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Prolonged treadmill walking in healthy participants with and without the use of foot orthoses to support the medial longitudinal arch

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

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Prolonged treadmill walking in healthy participants with and without the use of foot orthoses to support the medial longitudinal arch

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by

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Graduate Program in Kinesiology

A thesis submitted in partial fulfillment
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London, Ontario, Canada

THE UNIVERSITY OF WESTERN ONTARIO

SCHOOL OF GRADUATE AND POSTDOCTORAL STUDIES

Certificate of Examination

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The thesis by

Daisy K. Ng

entitled:

Prolonged treadmill walking in healthy participants with and without the use of foot orthoses to support the medial longitudinal arch

is accepted in partial fulfillment of the
requirements for the degree of

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Abstract

In the research setting, instrumented treadmills are often used to study prolonged periods of walking. This thesis examines the effects of in-shoe foot orthoses on walking gait during prolonged periods of treadmill walking. The two types of foot orthoses investigated were: 1) a pedorthist hand-made orthotic with medial longitudinal arch (MLA) support and 2) a proprioceptive feedback-type orthotic designed to stimulate the intrinsic foot muscles of the MLA. The three kinematic variables observed over 60 minutes of intermittent treadmill walking were toe-out angle in the transverse plane, pelvic tilt angle in the sagittal plane, and trunk lean angle in the frontal plane. Kinematic data were collected with a real-time optical motion capture system that consisted of five high resolution digital cameras which tracked the location of the reflective markers placed on the surface of skin.

Static and dynamic trials were collected and analyzed to calculate the change in joint angles every 5 minutes of testing. Due to the appearance of three distinct groups for the kinematic variables, each participant was assigned into one of the following groups: Increase Group, No Change Group, or Decrease Group based on the magnitude of the change in joint angles during the 60 minutes of treadmill walking. To be assigned into either the Increase or Decrease Groups, the kinematic variable had to change by at least 1.5°.

In all three conditions, data interpreted within the three subgroups showed statistical significance. In the Control condition, statistical significance was detected in the Increase Group for pelvic tilt angle and the Decrease Group for toe-out angle. In the MLA orthotic condition, statistical significance was detected in the Increase Group for pelvic tilt angle and the Decrease Group for trunk lean angle. In the Proprioceptive orthotic condition, statistical significance was detected in the Increase Group for pelvic tilt angle and the Decrease Group for trunk lean angle. Overall, generic insoles and the two types of foot orthoses have minimal changes on the three kinematic gait variables over 60 minutes of treadmill walking.

Keywords: Prolonged Treadmill Walking, Medial Longitudinal Arch Orthotics, Proprioceptive Feedback-type Orthotics, Kinematics, Toe-out Angle, Pelvic Tilt Angle, Trunk Lean Angle

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Co-Authorship

All the chapters in this thesis were written by Daisy Ng.

Collection, analysis, and interpretation of the data for all the studies were by Daisy Ng.

Dr. Thomas Jenkyn assisted in revisions to the thesis, study design, and interpretation of the data.

Table of Contents

Certificate of Examination ii

Abstracts and Keywords iii

Acknowledgments v

Co-Authorship vi

Table of Contents vi

List of Tables x

List of Figures xv

List of Appendix xxii

List of Abbreviations xxiii

Chapter 1 Anatomy on the lower extremities involved in walking and review of treadmill walking and foot orthotic research 1

1.1 Introduction 1

1.2 Foot anatomy 2

1.3 The arches of the foot 5

1.3.1 Medial longitudinal arch 6

1.3.2 Lateral longitudinal arch and the transverse arch 7

1.4 Foot orthotics 8

1.5 Rigid body segment kinematics 19

1.6 Optical motion capture 22

1.6.1 Helen Hayes marker configuration 13

1.7 Toe-out angle 8

1.8 Pelvic tilt angle 19

1.9 Trunk lean angle 12

1.10 Compensatory gait mechanisms for reducing lower extremity loading 19

1.11 Treadmill versus overground walking 28

1.12 Prolonged treadmill walking over 60 minutes 22

1.13 Thesis objective 24

1.13.1 Outline 26

1.14 References 28

Chapter 2 Changes in gait kinematics over 60 minutes of treadmill walking 32

2.1 Introduction 32

2.1.1 Kinematic variable definitions 35

2.1.2 Purpose of study 37

2.2 Methods 38

2.2.1 Participants 38

2.2.2 Protocol 38

2.2.3 Data analysis 41

2.2.4 Statistical analysis 43

2.3 Results..45

2.3.1 One overall group analysis on mean, SD, & 95% CI.......................................45

2.3.1.1Calculated angles and SD 45

2.3.1.2 True or population value within 95% confidence interval (n=20) 50

2.3.2 Group division based on relative change in calculated angles.........................51

2.3.2.1 Change in toe-out angle over time (slope of the linear regression line) 56

2.3.2.2 Change in pelvic tilt angle over time (slope of the linear regression line) 59

2.3.2.3 Trunk lean angle and linear regression line...62

2.4 Discussion 64

2.5 References 69

Chapter 3 Kinematic gait changes in medial longitudinal arch orthotic and proprioceptive feedback-type orthotic over 60 minutes of treadmill walking 71

3.1 Introduction 71

3.1.1 Purpose of study 77

3.2 Methods 79

3.2.1 Participants 79

3.2.2 Protocol 79

3.2.2.1Description of foot orthoses used 82

3.2.3 Data analysis 84

3.2.4 Statistical analysis 86

3.3 Results..88

3.3.1 One overall group analysis on mean, SD, & 95% CI.......................................88

3.3.1.1Calculated angles and SD 88

3.3.1.2 True or population value within 95% confidence interval (n=20)........96

3.3.2 Group division based on relative change in calculated angles 98

3.3.2.1Change in toe-out angle over time (slope of the linear regression line) 109

3.3.2.2 Change in pelvic tilt angle over time (slope of the linear regression line) 114

3.3.2.3 Change in trunk lean angle over time (slope of the linear regression line) 119

3.4 Discussion 124

3.5 References 130

Chapter 4 Discussion 133

4.1 Overview 133

4.2 Future research 134

4.3 References 136

Appendix A - Ethics Approval 137

Curriculum Vitae 138

List of Tables

Table 2.1- Anthropometric measurements and walking speed of the participants (n=20; 9 males and 11 females)…………………………………………………………...………45

Table 2.2- Difference in toe-out angle between 60 min and 0 min showing the change in angle from the end and start of testing for the control condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min. Eleven participants had an increase in toe-out over the 60 minutes of walking…………………………….…47

Table 2.3- Difference in pelvic tilt angle between 60 min and 0 min showing the change in angle from the end and start of testing for the control condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min. Three quarters of the participants had increased anterior pelvic tilt angle over the 60 minutes of walking…..48

Table 2.4- Difference in trunk lean angle between 60 min and 0 min showing the change in angle from the end and start of testing for the control condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min. The symbol "—" represents zero change. One participant had no change in trunk lean over the 60 minutes of walking……………………………………………………………………………..49

Table 2.5- Average relative change in angle over 60 minutes of prolonged walking for the three kinematic gait variables are shown with SD and the upper and lower limits of the 95% confidence interval. Since all three kinematic gait variables had zero within their respective 95% confidence interval then there was no significant change in these variables after 60 minutes of prolonged walking at p<0.05……………………………50

Table 2.6- Assignment of each participant to one of three groups based on the magnitude of the change in each of the three kinematic gait variables over 60 minutes of prolonged walking. The three groups are "no change", "increase" (white box; > +1.5°) and "decrease" (black box; < -1.5°). Trunk lean angle did not change significantly for any of

the 20 participants. Five of the twenty participants (a quarter of participants) changed in toe-out angle and six of the twenty participants changed in pelvic tilt angle……..……52

Table 2.7- The average change over 60 minutes of prolonged walking for the three kinematic gait variables is shown with SD and the upper and lower limits of the 95% confidence interval. Statistically significant differences is indicated with an asterisk (*) at $p<0.05$. In the control condition, toe-out angle decrease in the decrease group and pelvic tilt angle increase in the increase group…………………………………………………53

Table 2.8- The slopes (in degrees per hour) as determined by the linear regression, along with the upper and lower limits of the 95% confidence intervals for the change in toe-out angle, trunk lean angle and pelvic tilt angle are listed for each of the three groups: increase, no change and decrease. For each subgroup, the sample size is also given. For toe-out angle, decrease group showed significant differences but had only one participant belonged in this group. All three groups showed significant differences in the slope of the pelvic tilt angle because the range of the 95% confidence interval had no overlaps….…54

Table 2.9- Toe-out, pelvic tilt, and trunk lean angles in the proprioceptive orthotic condition are listed in the R^2 value table. The R^2 values for the increase, no change, and decrease groups are presented. The R^2 value represents the proportion of the kinematic gait variable that is explained by time in the control condition. The decrease group showed the greatest variance in toe-out angle. The increase group showed the greatest variance in pelvic tilt angle. The no change group showed the least variance among the three kinematic gait variables……………………………………………………………55

Table 3.1- Anthropometric measurements and walking speed of the participants (n=20; 9 males and 11 females)……………………………………………………………………..89

Table 3.2- Difference in toe-out angle between 60 min and 0 min showing the change in angle from the end and start of testing for the MLA orthotic condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. The symbol “—” represents zero change. Toe-out angle had one participant who showed no difference (60-0 min)……………………………………………………………………91

Table 3.3- Difference in pelvic tilt angle between 60 min and 0 min showing the change in angle from the end and start of testing for the MLA orthotic condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. Pelvic tilt angle had the greatest number of participants who showed difference greater than zero……………………………………………………………………………………92

Table 3.4- Difference in trunk lean angle between 60 min and 0 min showing the change in angle from the end and start of testing for the MLA orthotic condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. The symbol “—” represents zero change. Trunk lean angle had one participant who showed no difference (60-0 min)……………………………………………………………….…….93

Table 3.5- Difference in toe-out angle between 60 min and 0 min showing the change in angle from the end and start of testing for the proprioceptive orthotic condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min…………94

Table 3.6- Difference in pelvic tilt angle between 60 min and 0 min showing the change in angle from the end and start of testing for the proprioceptive orthotic condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. The symbol “—” represents zero change. Pelvic tilt angle had two participants that showed no difference (60-0 min)…………………………………………………………………95

Table 3.7- Difference in trunk lean angle between 60 min and 0 min showing the change in angle from the end and start of testing for the proprioceptive orthotic condtion. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. The symbol “—” represents zero change. Trunk lean angle had one participant that showed no difference (60-0 min)……………………………………………………………….……96

Table 3.8- (Top table) MLA orthotic (Bottom table) proprioceptive orthotic conditions are shown. The average relative change in angle over 60 minutes of prolonged walking for the three kinematic gait variables are shown with SD and the upper and lower limits of the 95% confidence interval. Since all three kinematic gait variables had zero within their respective 95% confidence interval, there was no significant change in these variables after 60 minutes of prolonged walking at $p<0.05$………………………..…98

Table 3.9- Assignment of each participant to one of three groups based on the magnitude of the change in each of the three kinematic gait variables over 60 minutes of prolonged walking. The three groups are "no change", "increase" (white box; > +1.5°) and "decrease" (black box; < -1.5°). Seven participants change in toe-out angle, followed by six participants change in pelvic tilt angle and only one participant change in trunk lean angle…………………………………………………………………………..…101

Table 3.10- Assignment of each participant to one of three groups based on the magnitude of the change in each of the three kinematic gait variables over 60 minutes of prolonged walking. The three groups are "no change", "increase" (white box; > +1.5°) and "decrease" (black box; < -1.5°). Nine participants change in toe-out angle, followed by six participants changed in pelvic tilt angle and only one participant changed in trunk lean angle………………………………………………………………………….102

Table 3.11- The average change over 60 minutes of prolonged walking for the three kinematic gait variables is shown with SD and the upper and lower limits of the 95% confidence interval. Statistically significant differences is indicated with an asterisk (*) at $p<0.05$. In MLA orthotic condition, one participant had a decrease in trunk lean over the 60 minutes of walking……………………………………………………………..104

Table 3.12- Average change over 60 minutes of prolonged walking for the three kinematic gait variables is shown with SD and the upper and lower limits of the 95% confidence interval. Statistically significant differences is indicated with an asterisk (*) at $p<0.05$. In proprioceptive orthotic condition, significant differences were detected in decrease group for toe-out angle, increase group for pelvic tilt angle and decrease group for trunk lean angle……………………………………………………………………..105

Table 3.13- The MLA orthotic slopes (in degrees per hour) as determined by the linear regression, along with the upper and lower limits of the 95% confidence intervals for the change in toe-out angle, trunk lean angle and pelvic tilt angle are listed for each of the three groups: increase, no change and decrease. For each subgroup, the sample size is also given……………………………………………………………………………106

Table 3.14- Toe-out, pelvic tilt, and trunk lean angles in the MLA orthotic condition are listed in the R^2 value table. The R^2 values for the increase, no change, and decrease groups are presented. The R^2 value represents the proportion of the kinematic gait variable that is explained by time in the MLA orthotic condition. The increase group showed the greatest variance in toe-out angels. The decrease group showed the greatest variance in both the pelvic tilt and trunk lean angles. The similarity between the variance in both angles was having only one participant in the decrease group, however not the same participant…………..……………………………………………………………107

Table 3.15- The proprioceptive orthotic slopes (in degrees per hour) as determined by the linear regression, along with the upper and lower limits of the 95% confidence intervals for the change in toe-out angle, trunk lean angle and pelvic tilt angle are listed for each of the three groups: increase, no change and decrease. For each subgroup, the sample size is also given………………………………………………………………………….....108

Table 3.16- Toe-out, pelvic tilt, and trunk lean angles in the proprioceptive orthotic condition are listed in the R^2 value table. The R^2 values for the increase, no change, and decrease groups are presented. The R^2 value represents the proportion of the kinematic gait variable that is explained by time in the proprioceptive orthotic condition. The decrease group showed the greatest variance in toe-out angle. The increase group showed the greatest variance in pelvic tilt angles. The decrease group showed the greatest variance in trunk lean angles………………………………………………………………109

List of Figures

Figure 1.1-Dorsal view of the foot displays 26 bones (the 2 sesamoid bones are located on the plantar surface). The forefoot consists of the phalanges and metatarsals. The midfoot consists of the three cuneiforms, navicular, and cuboid. The hindfoot consists of the calcaneus. The talus articulates with the lower leg…………………………………....2

Figure 1.2 -Posterior view of the subtalar joint (solid line) and ankle joint (dotted line). The subtalar joint is the joint between the calcaneus and talus. The ankle joint is the joint between the talus and the two long bones of the lower leg: tibia and fibula……………..3

Figure 1.3 -The medial longitudinal arch (MLA) of the medial aspect of the foot. The MLA is formed by the first metatarsal, the medial cuneiform, the navicular, and the calcaneus as indicated by the curve in black. The MLA has a more profound arch then the lateral and transverse arches……………………………………………………………6

Figure 1.4- (A) Lateral longitudinal arch (LLA) of the left foot in the lateral view. Foot bones that form the lateral longitudinal arch are the calcaneus, cuboid, fourth metatarsal, and fifth metatarsal. (B) Transverse arch of the right foot in the dorsal view. Foot bones that form the transverse arch are the cuboid and the three cuneiforms. The curves in black represent the arches…………………………………………………………………………7

Figure 1.5- Definition of the rigid body segments used to measure body kinematics. Head, two arms, and trunk are considered as one segment. The thighs, lower legs, and feet are each individual segment………………………………………………………11

Figure 1.6- Toe-out angle is the angle between the line of forward progression and the midline of the foot. The midline of the foot is defined by the heel marker and toe marker (on the second metatarsal-phalangeal joint) for the optical motion capture system. Positive toe-out angle is when the toes point laterally outward. Negative toe-out angle is when the toes point medially inward……………………….………..………15

Figure 1.7- The reflective markers (ASIS and sacral markers) are shown as black dots. Pelvic tilt angle is the angle between the line connecting the two reflective markers and

the horizontal. Forward pelvic tilt is represented by a positive angle and backward pelvic tilt is represented by a negative angle……………………………………………………16

Figure 1.8- The trunk segment is shown in the anterior view during single limb support in walking gait. A positive trunk lean angle is when body leans towards the stance leg (left diagram). A negative trunk lean angle is when body leans towards the swinging leg (right diagram). When the trunk segment is vertical, there is no trunk lean angle……………..18

Figure 2.1- The reflective markers are shown as black dots. (**A**) Positive toe-out angle is when the toes point laterally outward. Negative toe-out angle is when the toes point medially inward. (**B**) The line connecting the two markers and the horizontal line defines the pelvic movement in the anterior and posterior direction. Forward pelvic tilt angle is indicated by a positive value. Backward pelvic tilt angle is indicated by a negative value. (**C**) Positive trunk lean angle is when body leans toward the stance leg. (**D**) Negative trunk lean angle is when body leans toward the swinging leg…………………………...36

Figure 2.2- The first three right foot strikes were used from each of the 15 seconds collected. Four left foot strikes of the same foot equal to three strides………………….41

Figure 2.3- Average change in toe-out angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R^2values and equations…………………………………………………..…….57

Figure 2.4- The average slope of the linear regression line on toe-out angle in the control condition with 95% CI bars shown for each of the three groups. The toe-out angle in the Decrease Group was significantly different from both the toe-out angle in the Increase and No Change Groups. However, the toe-out angle in the remaining two groups was not significantly different from one another. Significant difference between the Decrease Group and the remaining two groups is indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs……...……….58

Figure 2.5- Average change in pelvic tilt angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R^2 values and equations…………………………………………..……………60

Figure 2.6- The average slope of linear regression on pelvic tilt angle in the control condition with 95% CI error bands shown for each of the three groups. All three groups were significantly different. Significant differences are denoted with a symbol to indicate a significance level of p= 0.05. The asterisk (*) represents a significant difference between the Increase Group and No Change Group. The dagger (†) represents a significant difference between the No Change Group and Decrease Group. The number sign (#) represents a significant difference between the Increase Group and Decrease Group. The triangles reflect the mean slopes and the ranges represent the 95% CIs……..…………………………………………………………...…………..61

Figure 2.7- Average change in trunk lean angle with the linear regression line for every 5 min interval from 0 to 60 minutes of prolonged treadmill walking. Also shown are the R^2value and equation……………………………………………………………….…63

Figure 2.8- Average slope of the linear regression on trunk lean angle with 95% CI error bands shown for no change group only. No comparisons were made since all participants belonged to one group. The triangle reflects the mean slope and the range represents the 95% CI…………….…………………………………………………...……………63

Figure 3.1- Walking participant on the treadmill with 22 reflective markers on bony landmarks from the shoulders down to the feet…………………………………….……81

Figure 3.2- Lateral view of the right MLA foot orthosis. Darken black area shows the location of the medial longitudinal arch support in the midfoot area and the heel wedge under the heel. The MLA orthotic was made from soft material known as plastazote….83

Figure 3.3- Proprioceptive feedback-type orthotic top and bottom view. The dome contour is to support the medial longitudinal arch located in the midfoot area. Insets are placed in the dome on the plantar surface of the insole…………………………………84

Figure 3.4- The first three right foot strikes were used from each of the 15 seconds collected. Four left foot strikes of the same foot equal to three strides………………….85

Figure 3.5- Generated animated three-dimensional stick figure, walking area represented by two darken squares (two force plates which the participant was on), and the location of the five cameras. The figure shows the front projection of the recorded 3D motion……86

Figure 3.6- MLA orthotic average change in toe-out angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R^2values and equations………………………………………………………111

Figure 3.7- The average slope of the linear regression on toe-out angle in MLA orthotic condition with 95% CI error bars shown for each of the three groups. The toe-out angle in the Decrease Group was significantly different from the toe-out angle in the Increase Group and the No Change Group. The remaining two groups were not significantly different from one another. Significant difference between the Decrease Group and the remaining two groups is indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs …………………………….………112

Figure 3.8- Proprioceptive orthotic toe-out average from 0-60 minutes in the three groups are shown along with line of best fit and R^2 values….……………………………………113

Figure 3.9- The average slope of the linear regression on toe-out angle in proprioceptive orthotic condition with 95% CI error bands shown for each of the three groups. The toe-out angle in the Decrease Group was significantly different from both the Increase and the No Change Groups. The toe-out angles in the remaining two groups were not significantly different from one another. Significant difference between the Decrease Group and the remaining two groups is indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs ………..………………………………………..……………………………………..114

Figure 3.10- MLA orthotic average change in pelvic tilt angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R^2values and equations……………………………………………116

Figure 3.11- The average slope of the linear regression on pelvic tilt angle in MLA orthotic condition with 95% CI error bands shown for each of the three groups. All three

groups were significantly different. Significant differences are denoted with a symbol to indicate a significance level of p= 0.05. The asterisk (*) represents a significant difference between the Increase Group and No Change Group. The dagger (†) represents a significant difference between the No Change Group and Decrease Group. The number sign (#) represents a significant difference between the Increase and Decrease Groups. The triangles reflect the mean slopes and the ranges represent the 95% CIs ……………………………………………………………………………………..117

Figure 3.12- Proprioceptive orthotic pelvic tilt average from 0-60 minutes in the three groups are shown along with line of best fit and R² values……………………………118

Figure 3.13- The average slope of linear regression on pelvic tilt angle in proprioceptive orthotic condition with 95% CI error bands shown for each of the three groups. All three groups were significantly different in pelvic tilt angle. Significant differences are denoted with a symbol to indicate a significance level of p= 0.05. The asterisk (*) represents a significant difference between the Increase Group and the No Change Group. The dagger (†) represents a significant difference between the No Change Group and the Decrease Group. The number sign (#) represents a significant difference between the Increase Group and the Decrease Group. The triangles reflect the mean slopes and the ranges represent the 95% CIs ………………………………………………………………….119

Figure 3.14- The MLA orthotic average change in pelvic tilt angle at each 5 min interval during the 60 min prolonged walking trials in the No Change and Decrease Groups. Zero participants belonged in the No Change Group. Also shown are linear regression lines and associated R² values and equation…………………………………………………121

Figure 3.15- The average slope of the linear regression on trunk lean angle in MLA orthotic condition with 95% CI error bands shown for each of the three groups. The trunk lean angle in the Decrease Group was significantly different from the No Change Group and vice versa. No participant belonged in the Increase Group. Significant differences between the No Change Group and Decrease Group are indicated with an asterisk (*) at p<0.05. The triangles reflect the mean slopes and the ranges represent the 95% CIs ……………………………………………………………………………………………122

Figure 3.16- Proprioceptive trunk lean average from 0-60 minutes in the No Change and Decrease Groups are shown along with line of best fit and R2………………………...123

Figure 3.17- The average slope of the linear regression on trunk lean angle in proprioceptive orthotic condition with 95% CI error bands shown for each of the three groups. The trunk lean angle in the Decrease group and the No Change Group were significantly different from each other. No participant belonged in the Increase Group. Significant differences between the No Change Group and Decrease Group are indicated with an asterisk (*) at p<0.05. The triangles reflect the mean slopes and the ranges represent the 95% CIs……………………………………………………………….124

List of Appendix

Appendix A - Ethics Approval 138

List of Abbreviations

ASIS- Anterior Superior Iliac Spine

BMI- Body Mass Index

CI- Confidence Interval

COM- Center of Mass

COG- Center of Gravity

EDL- Extensor Digitorum Longus

EHL- Extensor Hallucis Longus

ICC- Intraclass Correlation Coefficient

MLA- Medial Longitudinal Arch

PSIS- Posterior Superior Iliac Spine

SD- Standard Deviation

SEM- Standard of Error

STJ- Subtalar Joint

TA- Tibialis Anterior

TP- Tibialis Posterior

Chapter 1:

Anatomy on the lower extremities involved in walking and review of treadmill walking and foot orthotic research

1.1 Introduction

The first chapter is an overview of the foot anatomy. To move from one place to another, the feet must land successfully on the ground then propel the body to take a step. With each step the foot must adapt quickly to the surface on which it lands. Whenever the foot is placed on uneven terrains, the foot has to adapt quickly to its surroundings during landing. Therefore the sole of the foot, the plantar surface, is of great importance in ensuring successful walking gait.

Excessive foot motion of foot bones during stance phase in walking may affect bone alignment in the lower extremities. Functional implications of the bones and muscles in the body lead to musculoskeletal disorders, such as osteoarthritis which is a degenerative joint disease that commonly affects the knee joint. The wear and tear of knee cartilage thins the cartilage which causes excessive load on the contra-lateral cartilage of the same knee. Overtime, the height of the cartilage diminishes leading to knee malalignment. Foot orthotics are often prescribed to correct the alignment of the ground reaction force acting on the knee joint in order to reduce the knee compression force.

Another frequent challenge for the foot is shoe wear because shoes constrain the foot in a restricted space that limits the foot joints from performing full range of motion.

1.2 Foot anatomy

The human foot is composed of 28 bones (see Figure 1.1), including 7 tarsal, 5 metatarsal, 14 phalangeal, and 2 sesamoid bones. The side of the foot that contacts the ground is known as the plantar surface (i.e. the sole of the foot). The two sesamoid bones are located on the plantar surface of the first metatarsophalangeal joint (Standring et al., 2008). The sesamoid bones aid in reducing pressure in weight bearing and act as sliding pulleys for the tendons (Sarrafian, 1993).

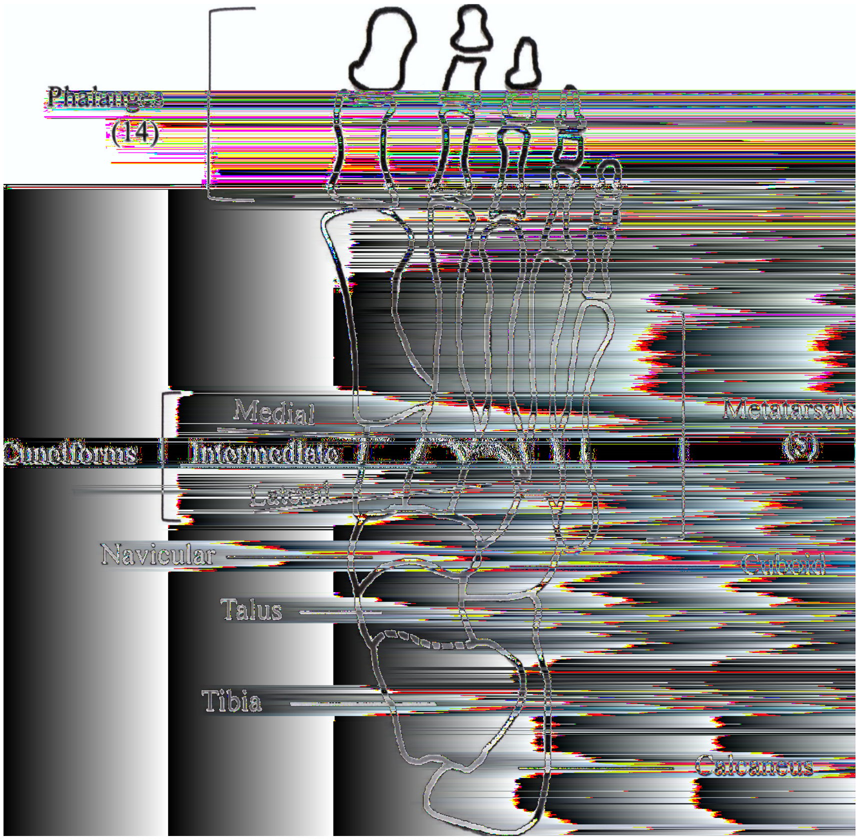

Figure 1.1-Dorsal view of the foot displays 26 bones (the 2 sesamoid bones are located on the plantar surface). The forefoot consists of the phalanges and metatarsals. The midfoot consists of the three cuneiforms, navicular, and cuboid. The hindfoot consists of the calcaneus. The talus articulates with the lower leg.

The *tarsals* are located in the proximal half of the foot. The seven tarsal bones are talus, calcaneus, cuboid, navicular, medial cuneiform, intermediate cuneiform, and lateral cuneiform (see Figure 1.1).

The *talus* links the foot with the lower leg through the ankle joint and articulates with the tibia-fibular mortice at the ankle. Second in size of the tarsal bone is the talus, locates between the calcaneus and the two long bones of the lower leg (Standring et al., 2008). The *calcaneus* is the largest tarsal bone, also known as the heel bone, and its role is to transfer the weight of the body onto the ground (Standring et al., 2008). The calcaneus is the only bone in the hindfoot portion of the foot that articulates with the talus at the subtalar joint (see Figure 1.2).

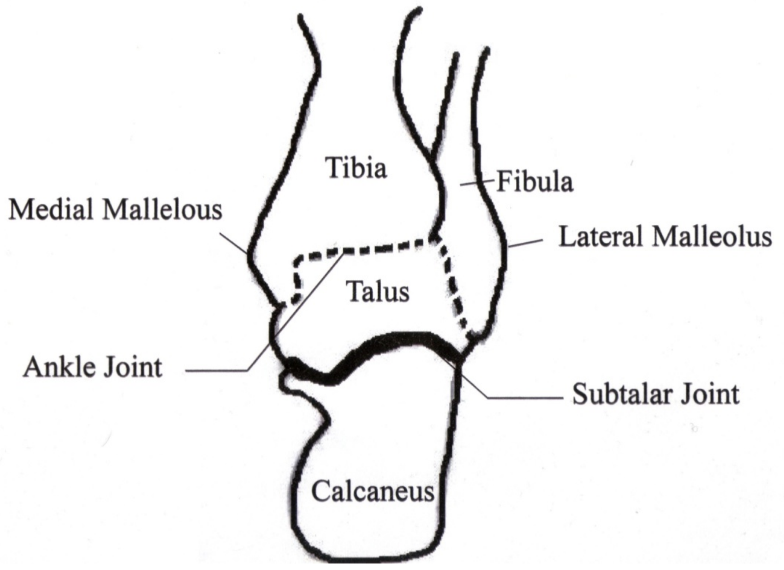

Figure 1.2 -Posterior view of the subtalar joint (solid line) and ankle joint (dotted line). The subtalar joint is the joint between the calcaneus and talus. The ankle joint is the joint between the talus and the two long bones of the lower leg: tibia and fibula.

The midfoot consists of five tarsal bones: cuboid, navicular and the three cuneiforms. The forefoot consists of the metatarsals and phalanges (see Figure 1.1). The metatarsals are the five bones in between the tarsals and the phalanges. The ball of the foot is located on the distal portion of the metatarsals that is used in propelling the body forward. Phalanges are the bones of the toes and the main functions of the toes are to propel the body and provide a wider base of support for balance. The great toe is also known as the hallux that consists of two phalanges, whereas the other four toes consist of three phalanges each (Standring et al., 2008).

Motion of the foot with respect to the lower leg can occur in all three planes of the body. Sagittal plane movements are dorsiflexion (foot towards lower leg in upward direction) and plantarflexion (foot away from lower leg in downward direction). Transverse plane movements are adduction (foot toward midline) and abduction (foot away from midline). Frontal plane movements are inversion (plantar surface of foot towards midline) and eversion (plantar surface of foot away from midline).

Foot motion during walking gait is often described as supination and pronation, which are combinations of simultaneous motions in the three planes. In particular, the subtalar joint is primarily responsible for foot supination and foot pronation. Foot pronation is a combined movement of dorsiflexion, eversion, and abduction. In other words, the sole of the foot is turned laterally. Foot supination is a combination of plantarflexion, inversion, and adduction that causes the sole of the foot to turn medially (Close, Inman, & Poor, 1967).

1.3 The arches of the foot

The bones of the foot are organized into three arches that give the plantar surface of the foot its concave shape. These arches are maintained passively by the shapes of the articulations between the individual bones of the foot and by the ligaments connecting the bones. The arches are also actively maintained by the intrinsic musculature of the foot. The three arches of the foot are the medial longitudinal, lateral longitudinal, and transverse arches (see Figures 1.3 and Figure 1.4).

During walking gait, the foot and its arches are repeatedly loaded and unloaded. In early stance phase when the foot is loaded, the arches tend to flatten as the foot pronates. In the second half of stance phase, the arches tend to rise as the overall foot becomes more supinated. Foot supination transforms the foot into its rigid configuration by making it an effective lever with which to propel the body forward (Franco, 1987; Sarrafian, 1987).

1.3.1 Medial longitudinal arch

The medial longitudinal arch (MLA) extends along the medial side of the foot from the calcaneus, through the navicular, to the medial cuneiform, and continues to the distal head of the first metatarsal (see Figure 1.3).

The plantar fascia ligament helps maintain the shape of the MLA, since this ligament locates along the plantar aspect of the foot from the calcaneus to the metatarsophalangeal joints. Stability of the MLA is influenced primarily by the plantar fascia ligament which acts as a tie beam between the two ends of the arch. Second in importance are the long and short plantar ligaments, then the spring ligament to hold the navicular and calcaneus together (Sammarco & Hockenbury, 2001). Other ligaments active in maintaining the MLA stability are the talocalcaneal ligament and the anterior fibers of the ankle deltoid ligament (Standring et al., 2008).

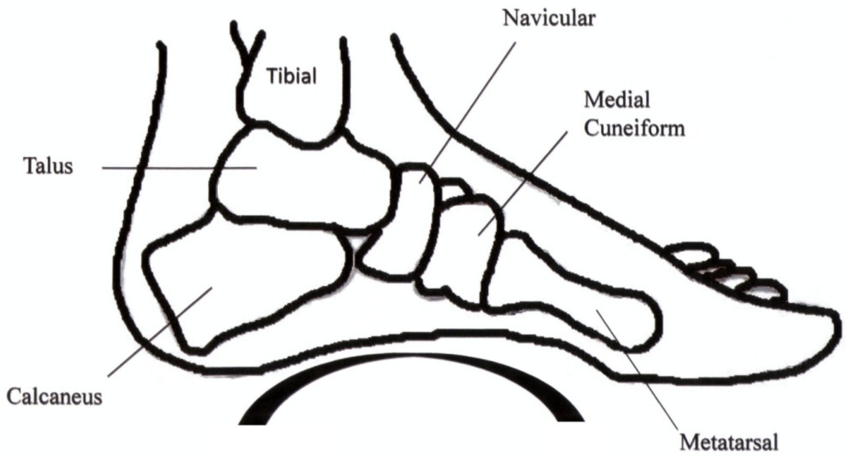

Figure 1.3 -The medial longitudinal arch (MLA) of the medial aspect of the foot. The MLA is formed by the first metatarsal, the medial cuneiform, the navicular, and the calcaneus as indicated by the curve in black. The MLA has a more profound arch then the lateral and transverse arches.

1.3.2 Lateral longitudinal arch and the transverse arch

The lateral longitudinal arch (LLA) runs along the lateral side of the foot from the calcaneus through the cuboid to the distal head of the fourth and fifth metatarsals (Standring et al., 2008). LLA is less concave than the MLA (see Figure 1.4). The peroneus longus tendon is significant in maintaining the shape of the LLA. Other foot muscles involved are the lateral two tendons of the flexor digitorum longus, peroneus brevis, peronueus tertius and abductor digiti minimi (Standring et al., 2008).

The transverse arch runs laterally across the midfoot from the lateral border at the cuboid through the three cuneiforms to the medial border (see Figure 1.4). The transverse arch runs just about the proximal metatarsal heads (Standring et al., 2008).

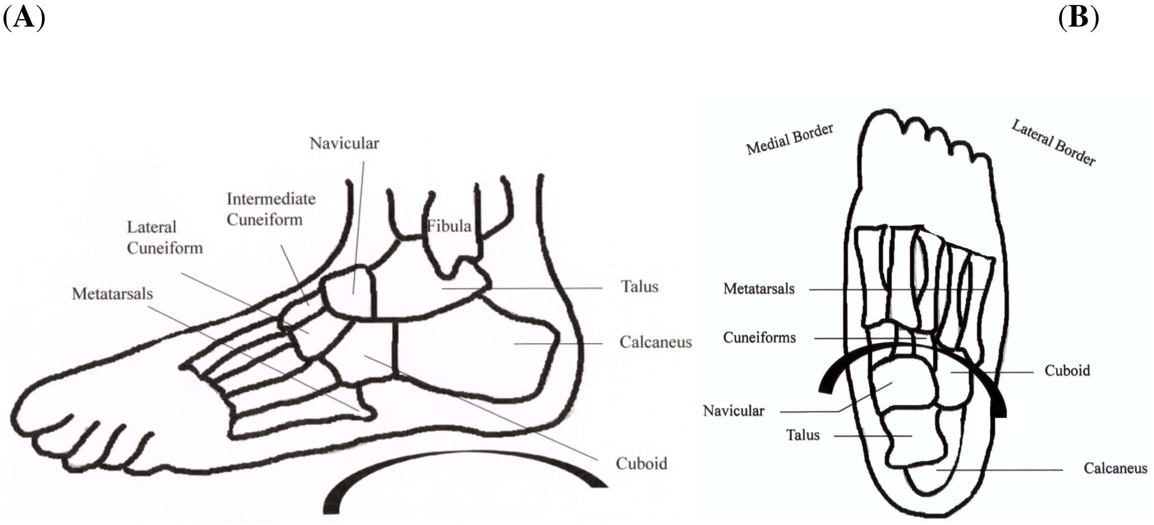

Figure 1.4- (A) Lateral longitudinal arch (LLA) of the left foot in the lateral view. Foot bones that form the lateral longitudinal arch are the calcaneus, cuboid, fourth metatarsal, and fifth metatarsal. (B) Transverse arch of the right foot in the dorsal view. Foot bones that form the transverse arch are the cuboid and the three cuneiforms. The curves in black represent the arches.

1.4 Foot orthotics

A foot orthotic is a device that is placed within a shoe to correct, straighten, and hold the foot upright. The purpose of foot orthoses is to realign the bones in the foot to alleviate stress (Mundermann, Wakeling, Nigg, Humble, & Stefanyshyn, 2006). By correcting the kinematics of the bones within the foot, stress is reduced on the load bearing structures of the foot. So far in the research of foot orthotics, not much has been studied on the kinematics of the hip, knee, and pelvis (Nester, Linden, & Bowker, 2003). Studies conducted were often involved with healthy participants and not patients with musculoskeletal pathologies (Mundermann et al., 2006).

Foot orthotics are constructed from hard to soft materials, such as soft flexible (e.g. plastazote), or rigid plastic material (e.g. high density polyethylene foam), or semi-rigid (e.g. high density ethylene vinyl acetate). The length of orthotics often extends from the heel to toe (Philps, 1995). The primary roles of MLA orthotics are to support the medial longitudinal arch concavity by holding the arch up structurally on the plantar surface of the foot and to maintain the heel in a neutral position to prevent excessive foot motion during load bearing. Increasing the concavity of the foot arches by applying a tactile stimulus to the plantar surface of the foot is to activate the intrinsic foot muscles. Foot orthotics of this type are known as proprioceptive orthotics.

Typically foot orthotics research have focused on joint kinematics, such as rearfoot eversion (Torburn, Perry, & Gronley, 1998), talocrural joint inversion moment (Stacoff, Reinschmidt, Nigg, Bogert, Lundberg, Denoth, & Stussi, 2000), and maximum knee adduction moment (Andrews, Noyes, Hewett, & Andriacchi, 1996; Lin, Lai, Chou, & Ho, 2001; Hurwitz, Ryals, Case, Block, & Andriacchi, 2002; Jenkyn, Hunt, Jones, Giffin, & Birmingham, 2008). Foot orthoses have been reported to reduce the average maximal foot eversion and tibial rotation during ground contact (Eng & Pierrynowski, 1994). Researchers have suggested the effects of foot orthoses should focus on the movement of the midfoot and forefoot (Stacoff et al., 2000).

1.5 Rigid body segment kinematics

When studying how the thigh, lower leg, and foot move during walking and running gait, it is useful to functionally divide the body into segments. In analyzing gait movements, the body segments are assumed to be rigid bodies, all linked together by joints.

Kinematics is the measurement of the motions of these segments, such as the angle between the trunk and the thigh during walking gait. Kinematic describes the linear and angular positions, velocities, and accelerations of the segments. The angle created by either bringing the two segments closer or farther apart from each other at the junction of a joint is the joint angle (Zatsiorsky, 1998).

For the purposes of this thesis, the head, arms, and trunk are considered as one segment also known as the H.A.T. (Winter, 1991). The trunk segment connects the pelvic segment at the junction between the lumbar spine and the sacral bone of the pelvis. The pelvis is considered as a segment and articulates with the left and right thigh segments via the left and right hip joints. The lower extremities are defined as two thigh segments, two lower leg segments, and two foot segments. The thigh segment is between the hip to the knee joints. The lower leg is the segment between the knee joint and ankle joint and articulates with the foot segment at a generalized joint that combines the ankle and subtalar joints (see Figure 1.5).

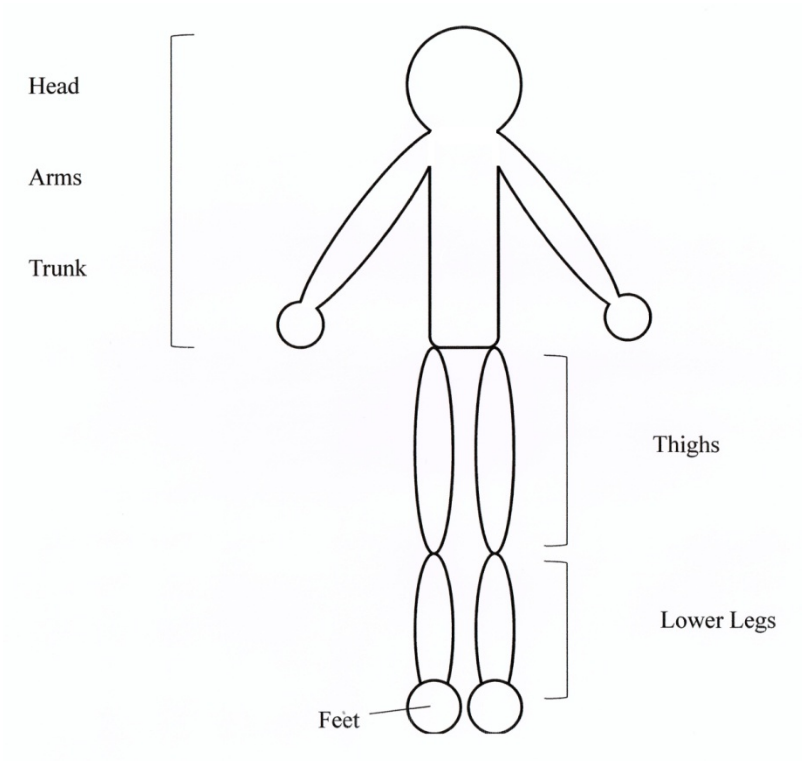

Figure 1.5- Definition of the rigid body segments used to measure body kinematics. Head, two arms, and trunk are considered as one segment. The thighs, lower legs, and feet are each individual segment.

1.6 Optical motion capture

The optical motion capture system is one of the best ways in quantifying intersegmental kinematics during activities, such as walking. The three-dimensional positions of reflective markers are measured with multiple digital cameras (Cortex 2.6.2 system, Motion Analysis Corp., Santa Rosa, CA, USA). The markers can be passively reflecting light emitted by the cameras, or can be an active source of light. One of the major advantages in using passive markers is the absence of wires; the wires can potentially restrict the participants in performing natural gait movements.

The three dimensional position of markers can be determined, as long as two cameras can spot a single marker. A minimum of two cameras are required to properly track body movements (Perry & Burnfield, 2010). The markers are attached to points of interest on the skin or clothing of the participants or on equipment that they are using. The cameras transmit information on marker positions to a computer with a tracking and filtering software (Cortex 2.6.2 system, Motion Analysis Corp., Santa Rosa, CA, USA) and analysis software to calculate relative intersegmental kinematics (OrthoTrak 6.6.1 system, Motion Analysis Corp., Santa Rosa, CA, USA).

Marker-based tracking system provides three-dimensional locations of the markers in space, tracking a set of markers in one frame allows a replication of the participants in a stick figure format.

1.6.1 Helen Hayes marker configuration

A complete set of Helen Hayes marker consists of 26 spherical reflective markers, in which four of the 26 markers are removed after the static trials. The purpose of the four extra markers in the static trials is to provide more detail for camera recognition in identifying the knee and ankle joint centers, and axes of rotation. On each limb, two extra markers on the medial knee femoral epicondyle and medial ankle malleolus, total of four extra markers. Three-dimensional movement of the leg can be closely monitored through 10 cm wand attached laterally on the thigh and shank of each leg. For the dynamic trials, only 22 markers are placed on participants (Perry & Burnfield, 2010).

1.7 Toe-out angle

Toe-out angle is defined as the angle between the direction of walking progression and the midline of the foot. The midline of the foot is measured at the line jointing the reflective marker attached to the heel with the reflective marker on the second metatarsal-phalangeal joint (see Figure 1.6). In whole-body gait analysis, the foot is considered as a single rigid segment articulating with the lower extremity (Perry & Burnfield, 2010). A positive toe-out angle indicates the toes are pointing outward (i.e. toeing out). A negative toe-out angle indicates the toes are pointing inward (i.e. toeing in).

In a study on 50 healthy participants, they were asked to walk over a 5m walkway at a comfortable pace and found an average toe-out angle of 7.3° with a standard deviation (SD) of 5° (Rutherford, Hubley-Kozey, Deluzio, Stanish, & Dunbar, 2008). In another study on prolonged treadmill walking, the toe-out angle was initially 10.10±4.84° and at the end of 60 minutes was 10.72±5.39° (Bechard, Birmingham, Zecevic, & Jenkyn, 2011). Healthy children aged 11 to 13 years old were studied on intentional toeing out and toeing in (Lin et al., 2001). The toe-out angle was 10±3°on average, intentional toeing-in averaged 15±5°, and intentional toeing-out averaged 30±6°.

In patients with knee osteoarthritis, by pointing the toes out laterally the knee frontal plane lever arm reduced significantly. During early stance phase, the knee sagittal plane lever arm increased significantly. The results suggested toe-out reduces knee frontal plane lever arm by transferring the adduction moment acting at the knee joint to a flexion moment (Jenkyn et al., 2008).

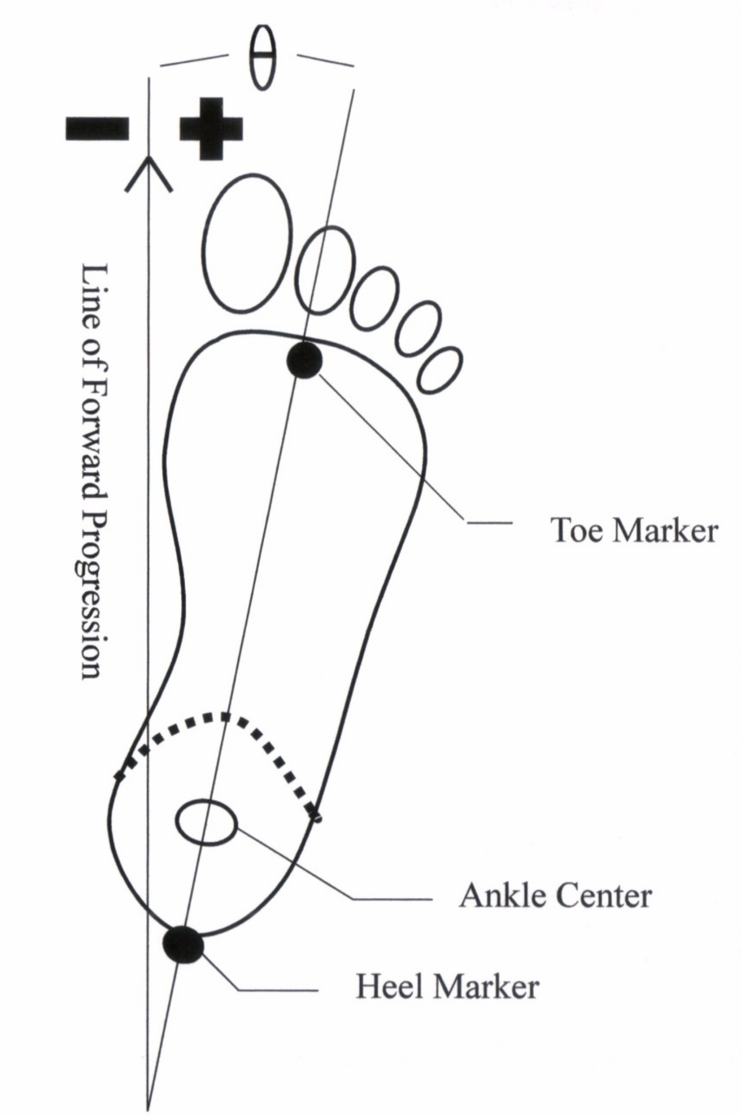

Figure 1.6- Toe-out angle is the angle between the line of forward progression and the midline of the foot. The midline of the foot is defined by the heel marker and toe marker (on the second metatarsal-phalangeal joint) for the optical motion capture system. Positive toe-out angle is when the toes point laterally outward. Negative toe-out angle is when the toes point medially inward.

1.8 Pelvic tilt angle

Pelvic tilt angle is defined as the angle between the horizontal and a straight line joining the anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS). The straight line is defined as the imaginary midpoint between the left and right markers placed on the ASISs to the third marker midway between the two PSISs (see Figure 1.7). A forward pelvic tilt angle is indicated by a positive value. A backward pelvic tilt angle is indicated by a negative value. The direction of the pelvic movement is determined with respect to the reference position in quiet bipedal standing.

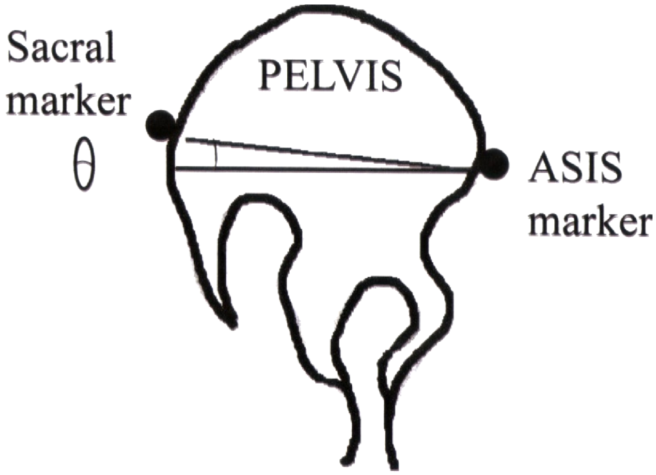

Figure 1.7- The reflective markers (ASIS and sacral markers) are shown as black dots. Pelvic tilt angle is the angle between the line connecting the two reflective markers and the horizontal. Forward pelvic tilt is represented by a positive angle and backward pelvic tilt is represented by a negative angle.

Forty young healthy participants (18-40 years old) had an average 2.8° pelvic tilt angle over three days, in which each day tested three times (Kadaba, Ramakrishnan, & Wootten, 1990). The pelvic tilt angles were measured during overground walking and represented the time when the foot struck the forceplate. Pelvic tilt was examined in one study at initial contact (the start of stance phase) and toe-off (the end of stance phase) during both treadmill and overground walking (Chockalingam, Chatterley, Healy, Greenhalgh, & Branthwaite, 2012). The pelvic tilt angle during treadmill walking at initial contact was 9.62±5.06° in women and 8.85±3.30° in men. At toe-off, women had 8.65±5.10° and men had 6.55±2.90° (Chockalingam et al., 2012).

1.9 Trunk lean angle

Trunk lean angle is defined as the angle between the vertical and a straight line connects to the midpoint of the ASIS markers and the midpoint of the shoulder markers. A positive trunk lean angle is when the trunk leans towards the stance limb. A negative trunk lean angle is when trunk leans towards the swinging limb (see Figure 1.8).

In a study on treadmill walking, the trunk lean angle at the start of testing was 0.66±1.09˚ and changed to 1.03±1.48˚ after 60 minutes of walk (Bechard et al., 2011). In a study that looked at intentional increase in medio-lateral trunk sway, the average trunk lean was 10±5° reduced 65.0% in knee adduction moment (Mundermann, Asay, Mundermann, & Andriacchi, 2008). The knee flexion angle at heel-strike was greater in the medial-lateral sway trials than the normal trunk sway trials (Mundermann et al., 2008).

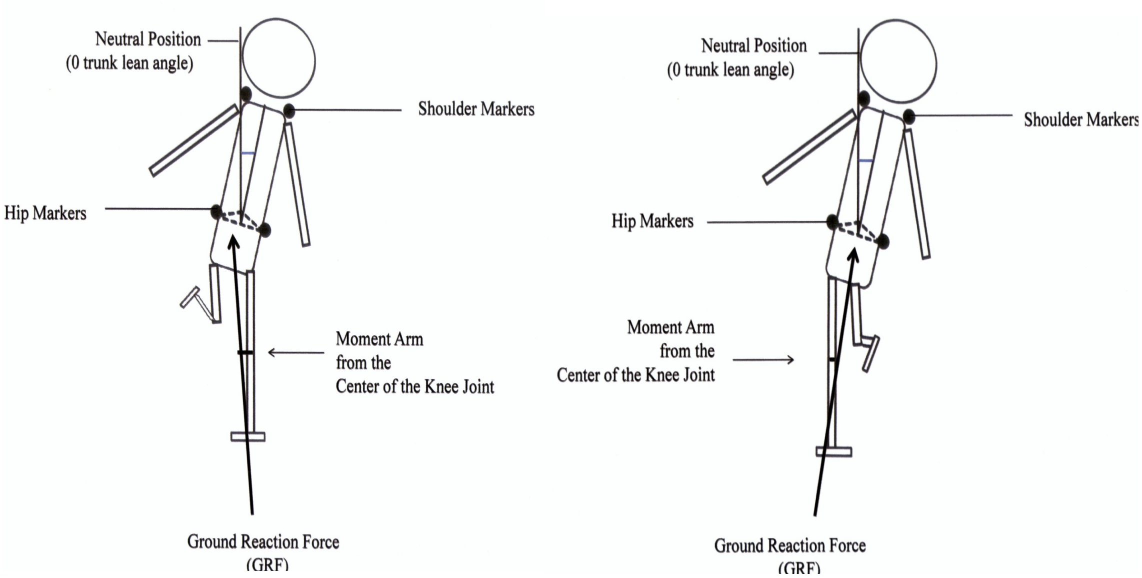

Figure 1.8- The trunk segment is shown in the anterior view during single limb support in walking gait. A positive trunk lean angle is when body leans towards the stance leg (left diagram). A negative trunk lean angle is when body leans towards the swinging leg (right diagram). When the trunk segment is vertical, there is no trunk lean angle.

1.10 Compensatory gait mechanisms for reducing lower extremity loading

The joints of the lower extremity and pelvis are loaded during normal walking gait. Musculoskeletal disorders, such as osteoarthritis, cause pain during loading. Compensatory gait mechanisms are non-invasive method in reducing the load acting at the knee joint, including toe-out angle and trunk lean angle. Increasing toe-out angle reduces the loads at the knee joint by laterally shifting the ground reaction force vector closer to the knee joint center, ultimately reducing the adduction moment at the knee joint (Andrews et al., 1996; Lin, et al., 2001; Hurwitz et al., 2002; Jenkyn et al., 2008). The toe-out movement of the foot causes a rotation at the ankle (Lin, et al., 2001). The increased toe-out position causes the knee adduction moment to convert into a knee flexion moment (Jenkyn et al., 2008).

The trunk leans over the stance limb reduces the knee adduction moment (Mundermann et al., 2008). Research have suggested both toe-out angle and trunk lean angle are indicators of knee joint loading (Andrews et al., 1996; Lin, et al., 2001; Hurwitz et al., 2002; Jenkyn et al., 2008; Mundermann et al., 2008).

1.11 Treadmill versus overground walking

Treadmills are often used in gait laboratories to replicate real-life long periods of walking. Researchers have questioned about the similarities and differences between treadmill gait and overground gait (van Ingen Schenau, 1980; Alton, Braldey, Caplan, & Morrissey, 1998; Matsas, Taylor, & McBurney, 2000; Wass, Taylor, & Matsas, 2005; Rosenblatt & Grabiner, 2010; Chockalingam et al., 2012). Initially, treadmill and overground gait were viewed to have the same mechanics when the treadmill belt moved at a constant speed (van Ingen Schenau, 1980). In general, the kinematics and kinetics between overground walking and treadmill walking are very similar (Riley, Paolini, Croce, Paylo, & Kerrigan, 2007). However, the differences between treadmill walking and overground walking have been investigated in young adults (Murray et al., 1985; Alton et al., 1998; Matsas et al., 2000; Riley et al., 2007). Studies examined spatial gait parameters were different between treadmill walking and overground walking. The results have indentified longer double-limb support (i.e. both feet in contact with the ground) which is an equivalent of shorter swing phase (i.e. one foot in contact with ground) during treadmill walking. Longer periods of double limb support equals to greater cadence (steps/min) and shorter step length (Murray, Spurr, Sepic, Gardner, & Mollinger, 1985). In another study, participants took wider step width when walking on the treadmill (131.2 ± 24.3 mm) than overground (111.8 ± 18.9 mm); 15% larger step width in treadmill walking (Rosenblatt and Grabiner, 2010).

Treadmill walking and overground walking were significantly different when familiarization time of less than three minutes gave to participants (Alton et al., 1998). Knee kinematics in 16 healthy participants were examined throughout 15 minutes of treadmill walking and reliable knee joint measurement was collected by 4 minutes of treadmill walking (Matsas et al., 2000). At least four minutes of treadmill walking was required for participants to acclimatize to the treadmill.

Nonetheless, there are positive factors in testing participants on the treadmill rather than overground. First, treadmills can maintain constant speed or select various set of speeds for participants to follow throughout testing. Second, treadmill belt provides a continuous walking path to collect long periods of walking data. Third, the treadmill belt provides an uninterrupted path to collect consecutive gait cycles.

1.12 Prolonged treadmill walking over 60 minutes

Walking speed on the treadmill in previous research was within the range of 1.1 to 1.9 m/s (Matsas et al., 2000; Bechard et al., 2011). Previous research from our laboratory on 60 minutes of treadmill walking, the trunk lean angle was initially 0.66±1.09° and at the end of the walk was 1.03±1.48°. The toe-out angle was initially 10.10°±4.84 and at the end of 60 minutes was 10.72°±5.39 (Bechard et al., 2011).

Retest in the same week showed an average increase of 0.11° in trunk lean angle and an average increase of 0.42° toe-out angle at the start (5 to 15 minutes) of treadmill walking. At 50 to 60 minutes of treadmill walking, an average decrease of 0.41° trunk lean angle and an average increase of 0.17° toe-out angle (Bechard et al., 2011).

The intraclass correlation coefficient (ICC) value showed treadmill walking had small variation with overground walking. A major finding was trunk lean angle during overground walking (1.52°, SD 1.01) was higher than treadmill walking (0.71°, SD 1.01) in pre-test. The difference between the two conditions was 0.8°. The next session was at least 24hrs after the pre-test, the average trunk lean angle (1.23°, SD is 1.08) during overground walking was greater than treadmill walking (0.82°, SD is 1.24). The difference in between the two conditions was 0.41°. The ICCs for both test days were 0.88 for trunk lean angle (Bechard et al., 2011).

During overground walking, the average toe-out angle was 9.52° (SD 5.03°) that was less than treadmill walking of 10.31° (SD 4.78). The difference in toe-out angle between overground and treadmill walking was by a small difference of 0.79°. On the next session, at least 24hrs after the pre-test, the toe-out angle in overground walking (9.65°, SD 5.08°) had a lesser value than treadmill walking (10.82°, SD 5.27°). The toe-out angle difference between the two conditions was 1.17° which was greater than the difference of 0.79° on the first attempt. The ICC was 0.92 for toe-out angle between the two conditions of walking: treadmill and overground. Hence, toe-out and trunk lean angles measured during treadmill walking were similar to overground walking. Treadmill is a reliable tool to represent prolonged periods of walking or day-to-day walking when measurements are on trunk lean and toe-out angles (Bechard et al., 2011).

Temporal gait measure on leg kinematics presented few differences between split-belt treadmill and overground walking in 19 healthy participants; less dorsiflexor moments, knee extensor moments, and greater hip extensor moments. Muscle activation patterns, joint moments, and joint powers were similar between the split-belt treadmill and overground walking (Lee and Hidler, 2007).

Consecutive gait cycles of walking on the treadmill over a prolonged period tends to tire the participants compare to the start of the walk. Hence, there is the possibility that the participant walking movements is more representative of daily lives.

1.13 Thesis objective

The primary objective of this thesis is to examine the kinematic effects of two different types of orthotics on toe-out angle, pelvic tilt angle, and trunk lean angle in healthy participants over 60 minutes of walking. In the past few years, researchers have suggested that the biomechanical effects of foot orthoses during walking need further investigation (Stacoff, Quervain, Dettwyler, Wolf, List, Ukelo, & Stussi, 2007). Previous studies have postulated positive results with the use of foot orthoses that are either related to structural or proprioceptive mechanisms of orthotics (Nurse & Nigg, 1999; Nurse & Nigg, 2001). However, both mechanisms have not been studied to date during prolonged walking. Two types of orthotics will be studied. A certified pedorthist made the medial longitudinal arch insoles used in this study by hand, therefore the insoles are considered hand-made from this point on. The custom-made orthotic is designed to support the MLA structurally by holding the arch up on the plantar surface of the foot. The other orthotic used in this study provides a tactile stimulus to the plantar surface of the midfoot. The stimulus activates the intrinsic foot muscles to support the arch shape. Both orthotics are compared with generic insoles of each participant's own shoes.

In this thesis, a single experiment is conducted on healthy participants in walking on a treadmill for 60 minutes. For the majority of the time, the participants will be walking in their own shoes with generic insoles. Every 5 min interval the participants will be briefly stopped and two different types of orthotic as described above will be placed in the shoes. The participants will then walk for about 15 seconds with each orthotic and their gait kinematics measured. Then the orthotic is removed and the participants walk again with generic insoles.

The two hypothesis of this thesis are listed as follows.

1) The toe-out, pelvic tilt, and trunk lean angles will significantly increase over 60 minutes of treadmill walking.

It is hypothesized that this will occur as the participants walk naturally over time because there are no forceplate targets to aim or the participants have acclimatized to the test environment and equipment. It is also hypothesized that this will occur as the participants tire and they begin to employ compensatory gait mechanisms in order to reduce lower extremity biomechanical loading to reduce muscle activation.

2) The hand-made MLA orthotic and proprioceptive feedback-type orthotic will cause a significant decrease in the toe-out, pelvic tilt, and trunk lean angles over 60 minutes of treadmill walking compared to the generic insoles.

This is hypothesized to occur since the orthotics will shift the foot into a more supinated position. More foot supination will cause the center of pressure (COP) to move medially with respect to the knee joint and the line of action of the ground reaction force moves laterally. This reduces the moment arm of the ground reaction force about the knee and thereby reducing the muscle activation required to stabilize the knee in the frontal plane.

This thesis uses soft orthotics made by plastazote in the MLA orthotic condition and soft level of inserts in proprioceptive orthotic condition.

1.13.1 Outline

Chapter 1 is a review of the functional anatomy, biomechanics of the foot, and literature review on foot orthotics and treadmill walking. The method of optical motion capture is introduced in this chapter and the definition of rigid body segments are given that will be used for the rest of this thesis. Then a literature review is presented on the three selected gait variables: toe-out, pelvic tilt, and trunk lean angles. The similarities and differences between treadmill walking gait and overground walking gait are also included in the literature review. Chapter 1 concludes with the objective and two research hypotheses of this thesis.

Chapter 2 investigates the change in the three kinematic gait variables in healthy participants during 60 minutes of treadmill walking. The result examines the use of generic insoles. The three kinematic gait variables are toe-out, pelvic tilt, and trunk lean angles. Toe-out and trunk lean angles are indicators that a compensatory gait mechanism is being used to reduce knee joint loading. The interface between the human foot and the ground plays a crucial role in locomotion. Toe-out angle is selected because the foot is the only part of the body that has direct contact with the insole and the ground. The H.A.T. accounts for two-thirds of the total body mass (Winter, 1991). This indicates the importance in controlling trunk motion during locomotion. Hence, the trunk lean angle is selected as one of the three kinematic gait variables. The distal segments of the body (i.e. the foot and the trunk) are selected as kinematic gait variables, there is a need to examine the proximal changes of the body over 60 minutes. Hence, pelvic tilt angle is also selected as one of the three kinematic gait variables.

Chapter 3 investigates the effects of MLA orthotics and proprioceptive feedback-type orthotics on the three gait variables during 60 minutes of treadmill walking. The three kinematic gait variables are toe-out, pelvic tilt, and trunk lean angles. Contour surfaces of foot orthoses changed the orientation of foot position and the loading response of the foot onto the ground. It has been proposed by other researchers that foot orthoses can alter joint kinematics by sensory feedback through the stimulus from the feet (Stacoff et al., 2000). In discussion, results are compared between the MLA orthotic and proprioceptive orthotic with respect to 60 minutes of treadmill walking.

Chapter 4 is a discussion on the results in Chapter 2 and 3. Little is known on prolonged treadmill walking, especially on the effects of foot orthoses with MLA support on body kinematics. Chapter 4 concludes with possible areas for future research.

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Chapter 2:

Changes in gait kinematics over 60 minutes of treadmill walking

2.1 Introduction

Treadmills in gait laboratories have become more common as an alternative for overground walking, yet few studies have examined the changes in gait kinematics that occur during prolonged periods of treadmill walking. Testing with a treadmill allows participants to walk for a long period without the need to change direction because the treadmill belt provides a continuous and uninterrupted walking path.

When participants enter the gait laboratory, which houses state-of-the-art equipment use for testing, they instinctively feel committed to perform at their best. There is a good chance the results consist of a potential error: controlled setting. Participants often walk in a careful and steady but stiff manner. It has also been reported that walking on a treadmill increases stiffness of the trunk when compared to overground walking (Vogt, Pfeifer, & Banzer, 2002).

The goal of this research was to collect data that best represents natural daily life movements. Typically in gait laboratory, participants are tested over a couple of foot strikes on the force plate, in which participants way of walking could alter due to stress, unfamiliarity with the lab environment, or other factors that might affect walking movements. However, testing participants over a longer time, such as 60 minutes of treadmill walking, can get them to walk the way they do on a daily basis. The reason is because consecutive walking gait cycles are required on the treadmill. Participants do not need to pause or alter their way of walking to step on a target (i.e. forceplate). Another reason could be participants tire with the prolonged effort, excessive joint motions that cannot be spotted earlier in the trials then become apparent.

Drawing on all of this information, we assumed natural movement patterns were collected when participants walked over 60 minutes on the treadmill. As time passes, walking becomes more natural for participants to feel comfortable with the operation of the equipment and with being observed by the researchers. In a gait laboratory, participants are asked to walk naturally to mimic daily walking movement patterns. This study will have participants walk for 60 minutes to capture movements most representative of natural day-to-day walking.

Previous research from our lab examined how walking gait kinematics changed over 60 minutes of treadmill walking in healthy participants (Bechard, Birmingham, Zecevic, & Jenkyn, 2011). This previous study examined two kinematic variables, toe-out angle in the transverse plane and runk lean angle in the frontal plane. A strong association existed between the two angles in decreasing knee joint loading (Bechard et al., 2011). The findings in one study suggested that an intentional increase in medio-lateral trunk sway is a non-invasive method in reducing the knee adduction moment and may be effective in slowing down the progression of degenerative joint disease, such as knee osteoarthritis. Average reduction of 65.0% in knee adduction moments was found when participants increased medio-lateral trunk sway by 10±5° (Mundermann, Asay, Mundermann, & Andriacchi, 2008).

Increase in toe-out angle has shown to reduce the loads at the knee joints (Andrews, Noyes, Hewett, & Andriacchi, 1996; Lin, Lai, Chou, & Ho, 2001; Hurwitz, Ryals, Case, Block, & Andriacchi, 2002; Jenkyn, Hunt, Jones, Giffin, & Birmingham, 2008). In healthy children (aged 11 to 13 years old), the average toe-out angle was 10±3° (Lin et al., 2001). Intentional toeing in averaged 15±5° caused an increase in the knee adduction moment (Lin et al., 2001). In another study on 50 healthy individuals, the average toe-out angle was 7.3° with a SD of 5° (Rutherford, Hubley-Kozey, Deluzio, Stanish, & Dunbar, 2008).

This thesis examines both the toe-out and trunk lean angles. In addition, the pelvic tilt angle is also examined in the sagittal plane. In a study on 40 young healthy participants, an average of 2.8° on pelvic tilt angle was obtained over three days during overground walking (Kadaba, Ramakrishnan, & Wootten, 1990). The pelvic tilt angles during treadmill walking at initial contact were 9.62±5.06° in women and 8.85±3.30° in men. At toe-off, women had 8.65±5.10° and men had 6.55±2.90°.(Chockalingam, Chatterley, Healy, Greenhalgh, & Branthwaite, 2012).

Prolonged treadmill walking was conducted in a study that looked at trunk lean and toe-out angles in 20 healthy participants during overground walking and 60 minutes of treadmill walking (Bechard et al., 2011). Small differences in toe-out and trunk lean angles were detected between treadmill and overground walking. The findings concluded both toe-out and trunk lean angles measured during treadmill walking were similar to overground walking.

2.1.1 Kinematic variable definitions

Toe-out, pelvic tilt, and trunk lean angles were the selected kinematic variables calculated in this study over 60 minutes in 5 minute intervals.

Toe-out angle is defined as the angle between the direction of walking progression and the midline of the foot. The midline of the foot is measured at the line jointing the reflective marker attached to the heel with the reflective marker on the second metatarsal-phalangeal joint (see Figure 2.1). In whole-body gait analysis, the foot is considered as a single rigid segment articulating with the lower extremity (Perry & Burnfield, 2010). A positive toe-out angle indicates the toes are pointing outward (i.e. toeing out). A negative toe-out angle indicates the toes are pointing inward (i.e. toeing in).

Pelvic tilt angle is defined as the angle between the horizontal and a straight line joining the anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS). The straight line is defined as the imaginary midpoint between the left and right markers placed on the ASISs to the third marker midway between the two PSISs (see Figure 2.1). A forward pelvic tilt angle is indicated by a positive value. A backward pelvic tilt angle is indicated by a negative value. The direction of the pelvic movement is determined with respect to the reference position in quiet bipedal standing (Kadaba et al., 1990).

Trunk lean angle is defined as the angle between the vertical and a straight line connects to the midpoint of the ASIS markers and the midpoint of the shoulder markers (see Figure 2.1). A positive trunk lean angle is when the trunk leans towards the stance limb. A negative trunk lean angle is when trunk leans towards the swinging limb (Mundermann et al., 2008).

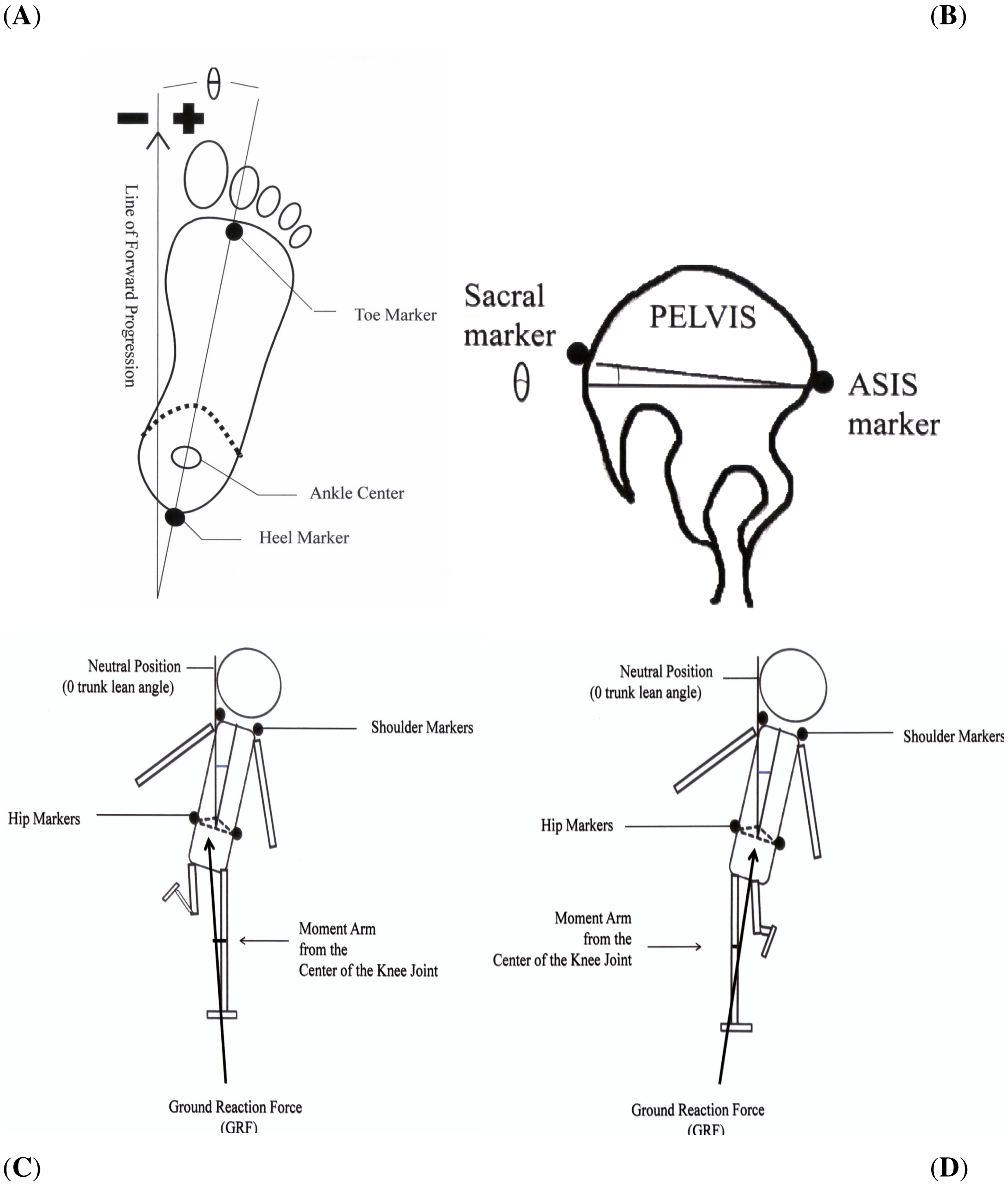


Figure 2.1- The reflective markers are shown as black dots. (**A**) Positive toe-out angle is when the toes point laterally outward. Negative toe-out angle is when the toes point medially inward. (**B**) The line connecting the two markers and the horizontal line defines the pelvic movement in the anterior and posterior direction. Forward pelvic tilt angle is indicated by a positive value. Backward pelvic tilt angle is indicated by a negative value. (**C**) Positive trunk lean angle is when body leans toward the stance leg. (**D**) Negative trunk lean angle is when body leans toward the swinging leg.

2.1.2 Purpose of study

This study examined body kinematics adapted by healthy individuals while wearing their own generic insoles over 60 minutes of intermittent treadmill walking. Joint angles are examined in three kinematic gait variables: toe-out angle in transverse plane, pelvic tilt angle in sagittal plane, and trunk lean angle in frontal plane. Generic insoles are designed to fit a broad range of footwear which typically does not have customed support, cushioning, or contours designed to fit each individual.

This study has three objectives. The first and second objectives have all the participants in one sample group (n=20) to determine the magnitude of toe-out angle, pelvic tilt angle, and trunk lean angle when walking on the treadmill:

(1) at the start (0min) and finish (60 min)

(2) between start to finish in angular changes (i.e. 60min-0min).

(3) The third objective is to examine the magnitudes of angle changes in each of three groups over 60 minutes of treadmill walking.

Groups are divided by assigning participants in one of the three groups based on gait changes: Increase, No Change, and Decrease Groups. The third objective is to evaluate whether all the participants show similar trends in gait changes over time.

It is hypothesized that toe-out, pelvic tilt and trunk lean angles will change significantly over 60 minutes of treadmill walking.

2.2 Methods

2.2.1 Participants

Twenty healthy participants (9 males, 11 females) were primarily recruited from a local running group and from the university student population. The method of recruitment was by one-on-one invitation. Participants were screened based on four criteria:1) no previous use of foot orthoses, 2) no ankle injuries in the past year, 3) no abnormalities that might affect their ability to walk on the treadmill and 4) independent mobile. Ethical approval was obtained from the institution's Research Ethics Board for Health Sciences and informed consent was signed by each participant before testing.

2.2.2 Protocol

Each participant walked on the treadmill for 60 minutes and paused to change foot orthoses every 5 minutes. Data was collected in 5 min time interval in the following sequence: own shoe insole (Control), medial longitudinal arch (MLA) orthotic and proprioceptive feedback-type orthotic. However, this chapter is concentrated on the data from the own shoe insole condition rather than foot orthoses used during testing (see chapter 3 for details on orthoses).

A total of 13 cycles of data collection over 60 minutes of testing was collected for each condition. The first interval of the testing session, between 0 to 5 min, ensured that every participant got at least five minutes of familiarization with the treadmill. Data was collected in the last 15 seconds of every 5 min time interval

Kinematic data was collected with a five-camera motion capture system at a sampling frequency of 60 frames per second (Hawk cameras, Cortex 2.6.2 system, Motion Analysis Corp., Santa Rosa, CA, USA). During data collection, participants walked on a level force-plate instrumented treadmill (Gaitway model, Kistler Instrument Corp., Amherst, NY, USA). Each participant wore a T-shirt, shorts and own choice of running shoes during the session from start to finish, and the time to complete testing was about 2 ½ hours.

The speed at which each participant walked on the treadmill was calculated at the beginning of the session. Participants first walked at their self-selected comfortable walking speed over tape marked 6 meters of level floor walkway. Stopwatch was used to record the time required to walk over that distance. The distance was then divided by the time; participant's walking speed on the treadmill was calculated.

Passive reflective markers (22 markers; 1.25 cm diameter each) were placed on bony landmarks of the participants in a modified Helen Hayes configuration (Kadaba et al., 1990) to track body segments kinematics.

Once treadmill speed had been calculated, participants walked at that speed on the level treadmill. A practice trial of up to five minutes was given to the participants to get familiarised with the treadmill. During the familiarization period, participants could increase or decrease speed to achieve comfortable self-selected walking pace on the treadmill. However, all the participants preferred to remain at the same speed from start to finish.

Before data collection on prolonged treadmill walking, four initial trials (two static standing, one left leg dynamic and one right leg dynamic) were required for the cameras to recognize the orientation of markers. In addition to the 22 reflective markers, two extra markers on each limb; one on the medial femoral epicondyle of the knee and one on the medial malleolus of the ankle to determine the knee and ankle joint centers. The four extra markers were removed after the initial trials, and then 60 minutes of treadmill walking began. A total of 13 time intervals collected over 60 minutes.

2.2.3 Data analysis

To reconstruct three-dimensional marker trajectories, the Cortex 2.6.2 reconstruction software system (Motion Analysis Corp., Santa Rosa, CA, USA) was used to replicate the movements of the participants in a stick-figure format. The collection of kinematic data was through the placement of reflective markers on the surface of body segment. The product of data collection was frames of kinematic data over 15 seconds of data collection. In each frame, three-dimensional spatial locations of the reflective markers were displayed. The body segments tracked were the foot, shank, leg, pelvis, trunk and arms. Reflective marker kinematics were low pass filtered with a cutoff at 6 Hz using 4th order Butterworth with zero lag. Based on the filtered data, toe-out, pelvic tilt and trunk lean angles were calculated (Jenkyn et al., 2008).

The first three right foot strikes were used from each of the 15 seconds collected. Four foot strikes of the same foot equal to three gait cycles. For each time interval, three gait cycles were analyzed (see Figure 2.2). The kinematic gait variables in each time interval were calculated based on the average over three strides.

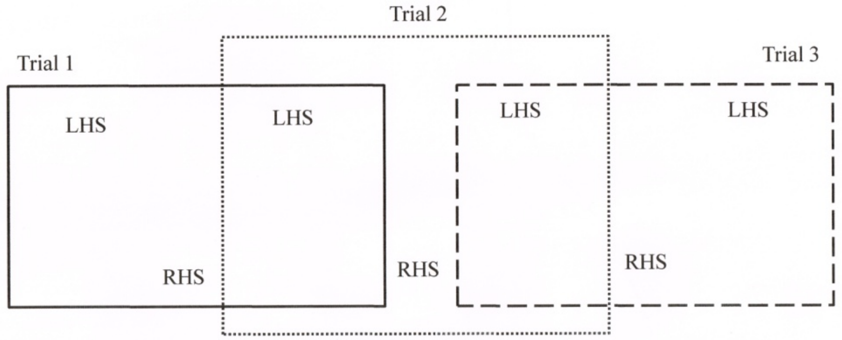


Figure 2.2- The first three right foot strikes were used from each of the 15 seconds collected. Four left foot strikes of the same foot equal to three strides.

Rigid body motion for the segments of the body was calculated from the filtered marker trajectories using analysis software (OrthoTrak 6.6.1, Motion Analysis Corp., Santa Rosa, CA, USA). The identification of left and right foot strike and toe-off were required from each tracked trial. From the three-dimensional segment motions, the three kinematic gait variables (toe-out, pelvic tilt, and trunk lean angles) were calculated using custom-written software (Excel, Microsoft Corp., 2010).

2.2.4 Statistical analysis

The analyzed data are displayed in one of the following ways: one sample group (n=20) or in one of the three subgroups (Increase, No Change, and Decrease Groups). For each kinematic gait variable, the degree of change in angle from start (0 min) and finish (60 min) were examined to determine the magnitude of change (60 minutes time interval minus 0 minute time interval; 60-0min) from start till end of treadmill walking (see Table 2.2 through 2.4).

Calculated angles for the three kinematic gait variables were determined for each time interval (5 min per interval) over the 60 minutes of testing was by taking the averages over the first three right foot strikes. To determine the amount of change that occurred at each interval since the start of the test, the value of the variable at 0 min was subtracted from each time interval (i.e. specific time interval minus 0 min), known as the relative change in angle.

Relative change in angle = angle at that specific time interval – angle at 0 min

For each participant, there were 13 relative changes in angle values because there were 13 time intervals throughout testing. The average of the 13 relative changes in angle values was known as the average relative change in angle from this point on.

To determine statistical significance in one sample group and the three subgroups, mean, standard deviation (SD), upper and lower limits of the 95% confidence interval (CI) were calculated based on the averages of the 13 relative change in angles (i.e. 5 min interval per calculated angle) for each kinematic gait variable. These analyses tested whether any changes were significant over time at $p<0.05$ with respect to the value zero (no change).

Group division was based on the average relative change in angle of each participant compared to the 1.5° cut-off value. The cut-off value of 1.5° was subjectively determined based on how clustered the calculated angles were between participants (n=20). The participants were divided into one of the three subgroups: Increase Group, No Change Group, and Decrease Group. The Increase Group had the average relative change in angle value above +1.5° (represented by white box). The No Change Group had the average relative change in angle value between +1.5° to -1.5° (represented by the word "same"). The Decrease group had the average relative change in angle value less than -1.5° (represented by black box).

The linear regression line was plotted against time and each kinematic gait variable. On each graph, coefficient of determination (R^2) was calculated by Excel. The slope and standard error of the mean (SEM) for the toe-out, pelvic tilt, and trunk lean angles were calculated using LINEST function in Excel. The slope represents the amount of change in the kinematic gait variable has on average for each 5 min time interval. The SEM indicates the amount of error in predicting the mean of the population based on the sample group. However, the values calculated were to two to three decimal places. There was the need to report the slope in degrees per hour for each kinematic gait variable versus walking time duration.

The multiple comparison tests on SEM are to determine if a significant relationship existed between the kinematic gait variables and walking time duration (0 to 60 minutes) among the Increase, No Change, and Decrease Groups. For each gait variable, an overlap of the 95% CI constructed by SEM on slope values among the three groups shows statistical significance existed.

2.3 Results

Mean and standard deviation (SD) on anthropometric measurements and walking speed of the participants are presented in Table 2.1. The three kinematic gait variables (toe-out, pelvic tilt and trunk lean angles) of the 20 participants did not change significantly over 60 minutes of prolonged walking ($p<0.05$).

Table 2.1- Anthropometric measurements and walking speed of the participants (n=20; 9 males and 11 females).

	Mean	SD	Range (Max to Min)
Age	45.6	20	19 – 74
Height (m)	1.69	0.1	1.52 - 1.88
Mass (kg)	70.7	14.8	47.6 - 92.4
BMI (kg/m^2)	24.5	3.72	18.5 - 33.1
Walking Speed (m/s)	1.33	0.29	0.8 - 1.9

2.3.1 One overall group analysis on mean, SD, & 95% CI

2.3.1.1 Calculated angles and SD

For each kinematic gait variable, the calculated angle at 0 min, 60 min, and 60 min minus 0 min (60-0 min) for each participant are presented in Table 2.2 through Table 2.4.

At 0 min (start of testing), the average toe-out angle was 8.32±5.38˚, the average pelvic tilt angle was 3.45±2.24˚, and the average trunk lean angle was 0.94±1.11˚. At 60 min (end of testing), the average toe-out angle was 8.55±5.12˚, the average pelvic tilt angle was 4.28±2.31˚, and the average trunk lean angle was 0.795±1.34˚

In the control condition, more than half the participants (11 out of 20) had an increase in toe-out over 60 minutes of walking. Approximately half of the participants (9 out of 20) had a decrease in toe-out angle over the 60 minutes of walking. Out of the three kinematic gait variables, difference in pelvic tilt angle (60-0min) had three quarters of the participants (15 out of 20) had increased anterior pelvic tilt angle over the 60 minutes of walking. Difference in trunk lean angle (60-0min) was more variable. A little more than half of the participants (11 out of 20 participants) had a decrease in trunk lean over the 60 minutes of walking. Approximately, one quarter of the participants (8 out of 20 participants) had an increase in trunk lean and one participant had no change over the 60 minutes of walking.

Table 2.2- Difference in toe-out angle between 60 min and 0 min showing the change in angle from the end and start of testing for the control condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. Eleven participants had an increase in toe-out over the 60 minutes of walking.

Difference in *Toe-out* angle from start to finish (60-0 min) in *Control*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	5.1	3.3	1.8	Increase
2	9.7	8.7	1.0	Increase
3	0.4	0.7	-0.3	Decrease
4	14.3	9.2	5.1	Increase
5	11.7	10.1	1.6	Increase
6	3.4	5.3	-1.9	Decrease
7	18.1	18	0.1	Increase
8	12.5	13.5	-1.0	Decrease
9	4.1	5.9	-1.8	Decrease
10	8.1	19.3	-11.2	Decrease
11	12.3	9.8	2.5	Increase
12	2.0	2.8	-0.8	Decrease
13	6.0	6.6	-0.6	Decrease
14	7.2	6.1	1.1	Increase
15	16.2	15.5	0.7	Increase
16	10.8	11.0	-0.2	Decrease
17	9.4	9.6	-0.2	Decrease
18	0.4	-0.3	0.7	Increase
19	6.2	2.7	3.5	Increase
20	13.1	8.6	4.5	Increase
Avg	8.55	8.32	0.23	
SD	5.12	5.38	3.30	
Max	18.1	19.3	5.1	
Min	0.4	-0.3	-11.2	
		Greater than 0	**11**	
		Lesser than 0	**9**	

Table 2.3- Difference in pelvic tilt angle between 60 min and 0 min showing the change in angle from the end and start of testing for the control condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min. Three quarters of the participants had increased anterior pelvic tilt angle over the 60 minutes of walking.

Difference in *Pelvic Tilt* angle from start to finish (60-0 min) in *Control*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	6.2	6.0	0.2	Increase
2	3.6	4.1	-0.5	Decrease
3	4.3	4.0	0.3	Increase
4	2.9	1.2	1.7	Increase
5	10.0	6.8	3.2	Increase
6	6.5	7.0	-0.5	Decrease
7	6.2	2.4	3.8	Increase
8	-0.4	3.8	-4.2	Decrease
9	5.1	4.3	0.8	Increase
10	4.2	2.2	2.0	Increase
11	3.2	3.1	0.1	Increase
12	2.4	0.2	2.2	Increase
13	3.6	1.6	2.0	Increase
14	1.3	-0.4	1.7	Increase
15	1.8	-0.5	2.3	Increase
16	4.7	6.4	-1.7	Decrease
17	3.0	4.0	-1.0	Decrease
18	5.4	4.2	1.2	Increase
19	4.5	3.7	0.8	Increase
20	7.1	4.8	2.3	Increase
Avg	4.28	3.45	0.835	
SD	2.31	2.24	1.85	
Max	10.0	7.0	3.8	
Min	-0.4	-0.5	-4.2	
		Greater than 0	**15**	
		Lesser than 0	**5**	

Table 2.4- Difference in trunk lean angle between 60 min and 0 min showing the change in angle from the end and start of testing for the control condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. The symbol “—” represents zero change. One participant had no change in trunk lean over the 60 minutes of walking.

Difference in *Trunk Lean* angle from start to finish (60-0 min) in *Control*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	0.6	0.9	-0.3	Decrease
2	0.5	0.3	0.2	Increase
3	-1.5	-0.3	-1.2	Decrease
4	0.1	-0.5	0.6	Increase
5	0.8	1.0	-0.2	Decrease
6	0.0	1.7	-1.7	Decrease
7	3.0	3.3	-0.3	Decrease
8	2.7	2.1	0.6	Increase
9	0.0	0.0	0.0	--
10	2.4	2.8	-0.4	Decrease
11	-0.8	0.3	-1.1	Decrease
12	2.1	1.0	1.1	Increase
13	1.8	1.3	0.5	Increase
14	1.8	0.9	0.9	Increase
15	0.4	0.6	-0.2	Decrease
16	1.8	2.8	-1.0	Decrease
17	-1.5	-0.3	-1.2	Decrease
18	1.1	0.9	0.2	Increase
19	-0.8	-0.1	-0.7	Decrease
20	1.4	0.0	1.4	Increase
Avg	0.795	0.935	-0.14	
SD	1.34	1.11	0.84	
Max	3.0	3.3	1.4	
Min	-1.5	-0.5	-1.7	
		Greater than 0	**8**	
		Lesser than 0	**11**	
		Equal to 0	**1**	

2.3.1.2 True or population value within 95% confidence interval (n=20)

No change in angle was represented by zero. All three kinematic gait variables had zero within the 95% confidence interval calculated by SD. Therefore, the average relative change in angles of the 20 participants for each of the kinematic gait variables did not change significantly over 60 minutes of prolonged walking ($p<0.05$; Table 2.5). This is indicated by the 95% CI for each angle crossing zero after 60 minutes.

Table 2.5- Average relative change in angle over 60 minutes of prolonged walking for the three kinematic gait variables are shown with SD and the upper and lower limits of the 95% confidence interval. Since all three kinematic gait variables had zero within their respective 95% confidence interval then there was no significant change in these variables after 60 minutes of prolonged walking at $p<0.05$.

Control **(n=20)**	Relative Change in Angle over 60 minutes	SD	95% CI lower limit	95% CI upper limit
Toe-out (deg)	0.275	1.44	-2.54	3.09
Pelvic Tilt (deg)	0.588	0.823	-1.02	2.20
Trunk Lean (deg)	-0.0501	0.577	-1.18	1.08

2.3.2 Group division based on relative change in calculated angles

For each kinematic gait variable, the 20 participants were divided into one of the three groups: Increase, No Change, and Decrease Groups (see Table 2.6) based on the average relative change in angles.

Most of the participants had changes of more than 1.5° in toe-out angle; they were classified into the No Change Group (n=15). Approximately one quarter of the participants were assigned to the Increase Group (n=4), and one participant was assigned to the Decrease Group (n=1) based on the relative change in toe-out angle.

Approximately three quarters of the participants were classified into the No Change Group (n=14), Increase Group (n=5), and Decrease Group (n=1) based on the pelvic tilt angle.

The trunk lean angle was quite distinct from the other two variables because all participants (n=20) showed no change in angle over the 60 minutes of walking. None of the participants had changes in trunk lean angle of more than 1.5° after 60 minutes of walking. However, a number of participants showed change greater than or lesser than 1.5° over the 60 minutes of treadmill walking in toe-out and pelvic tilt angles. General observation on the results indicated most of the participants belonged in the No Change Group for all three kinematic gait variables; angle change no greater than 1.5°. Participants were assigned to one of the three groups based on the behaviour of each gait variable.

Table 2.6- Assignment of each participant to one of three groups based on the magnitude of the change in each of the three kinematic gait variables over 60 minutes of prolonged walking. The three groups are “No Change Group” (the word “same”), “Increase Group” (white box; > +1.5°), and “Decrease Group” (black box; < -1.5°). Trunk lean angle did not change significantly for any of the 20 participants. Five of the twenty participants (a quarter of participants) changed in toe-out angle and six of the twenty participants changed in pelvic tilt angle.

Control (Own Insole Condition)			
		Avg on magnitude of change	
Participant #	**Toe-out**	**Pelvic Tilt**	**Trunk Lean**
1	same	same	same
2	same	same	same
3	same	same	same
4	□	same	same
5	□	□	same
6	same	same	same
7	same	□	same
8	same	■	same
9	same	same	same
10	■	same	same
11	same	same	same
12	same	□	same
13	same	same	same
14	same	□	same
15	same	□	same
16	same	same	same
17	same	same	same
18	same	same	same
19	□	same	same
20	□	same	same
Increase/20	*4*=**20**%	*5*= **25**%	/
Same/20	*15*= **75**%	*14*= **70**%	*20* = **100**%
Decrease/20	*1*= **5**%	*1*= **5**%	**/**
Total % Changed	***25%***	***30%***	***0%***

Table 2.7- The average change over 60 minutes of prolonged walking for the three kinematic gait variables is shown with SD and the upper and lower limits of the 95% confidence interval. Statistically significant differences is indicated with an asterisk (*) at p<0.05. In the control condition, toe-out angle decrease in the Decrease Group, and pelvic tilt angle increases in the Increase Group.

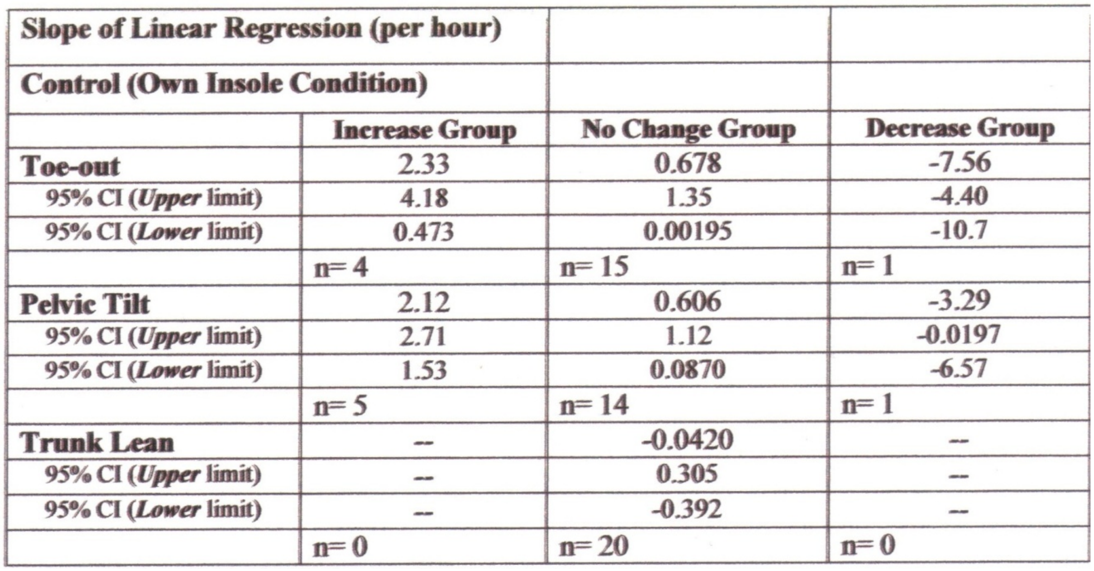
Control- Toe-out angle **(deg) averaged over 60 minutes**	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=4)	2.66	1.92	-1.10	6.43
No Change Group (n=15)	0.116	1.20	-2.24	2.47
Decrease Group (n=1)*	-6.88	3.00	-12.8	-0.995

Control- Pelvic tilt angle **(deg) averaged over 60 minutes**	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=5)*	2.12	0.937	0.286	3.96
No Change Group (n=14)	0.291	0.691	-1.06	1.65
Decrease Group (n=1)	-2.93	2.091	-7.03	1.17

Control- Trunk lean angle **(deg) averaged over 60 minutes**	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=0)	--	--	--	--
No Change Group (n=20)	-0.0501	0.577	-1.18	1.08
Decrease Group (n=0)	--	--	--	--

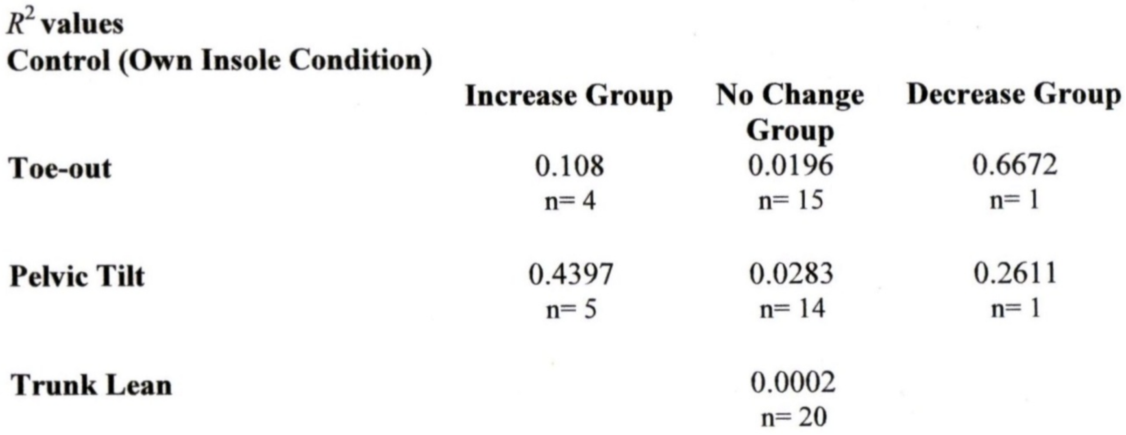
Slope of the linear regression line and upper and lower limits of the 95% CI calculated by SEM for each of the three kinematic gait variables in each of the three groups are shown in Table 2.7, and R² value are shown in Table 2.8.

Table 2.8- The slopes (in degrees per hour) as determined by the linear regression, along with the upper and lower limits of the 95% confidence intervals for the change in toe-out angle, trunk lean angle, and pelvic tilt angle are listed for each of the three groups: Increase, No Change, and Decrease. For each subgroup, the sample size is also given. For toe-out angle, decrease group showed significant differences but had only one participant belonged in this group. All three groups showed significant differences in the slope of the pelvic tilt angle because the range of the 95% confidence interval had no overlaps.



Slope of Linear Regression (per hour)			
Control (Own Insole Condition)			
	Increase Group	**No Change Group**	**Decrease Group**
Toe-out	2.33	0.678	-7.56
95% CI (*Upper* limit)	4.18	1.35	-4.40
95% CI (*Lower* limit)	0.473	0.00195	-10.7
	n= 4	n= 15	n= 1
Pelvic Tilt	2.12	0.606	-3.29
95% CI (*Upper* limit)	2.71	1.12	-0.0197
95% CI (*Lower* limit)	1.53	0.0870	-6.57
	n= 5	n= 14	n= 1
Trunk Lean	--	-0.0420	--
95% CI (*Upper* limit)	--	0.305	--
95% CI (*Lower* limit)	--	-0.392	--
	n= 0	n= 20	n= 0

Table 2.9- Toe-out, pelvic tilt, and trunk lean angles in the proprioceptive orthotic condition are listed in the R^2 value table. The R^2 values for the Increase, No Change, and Decrease groups are presented. The R^2 value represents the proportion of the kinematic gait variable that is explained by time in the control condition. The Decrease Group showed the greatest variance in toe-out angle. The Increase Group showed the greatest variance in pelvic tilt angle. The No Change Group showed the least variance among the three kinematic gait variables.



R^2 values
Control (Own Insole Condition)

	Increase Group	**No Change Group**	**Decrease Group**
Toe-out	0.108 n= 4	0.0196 n= 15	0.6672 n= 1
Pelvic Tilt	0.4397 n= 5	0.0283 n= 14	0.2611 n= 1
Trunk Lean		0.0002 n= 20	

2.3.2.1 Change in toe-out angle over time (slope of the linear regression line)

Plotted averages best fitted the linear regression line in the Decrease Group (n=1) and were most spread out in the No Change Group (n=15). The slope of the linear regression line had a weak relationship between toe-out angle and walking time duration in the Increase Group and the No Change Group. Although, there was a strong linear relationship observed in the Decrease Group but the sample size of the Decrease Group was one participant (see Figure 2.3). Within the three groups, the Decrease Group had the strongest relationship between toe-out angle and time for prolonged treadmill walking.

For toe-out angle, the Decrease Group was significantly different from the Increase and No Change Groups. The Decrease Group showed significant differences with the other two groups (Increase and No Change Groups) by the absence of overlap in the range of SEM values (see Figure 2.4).

As for the Decrease Group (n=1), the R^2 value for the Decrease Group had the highest variance in all three groups but the sample size was one. The statistical power in the Decrease Group for toe-out angle was weak (see Table 2.9).

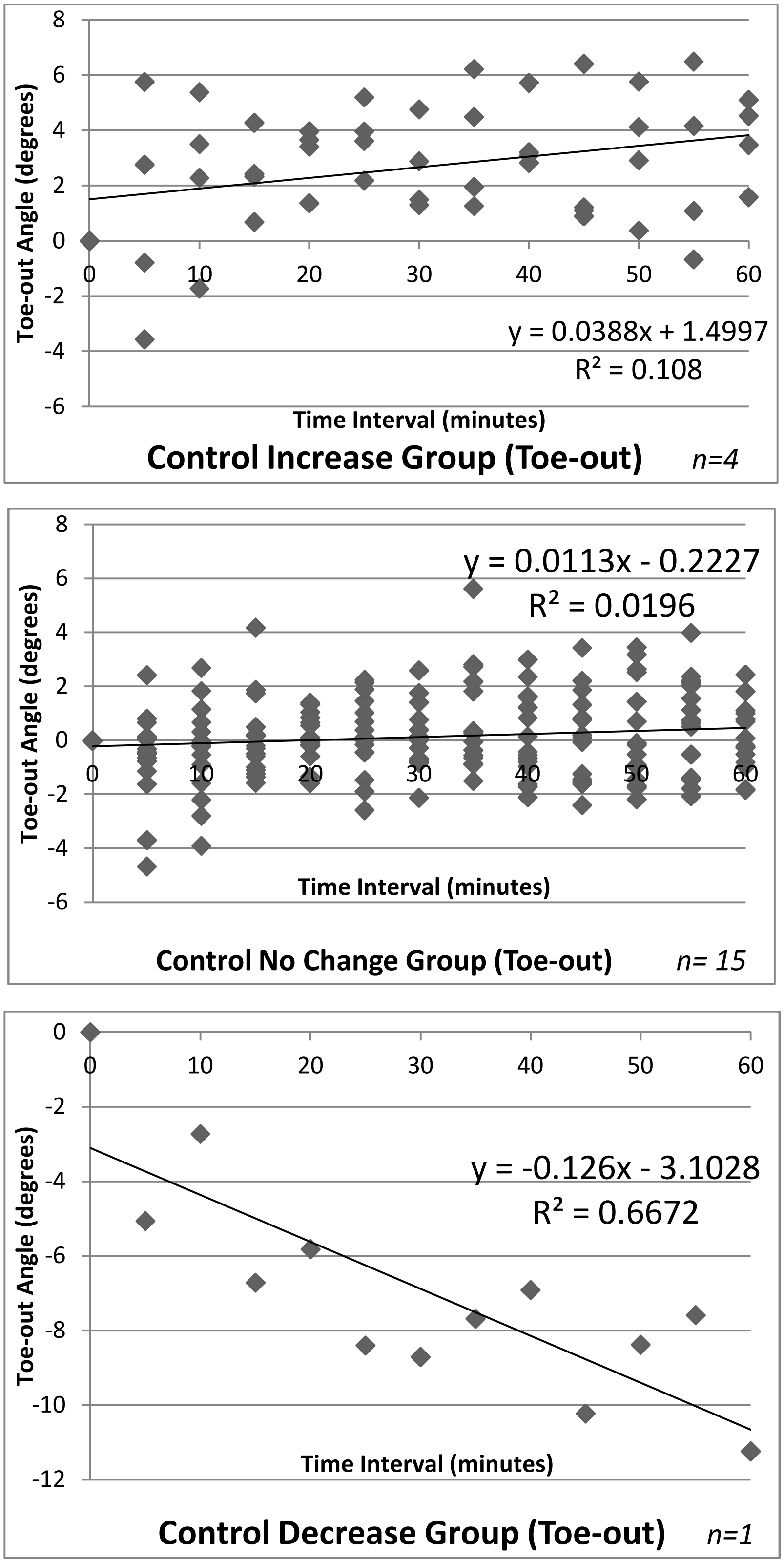


Figure 2.3- Average change in toe-out angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R^2values and equations.

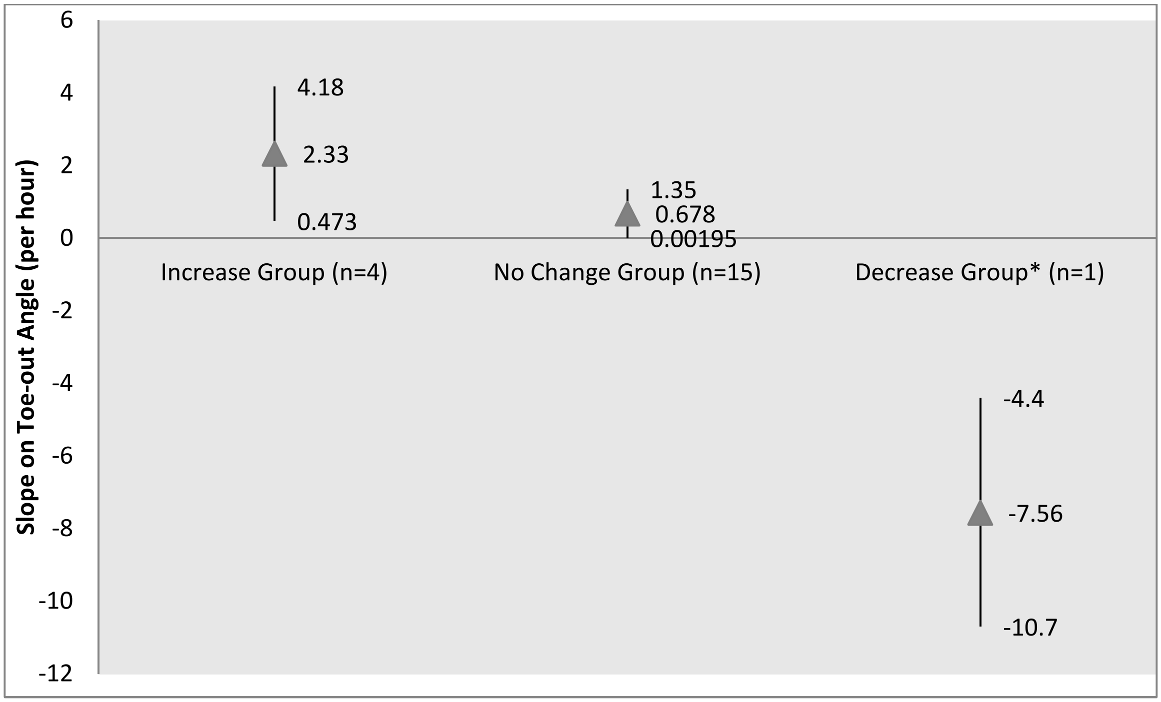


Figure 2.4- The average slope of the linear regression line on toe-out angle in the control condition with 95% CI bars shown for each of the three groups. The toe-out angle in the Decrease Group was significantly different from both the toe-out angle in the Increase and No Change Groups. However, the toe-out angle in the remaining two groups was not significantly different from one another. Significant difference between the Decrease Group and the remaining two groups is indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs.

2.3.2.2 Change in pelvic tilt angle over time (slope of the linear regression line)

For pelvic tilt angle, the slope of the linear regression line in all three groups (Increase Group, No Change Group, and Decrease Group) was significantly different from each other. Figure 2.4 shows plotted averages best fitted the linear regression line in the Increase Group (n=5) and were most spread out in the No Change Group (n=14).

The R^2 value in the Increase Group had the highest variance in all three groups (see Table 2.9). Conversely, the R^2 value for the No Change Group had a close to zero variance that could predict pelvic tilt by time.

Among the three groups on pelvic tilt angle, the Increase Group had the strongest relationship with prolonged treadmill walking followed by the Decrease and No Change groups.

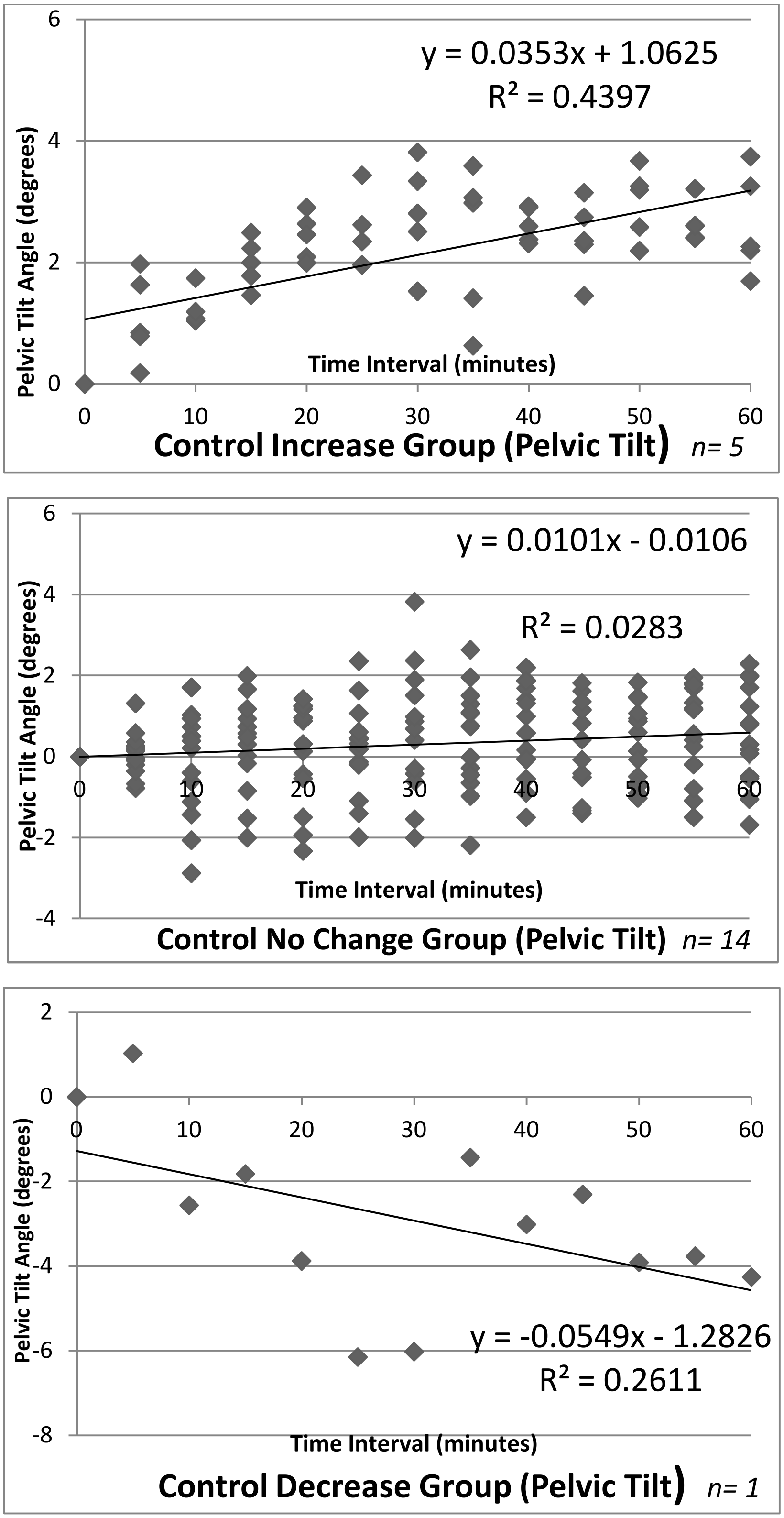


Figure 2.5- Average change in pelvic tilt angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R² values and equations.

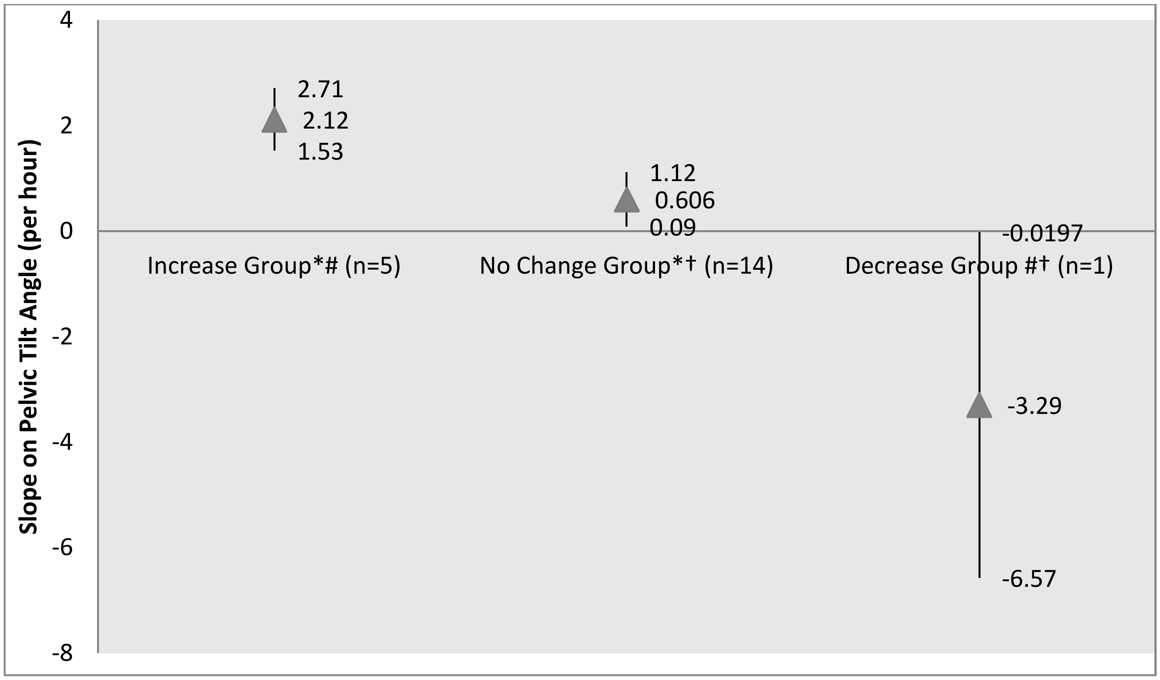


Figure 2.6- The average slope of linear regression on pelvic tilt angle in the control condition with 95% CI error bands shown for each of the three groups. All three groups were significantly different. Significant differences are denoted with a symbol to indicate a significance level of p= 0.05. The asterisk (*) represents a significant difference between the Increase Group and No Change Group. The dagger (†) represents a significant difference between the No Change Group and Decrease Group. The number sign (#) represents a significant difference between the Increase Group and Decrease Group. The triangles reflect the mean slopes and the ranges represent the 95% CIs.

2.3.2.3 Trunk lean angle and linear regression line

For the trunk lean angle variable, all 20 participants belonged in the No Change Group (see Table 2.6). Each participant's overall average change in trunk lean angle stayed within the range of +1.5 to -1.5° (see Figure 2.7). Trunk lean angle in all the participants belonged in the No Change Group and there was only one range of SEM values to compare (see Figure 2.8). Hence, no significant difference was detected at $p<0.05$. In other words, trunk lean angle was not significantly different among the groups because all the participants belonged in the No Change Group.

The R^2 value in all the participants for trunk lean angle was 0.02% of the variance was predicted by time (see Table 2.9). Linear relationship between trunk lean angle and walking time duration was close to zero. An orthogonal relationship was seen between trunk lean angle and prolonged treadmill walking.

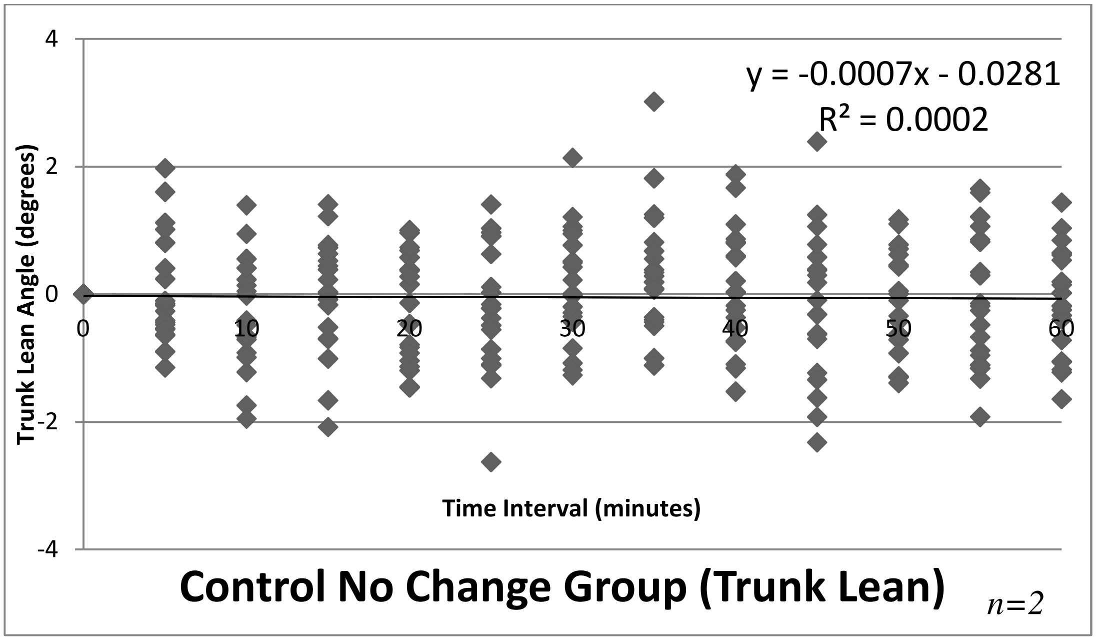


Figure 2.7- Average change in trunk lean angle with the linear regression line for every 5 min interval from 0 to 60 minutes of prolonged treadmill walking. Also shown are the R^2value and equation.

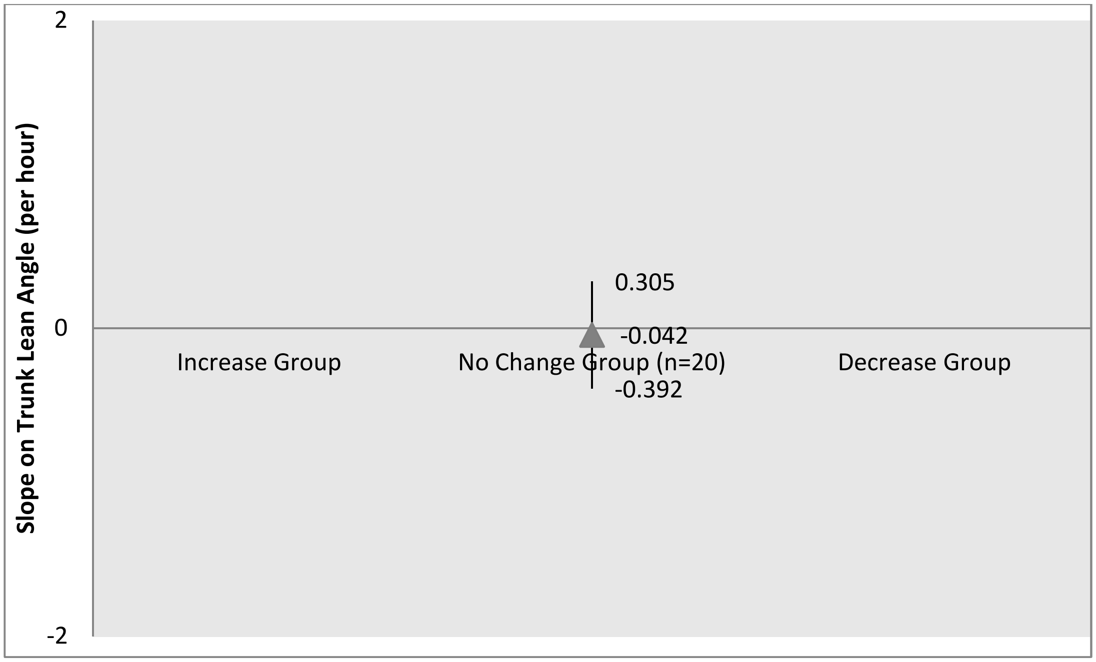


Figure 2.8- Average slope of the linear regression on trunk lean angle with 95% CI error bands shown for no change group only. No comparisons were made since all participants belonged to one group. The triangle reflects the mean slope and the range represents the 95% CI.

2.4 Discussion

The objective of this study was to evaluate toe-out angle, pelvic tilt angle, and trunk lean angle changes and tested for statistical significance over 60 minutes of treadmill walking. Statistical significance would mean that the three kinematic gait variables changed throughout the duration of walking, but all three gait variables showed no statistical significance during prolonged walking on the treadmill ($p<0.05$). Small fluctuations in data were observed within each participant's data over the 60 minutes of walking.

There is a need to investigate whether or not statistical significance exists within the subgroups: Increase, No Change, or Decrease Groups. Trunk lean angle in the No Change Group ($n=20$) had the weakest association with treadmill walking over 60 minutes, which suggested the trunk lean angle and walking time duration were not related to one another. Toe-out angle in the Decrease Group ($n=1$) had the strongest association with 60 minutes of treadmill walking. Followed by pelvic tilt in the Increase Group ($n=5$), which had the second strongest association. The correlation values were high but few participants were within the groups to support significance between the variables with walking time duration.

Toe-out angle

In a similar study performed on prolonged walking, the calculated toe-out angle was averaged every 15 minutes out of the total 60 minutes collected (Bechard et al., 2011). The mean toe-out angles reported were 10.10° (4.84), 10.59° (5.16), 10.54° (4.98), and 10.72° (5.39). The four means on toe-out angle reported were similar to this study. In this study, toe-out angle averaged over 60 minutes was 8.55° (5.12). The average change in toe-out angle was very similar to the values reported for overground walking. Rutherford et al. (2008) studied 50 healthy individuals walking at a comfortable pace on a 5m walkway for at least three walking trials and found an average positive toe-out angle of 7.3° with SD of 5. In another study on healthy children aged 11 to 13, the average toe-out angle was 10°±3° (Lin et al., 2001). The difference in a couple of decimal places in degrees is not obvious in real-life.

Pelvic tilt angle

The pelvic tilt angle reported in this study is less than other research findings for over ground walking. Kadaba et al. (1990) found an average of 2.8° on pelvic tilt in 40 young healthy individuals (18-40 years old). Another study analyzed the pelvic complex at initial contact and toe-off during treadmill and overground walking (Chockalingam et al., 2012). Pelvic tilt angle during treadmill walking at initial contact was 9.62±5.06° in women and 8.85±3.30° in men. At toe-off, women had 8.65±5.10° and men had 6.55±2.90°. The ranges of the reported values are higher than the result found in this study over 60 minutes. This study reported the average change in pelvic tilt angle was 4.28°±2.31°. It is because the data presented looked at change over 60 minutes of treadmill walking rather than the average at the instance the foot strikes the ground over four set of trials.

Double limb support is when both feet are touching the ground, representing 20% of the gait cycle. As the walking speed increase, double limb support decrease in percentage over the entire gait cycle and eventually equals to zero as one begins to run. Conversely, as walking velocity decrease, double limb support occupies a greater percentage in the gait cycle. Walking speed is a potential factor in determining pelvic movement (Taylor, Goldie, & Evans, 1999). Anterior pelvic tilt angle is greatest at double limb support compared to single limb support during the gait cycle. Positive values on pelvic tilt angles should be seen more in individuals spent greater amount of time in double limb support. At slower speeds, the percentage of time spent in double limb support should be close to 20%. The participants with greater anterior pelvic tilt in this study were assumed to have longer double limb support and walked at a slow speed.

Trunk lean angle

The reported mean trunk lean angles were 0.66° (1.09), 0.72° (1.20), 0.81° (1.25), and 1.03 (1.48°) (Bechard et al., 2011). The four means on trunk lean angle were also similar to the one in this study. In this study, the average calculated angle for trunk lean was 0.80° (1.34) which was averaged over 60 minutes. The difference in two degrees is not obvious in real-life. The cause of the difference in error could be by soft-tissue error (Holden, Orsini, Siegel, Kepple, Gerber, & Stanhope, 1997), or the movement of clothing (Pritchard & Heidrich, 2003), or simply the characteristics of the sample group.

Previous research has suggested that an increase in medio-lateral trunk sway by 5 to 15° in healthy participants helped to reduce knee adduction moment (Mundermann et al., 2008). An intentional increase in medio-lateral trunk sway by healthy participants reduced the knee adduction moment. Moment is calculated by force times distance. If one or both factors in the multiplication equation increases, the moment will increase. If the knee adduction moment decreases, then one or both factors (force and distance) at the knee will decrease. In the past, research was conducted in nineteen healthy subjects walking across a 10m walkway at self selected speeds with increased medio-lateral trunk sway by moving the trunks from side to side. During the entire test period, participants did not increase foot strike force. The increase in trunk lean angle led to a lesser load acting on the compartments of the knee joint because the ground reaction force was brought closer to the knee center. Another determinant of knee adduction moment is the knee frontal distance. The knee frontal distance is defined as the lever arm perpendicular to the distance between the ground reaction force and the knee joint center (Perry and Burnfield, 2010). The center of mass (COM) is moved medio-laterally closer towards or further away from the knee joint center by the movement of the trunk from side to side. The knee frontal distance decreased when medio-lateral trunk sway increased as reported in Mundermann et al. (2008). Trunk lean angle leads to changes in knee frontal distance, which relates to changes in knee adduction moment.

The findings in Mundermann et al. (2008) study suggested that an intentional increase in medio-lateral trunk sway is a non-invasive method in reducing the knee adduction moment and could be an important factor in slowing down the progression of degenerative joint disease, such as knee osteoarthritis. Average reduction of 65.0% in knee adduction moments were found when participants increased medio-lateral trunk sway (10±5°), and only one participant increased adduction moments at the knee in the medial–lateral trunk trials.

The angle values on the three gait variables over 60 minutes of treadmill walking are consistent with previously reported findings on walking (Kadaba et al., 1990; Lin et al., 2001; Mundermann et al., 2008; Rutherford et al., 2008; Bechard et al., 2011;

Chockalingam et al., 2012). If this experiment was performed a large number of times, then the SEM range should show statistical significance on pelvic tilt angle in the Increase Group, No Change Group, and Decrease Group. The SEM range should also show significance in toe-out angle for the Decrease Group. The SD showed the variability of the calculated kinematic variables. The average relative change in angle over 60 minutes in all 20 participants showed the greatest range existed in toe-out angle. The results of this study suggest the effects of MLA orthotic and proprioceptive orthotic during 60 minutes of walking may only be small.

Currently little understood in prolonged treadmill walking on joint angles of the foot, pelvis, and trunk segments. There are many areas for further experiments on prolonged treadmill walking. For examples, evaluation on kinetics, such as the forces acting through the joints, different foot types (pes cavus and pes planus), and various walking or running speed on the treadmill. More investigations on prolonged treadmill walking can further enhance the understanding of whole-body movement during prolonged walking.

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Chapter 3:

Kinematic gait changes in medial longitudinal arch orthotic and proprioceptive feedback-type orthotic over 60 minutes of treadmill walking

3.1 Introduction

Walking on the treadmill has become a common practice, yet still few studies have focused on adaptations in gait that occur during prolonged periods of treadmill walking. Studies on the kinematics of the foot, pelvis and trunk during walking, to date, have primarily been focused on analysis of data corresponding to a couple of foot strikes on the force plate. To reflect the most realistic walking movements of the lower limb segments during prolonged walking, it is best to observe participants over a long period, such as continuous walking on an instrumented treadmill. The treadmill is the most common instrument used in motion analysis laboratories to replicate long durations of day-to-day walking.

In human locomotion, the foot is the only part of the body that has direct contact with the ground. An alteration in the foot structure could cause other body segments to alter, since the whole body is a linked chain (Zatsiorsky, 1998). Structural aspects of the foot bones determine foot functions during gait. The arched shaped structure formed by foot bones, known as the medial longitudinal arch (MLA), is sustained by ligamentous support of the plantar fascia (Kogler, Solomonidis, & Paul, 1996). The plantar fascia originates on the medial calcaneal tuberosity and divides into five slips to insert onto each proximal phalanx that passes beyond the metatarsophalangeal joints (Standring et al., 2008). Often, the plantar fascia is described as the most important ligament in transforming the foot into a rigid lever to perform efficient proplusion (Hicks, 1954; Sarrafian, 1987). The height of the medial longitudinal arch has been recognized as a predisposing factor for musculoskeletal injury (Knapik et al., 2009).

The interface between the human foot and the ground plays a crucial role in locomotion. Footwear is a regular practice in modern society and shoes vary in hardness and geometry, but the underlying function is to protect the foot from shocks during heel contact with the ground (Divert, Mornieux, Baur, Mayer, & Belli, 2005). The insoles within shoes are not made to fit everyone's feet, since generic insoles are designed to fit a broad range of footwear which typically does not have customized support, cushioning, and contours. Foot orthotics are often recommended to provide the necessary adjustments (Kogler et al., 1996).

Foot orthoses that insert between the foot and the shoe are designed to modify foot biomechanics. Contour surfaces of foot orthoses change the orientation of foot position and loading response (Kogler et al., 1996). Foot orthoses act as external corrective devices in realigning the ground reaction force acting on the foot (Stacoff, Reinschmidt, Nigg, Bogert, Lundberg, Denoth, & Stussi, 2000). Any alterations in foot structure might result in compensation of other body segments (hip, knee and ankle). For example, foot orthoses are related to muscle activation and have a role in propriception of body segments (Stacoff et al., 2000). Foot orthoses are an additional interface between the ground and the foot in providing mechanical and skeletal support to the foot.

One of the best ways to quantify movement patterns during walking is by three-dimensional gait analysis. In a motion analysis laboratory, participants' gait patterns are often analyzed. In gait testing, the foot is observed for proper push-off and the absence of excessive pronation or supination during weight-bearing. Both observations can lead to greater understanding of the medial longitudinal arch structure, since the medial longitudinal arch is of clinical significance when determining foot conditions (Saltzman, Nawoczenski, & Talbot, 1995).

The ability to walk upright depends on the structure of the whole-body; however major movements in walking are accomplished by the lower extremities (the pelvis, thigh, knee, and the foot). So far not much research on foot orthotics has studied the kinematics of the hip, knee, and pelvis (Nester, Linden, & Bowker, 2003). Therefore, this study examined body kinematics of healthy individuals while wearing two types of foot orthoses over 60 minutes of treadmill walking. Joint angles were examined in three kinematic gait variables: toe-out angle in transverse plane, pelvic tilt angle in sagittal plane and trunk lean angle in frontal plane.

There were two conditions tested for in this study. We studied insoles custom made by the pedorthist at the Fowler Kennedy Sport Medicine Clinic (London, ON, Canada) and pre-fabricated proprioceptive-feedback type orthotic (Barefoot Science, Mississauga, ON, Canada).

Medial longitudinal arch (MLA) orthotics

The medial longitudinal arch support in foot orthoses is an efficient mechanism in preventing the arch from flattening (Kogler, Solomonidis, & Paul, 1995). Medial longitudinal arch support placed under the sustentaculum tali of the calcaneus, which is located on the posterior aspect of the midfoot (inferior aspect of the head of talus and inferior aspect of the navicular), could reduce initial pronation (Kogler et al., 1996). In walking, foot goes into pronation in early stance. The MLA support in foot orthoses is designed for those with flat foot or the presence of excessive foot pronation. If reduction in initial pronation of the foot occurs, then the MLA flattens even more.

Proprioceptive orthotics

The foot contains many proprioceptive sensory receptors which make the foot an important site for sensory input. The material used to make orthotics could affect how the overall body may react, since the human foot is sensitive and capable of detecting stimuli. Proprioceptive foot orthoses function as an external stimulator on the plantar surface of the foot. In one study, the foot was viewed as three filters with the first filter as the sole of the shoe, second filter as the orthotic and the third filter as sole of the foot. The afferent signal sent back to the central nervous system of the body should provide sensory feedback to the muscles of the body, in other words, the body segments should become more readily adapted. The findings suggested muscle activation was less in foot orthoses with a design that support the natural movements of joints along with the ligaments, and the opposite effect was the result of more muscle activation when foot orthoses opposed joint movements (Nigg, Nurse, & Stefanyshyn, 1999).

Interestingly, most of the studies performed by the motion analysis system have concentrated on overground walking rather than prolonged treadmill walking. Overground walking and treadmill walking generally display small differences in gait patterns. Both conditions have similar ground reaction force values indicating that the mechanics of both conditions are similar (Dierick, Penta, Renaut, & Detrembleur, 2004).

Previous work from our laboratory showed small differences in the trunk lean and toe-out angles were detected between treadmill and overground walking in 20 healthy participants (Bechard, Birmingham, Zecevic, & Jenkyn, 2011). The findings showed trunk lean and toe-out angles measured during treadmill walking were similar to overground walking, in which overground gait analysis is known as the current gold standard. Trunk lean and toe-out angles measured during treadmill and overground walking had good agreement shown by high intra-class correlation (ICC) values between 0.88 to 0.92 (Bechard et al., 2011). There were no statistical differences detected between the four time windows. Trunk lean angle (1.52˚, SD 1.01) during overground walking was higher than treadmill walking (0.71˚, SD 1.01). The difference between the two conditions was 0.8˚. Overground walking showed an average of 9.52˚ in toe-out angle (SD 5.03) which was less than treadmill walking of 10.31˚ (SD 4.78). The trunk lean angle measured in overground walking and treadmill walking were small in degree values (Bechard et al., 2011).

Treadmill walking and overground walking have shown significant differences when familiarisation time was less than three minutes long (Alton, Braldey, Caplan, & Morrissey, 1998). In one study, 16 healthy participants were studied throughout 15 minutes of treadmill walking (Matsas, Taylor, & McBurney, 2000). The findings showed reliable knee joint measurements were obtained after four minutes of treadmill walking.

3.1.1 Purpose of study

This thesis has three objectives. The first and second objectives have all the participants in one sample group (n=20) to determine the magnitude of toe-out angle, pelvic tilt angle, and trunk lean angle when walking on the treadmill:

(1) at the start (0min) and finish (60 min)

(2) between start to finish in angular changes (i.e. 60min-0min).

(3) The third objective is to examine the magnitudes of angle changes in each of three groups over 60 minutes of treadmill walking.

Groups are divided by assigning participants in one of the three groups based on gait changes: Increase, No Change, and Decrease Groups. The third objective is to evaluate whether all the participants show similar trends in gait changes over time.

It is hypothesized the medial longitudinal arch orthotics and proprioceptive feedback-type orthotics cause significant decrease in toe-out, pelvic tilt, and trunk lean angles over 60 minutes of treadmill walking compared to generic insoles (Control condition).

When participants entered the gait laboratory, which houses state-of-the-art equipment used for testing, they instinctively felt committed to perform at their best. There is a good chance the results consist of a potential error: controlled setting. Participants often walk in a careful and steady but stiff manner. It has also been reported that walking on a treadmill increases stiffness of the trunk when compared to overground walking (Vogt, Pfeifer, & Banzer, 2002).

The goal of this research was to collect data that best represents natural daily life movements. Typically in gait laboratory, participants are tested over a couple of foot strikes on the force plate, in which participants way of walking could alter due to stress, unfamiliarity with the lab environment, or other factors that might affect walking movements. However, testing participants over a longer time, such as 60 minutes of treadmill walking, can get them to walk the way they do on a daily basis. Since consecutive walking gait cycles are required on the treadmill.

Drawing on all of this information, we assumed natural movement patterns were collected when participants walked over 60 minutes on a treadmill. As time passes, walking becomes more natural for participants to feel comfortable with the operation of the equipment and with being observed by the researchers.

3.2 Methods

3.2.1 Participants

Twenty healthy participants (9 males, 11 females) were primarily recruited from a local running group and from the university student population. The method of recruitment was by one-on-one invitation. Participants were screened based on four criteria:1) no previous use of foot orthoses, 2) no ankle injuries in the past year, 3) no abnormalities that might affect their ability to walk on the treadmill and 4) independent mobile. Ethical approval was obtained from the institution's Research Ethics Board for Health Sciences and informed consent was signed by each participant before testing.

3.2.2 Protocol

Each participant walked on the treadmill for 60 minutes. The participants paused to change their insoles every 5 minutes of treadmill walking. They started in their own shoe insoles, walked for 5 minutes on treadmill. Then they changed into MLA orthotics and walked for 15 seconds on the treadmill. Finally they changed into proprioceptive orthotics and walked for 15 seconds on treadmill. Then they changed back into their own shoe insoles. This was considered as one cycle of data collection, and participants repeated the cycle every 5 minutes until 60 minutes of treadmill walking was completed. A total of 13 cycles of data collection over 60 minutes of testing. Data collection started in the last 15 seconds of every 5 min time interval, each collection lasted for 15 seconds.

Kinematic data was collected with a five-camera motion capture system at 60 Hz (Hawk cameras, Cortex system, Motion Analysis Corp., Santa Rosa, CA, USA) and Kistler instrumented treadmill that consisted of two force plates under the treadmill belt (Gaitway model, Kistler Instrument Corp., Amherst, NY, USA). Participants wore T-shirts, shorts and comfortable running shoes to the testing session, and the time to complete the gait analysis testing was about 2 ½ hours. To determine walking speed on the treadmill, participants walked at their typical walking pace over 6 meters of level floor divided by time taken. Stopwatch was used to record the time required.

Passive reflective markers (22 markers; 1.25 cm diameter each) were placed on bony landmarks of the participants in a modified Helen Hayes configuration (Kadaba, Ramakrishnan, & Wootten, 1990) to track body segments kinematics (see Figure 3.1).

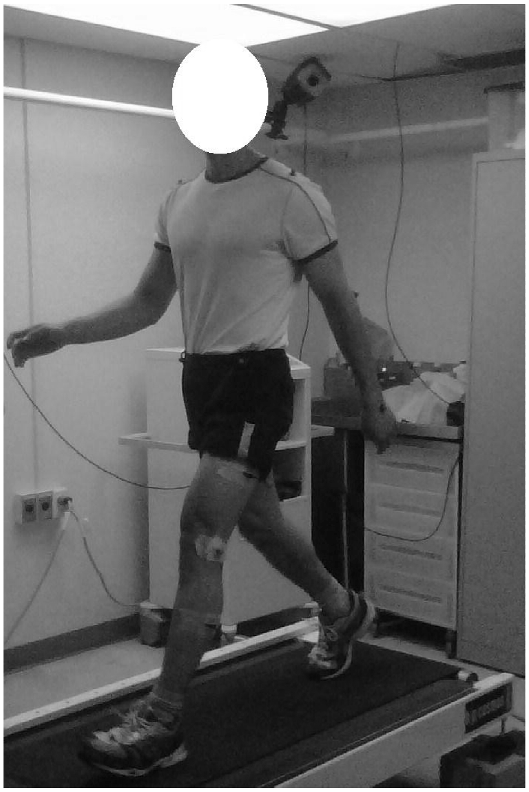


Figure 3.1- Walking participant on the treadmill with 22 reflective markers on bony landmarks from the shoulders down to the feet.

Once walking speed on treadmill was calculated, participants walked at that speed on the level treadmill. Upon request anytime during testing, participants could increase or decrease speed to achieve comfortable self-selected walking pace on the treadmill. All participants remained at the same speed from start to finish.

Before data collection of prolonged treadmill walking, four initial trials (two static standing, one left leg dynamic and one right leg dynamic) were required for the motion analysis system to recognize the orientation of markers. In addition to the 22 reflective markers, two extra markers were placed on each limb (one on the medial femoral epicondyle of the knee and one on the medial malleolus of the ankle) to determine the knee and ankle joint centers. The four extra markers were removed after the initial trials.

A practice trial of up to five minutes was given to the participants to get familiarised with the treadmill, and then the 60 minutes of treadmill walking began. Three conditions were tested for every 5 min time interval in the following order: own shoe insole (control), medial longitudinal arch (MLA) orthotic made by the pedorthist, and proprioceptive feedback-type orthotic.

3.2.2.1 Description of foot orthoses used

The MLA orthotic was 4mm plastazote (soft material) made by foam box technique casted by Canadian certified pedorthist at the Fowler Kennedy Sport Medicine Clinic, London, ON. The MLA orthotic used in this study had a medial longitudinal arch support under the midfoot area and a heel wedge in the heel area (see Figure 3.2). The MLA orthotic insole was designed to provide medial longitudinal arch support and heel wedge for rearfoot stabilization. Also, the MLA orthotic was designed to promote proper foot pronation and to stabilize the calcaneous from excessive foot movement.

Figure 3.2- Lateral view of the right MLA foot orthosis. Darken black area shows the location of the medial longitudinal arch support in the midfoot area and the heel wedge under the heel. The MLA orthotic was made from soft material known as plastazote.

The proprioceptive orthotics that were used in this study (Barefoot Science; Mississauga, ON, Canada) stimulated the plantar aspect of the foot. The dome-shaped contour under the midfoot area allowed the placement of inserts to provide additional arch support (see Figure 3.3). Progressively firmer insert levels was a feature of the prorioceptive orthotics which included five levels. The soft-medium insert, level 3, was used in all participants from start to finish in testing. Full length insoles were used for this study. The full-length insole extended from the end of the heel to the tip of the toes to support the entire plantar aspect of the foot.

Figure 3.3- Proprioceptive feedback-type orthotic top and bottom view. The dome contour is to support the medial longitudinal arch located in the midfoot area. Insets are placed in the dome on the plantar surface of the insole.

3.2.3 Data analysis

The dynamic trial collected at 0min was only on the control condition (own insole) however, the data at 0 min was used among the three conditions (control, MLA and Proprioceptive) because 0 min time interval served as a familiarization trial.

To reconstruct three-dimensional marker trajectories, the Cortex 2.6.2 reconstruction software system (Motion Analysis Corp., Santa Rosa, CA, USA) was used to replicate participants' movements. In each frame, three-dimensional spatial locations of the reflective markers were displayed. Tracking of markers reproduced a stick-figure of the participant in each frame (see Figure 3.5). The body segments tracked were the foot, shank, leg, pelvis, trunk and arms.

The first three right foot strikes were used from each of the 15 seconds collected. In each collected trial, the first three right foot strikes were split into three trials (13 dynamic trials x 3 trials). A sum total of 39 walking trials were analyzed. Four foot strikes of the same foot equal to three gait cycles. For each time interval, three gait cycles were used to calculate each of the three kinematic gait variables (see Figure 3.4). The kinematic gait variables in each time interval were calculated based on the average over three strides.

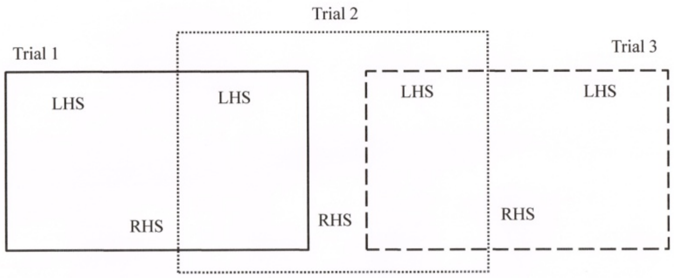


Figure 3.4- The first three right foot strikes were used from each of the 15 seconds collected. Four left foot strikes of the same foot equal to three strides.

Reflective marker kinematics were low pass filtered with a cutoff at 6 Hz using 4th order Butterworth with zero lag. Based on the filtered data, toe-out, pelvic tilt and trunk lean angles were calculated (Jenkyn, Hunt, Jones, Giffin, & Birmingham, 2008).

Rigid body motion for the segments of the body was calculated from the filtered marker trajectories using analysis software (OrthoTrak 6.6.1, Motion Analysis Corp., Santa Rosa, CA, USA). The identification of left and right foot strike and toe-off were required from each tracked trial. From the three-dimensional segment motions, the three kinematic gait variables (toe-out, pelvic tilt, and trunk lean angles) were calculated using custom-written software (Excel, Microsoft Corp., 2010).

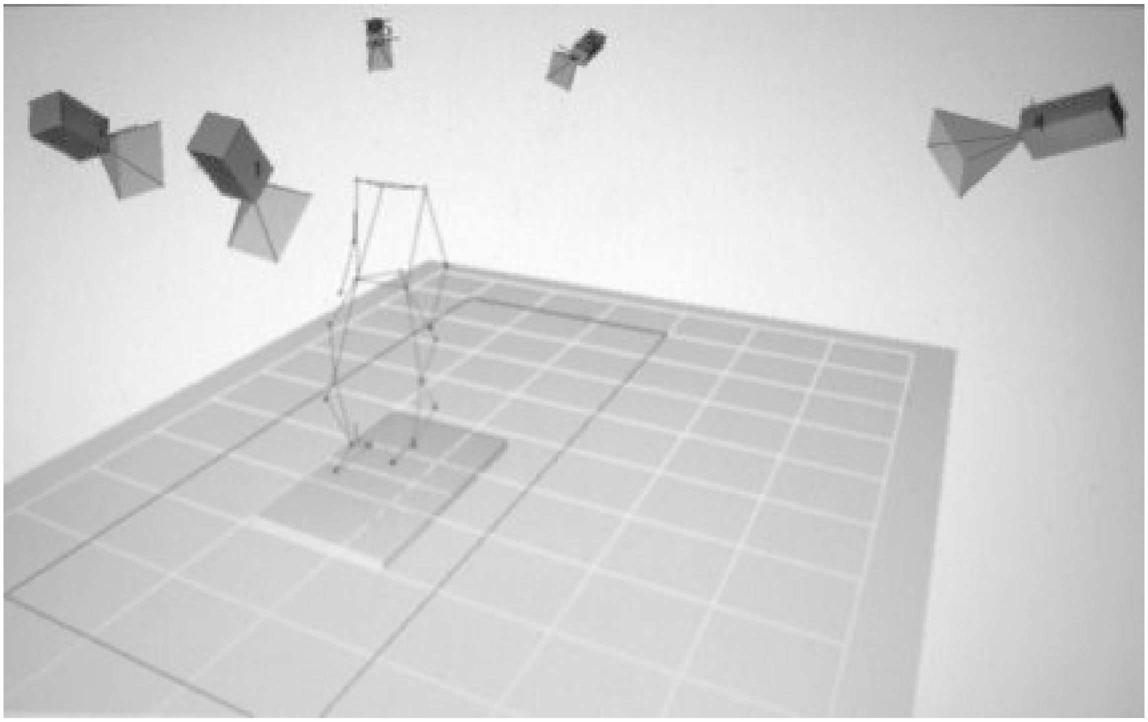


Figure 3.5- Generated animated three-dimensional stick figure, walking area represented by two darken squares (two force plates which the participant was on), and the location of the five cameras. The figure shows the front projection of the recorded 3D motion.

3.2.4 Statistical analysis

These data were analyzed using the same statistical analysis that I described in Chapter 2. The data were analyzed three different ways. At first the data was looked at as one sample group (n=20); angles on all three kinematic gait variables at 0 minute and over the course of 60 minutes were examined. For each kinematic gait variable, the degree of change in angle from start (0 min) and finish (60 min) were examined to determine the magnitude of change (60 minutes time interval minus 0 minute time interval; 60-0min) from start till end of treadmill walking (see Table 3.2 through Table 3.7).

The second method in determining statistical significance over time was by calculating mean, lower and upper limits on 95% CI constructed by SD based on average relative change in angle. Relative change in this study was defined as the magnitude of change in angle (degrees) with the inclusion of the original kinematic gait angle (toe-out, pelvic tilt, and trunk lean angles) of each participant.

Relative change in angle= angle at that specific time interval – angle at 0 min

For both foot orthotic conditions, mean, standard deviation (SD), and upper and lower limits of the 95% confidence interval (CI) were calculated to determine if statistical significance over time was detected in each kinematic gait variable. These analyses tested whether any changes were significant at $p<0.05$.

The third method was to assign the twenty participants into one of the three groups: Increase Group, No Change Group, and Decrease Group. Group division was based on the average relative change in angle compared to the 1.5° cut-off value. The cut-off value of 1.5° was subjectively determined based on how clustered the relative change in angles were between participants (n=20). The Increase Group had the average relative change in angle value above +1.5°. The No Change Group had the average relative change in angle value between +1.5° to -1.5°. The Decrease Group had the average relative change in angle value less than -1.5°.

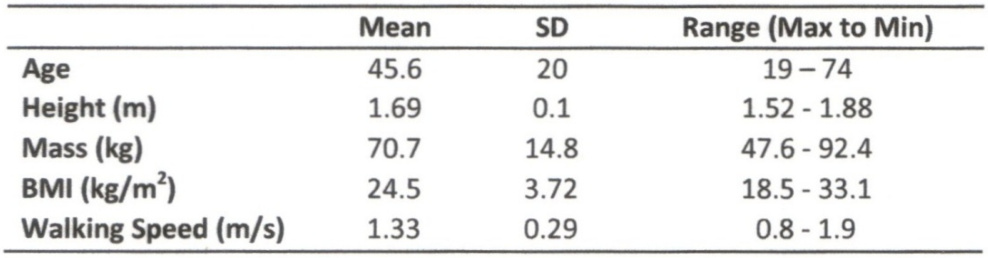
The linear regression line was plotted against time and each kinematic gait variable. On each graph (kinematic gait variable versus walking time duration), the coefficient of determination (R^2) was calculated by Excel. The slope and standard error of the mean (SEM) for the toe-out, pelvic tilt, and trunk lean angles were calculated using LINEST function in Excel. The slope represents the amount of change in the kinematic gait variable has on average for each 5 min time interval. The SEM indicates the amount of error in predicting the mean of the population based on the sample group. The values calculated were to two to three decimal places and were reported in degrees per hour to magnify the slope values.

Within the groups, the slope of the linear regression line and 95% CI range were calculated using the SEM values. The multiple comparison tests on SEM to determine if a significant relationships between the kinematic gait variables and walking time duration (0 to 60 minutes) among the Increase, No Change, and Decrease Groups. For each gait variable, an overlap of the 95% CI constructed by SEM on slope values among the three groups showed statistical significance existed.

3.3 Results

In MLA orthotic and proprioceptive orthotic conditions, the average toe-out, pelvic tilt and trunk lean angles of the 20 participants did not change significantly over 60 minutes of walking ($p<0.05$).

Table 3.1- Anthropometric measurements and walking speed of the participants (n=20; 9 males and 11 females).



	Mean	SD	Range (Max to Min)
Age	45.6	20	19 – 74
Height (m)	1.69	0.1	1.52 - 1.88
Mass (kg)	70.7	14.8	47.6 - 92.4
BMI (kg/m^2)	24.5	3.72	18.5 - 33.1
Walking Speed (m/s)	1.33	0.29	0.8 - 1.9

3.3.1 One overall group analysis on mean, SD, & 95% CI

3.3.1.1 Calculated angles and SD

The average angles and standard deviations on all 20 participants for each of the three kinematic gait variables examined at 0 min are shown in Table 3.2 through Table 3.7.

At 0 min, the average toe-out angle was 8.32±5.38°, the average pelvic tilt angle was 3.45±2.24°, and the average trunk lean angle was 0.94±1.11°. The average angles at 0 min were small. In the MLA condition at 60 min, the average toe-out angle was 8.30±4.84°, the average pelvic tilt angle was 4.27±2.24°, and the average trunk lean angle was 0.90±1.31°. In the proprioceptive condition at 60 min, the average toe-out angle was 8.75±5.97°, the average pelvic tilt angle was 4.08±2.27°, and the average trunk lean angle was 1.11±1.35°.

MLA orthotic condition: The difference in toe-out angle from start to finish had exactly half the participants (10 out of 20 participants) with angle greater than zero. Approximately one fourth of the participants (9 out of 20 participants) had a decrease in toe-out angle over the 60 minutes of walking. One participant had no change in toe-out angle from start to finish. Out of the three kinematic gait variables, the difference in pelvic tilt angle (60-0min) had the most participants (15 out of 20 participants) with an increase in forward tilt of the pelvis. Exactly half of the participants (10 out of 20 participants) had a decrease in trunk lean over the 60 minutes of walking. Followed by approximately half of the participants had an increase (9 out of 20 participants) in trunk lean and one participant had no change in trunk lean over the 60 minutes of walking (see Table 3.2 through Table 3.4).

Proprioceptive orthotic condition: The majority of the participants (13 out of 20) had an increase in toe-out over the 60 minutes of walking. Approximately one third of the participants (7 out of 20) had a decrease in toe-out over the 60 minutes of walking. Out of the three kinematic gait variables, difference in pelvic tilt angle (60-0min) had two participants that showed no change from start to finish. Approximately two thirds of the participants (14 out of 20) had increased anterior pelvic tilt angle over the 60 minutes of walking and few participants (4 out of 20 participants) had posterior pelvic tilt angle over the 60 minutes of walking. Exactly half of the participants (10 out of 20 participants) had a decrease in trunk lean over the 60 minutes of walking. Approximately half of the participants (9 out of 20 participants) had an increase in trunk lean and one participant had no change in trunk lean over the 60 minutes of walking (see Table 3.5 through Table 3.7).

Table 3.2- Difference in toe-out angle between 60 min and 0 min showing the change in angle from the end and start of testing for the MLA orthotic condition. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. The symbol “—” represents zero change. Toe-out angle had one participant who showed no difference (60-0 min).

Difference in *Toe-out* angle from start to finish (60-0 min) in *MLA Orthotic*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	5.2	3.3	1.9	Increase
2	8.8	8.7	0.1	Increase
3	3.4	0.7	2.7	Increase
4	14.4	9.2	5.2	Increase
5	12.1	10.1	2.0	Increase
6	3.9	5.3	-1.4	Decrease
7	15.1	18.0	-2.9	Decrease
8	13.5	13.5	0.0	--
9	3.2	5.9	-2.7	Decrease
10	9.6	19.3	-9.7	Decrease
11	10.0	9.8	0.2	Increase
12	2.3	2.8	-0.5	Decrease
13	9.1	6.6	2.5	Increase
14	3.7	6.1	-2.4	Decrease
15	16.2	15.5	0.7	Increase
16	10.7	11.0	-0.3	Decrease
17	9.4	9.6	-0.2	Decrease
18	-0.8	-0.3	-0.5	Decrease
19	4.5	2.7	1.8	Increase
20	11.7	8.6	3.1	Increase
Avg	8.3	8.32	-0.02	
SD	4.84	5.38	3.08	
Max	16.2	19.3	5.2	
Min	-0.8	-0.3	-9.7	
		Greater than 0	**10**	
		Lesser than 0	**9**	
		Equal to 0	**1**	

Table 3.3- Difference in pelvic tilt angle between 60 min and 0 min showing the change in angle from the end and start of testing for the MLA orthotic condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min. Pelvic tilt angle had the greatest number of participants who showed difference greater than zero.

Difference in *Pelvic Tilt* angle from start to finish (60-0 min) in *MLA Orthotic*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	6.1	6.0	0.1	Increase
2	3.7	4.1	-0.4	Decrease
3	3.8	4.0	-0.2	Decrease
4	3.4	1.2	2.2	Increase
5	9.2	6.8	2.4	Increase
6	7.1	7.0	0.1	Increase
7	5.7	2.4	3.3	Increase
8	-0.7	3.8	-4.5	Decrease
9	5.5	4.3	1.2	Increase
10	4.9	2.2	2.7	Increase
11	3.7	3.1	0.6	Increase
12	3.0	0.2	2.8	Increase
13	3.4	1.6	1.8	Increase
14	1.2	-0.4	1.6	Increase
15	1.7	-0.5	2.2	Increase
16	4.7	6.4	-1.7	Decrease
17	2.1	4.0	-1.9	Decrease
18	6.2	4.2	2.0	Increase
19	5.2	3.7	1.5	Increase
20	5.4	4.8	0.6	Increase
Avg	4.27	3.45	0.82	
SD	2.24	2.24	1.91	
Max	9.2	7.0	3.3	
Min	-0.7	-0.5	-4.5	
		Greater than 0	**15**	
		Lesser than 0	**5**	

Table 3.4- Difference in trunk lean angle between 60 min and 0 min showing the change in angle from the end and start of testing for the MLA orthotic condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min. The symbol "—" represents zero change. Trunk lean angle had one participant who showed no difference (60-0 min).

Difference in *Trunk Lean* angle from start to finish (60-0 min) in *MLA Orthotic*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	1.1	0.9	0.2	Increase
2	-0.9	0.3	-1.2	Decrease
3	-1.3	-0.3	-1.0	Decrease
4	1.5	-0.5	2.0	Increase
5	0.6	1.0	-0.4	Decrease
6	0.5	1.7	-1.2	Decrease
7	2.9	3.3	-0.4	Decrease
8	2.7	2.1	0.6	Increase
9	0.6	0.0	0.6	Increase
10	3.6	2.8	0.8	Increase
11	-0.3	0.3	-0.6	Decrease
12	1.6	1.0	0.6	Increase
13	2.4	1.3	1.1	Increase
14	0.8	0.9	-0.1	Decrease
15	0.6	0.6	0.0	--
16	0.8	2.8	-2.0	Decrease
17	-0.9	-0.3	-0.6	Decrease
18	1.2	0.9	0.3	Increase
19	-0.3	-0.1	-0.2	Decrease
20	0.8	0.0	0.8	Increase
Avg	0.9	0.94	-0.04	
SD	1.31	1.11	0.94	
Max	3.6	3.3	2.0	
Min	-1.3	-0.5	-2.0	
		Greater than 0	**9**	
		Lesser than 0	**10**	
		Equal to 0	**1**	

Table 3.5- Difference in toe-out angle between 60 min and 0 min showing the change in angle from the end and start of testing for the proprioceptive orthotic condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min.

Difference in *Toe-out* angle from start to finish (60-0min) in *Proprioceptive Orthotic*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	3.5	3.3	0.2	Increase
2	8.3	8.7	-0.4	Decrease
3	2.0	0.7	1.3	Increase
4	13.7	9.2	4.5	Increase
5	11.0	10.1	0.9	Increase
6	4.9	5.3	-0.4	Decrease
7	20.2	18.0	2.2	Increase
8	16.1	13.5	2.6	Increase
9	2.6	5.9	-3.3	Decrease
10	11.5	19.3	-7.8	Decrease
11	11.1	9.8	1.3	Increase
12	1.0	2.8	-1.8	Decrease
13	8.5	6.6	1.9	Increase
14	6.5	6.1	0.4	Increase
15	19.6	15.5	4.1	Increase
16	9.4	11.0	-1.6	Decrease
17	10.1	9.6	0.5	Increase
18	-1.7	-0.3	-1.4	Decrease
19	4.5	2.7	1.8	Increase
20	12.1	8.6	3.5	Increase
Avg	8.75	8.32	0.43	
SD	5.97	5.38	2.8	
Max	20.2	19.3	4.5	
Min	-1.7	-0.3	-7.8	
		Greater than 0	**13**	
		Lesser than 0	**7**	

Table 3.6- Difference in pelvic tilt angle between 60 min and 0 min showing the change in angle from the end and start of testing for the proprioceptive orthotic condition. The word "increase" represents the angle at 60 min was larger than the angle at 0 min. The word "decrease" represents the angle at 60 min was lesser than the angle at 0 min. The symbol "—" represents zero change. Pelvic tilt angle had two participants that showed no difference (60-0 min).

Difference in *Pelvic Tilt* angle from start to finish (60-0min) in *Proprioceptive Orthotic*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	6.0	6.0	0.0	--
2	4.1	4.1	0.0	--
3	2.7	4.0	-1.3	Decrease
4	2.5	1.2	1.3	Increase
5	9.3	6.8	2.5	Increase
6	7.1	7.0	0.1	Increase
7	5.7	2.4	3.3	Increase
8	-0.9	3.8	-4.7	Decrease
9	4.6	4.3	0.3	Increase
10	3.7	2.2	1.5	Increase
11	3.9	3.1	0.8	Increase
12	3.3	0.2	3.1	Increase
13	3.5	1.6	1.9	Increase
14	0.4	-0.4	0.8	Increase
15	3.0	-0.5	3.5	Increase
16	4.5	6.4	-1.9	Decrease
17	2.1	4.0	-1.9	Decrease
18	5.8	4.2	1.6	Increase
19	4.7	3.7	1.0	Increase
20	5.6	4.8	0.8	Increase
Avg	4.08	3.45	0.64	
SD	2.27	2.24	1.99	
Max	9.3	7.0	3.5	
Min	-0.9	-0.5	-4.7	
		Greater than 0	**14**	
		Lesser than 0	**4**	
		Equal to 0	**2**	

Table 3.7- Difference in trunk lean angle between 60 min and 0 min showing the change in angle from the end and start of testing for the proprioceptive orthotic condtion. The word “increase” represents the angle at 60 min was larger than the angle at 0 min. The word “decrease” represents the angle at 60 min was lesser than the angle at 0 min. The symbol “—” represents zero change. Trunk lean angle had one participant that showed no difference (60-0 min).

Difference in *Trunk Lean* angle from start to finish (60-0min) in *Proprioceptive Orthotic*				
Participant #	60 min→END (deg)	0 min→START (deg)	60-0min (deg)	↑ or ↓
1	0.4	0.9	-0.5	Decrease
2	3.0	0.3	2.7	Increase
3	-1.1	-0.3	-0.8	Decrease
4	-0.2	-0.5	0.3	Increase
5	0.4	1.0	-0.6	Decrease
6	1.5	1.7	-0.2	Decrease
7	2.8	3.3	-0.5	Decrease
8	2.2	2.1	0.1	Increase
9	0.0	0.0	0.0	--
10	3.9	2.8	1.1	Increase
11	0.0	0.3	-0.3	Decrease
12	2.4	1.0	1.4	Increase
13	2.1	1.3	0.8	Increase
14	1.0	0.9	0.1	Increase
15	2.0	0.6	1.4	Increase
16	0.8	2.8	-2.0	Decrease
17	-0.6	-0.3	-0.3	Decrease
18	0.2	0.9	-0.7	Decrease
19	-0.2	-0.1	-0.1	Decrease
20	1.6	0.0	1.6	Increase
Avg	1.11	0.94	0.18	
SD	1.35	1.11	1.06	
Max	3.9	3.3	2.7	
Min	-1.1	-0.5	-2.0	
		Greater than 0	**9**	
		Lesser than 0	**10**	
		Equal to 0	**1**	

3.3.1.2 True or population value within 95% confidence interval (n=20)

The average relative change in angle of the 20 participants for each of the kinematic gait variables did not change significantly over 60 minutes of prolonged walking for both MLA orthotic and proprioceptive orthotic conditions ($p<0.05$; Table 3.8). For both foot orthotic conditions, all three kinematic gait variables showed no significant difference in all 20 participants because the value zero (representing no change) was within the 95% CI. In other words, no significant difference for each angle was indicated by the 95% CI crossing zero after 60 minutes.

Table 3.8- (Top table) MLA orthotic (Bottom table) proprioceptive orthotic conditions are shown. The average relative change in angle over 60 minutes of prolonged walking for the three kinematic gait variables are shown with SD and the upper and lower limits of the 95% confidence interval. Since all three kinematic gait variables had zero within their respective 95% confidence interval, there was no significant change in these variables after 60 minutes of prolonged walking at $p<0.05$.

MLA Orthotic **(n=20)**	Relative Change in Angle over 60 minutes	SD	95% CI lower limit	95% CI upper limit
Toe-out **(deg)**	0.0198	1.46	-2.83	2.87
Pelvic Tilt **(deg)**	0.551	0.830	-1.08	2.18
Trunk Lean **(deg)**	0.0614	0.606	-1.13	1.25

Proprioceptive Orthotic **(n=20)**	Relative Change in Angle over 60 minutes	SD	95% CI lower limit	95% CI upper limit
Toe-out **(deg)**	0.320	1.45	-2.52	3.16
Pelvic Tilt **(deg)**	0.450	0.807	-1.13	2.03
Trunk Lean **(deg)**	0.00281	0.609	-1.19	1.20

3.3.2 Group division based on relative change in calculated angles

For each kinematic gait variable, the 20 participants were divided into one of the three groups: Increase, No Change, and Decrease Groups based on the average relative change in calculated angles for MLA orthotic condition (see Table 3.9) and proprioceptive orthotic condition (see Table 3.10). Most of the participants in both orthotic conditions did not have changes of more than 1.5˚; they were classified into the No Change Group.

MLA orthotic condition: The participants were assigned to the No Change Group (n=13) when the average relative change in toe-out angle was within the range of -1.5˚ to 1.5˚. Only three of the twenty participants had change in toe-out angle more than 1.5˚. Four of the twenty participants had change in toe-out angle less than 1.5˚. Overall, seven participants showed change in toe-out angle that was greater or less than 1.5˚ over the 60 minutes of treadmill walking.

Interestingly, the majority of the participants was assigned to the No Change Group (n=14), followed by the Increase Group (n=5), and then the Decrease Group (n=1) based on the the pelvic tilt angle. Six participants showed change in pelvic tilt angle that was greater or less than 1.5˚ over the 60 minutes of treadmill walking.

The trunk lean angle was quite distinct from the other two variables because only one participant showed a decrease in angle over the 60 minutes while the rest of the participants were assigned to the No Change Group (n=19). Trunk lean angle had one participant who showed change greater than or less than 1.5˚ over the 60 minutes of treadmill walking.

Proprioceptive orthotic condition: Most of the participants were assigned to the No Change Group (n=11), followed by the Increase Group (n=6), and then Decrease Group (n=3) based on the average relative change in toe-out angle. Nine of the participants showed change in toe-out angle that was greater or less than 1.5° over the 60 minutes of treadmill walking.

Pelvic tilt angle had the majority of participants in the No Change Group (n=14), followed by the Increase Group (n=4), and then the Decrease Group (n=2). Similar to the MLA orthotic condition, only one participant was assigned to the Decrease Group based on the average relative change in trunk lean angle. The rest of the participants were assigned to the No Change Group (n=19). Six participants showed change in pelvic tilt angle and one participant showed change in trunk lean angle that was greater or less than 1.5° over the 60 minutes of treadmill walking.

Table 3.9- Assignment of each participant to one of three groups based on the magnitude of the change in each of the three kinematic gait variables over 60 minutes of prolonged walking. The three groups are "No Change" (the word "same"), "Increase" (white box; > +1.5˚), and "Decrease" (black box; < -1.5˚). Seven participants change in toe-out angle, followed by six participants change in pelvic tilt angle and only one participant change in trunk lean angle.

MLA Orthotic			
		Avg on magnitude of change	
Participant #	**Toe-out**	**Pelvic Tilt**	**Trunk Lean**
1	same	same	same
2	same	same	same
3	same	same	same
4	□	same	same
5	same	□	same
6	same	same	same
7	■	□	same
8	□	■	same
9	■	same	same
10	■	□	same
11	same	same	same
12	same	□	same
13	same	same	same
14	■	same	same
15	Same	□	same
16	Same	same	■
17	Same	same	same
18	Same	same	same
19	Same	same	same
20	□	same	same
Increase/20	*3*= **15%**	*5*= **25%**	/
Same/20	*13*= **65%**	*14*= **70%**	*19*= **95%**
Decrease/20	*4*= **20%**	*1*= **5%**	*1*= **5%**
Total % Changed	***35%***	***30%***	***5%***

Table 3.10- Assignment of each participant to one of three groups based on the magnitude of the change in each of the three kinematic gait variables over 60 minutes of prolonged walking. The three groups are “No Change” (the word “same”), “Increase” (white box; > +1.5˚), and “Decrease” (black box; < -1.5˚). Nine participants change in toe-out angle, followed by six participants changed in pelvic tilt angle and only one participant changed in trunk lean angle.

Proprioceptive Feedback-Type Orthotic			
		Avg on magnitude of change	
Participant #	**Toe-out**	**Pelvic Tilt**	**Trunk Lean**
1	same	same	same
2	same	same	same
3	same	same	same
4	⬜	same	same
5	⬜	⬜	same
6	same	same	same
7	same	⬜	same
8	⬜	⬛	same
9	⬛	same	same
10	⬛	same	same
11	same	same	same
12	same	⬜	same
13	⬜	same	same
14	⬛	same	same
15	⬜	⬜	same
16	same	⬛	⬛
17	same	same	same
18	same	same	same
19	same	same	same
20	⬜	same	same
Increase/20	*6*= **30%**	*4*= **20%**	/
Same/20	*11*= **55%**	*14*= **70%**	*19*= **95%**
Decrease/20	*3*= **15%**	*2*= **10%**	*1*= **5%**
Total % Changed	***45%***	***30%***	***5%***

MLA orthotic condition: The average angle over 60 minutes of treadmill walking in each subgroup is shown in Table 3.11 for each of the three kinematic gait variables. Statistical significances with respect to time were observed in the Increase Group for pelvic tilt angle and the Decrease Group for trunk lean angle. The rest of the subgroups had zero within their respective 95% confidence interval, hence no significant change with time.

Proprioceptive orthotic condition: The average angle over 60 minutes of treadmill walking in each subgroup is shown in Table 3.12 for each of the three kinematic gait variables. Statistical significances with respect to time were observed in the Increase Group for pelvic tilt angle and the Decrease Group for trunk lean angle. The rest of the subgroups had no significant change with time (zero was within their 95% confidence interval).

Table 3.11- The average change over 60 minutes of prolonged walking for the three kinematic gait variables is shown with SD and the upper and lower limits of the 95% confidence interval. Statistically significant differences is indicated with an asterisk (*) at $p<0.05$. In MLA orthotic condition, the Increase Group for pelvic tilt angle and the Decrease Group for trunk lean angle was statistically significant.

MLA Orthotic- ***Toe-out angle*** averaged over 60 minutes	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=3)	2.74	1.91	-1.01	6.48
No Change Group (n=13)	0.371	1.26	-2.09	2.83
Decrease Group (n=4)	-3.16	1.76	-6.60	0.284

MLA Orthotic- ***Pelvic tilt angle*** averaged over 60 minutes	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=5)*	2.07	1.04	0.0215	4.12
No Change Group (n=14)	0.274	0.677	-1.05	1.60
Decrease Group (n=1)	-3.16	1.91	-6.90	0.576

MLA Orthotic- ***Trunk lean angle*** averaged over 60 minutes	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=0)	--	--	--	--
No Change Group (n=19)	0.157	0.6	-1.02	1.33
Decrease Group (n=1)*	-1.75	0.719	-3.16	-0.344

Table 3.12- Average change over 60 minutes of prolonged walking for the three kinematic gait variables is shown with SD and the upper and lower limits of the 95% confidence interval. Statistically significant differences is indicated with an asterisk (*) at p<0.05. In proprioceptive orthotic condition, significant differences were detected in the Decrease Group for toe-out angle, the Increase Group for pelvic tilt angle, and the Decrease Group for trunk lean angle.

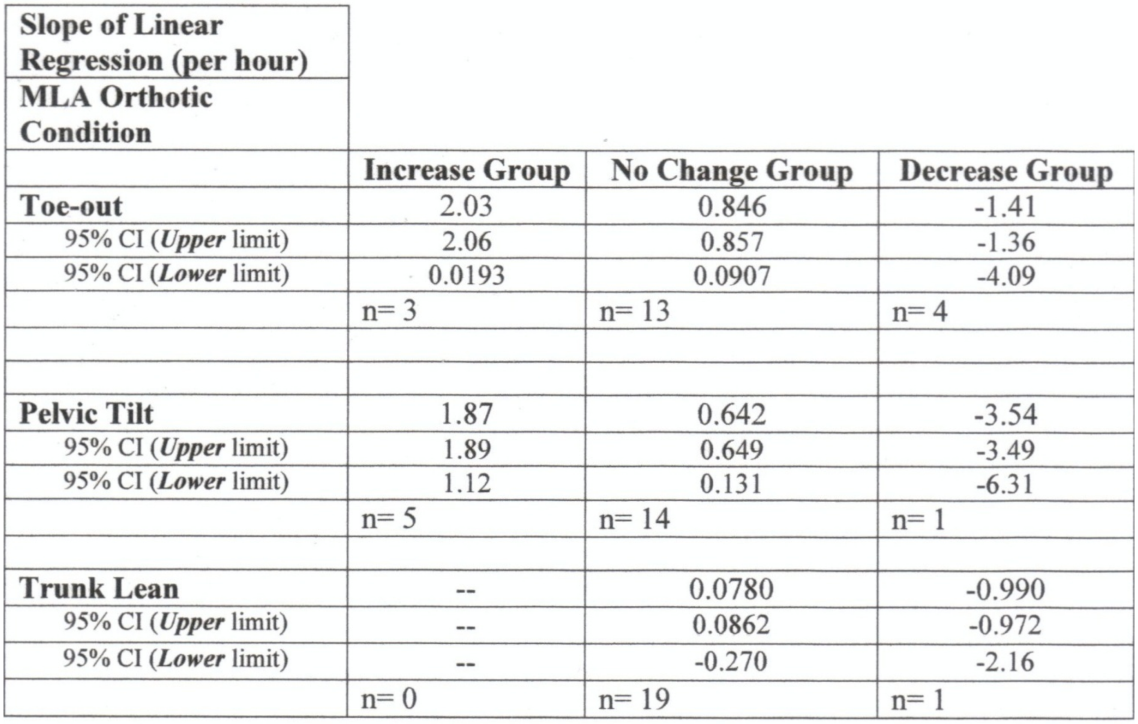
Proprioceptive Orthotic- Toe-out angle **(deg) averaged over 60 minutes**	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=6)	2.45	1.72	-0.915	5.82
No Change Group (n=11)	0.0441	1.21	-2.33	2.42
Decrease Group (n=3)	-2.93	1.80	-6.46	0.590

Proprioceptive Orthotic**-** Pelvic tilt angle **(deg) averaged over 60 minutes**	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=4)*	2.27	1.09	0.141	4.40
No Change Group (n=14)	0.316	0.643	-0.945	1.58
Decrease Group (n=2)	-2.24	1.39	-4.98	0.490

Proprioceptive Orthotic- Trunk lean angle **(deg) averaged over 60 minutes**	**Avg Angle (deg)**	**SD**	**95% CI lower limit**	**95% CI upper limit**
Increase Group (n=0)	--	--	--	--
No Change Group (n=19)	0.103	0.604	-1.08	1.29
Decrease Group (n=1)*	-1.89	0.717	-3.30	-0.486

Slope of the linear regression line and upper and lower limits of the 95% CI calculated by SEM for each of the three kinematic gait variables in each of the three groups are shown in Table 3.13 (MLA orthotic condition) and Table 3.15 (proprioceptive orthotic condition). The R² values are shown in Table 3.14 (MLA orthotic condition) and Table 3.16 (proprioceptive orthotic condition).

Table 3.13- The MLA orthotic slopes (in degrees per hour) as determined by the linear regression, along with the upper and lower limits of the 95% confidence intervals for the change in toe-out angle, trunk lean angle, and pelvic tilt angle are listed for each of the three groups: Increase, No Change, and Decrease. For each subgroup, the sample size is also given.



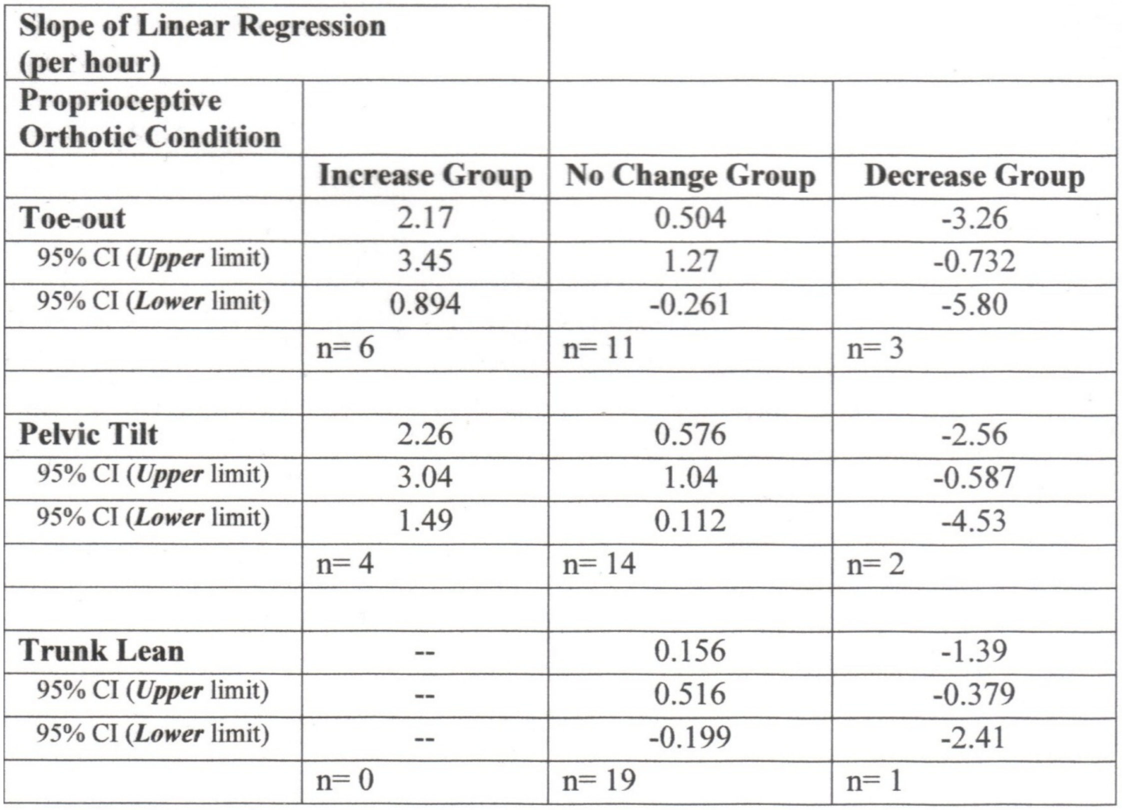
Slope of Linear Regression (per hour)			
MLA Orthotic Condition			
	Increase Group	**No Change Group**	**Decrease Group**
Toe-out	2.03	0.846	-1.41
95% CI (***Upper*** limit)	2.06	0.857	-1.36
95% CI (***Lower*** limit)	0.0193	0.0907	-4.09
	n= 3	n= 13	n= 4
Pelvic Tilt	1.87	0.642	-3.54
95% CI (***Upper*** limit)	1.89	0.649	-3.49
95% CI (***Lower*** limit)	1.12	0.131	-6.31
	n= 5	n= 14	n= 1
Trunk Lean	--	0.0780	-0.990
95% CI (***Upper*** limit)	--	0.0862	-0.972
95% CI (***Lower*** limit)	--	-0.270	-2.16
	n= 0	n= 19	n= 1

Table 3.14- Toe-out, pelvic tilt, and trunk lean angles in the MLA orthotic condition are listed in the R^2 value table. The R^2 values for the Increase, No Change, and Decrease Groups are presented. The R^2 value represents the proportion of the kinematic gait variable that is explained by time in the MLA orthotic condition. The Increase Group showed the greatest variance in toe-out angels. The Decrease Group showed the greatest variance in both the pelvic tilt and trunk lean angles. The similarity between the variance in both angles was having only one participant in the Decrease Group, however not the same participant.

R^2 **values**
MLA Orthotic Condition

	Increase Group	**No Change Group**	**Decrease Group**
Toe-out	0.0957	0.0281	0.0207
	n= 3	n= 13	n= 4
Pelvic Tilt	0.2724	0.0326	0.3626
	n= 5	n= 14	n= 1
Trunk Lean	--	0.0008	0.2006
		n= 19	n= 1

Table 3.15- The proprioceptive orthotic slopes (in degrees per hour) as determined by the linear regression, along with the upper and lower limits of the 95% confidence intervals for the change in toe-out angle, trunk lean angle, and pelvic tilt angle are listed for each of the three groups: Increase, No Change, and Decrease. For each subgroup, the sample size is also given.



Slope of Linear Regression (per hour)			
Proprioceptive Orthotic Condition			
	Increase Group	**No Change Group**	**Decrease Group**
Toe-out	2.17	0.504	-3.26
95% CI (***Upper*** limit)	3.45	1.27	-0.732
95% CI (***Lower*** limit)	0.894	-0.261	-5.80
	n= 6	n= 11	n= 3
Pelvic Tilt	2.26	0.576	-2.56
95% CI (***Upper*** limit)	3.04	1.04	-0.587
95% CI (***Lower*** limit)	1.49	0.112	-4.53
	n= 4	n= 14	n= 2
Trunk Lean	--	0.156	-1.39
95% CI (***Upper*** limit)	--	0.516	-0.379
95% CI (***Lower*** limit)	--	-0.199	-2.41
	n= 0	n= 19	n= 1

Table 3.16- Toe-out, pelvic tilt, and trunk lean angles in the proprioceptive orthotic condition are listed in the R^2 value table. The R^2 values for the Increase, No Change, and Decrease groups are presented. The R^2 value represents the proportion of the kinematic gait variable that is explained by time in the proprioceptive orthotic condition. The Decrease Group showed the greatest variance in toe-out angle. The Increase Group showed the greatest variance in pelvic tilt angles. The Decrease Group showed the greatest variance in trunk lean angles.

R² **values** **Proprioceptive Orthotic Condition**	**Increase Group**	**No Change Group**	**Decrease Group**
Toe-out	0.1276 n= 6	0.0117 n= 11	0.1471 n= 3
Pelvic Tilt	0.3952 n= 4	0.0318 n= 14	0.2122 n= 2
Trunk Lean	--	0.0031 n= 19	0.3971 n= 1

Similarities between the orthotic conditions based on slope

In both orthotic conditions, statistically significant relationships among the three groups on the slope of each kinematic gait variable were the same. For toe-out angle, the Decrease Group showed significant differences from the other two groups (see Figure 3.7 and Figure 3.9). Pelvic tilt angle showed significant differences among all three groups (see Figure 3.11 and Figure 3.13). Trunk lean angle showed significant difference in the No Change and Decrease Groups (see Figure 3.16 and Figure 3.18).

3.3.2.1 Change in toe-out angle over time (slope of the linear regression line)

For toe-out angle in both MLA and proprioceptive orthotic conditions, the slope of the linear regression line in the Decrease Group was significantly different from the Increase and No Change Groups. The Decrease Group showed significant differences with the other two groups (Increase and No Change Groups) by the absence of overlap in the range of SEM values (see Figure 3.7 and Figure 3.9).

MLA orthotic condition: There was a weak linear relationship between toe-out angle and walking time duration in all three groups. In the MLA orthotic condition, the Increase Group had the strongest relationship in toe-out angle with prolonged treadmill walking. The R^2 value for the Increase Group had the highest variance in all three groups (see Table 3.14). The No Change Group followed by the Decrease Group in the order of highest variance. The R^2 value for the Decrease Group had the lowest variance in all three groups, probably because only one participant belonged in the Decrease Group.

Proprioceptive orthotic condition: There was a weak linear relationship between the toe-out angle and the 60 minutes of treadmill walking in all three groups as shown by the R^2 values. All three R^2 values were less than 0.2, which means less than 20% of the variance was predicted by time. In proprioceptive orthotic condition, the toe-out angle had the strongest relationship with prolonged treadmill walking in the Decrease Group, followed by the Increase Group, and then the No Change Group.

The R^2 value for the Increase Group had the highest variance in all three groups. As for the Decrease Group (n=3), the R^2 value was the lowest among all three groups.

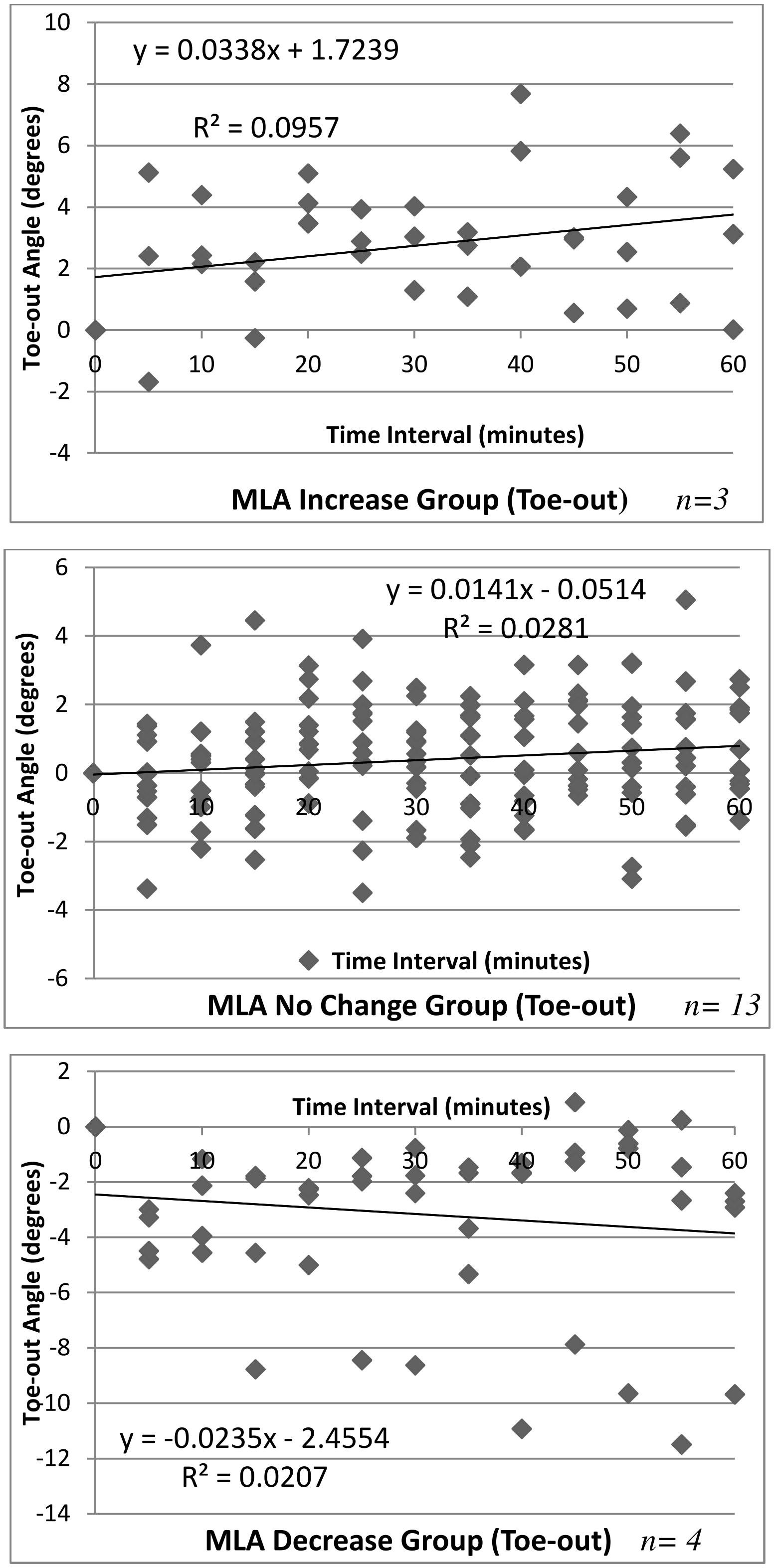


Figure 3.6- MLA orthotic average change in toe-out angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R²values and equations.

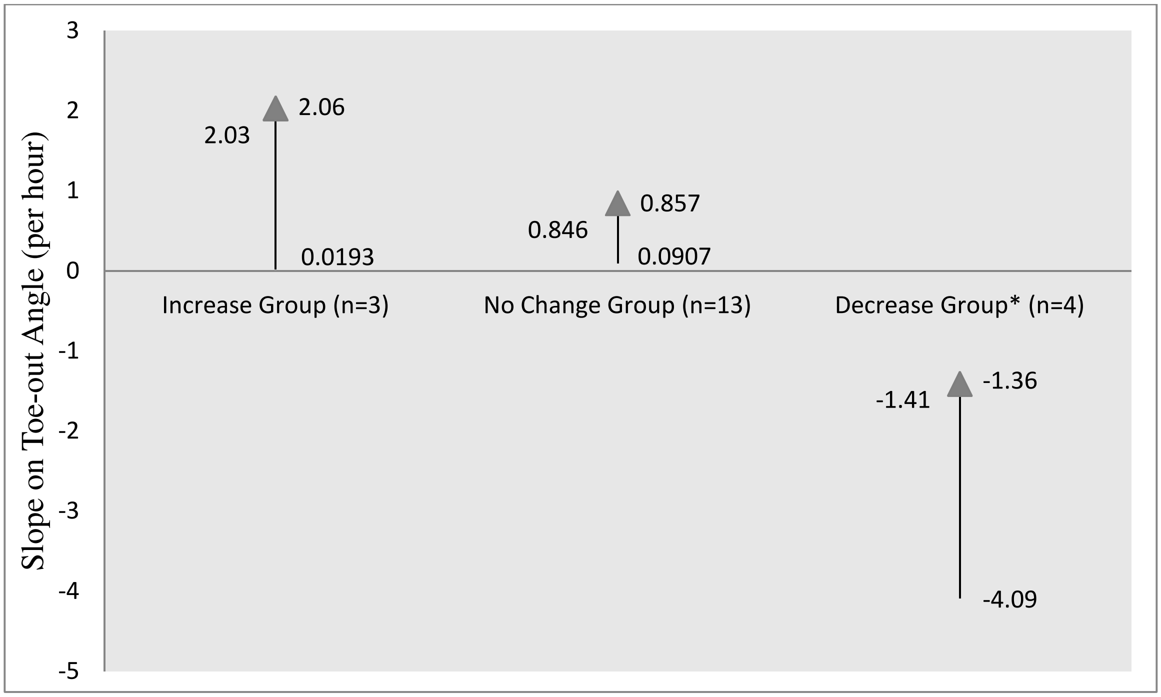
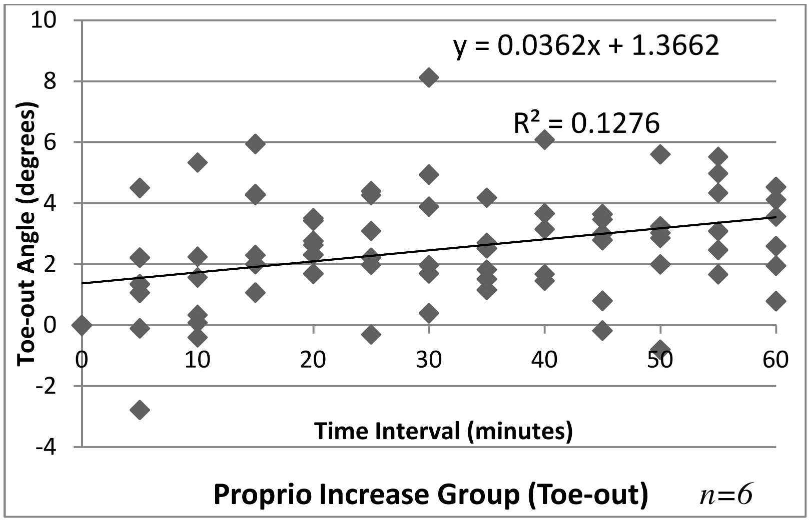
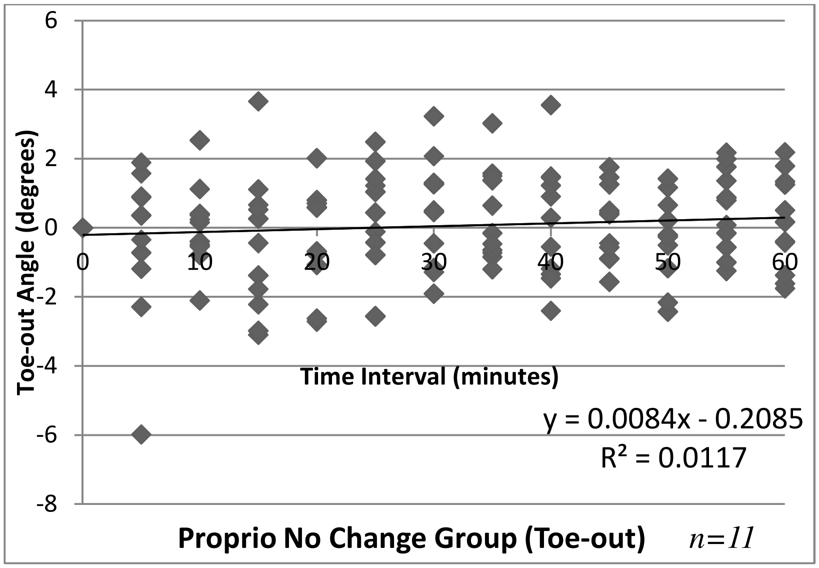


Figure 3.7- The average slope of the linear regression on toe-out angle in MLA orthotic condition with 95% CI error bars shown for each of the three groups. The toe-out angle in the Decrease Group was significantly different from the toe-out angle in the Increase Group and the No Change Group. The remaining two groups were not significantly different from one another. Significant difference between the Decrease Group and the remaining two groups is indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs.





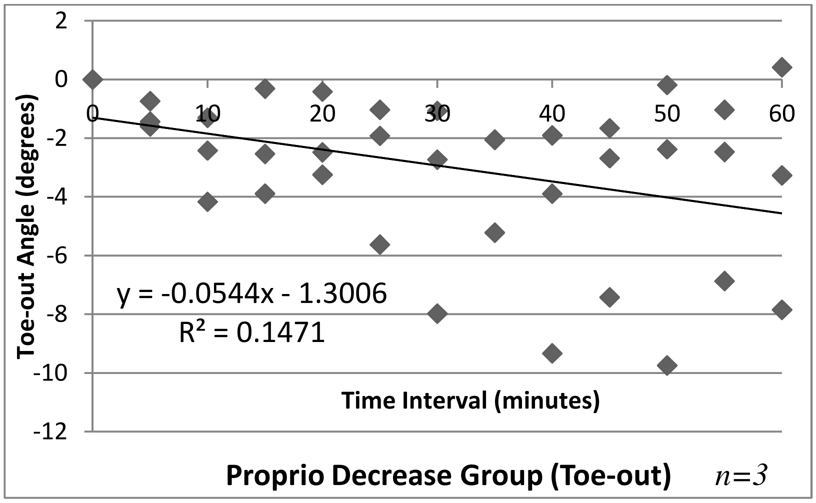


Figure 3.8- Proprioceptive orthotic toe-out average from 0-60 minutes in the three groups are shown along with line of best fit and R² values.

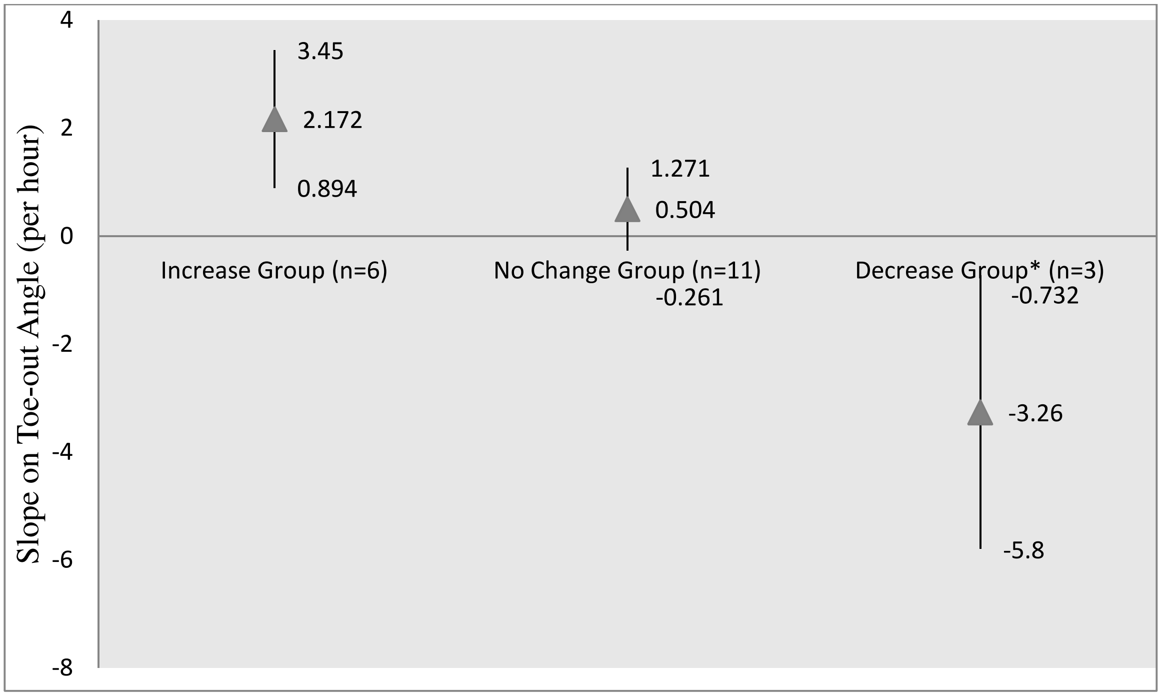


Figure 3.9- The average slope of the linear regression on toe-out angle in proprioceptive orthotic condition with 95% CI error bands shown for each of the three groups. The toe-out angle in the Decrease Group was significantly different from both the Increase and the No Change Groups. The toe-out angles in the remaining two groups were not significantly different from one another. Significant difference between the Decrease Group and the remaining two groups is indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs.

3.3.2.2 Change in pelvic tilt angle over time (slope of the linear regression line)

For pelvic tilt angle, the slopes of the linear regression line in all three groups (Increase Group, No Change Group, and Decrease Group) were significantly different from each other (see Figure 3.10 on MLA orthotic condition and Figure 3.12 on proprioceptive orthotics condition). Statistically significance was seen in all three groups because no overlap in the range of SEM values was seen in Figure 3.11 and Figure 3.13.

MLA orthotic condition: The R^2 value for the Increase Group on pelvic tilt angle had the highest variance in all three groups (see Table 3.14). The R^2 value for the No Change Group was close to none, in which the R^2 value was close to zero.

Among the three groups, the Decrease Group had the strongest relationship with prolonged treadmill walking, followed by the Increase Group, and then the No Change Group.

Proprioceptive orthotic condition: The R^2 value for the Increase Group on pelvic tilt angle had the highest variance in all three groups (see Table 3.16). The R^2 value for the No Change Group on pelvic tilt angle was close to zero; none of the variance was predicted by time.

Among the three groups, the Increase Group had the strongest relationship with prolonged treadmill walking, followed by the Decrease Group, and then the No Change Group.

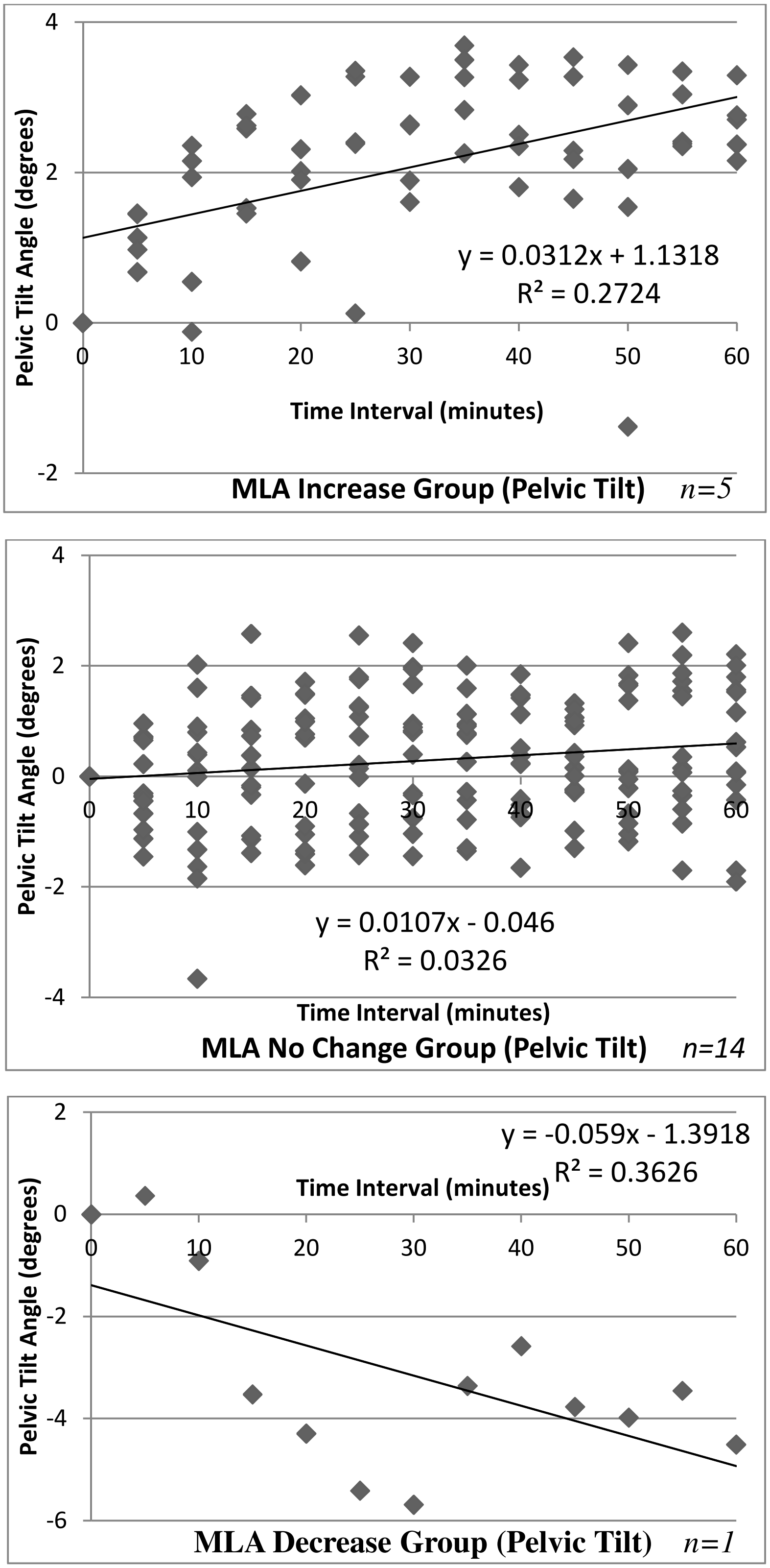


Figure 3.10- MLA orthotic average change in pelvic tilt angle at each 5 min interval during the 60 min prolonged walking trials in the three groups. Also shown are linear regression lines and associated R²values and equations.

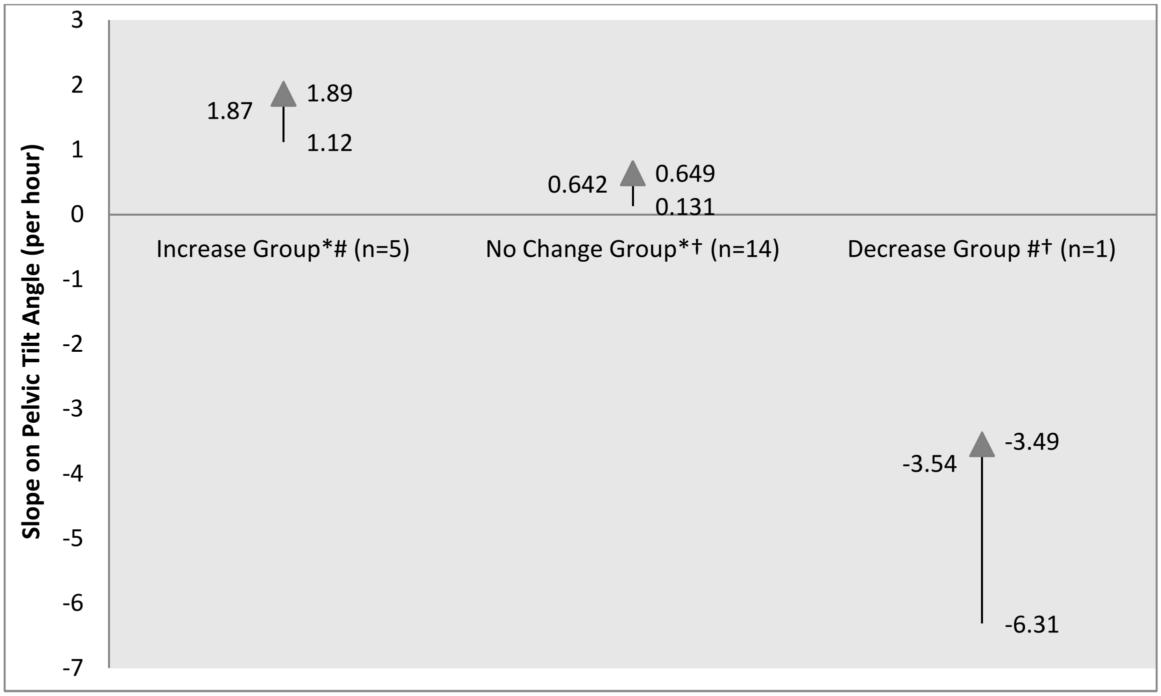


Figure 3.11- The average slope of the linear regression on pelvic tilt angle in MLA orthotic condition with 95% CI error bands shown for each of the three groups. All three groups were significantly different. Significant differences are denoted with a symbol to indicate a significance level of p= 0.05. The asterisk (*) represents a significant difference between the Increase Group and No Change Group. The dagger (†) represents a significant difference between the No Change Group and Decrease Group. The number sign (#) represents a significant difference between the Increase and Decrease Groups. The triangles reflect the mean slopes and the ranges represent the 95% CIs.

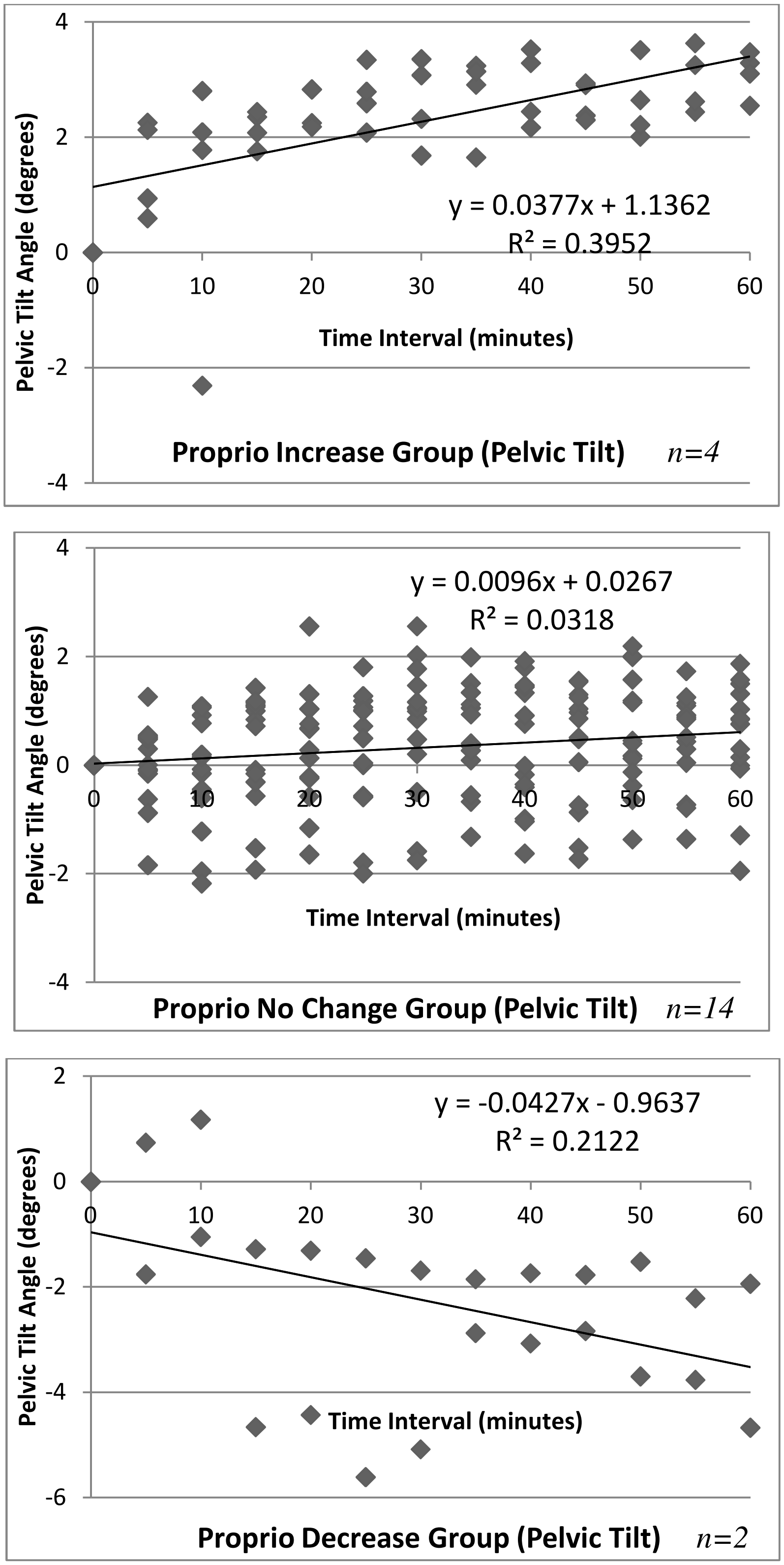


Figure 3.12- Proprioceptive orthotic pelvic tilt average from 0-60 minutes in the three groups are shown along with line of best fit and R² values.

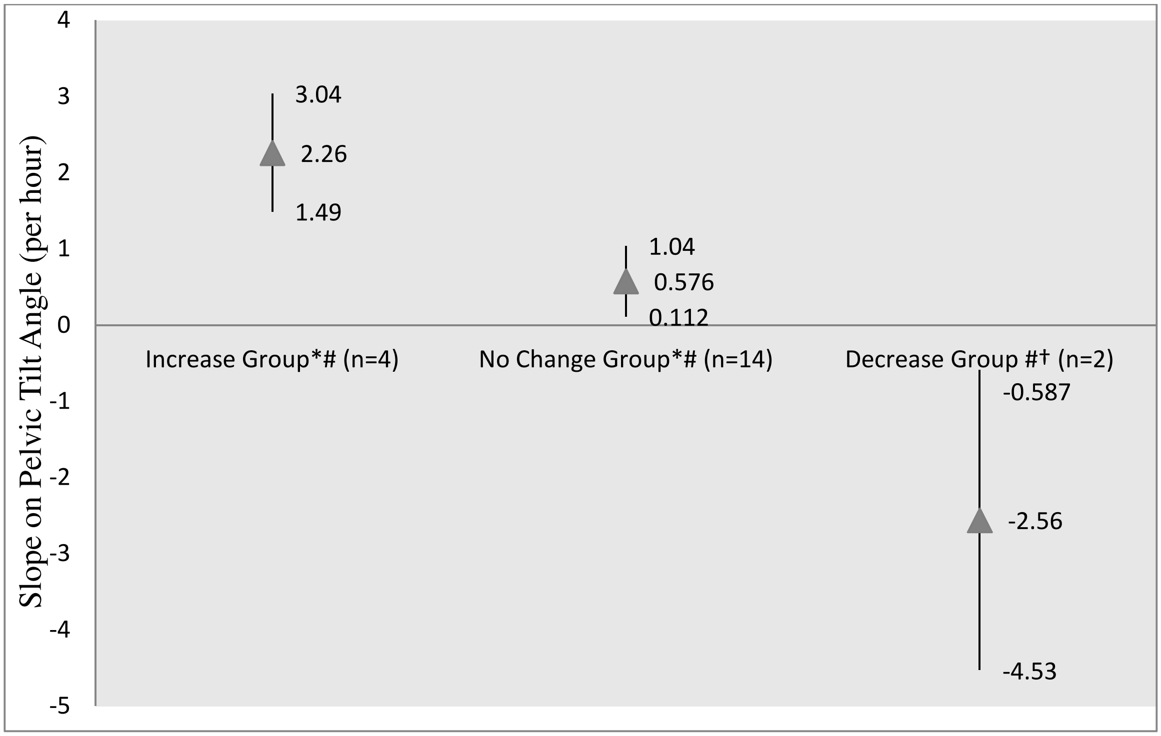


Figure 3.13- The average slope of linear regression on pelvic tilt angle in proprioceptive orthotic condition with 95% CI error bands shown for each of the three groups. All three groups were significantly different in pelvic tilt angle. Significant differences are denoted with a symbol to indicate a significance level of p= 0.05. The asterisk (*) represents a significant difference between the Increase Group and the No Change Group. The dagger (†) represents a significant difference between the No Change Group and the Decrease Group. The number sign (#) represents a significant difference between the Increase Group and the Decrease Group. The triangles reflect the mean slopes and the ranges represent the 95% CIs.

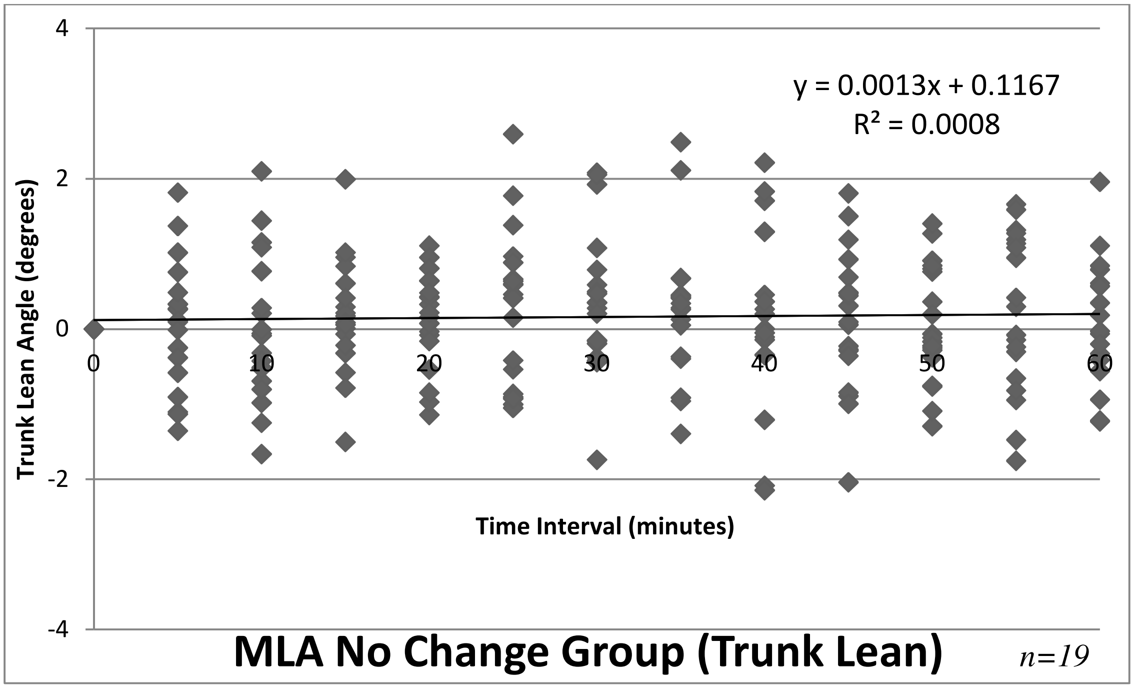
3.3.2.3 Change in trunk lean angle over time (slope of the linear regression line)

None of the participants had an average relative change in trunk lean angle greater than +1.5° (see Figure 3.14 on MLA orthotic condition and Figure 3.16 on proprioceptive orthotic condition).

MLA orthotic condition: In the No Change Group (n=19) for trunk lean angle, the R^2 value for the No Change Group was four decimal places, which meant the variance predicted by time was highly unlikely. The slopes of the trunk lean angle in the Decrease Group and the No Change Group were significantly different from each other (see Figure 3.15).

Proprioceptive orthotic condition: In the No Change Group (n=19) for trunk lean angle, the R^2 value for the No Change Group was very similar to the Decrease Group (n=1). A major difference between the two conditions was the number of participants assigned to each group. The statistical power in the No Change Group is higher than the Decrease Group, this judgement is based on the size of the sample group.

The slopes of the trunk lean angle in the Decrease Group and the No Change Group were significantly different from each other (see Figure 3.17).



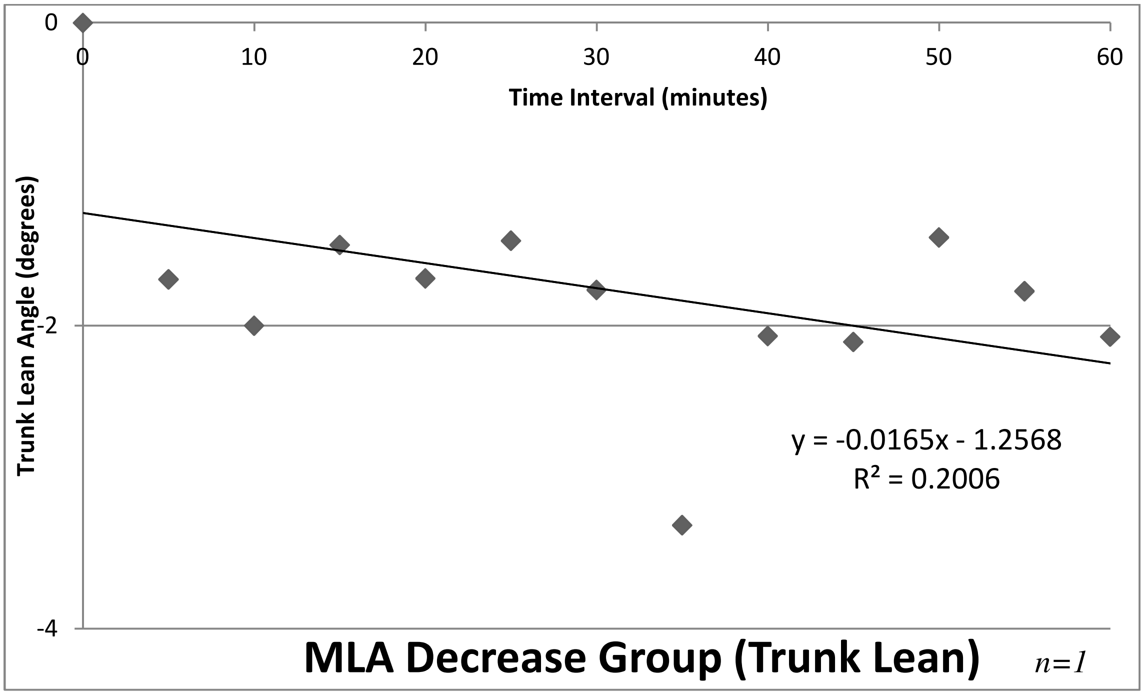


Figure 3.14- The MLA orthotic average change in pelvic tilt angle at each 5 min interval during the 60 min prolonged walking trials in the No Change and Decrease Groups. Zero participants belonged in the No Change Group. Also shown are linear regression lines and associated R² values and equation.

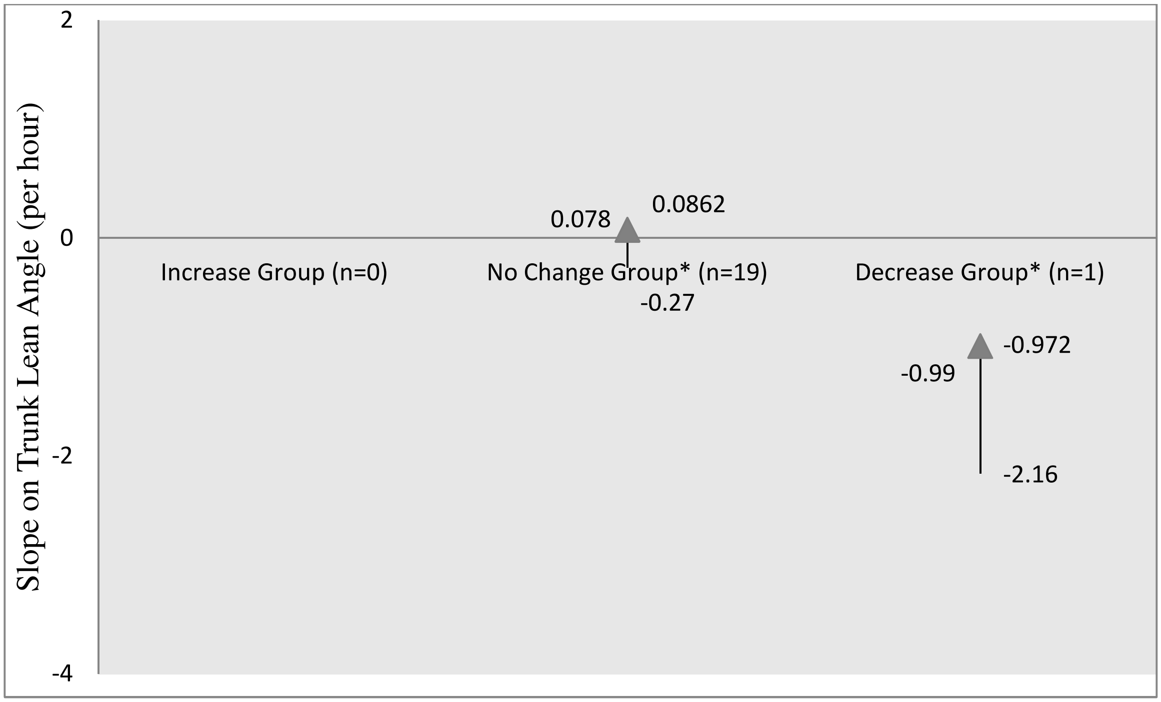
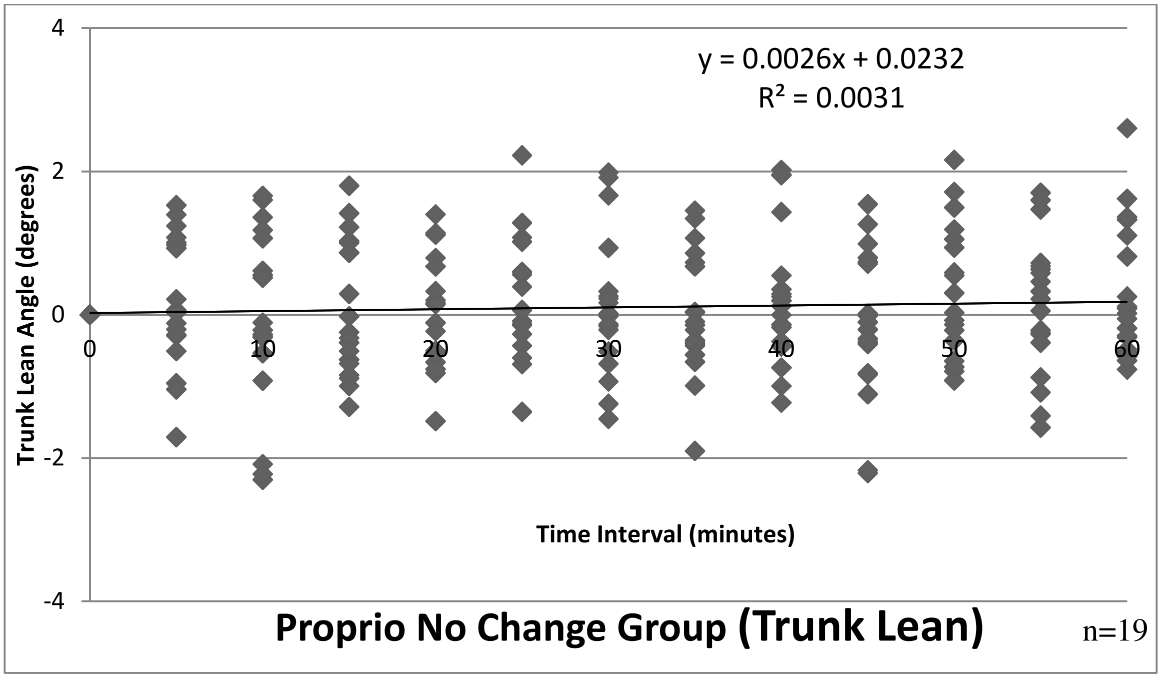


Figure 3.15- The average slope of the linear regression on trunk lean angle in MLA orthotic condition with 95% CI error bands shown for each of the three groups. The trunk lean angle in the Decrease Group was significantly different from the No Change Group and vice versa. No participant belonged in the Increase Group. Significant differences between the No Change Group and Decrease Group are indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs.



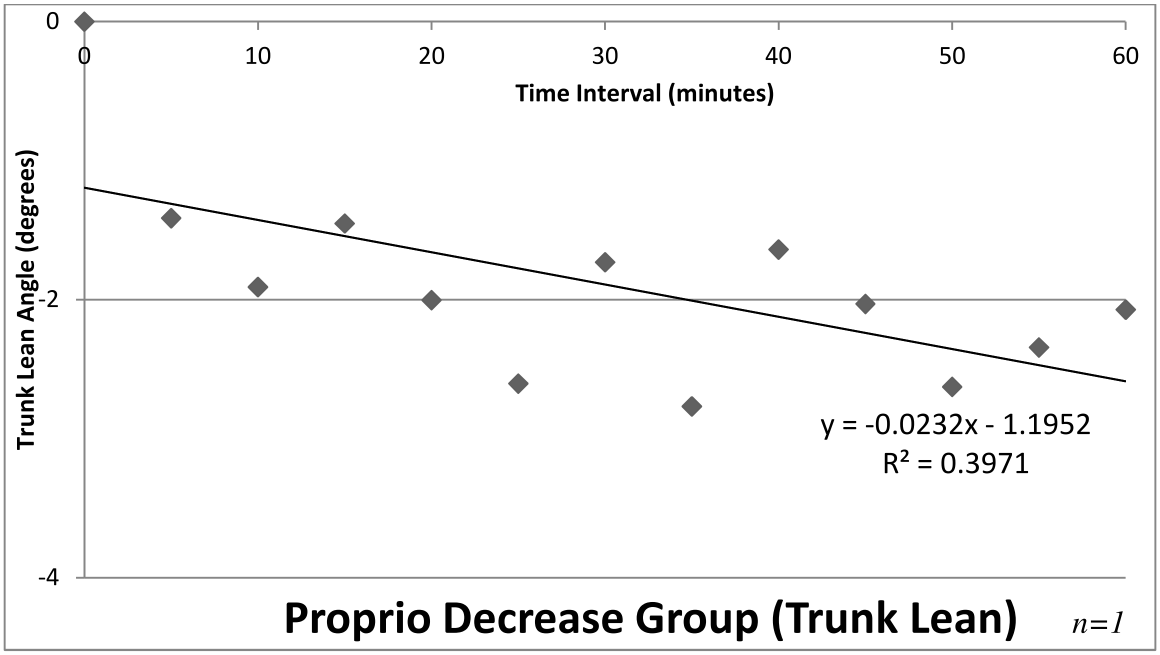


Figure 3.16- Proprioceptive trunk lean average from 0-60 minutes in the No Change and Decrease Groups are shown along with line of best fit and R2.

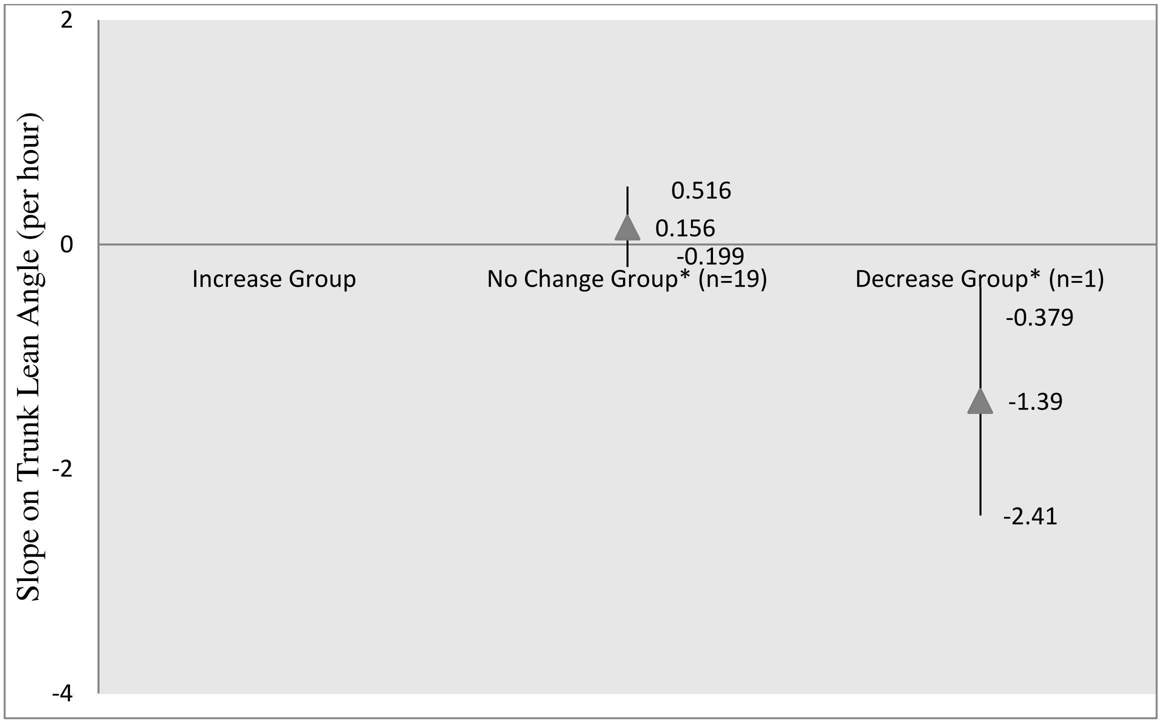


Figure 3.17- The average slope of the linear regression on trunk lean angle in proprioceptive orthotic condition with 95% CI error bands shown for each of the three groups. The trunk lean angle in the Decrease group and the No Change Group were significantly different from each other. No participant belonged in the Increase Group. Significant differences between the No Change Group and Decrease Group are indicated with an asterisk (*) at $p<0.05$. The triangles reflect the mean slopes and the ranges represent the 95% CIs.

3.4 Discussion

The objective of this study was to evalute the effects of foot orthoses on toe-out angle, pelvic tilt angle, and trunk lean angle over 60 minutes of treadmill walking. Statistical significance would mean that the three kinematic gait variables changed throughout the duration of walking, however, all three gait variables showed no statistical significance in prolonged walking on the treadmill ($p<0.05$). However, small fluctuations in data were observed within each participant's data over the 60 minutes of walking.

The magnitudes of toe-out angle, pelvic tilt angle, and trunk lean angle when walking on the treadmill at 0min and at 60 min were similar in values for both orthotic conditions. One noticeable difference between the two orthotic conditions at 60 min was the trunk lean angle in the MLA orthotic had 0.9° and the proprioceptive orthotic condition had 1.11°. The difference in angle was the largest among the three kinematic gait variables. However, the difference in angle is so small that there is no clinical importance.

The magnitude of change from start to finish (i.e. 60-0 min) in both orthotic conditions have similar positive average pelvic tilt angle. Note the MLA orthotic had an average negative toe-out angle meaning participants on average had toes pointing inward from start to finish. The proprioceptive orthotic had an average negative trunk lean angle meaning participants on average were leaning towards the swinging leg from start to finish in walking. Based on these two observations, we can conclude that the participants in this study preferred their feet in supination during walking in the MLA orthotics.

The magnitude of the average relative change in angle was within one of three areas: greater than 1.5°, close to 0°, and less than 1.5°. To understand the positive or negative relationship, there was a need to divide all 20 participants into subgroups to prevent the chance in cancelling out the changes between participants when average angles are calculated. For example, the Increase Group was classified as change in angle >1.5°. The change in angle values over 60 minutes had to be greater than the cut-off value of 1.5°. If there was an average change in angle of 3.0° in one participant, any average angle values less than the cut-off would not be included in the Increase Group. A negative angle value of -3.0° would be included, but result in the overall change in angle would be zero or none. No change in the participants would be detected which is not the case. Hence, there is the need to subdivide the groups to eliminate the cancelling effect.

The magnitude of angle changes in each of the three groups over 60 minutes of treadmill walking are summarized in three points.

1. The average relative change in toe-out angle in the Increase Group for the MLA orthotic condition and the Decrease Group for the proprioceptive orthotic condition had the closest relationship with prolonged walking.
2. The average relative change in pelvic tilt angle in the Decrease Group for MLA orthotic condition and the Increase Group for the proprioceptive orthotic condition had the closest relationship with the 60 minutes of prolonged walking.
3. The average relative change in trunk lean angle in the Decrease Group had the closest relationship with prolonged walking for both MLA orthotic and proprioceptive orthotic conditions.

In each of the three kinematic gait variables, all three groups had weak linear relationships between the change in angle and walking time duration. This is shown by the slopes and the R^2 values. The slope informs us on how much change in angle in the kinematic gait variable one expects on average over an hour.

The results in study included a practice trial of at least 5 minutes to eliminate potential differences on temporal measures on treadmill walking. The importance of practice time on a treadmill before data collection has been studied extensively. The findings were 4-6 minutes of practice time must be given to participants, in order for participants to get familiarized with the treadmill prior to testing (Alton et al., 1998; Matsas et al., 2000).

Only one other study has investigated 60 minutes of treadmill walking in measuring trunk lean and toe-out angles. The results in this study are in agreement with previous investigation (Bechard et al., 2011). Although that one study evaluated 20 healthy participants over four time windows, their findings on toe-out and trunk lean angles were very similar to those reported in this study. They reported mean toe-out angles were 10.10˚ (4.84), 10.59˚ (5.16), 10.54˚ (4.98), and 10.72˚ (5.39). The four means on toe-out angle reported were similar to this study. In this study, toe-out angle averaged over 60 minutes was 8.30˚ (4.84) for MLA orthotic condition and 8.75˚ (5.97) for proprioceptive orthotic condition. Although the toe-out angle is approximately two degrees less than their study, the kinematic gait variables in both studies were collected with the same equipment, methods, and data analysis. Hence, the findings in both studies are closely similar.

The mean trunk lean angles reported were 0.66° (1.09), 0.72° (1.20), 0.81° (1.25), and 1.03 (1.48°) (Bechard et al., 2011). The four means on trunk lean angle were also similar to the one in this study. In this study, the average calculated angle for trunk lean was 0.80° (1.34) which was averaged over 60 minutes. The difference in two degrees is not obvious in real-life. The cause of the difference in error could be caused by soft-tissue error (Holden, Orsini, Siegel, Kepple, Gerber, & Stanhope, 1997), or the movement of clothing (Pritchard & Heidrich, 2003), or simply the characteristics of the sample group.

The magnitude of change in toe-out angle (60-0 min), the initial angle at 0 min, and the angle at 60 min were very similar to overground toe-out angle. In one study, 50 healthy individuals had an average toe-out angle of 7.3° with SD of 5 (Rutherford, Hubley-Kozey, Deluzio, Stanish, & Dunbar, 2008). In another study on healthy children aged 11 to 13, the average toe-out angle was 10°±3° (Lin, Lai, Chou, & Ho, 2001). The difference of fraction of a degree is not obvious in real-life.

An important observation in this study, all the participants preferred to maintain at the same walking speed. Other researchers have discovered walking speed and stride length were larger in overground walking than treadmill walking when the speed of the treadmill was held constant (Riley, Paolini, Croce, Paylo, & Kerrigan, 2007). When interpreting the results in this thesis, one must keep in mind the data collected was based on the fact that the treadmill was kept at a constant speed from start to finish. The speed at which the participants walked on the treadmill could be a potential factor in determining the outcome of these results.

Potential limitations in this study include the small number of participants pooled from the general population. The studies would better reflect the general public if more participants were included in the experiment. There was a large range in age and BMI of the participants that were not controlled. If this study looked into the regularity of treadmill training of participants, then more in-depth understanding between training duration and outcome of 60 minutes of treadmill walking. In the 20 participants, there were only three kinematic gait variables examined on body movements. Other studies go into extensive detail on pelvic rotation and obliquity; in addition, the forces exerted on the body at each specific lower extremity joints. This study tested MLA orthotics and proprioceptive-feedback type orthotics only, but there are many other types of orthoses. For example, wedges on different segments of the foot. When interpreting the data presented in this study, one must note the action in switching in and out of the orthotics.

Shoe condition, such as the height of the heel, could affect the functions of foot orthoses on the foot. The heels of shoes elevate the foot from the ground, and the increase in height between the floor and the heel could disrupt the truss mechanism in providing foot stability (Kogler et al., 1995). Wear and tear of the shoe could affect the shock absorbed by the foot; therefore, having participants use the same shoe conditions would eliminate shoe error. The result of this study could have been influenced by the condition of the shoe. Another limitation to this study is the participants did not have time to acclimatize to the orthotics and were tested in them for each 5 min time interval.

This study is just the first step in understanding the effects of prolonged treadmill walking on joint angles of the foot, pelvis and trunk. There are many further experiments that can be conducted on prolonged treadmill walking with and without the use of foot orthoses to support the medial longitudinal arch. For example, evaluate kinetics such as the forces acting through the joints, different foot types (pes cavus and pes planus) with or without symptoms, foot orthoses that are custom-made to fit every participant, and various walking or running speed on the treadmill. More investigation on the use of foot orthoses to support the medial longitudinal arch during prolonged treadmill walking can further enhance this area of research.

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Chapter 4

Discussion

4.1 Overview

Few studies have examined prolonged walking on a treadmill. What might be more representative of everyday life is to study prolonged walking. The purpose of this thesis was to examine the effects of prolonged treadmill walking on segmental movements of the foot, pelvis, and trunk in healthy participants. A major category in kinematics is joint angle, which is often a quick and easy assessment performed in clinical settings to determine the range of motion. The results presented in this thesis set a fundamental baseline that future research can use as a comparison point for prolonged treadmill walking. The main findings in Chapter 2 on generic insoles and Chapter 3 on foot orthoses with medial longitudinal arch support are summarized in the following paragraphs.

Chapter 2: The three kinematic gait variables (toe-out, pelvic tilt, and trunk lean angles) of the 20 participants did not change significantly over the 60 minute period of prolonged walking ($p<0.05$). For toe-out angle on average slope, the Decrease Group was significantly different from the Increase and No Change Groups. The average slope for pelvic tilt angle showed statistical significance in all three groups. On the contrary, each participant's overall average change in trunk lean angle stayed within the range of +1.5 to -1.5°. All the participants were assigned to the No Change Group because trunk lean angle was not significantly different among the groups. Significant differences were detected at $p<0.05$.

Chapter 3: In both MLA orthotic and proprioceptive orthotic conditions, the three kinematic gait variables (toe-out, pelvic tilt, and trunk lean angles) of the 20 participants did not change significantly over 60 minutes of prolonged walking ($p<0.05$).

The MLA orthotic had a smaller change in average toe-out angle when compared with proprioceptive orthotic. The proprioceptive orthotic had a smaller change in average pelvic tilt angle and trunk lean angle when compared with MLA orthotic.

4.2 Future research

Further research should investigate the functional differences between pes planus and pes cavus during prolonged treadmill walking. Participants with symptomatic pes cavus or pes planus may show different outcomes than those with asymptomatic feet. A spectrum of foot types exists in the healthy population and not everyone’s feet are the same, so there is a need to evaluate and treat each case individually (Statler & Tullis, 2005). Custom-made orthoses are often the prescription for pathological foot problems, such as pes planus. If future research could customize the orthoses to fit each participant’s feet, then the results would be more accurate and reliable than one pair of orthoses used among all the participants.

Medial longitudinal arch support is affected by moulding techniques, cast modifications, the surface geometry of foot orthoses, and the material used to create the orthotic device for the foot (Kogler, Solomonidis, & Paul, 1995; Kogler, Solomonidis, & Paul, 1996). The material used in foot orthoses influences which loads are imposed on the foot. Foot pronation was reduced as a result of increased medial height thickness in insoles that were inserted into shoes during running (Cavanagh, 1980). The orthoses worn by the participants in this study were classified as “soft” material. If orthoses were harder in material than those used in this study, different results might arise over the duration of prolonged walking on the treadmill.

Besides the hardness in orthoses, the length of orthoses could affect outcomes. The proprioceptive-feedback orthotic used in this study was full-length. Other orthoses lengths, for example ¾ length, may have different outcomes.

Typically, foot orthotic research has examined foot orthoses over short periods of walking (i.e. a couple of foot strikes on the force plate or a few meters at a time), rather than the long term effects on the use of foot orthoses. Little is known of the relationship between prolonged walking and foot orthoses. In this thesis, the MLA orthotic and proprioceptive orthotic had minimal changes in toe-out, pelvic tilt, and trunk lean angles over 60 minutes of treadmill walking.

All of the above suggestions require further investigations to provide a broader understanding on the effects of these factors on prolonged treadmill walking. There are many areas for further experiments on prolonged treadmill walking and MLA foot orthoses. The studies in this thesis are just the first step in understanding the effects of prolonged treadmill walking on joint angles of the foot, pelvis, and trunk.

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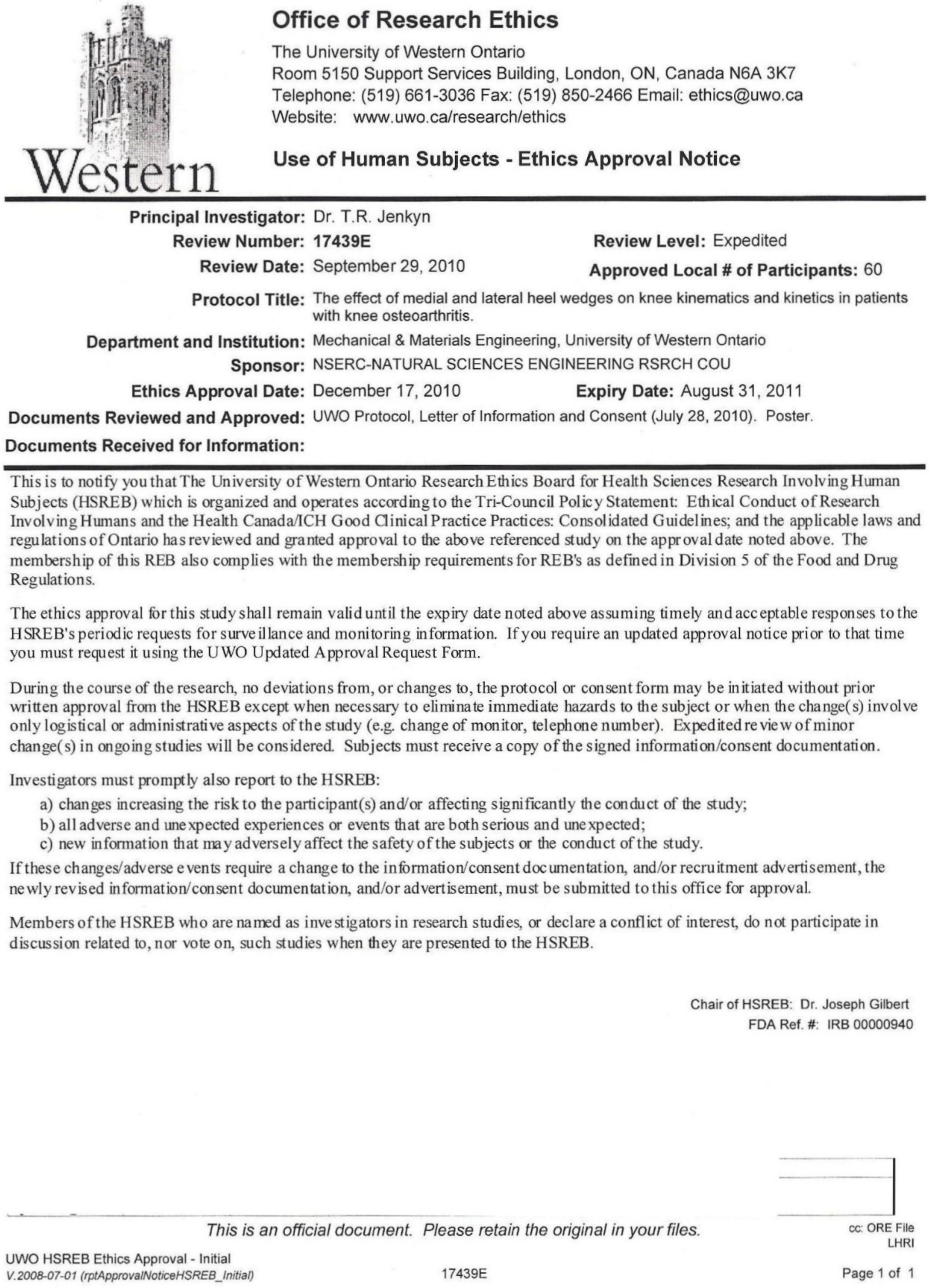
Appendix A - Ethics Approval



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Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. T.R. Jenkyn
Review Number: **17439E** **Review Level:** Expedited
Review Date: September 29, 2010 **Approved Local # of Participants:** 60
Protocol Title: The effect of medial and lateral heel wedges on knee kinematics and kinetics in patients with knee osteoarthritis.
Department and Institution: Mechanical & Materials Engineering, University of Western Ontario
Sponsor: NSERC-NATURAL SCIENCES ENGINEERING RSRCH COU
Ethics Approval Date: December 17, 2010 **Expiry Date:** August 31, 2011
Documents Reviewed and Approved: UWO Protocol, Letter of Information and Consent (July 28, 2010). Poster.
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

- a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
- b) all adverse and unexpected experiences or events that are both serious and unexpected;
- c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

Chair of HSREB: Dr. Joseph Gilbert
FDA Ref. #: IRB 00000940

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LHRI

UWO HSREB Ethics Approval - Initial
V.2008-07-01 (rptApprovalNoticeHSREB_Initial)
17439E
Page 1 of 1

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