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Development on Orthotics Insole for Flat Feet Focusing on Sport Usage Evaluated by Electromyography

Umi Hayati Binti Ahmad[1*], Mohd Hidayat Bin Ab Rahman[1], Lum Yee Sin[1], Nurul Ain Binti Maidin[1], Nur Farah Bazilah Binti Wakhi Anuar[1]

[1]Faculty of Mechanical and Manufacturing Engineering Technology,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, MALAYSIA

*Corresponding Author

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Abstract: Running is a method of terrestrial locomotion allowing humans to move rapidly on foot, which related to the movement of lower limb. But for flat feet, running or walking for a long period will give them a high-risk associate with a foot pain. In order to reduce the foot pain, an arch orthotics insole is advised to be wore by the flat feet. This paper provides an extensive study on orthotics insole focusing on sport usage for flat feet. For this silicon rubber Orthotics Insole is designed with sufficient arch support, sufficient thickness, metatarsal pad, heel pad, heel cup and ergonomics dimension specification. The objectives of this research are to design and improve the efficiency of orthotics insole for flat feet focusing on sport usage. Both new orthotics insole and existing insole will be evaluated by using electromyography (EMG) that will record the electrical potential which generated by muscle cells. The output of time domain feature and frequency domain feature for both insoles will be analyzed and compared. This Orthotics Sport Insole ideal to be used by flat feet especially during their sport activity specifically running in order to reduce muscle pain to prevent injuries.

Keywords: Electromyography, flat feet, orthotics insole, silicon rubber

1. Introduction

Running is a method of terrestrial locomotion that the characteristics feature of a running body from the viewpoint of spring-mass mechanics in which to change in kinetic and potential energy within a stride occur simultaneously, with energy storage accomplished by springy tendons and passive muscle elasticity. The main source of the impact shock is transmitted through the leg and the rest of the body from the events surrounding of the foot ground collision during running [1]. Unfortunately for flatfoot, running can weaken the tendon mostly affects the sports performance [2]. The aim of this research is to improve the efficiency of an orthotics insole for flat feet that able to reduce muscle fatigue to prevent injuries which cause due to running activity, thus improve their sport performance.

2. Research Methodology

A proper research flow is very important in order to plan and arrange the sequence of the process involving with. process, material, equipment and procedure for every stage of the research.

2.1 Customer Survey

A survey was distributed to 30 respondents to identify the customer needs and had been done manually and through online. For this survey, the total correspondents are 15 males and 15 female respondents. The correspondents

*Corresponding author: umihayati@utem.edu.my

are among the students in Universiti Teknikal Malaysia Melaka (UTeM). 5 of flat feet respondents are part of the 30 correspondents. The questionnaire has been done to identify an average foot size of respondent which later to be used in the research and also to determine the design requirement of orthotics insole that suitable with customer needs. As show in Fig.1, customer surveys are quite critical and needed in this research in order to find the average size of foot.

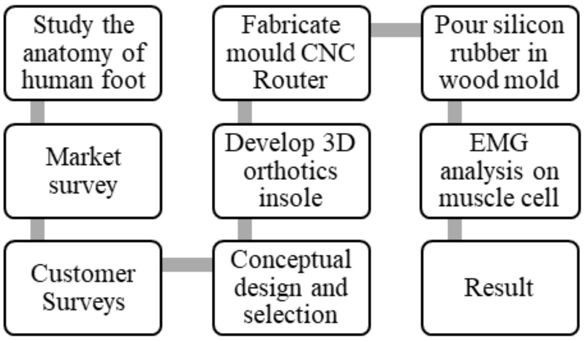

Fig. 1 - Method of study.

Fig. 2 - Flat feet respondent.

2.2 Conceptual Design

Several concept sketches have been designed based on customer survey that fulfill requirement of flat feet specifically for sport usage. The existing insole with the characteristics are sufficient arch support, deep heel cup and small holes to release heat will be compare with the fabricating orthotics insole. The graph as shown in Fig. 3, Fig. 4 and Fig. 5 shows the characteristics from the survey that had been done on 30 respondents that highly related to the creating each of the orthotics insole concepts which are having sufficient arch support, having a shock absorbing heel pad and having ergonomics deep heel cup.

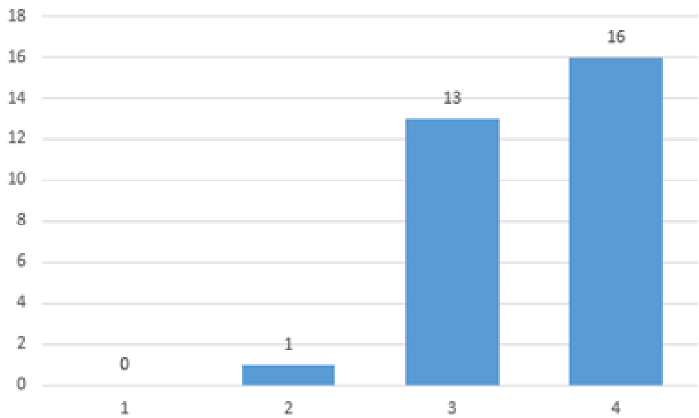

Fig. 3 - Analysis of sufficient arch support on orthotics insole.

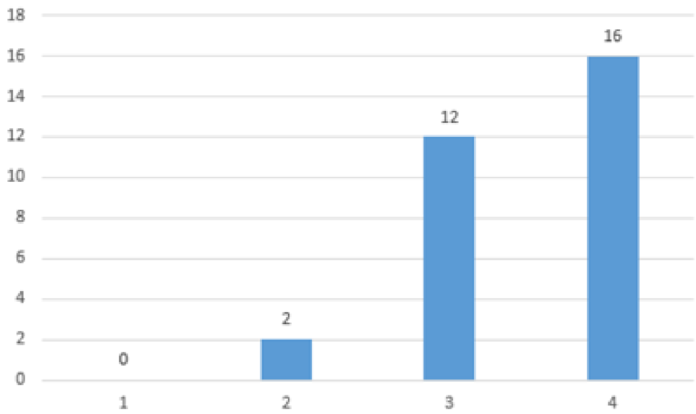

Fig. 4 - Analysis of heel pad on orthotics insole.

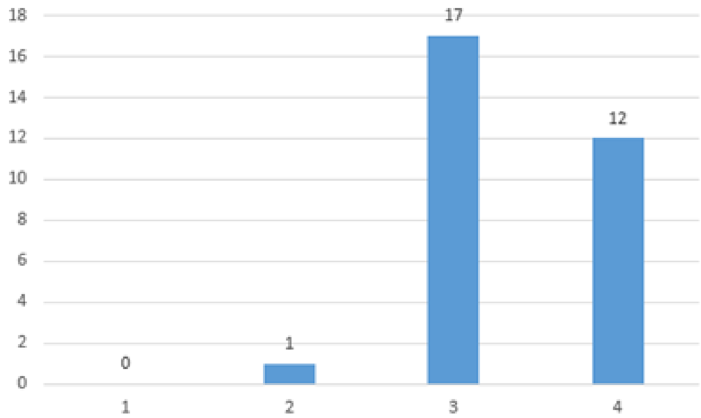

Fig.5 - Analysis of deep heel cup on orthotics insole.

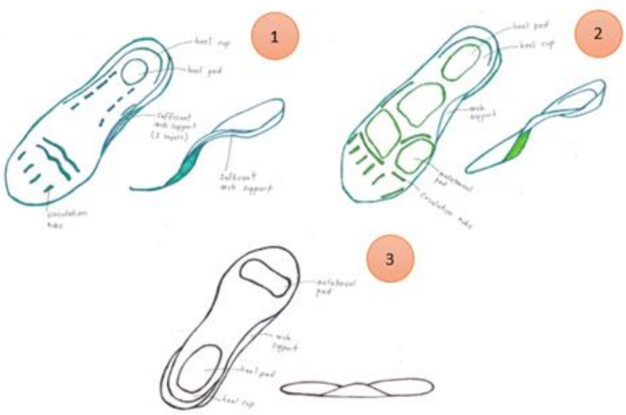

Fig. 6 - Concept 1-3.

Table 1 - Concept Screening.

Criteria	Concept 1	Concept 2	Concept 3	Datum
Arch support	0	0	0	0
Heel pad	+	+	+	0
Heel cup	+	+	-	0
Metatarsal pad	-	+	+	0
Circulation nubs	+	+	0	0
Layers arch support	+	+	-	0
Sum +'s	4	5	2	0
Sum 0's	1	1	2	6
Sum -'s	1	1	2	0
Net Score	3	4	0	0
Rank	2	1	3	4
Continue?	Yes	Yes	No	No

The selection of concept is based on the concept screening. Concept No. 1 and 2 has been chosen to be used for next stage.

Table 2 Design dimension of orthotics insole.

Dimension (mm)	Men orthotics insole (Left and right)	Women orthotics insole (Left and right)
Length	263	243
Metatarsal width	92	86
Heel width	62	47
Thickness	6	
Middle thickness	11	
Thickness of heel pad, Metatarsal pad	3	
Degree of arch support (°)	4	

The design dimension of orthotics insole from Table 2, respondents of the survey. The size of the chosen concept was then being developed with the design dimensions from the conducted survey from men and women orthotics insole categories as shown in Table 2.

Orthotics insole is designed with arch support in order to improve the medial longitudinal arch (MLA) of flatfoot and the ability dynamic balance of feet and lower limbs on exercise (running or walking) [3]. While the heel pad is to provide the shock absorption over the calcaneus during locomotion by reducing maximum stress and friction between heel and ground. On the other hand, heel pad increased the motion control, enhanced proprioception, and stability of the foot support. The metatarsal pad is used to redistribute pressure and stress from the metatarsal heads to the shafts and to support the foot in position [4].

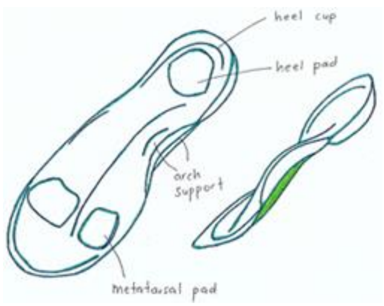

Fig. 7 - Selected Concept.

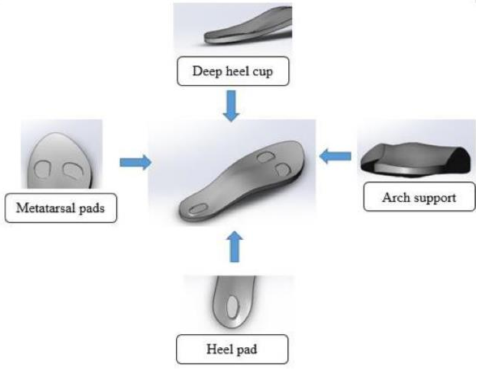

Fig. 8 - Characteristics of orthotics insole.

2.3 Orthotics Insole CAD Model

In this stage, CAD model for men and women with different dimensions were designed based on these characteristics; deep heel cup, heel pad, metatarsal pad, and sufficient arch support. Orthotics insoles CAD model (left and right) with the design requirements is shown in Figure 10.

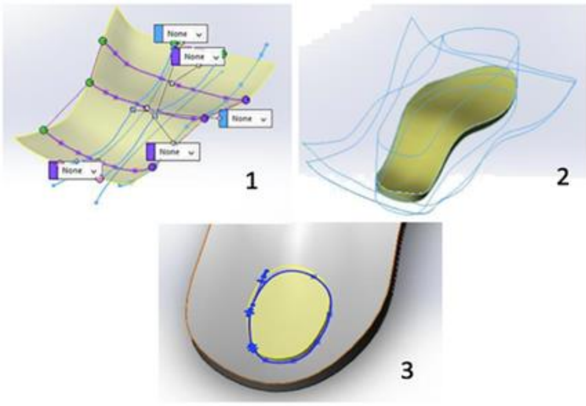

Fig.9 - Sequence to design 3D Orthotics insole.

Fig. 10 - 3D model of orthotics insole.

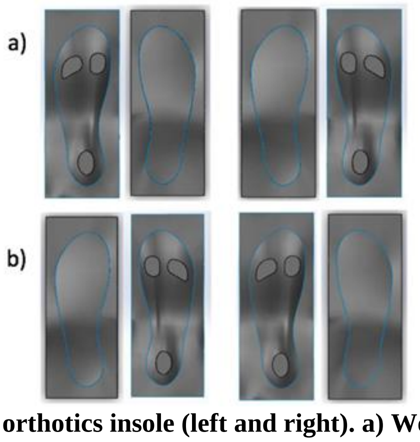

Fig. 11 - Cavity and core of orthotics insole (left and right). a) Women insole b) Male insole.

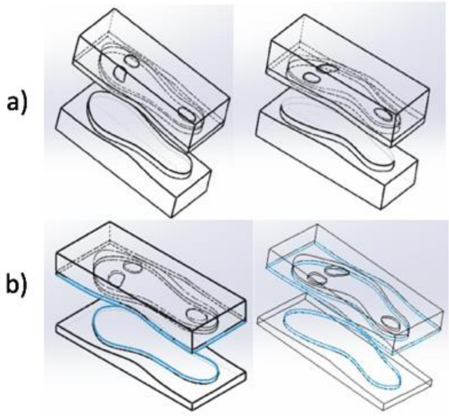

Fig. 12 - Isometric view of cavity and core of orthotics insole (left and right). a) Women insole b) Male insole.

2.4 Wood mould fabrication

The core and cavity of orthotics insole are machine by using CNC router machine with material of pine wood. The dimension of wood mould for men insole are 340mm length, 130mm width and 50mm height and for women insole are 300mm length, 105mm width and 80mm height. After machining, sandpaper was used to get a smooth surface of the mould and spray with paint on the wood to maintain the quality of wood.

Fig. 13 - Wood mould of orthotics insole (male and female)

After the wood mould is ready, the silicone rubber need to undergo several processes before it can be pour into the wood mould. The Vacuum Casting KLM-1000A Machine is used to remove the bubbles from the mixed material of silicone rubber with the hardener before pouring process.

Fig. 14 - Silicon rubber making process.

2.5 Experiment and evaluation process

Electromyography (EMG) equipment is used to detect and record the electrical potential that generated by muscle cells. EMG sensors are placed on major muscles of lower limb, which include Hamstrings (vastus medialis and rectus femoris), Tibialis Anterior and Calves (gastrocnemius and soleus). The Trigno EMG sensors of Delsys are used to evaluate the flat feet with insole during running and wireless transmit surface EMG (sEMG) signals to the Trigno Wireless Foundation System then analyzed it. Total of 5 respondents (3 males and 2 females) are volunteers for the testing stage. They had been tested on the existing insole and the new improvised insole which enable the data to be collected and observed by surface electromyogram. All the respondents are flat feet, aged between 17 and 24 and Universiti Teknikal Malaysia Melaka students. The specifications of the subjects recording to BMI as shown in the Table 3.

Table 3 - Subject's Specification.

Specification	Male	Female
Age	18-24	
Height	175±10cm	155±10cm
Weight	60kg - 90 kg	45kg - 60 kg
BMI	20-29	
Characteristic	Flat feet respondents	

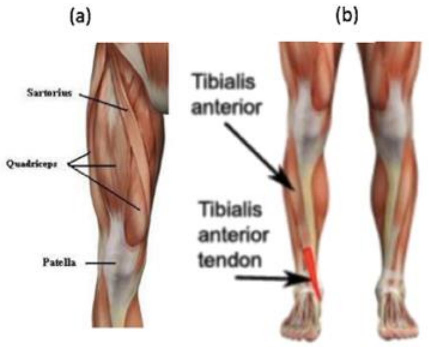

Fig. 15 - (a) Quadriceps [5] (b) Tibialis anterior [6]

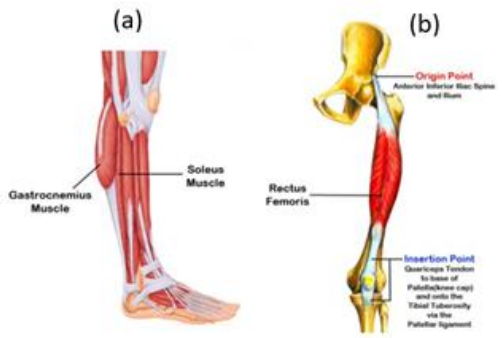

Fig. 16 - (a) Gastrocnemius, soleus [7] (b) Rectus femoris [5]

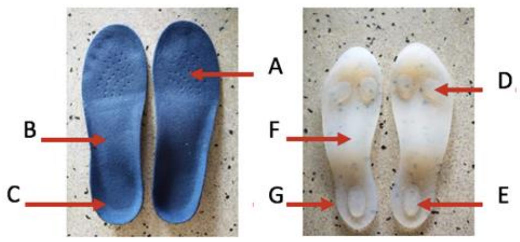

Fig. 17 - Orthotics insole existing and new improvised.

Table 4 - Orthotics insole specification.

Item	Existing Insole	Item	Redesign Orthotics Insole
A	Small holes to release heat	D	Metatarsal pad
B	Sufficient arch support	E	Heel pad
C	Deep heel cup	F	Sufficient arch support
		G	Deep heel cup

Raw signal that obtained from surface electrodes sensor is influenced by surrounding factors such as electronic noise, motion artifacts, location of muscles and inter-electrode distance. The signals are sampled at 1000 Hz and signal processing through the Delsys EMGwork analysis. All the raw signals collected were filtered with band pass filter range from 50 - 500 Hz with 2nd order Butterworth filter. The time domain analysis of amplitude with RMS and frequency domain of median frequency were analyzed. From the collecting signals, the determination of muscle fatigue of respondents by increase root mean square (RMS) and decrease of median power frequency (MDF).

Fig. 18 - Sensor of wireless electromyography.

Fig. 19 - Sensor placement in lower limb muscles (male and female).

3. Results and Discussion

In this stage, the signal result from the testing stage will be analyzed and discussed. Fig. 21 and Fig. 22 shows the raw signal between new improvised insole and existing insole of dynamic muscle contraction for gastrocnemius muscles. After rectification process, the negative amplitude signals are converted to positive amplitude signals which the starting point of y-axis is from zero, 0.

The raw signal will be filter by removing the noise from the surrounding. Normally, the high-pass filter with a cut-off frequency in the 15 to 20 Hz range. Whereas the low-pass filter with a cut-off frequency in the 500 to 1000 Hz range [8]. So that, the filtering of the signal in range of 50- 500 Hz with 2nd order Butterworth filter.

Electromyography is a technique to capture and measure electrical activity and muscle action potential [9]. Which is applied to specify production of force and analyse muscle fatigue.

The Root Mean Square (RMS) are used to analyse the EMG signal. It been used to quantify the electrical signal because it reflects the physiological activity in the motor unit during contraction [10].

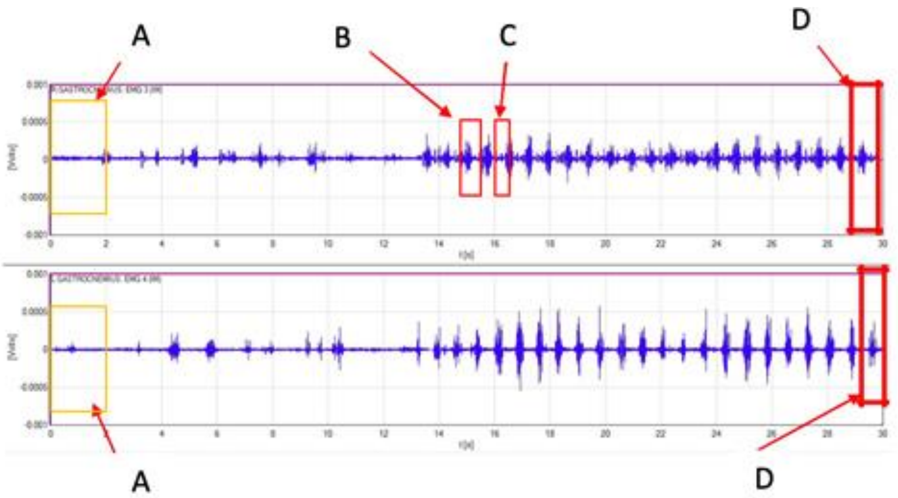

Fig. 20 - Raw signal of fabricating orthotics insole for gastrocnemius muscles. A. Pre-fatigue B. Contraction C. Rest period D. Post-fatigue (right and left foot).

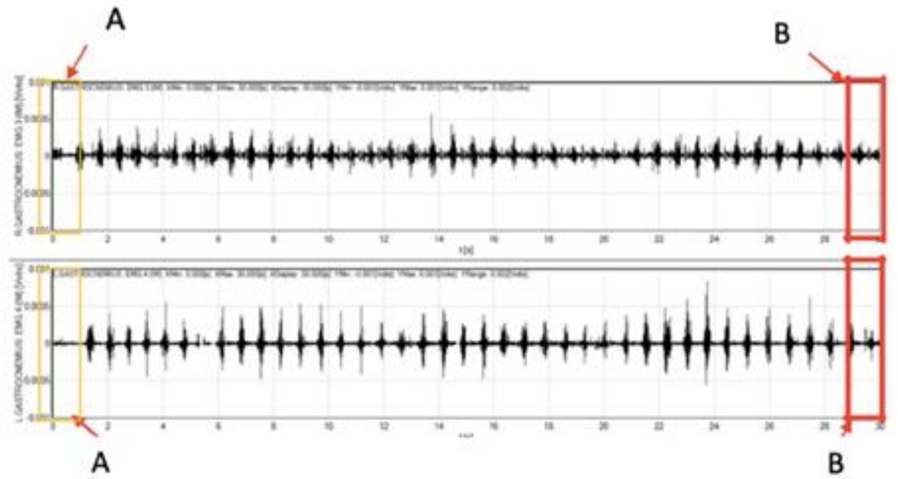

Fig. 21 - Raw signal of existing orthotics insole for gastrocnemius muscles. A. Pre-fatigue B. Post-fatigue (right and left foot)

In Fig. 22 and Fig. 23, the average RMS for left and right of rectus femoris muscle have a small different in muscle fatigue between fabricated insole and current insole. The fabricated insole contributes to an increasing value for muscle fatigue, but it is very minimum. The rectus femoris muscle on left side quite comfortable with the fabricated insole rather that the side. The 5th respondent show that he was very uncomfortable using the current insole on his left foot. The 4th respondent also show a quite different graph between right and left muscle but between the 2 insoles, there's only a little value difference for muscle fatigue.

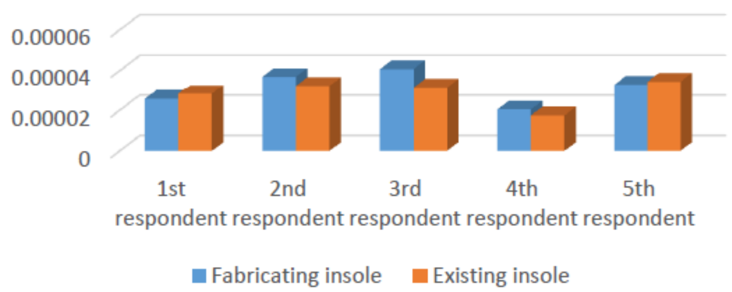

Fig. 22 - Average RMS of rectus femoris (right).

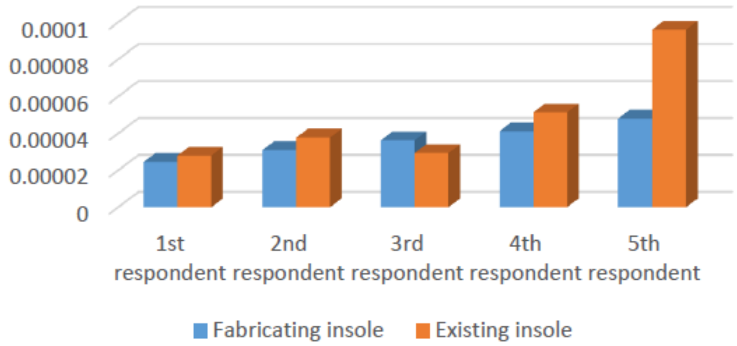

Fig. 23 - Average RMS of rectus femoris (left).

For average RMS of tibialis anterior muscle for right and left leg as in Fig.24 and Fig.25, the 3rd and 4th respondent gave a quite obvious result in the graph. The left muscle seems quite balance between 2 insoles. Meanwhile on the right muscle, both 2 insoles give an incline value. The muscle fatigue can be influenced due to tiredness of the participants itself. Other participants show a very minimum of muscle fatigue for both insoles.

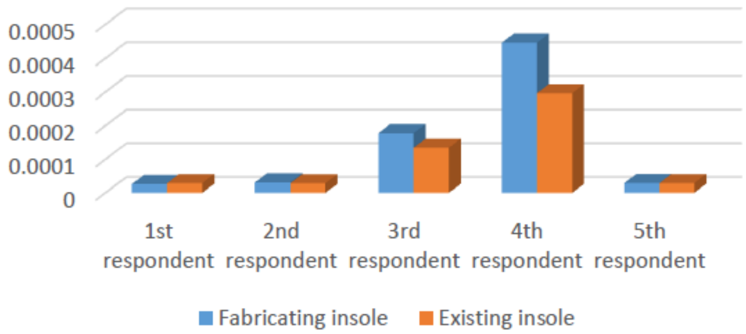

Fig. 24 - Average RMS of tibialis anterior (right).

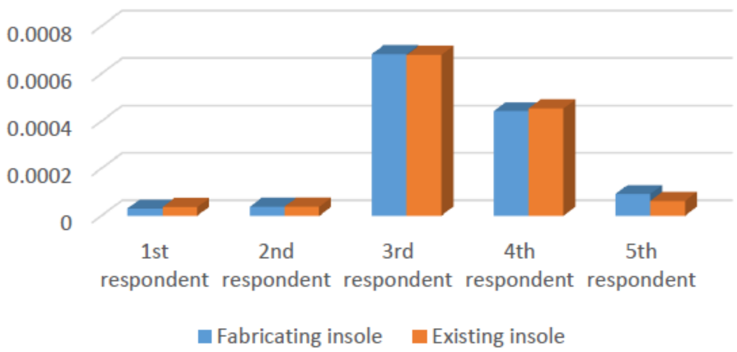

Fig. 25 - Average RMS of tibialis anterior (left).

Gastrocnemius muscle which located on lower leg in Fig. 26 and Fig. 27 show an unbalanced value between right and left muscle. However, between the 2 insoles, the value shows a small difference whether the value of muscle fatigue a little bit high or low. Further study needs to be done, in order to see whether the differences is due to the insole itself or because of the muscle. The 4th respondent graph's is however showing a high value of muscle fatigue for current insole. While for soleus muscle which also located at lower leg as in Fig. 28 and Fig. 29, also show unbalanced between right and left muscle, similar to the gastrocnemius muscle graph's. But for soleus muscle, most of the participants have less muscle fatigue when using the fabricating insole whether it is right or left muscle. The 3rd participant shows a high value of muscle fatigue for both insole, which is influenced by the participant fitness or the running posture.

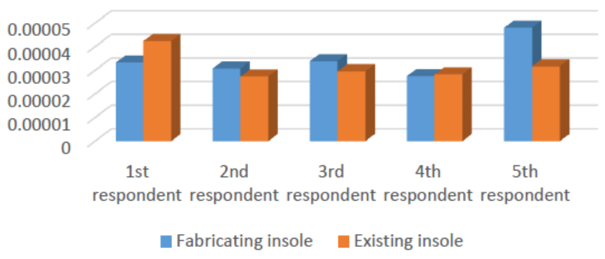

Fig. 26 - Average RMS of gastrocnemius (right)

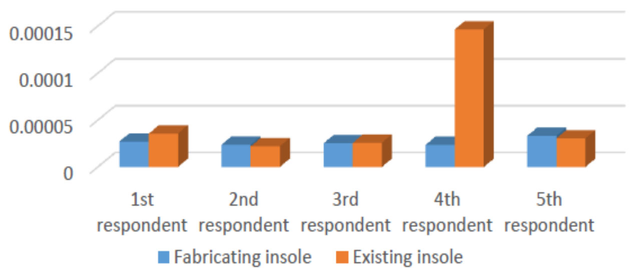

Fig. 27 - Average RMS of gastrocnemius (left)

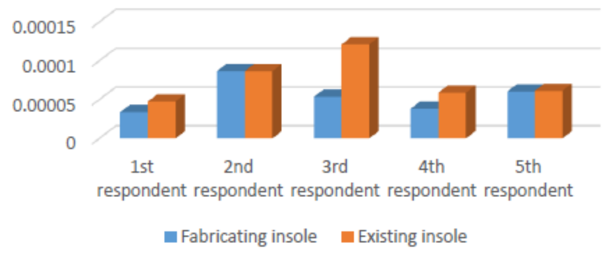

Fig. 28 - Average RMS of soleus (right)

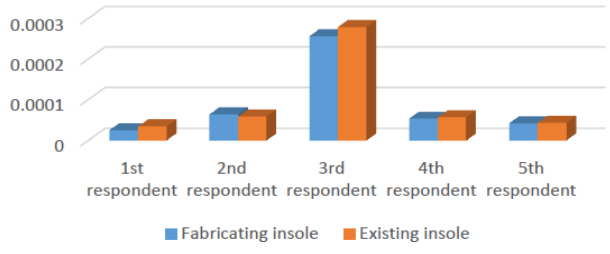

Fig. 29 - Average RMS of soleus (left)

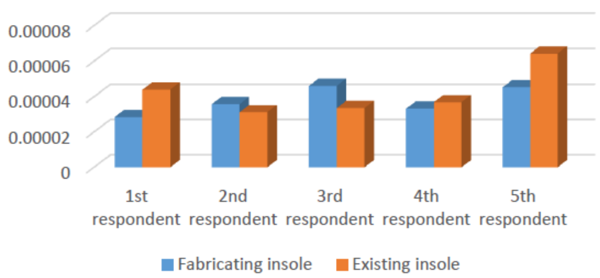

Fig. 30 - Average RMS of vastus medialis (right)

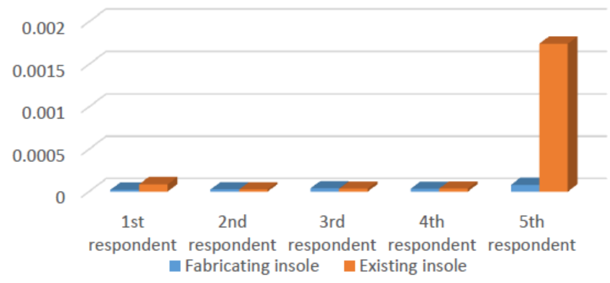

Fig. 31 - Average RMS of vastus medialis (left)

The participants vastus medialis muscle which located on their quadriceps muscle or tendon show quite a different graph between right and left muscle as shown in Fig. 30 and Fig. 31. The left muscle seems through a very little muscle fatigue when using the 2 insoles aside from the 5th participants shows that he really having a high muscle fatigue on using current insole on his left foot. While for the right muscle, the value increasing for both insoles. Participant 1st, 4th and 5th contribute to increasing value of muscle fatigue for current insole. Only 2nd and 3rd participants are a bit comfortable on fabricated insole.

4. Conclusion

The new design of Orthotics Sport Insole has an improvement from the reference insole. Even though it's only slight improvement but it still the efficiency of the insole is increase and better than the reference insole.

Acknowledgement

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