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Developing an AI-powered smart insole system to reduce the possibility of back pain among older workers: lessons from the Norwegian construction industry

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Abstract. Blue-collar workers are generally more susceptible to specific health conditions such as musculoskeletal disorders, among which back pain is a significant problem for older workers. This study presents the design of a smart insole system developed as a part of the research and the practicality of its use in the construction industry, including an evaluation of its benefits and limitations. Pressure sensors in the soles generate heatmaps that allow us to identify incorrect posture using an adaptable Artificial Intelligence lifting engine. The data is used to evaluate the lifting actions in real-time and preemptively warn the individuals. Using the principles of participatory design as a starting point, the pilot phase, and testing of the solution, the pre-use survey was conducted among construction workers to understand their experience while interacting with the solution. The user testing period was followed by the feedback and evaluation period, which included getting informal feedback on the system. While it has shown the promise of a new solution, it still needs improved robustness and simpler instructions. Some minor technical challenges must be addressed before moving to the commercial stage. The results are used to evaluate further, improve the system, and make decisions in the product design.

1. Introduction

The rapidly shifting demography and a spike in the old-age dependency ratio across Europe are expected to strain the local workforce's availability and increase demand for social safety programs [1, 2]. When we combine the increased presence of older workers and their heightened susceptibility to specific health-related issues (such as back pain, lung disease, etc.), we need to put a higher focus on developing solutions that allow this vulnerable group to carry on their daily tasks safely. A previous study from 2013 has shown that one of the major problems among older workers is back pain, much of which stems from heavy lifting [3]. However, emerging innovations and technologies have the potential to address these issues. Insole pressure sensors have been used in construction sites for fall detection [4] and risk perception mapping [5]. The SI-FOOtWORK project explores the possibility of using similar insole technology to reduce the likelihood of developing back pain.

The primary purpose of this paper is to cover how the end-users (blue-collar workers from the construction industry in Norway) were involved during the pilot testing phase of the smart insole system and the results of the real environment testing. We are looking for ways to improve the prototype, evaluate the system based on user feedback, and make evidence-based decisions in the final product design. Hence, the research question is related to the end-user perspective: *Do the test users experience improving their lifting technique while using the system?* From the clinical point of view, the hypothesis is that the solution (smart insole system) empowers the users to correct or avoid problematic situations (lifting, carrying, and inaccurately shifting the workloads), thereby reducing the risk of developing back pains in the long run.

2. Literature Review

2.1. Back pain in older blue-collar workers

The prevalence of long-term back injury among older workers is well documented. A study in the US found that older workers are 1.4 times more likely to suffer back problems than the average blue-collar workers [6]. In age-adjusted analyses of the risk of chronic LBP, both women and men showed significant increasing relationships with the level of physical activity at work [7], with about 30% higher risk in the categories involving walking and heavy lifting, particularly strenuous work compared to sedentary work. However, this issue is even more severe in the construction industry.

Several studies have shown that older construction workers are more vulnerable to emotional problems, musculoskeletal issues, and lung diseases than their counterparts working in other sectors [8]. In the USA, results showed that about 40% of older construction workers over 50 suffered from persistent back pain or problems [9]. In Scandinavia, a longitudinal study in the Dutch construction industry has found that while older construction workers are less prone to injuries in the workplace, they are more susceptible to musculoskeletal disorders than their younger counterparts [10]. In Sweden, statistics have shown that musculoskeletal injuries (such as lower back pain) are responsible for 72% of all sick leave over a four-week duration in the construction industry [11]. Moreover, in the construction industry, older workers are more likely to opt for disability retirement than to return to the workplace after an injury [12]. A study in the US construction industry by researchers at Johns Hopkins has found that a similar injury will result in more severe medical consequences for an older worker, which also translates to higher medical bills [13].

2.2. Co-design process

The pilot phase design and real environment testing of the smart insole system used in this study have been centred around optimizing user participation benefits. The traditional approach to finding a new solution has been that the users define a problem, and the designers develop a solution. But the issue is that on many occasions, these solutions are not well-tailored to meet the specific needs of users, partly as the users and designers have different perspectives of the problem [14]. Co-design (also known as participatory design) is a process of collaborative innovation where the users collaborate with the product designers/researchers to create a solution that is often more practical and is centred around the user's needs [15].

Co-design has been successfully used within the AEC domain in areas such as co-creating public spaces with citizen participation, and facilities management [16]. Involving and informing users before starting the process of co-design can ensure inclusiveness and collaboration throughout the whole process [17]. That way, users can become both, active participants and co-creators of solutions, alongside the relevant stakeholders [18]. Co-design has been proven to increase the uptake rate of solutions, turning them from ideas on paper into long-term sustainable innovations [19].

For the co-design method followed in this study, the involvement of the end-users evolves, starting from the inform phase at first where they are introduced to the concept, and it ends with empower stage, where the product or service is created through the process is handed over to the users for operational use. These stages are illustrated in figure1.

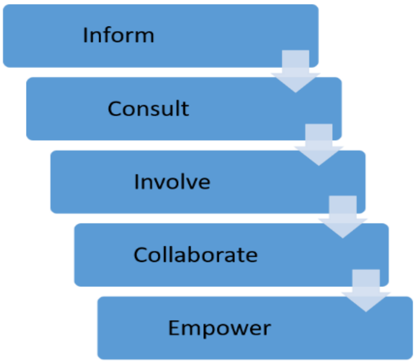


Figure 1. Stages of involvement in the co-design process [18].

2.3. Pressure sensors and incorrect lifting action

Insole pressure sensors have been used in construction sites for fall detection [4], risk perception mapping [5], etc. Specifically for the older population segment, sensor-based technology has been used to monitor health remotely, and the users generally have a positive attitude and high acceptance rate towards adapting such innovative solutions [20]. The basic principle is that, from the force sensors located inside the insole, the centre of pressure (COP) is computed [21]. A neural network is then employed to classify the current posture of a worker, and ultimately the user is notified via the mobile app, as illustrated in figure 2.

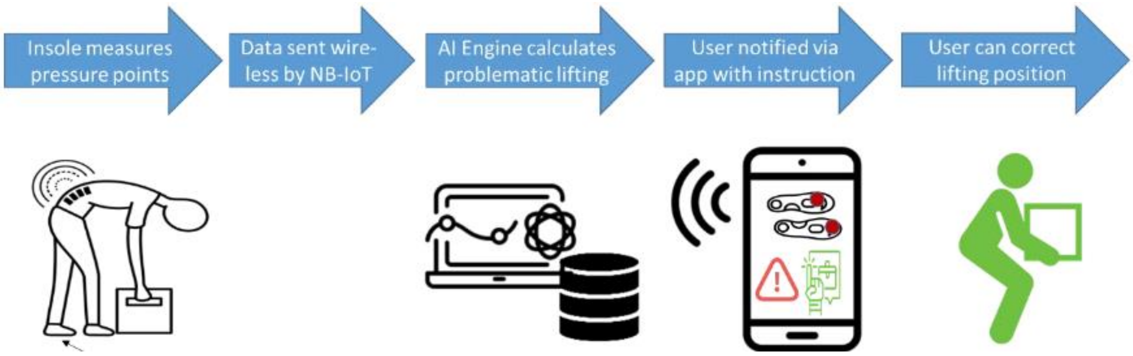


Figure 2. Lifting action detection from pressure sensors.

The data transmission from the insole device to the backend server takes place using narrowband IoT (NB-IoT) communication. NB-IoT is a robust technology that has been used in the healthcare research industry, with work underway to improve reliability even further and ensure there is no data loss [22]. A similar study has been conducted to determine the risk of developing work-related musculoskeletal disorders (WMSDs) [23] but is primarily focused on overexertion-related job tasks in a laboratory setting. We are attempting to cover all job tasks in an active construction site focusing on older blue-collar workers.

3. Research Methodology

3.1. Pilot testing

Pilot testing is essential for checking product readiness before full-scale implementation. It gives insights into the user's reaction to the system, and it is done to measure the system's success [24, 25]. When running the testing, we intend to visualize the realistic usage of the system in daily work. This mainly focuses on the functionalities of the system and the application (user satisfaction, etc.). A selected group of five end-users tried the system under test and provided feedback in this phase. The real environment testing consisted of four phases, as shown on the timeline in figure 3.

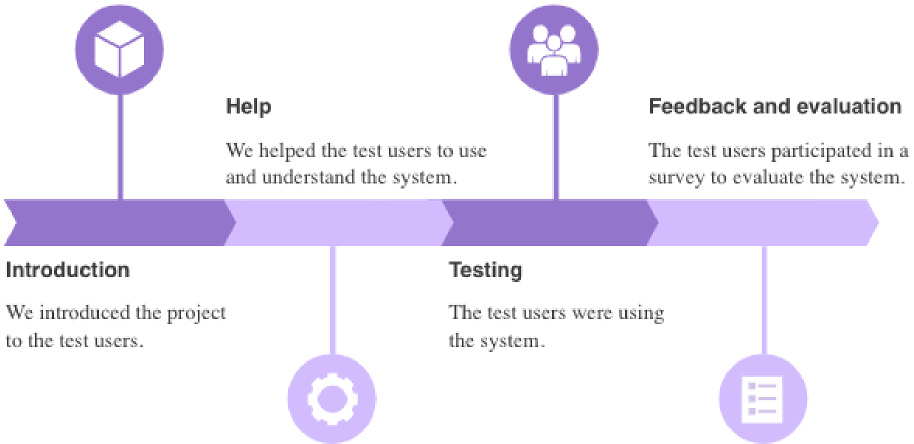


Figure 3. Timeline of the pilot testing.

3.1.1. Introduction of the project. In this phase, we introduced the project to the test users and explained the purpose and the objective. We gave the test users the equipment and instructions on how to use the system, including information on how to turn on the insoles, turn on the gateway, charge the devices, attach the box to the leg using the straps, etc. Some images of the final prototype are given in figure 4.

Figure 4. Prototype of the developed insole.

3.1.2. Helping the users. Here we distributed the shoes and the equipment and then helped the test users to use and understand the system (figure 5). We were present at the testing site, and the purpose was to answer any questions and dilemmas from the test users about the system. The included a detailed explanation of how to start, use and charge the system, as well as help with how to wear the system in the shoes. It also included recommendations on treating the system, so it does not get damaged.

Figure 5. Construction workers are charging and using the insole.

3.1.3. User testing. The user testing period included the test users wearing and using the system at their workplace daily for two weeks. During this period, we were regularly present at the testing site to help with any technical troubleshooting and answer any questions about the system. The purpose of this period was to gather data from the insoles for the future development of the application and to get informal feedback about the system and the application.

3.2. Data visualization used in mobile application

In the visualization presented to the users on their mobile application, each coloured square represents a pressure sensor in the insole. The pressure sensors generate colours based on the load described in table 1.

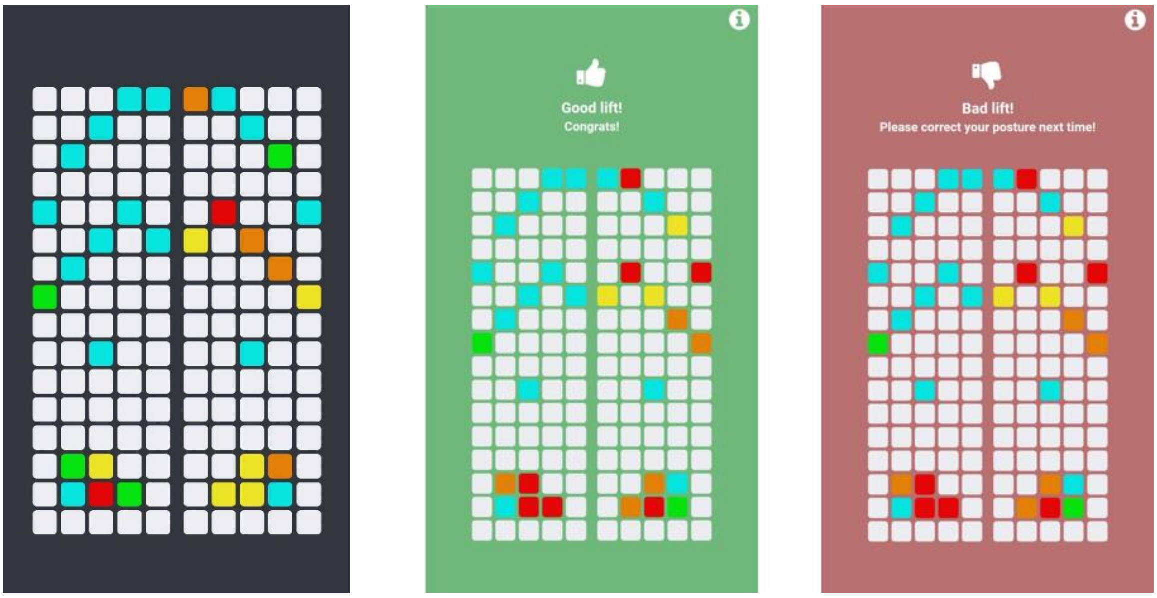
Table 1. Colour codes are used in visualization.

Colour code	Blue	Green	Yellow	Orange	Red
Remarks	Low pressure	←	Medium pressure	→	High pressure

The user was asked to perform the following steps several times to understand how his posture can determine a good or bad lift.

i) Start by trying to pick up an object.
ii) The app will follow your movements and show a correct or incorrect lift after about 3 seconds (the average lifting time).
iii) Repeat until all your tries are correct lifts.
iv) The app will continue following the movements and storing the data for future analysis.

The app will show the sensor data by default when no lift is detected. When a lifting action is detected, the app will show whether it is a good or bad lifting posture, as illustrated in figure 6.



No-load (default) Good lift Bad lift

Figure 6. Pressure map generated from pressure sensors.

3.3. Data collection
Data was collected from different sources, including surveys (the pre-use survey), data sent from the insoles to the server, and informal feedback (comments and observations from test users).

3.3.1. Pre-use survey. The pre-use survey was done in the introduction period before the start of real environment testing. It included questions about the test user's age, gender, weight, height, repeatedly performed actions at work, and their history of back pain injuries. This survey's purpose was to gain insight into the test user group.

3.3.2. Data from insoles. The insoles sent data through a gateway to the server. In real-time, the application uses this data to give the test user feedback on their posture and remind them to correct their posture while, for example, lifting heavy things. This data is also used for further use and improvement of the application to better predict and differ between a correct and an incorrect posture.

3.3.3. Informal feedback. As part of informal feedback, we collected data from the test users, including their comments and observations about the system, problems, and general satisfaction or displeasure with the system.

4. Findings and discussion
The overall goal of the pilot testing phase was to understand the users' experience with using the system and use their feedback to focus on how the solution can be further improved. Pilot testing was done in four periods: the introduction, the helping, the user testing, and the feedback and evaluation period. The findings described below are part of the feedback and evaluation period and include informal feedback from the user testing period. Instead of filtering by personal characteristics (age, gender, IT skills), participants were recruited from: active workers, still working, or have experience in the construction field because we are interested in collecting valuable feedback (e.g., what users need and how they use the system, was it easy to use, etc.). We ran the pilot test with a small number of construction workers in Trondheim, Norway (Backe AS) to verify the entire system operating in real-time. They also gave us comments and recommendations that will be used for prototyping and to offer a better product.

4.1. Pre-survey results
The pre-survey included questions about the test user's age, gender, weight, height, repeatedly performed actions at work, and history of back pain injuries. With the results, we intend to evaluate the individual's functioning (or functional status), meaning that no health problems or pre-existing conditions are putting them at risk. All five participants have the ability to perform physical activities, and all of them reported they repeatedly perform manual labour, heavy lifting, and standing on their feet for long periods at the workplace. Out of five persons, three reported they had had back pain in the last six months, one of them described it as severe (7 on a scale from 1 to 10), while the other two described it as mild back pain (2 on a scale from 1 to 10).

4.2. Informal feedback
4.2.1. Technology. Handling the technology was easy; for example, participants had no difficulties in putting the shoes on, and wearing the black box and carrying the orange box (gateway) did not bother them. However, it could be uncomfortable to wear it for a long period or when they have to respect norms for work protection or health protection rules. The users need clear instructions to use and charge the system daily and respect all the rules. Even so, most agree that change is possible if workers foresee the significant benefits and real support to alleviate their suffering.

4.2.2. Comfort. The test users reported that they had no difficulties putting the shoes on, but wearing them for a long period could be uncomfortable. Some test users also suggested including an audible notification to alert the incorrect lifting. The test users reported that the plastic material was uncomfortable to wear while working, as it was not very pleasant on the skin. For that purpose, we put some soft material on the underside of the box that touches the skin. The solution helped and made the system more comfortable to wear while working. We also observed that when we first handed them the shoes with the insoles, they were handling them with force, which could damage the sensors. The test users gave no feedback regarding the mobile application, as we could not connect the sensors to the application.

4.2.3. Behaviour change. Behaviour change discusses the potential to correct or adjust people's personal habits (the way of lifting, heavy workloads, and movement) to prevent back pain. As factors in behavioural determination, we assume that the participants have the skills to adopt a smart insole (self-efficacy) and use it because wearing the smart insole system will be beneficial to preventing the appearance of back pain (performance expectancy). Wearing the system could be a powerful tool for changing their lifting and daily routines after receiving feedback from the app.

5. Research limitations

The target group in the SI-FOOtWORK project is older adult workers (above 50 years) who actively participate in manual labour in the workplace. By definition, this includes participants from various industries where such manual labour is used, such as the construction industry, healthcare sector, and others. However, this trial is focused only on end-users within the construction industry in Norway. Also, we need to be aware that not all types of back pains are immediate, some may show up after weeks or even months of incorrect lifting [26], and these cannot be registered in the existing system. Hence, we have intentionally left out the passive injuries that occur from long-term heavy lifting for this study.

6. Further research

Although the features provided by the system were well received, several improvements and requests have been identified that could potentially provide more value to the user in the long term. Preliminary feedback suggests that the use of the application could adversely impact the overall productivity, as the users will have to register a lifting action before and interact with the app on their phone afterwards. This takes time and acts as a distraction that may impact the overall productivity. The robustness of the smart insole has also been a concern area for the test users in Norway since it will be used in a harsh environment. There could also be cellular network availability issues because the gateway needs to be connected to the network to send data to the server, which is important for giving real-time feedback to the test users. During the testing phase, we also ran into connectivity issues with some of the devices where they were unable to transmit the data from the insoles to the server. So far, we have identified the following set of future improvements that we may be able to add within a future project or as part of a commercial effort to bring the system to the market:

i) Add background processing for the mobile app so that notifications for lifts are sent even if the app is not running in the foreground.
ii) Add and improve the detection algorithm to give recommendations for good/bad lifts while the phone sits inside the pocket.
iii) Reduce battery consumption for the screen on/off by integrating a real-time framework for communication with the back end.
iv) Provide more explicit instructions on what was wrong in the posture when a bad lift is detected.

7. Conclusions

Collecting and evaluating feedback from test users who wore the shoes equipped with smart insoles gave us vital information needed to respond to the user requirements and develop a sustainable solution that is both practical and useful. We assume that implementing such a system may lead to a change in behaviour and thus help reduce the possibility of back pain. We learned that the instructions and recommendations on using the system with care should be more specific and highly important, as it prevents the insoles from being damaged. Another thing we learned was that the application should be tested for robustness to ensure it works at all times and under all conditions. These results will be used to provide direction in the areas of user requirements and product specifications and, finally, to commercialize the SI-FOOtWORK as a personalized solution for workers and personal training. Subsequently, we anticipate raising awareness of the users that may lead to a reduced risk of long-term back injuries.

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