Evaluation of Gait Asymmetry by Mapping Pressure on the Basis of Body Mass Index

Author

Maria Rashid

Registration Number

00000206346

Supervisor

Dr. Umar Ansari

Department of Biomedical Engineering and Sciences

School of Mechanical & Manufacturing Engineering

National University of Sciences and Technology

H-12, Islamabad, Pakistan

March, 2020

Evaluation of Gait Asymmetry by Mapping Pressure on the Basis of Body Mass Index

Author

Maria Rashid

Registration Number

00000206346

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

Biomedical Science

Thesis Supervisor

Dr. Umar Ansari

Thesis Supervisor's Signature: ________________________________

Department of Biomedical Engineering and Sciences

School of Mechanical & Manufacturing Engineering

National University of Sciences and Technology

H-12, Islamabad, Pakistan

March, 2020

FORM TH-4

National University of Sciences and Technology

MASTER THESIS WORK

We hereby recommend that the dissertation prepared under our supervision by **Maria Rashid Registration No. 00000206346** titled **Evaluation of Gait Asymmetry by Mapping Pressure on the basis of Body Mass Index** be accepted in partial fulfillment of the requirements for the award of MS Biomedical Sciences degree with Grade (___)

Examination Committee Members

1. Name: Dr. Omer Gilani Signature:_______________

2. Name: Dr. Asim Waris Signature:_______________

Supervisor's name: Dr. Umar Ansari Signature:_______________

Date:___________________

________________________ _________________

Head of Department Date

COUNTERSIGNED

Date: _______________ _____________________

Dean/Principal

Thesis Acceptance Certificate

It is certified that final copy of MS thesis written by MARIA RASHID Registration No. 00000206346 of SMME has been vetted by undersigned, found complete in all aspects as per NUST Statutes/Regulations, is free of plagiarism, errors and mistakes and is accepted as partial fulfillment for the award of MS degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said dissertation.

Signature with stamp: ______________________

Name of the supervisor: Dr. Umar Ansari

Date: __________________

Signature of HoD with stamp: __________________

Date: __________________

Countersigned by

Dean/Principal

Signature: ________________

Date: ____________________

Declaration

I certify that this research work titled *"Evaluation of Gait Asymmetry by Mapping Pressure on the Basis of Body Mass Index"* is my own work. The work has not presented elsewhere for assessment. The material that used from other sources in this work has been properly acknowledged and referenced.

Signature of Student

Maria Rashid

00000206346

Plagiarism Certificate (Turnitin Report)

This thesis has been checked for plagiarism. Turnitin report endorsed by supervisor is attached at the end of this report.

Signature of Student

Maria Rashid

Registration Number

00000206346

Signature of Supervisor

Dr. Umar Ansari

Copyright Statement

Acknowledgements

Firstly, I am thankful to my creator Allah Almighty. I would like to express heartfelt gratitude to my parents as they always supported me and never let my passion die out. I can never pay back for their unconditional support and love.

I would like to thank my supervisor, Dr. Umar Ansari, for his guidance and time throughout the duration of this project. Without his support and feedback, I wouldn’t have been able to complete my project. I am, also, thankful to Dr. Omer Gilani and Dr. Asim Waris for the assistance they provided.

Moreover, I would like to thank my lab fellows especially Hassan Nawazish for providing his help to develop the electronic components and Ahmad Subhani for helping me to debug Bluetooth connection errors. I highly appreciate their time and contribution.

Last but never the least, I am extremely thankful to all the subjects who participated in this study and made me achieve my goal. Without them, it would have never been possible.

Dedicated to my parents for their tremendous support and cooperation

Mr. and Mrs. Muhammad Rashid

Abstract

Gait symmetry, synonymously, called as normal walking is the notion that bilateral aspects of the lower limbs are identical. Any mismatch or lack of coordination results in an asymmetric gait pattern which often serves as an indicator of gait pathology. Quantification of gait asymmetry by an index, difference or ratio calculation has been done by using various sensing. For the sake of present study, we developed a cost-effective and portable system consisting of an insole. The insole is equipped with force-sensitive resistors at the points of maximum plantar pressure for extracting spatiotemporal features of gait. For assessment of asymmetry, we recruited subjects with BMI in underweight range (> 18.5), normal range (18.0-24.9), overweight range (25.0-29.9) and obese range (<30.0). Asymmetry has been quantified by using temporal parameters particularly swing time. The mean swing of right and left foot was used to determine the ratio of short swing time (SSWT) and long swing time (LSWT). The ration was, then, used to calculate gait asymmetry of all the groups. Degree of asymmetry showed a direct proportionality with BMI of subjects. For further analysis, one-way ANOVA was performed. Results showed that BMI has a statistically significant effect with F-value (3, 46) = 8.62, $p < 0.05$ on the overall walking pattern of humans. This system can be further used to assess gait parameters in different population groups. It can, also, be used in gait training and rehabilitation protocol

Key Words:

Gait Asymmetry (GA), Swing time (SW), Force-sensitive resistors (FSRs)

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Human gait has been characterized as one of the complex, cyclic and coordinated neuromuscular processes of motor control. This makes it vulnerable for diseases affecting motor abilities. Also, several other physiological and anatomical factors seem to be associated with gait disorders. Generally, it is maintaining balance followed by three main components. These include initiation of locomotion, maintenance of rhythmic stepping and the ability to adapt to the environmental changes. Any disturbances in the these three components could cause gait abnormalities (Snijders, Warrenburg, Giladi, & Bloem, 2007). Gait disorders caused by Parkinson's disease, epilepsy and various other neurological defects have been summarized by Snijders et al. (2007) and classified into different types based on clinical signs and symptoms.

Gait analysis serves as an important measure in assessing the underlying defects thus guiding clinical decisions and assessing rehabilitation outcomes. Previously, the pattern of walking has been characterized as an indicator of life's quality and functional status (Perry, Garrett, Gronley, & Mulroy, 1995). But recently, the asymmetry parameters are taken more into account for a detailed insight into gait analysis (Bowden, Balasubramanian, Neptune, & Kautz, 2006).

Symmetry has been defined as the lack of statistically evident differences between lower limbs during able-bodied gait. Physiological and anatomical factors are, somewhat, taken into account while quantifying gait symmetry (Sadeghi, Allard, Prince, & Labelle, 2000). Assessment of asymmetry is important as it may have certain risk factors associated with it. These may include challenges to balance control, deterioration of bone mass density in paretic limb and musculoskeletal injury in the non-paretic limb (Jørgensen, Crabtree, Reeve, & Jacobsen, 2000). Age is also an important factor that alters spatiotemporal gait parameters. Symmetry in gait could be a valuable measure in quantification of these parameters in addition to gait velocity (Patterson, Nadkarni, Black, & McIlroy, 2012)

1.1. Background

Asymmetry in various gait parameters has been quantified by using different methods depending upon the requirement and aims of the research. Plantar pressure is one of the most widely used variable and is defined as pressure experienced on the foot's skin during routine activities and walking. Mapping of this pressure under the foot is reliable way to assess gait dysfunction. This technique utilizes two types of systems a) force platforms and b) pressure-sensitive insoles. Force platforms are typically high-frequency and high-resolution based surface mounted force mats. Commercially, this system has been provided by EMED®-SF (Novel USA, Inc., Minneapolis, MN, USA). On the other hand, commercial pressure-sensitive foot insoles have been provided by F-Scan® system (Tekscan Inc., Boston, MA, USA), Pedar® system (Novel GmbH, Germany) and Paromed® (Vertriebs GmbH & Co, Neubeuern, Germany) (Rossi et al., 2011).

Clinically, these systems provide valuable insights into different gait parameters. However, their cost and high-profile makes them limited for use in research laboratories.

1.2. Problem Statement

Gait analysis is one of the primary task in designing and training of various rehabilitation protocols. Assessment of asymmetry is important as it may have certain risk factors associated with it. The factors may include challenges to dynamic balance control, correlation with certain diseases such as knee osteoarthritis (Worsley, Stokes, Barrett, & Taylor, 2013), obesity (Ling, Kelechi, Mueller, Brotherton, & Smith, 2012) and medical conditions such as heel pain and bunions due to imbalanced joint loading. The use of piezo-resistive pressure sensors embedded in an insole has led to the development of a cost-effective and portable system for extracting spatiotemporal features of gait and quantify asymmetry.

1.3. Objectives

The prime objectives of the study are to:

- Design a cost-effective and reliable pressure mapping system
- Extract temporal gait parameters to quantify gait asymmetry

1.4. Areas of application

- Hospitals
- Prosthetic and orthotic centers
- Rehabilitation centers

1.5. Thesis overview

In this thesis, chapter 1 includes the introduction and explanation of the problem along with proposed solution. Chapter 2 includes the work that has been done in the same or related entity. Chapter 3 provides information about the design and working of the fabricated device. It contains all the methods and procedures used to develop and operate the device. Chapter 4 includes the results obtained from the device and analysis of the same results. Chapter 5 consists of the discussions of obtained results and finally a conclusion of this whole work. Chapter 6 enlists all the sources from where material has been obtained and properly referenced.

Chapter 2: Literature Review

Gait symmetry, synonymously, called as normal walking is the notion that bilateral aspects of the lower limbs are identical. Any mismatch or lack of coordination results in an asymmetric gait pattern which often serves as an indicator of gait pathology. This asymmetry could be a consequence of a disease, altered neural input and functional disability which is task-difference between dominant and non-dominant limb (Moreno Hernández, 2012). A complete gait cycle consists of two successive heel strikes of the same foot. In men, it usually lasts from 0.98-1.07 sec (Murray, Kory, & Clarkson, 1969).

2.1. Spatiotemporal Parameters

Spatiotemporal and biomechanical parameters of gait offer valuable insights into different gait patterns and classes. These include distance and time parameters.

2.1.1. Spatial parameters

Step length: The distance between points of initial contact of one foot to the initial contact of the other foot.

Stride length: The distance between points of initial contact of one foot to the initial contact of the other foot.

2.1.2. Temporal parameters

Cadence: It is defined as number of steps per unit time.

Swing time: The time during which foot is not in contact with the ground while other foot is in ground-contact.

Stance time: The time during which foot is in contact with the ground while other foot is in air

Speed: This is the distance covered by the body per unit time.

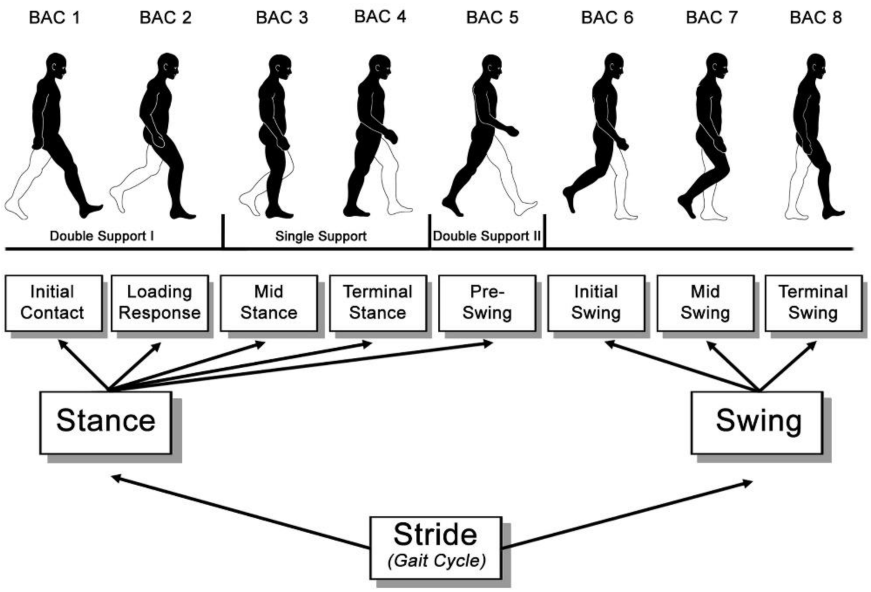


Figure 1: Functional Representation of Gait Cycle (Perry and Burnfield, 2010)

2.2. Gait Phases

Generally, there are two phases in one gait cycle a) Stance phase and b) Swing phase. Stance phase roughly comprises of 60% while swing phase makes up 40% of the one gait cycle. Sub-categories within these phases, as reviewed by different researchers, are briefly described below (Bhosale, Kudale, Kumthekar, Garude, & Dhumal, 2016).

2.2.1. Stance phase

Initial contact: The phase in which the foot touches the ground and joint patterns determine the loading pattern of limbs at this time.

Loading response: the phase which describes the initial double-stance starting with initial contact of the first foot lasting until the second foot is lifted for the swing.

Mid-stance: The phase marking the half of single-limb support time interval beginning with the lift of other foot lasting until the whole weight is shifted over the forefoot.

Terminal stance: The phase beginning with heel lifting and lasting until the other foot lands over.

Pre-swing: The phase marking the final stance beginning with initial contact of the opposite foot ending with toe-off of the first foot.

2.2.1. Swing phase

Initial swing: The phase begins with lifting of foot in the air lasting until that foot is right opposite of the stance phase.

Mid-swing: The phase in which swinging foot is opposite of the stance foot ending with swing foot being in forward direction.

Terminal swing: The phase beginning with vertical tibia and ending with the swinging foot finally landing on the floor.

2.3. Quantification of Asymmetry Parameters

The simplest method to quantify asymmetry is to find the difference between both sides of the body. In an attempt to quantify asymmetry, various equations have been developed. These equations mainly calculate a ratio, index or an angle and return values which depict degrees of asymmetry. Following two factors are important while quantifying differences between both the limbs (Patterson, Gage, Brooks, Black, & McIlroy, 2010).

A) Equations used to calculate asymmetry
    a. Index or difference calculation
    b. Ratio
B) Spatiotemporal parameters used in the equation
    a. Step length
    b. Stride length
    c. Swing time
    d. Stance time
    e. Double support time
    f. Single support time

Previously, Robinson et.al (1987) provided a symmetry index to analyze variations in ground reaction force patterns.

$$SI = \frac{(Xr - Xl)}{0.5(Xr + Xl)} \times 100\%$$

where X_r and X_l are the values measured for right and left foot respectively. The values of SI=0 reflect perfect symmetry. However, these differences depict values referred against the average value of that particular measure (Robinson, Herzog, & Nigg, 1987).

Another ratio for extraction of temporal parameters is calculated by diving mean swing times.

$$GA = 100 \times |ln\,(\frac{SSWT}{LSWT})|$$

Where SSWT and LSWT are mean value of short and long swing times for either of the limbs respectively. This equation has been used for quantifying asymmetry in patients with Parkinson’s disease and elderly fallers (Yogev, Plotnik, Peretz, Giladi, & Hausdorff, 2007). Some other variations within the ratio equation also exist as the researchers have used an angle calculation method in which angle formed between x-axis and vector of a specific gait parameter is calculated (Zifchock, Davis, Higginson, & Royer, 2008).

2.4. Correlation of Gait Asymmetry with Diseases

Comparative studies between stroke and healthy population group analyzing various gait parameters have been carried out. Walking on a pressure sensitive mat, with or without support, is a must in most of the cases. The mat is GaitRite^{TM}, CIR Systems, Clifton, NJ) consisting of a grid of sensors (Patterson et al., 2010).

Gait differences between different healthy age groups have also been studied apart from diseased cases. One study compared the gait symmetry of healthy older adults to that of patients with Parkinson’s disease and healthy young adults. The results implied that coordination between limbs significantly decreases with age and further with PD (Plotnik, Giladi, & Hausdorff, 2007).

Functional ability to do routine life activities is severely affected in people with class III obesity. Activity capacity, speed and cadence are decreased indicating a pathological gait (Ling et al., 2012).

Fibromyalgia also seemed to significantly decrease the gait speed and bilateral coordination in women. Stride length, step width, swing time and active walking speed exhibited differences and were used to quantify asymmetry (Heredia-Jimenez, Orantes-Gonzalez, & Soto-Hermoso, 2016).

2.5. Sensing Technologies to Quantify Gait Asymmetry

Ground reaction forces on plantar surface are typically measured by employing piezoelectric (Hidler, 2004), piezoresistive, capacitive transducers (Šantić, Bilas, & Lacković, 2006) and strain gauges (Faivre, Dahan, Parratte, & Monnier, 2004).

Piezoresistive, piezoelectric and capacitive motion sensors mainly accelerometers have been used for measuring the motion during human gait analysis. Accelerometers were attached with lower limbs and to find linear velocity components (Zeng & Zhao, 2011). For calculating angular velocity, gyroscopes have been used to determine posture of a segment of lower body to determine features of gait (Catalfamo, Ghoussayni, & Ewins, 2010). Additionally, inertial sensors worn on foot were used to assess temporal parameters while running based on initial and final contact (Falbriard, Meyer, Mariani, Millet, & Aminian, 2018).

Technologically advanced sensing fabrics were used for plantar pressure measurements. The fabric consisted of a sensing array providing high-pressure sensitivity in both static and dynamic measurements (Shu et al., 2010). Electronic components used in sensing fabric technology are either place on the surface of fabrics where sensors are embedded or the electronic components are made from fabric materials. This technology was primarily developed to enhance comfortability during measurements of posture and movement. Carbon-based polymers embedded in stretchable fabrics have been used for gait analysis (Tognetti, Bartalesi, Lorussi, & De Rossi, 2007).

In another study, magnetoresistive sensors were used to determine orientation changes in the body relative to magnet's or vertical axes (O'Donovan, Kamnik, O'Keeffe, & Lyons, 2007). Moreover, goniometers of various types to measure changes in spinal motion and human posture have been employed. One of the research groups determined the motion of knee joint by measuring the displacement of two wires in longitudinal axis (Roduit, Besse, & Micallef, 1998).

Surface electromyography has been a common practice for the indirect estimation of gait features by monitoring underlying muscles' activity. Walking performance can be easily assessed by using EMG-based sensors for detecting anomalies in the lower limbs (Rainoldi, Melchiorri, & Caruso, 2004).

2.6. Extraction of Gait features by Neural Networking

Algorithm-based extraction of gait features by using a specific sensor has been a common practice since then. The approach has been used by many researchers and across many categories (Godfrey, Del Din, Barry, Mathers, & Rochester, 2015).

Algorithm-based gait analysis to improve accuracy is the best alternate to video camera-based gait detection. Double-sided fourier correction based on spatial-temporal HOG for motion estimation has been used. The said algorithm has been used to detect different gait motion angles (Liu, Zhong, & Li, 2019).

Neural network model, particularly deep neural network (DNN) model, for predicting temporo-spatial parameters from foot characteristics has been used widely (Mun, Song, Chun, & Kim, 2018).

Chapter 3: Methodology

The methodology followed for this study comprised of various modules which included

- Device design and manufacturing
- Data Acquisition
- Data Analysis

3.1. Design and Manufacturing

Pressure mapping by using various types of sensors have been in practice. Using pressure sensitive mats, force plates and motion capture systems has been used for extracting different components in gait cycle and deriving medical observations (Bamberg, Benbasat, Scarborough, Krebs, & Paradiso, 2008) (Huang, Chen, Shi, & Xu, 2007). Pressure-sensitive insoles allow dynamic analysis of gait patterns as compared to force plates because measurements taken by plates are generally of barefoot without any shoes or orthoses representing single steps (Harris & Wertsch, 1994).

3.1.1. Insole Fabrication

Insole material must possess certain properties to facilitate overall experimental process. Flexibility, ease of fabrication and availability are some of the pre-requisites for the process. Because of these properties, pellite was used to fabricate insole that can easily fit within any shoe.

3.1.2. Sensor selection and specifications

Force sensitive resistors (FSRs) were used to map pattern of loading under the foot. These sensors were used due to their accurate and linear response. Moreover their flexibility makes them the ideal choice for the said purpose. The specifications of the sensors have been summarized in the following table.

Table 1: Datasheet of FSRs

Model	**IMS-C20**
Sensor type	Single point
Sensor shape	Round
Appearance diameter(width)	26mm
Induction zone diameter	20mm

Sensor length	126mm
Money length	100mm
Wire material/width/spacing	Silver/1.5mm/2.54mm
Sensor thickness	S0.25mm
Range	50g/cm^2-100kg
Terminal type	No terminal/Male terminal/Female Terminal
Working power	Type +5V, Type SmA (Max)
Sensor type	Piezoresistive
Service life	≥100000 times
Linear error	S +3%
Repeatability	S±2.5% of full scale
Hysteresis	S±4.5% of full scale
Drift	S5%/ logarithmic time scale
Reaction time	S 5uS
Range of working temperature	40°C-60°C
Temperature drift	S02%/°C

3.1.3. Sensor Calibration

Sensors were calibrated by using loads of known weights and noticing the response. Plotting the sensors data against known weights generated almost a linear curve. All of the sensors were calibrated three times to ensure repeatability and accuracy of results.

3.1.4. Sensor placement criteria

Sole of foot is divided into 4 areas important in weight bearing such heel, mid-foot, metatarsal and toe. These are the areas which adjust the body balance by supporting its weight. Plantar pressure measured at these points can be used to extract anatomical and physiological components of the lower limbs. Four sensors were placed at following points on each insole (Shu et al., 2010).

- Heel
- Lateral midfoot
- Head of first metatarsal
- Hallux

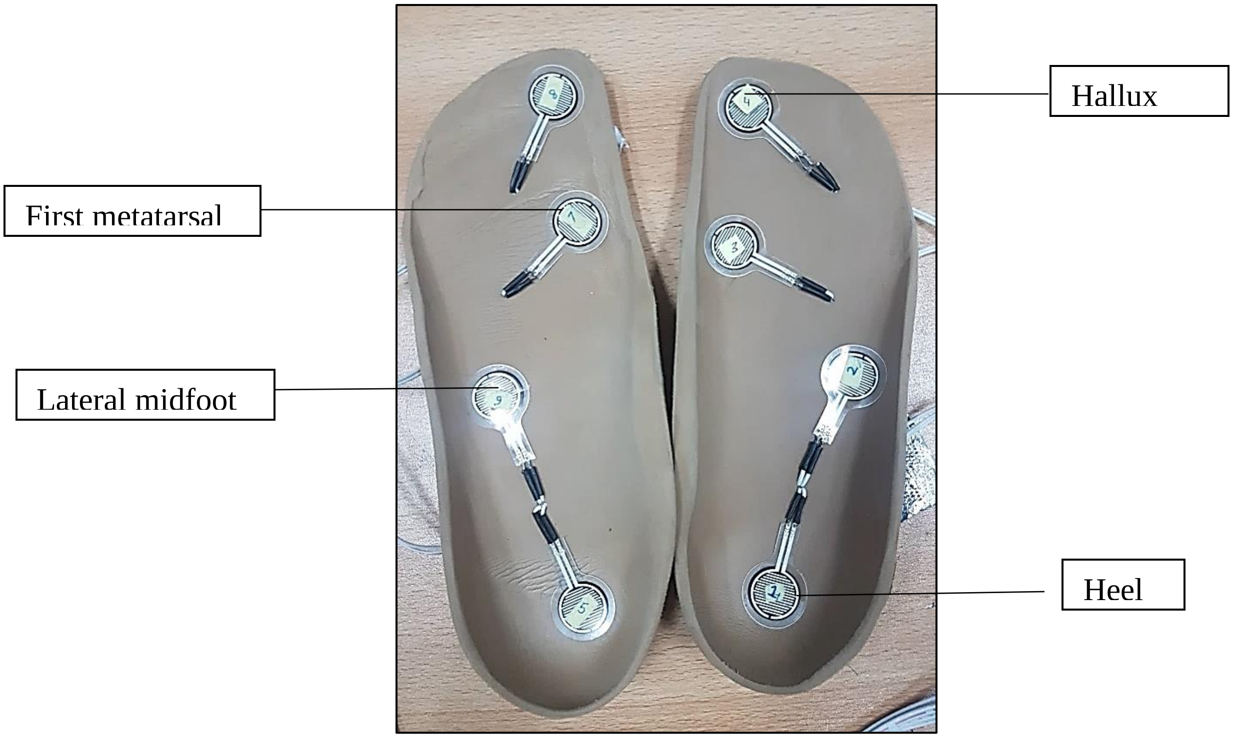


Figure 2: Labelled insole with sensors positions

3.1.5. Printed Circuit Board

Eight sensors were connected in series along with resistors of 10K ohms. Wires of sensors were connected at analog inputs channels of Arduino Mega 2560. The board was powered by using a battery of 7.4V lithium-polymer.

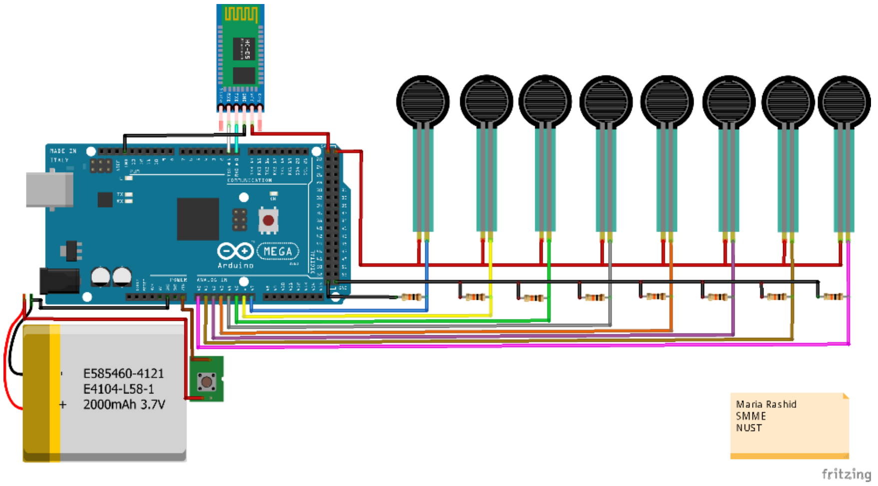


Figure 3: Circuit diagram of device

3.1.6. Data processing unit

The microcontroller used was Arduino Mega 2560. Eight analog input pins were used to interface sensors with PC. The board was powered by using a 7.4V lithium-polymer battery. The time-stamped values from sensors above set threshold values are then serially transferred to a PC and stored in a file which was then imported to MATLAB for further processing.

3.1.7. Bluetooth module

The bluetooth module used for serial interfacing is HC-05 with a baud rate of 115200. This particular module was used because of its' range and ease of use with Arduino boards. The module, in data mode, was connected to Tx/Rx pins of Arduino and paired with bluetooth of the PC for transferring data from sensor

Figure 4: Bluetooth Module HC-05

3.2. Data Acquisition

3.2.1. Data Sampling

The data was sampled at a rate of 35 samples per second for extracting temporal features of gait. The abovementioned hardware was used to fetch data from all the sensors by running code in Arduino Mega. These numerical values along with their time stamps were used for interpretation of different gait phases.

3.2.2. Experimental protocol

3.2.2.1. Inclusion and exclusion criteria

All of the subjects who participated in this research were healthy and had no history of neuromuscular or motor control disease. The subjects had no history of amputation, leg length discrepancies and idiopathic falling. The subjects had mean age of 25 ± 1 years with an almost equal ratio of men to women.

3.2.2.2. Sample size

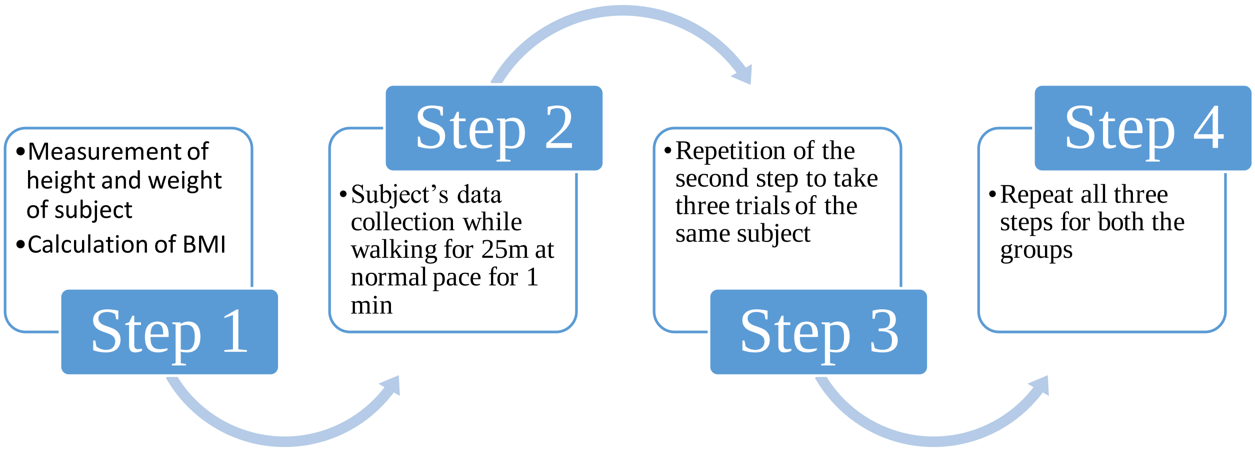
Body mass index is a calculation used to measure body fat based on weight and height of individuals. It is calculated by dividing weight in kilograms with square of height in metres. An alternative calculation method used is dividing weight in pounds by square of height in inches with a conversion factor of 703. Both of these formulas yield the same result. BMI was the classifier of all the groups in this research. These groups along with their sample sizes has been summarized in the following table.

Table 2: Sample size of various groups

Sr. No.	Category	BMI Range	Sample Size
1.	Underweight	< 18.5	5
2.	Normal weight	18.5-24.9	20
3.	Overweight	25.0-29.9	20
4.	Obese	=30.0 or greater	5

3.2.2.3. Protocol

The experimental protocol consisted of following four steps:



3.3. Data Analysis

Sensor values logged from the insole were stored in a file and imported to MATLAB R2013a for further. The time-stamped values indicating heel-strike and toe-off of the foot were extracted by using a code. Following variables were calculated by employing this system.

1. Left swing time: time of left foot in the air averaged across all strides
2. Right swing time: time of right foot averaged across all strides
3. Left swing variability: Co-efficient of variation CV: 100x SD/mean
4. Right swing variability: CV: 100xSD/mean
5. Short and long swing time SSWT and LSWT: determine which foot had shorter and longer swing times by comparing the average swing durations
6. CV values of SSWT and LSWT
7. Gait asymmetry: GA= 100 (ln |SSWT/LSWT|) (Yogev et al., 2007).

Chapter 4: Results

By employing the over mentioned methodology, swing time of right and left foot was calculated for all the subjects. This swing time was, then, used to quantify asymmetry by using the following equation (Yogev et al., 2007).

$$GA = 100 \times |\, ln\,(\frac{SSWT}{LSWT})|$$

4.1. Mean swing values

Swing phase corresponds to the time of foot when it is not in contact with the ground. The mean swing time for left and right foot are summarized in the following table:

Table 3: Mean values of swing times of right and left foot

Swing time (sec)	Underweight	Normal weight	Overweight	Obese
Right (SW_R)	0.440 ± 0.008	0.453 ± 0.011	0.448 ± 0.017	0.402 ± 0.027
Left (SW_L)	0.435 ± 0.005	0.455 ± 0.011	0.446 ± 0.013	0.427 ± 0.014

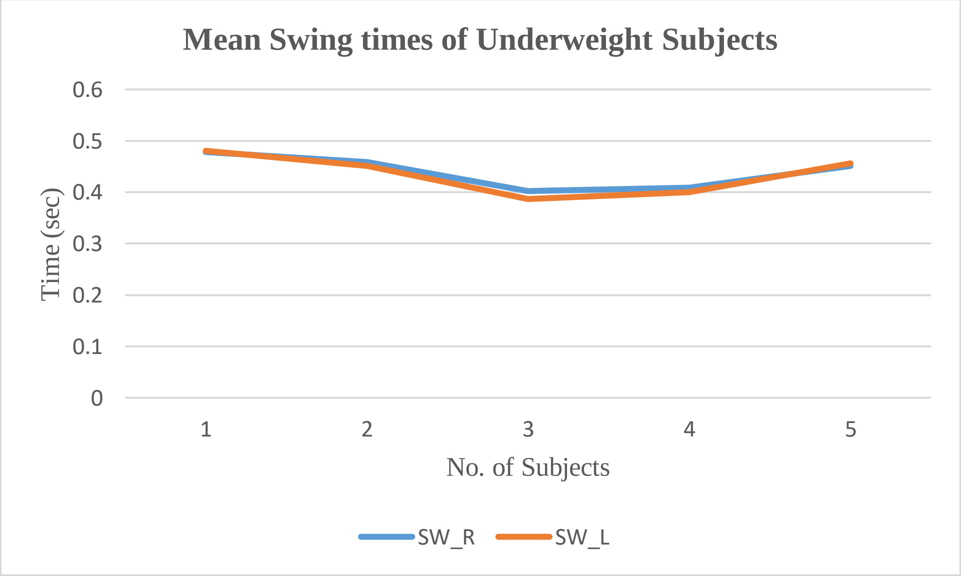


Figure 5: Underweight Subjects

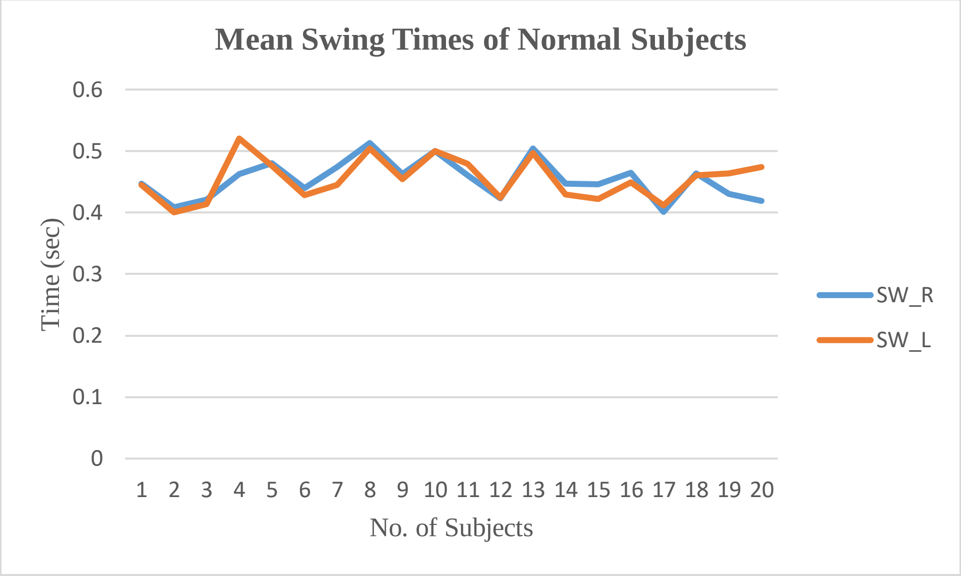


Figure 6: Normal Subjects

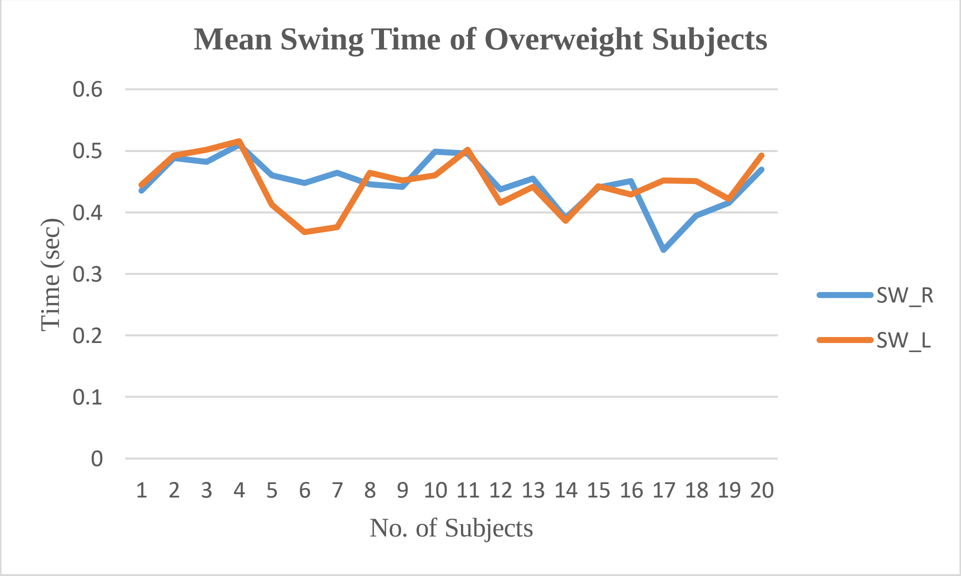


Figure 7: Overweight Subjects

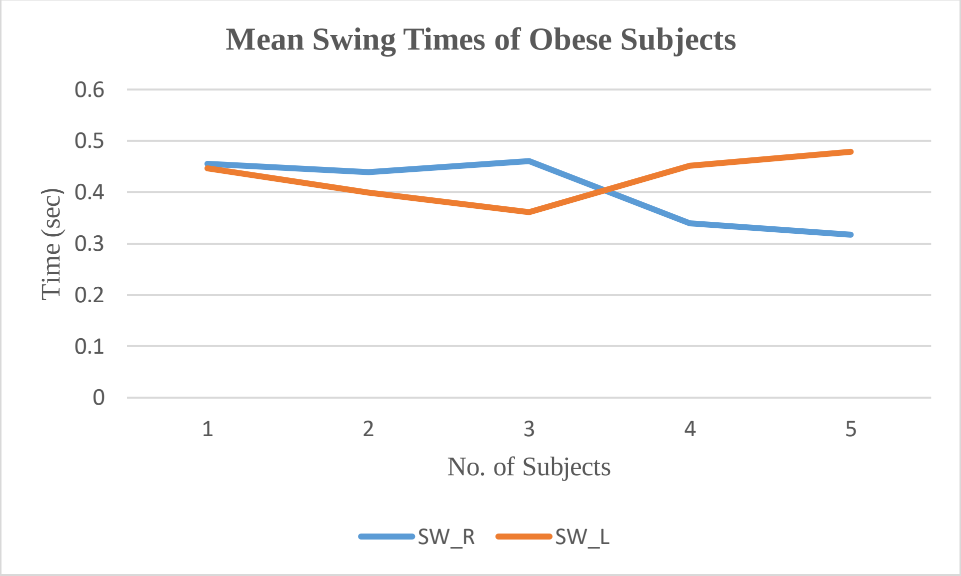


Figure 8: Obese Subjects

4.2. Short swing time and long swing time

Short (SSWT) and long swing times (LSWT) were selected by manually looking at the mean values of both the feet. A summary of SSWT and LSWT is given in the following table.

Table 4: Short swing time and long swing time of right and left foot

Swing times	Underweight	Normal weight	Overweight	Obese
Short swing time (SSWT)	0.433	0.446	0.432	0.373
Long swing time (LSWT)	0.441	0.462	0.462	0.457

4.3. Gait Asymmetry

Above-mentioned values of short and long times were used to calculate differences between lower limbs of subjects. These values were calculated by taking a ratio of short to long times for all the subjects. Various values have been observed across all the groups. These values reflected degree of gait asymmetry between lower limbs of individuals. Values closer to zero reflect a perfectly symmetric gait while values going away from zero reflect higher degrees of asymmetry. Higher values reflecting gait asymmetry in patients of motor or neurodegenerative disease lie in the range of 55-60 (Yogev et al., 2007). A brief summary of these asymmetry values for all the group is given in the following table:

Table 5: Gait Asymmetry of different groups

Sr. No:	Underweight	Normal Weight	Overweight	Obese
1.	0.491	0.421	2.131	1.953
2.	1.565	1.933	1.120	9.445
3.	3.934	1.702	3.997	24.328
4.	1.933	0.870	2.396	28.655
5.	1.157	1.815	1.156	41.138

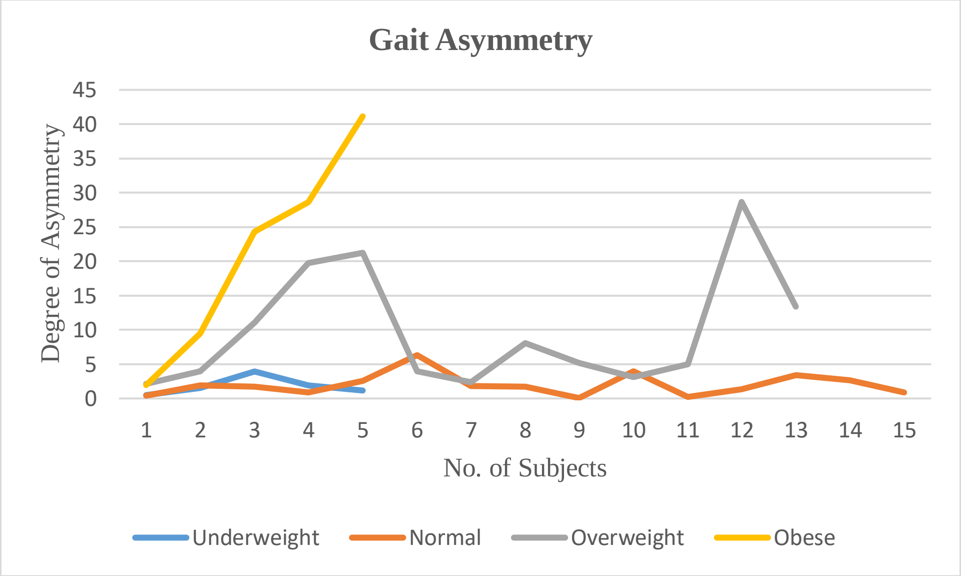


Figure 9: Gait Asymmetry of different population groups

4.4. Statistical Significance

To further verify these results and correlate gait asymmetry with body mass index, one-way ANOVA test was performed. Results showed that BMI has a statistically significant effect with F-value (3, 46) = 8.62, $p < 0.05$ on the overall walking pattern of humans. This disturbed pattern and unequal loading on the underlying joint poses major concerns and serve as a risk factors for various other medical complications.

Chapter 5: Discussions

Gait symmetry is the notion that bilateral aspects of lower limbs are identical. Any lack of coordination results in an asymmetric gait causing disturbed loading on the underlying joints in foot (Moreno Hernández, 2012). Various factors, in combination or as a whole, contribute to the origin of this asymmetry such as diseases affecting motor cortex (Hsu, Tang, & Jan, 2003) (Plotnik, Dagan, Gurevich, Giladi, & Hausdorff, 2011) , limb-length inequality (Perttunen, Anttila, Sodergard, Merikanto, & Komi, 2004) (Aiona, Do, Emara, Dorociak, & Pierce, 2015) and amputation (Schaarschmidt, Lipfert, Meier-Gratz, Scholle, & Seyfarth, 2012).

Clinical gait analysis is the major indicator of gait pathology and driver for formation of appropriate rehabilitation protocols. Up till now, two protocols were being followed for clinical gait analysis either by the visual observation of gait patterns by a clinician or by using highly accurate forces and tracking systems in established motion laboratories. First method is unreliable and qualitative but is inexpensive while the second one is expensive and cumbersome to the patient but yields quantifiable results for short distance ambulation (Bamberg et al., 2008).

With the advent of technology, many insoles and shoe based devices have been fabricated to accurately map the pressure patterns under the foot and utilize it for various purposes such as feedback (Zhu, Wertsch, Harris, Loftsgaarden, & Price, 1991) (Rossi et al., 2011) (Plauche, Villarreal, & Gregg, 2016).

For the sake of present study, an insole with FSRs at points of maximum plantar pressure has been used. The purpose of using this was to evaluate gait asymmetry in able-bodied subjects and to assess whether or not body mass index has an effect on the overall gait parameters.

Mean swing times for both the feet were employed to calculate asymmetry measures. The analysis showed a direct proportionality of BMI and gait asymmetry. Asymmetry values increased as the body weight increased w.r.t height. However, there has been evident differences in values where overweight subjects had a near-to-perfect symmetric gait and subjects with normal weight showed comparatively higher values. The device was able to quantify asymmetry of varying degrees in obese subjects. This depicts that body mass index along with another factor has an effect on the symmetry of lower limbs. Furthermore, statistical analysis of data showed a codependence of gait on height and weight of individuals with a p-value < 0.05.

5.1. Conclusion

Asymmetry in gait serves as an indicator of gait pathology and underlying medical complications. Quantification of various gait parameters has been in practice for so long by using force-sensitive mats in well-established motion labs. In an attempt to quantify asymmetry using limited resources, an insole with FSRs have been developed. The system was, then, employed for subjects' lying in different BMI ranges. Gait asymmetry increased as the body weight increased w.r.t height. The same system can be used for various other groups for research purposes.

Chapter 6: References

Aiona, M., Do, K. P., Emara, K., Dorociak, R., & Pierce, R. (2015). Gait patterns in children with limb length discrepancy. *Journal of Pediatric Orthopedics*, *35*(3), 280–284.

Bamberg, S. J. M., Benbasat, A. Y., Scarborough, D. M., Krebs, D. E., & Paradiso, J. A. (2008). Gait analysis using a shoe-integrated wireless sensor system. *IEEE Transactions on Information Technology in Biomedicine*, *12*(4), 413–423.

Bhosale, T., Kudale, H., Kumthekar, V., Garude, S., & Dhumal, P. (2016). Gait analysis using wearable sensors. *International Conference on Energy Systems and Applications, ICESA 2015*, 267–269.

Bowden, M. G., Balasubramanian, C. K., Neptune, R. R., & Kautz, S. A. (2006). Anterior Posterior Ground Reaction Forces as a Measure of Paretic Leg Contribution in Hemiparetic Walking. *Stroke*, *37*(3), 872–876.

Catalfamo, P., Ghoussayni, S., & Ewins, D. (2010). Gait Event Detection on Level Ground and Incline Walking Using a Rate Gyroscope. *Sensors*, *10*(6), 5683–5702.

Faivre, A., Dahan, M., Parratte, B., & Monnier, G. (2004). Instrumented shoes for pathological gait assessment. *Mechanics Research Communications*, *31*(5), 627–632.

Falbriard, M., Meyer, F., Mariani, B., Millet, G. P., & Aminian, K. (2018). Accurate estimation of running temporal parameters using foot-worn inertial sensors. *Frontiers in Physiology*, *9*(JUN), 1–10.

Godfrey, A., Del Din, S., Barry, G., Mathers, J. C., & Rochester, L. (2015). Instrumenting gait with an accelerometer: A system and algorithm examination. *Medical Engineering and Physics*, *37*(4), 400–407.

Harris, G. F., & Wertsch, J. J. (1994). Procedures for gait analysis. *Archives of Physical Medicine and Rehabilitation*, Vol. 75, pp. 216–225.

Heredia-Jimenez, J., Orantes-Gonzalez, E., & Soto-Hermoso, V. M. (2016). Variability of gait, bilateral coordination, and asymmetry in women with fibromyalgia. *Gait and Posture*, *45*, 41–44.

Hidler, J. (2004). Robotic-assessment of walking in individuals with gait disorders. *Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings*, *26 VII*, 4829–4831.

Hsu, A. L., Tang, P. F., & Jan, M. H. (2003). Analysis of impairments influencing gait velocity and asymmetry of hemiplegic patients after mild to moderate stroke. *Archives of Physical Medicine and Rehabilitation*, *84*(8), 1185–1193.

Huang, B., Chen, M., Shi, X., & Xu, Y. (2007). Gait event detection with intelligent shoes. *Proceedings of the 2007 International Conference on Information Acquisition, ICIA*, 579–584.

Jørgensen, L., Crabtree, N. J., Reeve, J., & Jacobsen, B. K. (2000). Ambulatory level and asymmetrical weight bearing after stroke affects bone loss in the upper and lower part of the femoral neck differently: bone adaptation after decreased mechanical loading. *Bone*, *27*(5), 701 707.

Ling, C., Kelechi, T., Mueller, M., Brotherton, S., & Smith, S. (2012). Gait and function in class III obesity. *Journal of Obesity*, *2012*.

Liu, G., Zhong, S., & Li, T. (2019). Gait recognition method of temporal–spatial HOG features in critical separation of Fourier correction points. *Future Generation Computer Systems*, *94*, 11–15.

Moreno Hernández, A. (2012). *Using measures of external work to assess the degree of gait symmetry*. (November).

Mun, K. R., Song, G., Chun, S., & Kim, J. (2018). Gait Estimation from Anatomical Foot

Parameters Measured by a Foot Feature Measurement System using a Deep Neural Network Model. *Scientific Reports*, *8*(1), 13–15.

Murray, M. P., Kory, R. C., & Clarkson, B. H. (1969). Walking Patterns in Healthy Old Men. *Journal of Gerontology*, *24*(2), 169–178.

O'Donovan, K. J., Kamnik, R., O'Keeffe, D. T., & Lyons, G. M. (2007). An inertial and magnetic sensor based technique for joint angle measurement. *Journal of Biomechanics*, *40*(12), 2604–2611.

Patterson, K. K., Gage, W. H., Brooks, D., Black, S. E., & McIlroy, W. E. (2010). Evaluation of gait symmetry after stroke: A comparison of current methods and recommendations for standardization. *Gait & Posture*, *31*(2), 241–246.

Patterson, K. K., Nadkarni, N. K., Black, S. E., & McIlroy, W. E. (2012). Gait symmetry and velocity differ in their relationship to age. *Gait and Posture*, *35*(4), 590–594.

Perry, J., Garrett, M., Gronley, J. K., & Mulroy, S. J. (1995). Classification of walking handicap in the stroke population. *Stroke*, *26*(6), 982–989.

Perttunen, J. R., Anttila, E., Sodergard, J., Merikanto, J., & Komi, P. V. (2004). Gait asymmetry in patients with limb length discrepancy. *Scandinavian Journal of Medicine and Science in Sports*, *14*(1), 49–56.

Plauche, A., Villarreal, D., & Gregg, R. D. (2016). A Haptic Feedback System for Phase-Based Sensory Restoration in Above-Knee Prosthetic Leg Users. *IEEE Transactions on Haptics*, *9*(3), 421–426.

Plotnik, M., Dagan, Y., Gurevich, T., Giladi, N., & Hausdorff, J. M. (2011). Effects of cognitive function on gait and dual tasking abilities in patients with Parkinson's disease suffering from motor response fluctuations. *Experimental Brain Research*, *208*(2), 169–179.

Plotnik, M., Giladi, Æ. N., & Hausdorff, Æ. J. M. (2007). *RESEARCH ARTICLE A new measure* *for quantifying the bilateral coordination of human gait : effects of aging and Parkinson ' s disease*.

Rainoldi, A., Melchiorri, G., & Caruso, I. (2004). A method for positioning electrodes during surface EMG recordings in lower limb muscles. *Journal of Neuroscience Methods*, *134*(1), 37–43.

Robinson, R. O., Herzog, W., & Nigg, B. M. (1987). Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *Journal of Manipulative and Physiological Therapeutics*, *10*(4), 172–176.

Roduit, R., Besse, P. A., & Micallef, J. P. (1998). Flexible angular sensor. *IEEE Transactions on Instrumentation and Measurement*, *47*(4), 1020–1022.

Rossi, S. M. M. De, Lenzi, T., Vitiello, N., Donati, M., Persichetti, A., Giovacchini, F., Carrozza, M. C. (2011). Development of an in-shoe pressure-sensitive device for gait analysis. *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 5637–5640.

Sadeghi, H., Allard, P., Prince, F., & Labelle, H. (2000). Symmetry and limb dominance in able bodied gait: A review. *Gait and Posture*, *12*(1), 34–45.

Šantić, A., Bilas, V., & Lacković, I. (2006). A system for measurement forces in feet and crutches during normal na pathological gait. *Periodicum Biologorum*, *104*(3), 305–310.

Schaarschmidt, M., Lipfert, S. W., Meier-Gratz, C., Scholle, H. C., & Seyfarth, A. (2012). Functional gait asymmetry of unilateral transfemoral amputees. *Human Movement Science*, *31*(4), 907–917.

Shu, L., Hua, T., Wang, Y., Li, Q., Feng, D. D., & Tao, X. (2010). In-shoe plantar pressure measurement and analysis system based on fabric pressure sensing array. *IEEE Transactions on Information Technology in Biomedicine*, *14*(3), 767–775.

Snijders, A. H., Warrenburg, B. P. Van De, Giladi, N., & Bloem, B. R. (2007). *Neurological gait* *disorders in elderly people : clinical approach and classifi cation*. *6*(January), 63–74.

Tognetti, A., Bartalesi, R., Lorussi, F., & De Rossi, D. (2007). Body segment position reconstruction and posture classification by smart textiles. *Transactions of the Institute of Measurement and Control*, *29*(3–4), 215–253.

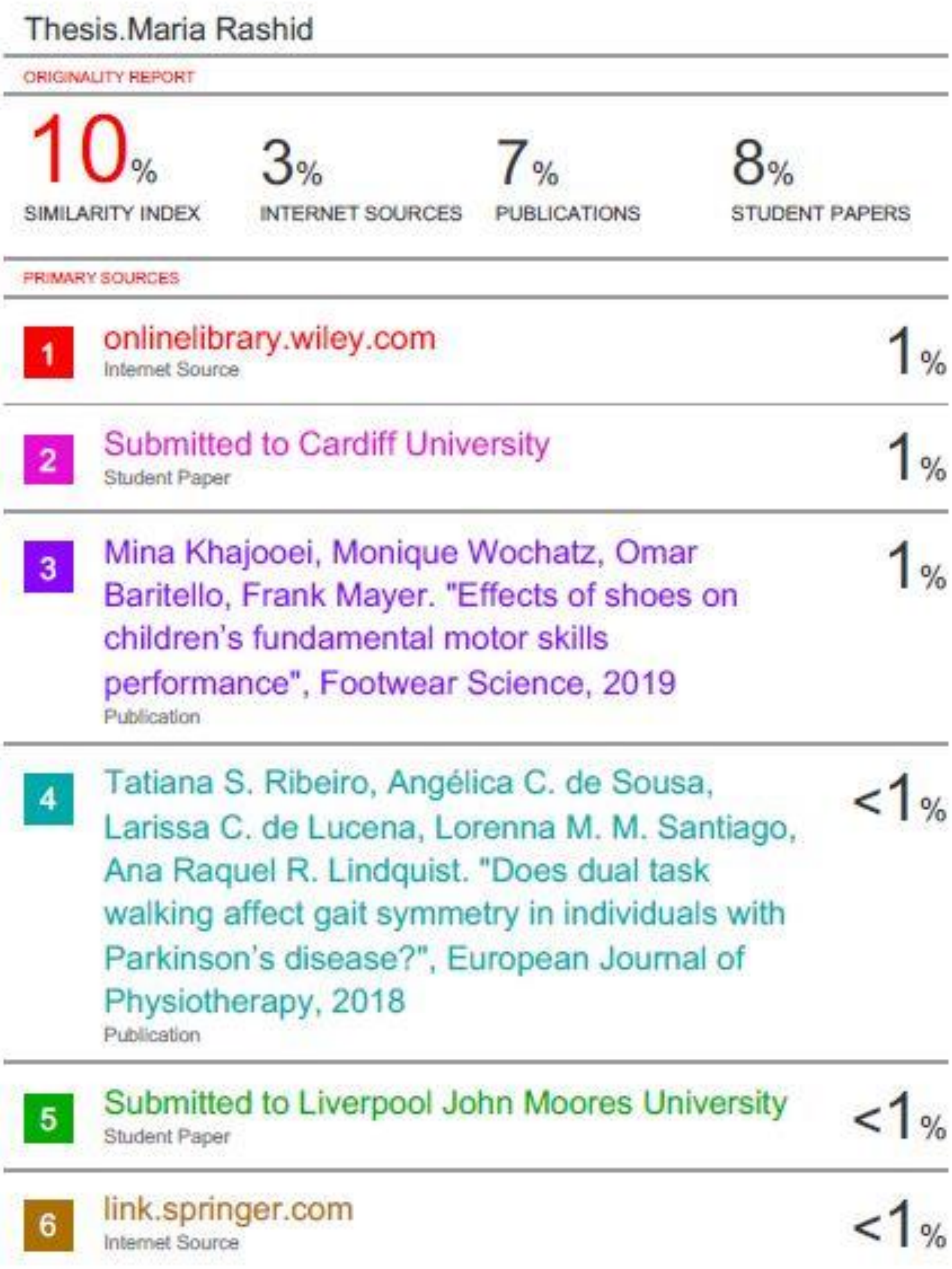
Worsley, P., Stokes, M., Barrett, D., & Taylor, M. (2013). Joint loading asymmetries in knee replacement patients observed both pre- and six months post-operation. *Clinical Biomechanics*, *28*(8), 892–897.

Yogev, G., Plotnik, M., Peretz, C., Giladi, N., & Hausdorff, J. M. (2007). Gait asymmetry in patients with Parkinson's disease and elderly fallers: When does the bilateral coordination of gait require attention? *Experimental Brain Research, 177*(3), 336–346.

Zeng, H., & Zhao, Y. (2011). Sensing Movement: Microsensors for Body Motion Measurement. *Sensors, 11*(1), 638–660.

Zhu, H., Wertsch, J. J., Harris, G. F., Loftsgaarden, J. D., & Price, M. B. (1991). Foot pressure distribution during walking and shuffling. *Archives of Physical Medicine and Rehabilitation*, *72*(6), 390–397.

Zifchock, R. A., Davis, I., Higginson, J., & Royer, T. (2008). The symmetry angle: A novel, robust method of quantifying asymmetry. *Gait & Posture, 27*(4), 622–627.



Thesis.Maria Rashid

ORIGINALITY REPORT

10%	3%	7%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	onlinelibrary.wiley.com Internet Source	1%
2	Submitted to Cardiff University Student Paper	1%
3	Mina Khajooei, Monique Wochatz, Omar Baritello, Frank Mayer. "Effects of shoes on children's fundamental motor skills performance", Footwear Science, 2019 Publication	1%
4	Tatiana S. Ribeiro, Angélica C. de Sousa, Larissa C. de Lucena, Lorenna M. M. Santiago, Ana Raquel R. Lindquist. "Does dual task walking affect gait symmetry in individuals with Parkinson's disease?", European Journal of Physiotherapy, 2018 Publication	<1%
5	Submitted to Liverpool John Moores University Student Paper	<1%
6	link.springer.com Internet Source	<1%