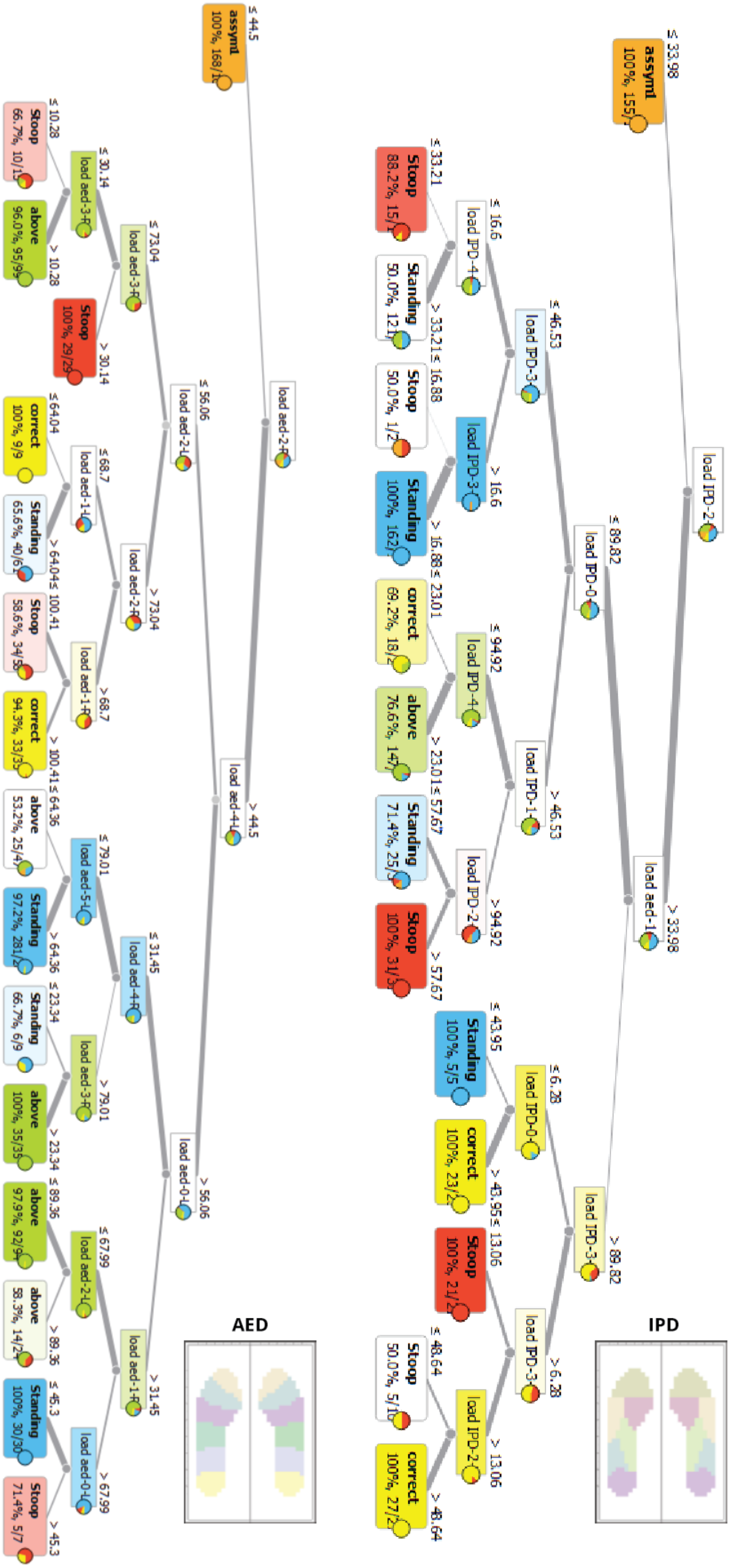
overview of pressure profiles for each participant of the lab tests (10kg weight)





- For some participants the video files inside the xsensor session got corrupted which made it extremely hard if not, impossible to synchronize their pressure readings with the postures that are derived from their video feed. Therefore, not all participants are included in the overview.
- Participant A2-3 reported he/she had recently had trouble with bending through their knees. It was chosen to exclude all postures that required bending and lifting,
- The correct lifting for participant t3 and t4 was excluded due to an error in the test procedure.
- Two variations of asymmetric lifting were performed. it was later decided to only focus on asymmetric 2 as it was not combined with bending over.

overview of pressure profiles for each participant of the warehouse tests (10kg weight)


IPD
AED

J: requirements testing

The feature layers presented in 04.2 are weighed against the requirements that were given in 01.3. Most of the requirements are covered in the first layer.

Layer 1
Layer 2

External requirements

- The SSS should adhere to the current NEN ISO safety standards of safety shoes
- The SSS should adhere to the data protection requirements of the European GDPR.
- The SSS must allow for integration with current workplace protocols
- Producing The SSS should be possible with as little change as possible to the existing production of safety shoes.

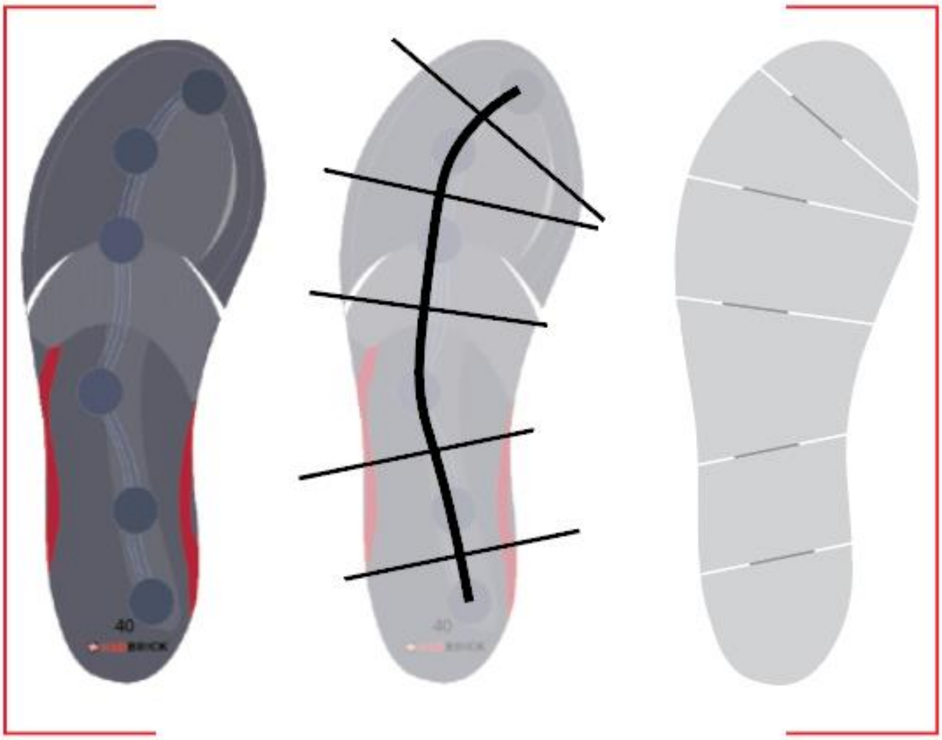
Technical requirements

- The SSS can detect predefined postures of multiple wearers with considerable accuracy (at least 90%).
- The electronic components in the SSS need to be able to withstand environmental conditions inside (safety) shoes.
  (Body temperature, moisture, weight/force, static electricity etc.)
- The number of sensors needed to detect a posture needs to be optimized to minimize costs and complexity,
- The SSS should be able to process the sensor data locally.
- The battery life of the SSS should be long enough for a working shift of 8 hours,
- The SSS should allow for the replacement or charging of its battery.
- In producing the SSS, an effort must be made to promote sustainability of the product itself.
  (Durability, repairability, recyclability)
- The SSS should be provided as a standalone solution, its core functionality is fully integrated into the shoe.
- Posture detection has to work offline without the need for connection to other equipment.

Experience requirements

- Beyond the core functionality of the SSS, its potential for more functionalities should be communicated to users
- The presence of electronic components in the SSS must not compromise the comfort of the shoe.
- The SSS users should not feel uncomfortable in being monitored while wearing the shoe,
- The wearer Should feel supported and looked after when the shoe gives feedback about lifting postures.
- The feedback given by the SSS must always be noticeable by the wearer.
- The weight of the SSS must be optimized to prevent it from becoming heavy and burdensome equipment
- Continuous usage of the SSS should result in improved posture for a user.
- Compared to regular safety shoes, the SSS should reduce the number of injuries a user can get.

K: other Design activities



Process for creating the AED layout for comparison with IPD layout.

الحمد لله