Malaysian Journal of Public Health Medicine 2018, Special Volume (2): 24-31

ORIGINAL ARTICLE

# ANALYSIS ON THE EFFECT OF PERSONALISED INSOLE FOR PROLONGED STANDING INDUSTRIAL WORKERS

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## ABSTRACT

*Working in prolonged standing position among industrial workers has been shown to be associated with different potentially serious health outcomes, namely lower back pain, leg pain, fatigue, discomfort, and other health issues. Personalisation of insole offers a solution that will provide a perfect fit and comfort to the shoes wearer based on the ergonomic considerations. It works in a way that it alters the pressure away from painful areas by increasing the surface area that supports the weight of the body and evenly distributes it to the whole plantar area. Survey was conducted among workers at a manufacturing industry company to study on the level of pain experienced by them together with their foot anthropometry. Then, the foot pressure of each of the workers was collected by using pressure measurement device (F-scan). Combination of these data was used to design the customized insole that is fit for the worker. The personalised insoles were fabricated by using Additive Manufacturing technology. After that, the insoles were validated by using the F-scan and Electromyogram (EMG) to ensure their effectiveness in reducing pressures on the foot and muscle activity hence improving the comfort of the shoe wearer. At the end of the experiment, it was found that the insole is able to reduce the peak pressure of four out of five areas of the worker's foot with the reduction of pressure percentage ranging from 6% to 28%.*

***Keywords***: *Personalised insole, additive manufacturing, foot pressure, muscle activity*

## INTRODUCTION

Within the current demand of working conditions, workers are required to stand for lengthy time periods without being able to sit while working. Many occupations such as automotive industry workers, cashiers, bank tellers, casino dealers[1], health care personnel, retail staff, and assembly line workers are required to work in prolonged standing position[2]. It was found that 47% of workers spent 75% of their working hours in standing position[2].

Researches shown that many of workers suffered with discomfort and pain as a result of spending most of their time by standing. Working in prolonged standing position will expose the workers to the risk of foot and lower leg deformities, back problems, lower extremity swelling, venous blood restrictions, and discomfort[3]. Moreover, prolonged standing is often associated with musculoskeletal disorder especially low back pain[1, 2, 4.]

Insole is an interior layer inside of shoes that provide additional comfort and supports the underside of the base. Insole has been used extensively around the world for the same purpose, come in many shapes, sized and used to fit a variety of different foot types. The functionality of the insole is to provide shock and foot sweat absorption from walking or running activities. Generally, the insole can be removed easily and replaced with another insole that comes separately for more comfort. There are many types of shoes that used insole such as sneakers, formal shoes, sport shoes, and boots. Nowadays, the insole contributes a lot of changes to get a healthy life. As a sport shoe, it could provide maximum comfort to the user because sport is one of the outdoor activities and rugged. The insole of the sport shoe also required the arch shape of foots that control the leg and pelvis while doing sport activities. At this stage, the sole is one of the parts of the shoe that is very important for comfort and stability[10].

In relation to working situation, the safety shoes or boots are preferably prepared for each and every company and every of their workers specifically in the production line. This is to ensure the safety of worker's foot and it is an effective way to protect the foot from any harm. The safety shoes mainly avoid slippery with respect to safety and balance performance in order to perform a job[11]. Generally, insoles were different between safety shoes and sport shoes. Safety shoes focus more on the outside part of the shoe and this is where the problems arise among the workers when the foot of the workers developed acute aches and sore feet due to the usage of less effective insoles. These causes also lead to changes of leg postural and musculoskeletal disorders[12].

Furthermore, the use of shoes and insole materials could cause the shock transmission to the spine if the material are not suitable[13]. This study stated their concerned about the insole that may have low shock absorbing behaviour. It was reported that the use of proper shock absorbing insole was one of the beneficial ways in reducing and treating the low back pain of the users due to the material of the insole. The report also suggested that proper selection of shoes and insoles could reduce external and internal forces around the lumbar spine.

In order to solve the problem, this project was conducted to design and develop personalised insole based on the peak pressure data and anthropometry of the production line workers that has been collected. The main purpose of the development of this personalised insole is expecting to help in improving the lumbar muscle fatigue that occurred to the workers in the production line. This personalised insole develops new level of insole usage which can be only worn individually whereby each design of personalised insole based on the individual anthropometric data and foot profile of the workers. This is a step closer to reduce the lumbar muscle fatigue and assist workers to increase their working productivity without any issues of medical sickness and absenteeism.

## METHODS

This study was carried out on the production workers at ABC Company Sdn. Bhd. who wears safety boot provided by the company. This study started with the distribution of questionnaire to a total of 45 workers based on the calculated sample size based on the total number of the workers at the production area. The questionnaire served the function of gathering data regarding the level of pain experienced by the workers. The workers were asked on their level of pain at their foot based on a figure provided in the questionnaire. The figure is shown in Figure 1 and it consists of a foot image with 5 separated areas which are heel area (M1), medial mid foot area (M2), lateral mid foot area (M3), metatarsal phalangeal joint area (M4), and toe area (M5)[5].

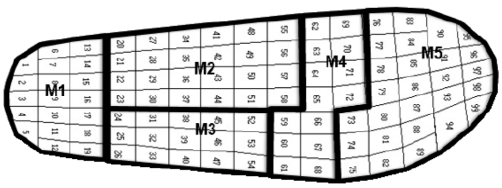



*Figure 1 -The five area of the foot : heel area (M1), medial mid foot area (M2), lateral mid foot area (M3), metatarsal phalangeal joint area (M4), and toe area (M5)*[5]

Then, a pressure measuring device, F-scan from Tekscan Inc. was used to collect the pressure distribution of the workers' foot. The experiment setup is shown in Figure 2. F-scan which is an in-shoe assessment device was chosen to be used in this experiment since it is flexible and embedded in the shoe thus producing measurements that reflected the interface between the foot and the shoe[6]. The pressure of the foot was collected by asking the worker to walk a distance of 10 meters along the walkway with the sensor inserted in the safety shoes. This method was performed in accordance to the previous study done by Mueller et al.[8] The study stated that taking a mean of 3 steps will enhance the reliability of the plantar pressure measures to an acceptable level (reliability coefficients > 0.70).

*Figure 2a - F-scan sensor inserted in the safety shoes*

*Figure 2b - F-scan experiment setup on subject*

*Figure 2c -F-scan software display at the laptop*

Information from the questionnaires and F-scan results were used to develop shoes insole that is personalised based on the needs and criteria possessed by the workers. In the development process, the insoles were designed by using Solid works software and fabricated by using Additive Manufacturing (AM) technology. The material that was used in printing the insoles is Acrylonitrile Butadiene Styrene (ABS) with the reference to the result of CES Edupack software. The insoles were validated by testing them with two experiments. First experiment is by checking on the foot peak pressure through F-scan and second experiment is by checking on the muscle activity of the low back muscles (thoracic erector spine, erector spine and multifiduus lumbar) and leg muscles (gastrocnemius and soleus).

## RESULTS AND DISCUSSIONS

There are five areas of insole that were considered in this study which areM1, M2, M3, M4 and M5[5]as shown in Figure 1. The respondent should respond on each area based on the five level of scales where level 1 is no pain, level 2 (light pain), level 3 (moderate pain), level 4 (very pain), and level 5 (extreme pain). Figures 3 and 4 depicted the analysis on the level of foot pain experienced by the workers.

Based on Figures 3 and 4, it is shown that there are three major areas that are chosen to be the most painful areas for both left and right feet which are M1, M4, and M5. Both feet have the same percentage for the sum of pain percentages which are51% for M1, 40% for M4, and 32% for M5. However, among all of the three areas, the M1 area is shown to be the area with the most pain. 18% of the workers admitted that they experienced very pain at this area for left foot while 22% of the workers experienced very pain at the right foot.

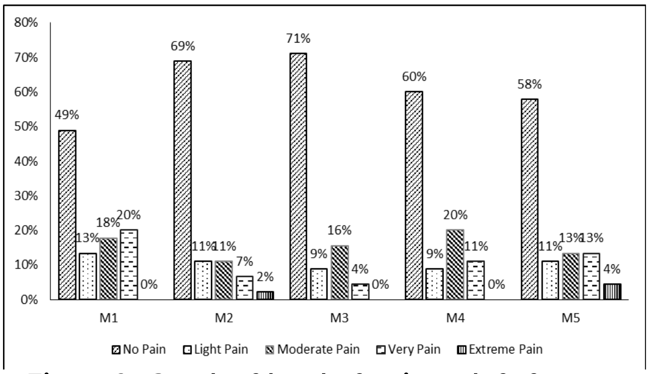



*Figure 3 -Graph of level of pain on left foot*

F-Scan Sensor was used to obtain the pressure under the foot. This equipment was used because it is able to measure the plantar pressure in order to analyse the peak pressure under the foot. The software also provides the ability to show the distribution of pressure at the foot area and the location of the peak pressure.

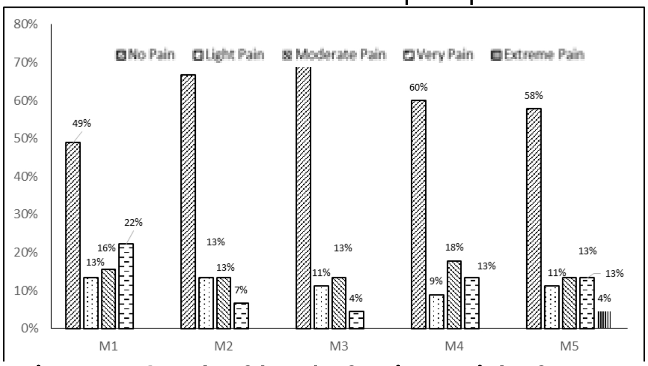



*Figure 4 -Graph of level of pain on right foot*

The data collection for pressure under the foot was collected among 23 subjects. Later, all information of the data was analysed using the F-Scan software. The priority of the study is to find out the highest pressure among the 23 subjects and the result is shown in Figures 5 and 6.

Figures 5 and 6 show the peak pressure of 23 subjects. Subject with the highest peak pressure is ID13 where the pressure of his left foot is 802 kPa as shown in Figure 5 while the right foot is 306 kPa as shown in Figure 6. Subject ID22 represents the lowest peak pressure, 331 kPa and 159 kPa for left and right feet respectively. Peak pressure was chosen as the main focus on this study because the aim is to locate the contact area that contributed to the most pressure under the foot which is the critical part under the foot of the workers. High pressure resulted from wearing ill-fitting orthotics or footwear is the source of pain sensation experienced by the workers. The fundamental method to reduce the pain originated by the orthotics or footwear is by reducing the offending pressure[7]. The offending pressure can be reduced by maximising the contact area of the insole to the foot[7].

In order to analyse the contact area of peak pressure, the data were analysed from five areas which is M1, M2, M3, M4 and M5. These five areas are the criteria to develop an insole with the purpose of reducing the pressure and lead to the introduction of the new personalised. The personalised insole is functioned to redistribute the pressure under the foot so that the peak pressure will be reduced. Hence, reduce in the pain and discomfort is experienced by the subject.

In this study, the top five respondents with the highest peak pressure were chosen in the development of the personalised insole. All of them were selected to be involved in the development of the new personalised insole. Figure 5 shows the subjects with the top five highest peak pressures. Figure 7 provides the data for the subjects who are the top five highest peak pressure namely ID2, ID12, ID13, ID15, and ID20 with respective peak pressure value of left and right feet, ID2 (655kPa, 494kPa), ID12 (637kPa, 437kPa), ID13 (802kPa, 306kPa), ID15 (553kPa, 455kPa), ID20 (673kPa, 520kPa) respectively.

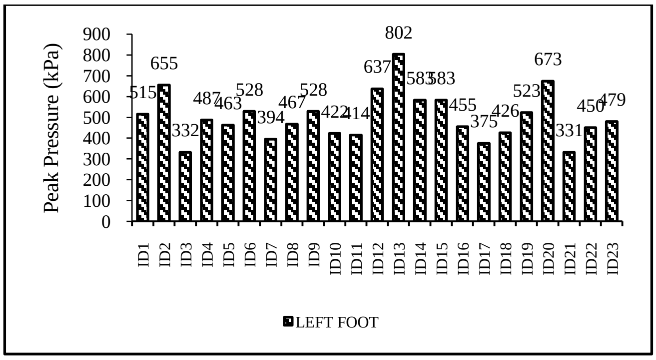


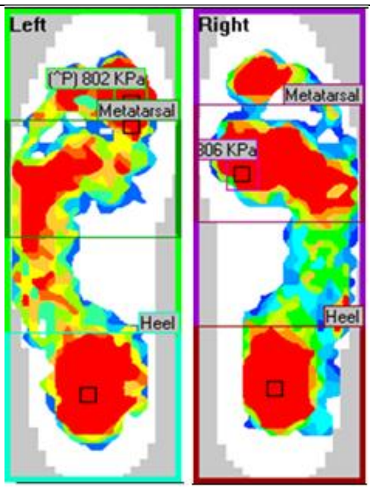
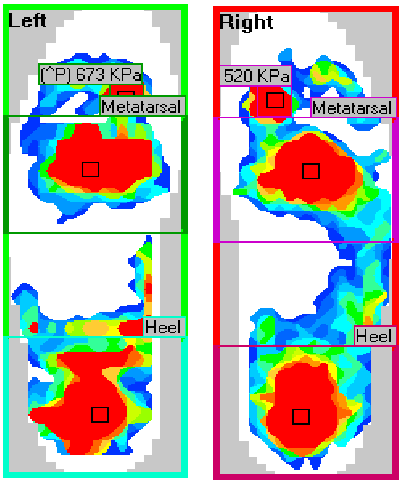
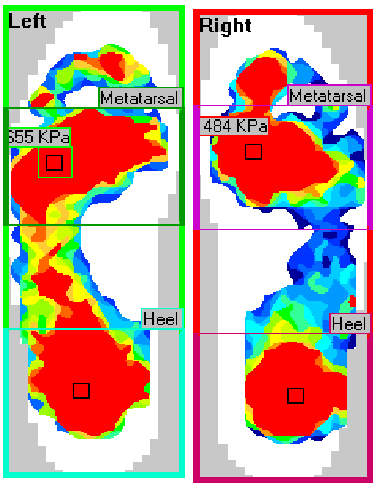

***Figure 5 - Graph of peak pressure of the subject on the left foot.***

The images provided by the F-scan software displayed the distribution of pressure on the area of the foot. The pressure was represented by three main colours. Red indicated the highest or maximum pressure, green indicated moderate pressure, and blue indicated the lowest or minimum pressure of the foot. Table 1 shows the foot images of five subjects with the highest foot profile pressure. Based on the images, it can be seen that the red colour is prone to exist at M1 and M4 area of the foot. This indicates that the pressures at both of the areas are high. Previous study has also showed the same result where

Salles and Gyi found that pressure at the forefoot and heel are the highest among all areas of the foot[8].

The design of the insole was developed based on the foot profile from the F-scan sensor that was analysed. The design was focused on the peak pressure of the top five respondents that have the highest peak pressure.

*Table 1 – The top five subjects with highest peak pressure*

<table>
<tr><td>ID name: ID2<br>BMI: 20.82 (Normal)<br>Shoe Size: 7 UKs</td><td>ID name: ID3<br>BMI: 20.82 (normal)<br>Shoe Size: 7 UKs</td><td>ID name: ID2<br>BMI:17.63 (Underweight)<br>Shoe Size: 6 UKs</td></tr>
<tr><td>
</td><td>
</td><td>
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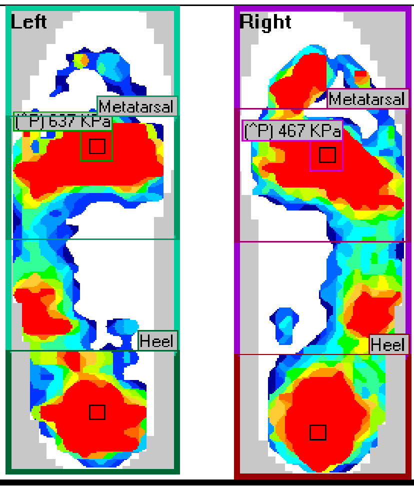
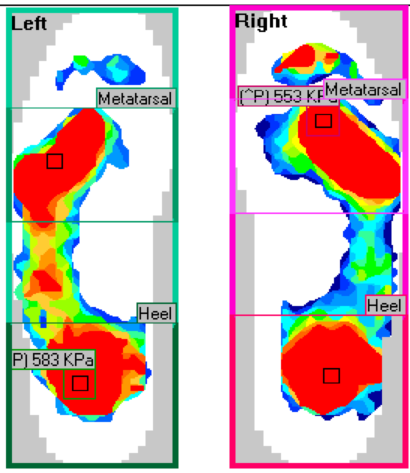
<table>
<tr><td>ID name: ID12<br>BMI: 22.34 (Normal)<br>Shoe Size: 10 UKs</td><td>ID name: ID15<br>BMI: 25.26 (Overweight)<br>Shoe Size: 6 UKs</td></tr>
<tr><td>
</td><td>
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Based on the top five respondents, it shows that the M1, M4 and M5 are the most common areas that contributed to the high peak pressure.

The design of personalised insole referred on these three major areas and is aimed to reduce the peak pressure under foot by using the personalised insole. In order to meet the requirement of the area under the foot, three design concepts were develop through Solid Works software. One design was chosen as the best insole design is shown in Figure 6.

The selected design was fabricated using a 3D printer using an AM machine, Stratasys Fortus Model. The fabrication took for about 12 hours to complete a pair of insoles. Figure 7 shows the new fabricated personalised insole.

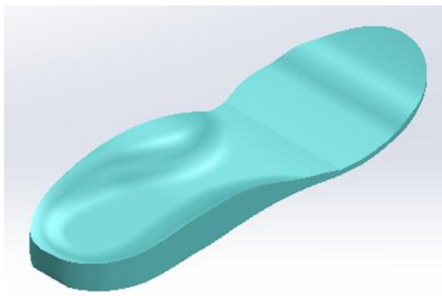


*Figure 6 - Design of the personalised insole*

*Figure 7 - The fabricated insole*

Validation process was done manually in which the subject was asked to walk with the personalised insole attached inside his safety boot. The validation process of this study was divided into two parts where the first part was performed with the purpose of checking the foot pressure by using the F-scan. This was done by letting the subject to wear only the original insole of the safety boot. The second part was done with the subject wearing the new personalised insole that substituted the current safety shoes insole. Table 2 shows the percentage of pressure differences between the current insole and the new personalised insole.

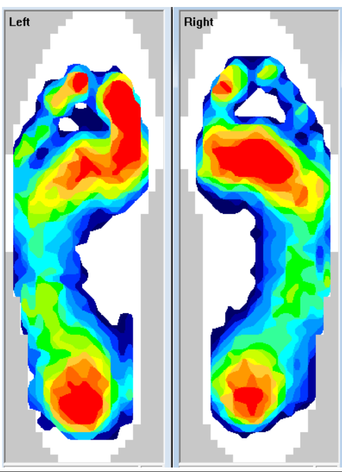
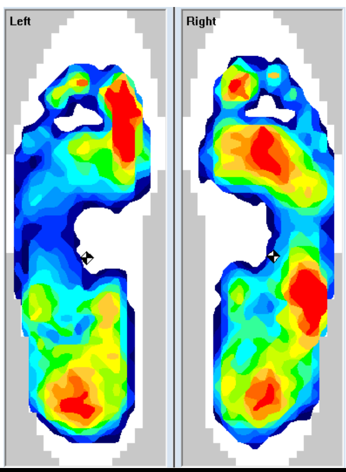
Table 2 depicts that the five areas of insole from M1 to M5 which are contributing to the pressure distribution for both of the current insole and personalised insole. From the table, it shows that the new personalised insole has been able to reduce the pressure for four out of five areas of the foot. The reduction of pressure percentage is ranging from 6% to 28%. However, M4 area for left foot and M3 area for right foot have increased in the foot pressure. Nevertheless, it is concluded that the majority of the pressure distribution are reduced after using the new personalised insole compared to the current insole. Previous studies had also reported that personalised insole that is produced by considering the contour and anthropometry of the foot will reduce the foot pressure as compared to the mass production insoles[8, 9, 7].

The result can also be seen on the foot pressure mapping based on the colours that are present at the foot mapping image. Table 3 shows the result of pressure distribution of foot profile. Based on the figure, it can be seen that the red area has been reduced with the new insoles. The image shows that the pressure has been redistributed as it is observed that the colour scale for the personalised insole has been relocated as compared to the current insole.

*Table 2 - Pressure distribution of both insole*

| Area | Current Insole | | New Personalised Insole | | Percentage of Pressure Differences (%) | |
|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right |
| M1 | 174 | 173 | 145 | 140 | 16 | 19 |
| M2 | 115 | 93 | 104 | 82 | 9 | 11 |
| M3 | 84 | 130 | 79 | 185 | 6 | -29 |
| M4 | 148 | 210 | 189 | 161 | -21 | 23 |
| M5 | 379 | 196 | 271 | 160 | 28 | 18 |

*Table 3 - Foot Mapping (Pressure distribution based on colour scale)*

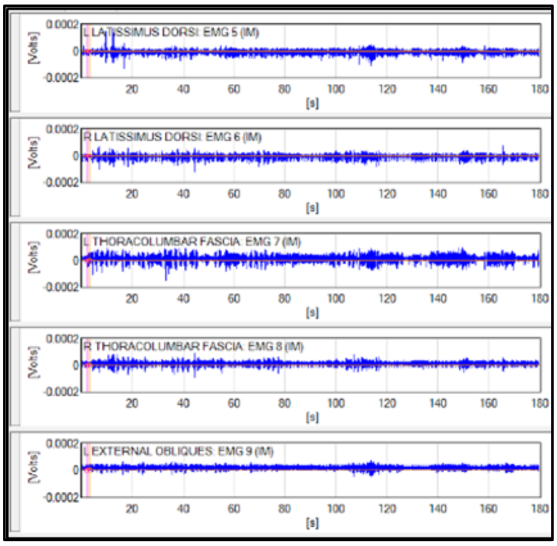
| Current Insole | Personalised Insole |
|---|---|
|  |  |



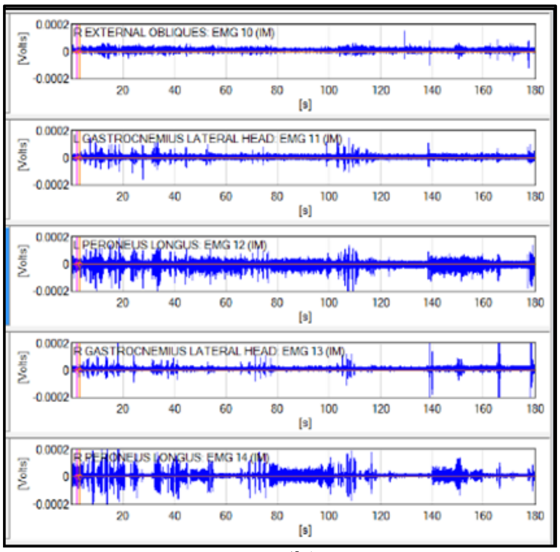
EMG was used to validate the muscle activity with the presence of the new personalised insole. The validation is done based on the real time of the workers at their work station back in the factory and the same working activities were performed which took for 5 hours excluding rest time. The muscle activity was measured by using EMG equipment where the sensors that were attached to the selected muscle. The validation was run using two type of insoles which arethe current and the new personalised insole. There are five muscles that were involved in the experiment with reference to the study regarding prolonged standing in the industry that was performed previously[10].

*Figure 8 - Validation of EMG on selected muscle.*

Table 4 shows the result of EMG before and after using the new personalised insole. From the table, it is depicted that there is no reduction on the amplitude value when the subject is using the new personalised insole. The value increased after using the personalised insole as well as the amplitude as shown in Figure 10. It is concluded that the new personalised insole increased the muscle activity of the subject. Further studies should be done in future to study the effect of the personalised insole as not many previous studies have been done in studying this interaction.

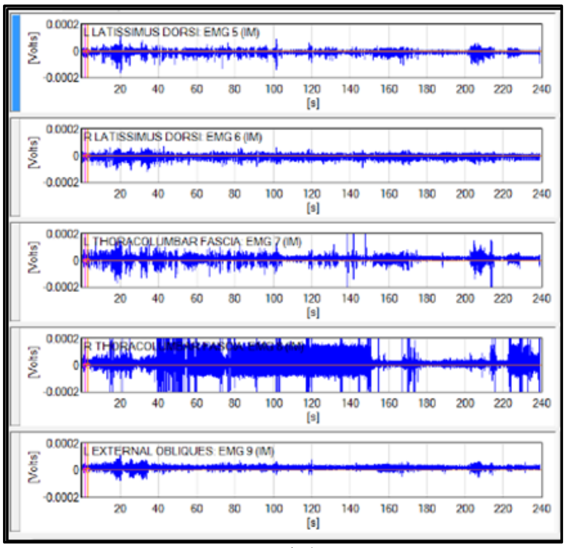



*(a)*

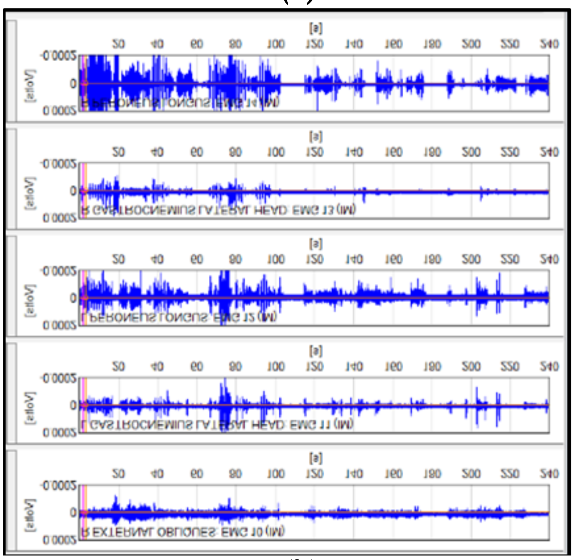



*(b)*

*Figure 9(a and b) - EMG amplitude of current insole.*




*(a)*



*(b)*

*Figure 10(a and b) - EMG amplitude of new personalised insole*

*Table 4 – Comparison of the EMG Result for Current Insole and Personalised Insole*

| Muscle | Histogram Output (n) | |
|---|---|---|
| | Current insole | New personalized insole |
| Thoracic erector spine (L) | 170000 | 200000 |
| Thoracic erector spine (R) | 100000 | 150000 |
| Erector spine fasia (L) | 100000 | 180000 |
| Erector spine (R) | 80000 | 0 |
| Multifiduus lumbar (L) | 100000 | 180000 |
| Multifiduus lumbar(R) | 150000 | 130000 |
| Soleus (L) | 100000 | 200000 |
| Soleus (R) | 180000 | More than 200000 |
| Gastrocnemius (L) | 100000 | More than 200000 |
| Gastrocnemius (R) | 200000 | 200000 |

Overall, based on the findings of all of the steps which are survey, peak pressure analysis, and EMG analysis, it was found that the subjects experience pain the most at M1, M4, and M5 areas. Moreover, the peak pressure of the foot collected shows that all of the subjects have the highest pressure on those three areas. By considering this information, the insole was developed and it is able to reduce the peak pressure for the right foot on the three areas. However, the pressure at M4 area increases for 21% in the left foot. However, since this study is still on-going, more findings are hopefully will be able to be captured.

## CONCLUSION

As a conclusion, the personalised insoles are able to reduce the foot pressure distribution of the worker where the peak pressure for four out of five areas of the foot have been reduced with the reduction of pressure percentage ranging from6% to 28%. However, the muscle activity shows a contradict result where the amplitude for the personalised insoles are increased.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the Ministry of Higher Education (MOHE) for funding this research under Research Acculturation Grant Scheme (RAGS) (Research Acculturation Grant Scheme RAGS MOHE RAGS/1/2015/TK0/UTEM,03/7), Faculty of Manufacturing Engineering of UTeM and Centre for Research and Innovation Management (CRIM) for providing facilities and assistance throughout this study.

## COMPETING INTERESTS

There is no conflict of interest.

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