ESTIMATION AND MODELING OF FORCES, POWER AND PRESSURE EXERTED ON FEET DURING GAIT ANALYSIS USING ARTIFICIAL NEURAL NETWORK

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by

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June, 2018

CERTIFICATE

I hereby declare that the thesis report entitled **"Estimation and Modeling of Forces, Power and Pressure Exerted on Feet During Gait Analysis using Artificial Neural Network"** is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **CAD/CAM & Robotics** at **Thapar Institute of Engineering and Technology, Patiala** under the supervision of **Dr. Vineet Srivastava** and **Dr. Madhusudan Pal** during **June 2017** to **July 2018.** No part of the matter embodied in this report has been submitted to any university or institute for the award of any degree.

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KAMALPREET SANDHU

Abstract

This study has been conducted to predict the forces and power excreted on the feet during Gait analysis. The weight of the human, the height of the human and weight of the shoe were the input process parameters for this study. 10 subjects were observed with two types of shoes namely heavyweight shoes and lightweight shoes. The data for the gait analysis was obtained by Kistler Force Plate System. In order to predict the accuracy of the measurements, Artificial Neural Network (ANN) has been used to analyze in swing and stance phase. The robustness of the model has been verified through 10 cross-validation method (k-fold). It was observed that the coefficient of determination (R^2) was 78.2% for heavyweight shoes and 98.28% for lightweight shoes in medial-lateral direction (Fx). Similarly, it was 82.8% for heavyweight shoes and 87.1% for lightweight shoes in the anterior-posterior direction (Fy). For vertical direction (Fz) the values were 83.9% for heavyweight shoes and 92.1% in lightweight shoes. It has been observed that R^2 value for power was 87.9% for heavyweight shoes and 96.6% for lightweight shoes. To predict pressure the Artificial Neural Network has been used to develop the model in the swing and stance phase, hence validating the predicted parameter values with experimental ones. 18 subjects were observed with four types of insoles having different materials with lightweight shoes. Analysis of variance (ANOVA) has been used for selecting the input parameters. The robustness of the model has been certified through a ten cross-validation method (K-fold). Four types of insoles have been used in this study. R^2 for the pressure were 89.3%, 86.9%, 85% and 83% in Insole1, 2, 3 and 4 respectively. The outcomes of this research were tested with further subjects and results were found to be in close proximity.

Keywords: Gait analysis, Artificial Neural Network, Force plate, Force, Power Voxel care foot scan insole, Pressure.

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Nomenclature

3D	Three Dimensional
GRF	Ground Reaction Force
COP	Center of Pressure
COM	Center of Mass
ML	Medial Lateral
AP	Anterior Posterior
HWS	Heavyweight Shoe
LWS	Lightweight Shoe
ANN	Artificial Neural Network
r	Correlation Coefficient
R^2	Coefficient of Determination
MAE	Mean Absolute Error

Ergonomics is the study of individuals at work. This field got its name in the mid-year of 1949 when a group of intrigued people gathered in Oxford, England to discuss human performance and its limits. Ergonomics comes from Greek word 'Ergo' and 'Nomics'. 'Ergo' implies work and 'Nomics' implies study. A few specialists define the objective of ergonomics and as designing machines to fit the human operator requirements. However, it is also necessary to fit operations to machine in the form of personnel channel selection and training. It is probably more accurate to describe this field as the study of human machine systems, with an emphasis on the human aspects.

1.1 HUMAN ERGONOMICS

Ergonomists deals with the fact that people come in different sizes and shapes, varying greatly in their strength, endurance and work capacity. A basic understanding of human anatomy, physiology and psychology can help ergonomists to find solutions that deal with these issues and help to prevent problems that can cause injury to workers. Scope of this problem, can be studied by considering some of the components system terms by the human body.

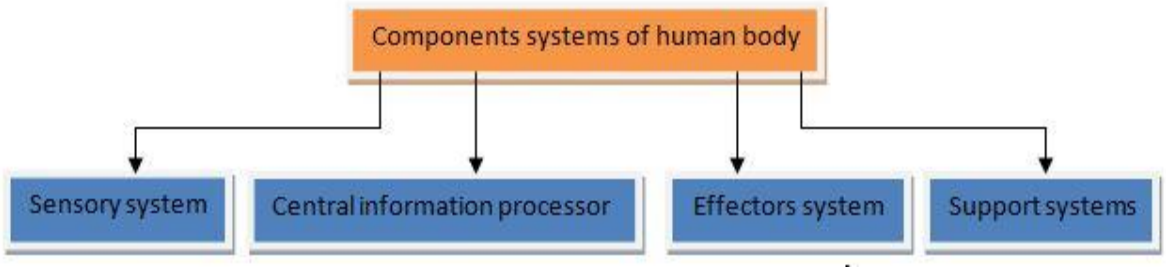


Figure 1: Components systems of human body

1.1.1 Sensor frameworks- (vision, hearing, position, contact, taste and smell) are reproduced by vitality sources (i.e. light, stable or warmth) or materials (e.g. air borne synthetics, corrosive or skin, support on tongue) in the outside condition.

1.1.2 Central information process- (brain and nervous system) provide information acquired from the sensory systems.

1.1.3 Effectors systems- (arms, hands, eyes, legs etc) are consciously controlled to modify the environment and acquire information.

1.1.4 Support systems- (circulatory digestive, metabolic, heat regulators) act in various ways to keep the other systems functioning.

1.2 ANATOMY OF FOOT

The human foot comprises of three sections i.e. Mid-foot, Forefoot and Ankle/Heel. The forefoot comprises five metatarsals. Pyramid structure called mid-foot which frames the curve of the foot. The lower leg/heel underpins the leg bones. Figure2 demonstrates the life structures of the foot.

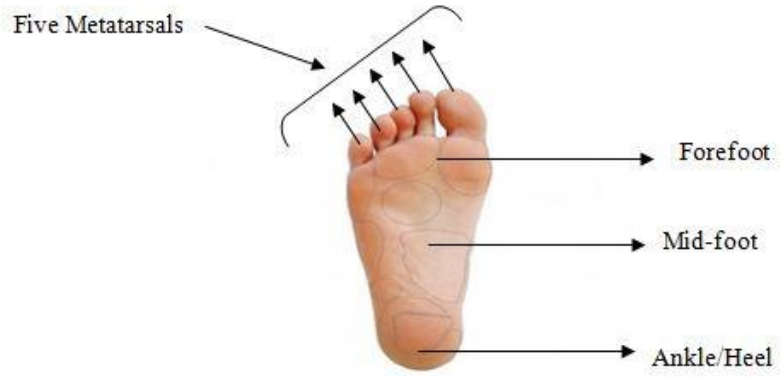


Figure 2: Anatomy of foot

Today the life of human becomes very busy. In daily routine, a human have to work a lot for a different reasons and works. Due to this, a large number of people suffer foot pain problems. Foot pain mainly results from plantar fasciitis, fallen arch, diabetes, uncomfortable shoes and wrong method for arch support. A shoe is a thing which is utilized by an individual to ensure their feet. A good footwear choice a significant role for reduces foot pain. Figure3 shows the revealed information identified with the foot pain [1].

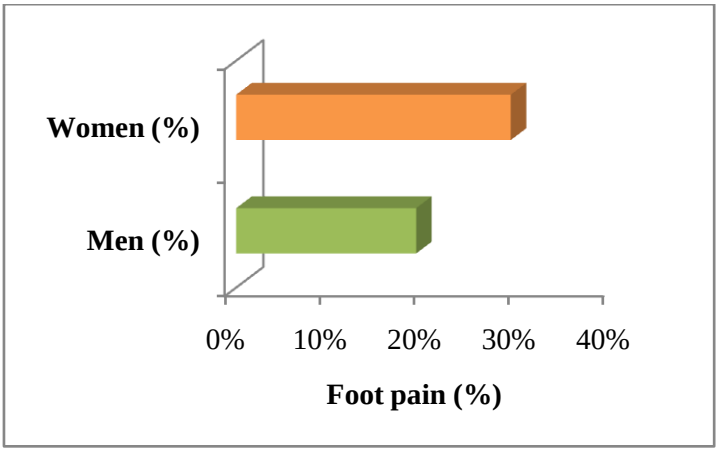


Figure 3: Percentage of Foot pain [1]

1.3 HUMAN GAIT

Human foot movement is based on the gait cycle. Walking is characterized by Gait. Locomotion produced through the movement of human limbs. Gait defines the bipedal and forward propulsion of COG of the human body. Natural gaits are of two types i.e. Walk and skip. The healthy person up to 6 years follows walking while under age of the 4 to 5 years called as skipping by children. The various stages of the gait cycle show in Figure4 are Heel contact, Flat foot, Mid-stance, Heel off and Toe off.

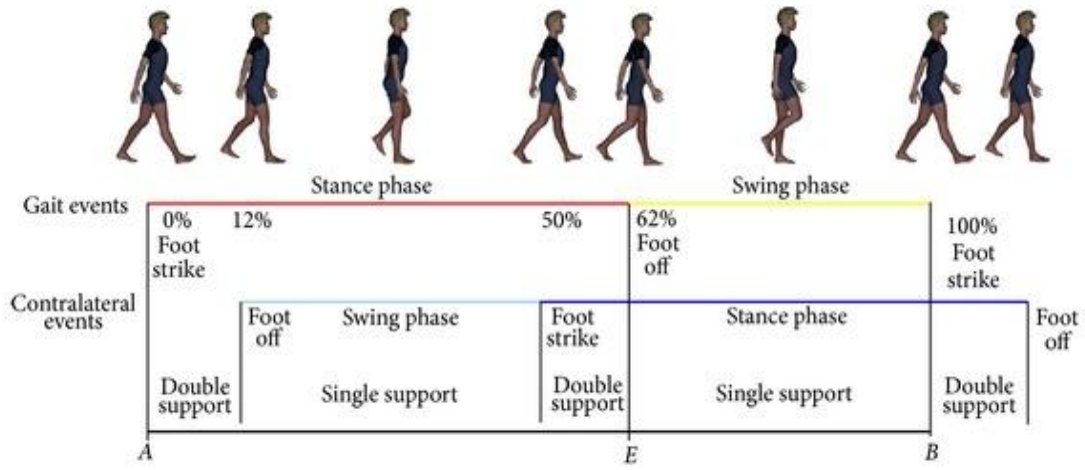


Figure 4: Various stages of the gait cycles [2]

1.3.1 Heel contact- The starting of the stance phase is called the heel-strike because there is an impact between the heel and the ground.

1.3.2 Foot flat- After heel contact, the rest of the foot comes in contact with the ambulatory surface at foot flat. This generally occurs at about 8% of the gait cycle, just before toe off of the opposite leg. During the interval between heel strike and foot flat the GRF increase rapidly in magnitude.

1.3.3 Mid stance- The period of time between foot flat and heel off which occurs at about 30% of the gait cycle. At this point, the swing phase leg passes the stance phase leg.

1.3.4 Heel off - When the heel begins to lift from the walking surface. It occurs between 40-50% of the gait cycle.

1.3.5 Toe off- This occurs at about 60% of the gait cycle when the stance phase ends and swing phase begins. This phase is also commonly called the push off phase.

1.3.6 Mid swing- This is the opposite of midstance as the mid-swing on one leg corresponds to the midstance of the other. It is the time when the swinging leg passes the stance leg.

1.4 DIRECTION WITH ASSOCIATION TO THE CENTER OF THE BODY

a) Anterior

b) Posterior

c) Superior

d) Inferior

e) Left

f) Right

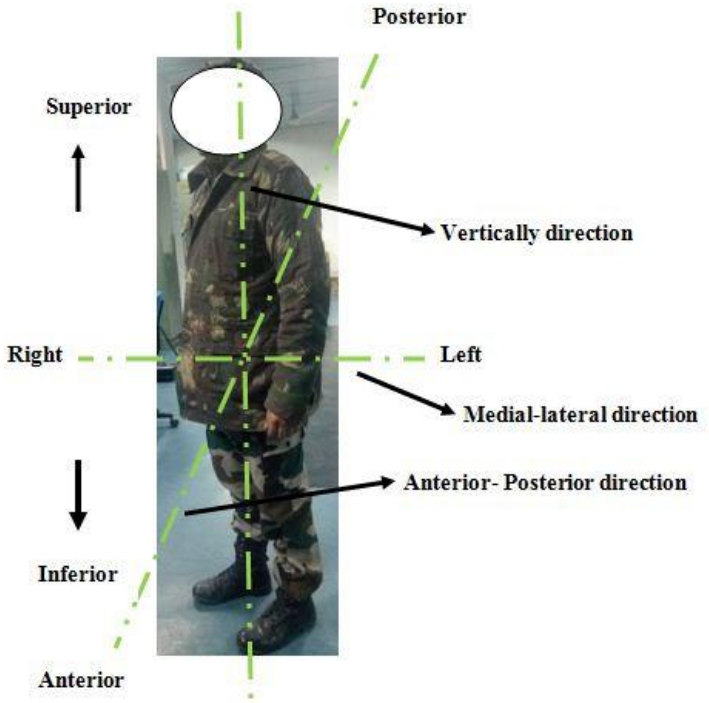


Figure 5: Six terms to define the human COP (Courtsey: DIPAS, DRDO, Delhi)

Three types of directions namely Medial-lateral direction, Anterior-Posterior direction, and Vertical direction. Medial-lateral direction and Anterior-Posterior direction belong to Horizontal forces (Fx and Fy) while vertical direction refers to Fz force.

1.4.1 Medial lateral direction

When the body moves in a straight line, The Ground Reaction Forces (GRF) in the medial-lateral direction is very small. This is because for linear walking the centripetal component of friction is absent. Medial-lateral Ground reaction forces and inversion of the foot can be distinctly

observed when walking in a curve or circular trajectories. For most of the stance phase of the right foot, the medial-lateral Ground Reaction Forces accelerates the centre of mass of the body slightly towards the left side of the body to maintain balance during single stance. For normal gait, the left foot follows a similar pattern.

1.4.2 Anterior-Posterior direction

In the Anterior-Posterior direction, the right foot applies first braking force during the first half the stance phase and a propulsion force during the second half.

1.4.3 Vertical direction

The vertical ground reaction forces show two peaks. The first humps result from an upward acceleration of the centre of mass during the early part of the stance phase. The vertical reaction force shows a rapid rise at level contact, usually occurring between 5-10% of the gait cycle. During midstance, a reduction in the vertical ground reaction forces is observed as the knee flexes during midstance as the body guides glide over the stance legs. The flexion of the knee assists in lowering in vertical ground reaction force as the knee flexor muscles absorb parts of the forces. The vertical ground reaction forces are usually between 0.7 and 0.9 times the BW. During the last part of the stance phase, at toe-off, the plantar flexors are active in causing ankle plantar flexion and the ankle generates the greatest amount of energy. Thus, in second peak force greater than BW as the centre of gravity is again accelerating upwards.

1.5 RUNNING

Running is a strategy for natural velocity enabling people and different creatures to move. Distinctive sorts of running are: Base run, Progression run, Long run, Fartlek interims, Tempo run, Hill rehashes and Recovery run.

1.6 WALKING

Walking is very important exercise associated with human being. There are different types of walking i.e. Brisk walking, Treadmill waking, Interval walking, Water walking and Hill walking. Human want to walk for the purpose of the health benefits also. The human being has a stride length of 640.08 to 742mm, it take over 2000 steps to walk one mile. On an average a person covers 10,000 steps a day.

1.6.1 Brisk walking –Brisk walking has basically belong to activity when human being runs slow or quite speedy for others. It depended upon the fitness level. It measured in term of step per minute. Normally, a human puts 100 steps per minute and cover 4 miles per hour. The

benefits of the brisk walking reduce weight, improve diabetes, strong heart, increase life and decrease the cholesterol level of the patients.

1.6.2 Treadmill walking – The treadmill is a device generally used in the gym and experimental laboratories for walking, running and climbing. The belt moves, person coordinate the speed with the moving belt.

1.6.3 Interval walking – In this type of walking a person runs for 20-40 sec than take rest for few seconds and run again. This activity is repeated many times for 20-30 minutes.

1.6.4 Water walking – Waking on water is impossible. It should be referred to animal locomotion on the water surface and swimming by the human being. It is the very effective type of exercise. It can be done in swimming pool, lake and water parks. It is very useful to reduce stress, reduce weight, good for patients with back pain and joint pain problems. Burns more calories than another walking during and after exercise.

1.6.5 Hill Walking- Hill walking is the walking in the hilly areas. It helps to strengthen in legs muscles, calories burn and reduce weight.

1.7 ERGONOMICS IN DEFENCE

Human characters, behaviour and performance and human interaction with technology are vital elements in maintain health sustainability of an individual in stressful environment. Over many years ergonomics has played an increasing important role for improving living and working conditions for the soldiers in soldiers. Through basic improvement at the workspace level and ergonomics interventions one can reverse the negative effect of physically exhaustive work, low productivity, poor living conditions and health problem of the population. However, the role of ergonomics in maintains and improving the health sustainability is poorly understood and seldom consider in India. There are some basic approaches in ergonomics which has been followed in improving the living and working of Indian soldiers in difficult terrains and extreme conditions. They are developing anthropometric database and designing products, equipments and workplace for optimal fit of the propulsion in use.

Reducing the co-genitive load for optimum man, machine interface etc. Improving ergonomics standards at workplace improve workplace safety reduces accidents and enhances human performance there by health and overall productivity of the organization. Maintain health

sustainability at workplace is a big organisational challenge involving macro or micro ergonomics approaches. Presently, researchers designed load carriage norms at difficult terrains, designing military hardware and software.

1.8 ERGONOMICS IN FOOTWEAR

Foot belongs to effectors systems of the human ergonomics. A shoe is worn by the human being to protect their feet during walking, running and performing different activities, so to maintain the balance for peoples, the footwear ergonomics is very important. The type of shoe has a serious effect on the feet during these activities as the extreme force and power developed, is transmitted through the feet. Due to uncomfortable conditions developing during the process, the human being feels the sensation of pain in the feet. On continues discomfort and pain for a substantial period of time, results in injury or deformation in the feet. The type of footwear is very important for military personnel. The shoes have two essential capacities to perform and accomplished during that time other lesser ones. There are two primary functions of shoes. First one is to protect the sole of the foot from the warmth, frosty, clamminess, earth and harshness of the ground in walking and standing. Second one is protect the upper piece of the foot, and if required the leg from the icy, rain, thistles and embed or different nibbles.

1.9 MOTIVATION

These days, foot injury is very common in society due to diabetes, uncomfortable shoes, and wrong way of arch support. A shoe is a thing which is used by human being to protect their feet for doing various activities like agriculture work, sports, safety purposes in industries, army but the uncomfortable or heavy shoes may affect on their feet.

Footwear is very important for the army people as army soldiers need to carry heavy load in their routine activity. A soldier weighting approximately 64 kg absorbs 39N additional force on the supporting leg at every stride due to weight of the rifle. An army person an average walk 9000 steps daily so, a heavy amount of force is observed per day and transmitted to lower extremity joints. This results in approximately 2600 injuries per year which includes around 26.4% fracture (Dislocation), 28% soft tissue injuries like muscle strain and 30% ankle, knee joint injuries. Amount of injuries results in significant amount of down time to the soldiers. Apart of this, it is very important for a army personal to maintain balance so as to support duty positions and face physical challenges of fighting in the spectrum of combat operations in difficult terrain conditions such as High altitude, Glacier, Jungle and Deserts.

Identifying a problem and devising a strategy to solve it is one of the main task's of the current work as it gives a direction to the research and determines whether the research will

contribute something to the society or not. After that the next logical step is the clearing of all the theoretical and practical concepts related to the problem and study of all the relevant literature in detail.

1.10 THESIS ORGANIZATION

Thesis work is divided into six chapters as describe below:

Chapter 1 presents the essential of ergonomics, human ergonomics, ergonomics in a defence, footwear ergonomics, foot anatomy, gait cycle and the direction of the body. From that point, the inspiration driving attempting this research has been presented.

Chapter 2 is the investigation of past work done as such far by various individuals till date at researching and understanding. This chapter also depicts the reason for this work from literature gap and after that frames the objectives of the research work.

Chapter 3 introduces the different kinds of technology utilized for measuring gait and data capturing method for experiments used in this research. Then it discusses the selection of different types of insole materials.

Chapter 4 describes the estimating of force, pressure and power excreted on feet during gait analysis. Then, it discusses the input and output parameters used for model.

Chapter 5 presents the result and discussion. Thus find out the better shoe and insole for maintain balance among peoples.

Chapter 6 brings the entire thesis to an end by the conclusion, future work, and scope of this research.

According to discussion in the past chapter, the measurement of Gait analysis is essential. In order to understand this, it is helpful to study the work done by different specialists in a similar field. Some of the literature available for the gait analysis is given below:

2.1 LITERATURE REVIEW FOR GAIT ANALYSIS

Wang *et.al* [3] researched the fitting of the human foot in various shoe insoles. Grey relational approach was utilized to evaluate the foot shapes and shoe insoles. ANN (Backpropagation neural networks) was utilized to predict the most proper insoles for the foot. Results from plantar pressure experiment were analyzed with grey relational calculations and found the best insole for the human foot.

Joo *et.al* [4] predicted gait speed in stance and swing stage in reference to foot scan insole data gained by the plantar pressure measuring device. Information was gathered from 20 adults (10 guys and 10 females) having age 24.5±.3years and height 1.68±0.08m. The data collection was filtered with cut off frequency of 100 Hz. ANN was utilized to predict the gait speed. 99 weight sensors were used to create input information for the model. Robustness of models was checked by five k-fold validation. The model was evaluated for gait speed in three unique conditions normal walking, slow walking and fast walking. The correlation coefficient (r) was calculated and found 0.963 for normal walking, 0.998 for slow walking and 0.95 for fast walking.

Favre *el.al* [5] used ANN to predict knee adduction moments during walking based on the Ground Reaction Forces (GRF) and Anthropometric measurements. Force plate was used to measure forces and human link locomotion was capture by motion capture camera. The model was evaluated by using a correlation coefficients and mean absolute error. Correlation coefficients(r) were calculated for slow speed (mid-stance peak-0.74, terminal stance peak-0.55, mid stance angular impulse-0.78 and terminal stance angular impulse-0.63), normal speed (mid-stance peak-0.76, terminal stance peak-0.64, mid stance angular impulse-0.77 and terminal stance angular impulse-0.74) and fast speed (mid-stance peak-0.78, terminal stance peak-0.64, mid stance angular impulse-0.76 and terminal stance angular impulse-0.69).

Kuan Zhang *et.al* [6] suggested new method for measuring human locomotion. Portable insole system was used to measure the Ground Reaction Forces (GRF). Data from 40 participated was

collected in different conditions i.e. walking, running, ascending and descending stairs in slow, normal and fast speed. ANN was used to predict the type of walking and indentify the human gait patterns. The model was evaluated on the basis of accuracy. Accuracy recorded 98.77%, 98.3% for 97.3% and 97.2% for walking, running, ascending and descending respectively.

OH *el.al* [7] described the prediction of Ground Reaction Forces during gait, based on kinematics. In this study Newtonian mechanics and ANN was used. The data was filtered with the cut off frequency of 120 Hz and walking time of 10 minute. The characteristics of ANN used were self weighting and bipolar sigmoid. The input of the model was gait cycle and output was forces and moments in X, Y and Z directions. Ten k-fold cross validation was used to check the robustness of the model. The model was evaluated by using correlation coefficient and root mean square error (RMSE). Correlation coefficients(r) found for forces in X, Y and Z directions were 0.91, 0.98 and 0.99. A recorded value of moments in X, Y and Z directions were 0.98, 0.89 and 0.86.

Nag *et.al* [8] studied the human activity during balance and walking. Different types of shoes were compared during quiet standing and walking on force plate. Three types of shoes namely laced shoes (2.5cm), flat heel (9cm) and pencil heel (7cm and 13cm) were used on a sample size of 15 women. Forces during walking and COP during balance was calculated using kistler force plate. One way ANNOVA was used. To analyse electromyography activity post hoc was used. Laces shoes showed better result in case of balance and walking both.

Toso *el.al* [9] calculated vertical force (Fz) on force plate system. It calibrated using artificial neural networks to reduce uncertainties. Math-works (2011) was used in this work. Model was runs on default settings. Each cell data calculated from force plate was used as input for the ANN. ANN model predicted force (Fz) accurately.

Kong *et.al* [10] designed a new type of insole which is based an air- pressure sensor using modern mechatronics technology. Fuzzy logic method was used for detecting the gait phases. In this paper, advanced higher level algorithm was introduced. This insole based upon the modern mechatronics technology. The insole containing sensors was embedded in the shoes called smart shoes. Four sensors were installed between the pad and sole. The performance of the sensors was found to be depended on the tubes character and dimensions of the tube. Tubes material was used like nylon and silicon. Sensor type insole checks the normal and abnormal gait of the human being during gait analysis.

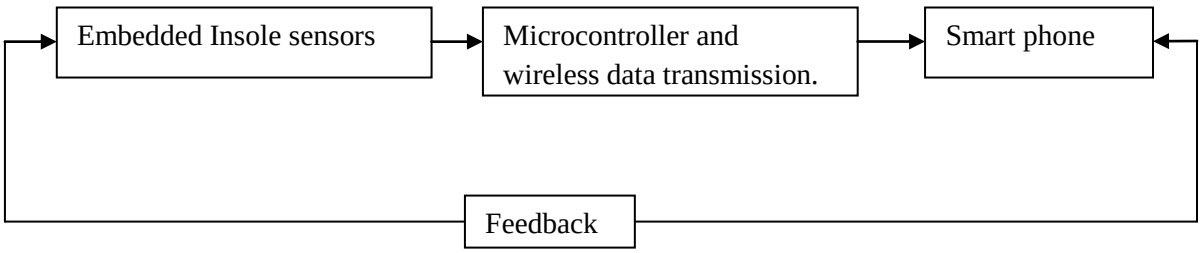
Lei *et al* [11] for human locomotion used motion capture camera with CCTV. Total subjects participated in this study is 18. The fluorescent balls were stick on leg and two balls were fixed on the edges of treadmill. Stride length and gait speed was determined.

Paul *et.al* [12] investigated the risk of muscle injury to Indian army soldiers carrying load during travel in border area found. Total 11 fit army soldiers participated in this study having weight range between 60 to 70kg, age 24 to 35 years and height 16 to 171cm. The subject walked on treadmill at different speeds (2.5 and 4.5km/hr) with load and without load. The gradients used were 0, 5, 10, 15, 20 and 25%. Study found heavy weight shoes as a main reason for he foot pain and risk of injury with the increased of speed and gradients.

Poorima *et.al* [13] suggested a ramp based for sensing gait During gait analysis the parameters considered were age, height, weight, health and speed. The developed technique was compared with different types of available technique like force plate. This system was similar to the motion capturing system but in this technique CCTV camera was used for capturing the human locomotion on a ramp mounted on the ground, like force plates to measure forces, acceleration, velocity, impulse and human being while standing and walking. The sensors connected to the ramp on the ground, collected the data. This system can check the working style of the person with the stored data.

Pal *et.al* [14] perform on a group of people's (n=7) aged between 25.6 (±5.04) years, Height- 170.66 (±4.51) cm, weight- 70.57 (±10.97) kg. Experiments with light weight shoes with or without Shock Absorber Material (SAM). Pressure distribution area in x and y direction was found to be more dispersed in case of insole without SAM than the insole with SAM, thus indicating more stability of insole with SAM.

Redd *et.al* [15] revealed a new sensing technique for the collection of human gait pattern. The technique contained wireless transmission of ambulation data for real-time feedback. The portable force sensing insole was designed and embedded into the shoes. Data collecting by describing block diagram discus below:



Mohd *el.at* [16] investigated the effect of the plantar pressure on foot type and its relationship with pressure distribution. The study was conducted on the group of 15 men between age 69.98±5.98 and divide the group based on the foot index. Rscan platform was used to measure pressure at every pressure point –forefoot, heel, mid-foot, lateral, medial, 5 metatarsal, rear-feet and toe. Kruskal-wall was used to compare the correlation coefficients(r) plantar pressure between foot types. The significant values were checked by post hoc. Maximum pressure was observed at forefoot area in all types of foot.

Rai *et al* [17] found that the human being during bipedal balance provides information of load on foot in various posture activities. The study was conducted on a group (N=66) aged between age 11 to 59 years. The instruments used were Computer based optical Pedobarograph and Asha 3D software. The Pressure was measured with or without SAM. Result showed that the wearing of insoles improve human posture and standing comfort. The insoles distributed the peak pressure uniformly on the plantar area of the foot.

Deschamps *et.al* [18] used was Semi automatic total mapping technique for the identification of forefoot pressure in diabetics patients. Total number of subjects (N=97) with barefoot. Plantar pressure insole was used and Analysis of variance (ANOVA) was used to check the difference regions of interest and clusters. Plantar pressure distribution provided the information for the prevention, treatment and diabetic foot.

HO I.J *et.al* [19] studied the effect of planar pressure distribution during walking on the treadmill at various speeds (1.5, 2 and 2.5 m/s) and gradients (0%, 5%, 10% and 15%). A group of healthy girls having mean age of 20.7 years, mean height of 1.60 m and mean weight of 53.3 kg was selected for this study. Post hoc and F-value test was calculated for different gradient and different speeds. With the increase in speed and gradient peak pressure of all regions decreased, except medial forefoot and hallux.

Johnson *et.al* [20] investigated the use of nine different types of shock-absorber insoles in four different types of shoes during normal walking. An accelerometer was mounted at left ankle and Fourier transform of the axial acceleration was recorded. The shock magnitude was calculated by the shock factor. The frequency used in this study 50 Hz and 150 Hz. The result was compared with the shoes without SAM.

Taghi *et.al* [21] in this study 40 normal people participated. The force plate instrument was used to calculate the forces. The data was filtered at a cut off frequency of 10 Hz and standing time on force plate is 5 minute. The conditions were used 1 and 2 cm height of heel for men and 2 and 3 cm heel height for women. For testing unstable position pair ($p< 0.05$) t-test calculated. Result shows good balance in Fx as compare to Fy.

Cotoros *et.al* [22] applied rapid prototyping technology for the making of insoles. Data for fitness of the insoles was collected on different points i.e. Heel, forefoot, mid-foot, lateral, medial and overall. After collecting points scan system used for collected could data for making the CAD model, CATIA (Three dimensional) 3D software was used in this study to make a three-dimensional model of the insole. A rough design of foot insole made with hand was compared with 3D- models.

Ruperez *et.al* [23] predicted of pressure on the foot surface using artificial neural networks model using Multilayer perception. Inputs used for ANN model was characteristics of materials and data obtained from 14 sensors. The prediction values were compared with the measured values. The value of correlation coefficients(r) was found to be close to 0.9.

2.2 PROPOSED SOLUTION FOR PROBLEMS

To prevent these foot pain problems there is need to insert any shock absorbing in-socks (SAI) which

- Can act as a shock absorber and is an elastic solid when at rest.
- Can protect the heel by reduction of load on the foot.
- Can absorb the energy from the shock by decreasing the amplitude of the shock waves. Give proper balance to the body by concentrating the sway area (movement of COP of the body).

2.3 RESEARCH GAP

- It has been observed that the amount of force excreted on feet is very high which leads to significant damage and injury of feet.
- The material used for insole needs to be modified as the load absorption capacity of the present shoe is very low with respect to the amount of work being done.

2.4 RESEARCH OBJECTIVE

The work is proposed to be fulfilled by the following steps:

- Identification and data collection of forces, power, and pressure for the different pressure points of the feet during walking and standing without external load.
- Development of a predictive model to estimate the forces, pressure, and power at various pressure points during no load.
- Develop a support or assistance device (insole) to reduce the impact of forces and power on the feet reducing the risk of foot injuries during walking for no load.

2.5 METHODOLOGY

2.5.1 METHODOLOGY FOR FORCE PLATE

Comparative study of two types of shoes i.e. Heavyweight Shoes (HWS) and Lightweight Shoes (LWS).

1. For data collection Kistler Force Plate was used.

2. Input parameters used were cut off frequency of 100 Hz for quiet standing and 50 Hz for walking. Time of collected data was 30 seconds for stand and 4 seconds for walking.

3. Collect Forces and Power as output parameters. In case of balance quiet standing calculated Standard deviation in x and y-direction, Planar deviation (PD) and Area (A). In case of walking three forces were calculated i.e. Medial-lateral, Anterior-posterior and vertical in X, Y and Z directions (Both foot).

4. For prediction Forces and Power Artificial neural network (ANN) machine learning model was used.

5. Weight of the human, height of the human and weight of the shoe were the input process parameters for this study.

6. Model run on its default setting. 75% data was used for testing and 25% data was used for validation.

7. Model was evaluated by correlation coefficients(r), R^2 and mean absolute error (MAE).

8. Compared the predicted and measured values.

2.5.2 METHODOLOGY FOR FOOT SCAN INSOLE

Comparative study of four types of insoles with one type of shoes i.e. Light Weight Shoes (LWS).

1. Firstly, made insoles by using mould. Four types of insoles were used having different materials.

2. For data collecting Voxel Foot Scan Insole was used.

3. Input parameters used were cut off frequency of 50 Hz for walking, Age, Height and Weight. Walking on treadmill at a speed of 4.5 km/hr for 5 minute.

4. Collect Pressure as output parameters. Calculate pressure at different points on the foot i.e. Forefoot, Mid-foot, Heel, Medial, Lateral and Overall.

5. For prediction Pressure Artificial neural network (ANN) machine learning model was used.

6. Used Analysis of variance (ANOVA) to find the significant ($P>0.05$) parameters affect the pressure. Significant parameters used as input for ANN model.

7. Model run on its default setting. 75% data was used for testing and 25% data was used for validation.

8. Model was evaluated by correlation coefficients(r), R^2 and mean absolute error (MAE).

9. Compared the predicted and measured values.

2.6 CHAPTER SUMMARY

Thus finally, to summarise this chapter, based on literature survey of various works done with regard to understanding the different parameters of gait analysis, it was found that the amount of force excreted on feet is very high which leads to significant damage and injury of feet. The material used for insole needs to be modified as the load absorption capacity of the present shoe is very low with respect to the amount of work being done. To study these, an objective was prepared and the methodology to reach this objective was planned. Based on this plan, further work was done to achieve the objectives.

This Chapter describes the data capturing method and experiments. There are different types of systems used to check the gait patterns and parameters. The current gait measurement systems are Motion capture camera, Force plate, Foot-scan insole, Electromyography, sensor-based insole and inertial measurement. In this study used Force plate and Foot scan insole for data capturing.

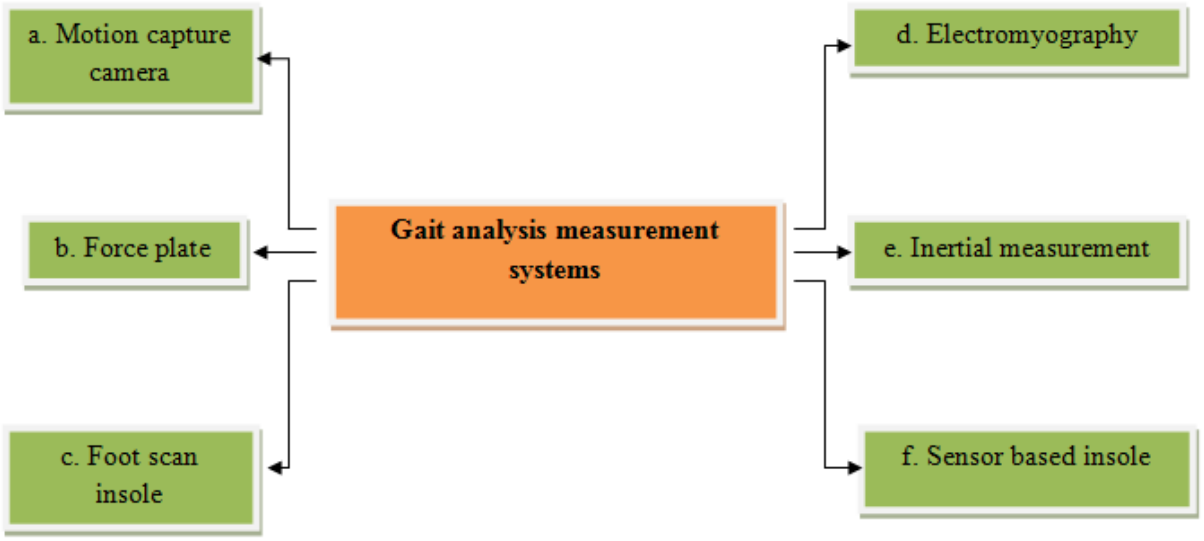


Figure 6: Current Gait measurement technologies

3.1 DIFFERENT TYPES OF CURRENT GAIT MEASUREMENT TECHNOLOGIES

3.1.1 Motion capture camera

This system consists of camera, which records the reading of joint when body moves.

3.1.2 Force plate

The first force plate discovered in 1969[24]. The force plate consists of piezoelectric load cells mounted between two plates. Force plate basically used for measuring forces in three-dimensions (x, y, and z). A force plate was rigid on the ground.

3.1.3 Foot scan insole

As we know that force plate is a stationary system, it will give only forces at three points on the foot but foot scan insoles give every important pressure point on the foot. Foot scan insole consists of pressure sensors which record the pressure applied by the foot. Embed into the shoes to collect pressure.

3.1.4 Electromyography

It measures the electrical activity of the muscles. Sensors are placed on the skin. The wire is inserted into the muscles. Sensors placed on the skin gives the reading of muscle activities.

3.1.5 Inertial measurement

It works on the moment of inertia. It consists of three- dimensional gyroscope and accelerometers. The lightweight sensors are placed on the human body.

3.1.6 Sensor based insole

It consists of different types of sensors. The typically used sensors are force sensitive resistors, PVDF, air pressure sensors, bi-directional sensors, bend sensor, flex sensors and electric field height sensors. This type of insole embeds into the shoes to collect pressure.

3.2 FORCE PLATE

Kistler force plate used for data capturing. The force plate gives a data in three dimensions. Three types of forces give by force plate i.e. Medial-lateral force in the x-direction, Anterior- posterior force in the y-direction and vertical force in the z-direction. A Kistler force plate is a very sensitive through robust measurement devices. It is able to resolve forces down to 10 Mn and still cover a measuring range up to 20KN (depending on the type of force plate). The force plate should be mounted level with the surrounding floor to make it easily accessible and safe. The top plate of the force plate must never touch the walls of the pit or neighbouring force plate at any point. The force plate should have the same floor covering as the surrounding (safety and psychological effects). The ground on which the force plate is mounted has to be solid, rigid and free of vibration. To obtain the good results, the environment in which the force plate is operating- The temperate has to be kept constant. Temperature transients can easily lead to temperature error in the measurements. Leave the charge amplifier switched on at all times. This creates a warm and protective atmospheric inside. Force plate sensitivity is not affected by environmental parameters. Large temperature changes can create inner stresses and excessive load due to the thermal extension of the force plate structure. Protect the force plate against direct sunlight to avoid temperature transients. Force plate and mounting frame must have the same temperature before tightening the bolts. Condensation of humanity on the force plate or the foundation must be prevented. In critical cases, the simple measure is to place a light bulb (25 or 20W) beneath the force plate. Force plate shows in figure 7.

Figure 7: Force plate (Courtsey: DIPAS, DRDO, Delhi)

Force plate is used in a wide variety of applications and therefore available in different sizes and designs. They are arranged case by case depending on the applications. As a general rule of the force, the plate should be mounted in the centred of a space of at least 10x10x2m. Force plate may be mounted in any position on ramps, walls, and ceilings, it will perform within specifications provided the mounting instructions following strictly. Force plate is the foundation with damping from an external source of vibrations. If you have to live with the external vibrations the foundation must be isolated from the surrounding. Call in specialists because foundation mass and damping material must be tuned to dynamic characteristics of the mounting spot as the part of the building structure. Nonprofessional design can result in worsening instead of improving the situation. The internal source of vibration is the dynamic interaction between the force plate and its foundation. The application of the force plate is:

1. Ergonomics
2. Kicking, Boxing
3. Industrial force measurement

Force plate and charge amplifier special high insulated cables, available only from Kistler, must be used. Otherwise, the signals may show drift. Cables with plastic covering are quite flexible and thin suitable for indoors, not exposed to rough handling. Cable in the metal tubing is rugged, 12mm thick and suitable for the rough environment and handing. Water resistant versions are available for force plate. Cables ducts must be dry and connections (expect water resistant one) must never be submerged.

Today ten fit armed force soldiers took an interest in this investigation. Two types of shoes named as Heavyweight shoes (HWS) and Lightweight shoes (LWS) is utilized having different weights 1.5kg and 0.9kg individually. An aggregate number of experiments in balance are 20 and for walking are 10. The characteristics of the subject given in the table: 1.

Table 1: The characteristics of the subjects participated in this study

Subject	Age	Height(cm)	Weight (Kg)
1	37	172	75
2	22	173	74
3	28	173	75
4	36	162	74
5	24	172	60
6	31	175	86
7	36	168	74
8	35	178	90
9	37	165	70
10	53	163	91

The subject remains on a Force plate for 30 sec, they were told to look straight ahead to watch an objective (Black circle), with their head erect and their arms at their sides in the comfortable position. The data collection was filtered with the cut off frequency of 100Hz for standing.

Figure 8: Standing (Courtsey: DIPAS, DRDO, Delhi)

Walking on a Force plate for 4 sec (Touch time). The data collection was filtered with the cut off frequency of 50 Hz for walking. The experiment has been approved by the Ergonomics lab Defense Institute of Physiology in Delhi.

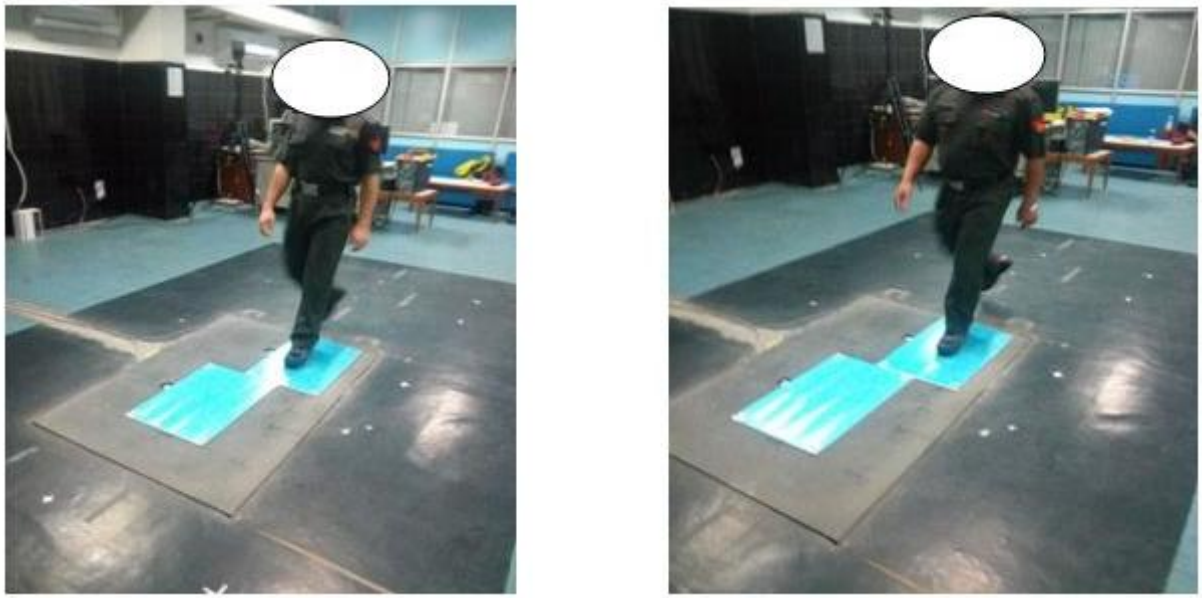


Figure 9: Walking (Courtsey: DIPAS, DRDO, Delhi)

The methodology of the data capturing is given below as shown in Figure 10:

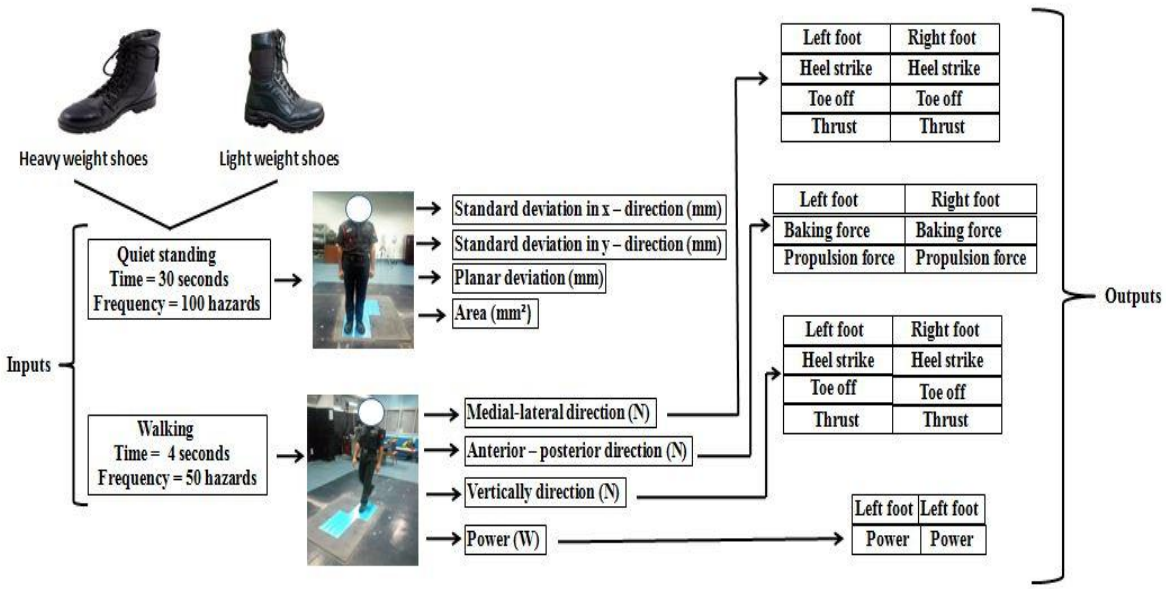


Figure 10: Data capturing method

Table 2: Standing experiments for Heavy weight shoes and Light weight shoes

HWS				**LWS**			
Sdx(mm)	Sdy(mm)	Pd(mm)	Area(mm²)	Sdx(mm)	Sdy(mm)	Pd(mm)	Area(mm²)
0.0579	0.053	0.0785	11.46	0.0504	0.0588	0.0843	9.73
0.0597	0.0544	0.0808	11.1	0.0592	0.0567	0.082	9.53
0.0537	0.0539	0.0761	10.46	0.0515	0.0564	0.0805	9.02
0.0583	0.0576	0.082	12.65	0.0566	0.0553	0.0791	9.32
0.0653	0.0531	0.0842	12.79	0.0646	0.0575	0.0805	8.55
0.0632	0.0532	0.0826	12.22	0.0611	0.0559	0.0858	8.66
0.0586	0.0532	0.0791	11.53	0.0538	0.0506	0.0739	8.03
0.0669	0.0718	0.0982	31.43	0.0555	0.0505	0.075	8.78
0.0119	0.0461	0.0128	15.15	0.0558	0.0479	0.0983	7.57
0.0109	0.0474	0.0119	14.8	0.0523	0.0456	0.094	8.54
0.0681	0.048	0.0833	10.16	0.0635	0.0494	0.0505	8.96
0.0669	0.0456	0.081	9.57	0.0621	0.0473	0.078	7.54
0.0897	0.0917	0.218	30.2	0.0682	0.0525	0.128	32.09
0.0899	0.0844	0.123	28.9	0.0664	0.637	0.128	32.12
0.105	0.074	0.128	28.1	0.108	0.0691	0.134	31.86
0.0956	0.0673	0.117	20.57	0.101	0.0697	0.129	30.5
0.0824	0.0806	0.115	29.17	0.0692	0.0502	0.0806	19.26
0.096	0.0869	0.13	32.64	0.0607	0.0658	0.0866	19.55
0.0699	0.54	0.0915	14.52	0.0675	0.0572	0.0885	14.57
0.0687	0.0584	0.0902	14.1	0.0665	0.0605	0.0899	14.68

Table 2 shows when subject stand on force plate while wear HWS footwear, indicates generally higher back muscle action and higher COP, showing high muscle load and posture instability. When wearing HWS, higher muscle movement reported in the back could increase back muscle fatigue and prompt posture irregularity. For experiment information, it was cleared that the values of all parameters lesser in case of LWS. It was watched that variety of COP is more in case of HWS. The moving of sway area cleared the uncomfortable position while wearing HWS.

Table 3: Heavy weight shoes Forces in Medial- lateral direction (Fx)

HWS Right Foot				HWS Left Foot		
Subject	Heel strike	Toe off	Thrust	Heel strike	Toe off	Thrust
1	-52.87	-40.944	-30.3	61.21	81.06	37.83
2	-57.47	-33.78	-21.3	50.03	48.95	18.72
3	-56.65	-32.55	-19.54	50.83	51.46	29.62
4	-47.79	-74.46	-45.24	74.22	57.5	37.38
5	-47.51	-40.4	-22.91	60.43	58.86	29.62
6	-36.21	-42.98	-17.18	45.74	57.82	28.77
7	-27.65	-29.33	-9.81	35.78	43.76	31.39
8	-54.77	-47.05	-16.63	89.08	90.96	41.43
9	-44.47	-49.99	-39.36	46.91	53.71	39.81
10	-48.04	-33.31	-19.23	44.06	48.51	27.02

Table 4: Light weight shoes Forces in Medial- lateral direction (Fx)

LWS Right Foot				LWS Left Foot		
Subject	Heel strike	Toe off	Thrust	Heel strike	Toe off	Thrust
1	-66.76	-46.64	-10.65	49.26	76.32	13.56
2	-46.11	-32.99	-10	55.01	77.26	21.55
3	-49.13	-17.47	-3.83	59.79	62.15	31.96
4	-46.59	-79.16	-3.82	106.89	57.52	25.46
5	-10.33	-31.56	-6.78	46.35	45.27	19.61
6	-41.06	-41.63	-12.39	61.06	64.52	20.51
7	-39.38	-32.77	-2.98	35.32	47.19	20.38
8	-66.72	-46.96	-11.66	75.36	79.33	28.81
9	-56.18	-71.07	-29.68	51.01	55.18	20.91
10	-40.54	-24.32	-4.07	40.41	62.54	19.61

As we probably aware of Medial-lateral (ML) direction When the body moves in a straight line, The Ground Reaction Forces (GRF) in the medial-lateral direction is very small. This is because for linear walking the centripetal component of friction is absent. Medial- lateral Ground reaction forces and inversion of the foot can be distinctly observed when walking in a curve or circular trajectories. For most of the stance phase of the right foot, the medial-lateral Ground Reaction Forces accelerates the center of mass of the body slightly towards the left side of the body to maintain balance during single stance. For normal gait, the left foot follows a similar pattern. Table 3 and 4 shows that when subject walking on force plate with HWS, higher Medial-lateral (ML) force in both left and right feet noted in comparison with walking on force plate with LWS, there was no significant change in muscle activity (Back and leg) when a subject walked with LWS conditions, there was an expansion in leg muscle activity when a subject walked with HWS.

Table 5: Heavy weight shoes Forces in Anterior-posterior direction (Fy)

HWS Right Foot			**HWS Left Foot**	
Subject	Baking Force	Propulsion Force	Baking Force	Propulsion Force
1	131.73	-173.9	208.01	-140.98
2	137.15	-164.89	155.55	-182.36
3	152.25	-171.87	145.72	-147.85
4	87.35	-179.44	239.92	-134.84
5	104.59	-191.98	149.4	-136.23
6	104.51	-181.89	150.62	-147.37
7	126.65	-140.31	162.05	-102.53
8	240.79	-210.36	223.43	-180.17
9	127.65	-147.6	163.84	-152.97
10	102.77	-130.45	133.37	-106.26

Table 6: Light weight shoes Forces in Anterior-posterior direction (Fy)

LWS Right Foot			**LWS Left Foot**	
Subject	Baking Force	Propulsion Force	Baking Force	Propulsion Force
1	125.65	-170.57	211.94	-144.46
2	148.27	-170.74	177.82	-164.41
3	149.97	-142.166	132.46	-108.96
4	76.72	-182.07	159.62	-106.26
5	128.55	-160.38	174.33	-132.99
6	132.84	-160.92	155.34	-124.25
7	95.32	-120.63	124.27	-103.36
8	197.76	-185.72	202.71	-161.91
9	113.77	-126.56	204.55	-126.72
10	85.06	-129.51	111.8	-102.86

As we know that, in Anterior-Posterior (AP) direction right foot applies first baking force amid the principal half of the position stage and Propulsion force amid the second half. The positive sign shows the forward heading of the body and a negative sign shows the reverse movement of the body. Table 5 and 6 demonstrates when a subject walking on force plate with HWS, a generally higher baking and Propulsion force in the two feet in comparison with the walking with the LWS, there was a no significant change in muscle action (back and leg) when a subject walked with HWS conditions, when the body pushes ahead it will require additional baking force and time. Similarly, Propulsion force is more when the body in reverse.

Table 7: Heavy weight shoes Forces in Vertical direction (Fz)

HWS Right foot				**HWS Left Foot**		
Subject	Heel strike	Toe off	Thrust	Heel strike	Toe off	Thrust
1	843.05	819.859	532.841	882.38	873.44	405.25
2	943.646	850.595	486.993	886.64	911.76	476.9
3	921.981	892.948	489.769	884.76	867.09	501.84
4	946.835	939.291	744.372	930.79	930.41	777.54
5	908.483	798.217	491.521	1030.63	825.56	434.65
6	897.213	963.205	669.785	978.86	969.03	646.05
7	828.53	806.76	496.71	821.29	810.28	494.89
8	1241.73	1028.66	564.31	1173.07	548.64	1049.4
9	860.83	840.61	552.21	905.84	880.14	524.95
10	767.83	784.42	665.1	720.01	709.36	401.14

Table 8: Light weight shoes Forces in Vertical direction (Fz)

LWS Right Foot				**LWS Left Foot**		
Subject	Heel strike	Toe off	Thrust	Heel strike	Toe off	Thrust
1	808.63	803.03	444.32	897.65	853.77	405.3
2	946.26	873.33	459.76	883.34	878.76	470.99
3	850.75	818.62	528.71	780.49	815.3	534.511
4	890.94	920.4	767.12	998.32	926.44	669.67
5	903.45	774.32	507.56	919.63	794.44	508.65
6	903.45	957.81	670.06	953.38	928.28	660.69
7	702.91	741.44	558.18	774.25	755.67	523.62
8	1122.3	961.94	587.61	1135.11	952.4	586.62
9	799.42	786.58	588.83	955.483	819.81	586.5
10	742.66	716.63	395.76	714.39	727.15	409.22

The vertical power has two peaks. Table 7 and 8 clarify that when a subject walked on force plate with HWS, a generally higher vertical force was seen in the two feet in comparison with the LWS. There was change in muscle (leg and back) when a subject walked with HWS and there was an expansion in leg muscle action when a subject walked with HWS.

Table 9: Power for Heavy weight shoes and light weight shoes

	HWS Right Foot	**HWS Left Foot**	**LWS Right Foot**	**LWS Left Foot**
Subject	Power	Power	Power	Power
1	3575.58	3727.55	3421.54	3727.47
2	3562.88	3893.6	3734.63	3771.67
3	4148.3	3966.36	3990.81	3678.09
4	5244.81	5872.33	5124.69	4965.56
5	3748.8	3867.79	3651.65	3841.72
6	4926.46	4848.689	399.081	4362.24
7	3879.82	3687.9	3483.68	3761.81
8	4977.77	4977.77	4525.21	4493.62
9	3986.63	3986.63	3677.66	3925.16
10	3459.2	2948.05	3127.78	3096.82

Table 9 shows that power is higher in the two feet in case of HWS when comparison with LWS. It obviously clear that subject bearing more power when wearing HWS.

For study we observed that the Force plate give Forces in 3-points i.e. heel strike, toe off and push and furthermore this is the stationary framework. According to Lt. Col. Dr. S.K. Sinha (Orthopedic) Military Hospital Jalandhar the main pressure point on the foot as given as below:

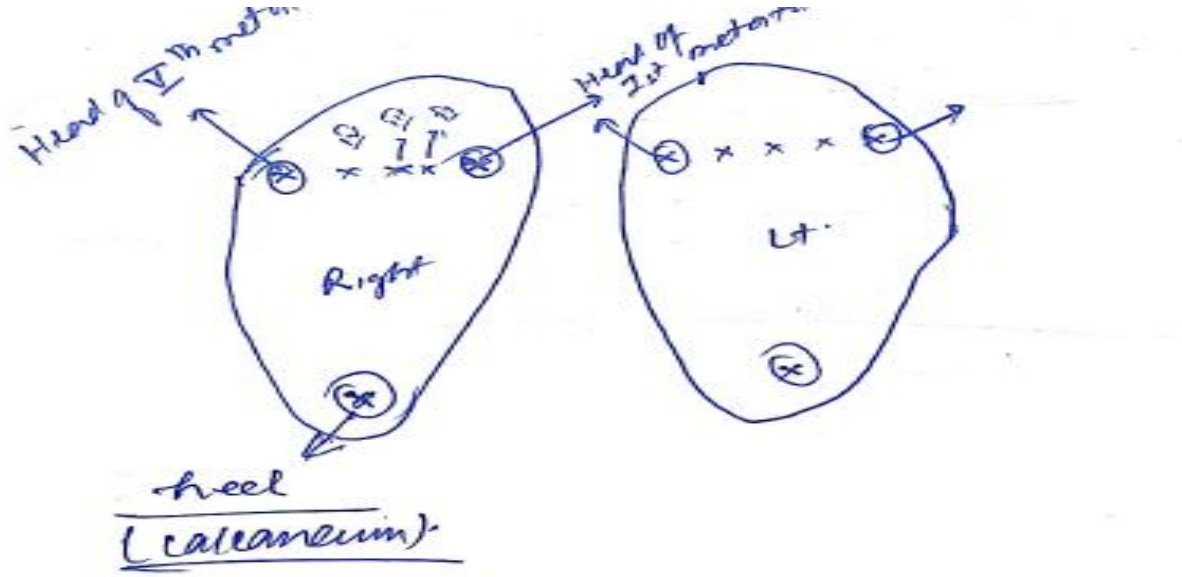


Figure 11: Pressure points on the feet (Courtsey: Lt. Col. Dr S.K. Sinha (Orthopaedic) Military Hospital, Jalandhar)

By observing issues faced by patients and Army Personal, make a four kind of insole having different materials for maintain balance among armed force soldiers. To make insoles pour the fluid material into the mold, after 24 hours of setting insoles were made. To check the

performance of 4 insoles voxel care foot scan insole system is utilized for measuring the pressure at various points on the feet.

Figure 12: Mold used

3.3 FOOT SCAN INSOLE

Foot scan insole used to collect the pressure on the foot. Foot scan insole consists of pressure sensitive sensors which record the pressure applied by the foot. The foot scan insole embedded into the shoes. It gives pressure on the foot in different points i.e. Forefoot consists of five metatarsal and toes, midfoot, heel, lateral, medial and overall.

Figure 13: Voxel care Foot scan insole (Courtsey: DIPAS, DRDO, Delhi)

Total n=18 fit armed force soldiers took part in this investigation. One shoe named light weight shoes (LWS) is utilized having weights 0.9kg and four types of various insoles utilized. The characteristics of the subject given in the table: 10.

Table 10: Characteristics of the subject

Subject	Age	Height (Cm)	Weight (Kg)
1	51	164	81
2	49	173	80
3	49	171	74
4	40	166	62
5	39	175	75
6	37	172	75
7	36	168	74
8	22	173	74
9	28	168	62
10	24	172	60
11	37	167	73
12	36	162	74
13	24	171	60
14	31	175	86
15	28	173	75
16	30	171	60
17	54	159	66
18	40	167	75

Foot scan insole embedded in the shoes. Subject need to walk on treadmill at a speed for 4.5km/hr for 5minute in each four conditions. The gradient of the treadmill is 0%. The cutoff frequency given is 60 Hz.

Figure 14: Embedded insole (Courtsey: DIPAS, DRDO, DELHI)

Figure 15: Treadmill Walking (Courtsey: DIPAS, DRDO, Delhi)

The methodology of the data capturing is given below as shown in Figure 16:

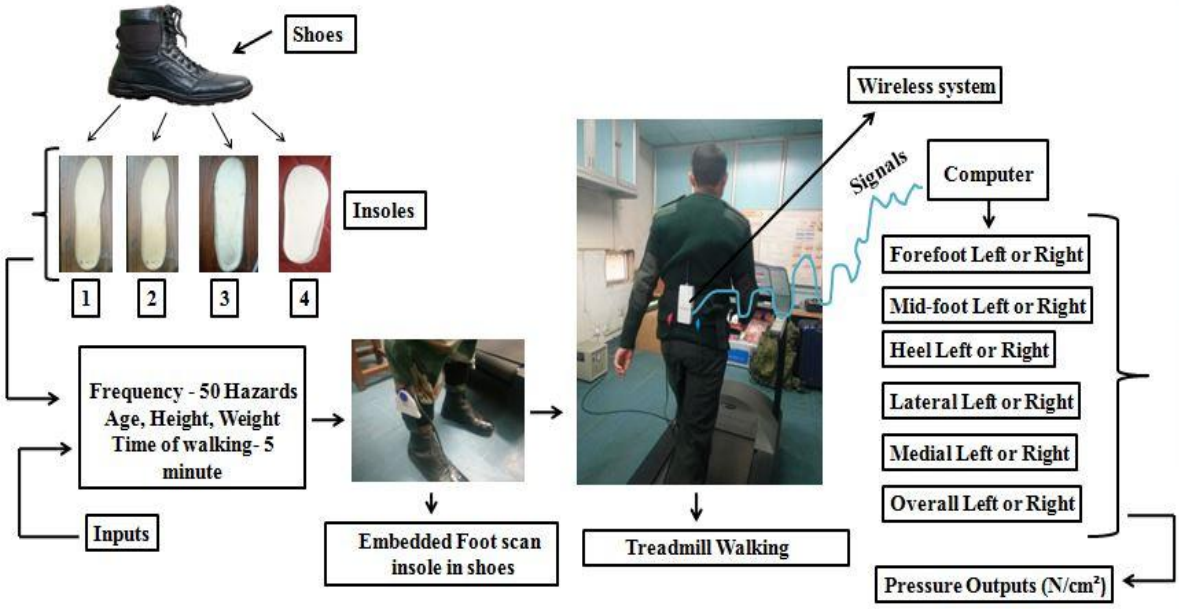


Figure 16: Data capturing method

Table 11: Experiment values of Insole 1

Subjects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Forefoot Left	2.7	4.2	1.8	3.9	2.8	3.8	1.7	5.1	2.9	3.8	2.3	4.4	3.4	4.4	3.5	3.5	3.2	2.2
Forefoot Right	2.6	4.8	2.5	4.2	4.0	5.1	4.7	5.7	3.5	4.4	2.8	4.3	4.3	3.4	3.4	3.7	3.5	3.1
Mid-foot Left	4.4	2.4	1.6	1.4	3.2	2.8	0.6	4.8	1.7	3.3	3.7	2.7	4.6	2.2	3.5	1.2	2.8	2.1
Mid-foot Right	5.4	1.6	1.7	1.5	2.9	3.2	0.7	4.6	2.0	2.9	3.6	2.0	4.8	5.0	3.7	2.0	3.7	2.7
Heel Left	3.8	6.2	4.4	3.4	6.1	5.9	3.3	5.4	3.5	4.8	2.8	4.5	3.4	5.0	3.3	3.8	3.3	2.6
Heel Right	1.3	4.6	4.2	3.1	5.9	5.3	2.6	5.2	3.0	4.7	2.8	4.3	3.8	4.6	2.6	4.1	3.1	3.3
Lateral Left	3.8	4.2	3.2	2.5	4.9	5.0	2.4	5.2	2.6	3.3	2.7	3.6	3.8	4.1	3.5	2.2	2.9	1.8
Lateral Right	2.8	4.0	3.5	2.7	4.5	4.9	3.0	5.5	2.9	3.3	3.7	3.7	3.8	3.5	1.9	3.3	3.0	3.6
Medial Left	3.2	4.2	2.1	3.2	2.9	3.2	1.3	5	2.8	4	2.7	3.9	4.3	3.3	4.0	3.2	3.3	2.7
Medial Right	3.1	3.6	2.2	3.1	3.9	4.2	2.9	4.9	3.1	3.9	3.2	4.2	3.6	4.0	4.5	3.4	3.8	2.6
Overall Left	3.5	4.2	2.6	2.9	3.9	4.0	1.8	5.1	3.9	4.9	5.7	4.8	4.0	3.7	3.7	3.2	3.1	2.3
Overall Right	2.9	3.8	2.9	2.9	4.2	4.5	2.9	5.2	31	3.91	3.2	4.29	1.1	1.6	3.2	3.4	3.4	2.0

Table 12: Experiment values of Insole 2

Subjects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Forefoot Left	4.7	1.7	2.4	3.7	2.5	2.7	1.7	6.0	3.2	3.6	2.	4.6	2.9	4.1	3.8	3.4	3.6	3.0
Forefoot Right	4.7	3.7	2.85	3.21	4.69	5.06	4.5	6.29	4.2	4.71	2.5	4.5	3.73	4.24	3.08	3.66	3.73	1.17
Mid-foot Left	1.3	4.37	1.9	1	3.2	3.4	0.72	4.1	1.8	3.1	3.	2.3	2.1	2.6	3.4	2.0	3.0	2.3
Mid-foot Right	2.2	4.1	2.2	2.1	2.2	3.6	0.6	4.2	3.72	4.8	2.9	4.4	3.4	2.1	4.3	4.3	3.9	4.3
Heel Left	5.9	2.9	4.6	3.6	6.2	6.1	3.7	4.2	3.7	4.8	2.9	4.4	3.3	4.8	4.0	4.2	3.6	3.4
Heel Right	4.3	3.9	4.7	3.2	5.6	5.1	2.7	4.6	3.3	4.2	3	5.6	4.2	5.4	3.8	3.4	3.9	2.8
Lateral Left	4.3	2.6	3.6	2.7	4.8	4.6	2.5	5.2	3.4	4.7	2.3	4.2	3.1	4.5	3.8	3.3	3.5	3.1
Lateral Right	3.7	3.8	4.2	2.5	4.7	5.2	2.9	5.6	3.3	4.7	2.4	4.2	3.7	3.4	3.0	3.3	2.7	2.0
Medial Left	4.1	3.0	2.5	3.2	2.7	3.1	1.5	4.7	2.6	3.4	3.	3.9	3.5	3.5	4.0	3.3	3.5	3.3
Medial Right	4.1	3.8	2.4	3.2	3.6	4.0	2.9	4.9	3.2	3.6	3.	4.2	3.3	3.9	4.4	3.6	3.9	2.4
Overall Left	4.2	2.8	3.0	2.9	3.8	3.8	2.0	4.9	3.0	4.0	2.8	4.0	4.0	4.1	3.9	3.3	0.8	4
Overall Right	3.9	3.8	3.3	2.8	4.2	4.6	2.9	5.2	3.2	4.1	3	4.2	2.3	1.2	4.2	3.4	3.9	3.2

Table 13: Experiment values of Insole 3

Subjects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Forefoot Left	4.42	4.1	2.5	3.6	2.5	2.7	2.1	6.1	3.	4.5	2.	4.3	4.3	3.7	4.6	3.1	3.7	3.5
Forefoot Right	4.82	4.3	3.0	3.8	4.3	5.1	5.4	5.9	5.	5.7	3.6	4.3	4.3	4.0	4.	3.0	3.6	4
Mid-foot Left	1.41	2.6	2.6	1.2	3.8	3.3	1.2	3.4	2.7	3.0	3.6	2.4	3.4	3.2	2	2.4	2.2	1.9
Mid-foot Right	2.14	2.8	2.6	1.5	2.8	3.4	1.2	3.6	2.3	3.0	3.5	2.0	4.5	6.0	3.4	5.1	3.7	2.9
Heel Left	6.54	5.3	5.7	4.7	7.5	5.9	4.6	4.6	5.	5.5	3.9	5.2	3.4	6	4.6	4.4	5.0	3.1
Heel Right	5.6	5.7	5.9	4.3	6.5	3.1	3.2	6.3	4.2	5.5	4.6	6.4	4.1	4.4	1.5	3.7	4.2	4.0
Lateral Left	4.48	3.6	4.1	3.2	5.3	4.3	2.9	4.7	4.3	5.3	3.2	3.8	3.8	4.3	3.5	3.7	3.6	4.0
Lateral Right	4.06	5.2	4.7	2.7	5.0	3.8	3.5	6.1	4.3	5.7	2.6	4.3	3.2	4.2	4.3	3.4	4.1	2.2
Medial Left	4.12	4.4	3.1	3.2	3.3	3.1	2.0	5.1	3.5	3.7	3.4	4.2	3.9	4.3	4.7	3.6	3.8	3.9
Medial Right	4.61	3.6	3.1	3.9	3.9	4.2	3.6	4.6	3.8	4.1	4.9	4.8	3.7	4.4	3.1	4.5	4.2	3.6
Overall Left	4.28	4.0	3.6	3.2	4.2	3.7	2.4	4.9	3.9	4.4	3.3	4.0	1.9	0.8	4.1	3.7	3.78	3.4
Overall Right	4.34	4.44	3.91	3.37	4.51	4.04	3.59	5.39	4.1	4.9	3.8	4.5	1.9	3.9	0.8	0	4.1	2.4

Table 14: Experiment values of Insole 4

Subjects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Forefoot Left	5.0	4.7	2.9	4.2	2.2	4.7	1.6	7.2	3.	4.0	3.9	4.7	5.1	3.7	5.6	3.5	4.4	3.6
Forefoot Right	5.7	4.9	3.0	4.0	4.6	5.0	4.9	6.2	5	5.0	4.1	5.0	4.8	4.5	4.7	3.2	4.4	4.2
Mid-foot Left	1.2	2.37	2.21	1.14	3.94	3.66	0.98	4.04	2.1	4.2	3	2.75	4.42	3.43	1.6	2.53	2.57	1.97
Mid-foot Right	1.8	2.1	2.1	0.8	3.1	3.2	0.7	3.5	2.5	3.0	3.1	2.5	4.5	3.2	4.6	4.8	3.3	2.7
Heel Left	6.6	5.9	5.9	4.8	5.8	2.8	5.1	2.1	4.9	5.4	4.1	4.7	4.5	5.0	4.1	4.8	4.8	3.9
Heel Right	5.4	5.5	5.5	5.5	6.5	5.5	3.7	5.0	4.3	5.2	5.1	6.5	4.5	5.6	4.7	3.2	3.8	2.8
Lateral Left	4.3	4.4	4.4	3.5	4.8	3.4	3.0	4.7	4.4	5.2	2.9	4.2	4.1	5.6	4.1	4.1	4.1	3.9
Lateral Right	4.9	4.6	4.8	4.1	5.2	4.8	3.6	4.8	3.9	5.2	3.7	5.0	3.7	3.9	4.2	3.6	4.0	3.5
Medial Left	4.7	4.4	3.0	3.4	2.7	4.2	1.8	4.9	3.2	3.9	4.4	3.9	5.2	4.1	4.3	4.1	4.1	3.2
Medial Right	4.2	4.2	2.5	3.2	4.2	4.4	3.2	5.4	4.2	3.9	4.	4.7	5.5	5.1	4.8	3.7	4.2	3.1
Overall Left	4.5	4.4	3.7	3.5	3.7	3.8	2.4	4.8	3.7	4.5	3.6	4.1	4.6	4.1	4.2	3.6	4.0	3.6
Overall Right	4.6	4.4	3.6	3.6	4.7	4.5	3.4	5.1	4.1	4.6	4	4.8	4.6	4.5	4.5	3.7	4.5	7.1

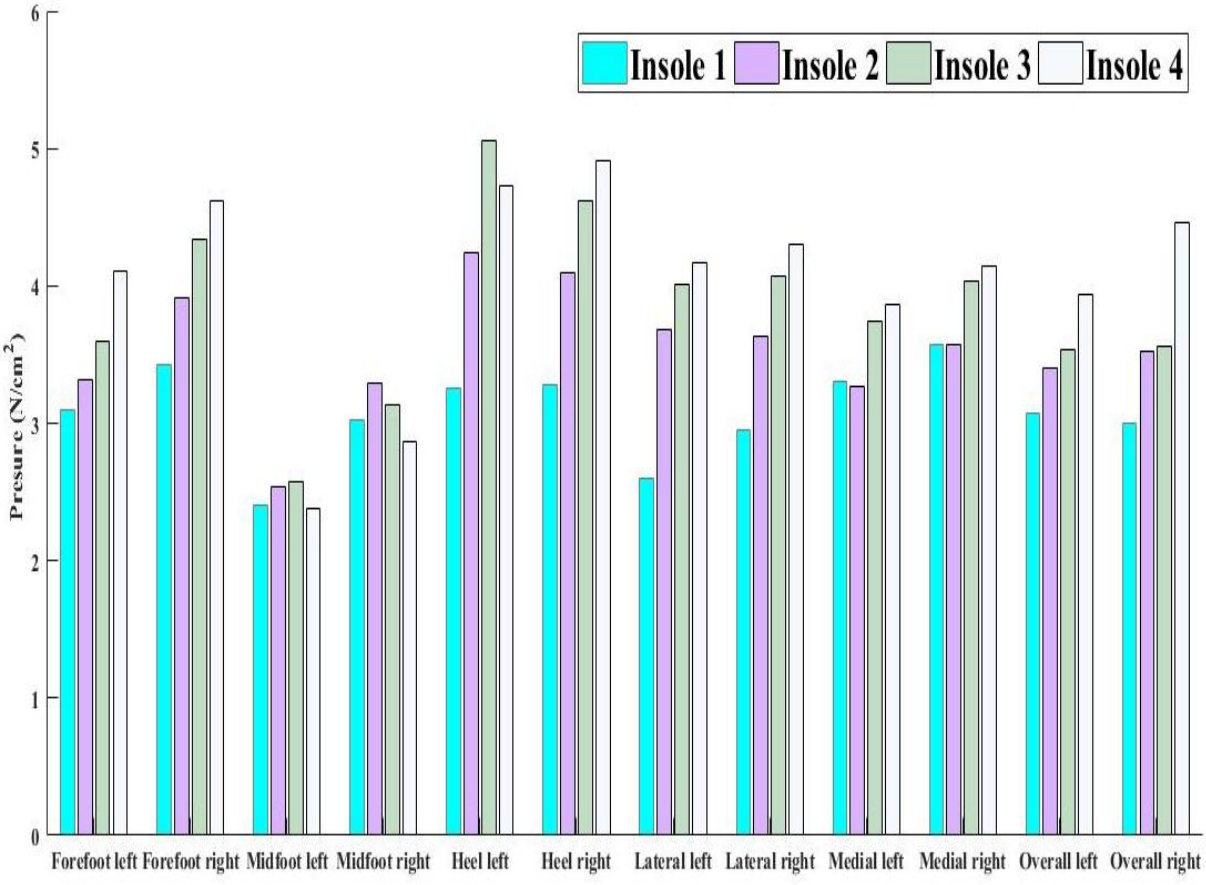


Figure 17: Mean of parameters

We can see from figure 17 Insole1 having pressure lesser in case of Forefoot left, Forefoot right, Heel left, Heel right, Lateral left, Lateral right, Overall left and Overall right to Insole 1,2 and 3. However, when we seen Insole 4 lesser pressure in case of Mid-foot left and Mid-foot as compared to another insole. In case of medial left and medial right Insole1 and Insole2 pressure likely nearer

to the each other. When we consider the general performance of the Insoles, the Insole1 gives lesser pressure than when contrasted with another.

3.4 CHAPTER SUMMARY

Finally, for this chapter, it can be summarised that, to study the effect of different walk and stand parameters of gait analysis. Analyses were performed using Kislter force plate and Voxel care foot scan insole on various subjects. Using this data, further analysis was done.

CHAPTER 4 MODELING METHOD AND METHODOLGY OF MODEL

This chapter describes the prediction method for Forces, Power and Pressure excreted on feet during gait analysis. Prediction was done using a machine learning method. The significant parameters used as input for the prediction model. It can get input information and used statistical analysis to predict the output value within an acceptable range.

4.1 MACHINE LEARNING

It is the use of man-made reasoning using for predicting the exact outcomes. It can get input information and used statistical analysis to predict the output value within an acceptable range. Machine Learning comprises of two types supervised and unsupervised. Learning has different models: decision tree, random forest, ada boost, support vector machine, linear model and artificial neural network. In this work the Artificial Neural Network (ANN) utilized.

4.1.1 Random Forest

Random Forest is a machine learning method mainly used in regression and classification problems. After training, it generates multiple numbers of decision trees. Random forest work when different subset of training data are selected and with replacement to train each tree. The remaining data used for error calculations and importance of variables. Numbers of votes from the entire tree select the class alignment.

4.1.2 Decision Tree

Decision tree is a machine learning method using a tree like graph of decision. It used a set of binary rules and calculates the target values. It can be used as classification as well as regression problems. To determine the best node different types of algorithm was used.

4.1.3 Ada Boost

Ada boost is the machine learning method plays a good rule in linear classification problems. This type of method basically used in combination with many classification algorithms for improve the performance of the model.

4.1.4 Support Vector Machine (SVM)

The support vector machine is supervised learning model. The SVM is basically like a one layer and multiple neural networks. All machine learning method working on linear regression but the support vector machine working on the Non-linear regression problems. It uses the quadratic optimization problems.

4.1.5 Linear Model

The linear model is machine learning model, it the least complex model among all models. It will be nearer to the linear regression model. It shows the connection between the dependent and independent variable. Only one independent variable, it called as a simple regression model. At least two independent variables, it called multiple linear regression models.

4.1.6 Artificial Neural Networks

Artificial neural networks used in supervised, unsupervised and reinforced learning. This model looks like a neurons working in the mind. Neurons passed signal to another signal till the output is given by the body. The fundamental condition of the neural systems is given beneath:

$$\text{Input} = W_1I1+W_2I2 +.....W_nI_n+ b \quad (1.1)$$

W= Weights

I= Inputs

b= bias

$$\text{Output} = f(WI+b) \quad (1.2)$$

4.2 TOOLS AND METHODOLOGY

Tools used for implementation of the problem solution are as follows:

- RATTLE: Version 3.4.1-win
- Microsoft Excel : 2007

It is watched that a force plate is expected to give us the GRF step by step [25] yet a few specialists express that the current strategies don't precisely reflect individual physical activity levels, and further techniques does not precisely respond individual physical action levels, and further strategies advancement of physical movement apparatuses should be high need of research [26]. It has been discovered that the utilization of ANN model in gait application is more desired than biomechanics strategies or different methods [27]. Analysts watched that ANN is a good model for discovering complex connections between examples of various signals [27, 28]. For a human locomotion, the ANN can be utilized to predict gait parameters [29] and gait patterns [27, 30]. It produces models of gait patterns [31], predicts horizontal GRF [32], vertically GRF, recognizes examples of stand [33], and predicts incline speed and distance of walking [34]. GRF has been utilized to decide the walking pattern [26, 35, 36] and balance of gait and posture [35, 37]. A study demonstrated relationship between the variety of walk forces parameters, speed, and

power, which vary with foot ground contact time [38, 39, 40, 41, 42, 43]. When human being increase the walking speed results in higher vertically force, horizontal force and decrease in the foot ground contact time [44,7].

4.3 NEURAL NETWORK ARCHITECTURE PREDICTION MODEL 1 FOR FORCE PLATE DATA

To determine whether the shoes are better in case of walking and standing; the data was used to ANN to predict the measure forces and power. It was found that for predicting the Forces and Power, the more significant parameters is human weight, human height and shoes weight. The ANN model consists of three inputs, ten hidden layer and one output. Figure 18 shows the neural network architecture. The inputs parameters were Human weight, human weight and shoes weigh. The artificial neural networking is a mathematical model. It is computational system inspired by the structure, processing method and learning ability of a biological brain. A cross-validation was used because it simulates the use of a generic ANN. According to biomechanics perspective, the neural system is utilized to check the non-direct connections between datasets [7]. In this study, the ANN is adopted to develop the model to predict forces and power in stance phase and the model to predict forces and power in the swing phase. The model is run on their default parameters shows in table 15. The equation can be written as:

$$\text{Input (I)} = W_1\text{human weight} + W_2\text{human height} + W_3\text{shoes weight} + b \quad (1.3)$$

$$\text{Output (Forces and Power)} = f(WI+b) \quad (1.4)$$

Where W= Weights

b= bias

Table 15: Machine learning method

Method	Package	Tuning parameters and values
neural networks	Neural network	hlayers=10, MAXNWts=10000, maxit= 100

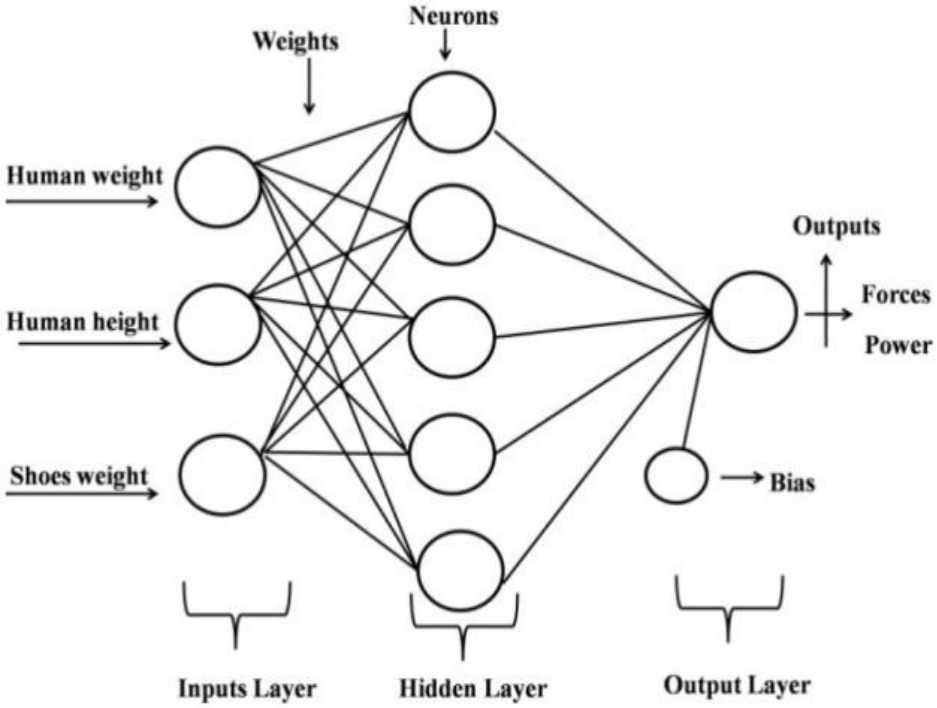


Figure 18: ANN architecture selected as prediction model for Forces and Power

4.4 NEURAL NETWORK ARCHITECTURE PREDICTION MODEL 2 FOR FOOT FSCAN DATA

To determine whether insole is better is case of walking, the data was used to ANN to predict the measure pressure. The methodology of model given below:

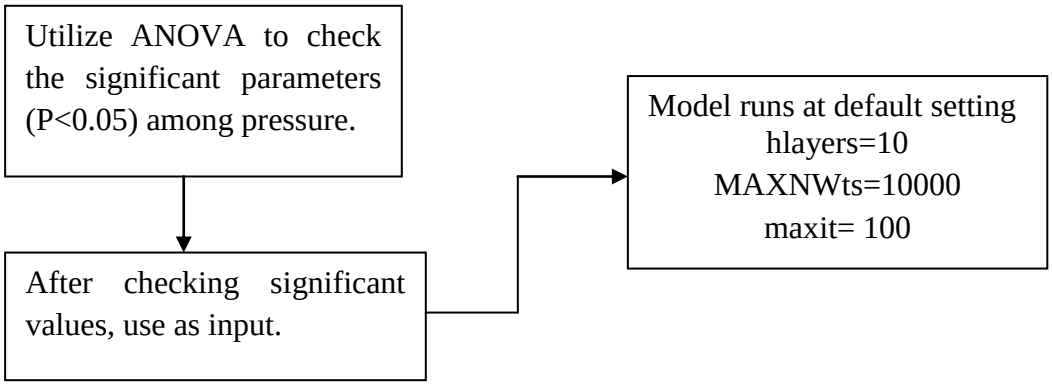


Table 16 shows the significant parameters:

Table 16: Significant parameters

P>0.05	Forefoot Left	Forefoot Right	Mid foot left	Mid foot Right	Heel left	Heel right	Lateral left	Lateral right	Medial left	Medial right	Overall left	Overall right
Speed [km/h]	**0.002509**	0.395411	**0.000733**	**0.002689**	0.626199	**0.008094**	**0.004076**	0.069671	**0.000112**	**0.033668**	0.071890	0.874511
Rel. Speed [1/s]	0.102077	0.328878	**0.021348**	0.227056	0.995316	0.970737	0.750670	0.658747	**0.011534**	**0.006157**	0.126340	0.837484
Double Step Length [m]	**0.000028**	**0.001832**	0.363691	**0.087304**	0.059866	**0.002372**	**0.000057**	**0.000117**	**0.000134**	**0.005934**	**0.000025**	0.822644
Double Step Length [m] Nominal	**0.001448**	0.642019	0.356449	0.561433	0.051871	0.144832	0.088202	0.292753	**0.044836**	0.172604	0.086620	0.925524
Rel. Double Step Length	**0.002273**	**0.001277**	0.666103	0.844899	0.181869	0.074955	0.064551	**0.003404**	**0.008691**	**0.009554**	0.830420	0.613429
Rel. Double Step Length Nominal	0.382277	0.916430	0.090833	**0.006263**	0.579501	0.972554	0.121551	0.643691	**0.049576**	0.066853	**0.000073**	0.535410
Double Step Duration [s]	0.848357	0.224983	0.570206	0.372097	**0.011756**	0.442184	**0.026881**	0.853012	0.239413	0.970724	0.762860	0.421628
Double Step Duration [s] Nominal	0.648581	0.801701	0.743498	0.671491	0.734750	**0.032068**	0.770740	0.210004	0.299268	0.428297	0.766200	0.460087
Two Leg Stance [%DSD]	0.069323	**0.000173**	**0.008577**	0.358284	0.916349	**0.000167**	**0.017857**	**0.034613**	0.260485	**0.000451**	**0.038040**	0.309055
Two Leg Stance [%DSD] Nominal	0.280308	0.738040	**0.024530**	0.376861	0.654666	0.508561	0.462540	0.432877	0.557846	0.496823	0.685590	0.933193
Stancephase Duration [%DSD] Left	**0.002892**	0.688290	0.950871	0.071051	0.074294	**0.003302**	0.257563	0.624568	**0.001644**	0.912464	0.588610	0.121084
Stancephase Duration [%DSD] Left Nominal	0.785891	**0.000760**	0.734002	0.224746	0.269051	0.163408	0.364603	**0.038813**	0.631667	**0.039119**	**0.00001**	**0.000275**
Stancephase Duration [%DSD] Right	0.503371	**0.000040**	0.147229	0.825210	0.096283	0.957559	0.097762	**0.001520**	0.343225	0.104465	0.220390	0.705531
Stancephase Duration [%DSD] Right Nominal	0.641874	0.431803	0.425576	0.356819	0.075759	0.112961	0.133068	0.225505	0.164337	0.551961	0.092800	0.649069
Effective Foot Length [%] Left	**0.044063**	0.177804	**0.000001**	**0.006309**	0.000732	0.103907	0.146227	0.185857	0.966852	0.804741	0.623850	0.430905
Effective Foot Length [%] Right	0.470871	0.110932	0.613655	0.210614	0.286502	**0.00263**	0.571396	**0.042787**	0.805982	**0.035586**	0.103340	0.117416
Width of Gait Line [%] Left	0.607957	0.212654	**0.002584**	0.870149	0.053120	**0.004830**	**0.001181**	**0.000616**	0.330691	0.406900	0.113980	0.533465
Width of Gait Line [%] Right	0.017417	0.116694	**0.020908**	0.865981	0.482194	0.364192	0.134153	0.401710	0.203099	0.082566	0.607650	0.675847
Double Step Duration	0.697993	0.661186	0.338144	0.327130	0.940912	0.597217	0.069435	0.531876	0.322035	0.532412	0.966100	0.213789
Stancephase Duration Left	0.643195	0.904805	0.691283	0.611406	0.247969	0.245969	0.792416	0.514014	0.932411	0.993766	0.728300	0.553972
Stancephase Duration Right	0.754369	0.653757	0.386233	0.496836	0.432654	0.230650	0.095748	0.169981	0.505685	0.140301	0.770520	0.257062

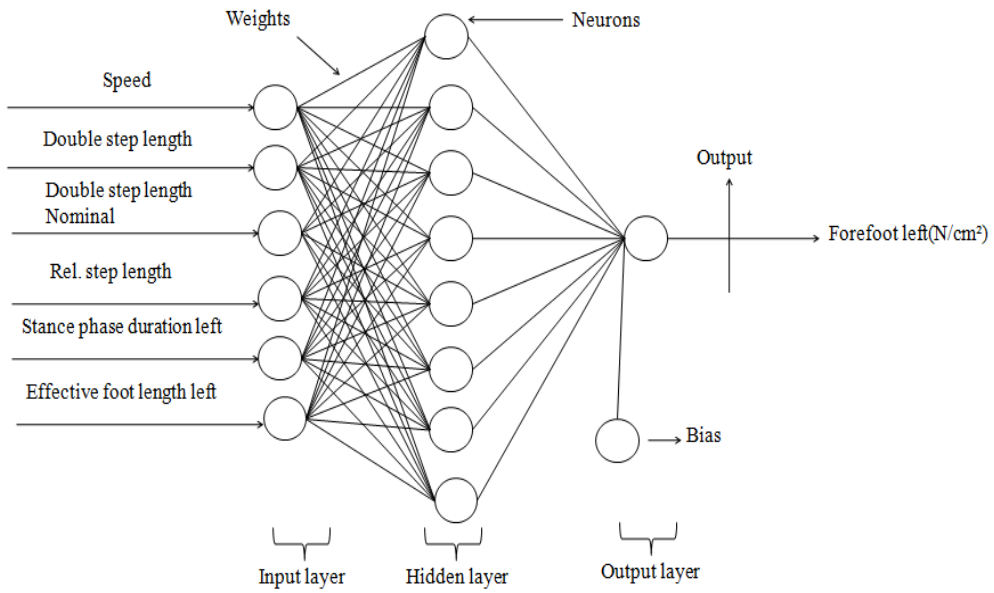


Figure 19: ANN architecture selected as prediction model for Forefoot left Pressure

Input(I) = W_1speed+W_2double step length+W_3double step length nominal+W_4rel.step length+W_5stance phase duration left+W_6effective foot length left+ b (1.5)

Output (Forefoot left (N/cm²) = f(WI+b) (1.6)

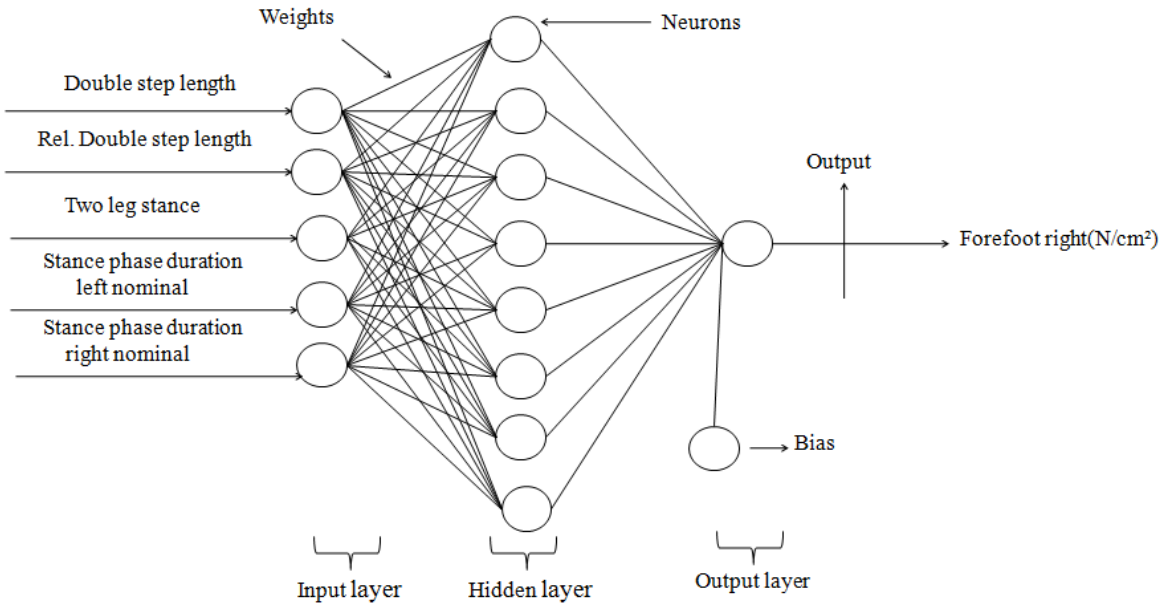


Figure 20: ANN architecture selected as prediction model for forefoot right Pressure

Input(I) = W_1double step length +W_2rel.double step length+W_3two legstance+W_4stance phase duration left nominal +W_5stance phase duration right nominal +b (1.7)

Output (Forefoot right (N/cm²) = f(WI+b) (1.8)

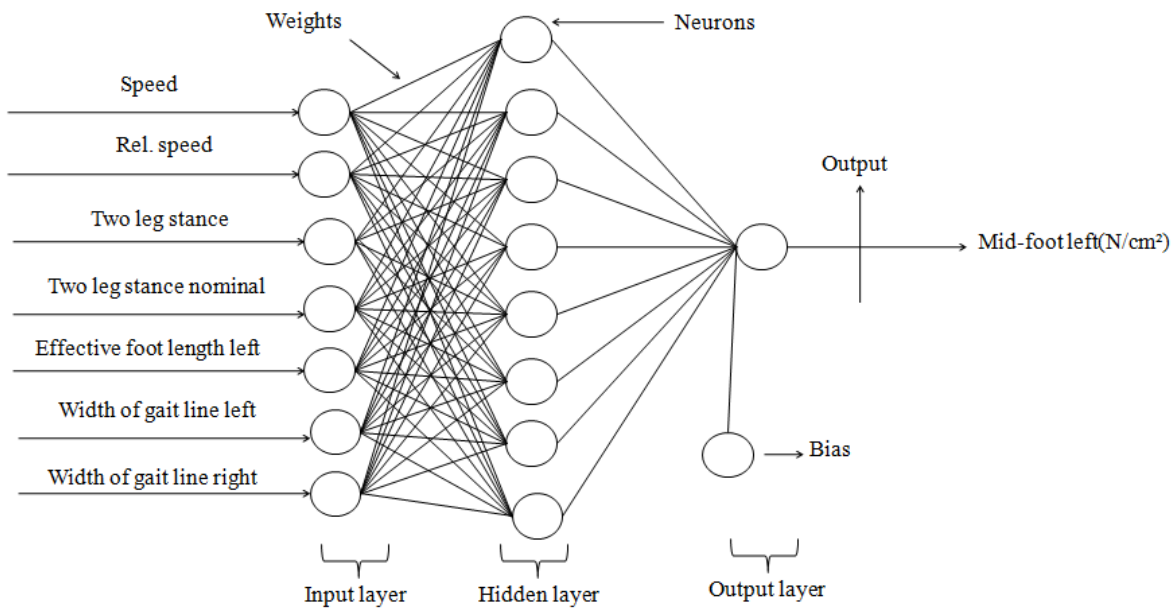


Figure 21: ANN architecture selected as prediction model for mid – foot left

Input(I) = W_1speed+W_2rel.speed+W_3two leg stance+W_4two leg stance nominal+W_5effective foot length left+W_6width of gait line left+W_7width of gait line right + b (1.9)

Output (Mid-foot left (N/cm²) = f(WI+b) (1.10)

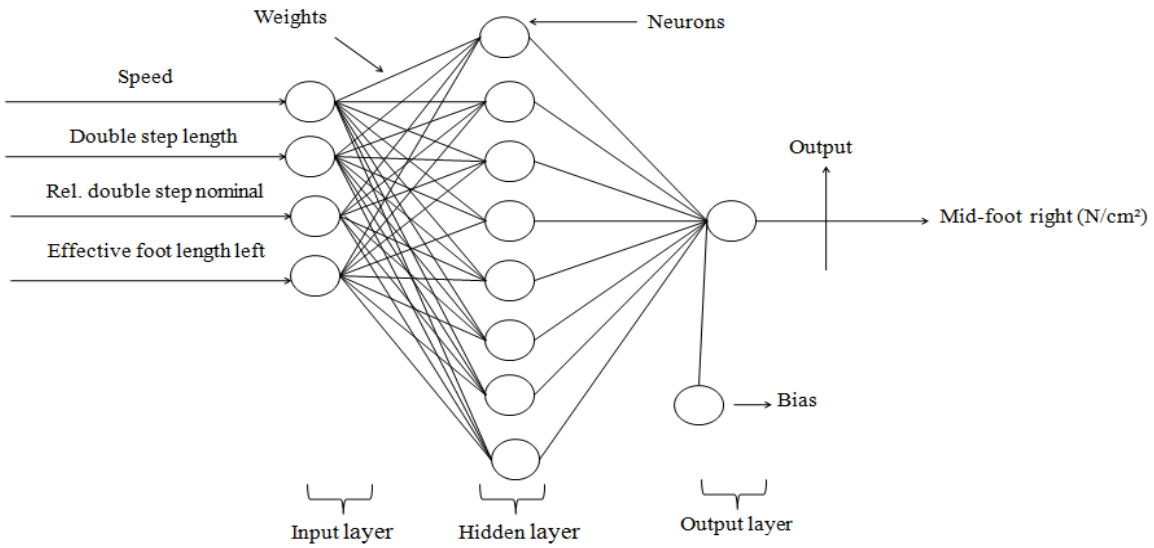


Figure 22: ANN architecture selected as prediction model for mid foot right

Input (I) = W_1speed+W_2double step length+W_3rel.double step nominal +W_4effective foot length left + b (1.11)

Output (Mid-foot right (N/cm²) = f(WI+b) (1.12)

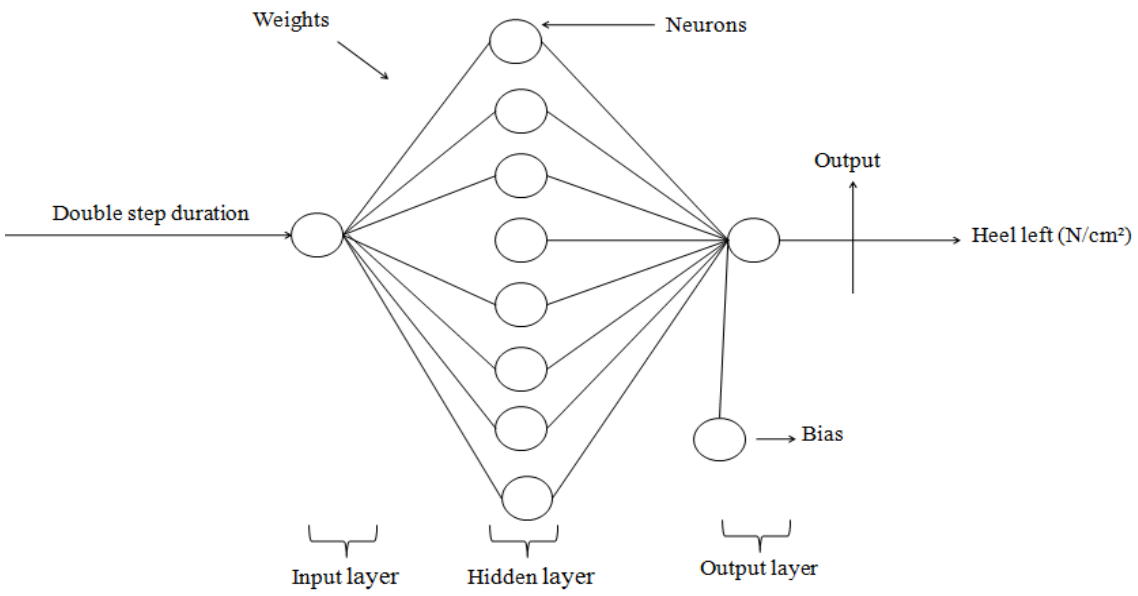


Figure 23: ANN architecture selected as prediction model for heel left Pressure

Input (I) = W_1double step duration + b (1.13)

Output (heel left (N/cm²) = f(WI+b) (1.14)

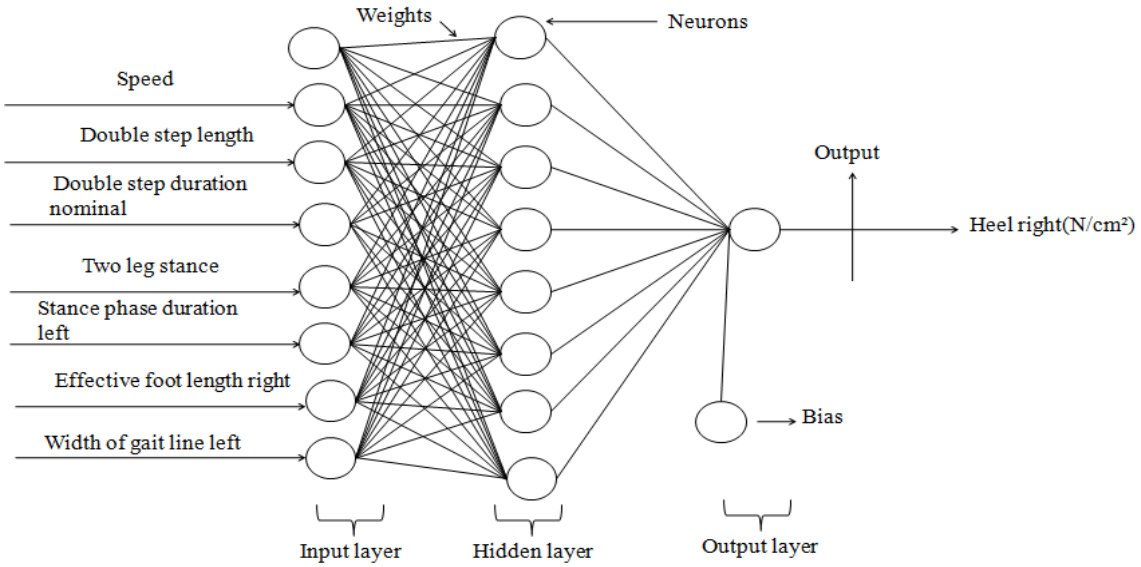


Figure 24: ANN architecture selected as prediction model for heel right Pressure

Input (I) = W_1speed + W_2double step length+W_3double step duration nominal+W_3two leg stance+W_4stance phase duration left+W_5effective foot length right+W_6width of gait line left+ b (1.15)

Output (heel right (N/cm²) = f(WI+b) (1.16)

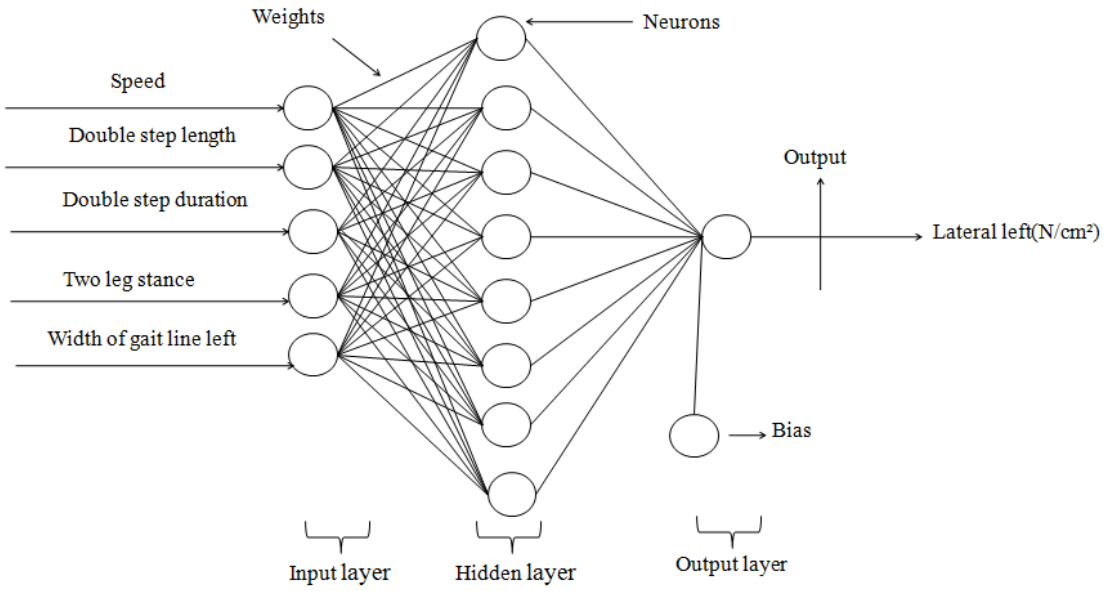


Figure 25: ANN architecture selected as prediction model for lateral left Pressure

Input (I) = W_1speed + W_2double step length+W_3double step duration+W_4two leg stance+W_5width of gait line left+ b (1.17)

Output (lateral left (N/cm²) = f(WI+b) (1.18)

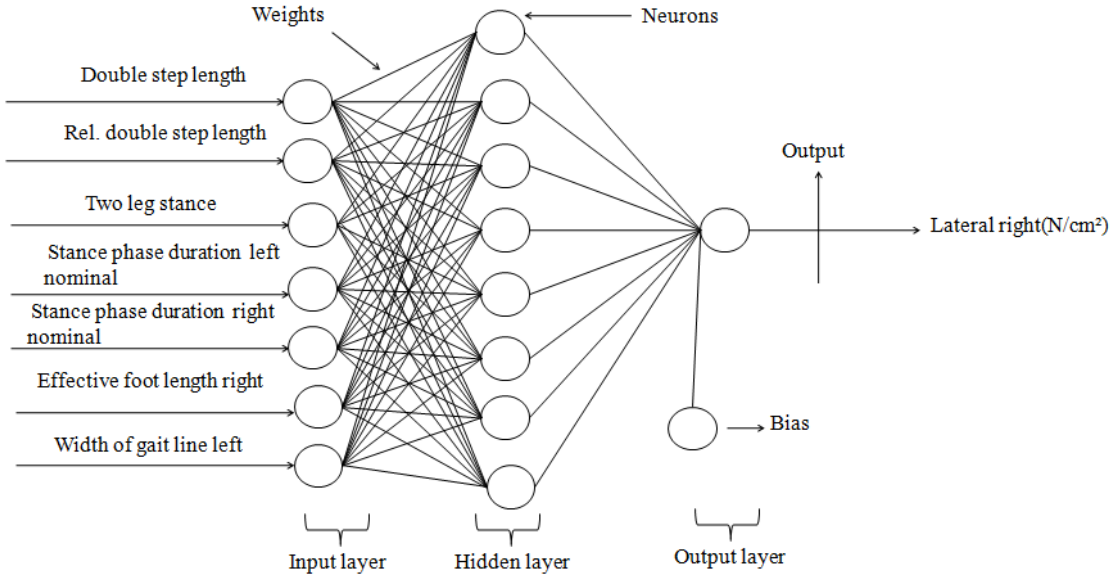


Figure 26: ANN architecture selected as prediction model for lateral right Pressure

Input (I) = W_1double step length + W2rel.double step length+W_3two leg stance+W_4stance phase duration left nominal +W_5stance phase duration right nominal+W_6effective foot length+W_7width of gait line+ b (1.19)

Output (lateral right (N/cm²) = f(WI+b) (1.20)

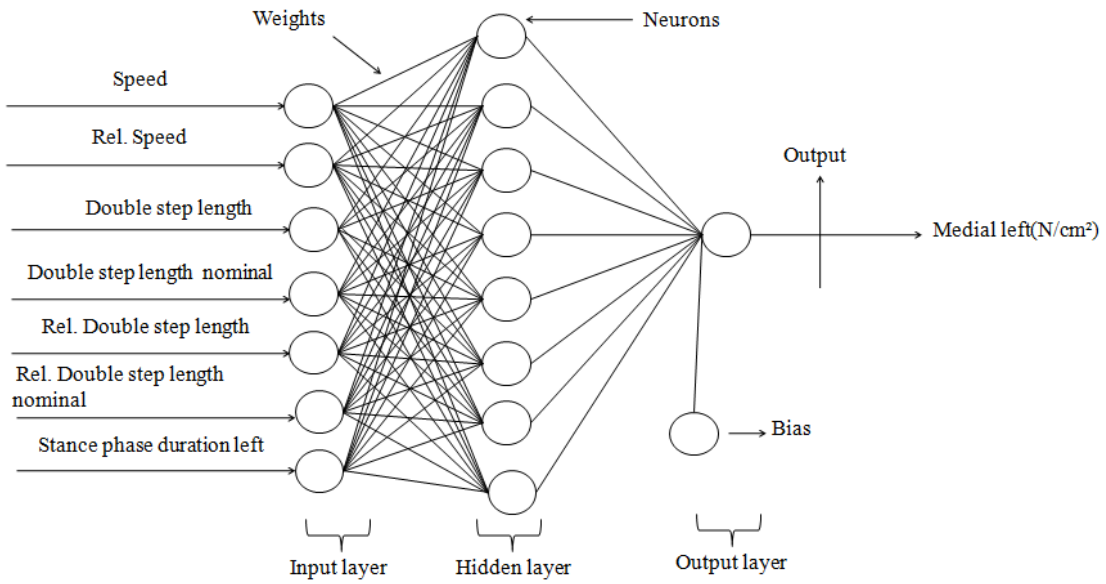


Figure 27: ANN architecture selected as prediction model for medial left Pressure

Input (I) = W_1speed + W2rel.speed+W_3double step length+W_4double step length nominal +W_5rel.double step length+W_6rel.double step length nominal+W_7stance phase duration left+ b (1.21)

Output (medial left (N/cm²) = f(WI+b) (1.22)

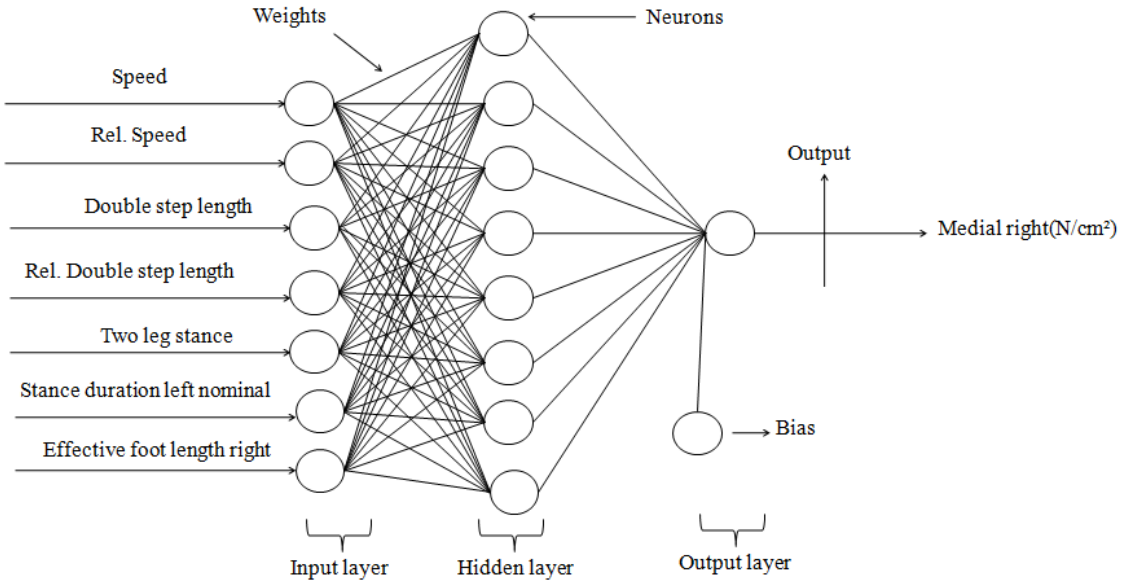


Figure 28: ANN architecture selected as prediction model for medial right Pressure

Input (I) = W_1speed + W2rel.speed+W_3double step length+W_4rel.double step length +W_5two leg stance+W_6stance duration left nominal+W_7effective foot length right+ b (1.23)

Output (medial right (N/cm²) = f(WI+b) (1.24)

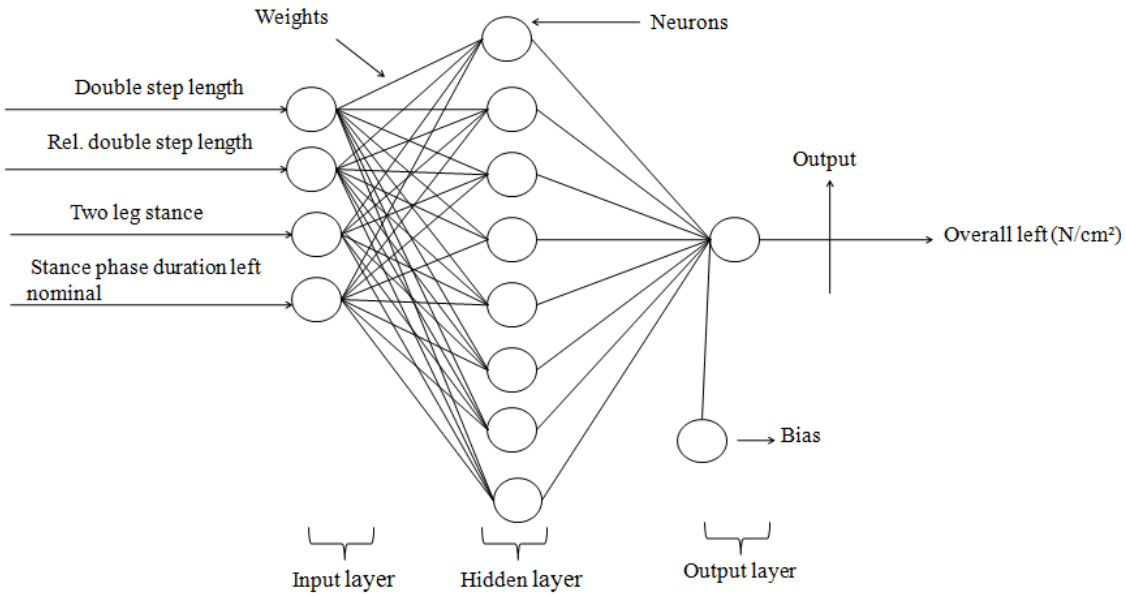


Figure 29: ANN architecture selected as prediction model overall left Pressure

Input (I) = W_1double step length + W2rel.double step length +W_3two leg stance+W_4stance phase duration left nominal+ b (1.25)

Output (overall left (N/cm²) = f(WI+b) (1.26)

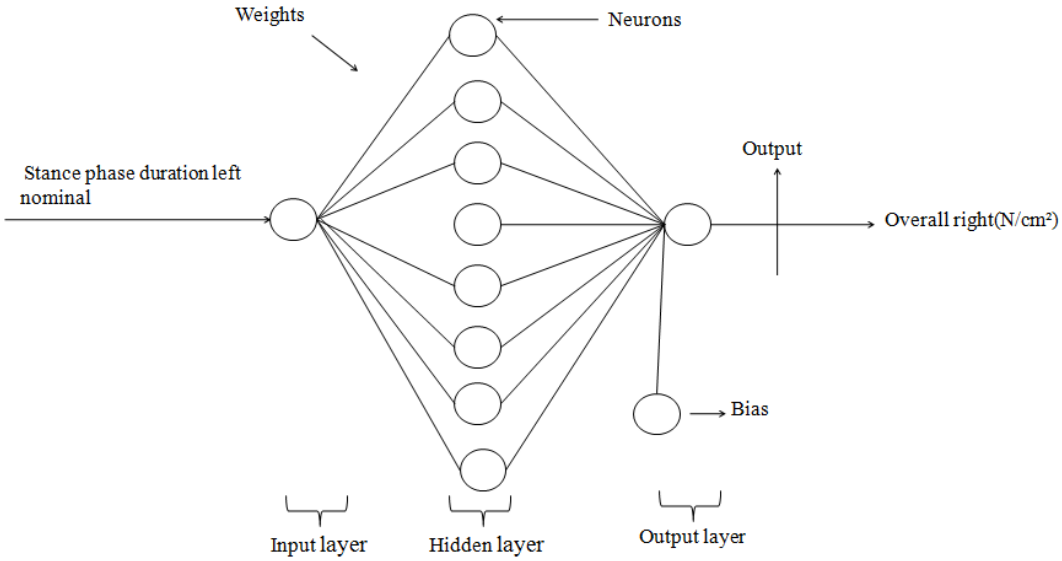


Figure 30: ANN architecture selected as prediction model overall right Pressure

Input (I) = W_1stance phase duration left nominal+ b (1.27)

Output (overall right (N/cm²) = f(WI+b) (1.28)

4.5 MODEL EVAUATION

4.5.1 Correlation Coefficient(r)

A correlation coefficient is a statistical relationship between the two variables. It is defined as follows:

$$\text{Correlation}=\frac{\sum_{i=1}^{n}(ki-\overline{k})(m-\overline{m})}{\sqrt{\sum_{i=1}^{n}(ki-\overline{k})^2 \quad \sum_{i=1}^{n}(m-\overline{m})^2}} \tag{1.29}$$

where, k is the actual value, m is the predicted value, $\overline{k}$ is the mean of the all actual values, $\overline{m}$ is the mean of the all predicted values and n is the number of instances. Correlation lies in $[0 \quad 1]$ and considered to be good if its value tends towards 1.

4.5.2 Coefficient of Determination (R^2)

The statistical measure of data which can be fitted regression line. The Coefficient of Determination is computed by taking the square the r (i.e. Correlation). It is defined as follows:

$$R= r \text{ x } r \tag{1.30}$$

4.5.3 Mean Absolute Error (MAE)

MAE is a popular formula to measure the error rate of a regression model. However, it can only be compared between models whose errors are measured in the same units. It is calculated as follows:

$$\text{MAE} =\sum_{i=1}^{n}\frac{|\text{qi}-\text{oi}|}{\text{n}} \tag{1.31}$$

Where oi is observed value, qi is predicted value and n is total number of instances.

4.5.4 K-fold

10-k-fold cross validation is used to measure the robustness of the predictive method. The original dataset is randomly partitioned into k equal size subsamples. Split the data into k-equal subsets, perform k rounds of learning on each round, 1/k of data is held out as a test set and the remaining as a training data. Compute the average test score of the k-rounds. The advantage of this method over repeated random sub-sampling is that all observations are used for both training and validation, and each observation is used for validation exactly once. A cross- validation was used in this study because it simulates the use of generic ANN was done at balance and walking parameters to check the robustness of the model.

4.6 CHAPTER SUMMARY

To summarise this chapter, it was found that after analysis of data Human weight, Human height, and Shoe weight were the most significant parameters for input to ANN in case of developing a Kistler force plate model.

Similarly, analysis of data for Voxel foot scan insole, ANOVA was performed for choosing the most significant parameters for input to ANN. At last, optimized parameters were calculated using RATTLE to predict the minimum response within the domain.

The experiments were performed using Force plate and Foot scan insole for both types of systems. The analysis was performed for left and right foot using different shoes and insoles materials. ANN was used for prediction of results. The details of results are discussed below:

5.1 FOR FORCE PLATE

Comparative study of two shoes namely Heavyweight shoes (HWS) and lightweight shoes (LWS). The weight of the human, the height of the human and weight of the shoe were the input process parameters for this study. The different results predicted using ANN having 70% data for training and 30% for validation.

Quiet standing data were given below (For one time training and testing data):

Table 17: Standard deviation in x- direction

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
0.064507	0.064491	1.63E-05	0.061837	0.061821	1.64E-05
0.061366	0.061379	1.25E-05	0.058826	0.058839	1.24E-05
0.063058	0.063051	6.57E-06	0.060448	0.060441	6.66E-06
0.063782	0.063794	1.17E-05	0.061142	0.061154	1.16E-05
0.070306	0.070297	9.01E-06	0.067396	0.067386	9.10E-06
0.063541	0.063562	2.10E-05	0.060911	0.060932	2.09E-05
0.074171	0.074152	1.96E-05	0.071101	0.071082	1.97E-05
0.061125	0.061147	2.18E-05	0.058595	0.051617	0.006978
0.06499	0.069002	0.004011	0.0623	0.062312	1.12E-05
0.068614	0.068624	1.01E-05	0.065774	0.065784	9.97E-06
0.07852	0.078517	2.51E-06	0.07527	0.079267	0.003997
0.068856	0.068857	7.33E-07	0.066006	0.064007	0.001999
0.061608	0.061611	3.17E-06	0.059058	0.059061	3.08E-06

Table 18: Standard deviation in y- direction

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
0.062798	0.062782	1.63E-05	0.056604	0.056588	1.65E-05
0.059741	0.059753	1.25E-05	0.053848	0.05386	1.25E-05
0.061387	0.061381	6.58E-06	0.055332	0.055325	6.69E-06
0.062093	0.062105	1.17E-05	0.055968	0.05598	1.17E-05
0.068443	0.068434	9.02E-06	0.061692	0.061683	9.15E-06
0.061858	0.061879	2.11E-05	0.055756	0.055777	2.10E-05
0.072206	0.074187	0.00198	0.065084	0.065064	1.98E-05
0.059506	0.059527	2.19E-05	0.053636	0.053658	2.18E-05
0.063269	0.06328	1.13E-05	0.057028	0.057039	1.12E-05
0.066797	0.069807	0.00301	0.060208	0.060218	1.00E-05
0.07644	0.076437	2.52E-06	0.0689	0.068897	2.63E-06
0.067032	0.067033	7.34E-07	0.06042	0.065421	0.0050006
0.059976	0.059979	3.17E-06	0.05406	0.054063	3.09E-06

Table 19: Planar deviation

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
0.090032	0.090017	1.59E-05	0.083838	0.083822	1.60E-05
0.085649	0.085661	1.22E-05	0.079756	0.079768	1.21E-05
0.088009	0.088003	6.40E-06	0.081954	0.081947	6.52E-06
0.089021	0.089032	1.14E-05	0.082896	0.082907	1.13E-05
0.098125	0.098116	8.77E-06	0.091374	0.091365	8.90E-06
0.088684	0.088704	2.05E-05	0.082582	0.082602	2.05E-05
0.10352	0.103501	1.91E-05	0.096398	0.096379	1.92E-05
0.085312	0.085333	2.13E-05	0.079442	0.079463	2.13E-05
0.090707	0.090718	1.10E-05	0.084466	0.084477	1.09E-05
0.095765	0.099775	0.00401	0.089176	0.089186	9.75E-06
0.10959	0.109588	2.44E-06	0.10205	0.102047	2.56E-06
0.096102	0.095103	0.000999	0.08949	0.089491	6.22E-07
0.085986	0.089989	0.004003	0.08007	0.089073	0.009003

Table 20: Area

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
12.23928	12.23946	0.000181	10.39164	10.39179	0.000151
11.64336	11.64322	0.000137	9.88568	9.885566	0.000114
11.96424	11.96431	7.38E-05	10.15812	10.15818	6.17E-05
12.10176	12.10163	0.000128	10.27488	10.27477	0.000106
13.33944	13.33954	0.000101	11.32572	11.3258	8.42E-05
12.05592	12.05569	0.000231	10.23596	10.63577	0.399808
14.07288	14.0731	0.000217	11.94844	11.94862	0.000181
11.59752	11.59728	0.00024	9.84676	9.84656	0.0002
12.33096	12.33084	0.000123	10.46948	10.76938	0.299897
13.01856	13.01845	0.00011	11.05328	11.05319	9.14E-05
14.898	14.89803	2.92E-05	12.649	12.64902	2.46E-05
13.0644	13.06439	6.76E-06	11.0922	11.29219	0.199995
11.6892	12.68917	0.999966	9.9246	9.924572	2.80E-05

Walking data were given below (For one time training and testing data):

Table 21: Medial lateral direction (Fx) heel strike left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
65.37228	67.57302	2.20074	52.60968	52.6097	1.63E-05
62.18936	62.19015	0.000787	50.04816	50.04818	1.62E-05
63.90324	63.904	0.000762	51.42744	51.42746	1.63E-05
64.63776	64.63851	0.000751	52.01856	52.01858	1.63E-05
71.24844	76.24909	5.000654	57.33864	57.33866	1.66E-05
64.39292	64.51367	0.120754	51.82152	51.82154	1.63E-05
75.16588	75.76648	0.600597	60.49128	60.4913	1.68E-05
61.94452	64.94531	3.00079	49.85112	49.85114	1.62E-05
65.86196	65.86269	0.000733	53.00376	52.00378	0.999984
69.53456	69.53524	0.000679	55.95936	57.95938	2.000017
79.573	79.77353	0.200532	64.038	64.03802	1.70E-05
69.7794	69.88008	0.100676	56.1564	56.15642	1.66E-05
62.4342	62.93498	0.500783	50.2452	50.24522	1.62E-05

Table 22: Medial lateral direction (Fx) thrust left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
29.72244	29.72344	9.30E-07	25.16208	25.11208	8.90E-07
28.27528	28.21528	9.10E-07	23.93696	23.13696	8.61E-07
29.05452	29.15452	9.20E-07	24.59664	24.58664	8.80E-07
29.38848	29.28848	9.30E-07	24.87936	24.82936	8.80E-07
32.39412	32.38412	9.89E-07	27.42384	27.41384	9.40E-07
29.27716	29.21716	9.26E-07	24.78512	24.78512	8.80E-07
34.17524	34.27524	1.02E-06	28.93168	28.91168	9.79E-07
28.16396	28.12396	9.00E-07	23.84272	23.84172	8.59E-07
29.94508	29.91508	9.39E-07	25.35056	25.35056	8.90E-07
31.61488	31.51488	9.70E-07	26.76416	28.75416	2.000001
36.179	34.379	1.999999	30.628	31.528	1.000001
31.7262	31.7362	9.80E-07	26.8584	26.8184	9.30E-07
28.3866	28.3766	9.10E-07	24.0312	24.0112	8.60E-07

Table 23: Medial lateral direction (Fx) toe off left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
86.57208	89.57207	2.999986	81.50976	81.50971	5.18E-05
82.35696	84.35695	1.999987	77.54112	77.54108	4.49E-05
84.62664	81.62663	3.000013	79.67808	79.67803	4.86E-05
85.59936	89.59935	3.999986	80.59392	80.59387	5.02E-05
94.35384	94.35382	1.65E-05	88.83648	88.83642	6.44E-05
85.27512	85.27511	1.35E-05	80.28864	83.28859	2.99995
99.54168	99.54166	1.83E-05	93.72096	96.72089	2.999927
82.03272	86.03271	3.999988	77.23584	77.2358	4.44E-05
87.22056	87.22055	1.42E-05	82.12032	82.12027	5.28E-05
92.08416	94.08414	1.999984	86.69952	86.69946	6.07E-05
105.378	105.378	2.02E-05	99.216	99.21592	8.22E-05
92.4084	92.40838	1.59E-05	87.0048	89.00474	1.999939
82.6812	82.68119	1.26E-05	77.8464	77.84635	4.55E-05

Table 24: Medial lateral direction (Fx) heel strike right foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
-56.46516	-56.4652	2.00E-08	-71.29968	-71.2997	2.00E-08
-53.71592	-53.7159	2.00E-08	-67.82816	-67.8282	2.00E-08
-55.19628	-55.1963	2.00E-08	-69.69744	-69.6974	2.00E-08
-55.83072	-55.8307	2.00E-08	-70.49856	-70.4986	2.00E-08
-61.54068	-61.5407	3.00E-08	-77.70864	-73.7086	4
-55.61924	-55.6192	2.00E-08	-70.23152	-70.2315	2.00E-08
-64.92436	-64.9244	3.00E-08	-81.98128	-81.9813	3.00E-08
-53.50444	-53.5044	2.00E-08	-67.56112	-67.5611	2.00E-08
-56.88812	-56.8881	2.00E-08	-71.83376	-71.8338	2.00E-08
-60.06032	-60.0603	3.00E-08	-75.83936	-75.8394	3.00E-08
-68.731	-68.731	3.00E-08	-86.788	-87.788	1
-60.2718	-65.2718	5	-76.1064	-78.1064	2
-53.9274	-53.9274	2.00E-08	-68.0952	-68.0952	2.00E-08

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Table 25: Medial lateral direction (Fx) thrust right foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
-11.0004	-11.0004	1.03E-07	-18.8502	-18.8502	1.10E-07
-10.4648	-10.4648	1.00E-08	-17.9324	-17.9324	1.01E-07
-10.7532	-10.7532	1.01E-07	-18.4266	-18.4266	1.00E-07
-10.8768	-10.8768	1.02E-07	-18.6384	-18.6384	1.00E-07
-11.9892	-11.9892	1.11E-07	-20.5446	-20.5446	1.00E-07
-10.8356	-10.8356	1.02E-07	-18.5678	-18.5678	1.00E-07
-12.6484	-12.6484	1.16E-07	-21.6742	-21.6742	1.20E-07
-10.4236	-10.4236	1.00E-08	-17.8618	-17.8618	1.10E-07
-11.0828	-11.0828	1.04E-07	-18.9914	-18.9914	1.10E-07
-11.7008	-12.7008	1	-20.0504	-20.0504	1.11E-07
-13.39	-13.39	1.20E-07	-22.945	-26.945	4
-11.742	-11.742	1.09E-07	-20.121	-20.121	1.11E-07
-10.506	-10.506	1.00E-08	-18.003	-18.003	1.01E-07

Table 26: Medial lateral direction (Fx) toe off right foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
-43.728192	-43.7288	6.00E-08	-49.81152	-49.8115	4.00E-08
-41.599104	-41.5992	4.00E-08	-47.38624	-47.3862	4.00E-08
-42.745536	-42.7456	4.00E-08	-48.69216	-48.6922	4.00E-08
-43.236864	-43.2369	3.00E-08	-49.25184	-49.2518	4.00E-08
-47.658816	-47.6588	4.00E-08	-54.28896	-54.289	4.00E-08
-43.073088	-43.0731	3.00E-08	-49.06528	-49.0653	4.00E-08
-50.279232	-50.2792	4.00E-08	-57.27392	-57.2739	5.00E-08
-41.435328	-41.4353	3.28E-08	-47.19968	-47.1997	4.00E-08
-44.055744	-54.0557	10	-50.18464	-50.1846	4.00E-08
-46.512384	-42.5124	2	-52.98304	-52.983	4.00E-08
-53.2272	-53.2272	4.10E-08	-60.632	-61.632	1
-46.67616	-46.6762	4.00E-08	-53.1696	-54.1696	1
-41.76288	-41.7629	3.31E-08	-47.5728	-48.5728	1

Table 27: Anterior-posterior direction (Fy) baking force left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
226.3519	226.1519	2.00E-01	222.1547	221.1547	1.00E+00
215.331	215.131	2.00E-01	211.3382	212.3382	1.00E+00
221.2654	221.3654	1.00E-01	217.1624	219.1624	2.00E+00
223.8086	223.2086	6.00E-01	219.6586	219.2586	4.00E-01
246.6982	246.5982	1.00E-01	242.1236	242.2236	1.00E-01
222.9609	222.6609	3.00E-01	218.8265	218.2265	6.00E-01
260.2623	260.3623	1.00E-01	255.4363	275.4363	2.00E+01
214.4833	215.6833	2.10E+00	210.5061	210.1061	4.00E-01
228.0474	228.3474	3.00E-01	223.8188	223.9188	1.00E-01
240.7638	240.7838	2.00E-02	236.2994	236.1994	1.00E-01
275.522	275.122	4.00E-01	270.413	270.113	3.00E-01
241.6116	241.2116	4.00E-01	237.1314	237.2314	1.00E-01
216.1788	216.5788	5.00E-01	212.1702	212.2702	1.00E-01

Table 28: Anterior-posterior direction (Fy) Propulsion force left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
-150.567	-150.467	1.00E-01	-154.283	-154.383	1.00E-01
-143.236	-143.136	1.00E-01	-146.771	-146.761	1.00E-02
-147.183	-147.383	2.00E-01	-150.816	-150.826	1.00E-02
-148.875	-148.675	2.00E-01	-152.55	-152.75	2.00E-01
-164.101	-164.301	2.00E-01	-168.151	-168.551	4.00E-01
-148.311	-148.411	1.00E-01	-151.972	-151.272	7.00E-01
-173.123	-173.023	1.00E-01	-177.397	-177.297	1.00E-01
-142.672	-149.572	6.90E+00	-146.194	-147.294	1.10E+00
-151.694	-151.794	1.00E-01	-155.439	-155.339	1.00E-01
-160.153	-160.053	1.00E-01	-164.107	-164.307	2.00E-01
-183.274	-183.174	1.00E-01	-187.798	-187.898	1.00E-01
-160.717	-160.017	7.00E-01	-164.684	-164.584	1.00E-01
-143.8	-143.9	1.00E-01	-147.349	-147.249	1.00E-01

Table 29: Anterior-posterior direction (Fy) baking force right foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
140.6876	140.5876	1.00E-01	134.1942	134.2942	1.00E-01
133.8377	133.3377	5.00E-01	127.6604	127.5604	1.00E-01
137.5261	137.4261	1.00E-01	131.1786	131.3786	2.00E-01
139.1069	139.2069	1.00E-01	132.6864	132.4864	2.00E-01
153.3337	153.4337	1.00E-01	146.2566	146.3566	1.00E-01
138.58	138.68	1.00E-01	132.1838	132.3838	2.00E-01
161.7644	161.5644	2.00E-01	154.2982	154.8982	6.00E-01
133.3108	133.6108	3.00E-01	127.1578	126.2578	9.00E-01
141.7415	149.6415	7.90E+00	135.1994	135.2994	1.00E-01
149.6453	149.5453	1.00E-01	142.7384	142.6384	1.00E-01
171.249	173.249	2.00E+00	163.345	163.445	1.00E-01
150.1722	150.2722	1.00E-01	143.241	143.141	1.00E-01
134.3646	134.2646	1.00E-01	128.163	128.263	1.00E-01

Table 30: Anterior-posterior direction (Fy) Propulsion force right foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
-182.169	-182.269	1.00E-01	-185.725	-185.225	5.00E-01
-173.299	-173.399	1.00E-01	-176.682	-176.582	1.00E-01
-178.075	-178.475	4.00E-01	-181.552	-181.352	2.00E-01
-180.122	-180.322	2.00E-01	-183.638	-183.438	2.00E-01
-198.543	-198.443	1.00E-01	-202.42	-202.32	1.00E-01
-179.44	-179.34	1.00E-01	-182.943	-189.343	6.40E+00
-209.46	-208.26	1.20E+00	-213.549	-223.449	9.90E+00
-172.617	-172.317	3.00E-01	-175.987	-178.287	2.30E+00
-183.533	-183.233	3.00E-01	-187.116	-187.216	1.00E-01
-193.768	-193.368	4.00E-01	-197.55	-197.25	3.00E-01
-221.741	-221.541	2.00E-01	-226.07	-226.027	4.30E-02
-194.45	-194.25	2.00E-01	-198.246	-198.146	1.00E-01
-173.981	-173.181	8.00E-01	-177.378	-177.178	2.00E-01

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Table 31: Vertical direction (Fz) force heel strike left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
958.6902	958.5902	1.00E-01	942.3818	943.3818	1.00E+00
912.0124	912.1124	1.00E-01	896.4981	896.3981	1.00E-01
937.1466	937.3466	2.00E-01	921.2047	929.3047	8.10E+00
947.9184	947.8184	1.00E-01	931.7933	931.4933	3.00E-01
1044.865	1044.265	6.00E-01	1027.09	1047.09	2.00E+01
944.3278	944.1278	2.00E-01	928.2638	921.2638	7.00E+00
1102.314	1102.214	1.00E-01	1083.563	1083.363	2.00E-01
908.4218	908.3218	1.00E-01	892.9686	899.9686	7.00E+00
965.8714	966.2714	4.00E-01	949.4409	969.4409	2.00E+01
1019.73	1019.33	4.00E-01	1002.384	1022.384	2.00E+01
1166.945	1166.345	6.00E-01	1147.094	1157.094	1.00E+01
1023.321	1023.221	1.00E-01	1005.913	1035.913	3.00E+01
915.603	915.503	1.00E-01	900.0276	880.0276	2.00E+01

Table 32: Vertical direction (Fz) force thrust left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
432.807	432.707	1.00E-01	432.8604	432.7604	1.00E-01
411.734	411.634	1.00E-01	411.7848	411.5848	2.00E-01
423.081	423.181	1.00E-01	423.1332	423.1232	1.00E-02
427.944	427.744	2.00E-01	427.9968	427.968	2.88E-02
471.711	471.811	1.00E-01	471.7692	471.692	7.72E-02
426.323	426.223	1.00E-01	426.3756	426.2756	1.00E-01
497.647	497.347	3.00E-01	497.7084	467.7084	3.00E+01
410.113	420.213	1.01E+01	410.1636	410.2636	1.00E-01
436.049	436.249	2.00E-01	436.1028	416.1028	2.00E+01
460.364	469.364	9.00E+00	460.4208	460.3208	1.00E-01
526.825	529.825	3.00E+00	526.89	526.79	1.00E-01
461.985	461.285	7.00E-01	462.042	462.142	1.00E-01
413.355	413.155	2.00E-01	413.406	413.306	1.00E-01

Table 33: Vertical direction (Fz) force Toe off left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
932.8339	932.7339	1.00E-01	911.8264	911.7264	1.00E-01
887.415	887.315	1.00E-01	867.4303	867.3303	1.00E-01
911.8714	911.6714	2.00E-01	891.3359	891.4359	1.00E-01
922.3526	922.2526	1.00E-01	901.5811	901.3811	2.00E-01
1016.684	1016.884	2.00E-01	993.7883	993.3883	4.00E-01
918.8589	918.2589	6.00E-01	898.166	898.466	3.00E-01
1072.584	1072.284	3.00E-01	1048.43	1048.53	1.00E-01
883.9213	883.7213	2.00E-01	864.0152	865.1152	1.10E+00
939.8214	939.7214	1.00E-01	918.6565	918.8565	2.00E-01
992.2278	992.1278	1.00E-01	969.8827	969.7827	1.00E-01
1135.472	1135.372	1.00E-01	1109.901	1109.801	1.00E-01
995.7216	995.3216	4.00E-01	973.2978	973.3978	1.00E-01
890.9088	890.3088	6.00E-01	870.8454	870.7454	1.00E-01

Table 34: Vertical direction (Fz) force heel strike right foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
900.3774	900.2774	1.00E-01	863.6168	863.1684	4.48E-01
856.5388	856.3388	2.00E-01	821.5681	821.3681	2.00E-01
880.1442	880.3442	2.00E-01	844.2097	844.1097	1.00E-01
890.2608	890.1608	1.00E-01	853.9133	853.8133	1.00E-01
981.3102	981.5102	2.00E-01	941.2453	941.1453	1.00E-01
886.8886	886.7886	1.00E-01	850.6788	850.3788	3.00E-01
1035.265	1035.365	1.00E-01	992.9976	992.8976	1.00E-01
853.1666	863.2666	1.01E+01	818.3336	818.2336	1.00E-01
907.1218	907.3218	2.00E-01	870.0859	871.1859	1.10E+00
957.7048	957.6048	1.00E-01	918.6037	918.2037	4.00E-01
1095.965	1095.865	1.00E-01	1051.219	1051.319	1.00E-01
961.077	961.177	1.00E-01	921.8382	921.3382	5.00E-01
859.911	859.811	1.00E-01	824.8026	824.7026	1.00E-01

Table 35: Vertical direction (Fz) force thrust right foot

Actual	ANN	MAE	Actual	ANN	MAE
474.5338	474.4338	1.00E-01	462.2742	462.1742	1.00E-01
451.4291	451.3291	1.00E-01	439.7665	439.3665	4.00E-01
463.8701	463.4701	4.00E-01	451.886	451.386	5.00E-01
469.2019	489.3019	2.01E+01	457.0801	457.2801	2.00E-01
517.1885	517.3885	2.00E-01	503.8269	503.7269	1.00E-01
467.4246	467.3246	1.00E-01	455.3487	455.2487	1.00E-01
545.625	565.425	1.98E+01	531.5287	531.3287	2.00E-01
449.6518	449.3518	3.00E-01	438.0351	438.2351	2.00E-01
478.0883	498.1883	2.01E+01	465.7369	465.8369	1.00E-01
504.7475	504.3475	4.00E-01	491.7074	491.3074	4.00E-01
577.616	577.316	3.00E-01	562.6933	562.3933	3.00E-01
506.5248	506.4248	1.00E-01	493.4387	493.3387	1.00E-01
453.2064	453.3064	1.00E-01	441.4978	441.3978	1.00E-01

Table 36: Vertical direction (Fz) force toe off right foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
875.6094	875.5094	1.00E-01	857.636	857.136	5.00E-01
832.9767	832.3767	6.00E-01	815.8785	815.5785	3.00E-01
855.9328	855.3328	6.00E-01	838.3633	838.2633	1.00E-01
865.7711	865.6711	1.00E-01	847.9997	847.7997	2.00E-01
954.3159	954.4159	1.00E-01	934.7269	934.3269	4.00E-01
862.4917	862.3917	1.00E-01	844.7876	844.3876	4.00E-01
1006.787	1006.887	1.00E-01	986.1208	986.3208	2.00E-01
829.6973	829.3973	3.00E-01	812.6664	812.3664	3.00E-01
882.1683	882.2683	1.00E-01	864.0603	865.0303	9.70E-01
931.3598	951.2598	1.99E+01	912.2421	912.2471	5.00E-03
1065.817	1095.217	2.94E+01	1043.939	1043.239	7.00E-01
934.6393	934.4393	2.00E-01	915.4542	915.3542	1.00E-01
836.2562	836.3562	1.00E-01	819.0906	819.9906	9.00E-01

Table 37: Power left foot

Heavy weight shoes (HWS)			**Light weight shoes (LWS)**		
Actual	ANN	MAE	Actual	ANN	MAE
3981.023	3981.323	3.00E-01	3980.938	3980.918	2.00E-02
3787.191	3787.291	1.00E-01	3787.11	3787.21	1.00E-01
3891.562	3891.362	2.00E-01	3891.479	3891.379	1.00E-01
3936.293	3986.283	5.00E+01	3936.208	3936.408	2.00E-01
4338.868	4388.868	5.00E+01	4338.775	4338.475	3.00E-01
3921.383	3921.183	2.00E-01	3921.298	3921.598	3.00E-01
4577.431	4557.411	2.00E+01	4577.333	4577.233	1.00E-01
3772.281	3772.181	1.00E-01	3772.2	3774	1.80E+00
4010.844	4010.444	4.00E-01	4010.758	4010.858	1.00E-01
4234.497	4234.597	1.00E-01	4234.406	4234.106	3.00E-01
4845.815	4845.915	1.00E-01	4845.711	4845.811	1.00E-01
4249.407	4249.307	1.00E-01	4249.316	4249.916	6.00E-01
3802.101	3902.301	1.00E+02	3802.019	3802.619	6.00E-01

Table 38: Power left foot

Heavy weight shoes (HWS)			Light weight shoes (LWS)		
Actual	ANN	MAE	Actual	ANN	MAE
3818.719	3818.929	2.10E-01	3654.205	3654.415	2.10E-01
3632.789	3532.723	1.00E+02	3476.285	3476.385	1.00E-01
3732.906	3832.006	9.91E+01	3572.088	3572.388	3.00E-01
3775.812	3775.825	1.26E-02	3613.146	3613.446	3.00E-01
4161.975	4261.858	9.99E+01	3982.673	3982.373	3.00E-01
3761.51	3761.989	4.78E-01	3599.46	3599.36	1.00E-01
4390.812	4390.851	3.90E-02	4201.651	4201.551	1.00E-01
3618.487	3618.126	3.61E-01	3462.598	3462.498	1.00E-01
3847.324	3887.125	3.98E+01	3681.577	3682.477	9.00E-01
4061.859	4061.156	7.03E-01	3886.869	3886.169	7.00E-01
4648.254	4648.855	6.01E-01	4448.002	4448.102	1.00E-01
4076.161	4076.156	5.59E-03	3900.556	3900.156	4.00E-01
3647.092	3647.286	1.94E-01	3489.971	3489.871	1.00E-01

5.2 CROSS VALIDATION OF RESULT (FORCE PLATE DATA)

For validation of result, the K- fold was used to check the robustness of the model. Ten K- fold cross validation was used to check the robustness of the model. The cross-validation of the results is given below.

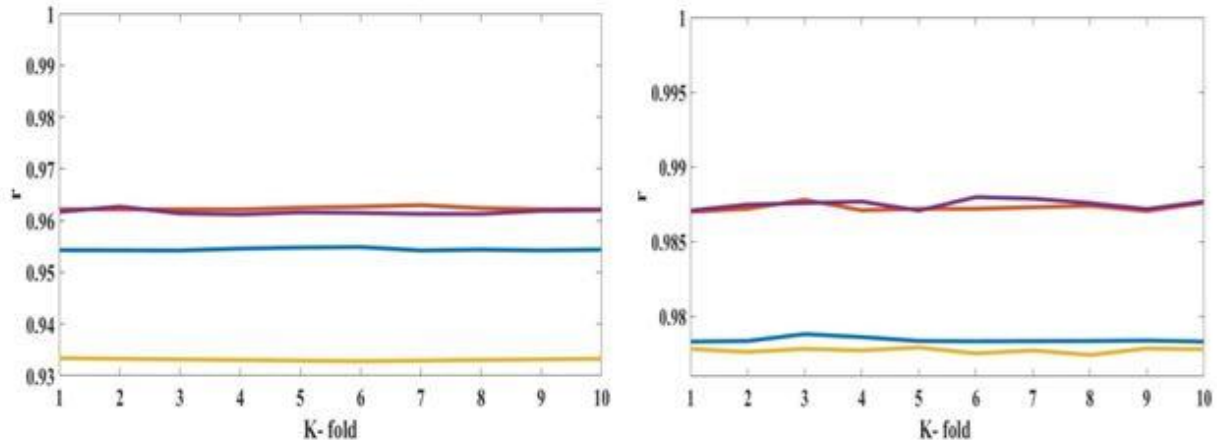


Figure 31: Stand correlation coefficient (HWS and LWS)

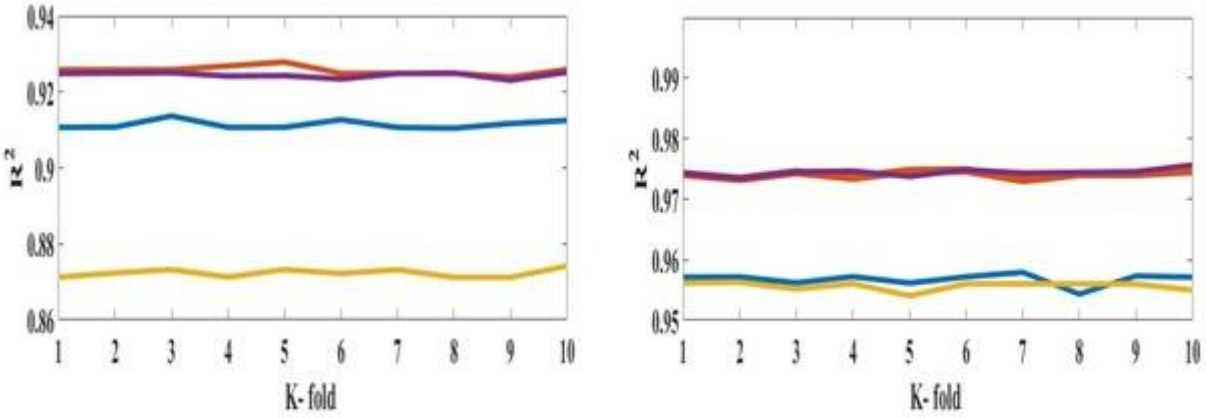


Figure 32: Stand coefficient of determination (HWS and LWS)

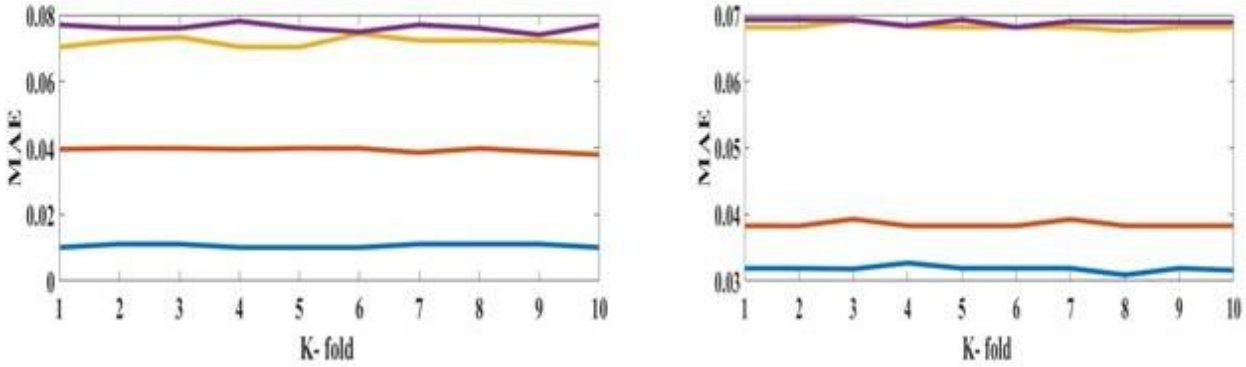
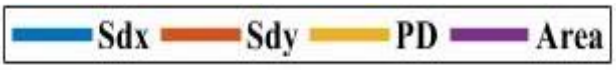


Figure 33: Mean absolute error (HWS and LWS)



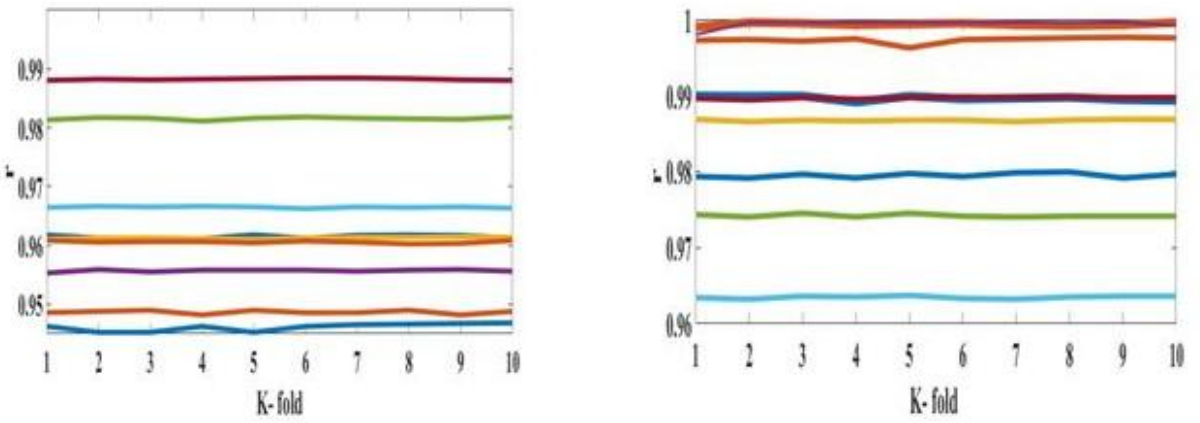


Figure 34: Walking left foot correlation coefficient (HWS and LWS)

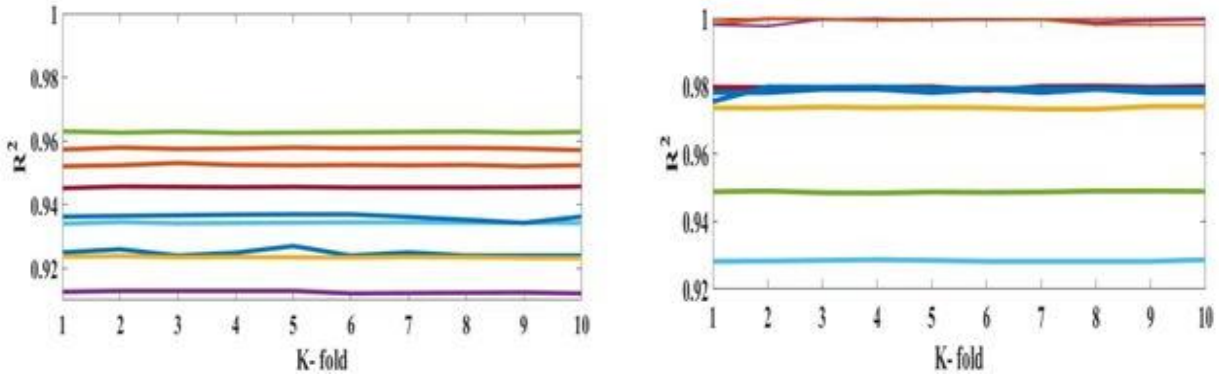


Figure 35: Walking left foot coefficient of determination (HWS and LWS)

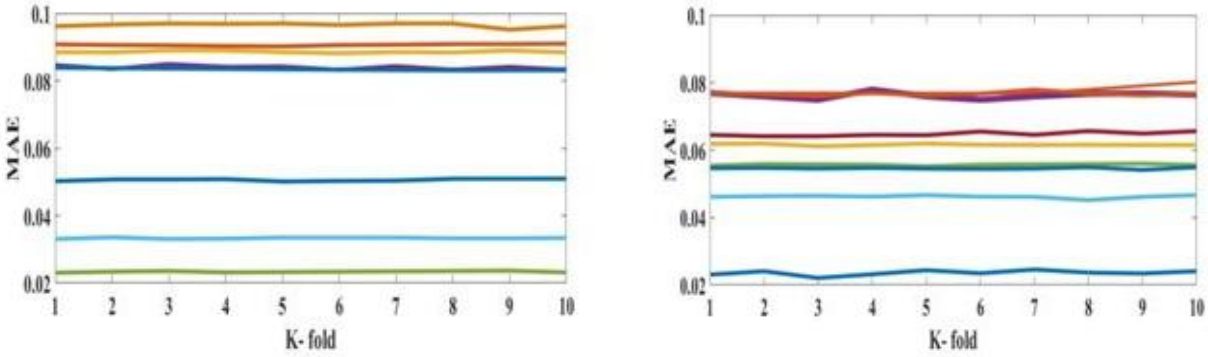


Figure 36: Walking left mean absolute error (HWS and LWS)

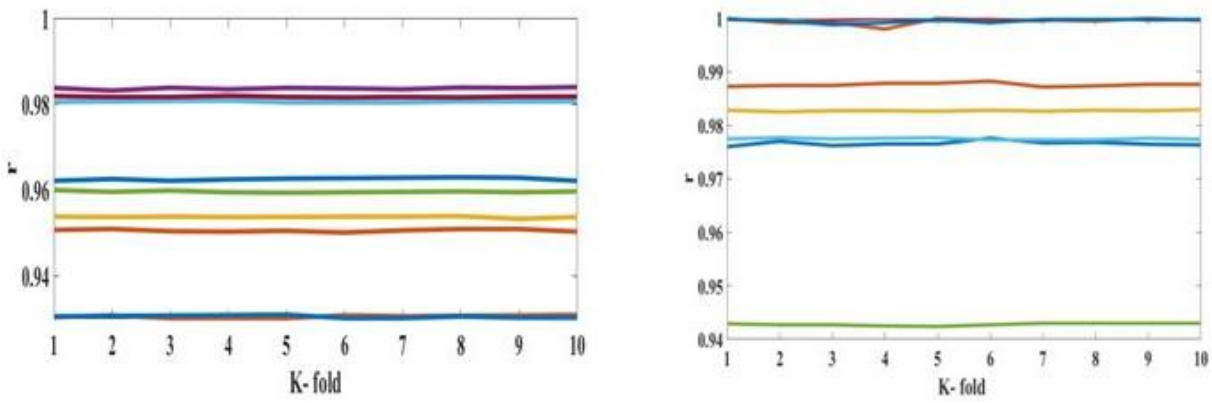


Figure 37: Walking right foot correlation coefficient (HWS and LWS)

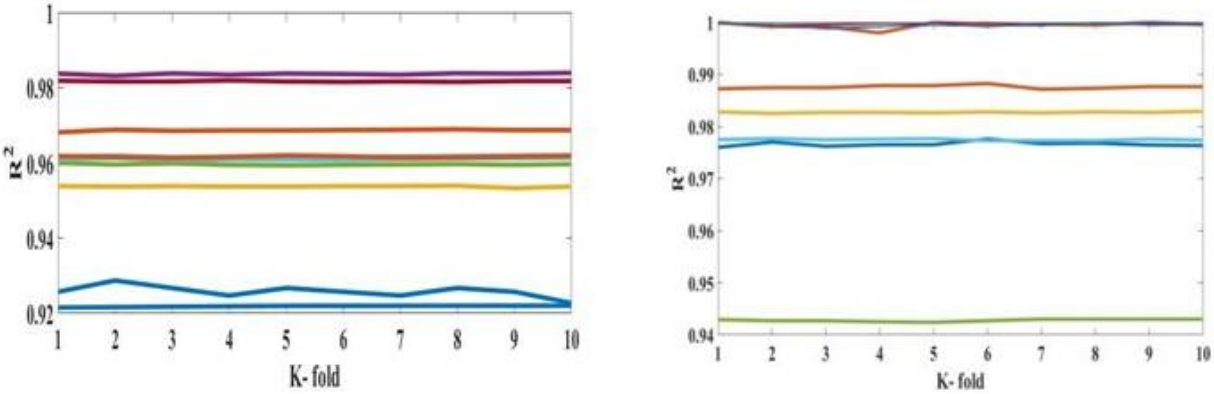


Figure 38: Walking right foot coefficient of determination (HWS and LWS)

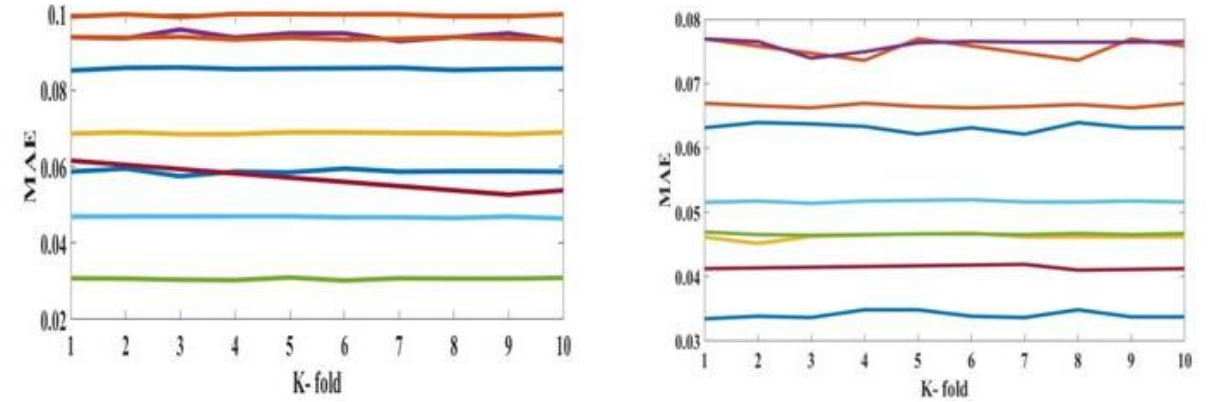


Figure 39: Walking right mean absolute error (HWS and LWS)

Table 39: Mean of Ten k- fold values in case of quiet standing

HWS	Area	PD	Sdx	Sdy	LWS	Area	PD	Sdx	Sdy
Correlation coefficient(R)	0.961697	0.93339	0.954284	0.962197	Correlation Coefficient(R)	**0.987082**	**0.977833**	**0.978324**	**0.987002**
R^2	0.924861	0.871217	0.910658	0.925823	R^2	**0.97433**	**0.956158**	**0.957118**	**0.974173**
MAE	0.077042	0.000703	0.001007	0.000396	MAE	**0.069288**	**0.000682**	**0.000319**	**0.000383**

Table 40: Mean of Ten k- fold values in case of waking (Forces)

Forces	**Left foot Fx Heel strike**		**Right foot Fx Heel strike**		**Left foot Fz Heel strike**		**Right foot Fz Heel strike**	
	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS
Correlation coefficient (R)	0.961757	**0.989947**	0.962147	**0.976006**	0.988586	**0.999994**	0.983929	**0.999993**
R^2	0.924976	**0.979996**	0.925726	**0.952587**	0.977302	**0.999988**	0.968117	**0.999985**
MAE	0.050225	**0.023078**	0.058462	**0.033846**	0.096154	**0.076923**	0.099231	**0.076923**
Forces	**Left foot Fx Thrust**		**Right foot Fx Thrust**		**Left foot Fz Thrust**		**Right foot Fz Thrust**	
	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS
Correlation coefficient (R)	0.974032	**0.981322**	0.942896	**0.959870**	0.963418	**0.966447**	0.977473	**0.980499**
R^2	0.948738	**0.962994**	0.889053	**0.921351**	0.928173	**0.934019**	0.955453	**0.961379**
MAE	0.055385	**0.023077**	0.076923	**0.030769**	0.046154	**0.033077**	0.051538	**0.046923**
Forces	**Left foot Fx Toe off**		**Right foot Fx Toe off**		**Left foot Fz Toe off**		**Right foot Fz Toe off**	
	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS
Correlation coefficient (R)	0.961073	**0.986764**	0.953818	**0.982815**	0.955305	**0.999994**	0.983736	**0.999992**
R^2	0.923661	**0.973702**	0.909769	**0.965925**	0.912607	**0.999988**	0.967736	**0.999985**
MAE	0.088462	**0.061541**	0.068462	**0.046154**	0.084615	**0.076923**	0.093846	**0.076923**
Forces	**Left foot Fy Propulsion force**		**Right foot Fy Propulsion force**		**Left foot Fy Baking force**		**Right foot Fy Baking force**	
	HWS	LWS	HWS	LWS	HWS	LWS	HWS	LWS
Correlation coefficient (R)	0.946234	**0.979348**	0.930579	**0.999782**	0.972195	**0.989620**	0.981841	**0.999720**
R^2	0.936234	**0.979348**	0.921535	**0.999565**	0.945162	**0.979348**	0.964012	**0.999441**
MAE	0.0838462	**0.054615**	0.085126	**0.063126**	0.09632	**0.0846154**	0.0615385	**0.041234**

ANN mean data of ten k-fold for quiet standing shows in Table 39. ANN was used to find the correlation coefficient(r), the coefficient of determination (R^2) and MAE using equation (1.29, 1.30 and 1.31 respectively) between the predicted and measured value. Human weight, human height,

and shoe weight were the inputs to ANN it was conducted with both HWS and LWS. The table 39 suggests that ANN predicted the data of LWS better than HWS as error associated with LWS was lesser. Table 40 encompasses the ANN walking forces data experienced by a human on his feet. There are three directions namely X-medial-lateral direction, Y-anterior-posterior direction and Z-vertical direction of left and right foot.HWS and LWS forces were target into ANN. The predicted data of ANN was compared with the measured data. The correlation coefficient(r), the coefficient of determination (R^2) and error were calculated using equation (1.29, 1.30, and 1.31 respectively) for both left and right foot in two different shoes. Heel strike, toe off and thrust force was calculated in the x and Z-directions. Propulsion and baking force were calculated in the y-direction. For each case, it was found that the LWS was better as the forces were less than HWS and ANN predicted the data better for LWS.

Table 41: Mean of Ten k- fold values in case of waking (Power)

Power	**Left foot Power**		**Left foot Power**	
	HWS	**LWS**	**HWS**	**LWS**
Correlation coefficient (R)	0.980848	**0.997256**	0.980710	**0.997256**
R^2	0.962062	**0.999999**	0.961792	**0.999999**
MAE	0.090769	**0.076923**	0.093846	**0.076923**

Table 41 shows the ANN walking power data experienced by a human on his feet. The correlation coefficient(r), the coefficient of determination (R^2) and error were calculated using equation (1.29, 1.30, and 1.31 respectively) for both left and right foot in two different shoes. For each case, it was found that the LWS was better as the power were less due to inputs using during training, testing and validation than HWS and ANN predicted the data better for LWS.

Table 42: Mean Comparison of predicted and measured values

Heavy weight shoes	**Measured**	**Predicted**	**Mean Absolute Error**
Balance (mm/mm^2)	3.73	3.57	**4.28**
Medial-lateral direction (Newton)	737.89	686.70	**6.93**
Anterior-posterior direction (Newton)	102.00	107.14	**5.03**
Vertically direction (Newton)	722.31	711.95	**1.43**
Power (Watts)	4020.90	3970.85	**1.24**
Light weight shoes	**Measured**	**Predicted**	
Balance (mm)	3.63	3.57	**1.65**
Medial-lateral direction (Newton)	657.25	664.69	**1.13**

Anterior-posterior direction (Newton)	99.98	104.96	**4.98**
Vertically direction (Newton)	716.51	719.33	**0.39**
Power (Watts)	3935.25	3946.87	**0.29**

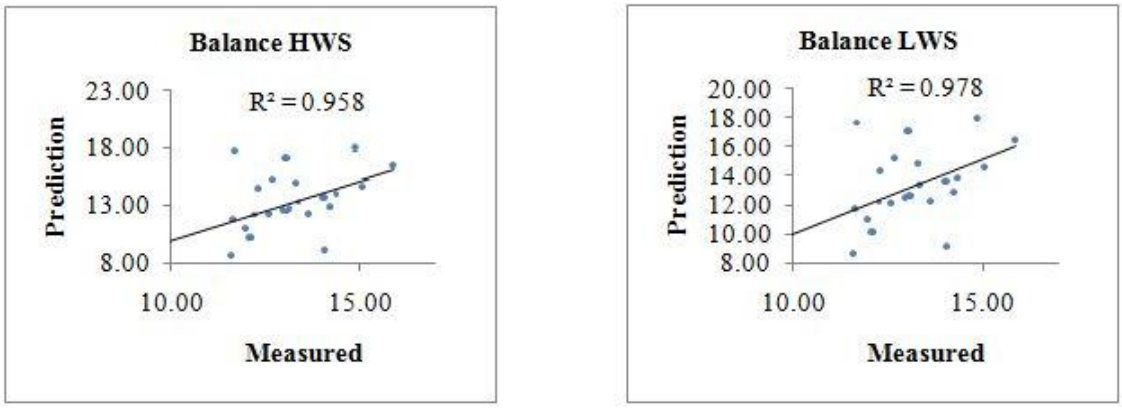


Figure 40: Data fitting stand (HWS and LWS)

Figure 40 shows that in case of HWS the coefficient of determination (R^2) of data fitting are 0.958 during Stand. It clearly shows that the error is more by using input parameters for ANN model in HWS. The coefficient of determination (R^2) is 0.978 in LWS during stand. The error is less than the HWS.

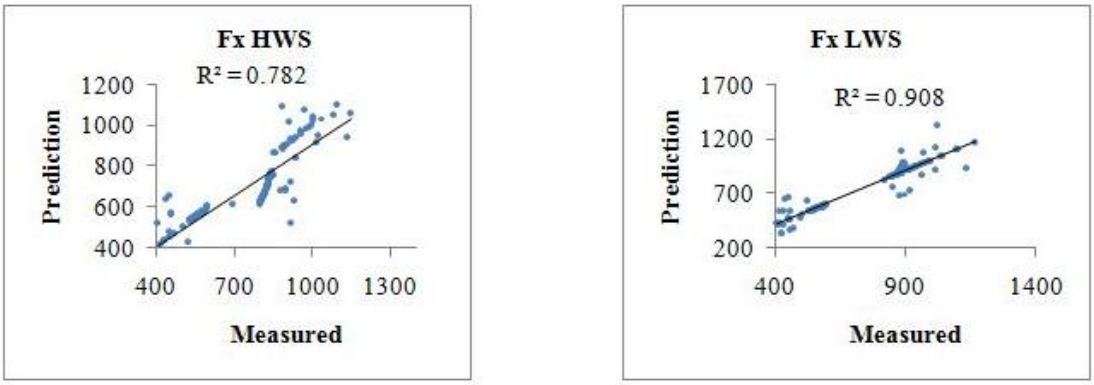


Figure 41: Data fitting walking medial- lateral direction (Fx) (HWS and LWS)

The ML direction, the magnitude of the force depends on the position of the center of the mass of the foot. Figure 41 show the coefficient of determination (R^2) is 0.782 in HWS during walking; the error is more than the LWS. It clarifies that human being during walking, the larger step width and greater force applied because of the greater angle between lower and extremity and the floor. The coefficient of determination (R^2) is 0.908 in LWS during walking. The error is less than the HWS. It shows that human being during walking; the step width is small and applied less force as compared to the HWS. The angle between the lower and extremity and the floor is small.

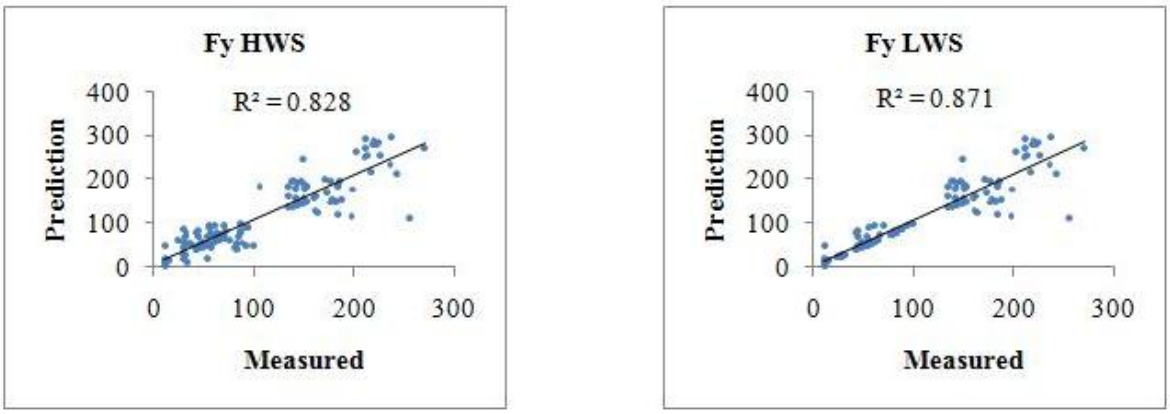


Figure 42: Data fitting walking anterior-posterior direction (Fy) (HWS and LWS)

In anterior-posterior direction, the right foot first applies a baking force during the first half of the stance and a propulsion force during the second half. The magnitude and direction of the anterior-posterior force depend on the position of the COM relative to the location of the foot. Figure 42 shows the coefficient of determination (R^2) is 0.828 in HWS during walking. It shows more error than LWS because in this case human bearing more force during the propelling the body forward. The larger step width and greater force applied because of the greater angle between lower and extremity and the floor. The coefficient of determination (R^2) is 0.871 in LWS during walking. It shows less error than HWS because in this case human bearing less force during the propelling the body forward. The smaller step width and greater force applied because of the smaller angle between lower and extremity and the floor.

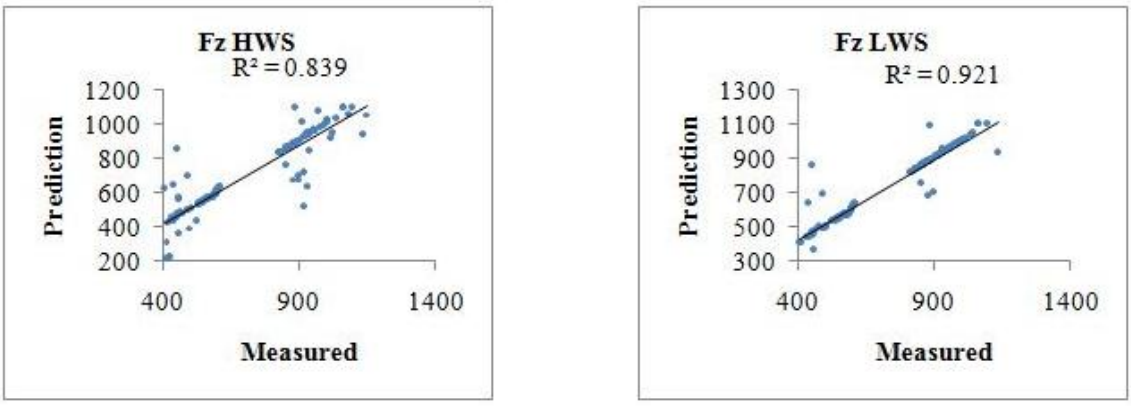


Figure 43: Data fitting walking vertical direction (Fz) (HWS and LWS)

The vertical force consists of double peaks. The first peak at heel strike, the action of body momentum and a second peak at toe off. From figure 43 shows that the coefficient of

determination (R^2) is 0.839 and error is more than LWS because in HWS BW during mid-stance is higher as a result of unbalancing the upward momentum of the center of mass. The coefficient of determination (R^2) is 0.921 in LWS and error is less than HWS because in LWS BW during mid-stance is lower as a result of balancing the upward momentum of the center of mass.

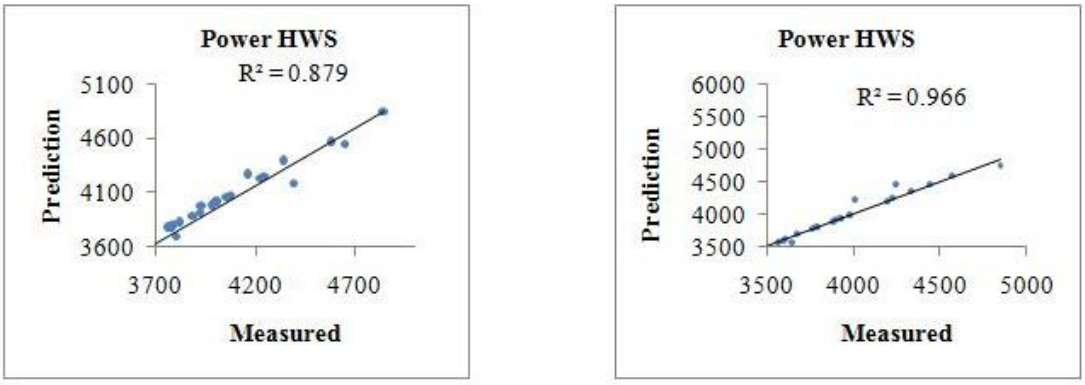


Figure 44: Data fitting walking Power (HWS and LWS)

Figure 44 shows that coefficient of determination (R^2) is 0.879 and error is more as compare to LWS because during walking human bearing more power and uncomfortable propelling the body forward. The coefficient of determination (R^2) is 0.966 in LWS and error is less as compare to HWS because during walking human bearing less power and comfortable propelling the body forward.

5.3 FOR FOOT SCAN INSOLE

Comparative study of four types of insoles having different materials and light weight shoes (LWS). Significant parameters were the input process parameters for this study. The different results predicted using ANN having 70% data for training and 30% for validation for one time.

Table 43: Forefoot left foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.44	4.903	4.63E-01	6.13	5.647	0.483	5.75	5.817	0.067	4.9	4.957	0.057
4.89	4.996	1.06E-01	5.64	5.461	0.179	5.68	5.741	0.061	5.04	4.200	0.840
5.15	4.868	2.82E-01	5.4	5.482	0.082	5.43	5.493	0.063	5.11	4.870	0.240
5.1	4.909	1.91E-01	4.24	4.419	0.179	4.25	4.211	0.039	7.06	6.318	0.742
5.09	4.836	2.54E-01	5.46	5.346	0.114	5.49	5.552	0.062	5.09	4.745	0.345
5.11	5.003	1.07E-01	3.82	3.851	0.031	3.82	3.812	0.008	6.33	6.316	0.014
4.38	4.957	5.77E-01	6.21	5.686	0.524	5.74	5.840	0.100	4.88	4.421	0.459
5.09	4.818	2.72E-01	5.23	5.106	0.124	5.26	5.250	0.010	5.16	4.934	0.226
5.1	4.961	1.39E-01	4.43	4.591	0.161	4.44	4.421	0.019	5.4	6.238	0.838
5.11	5.056	5.41E-02	3.35	3.504	0.154	3.35	3.436	0.086	5.54	5.515	0.025
5.11	5.256	1.46E-01	3.54	3.587	0.047	3.54	3.584	0.044	5.87	5.859	0.011
4.7	4.851	1.51E-01	5.84	5.386	0.454	5.89	5.893	0.003	4.98	4.999	0.019
5.12	5.232	1.12E-01	2.88	2.648	0.232	2.88	2.794	0.086	4.75	4.668	0.082
5.1	4.944	1.56E-01	4.47	4.538	0.068	4.48	4.446	0.034	5.39	6.317	0.927
5.12	5.104	1.64E-02	2.92	3.314	0.394	2.91	2.823	0.087	4.81	4.855	0.045

Table 44: Forefoot right foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.49	5.257	7.67E-01	4.02	3.698	0.322	5.6	5.732	0.132	4.25	4.364	0.114
4.21	5.169	9.59E-01	3.7	3.575	0.125	5.53	5.401	0.129	4.36	4.482	0.122
5.74	4.908	8.32E-01	3.54	3.594	0.054	5.29	5.217	0.073	4.43	4.479	0.049
4.36	4.006	3.54E-01	2.78	2.894	0.114	4.14	4.226	0.086	6.11	6.091	0.019
4.1	4.986	8.86E-01	3.57	3.503	0.067	5.35	5.213	0.137	4.41	4.311	0.099
3.88	3.897	1.72E-02	2.5	2.521	0.021	3.72	3.734	0.014	5.48	5.518	0.038
4.53	5.474	9.44E-01	4.07	3.726	0.344	5.59	5.715	0.125	4.23	4.318	0.088
5.53	4.599	9.31E-01	3.42	3.342	0.078	5.12	4.984	0.136	4.47	4.398	0.072
4.58	4.134	4.46E-01	2.9	3.009	0.109	4.33	4.337	0.007	4.68	4.456	0.224
3.36	3.335	2.54E-02	2.19	2.295	0.105	3.26	3.204	0.056	4.8	4.762	0.038
3.57	4.171	6.01E-01	2.32	2.348	0.028	3.45	3.379	0.071	5.08	5.064	0.016
4.32	4.986	6.66E-01	3.83	3.225	0.605	5.73	5.597	0.133	4.32	4.433	0.113
2.85	3.003	1.53E-01	1.89	1.737	0.153	2.8	2.817	0.017	4.12	4.144	0.024
4.63	4.191	4.39E-01	2.93	2.970	0.040	4.37	4.459	0.089	4.67	5.305	0.635
2.89	2.764	1.26E-01	1.91	1.681	0.229	2.83	2.812	0.018	4.17	4.305	0.135

Table 45: Mid-foot left foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
3.96	5.503	1.543	4.16	3.828	0.332	3.24	3.134	0.106	2.73	2.853	0.123
4.02	5.453	1.433	3.83	3.701	0.129	3.21	2.998	0.212	2.81	2.806	0.004
4.82	3.911	0.909	3.66	3.716	0.056	3.07	3.000	0.070	2.85	2.836	0.014
3.66	3.378	0.282	2.88	2.998	0.118	2.4	2.432	0.032	3.93	3.974	0.044
4.04	3.254	0.786	3.7	3.625	0.075	3.1	3.004	0.096	2.84	2.621	0.219
3.25	3.235	0.015	2.59	2.613	0.023	2.16	2.165	0.005	3.53	3.521	0.009
3.95	4.649	0.699	4.22	3.855	0.365	3.24	3.147	0.093	2.72	2.762	0.042
4.64	4.024	0.616	3.55	3.462	0.088	2.97	2.865	0.105	2.88	2.889	0.009
3.85	3.544	0.306	3.01	3.117	0.107	2.51	2.641	0.131	3.01	3.513	0.503
2.82	2.810	0.010	2.27	2.380	0.110	1.89	1.939	0.049	3.09	3.125	0.035
3	3.290	0.290	2.41	2.436	0.026	2	2.032	0.032	3.27	3.260	0.010
3.99	4.829	0.839	3.97	3.653	0.317	3.33	3.091	0.239	2.78	2.822	0.042
2.39	2.456	0.066	1.96	2.697	0.737	1.62	1.478	0.142	2.65	2.649	0.001
3.89	3.168	0.722	3.04	3.078	0.038	2.53	2.684	0.154	3	3.741	0.741
2.43	1.308	1.122	1.98	1.041	0.939	1.64	1.000	0.640	2.68	2.650	0.030

Table 46: Mid-foot right foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
3.83	4.360	5.30E-01	4.1	3.766	0.334	3.400	3.288	0.112	2.38	2.530	0.150
3.89	4.312	4.22E-01	3.77	3.640	0.130	3.370	3.148	0.222	2.45	2.491	0.041
4.67	4.076	5.94E-01	3.6	3.655	0.055	3.220	3.145	0.075	2.48	2.411	0.069
3.55	3.267	2.83E-01	2.83	2.946	0.116	2.520	2.552	0.032	3.43	3.245	0.185
3.92	4.118	1.98E-01	3.64	3.565	0.075	3.250	3.150	0.100	2.47	2.281	0.189
3.15	3.130	2.00E-02	2.55	2.573	0.023	2.260	2.274	0.014	3.07	3.189	0.119
3.82	4.502	6.82E-01	4.15	3.791	0.359	3.400	3.300	0.100	2.37	2.463	0.093
4.5	3.897	6.03E-01	3.49	3.408	0.082	3.110	3.006	0.104	2.51	2.350	0.160
3.73	3.430	3.00E-01	2.96	3.067	0.107	2.630	2.771	0.141	2.62	3.131	0.511
2.73	2.721	9.33E-03	2.24	2.345	0.105	1.980	2.036	0.056	2.69	2.664	0.026
2.9	3.187	2.87E-01	2.37	2.394	0.024	2.100	2.130	0.030	2.85	2.832	0.018
3.87	4.192	3.22E-01	3.9	3.592	0.308	3.490	3.241	0.249	2.42	2.553	0.133
2.32	2.382	6.16E-02	1.92	1.764	0.156	1.700	1.551	0.149	2.31	2.243	0.067
3.76	3.456	3.04E-01	2.99	3.029	0.039	2.660	2.915	0.255	2.62	3.079	0.459
2.35	3.535	1.19E+00	1.95	2.809	0.859	1.720	2.400	0.680	2.33	2.387	0.057

Table 47: Heel left foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.450	5.064	0.614	4.530	4.171	0.359	4.340	4.183	0.157	1.420	1.458	0.038
4.520	5.010	0.490	4.170	4.032	0.138	4.290	4.000	0.290	1.460	1.239	0.221
5.420	4.733	0.687	3.990	4.049	0.059	4.100	4.005	0.095	1.480	1.483	0.003
4.120	3.798	0.322	3.140	3.264	0.124	3.210	3.950	0.740	2.040	1.837	0.203
4.550	4.883	0.333	4.030	3.946	0.084	4.140	4.012	0.128	1.480	1.366	0.114
3.660	3.636	0.024	2.820	2.844	0.024	2.880	2.895	0.015	1.830	1.825	0.005
4.440	5.228	0.788	4.590	4.198	0.392	4.330	4.200	0.130	1.410	1.327	0.083
5.220	4.726	0.494	3.860	3.770	0.090	3.970	3.627	0.343	1.490	1.444	0.046
4.330	3.985	0.345	3.280	3.396	0.116	3.350	3.526	0.176	1.570	1.836	0.266
3.170	3.459	0.289	2.480	2.594	0.114	2.530	2.694	0.164	1.610	1.587	0.023
3.370	3.702	0.332	2.620	2.651	0.031	2.670	2.713	0.043	1.700	1.653	0.047
4.490	4.867	0.377	4.320	3.975	0.345	4.440	4.125	0.315	1.440	1.518	0.078
2.690	2.762	0.072	2.130	1.956	0.174	2.170	2.975	0.805	1.380	1.345	0.035
4.370	4.012	0.358	3.310	3.353	0.043	3.380	3.582	0.202	1.560	1.881	0.321
2.730	2.593	0.137	2.160	2.592	0.432	2.200	2.982	0.782	1.390	1.434	0.044

Table 48: Heel right foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.310	4.905	0.595	5.130	5.014	0.116	5.950	6.487	0.537	3.420	3.508	0.088
4.380	4.852	0.472	4.720	4.698	0.022	5.890	5.091	0.799	3.510	2.872	0.638
5.250	4.587	0.663	4.510	4.639	0.129	5.630	5.662	0.032	3.560	3.500	0.060
3.990	3.681	0.309	3.550	3.558	0.008	4.400	4.444	0.044	4.920	4.437	0.483
4.400	4.634	0.234	4.560	4.544	0.016	5.690	5.273	0.417	3.550	3.222	0.328
3.540	3.525	0.015	3.190	3.116	0.074	3.960	3.918	0.042	4.410	4.380	0.030
4.300	5.065	0.765	5.190	5.082	0.108	5.950	6.403	0.453	3.400	3.071	0.329
5.060	4.383	0.677	4.370	4.182	0.188	5.450	5.419	0.031	3.590	3.462	0.128
4.190	3.862	0.328	3.710	3.718	0.008	4.600	4.512	0.088	3.760	4.353	0.593
3.070	3.061	0.009	2.800	2.914	0.114	3.470	3.455	0.015	3.860	3.861	0.001
3.270	3.587	0.317	2.960	2.930	0.030	3.670	3.117	0.553	4.090	4.062	0.028
4.350	4.716	0.366	4.890	4.698	0.192	6.100	5.996	0.104	3.470	3.752	0.282
2.610	2.675	0.065	2.410	2.317	0.093	2.980	3.426	0.446	3.310	3.236	0.074
4.230	3.888	0.342	3.740	3.881	0.141	4.650	3.101	1.549	3.760	4.467	0.707
2.640	3.113	0.473	2.440	2.984	0.544	3.010	2.000	1.010	3.350	3.495	0.145

Table 49: Lateral left foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.330	4.935	0.605	5.470	5.029	0.441	4.470	4.312	0.158	3.210	3.382	0.172
4.400	4.880	0.480	5.030	4.864	0.166	4.420	4.128	0.292	3.290	3.246	0.044
5.280	4.612	0.668	4.810	4.884	0.074	4.220	4.126	0.094	3.340	3.371	0.031
4.010	3.698	0.312	3.780	3.935	0.155	3.300	3.349	0.049	4.610	4.263	0.347
4.430	4.660	0.230	4.870	4.761	0.109	4.270	4.132	0.138	3.330	3.082	0.248
3.570	3.543	0.027	3.400	3.434	0.034	2.970	2.983	0.013	4.140	4.280	0.140
4.320	5.096	0.776	5.540	5.065	0.475	4.460	4.327	0.133	3.190	3.299	0.109
5.090	4.407	0.683	4.660	4.550	0.110	4.090	3.944	0.146	3.370	3.157	0.213
4.210	3.879	0.331	3.950	4.095	0.145	3.450	3.634	0.184	3.530	4.225	0.695
3.090	3.079	0.011	2.990	3.130	0.140	2.600	2.670	0.070	3.620	3.595	0.025
3.280	3.609	0.329	3.160	3.197	0.037	2.750	2.795	0.045	3.840	3.844	0.004
4.370	4.741	0.371	5.210	4.797	0.413	4.580	4.250	0.330	3.260	3.254	0.006
2.620	2.594	0.026	2.570	2.361	0.209	2.240	2.039	0.201	3.110	2.927	0.183
4.260	3.708	0.552	3.990	4.045	0.055	3.490	3.692	0.202	3.520	4.176	0.656
2.660	2.926	0.266	2.600	3.285	0.685	2.260	3.144	0.884	3.140	3.051	0.089

Table 50: Lateral right foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.580	5.211	0.631	4.600	4.230	0.370	5.790	5.052	0.738	3.290	3.448	0.158
4.650	5.153	0.503	4.240	4.092	0.148	5.730	5.770	0.040	3.380	3.230	0.150
5.580	4.873	0.707	4.050	4.106	0.056	5.480	5.526	0.046	3.430	3.445	0.015
4.240	3.909	0.331	3.180	3.310	0.130	4.290	4.708	0.418	4.730	4.353	0.377
4.680	4.925	0.245	4.100	4.007	0.093	5.540	5.562	0.022	3.410	3.163	0.247
3.770	3.745	0.025	2.860	2.889	0.029	3.850	3.834	0.016	4.240	4.411	0.171
4.570	5.382	0.812	4.660	4.260	0.400	5.790	5.145	0.645	3.270	3.388	0.118
5.380	4.656	0.724	3.920	3.826	0.094	5.300	5.296	0.004	3.460	3.216	0.244
4.450	4.100	0.350	3.330	3.444	0.114	4.480	4.433	0.047	3.620	4.319	0.699
3.270	3.252	0.018	2.510	2.634	0.124	3.380	3.399	0.019	3.720	3.651	0.069
3.470	3.808	0.338	2.660	2.690	0.030	3.570	3.873	0.303	3.930	3.881	0.049
4.620	5.010	0.390	4.390	4.037	0.353	5.940	5.952	0.012	3.340	3.390	0.050
2.770	2.845	0.075	2.160	1.986	0.174	2.900	2.848	0.052	3.190	3.009	0.181
4.500	4.129	0.371	3.360	3.403	0.043	4.520	4.504	0.016	3.610	4.390	0.780
2.810	3.272	0.462	2.190	2.622	0.432	2.930	2.178	0.752	3.220	3.163	0.057

Table 51: Medial left foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.100	4.671	0.571	4.780	4.393	0.387	4.810	4.642	0.168	3.340	3.466	0.126
4.170	4.619	0.449	4.400	4.249	0.151	4.750	4.442	0.308	3.430	3.405	0.025
5.000	4.367	0.633	4.210	4.265	0.055	4.540	4.440	0.100	3.480	3.365	0.115
3.800	3.501	0.299	3.300	3.437	0.137	3.550	3.803	0.253	4.810	4.452	0.358
4.190	4.413	0.223	4.250	4.158	0.092	4.590	4.447	0.143	3.470	3.204	0.266
3.380	3.355	0.025	2.970	2.999	0.029	3.190	3.208	0.018	4.310	4.571	0.261
4.090	4.823	0.733	4.840	4.423	0.417	4.800	4.659	0.141	3.330	3.417	0.087
4.820	4.172	0.648	4.070	3.974	0.096	4.400	4.249	0.151	3.520	3.283	0.237
3.990	3.673	0.317	3.450	3.576	0.126	3.720	3.910	0.190	3.680	4.307	0.627
2.930	2.914	0.016	2.610	2.732	0.122	2.800	2.971	0.171	3.780	3.777	0.003
3.110	3.415	0.305	2.760	2.792	0.032	2.960	3.011	0.051	4.000	4.033	0.033
4.140	4.488	0.348	4.550	4.191	0.359	4.930	4.573	0.357	3.400	3.437	0.037
2.480	2.550	0.070	2.250	2.060	0.190	2.400	2.092	0.308	3.240	3.124	0.116
4.030	3.700	0.330	3.480	3.533	0.053	3.750	3.974	0.224	3.670	4.502	0.832
2.520	2.892	0.372	2.270	2.794	0.524	2.430	3.303	0.873	3.280	3.263	0.017

Table 52: Medial right foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.100	4.661	0.561	4.870	4.470	0.400	4.370	4.225	0.145	3.670	3.903	0.233
4.160	4.610	0.450	4.480	4.328	0.152	4.330	4.042	0.288	3.770	3.869	0.099
4.990	4.359	0.631	4.280	4.341	0.061	4.130	4.041	0.089	3.820	3.907	0.087
3.790	3.496	0.294	3.360	3.498	0.138	3.230	3.280	0.050	5.280	4.963	0.317
4.190	4.404	0.214	4.330	4.234	0.096	4.180	4.048	0.132	3.810	3.628	0.182
3.370	3.349	0.021	3.030	3.050	0.020	2.910	2.919	0.009	4.730	4.885	0.155
4.090	4.812	0.722	4.930	4.505	0.425	4.370	4.239	0.131	3.650	3.751	0.101
4.810	4.164	0.646	4.150	4.044	0.106	4.000	3.862	0.138	3.860	3.702	0.158
3.980	3.668	0.312	3.520	3.637	0.117	3.380	3.558	0.178	4.040	4.839	0.799
2.920	2.911	0.009	2.660	2.780	0.120	2.550	2.613	0.063	4.140	4.208	0.068
3.100	3.407	0.307	2.810	2.840	0.030	2.700	2.737	0.037	4.390	4.386	0.004
4.130	4.483	0.353	4.640	4.267	0.373	4.480	4.160	0.320	3.730	3.926	0.196
2.480	2.544	0.064	2.290	2.099	0.191	2.190	1.995	0.195	3.550	3.368	0.182
4.020	3.696	0.324	3.550	3.597	0.047	3.410	3.616	0.206	4.030	4.693	0.663
2.510	2.890	0.380	2.310	2.728	0.418	2.210	2.999	0.789	3.600	3.605	0.005

Table 53: Overall left foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.210	4.793	0.583	5.100	4.892	0.208	4.640	4.477	0.163	3.270	3.420	0.150
4.280	4.741	0.461	4.690	4.602	0.088	4.590	4.284	0.306	3.360	2.693	0.667
5.130	4.479	0.651	4.490	4.559	0.069	4.380	4.284	0.096	3.410	3.381	0.029
3.900	3.595	0.305	3.530	3.557	0.027	3.430	3.476	0.046	4.710	4.268	0.442
4.300	4.527	0.227	4.540	4.462	0.078	4.430	4.289	0.141	3.400	3.066	0.334
3.460	3.442	0.018	3.170	3.114	0.056	3.080	3.095	0.015	4.230	4.230	0.000
4.200	4.947	0.747	5.160	4.956	0.204	4.630	4.496	0.134	3.260	2.913	0.347
4.940	4.282	0.658	4.350	4.212	0.138	4.240	4.096	0.144	3.440	3.270	0.170
4.090	3.769	0.321	3.680	3.704	0.024	3.590	3.772	0.182	3.610	4.190	0.580
3.000	2.990	0.010	2.790	2.894	0.104	2.700	2.771	0.071	3.700	3.721	0.021
3.190	3.503	0.313	2.950	2.924	0.026	2.860	2.906	0.046	3.920	3.930	0.010
4.250	4.608	0.358	4.860	4.595	0.265	4.750	4.412	0.338	3.330	3.628	0.298
2.550	2.616	0.066	2.400	2.292	0.108	2.320	2.115	0.205	3.170	3.075	0.095
4.140	3.797	0.343	3.720	3.661	0.059	3.620	3.833	0.213	3.600	4.283	0.683
2.580	2.955	0.375	2.420	2.610	0.190	2.350	3.122	0.772	3.210	3.290	0.080

Table 54: Overall right foot pressure

Insole 1			Insole 2			Insole 3			Insole 4		
Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE	Actual	ANN	MAE
4.320	4.915	0.595	4.870	4.479	0.391	5.070	5.178	0.108	3.470	3.645	0.175
4.390	4.858	0.468	4.480	4.333	0.147	5.010	5.038	0.028	3.570	3.519	0.051
5.260	4.597	0.663	4.280	4.352	0.072	4.790	4.842	0.052	3.620	3.639	0.019
4.000	3.683	0.317	3.360	3.503	0.143	3.750	3.743	0.007	4.990	4.586	0.404
4.410	4.645	0.235	4.330	4.242	0.088	4.840	4.850	0.010	3.600	3.278	0.322
3.550	3.530	0.020	3.030	3.049	0.019	3.370	3.361	0.009	4.480	4.611	0.131
4.310	5.074	0.764	4.930	4.513	0.417	5.070	5.201	0.131	3.460	3.527	0.067
5.070	4.391	0.679	4.150	4.050	0.100	4.640	4.648	0.008	3.650	3.424	0.226
4.200	3.863	0.337	3.520	3.644	0.124	3.920	3.892	0.028	3.820	4.579	0.759
3.080	3.066	0.014	2.660	2.778	0.118	2.950	2.981	0.031	3.920	3.947	0.027
3.270	3.590	0.320	2.810	2.843	0.033	3.120	3.145	0.025	4.150	4.236	0.086
4.360	4.722	0.362	4.640	4.268	0.372	5.200	5.158	0.042	3.530	3.539	0.009
2.610	2.684	0.074	2.290	2.100	0.190	2.540	2.493	0.047	3.360	3.256	0.104
4.240	3.892	0.348	3.550	3.601	0.051	3.960	3.938	0.022	3.810	4.494	0.684
2.650	3.619	0.969	2.310	2.574	0.264	2.570	2.522	0.048	3.400	3.345	0.055

5.4 CROSS VALIDATION FOR FOOT SCAN INSOLE DATA

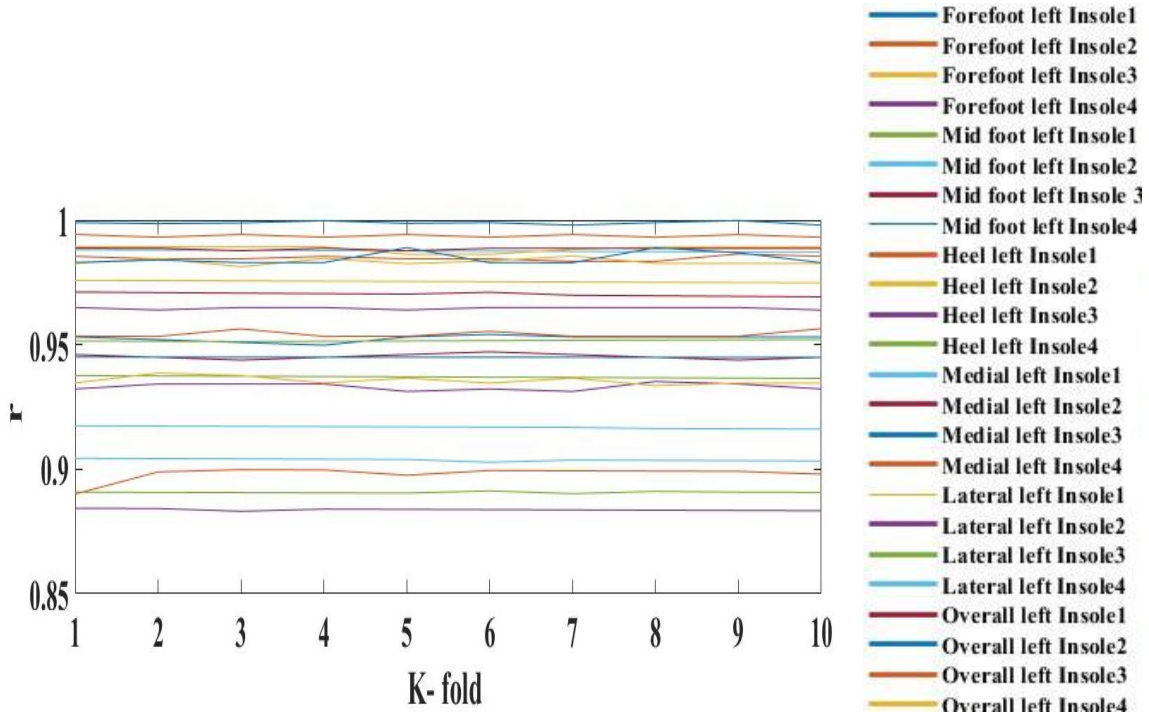


Figure 45: Correlation coefficient (r) left foot

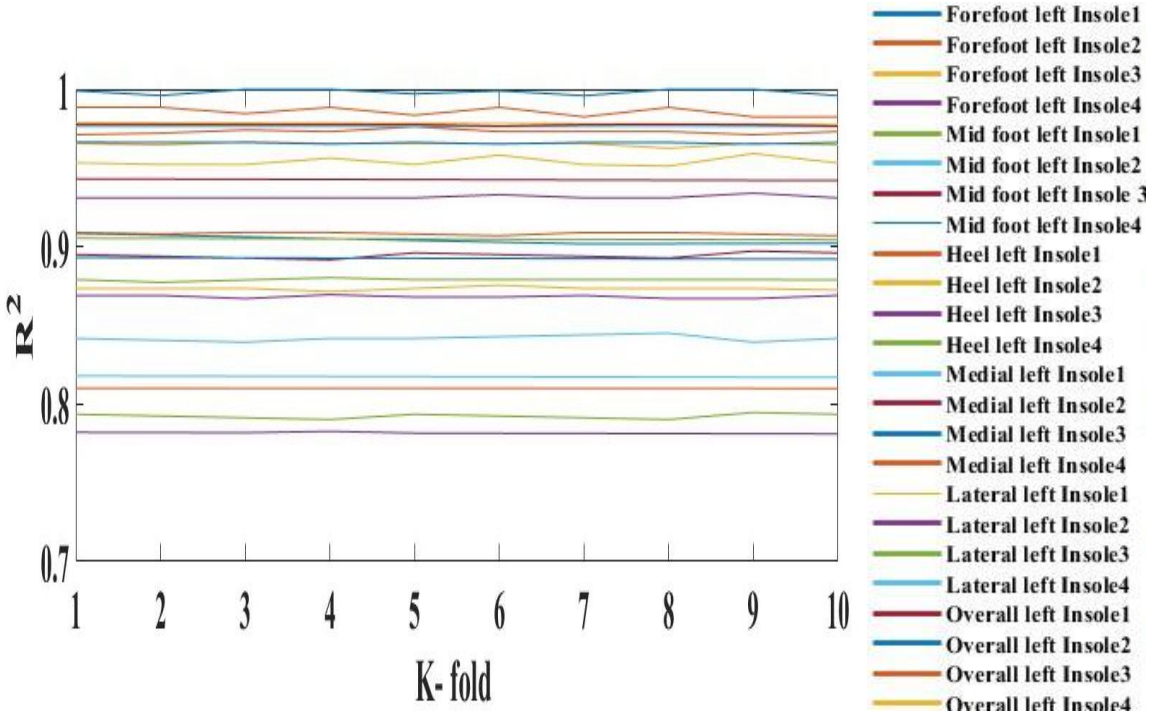


Figure 46: Coefficient of determination left foot

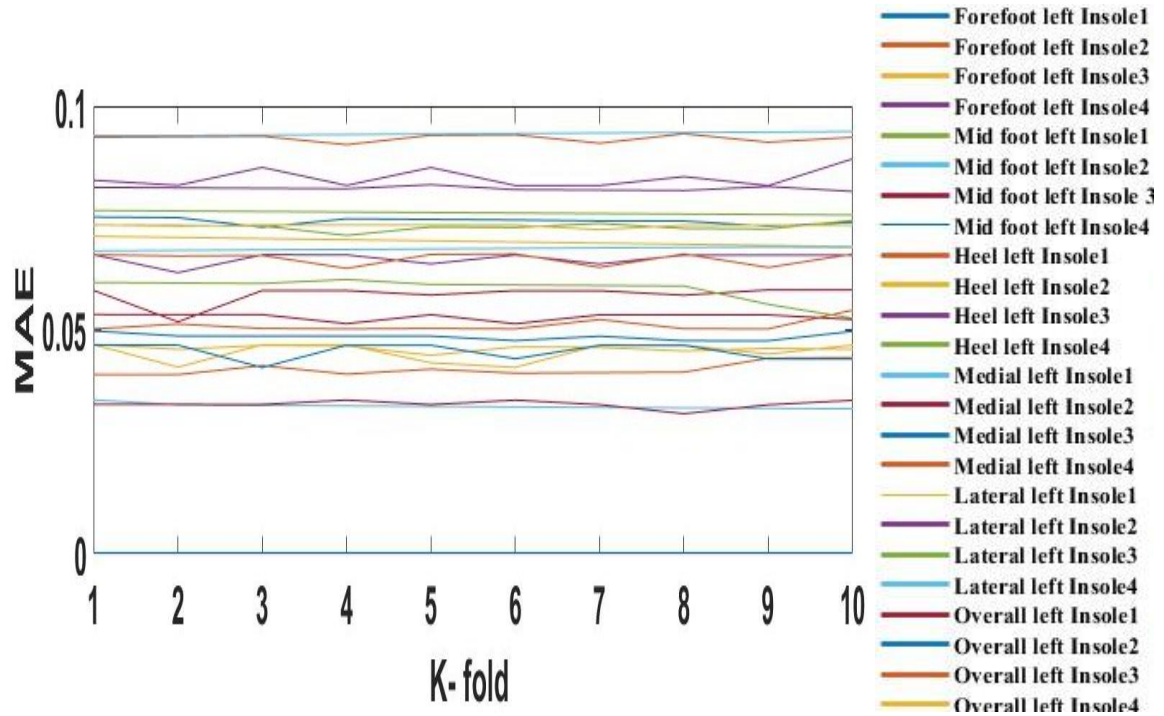


Figure 47: Mean absolute error (MAE) left foot

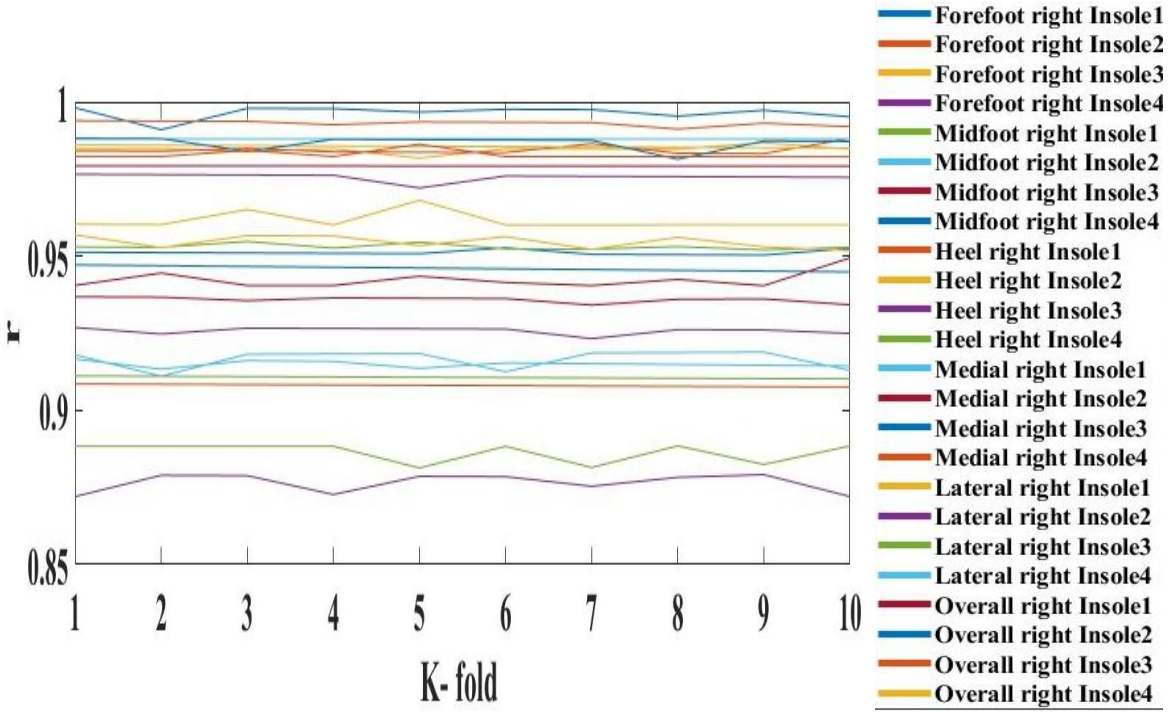


Figure 48: Correlation coefficient right foot

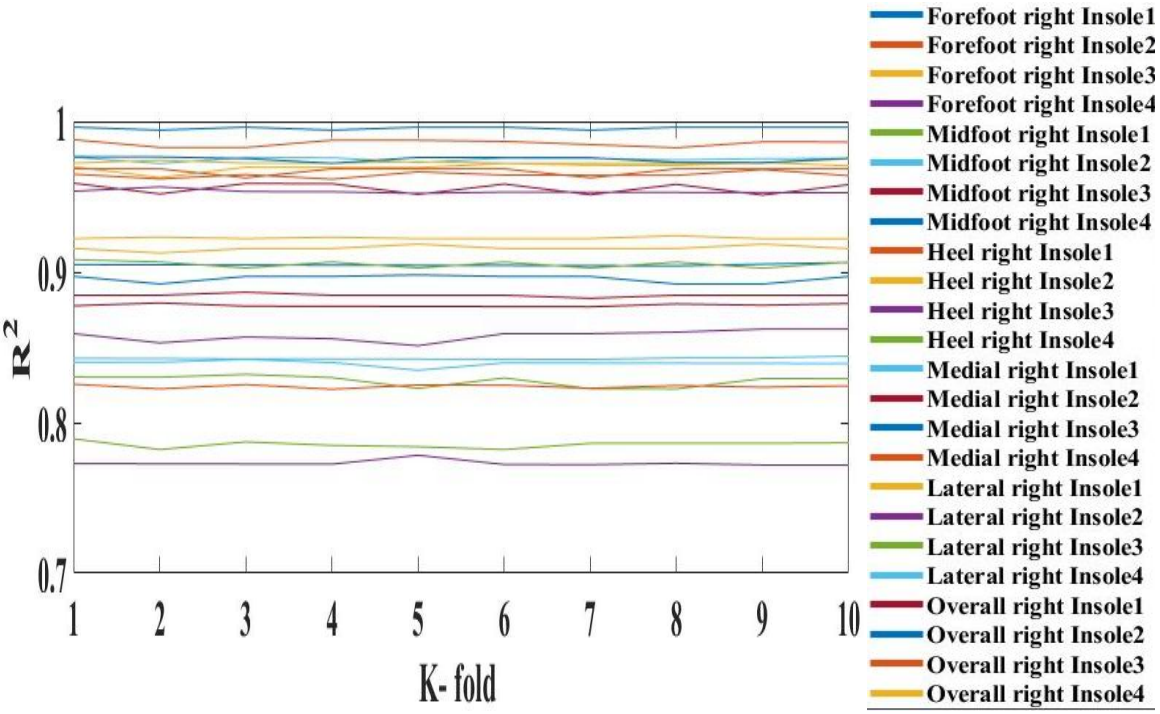


Figure 49: Coefficient of determination right foot

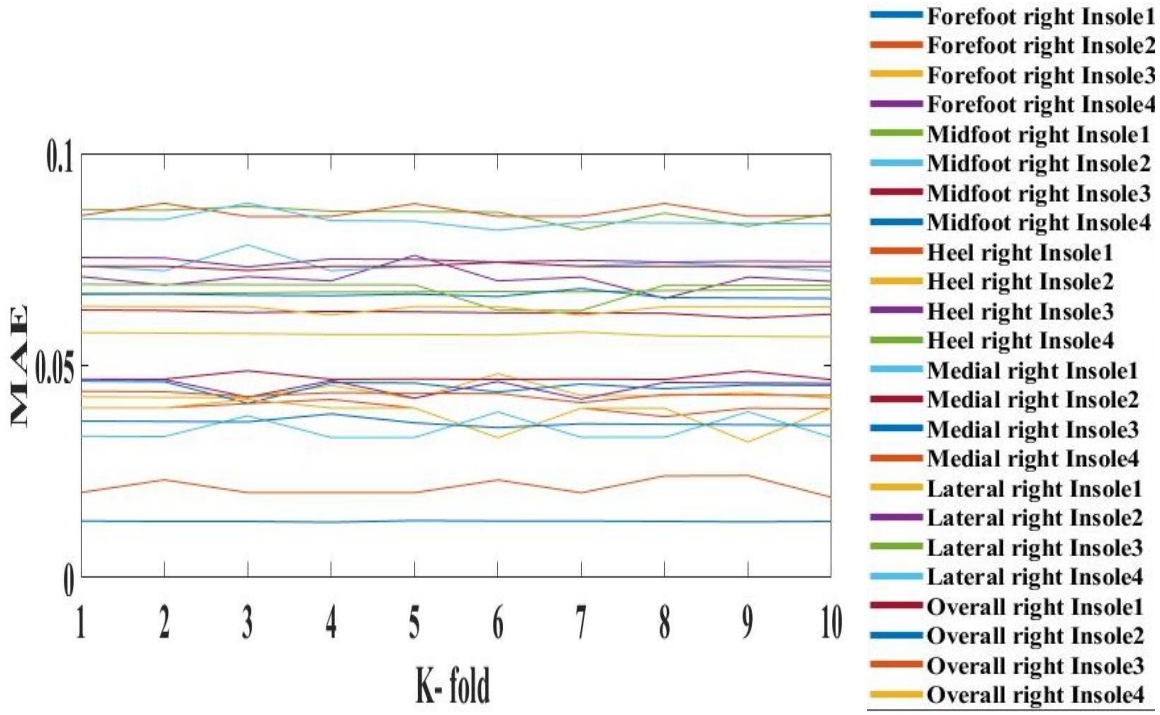


Figure 50: Mean absolute error (MAE) right foot

Table 55: Mean of Ten k- fold values

Forefoot left	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9999991**	0.9854349	0.9826098	0.9322064
R^2	**0.9999982**	0.9710820	0.9655220	0.8690088
MAE	**0.0001450**	0.0502288	0.0709305	0.0818593
Forefoot Right	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9981020**	0.9939059	0.9848216	0.9268650
R^2	**0.9962076**	0.9878490	0.9698737	0.8590787
MAE	**0.0133699**	0.0200782	0.0426196	0.0709509
Mid foot left	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	0.8908095	0.9174560	0.9460227	**0.9531173**
R^2	0.7935415	0.8417255	0.8949590	**0.9084327**
MAE	0.0766868	0.0676613	0.0588343	**0.0497695**
Mid foot Right	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	0.8883893	0.9179723	0.9367968	**0.9512564**
R^2	0.7892356	0.8426732	0.8775882	**0.9048888**
MAE	0.0867026	0.0734369	0.0630784	**0.0463076**
Heel left	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9942400**	0.9758193	0.8843289	0.9514835
R^2	**0.9885132**	0.9522234	0.7820376	0.9053208
MAE	**0.0400367**	0.0467763	0.0606037	0.0834300
Heel Right	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9841396**	0.9603174	0.8790642	0.9111903
R^2	**0.9685307**	0.9222094	0.7727538	0.8302677
MAE	**0.0400386**	0.0577551	0.0670141	0.0754434
Lateral left	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9893271**	0.9649117	0.9375640	0.9044051
R^2	**0.9787680**	0.9310546	0.8790262	0.8179486
MAE	**0.0467023**	0.0668098	0.0734568	0.0934436
Lateral Right	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9860557**	0.9765457	0.9530009	0.9166365
R^2	**0.9723058**	0.9536416	0.9082108	0.8402225
MAE	**0.0400428**	0.0467764	0.0691182	0.0845106
Medial left	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9880829**	0.9711196	0.9450215	0.9000358
R^2	**0.9763078**	0.9430733	0.8930656	0.8100644
MAE	**0.0333721**	0.0534423	0.0752227	0.0930564
Medial Right	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9880165**	0.9792766	0.9471595	0.9085802
R^2	**0.9761766**	0.9589826	0.8971111	0.8255179
MAE	**0.0333712**	0.0467867	0.0667895	0.3533002
Overall left	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	**0.9887203**	0.9829825	0.9534316	0.9346236
R^2	**0.9775678**	0.9662545	0.9090319	0.8735213
MAE	**0.0333715**	0.0466281	0.0667927	0.0734938
Overall Right	**Insole 1**	**Insole 2**	**Insole 3**	**Insole 4**
Correlation	0.9405247	0.9812033	0.9568806	**0.9823207**
R^2	0.8845867	0.9765457	0.9156206	**0.9849539**
MAE	0.0733745	0.0569352	0.0639352	**0.0439352**

Table 55 demonstrates that for forefoot left, insole1 having correlation coefficient was 0.999, R^2 is 0.999 and MAE is 0.000145. It was discovered that insole1 better for forefoot left. Also, for forefoot right connection coefficient is 0.998, R^2 is 0.996 and MAE is 0.0133. It was found that insole1 better for forefoot right. For the midfoot left, insole4 having correlation coefficient was 0.953, R^2 is 0.9084 and MAE is 0.049. It clearly shows insole4 better for the midfoot left. So also, for midfoot right correlation coefficient is 0.951, R^2 is 0.904 and MAE is 0.046. It justifies that insole4 better for the midfoot right. For heel left, insole1 having correlation coefficient was 0.994, R^2 is 0.988 and MAE is 0.040. It was found that insole1 better for heel left. Additionally, for heel right correlation coefficient is 0.984, R^2 is 0.968 and MAE is 0.040. It was discovered that insole1 better for heel right. For the lateral left, insole1 having correlation coefficient was 0.989, R^2 is 0.978 and MAE is 0.046. It was found that insole1 better for the lateral left. Similarly, for lateral right correlation coefficient is 0.986, R^2 is 0.972 and MAE is 0.040. It was found that insole1 better for the lateral right. Medial left, insole1 having correlation coefficient was 0.988, R^2 is 0.976 and MAE is 0.033. It was found that insole1 better for the Medial left. So also, for medial right correlation coefficient is 0.988, R^2 is 0.976 and MAE is 0.033. It demonstrates that insole1 better for the Medial right. Overall left, insole1 having correlation coefficient was 0.988, R^2 is 0.977 and MAE is 0.033. It was found that insole1 better for the overall left. Additionally, if there should be an occurrence of insole4 for overall right correlation coefficient is 0.982, R^2 is 0.964 and MAE is 0.043. It plainly demonstrates that insole4 better for the overall right.

Table 56: Mean Comparison of predicted and actual values

Insole 1		Insole 2		Insole 3		Insole 4	
Predicted	**Measured**	**Predicted**	**Measured**	**Predicted**	**Measured**	**Predicted**	**Measured**
4	4.01	3.59	3.67	3.8	3.88	3.58	3.61

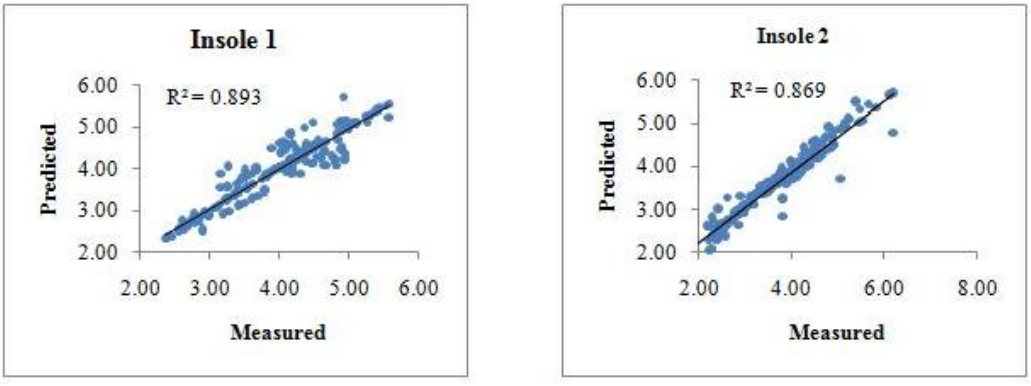


Figure 51: Data fitting of insole 1 and insole 2

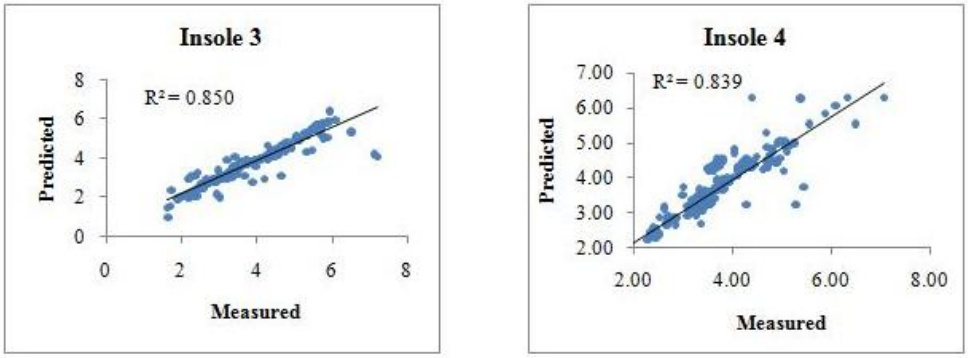


Figure 52: Data fitting of insole 3 and insole 4

Figure 51 and 52 demonstrates that data fitting of prediction and measured esteems. It was discovered that for anticipating the information, insole1 having a superior coefficient of determination (R^2) when contrasted with another insole. The coefficient of determination (R^2) for insole1 was 0.893. Essentially, for insole 1, 2, and 3 coefficient of determination (R^2) were 0.869, 0.850 and 0.839 respectively.

5.5 CHAPTER SUMMARY

To summarise the chapter, Machine learning model was done on Kistler power and Voxel care foot scan insole data. It was observed that for Kistler force plate data lightweight shoe was better in case stand, walking experimentally and prediction. Similiary, For Voxel care foot scan insole insole1, was better for forefoot(left/right), heel(left/right), medial(left/right), lateral(left/right) and overall(left). It was found that insole4 was better for midfoot(left/right) and overall(right).

6.1 CONCLUSION

The data obtained from the experiment has been analyzed and depending upon this data a predictive model using ANN has been developed.

6.1.1 FOR FORCE PLATE

- The study aimed to develop an ANN model to predict gait parameters based upon the inputs that were fixed to be Human weight, Human height and Shoes weight. The study can be said to be successful because the majority of the parameters are in sync with the experimentally evaluated data. Overall the model is in harmony with lightweight shoes as compared to the results depicted by heavyweight shoes in both experimental and prediction.
- Data proved that in case of the balance and walking, indicates that higher COP, Forces and Power when wearing HWS.

6.1.2 FOR FOOT SCAN INSOLE

- The study expected to develop an ANN model to predict gait parameters based upon the significant inputs parameters with pressure. The study can be said to be successful because significant parameters are in a state of harmony with the experimentally evaluated information. In case of lightweight shoes with insole1 when comparison with the outcomes portrayed by another insole in both experimental and prediction is better.
- From data shows in case of walking, shows less pressure when wearing LWS with insole1 as comparison with another.

6.2 FUTURE WORK

- Experiments with a larger domain of parameters can be performed to achieve better results.

- Same experiments work can be done during walking and stand under loading conditions.

- Force plate another parameters should to be utilized for future work.

- Another machine learning model can be used and comparative study could be performed.

- The study to reduce the weight of insole could be performed.

- Experiments with same parameters should be possible at various gradients.

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List of Publications

[1] Kamalpreet Sandhu., Vineet Srivastava., Madhusudhan Pal., "A review of force measurement methodologies used in smart insole system during gait analysis", Fipshysiocon International Conference, New Delhi, November 5-7, 2017. [Published]

Paper to be communicated

Investigation of Forces and Power excreted on feet during Gait Analysis using Artificial Neural Networks

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Abstract- This study has been conducted to predict the forces and power excreted on the feet during Gait analysis. The weight of the human, the height of the human and weight of the shoe were the input process parameters for this study. 10 subjects were observed with two types of shoes namely heavyweight shoes and lightweight shoes. The data for the gait analysis was obtained by Kistler Force Plate System. In order to predict the accuracy of the measurements, Artificial Neural Network (ANN) has been used to analyze in swing and stance phase. The robustness of the model has been verified through 10 cross-validation method (k-fold). It was observed that the coefficient of determination (R^2) was 78.2% for heavyweight shoes and 98.28% for lightweight shoes in medial-lateral direction (Fx). Similarly, it was 82.8% for heavyweight shoes and 87.1% for lightweight shoes in the anterior-posterior direction (Fy). For vertical direction (Fz) the values were 83.9% for heavyweight shoes and 92.1% in lightweight shoes. It has been observed that R^2 value for power was 87.9% for heavyweight shoes and 96.6% for lightweight shoes.

Modelling of Pressure absorbed by feet during walking using Machine Learning

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Abstract- To predict pressure the Artificial Neural Network has been used to develop the model in the swing and stance phase, hence validating the predicted parameter values with experimental ones. 18 subjects were observed with four types of insoles having different materials with lightweight shoes. Analysis of variance (ANOVA) has been used for selecting the input parameters. The robustness of the model has been certified through a ten cross-validation method (K-fold). Four types of insoles namely PU (Insole 1), Viscoelastic (Insole 2), PU1 (Insole 3) and Silicon rubber (Insole 4) have been used in this study. R^2 for the pressure were 89.3%, 86.9%, 85% and 83% in Insole1, 2, 3 and 4 respectively. The outcomes of this research were tested with further subjects and results were found to be in close proximity.

Kamal Thesis

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