ABSTRACT

Comparing the Pelvis Kinematics of Able-Bodied Children During Normal Gait and When Riding a Therapeutic Horse

Brandon Rhett Rigby, M.S.B.M.E.

Mentor: Brian A. Garner, Ph.D.

Hippotherapy is a treatment strategy that uses horse movement as physical therapy tool for clients with a broad range of diagnoses including cerebral palsy and multiple sclerosis. The prevailing theory is that the gait motion of the therapeutic horse provides sensory stimulus and movement patterns to the rider that mimic natural movements of healthy humans – patterns the patient is unable to produce. Nine able-bodied children (all inexperienced riders), boys and girls ages 8 through 12, participated in a series of riding and walking trials. Participants were fitted with adhesive markers on the pelvis, back, neck, and shoulders. A multi-camera video motion camera system recorded both riding and walking trials. The motion capture data was analyzed to reveal similar translational and rotational patterns of the pelvis between the two trials. The results provide a quantitative assessment of the validity of the prevailing theory about how hippotherapy may benefit disabled patients.

Comparing the Pelvis Kinematics of Able-Bodied Children During Normal Gait and When Riding a Therapeutic Horse

by

Brandon Rhett Rigby, B.S.

A Thesis

Approved by the Department of Mechanical Engineering

_____

William Jordan, Ph.D., Chairperson

Submitted to the Graduate Faculty of
Baylor University in Partial Fulfillment of the
Requirements for the Degree
of
Master of Science in Biomedical Engineering

Approved by the Thesis Committee

_____

Brian A. Garner, Ph.D., Chairperson

_____

Carolyn T. Skurla, Ph.D.

_____

Beth A. Lanning, Ph.D.

Accepted by the Graduate School
August 2009

_____

J. Larry Lyon, Ph.D., Dean

Page bearing signatures is kept on file in the Graduate School.

Copyright © 2009 by Brandon Rhett Rigby

All rights reserved

TABLE OF CONTENTS

List of Figures vi

List of Tables viii

List of Abbreviations ix

Acknowledgments x

Dedication xi

Chapter One – Introduction 1

Purpose 2

Thesis Overview 2

Chapter Two – Background: An Introduction to Hippotherapy 4

Conditions Treatable Using Hippotherapy 5

History 7

Mechanical Effects of Hippotherapy 8

Psychosocial Effects of Hippotherapy 8

Case Studies 9

Drawbacks 21

Conclusion 22

Chapter Three – Background: Human Pelvic Kinematics During Walking 24

History 24

Gait Analysis of Human Walking 26

Kinematics 27

Pelvic Kinematics During Gait 28

Conclusion 33

Chapter Four – Methods and Materials 35

Human Subjects 35

Horses 36

Data Collection 37

Protocol 38

Analysis 44

Chapter Five – Results 48

Pelvis Y-Translations vs. Gait Cycle 49

Pelvis X-Translations vs. Gait Cycle 52

Pelvis Z-Translations vs. Gait Cycle 54

Pelvis List vs. Gait Cycle 56

Pelvis Twist vs. Gait Cycle 58

Pelvis Trajectories in the Principal Planes 60

Chapter Six – Discussion 63

Significance 63

An Analysis of Data 64

Errors and Limitations 78

Future Work 80

Chapter Seven – Conclusion 84

Appendix A – Riding Data: Bailey 86

Appendix B – Riding Data: Bonnie 110

Appendix C – Riding Data: Dolly 126

Appendix D – Walking Data: 150

Appendix E – Statistics Tables 178

Bibliography 181

LIST OF FIGURES

Figure 1: Components of the gait cycle [29] 26

Figure 2: The movement of a subject through the gait cycle [29] 26

Figure 3a): Parallel lower extremities; 3b) the lower extremities [2] 29

Figure 4: Rotation of the pelvis in the a) coronal plane (front view); b) sagittal plane (side view); c) transverse plane (top view) 30

Figure 5: Measured rotation of the pelvis in the a) coronal plane; b) sagittal plane; c) transverse plane [33] 31

Figure 6: Rotations of the pelvis in the a) coronal plane; b) sagittal plane; c) transverse plane [34] 32

Figure 7: Pelvis bar with elastic belt 39

Figure 8a): Anterior view of subject with marker placement; b): Posterior view of subject with marker placement 40

Figure 9: Camera position setup for the riding trials 43

Figure 10: Camera position setup for walking trials 43

Figure 11: Pelvis y-translations for subject A on Bailey 50

Figure 12: Pelvis y-translations for all subjects on Bailey 50

Figure 13: Y-translations of the pelvis 51

Figure 14: Multiple comparisons of the y-translation ranges 52

Figure 15: X-translations of the pelvis 53

Figure 16: Multiple comparisons of the x-translation ranges 54

Figure 17: Z-translations of the pelvis 55

Figure 18: Multiple comparisons of the z-translation ranges 56

Figure 19: List angles of the pelvis 57

Figure 20: Multiple comparisons of the pelvis list ranges 58

Figure 21: Twist angles of the pelvis 59

Figure 22: Multiple comparisons of the pelvis twist ranges 60

Figure 23: Translations of the pelvis (side view) 61

Figure 24: Translations of the pelvis (top view) 61

Figure 25: Translations of the pelvis (back view) 62

Figure 26: Y-translations of the pelvis with gait cycle landmarks 65

Figure 27: X-translations of the pelvis with gait cycle landmarks 65

Figure 28: Z-translations of the pelvis with gait cycle landmarks 66

Figure 29: Translations and rotations of the trunk [23] 68

Figure 30: Translations of the pelvis along the: a): x-axis, b): y-axis, and c): z-axis 70

Figure 31: Translations of the pelvis along the: a): x-axis, b): y-axis, and c): z-axis [22] 70

Figure 32: Pelvis list with gait cycle landmarks 72

Figure 33: Pelvis twist with gait cycle landmarks 72

Figure 34: Pelvic rotations in the a): coronal plane and the b): transverse plane [28] 75

Figure 35: Pelvic rotations in the a): coronal plane and the b): transverse plane [25] 75

Figure 36: Pelvic rotations in the a): coronal plane and the b): transverse plane 75

Figure 37: Lissajous figures displaying the translations of the pelvis [22] 77

Figure 38: Pelvis trajectories viewed from the a): side; b): top; c) back 77

LIST OF TABLES

Table 1: Subject Profiles 35

Table 2: Protocol for Riding Set 1 in Session 1 41

Table 3: Protocol for Riding Set 2 in Session 1 41

Table 4: Protocol for Riding Set 3 in Session 1 42

Table 5: Protocol for the Walking Set in Session 1 42

Table 6: Overview of Translation Range Data 69

Table 7: Overview of Rotation Range Data 74

LIST OF ABBREVIATIONS

ADL – Activities of Daily Living

AHA – American Hippotherapy Association

ANOVA – Analysis of Variance

BABS – Brunel Active Balance Saddle

CNS – Central Nervous System

COG – Center of Gravity

CP – Cerebral Palsy

EMG - Electromyography

GMFM – Gross Motor Function Measure

HAT – Head, Arms, and Trunk

IRB – Institutional Review Board

LED – Light-emitting diode

LLD – Language-Learning Disabilities

MS – Multiple Sclerosis

NARHA – North American Riding for the Handicapped Association

SCI – Spinal Cord Injury

S.D. – Standard Deviation

ACKNOWLEDGMENTS

I would like to express my appreciation to my advisory committee: Dr. Brian Garner, Dr. Carolyn Skurla, and Dr. Beth Lanning. Thank you for giving me the opportunity to be part of the ongoing hippotherapy research here at Baylor. Special thanks to Dr. Garner for his time, patience, and understanding. Dr. Skurla, it has been an honor to learn from you. Also, thanks to Baylor University for their support in providing travel funds so that we may present what we have accomplished to many groups of individuals from different backgrounds.

My sincere thanks also go to the individuals at Camp Hope, particularly Mr. Larry Barnett. There are not enough words to describe how accommodating you were. I would also like to thank Ms. Nancy O'Meara at the Ride on Center for Kids and Ms. Shirley Wills at the Heart of Texas for their advisement and support.

To the biomechanics class of the fall of 2008, thank you for your help in setting up and conducting the experiments, as well as helping me track the unreal amount of data. Your assistance was much appreciated.

Another special thanks goes to my better half and friend. Mika, you gave me your unconditional support and love through this long process. Thank you for being there for me.

DEDICATION

To the four pillars of my life: God, my parents, and Mika. Without you, my life would fall apart.

I might not know where life's road will take me, but walking with you, God, through this journey You have given me strength.

Mom and Lyndel, you have given me so much, thank you for your faith in me, and for being there for me.

Dad, you always told me that I could be anything and always pushed me to be my best. Thank you for instilling the drive in me.

Mika, you are everything to me, without your love and understanding I would not be able to make it.

CHAPTER ONE

Introduction

The movement of the pelvis is important in many human activities including normal walking. Pelvic posture directly affects spine, head, and limb alignment, which are critical for proper musculoskeletal function and health [1]. The study of how the pelvis moves during normal human walking has been analyzed for more than 100 years. A landmark study published in the 1950s suggests that the pelvis is involved with three of the six major determinants of pathological walking gait [2]. For individuals with neuromotor disabilities, exercises that increase the pelvic range of motion can improve posture and limb alignment and increase functional abilities [1].

Over the past approximately fifty years an alternative therapeutic strategy has been increasingly practiced that utilizes equine (horse) movement for the treatment of individuals with various disabilities. The term “hippotherapy” derives from the Greek word “hippos”, for horse, and refers to a form of equine-assisted therapy that aims to improve functional abilities and quality of life for individuals with disabilities. The basic rationale for this strategy is that the horse reproduces for the rider movement patterns that are similar to those of natural human activities such as walking.

Although many studies have looked at pelvis motion during human walking, literature describing how the pelvis moves when a subject is riding a walking horse is very scant. Only one known study has reported quantitative similarities between pelvis motions during human walking and pelvis motions during horseback riding [3]. This one study reported averages of one angular displacement and one linear displacement of

the human pelvis, and it appears these data were collected from different trials possibly involving multiple human subjects.

Purpose

The purpose of the present study was to more thoroughly quantify and compare human pelvis kinematics (movements) during horseback riding to that during normal human walking. For the scope of this work the three-dimensional patterns of pelvic motion in able-bodied children were analyzed in terms of three linear and two angular displacements. The working hypothesis was that movement patterns of the pelvis when walking would show qualitative and quantitative similarities to those when riding a walking horse.

For the current study, children were used for several reasons. First, most of the patients in hippotherapy are children twelve years of age and younger. Second, previously published studies [4-10] suggest that hippotherapy has a greater impact on children than on adults. These studies described the benefits of hippotherapy using children as subjects, and nearly all the studies involving patients with cerebral palsy (CP) focused on children. Third, children were highly recruitable for this study and enjoyed participating in the riding and walking trials.

Thesis Overview

Chapters two and three provide the background information for this work. The concept of hippotherapy and its validity are presented in chapter two while a brief literature review of human pelvis kinematics during normal gait is presented in chapter three. Chapter four presents the methods of the study, which include data collection and

analysis of human pelvis kinematics while walking and while sitting astride a walking horse. The results of the study are presented in chapter five. These results are discussed more thoroughly and compared with past data from literature in chapter six. Finally, a conclusion for the study is given in chapter seven.

CHAPTER TWO

Background: An Introduction to Hippotherapy

The purpose of this chapter is to introduce hippotherapy and to present previous case studies in literature that suggest the therapy is a beneficial treatment option for individuals with many different forms of disability. An understanding of how hippotherapy is thought to benefit individuals with disabilities is a precursor to the methods of this study.

The validity of hippotherapy has been explored by many researchers from Europe and North America over the past two decades [4,11]. Many studies focused on specific clinical measures, testing the subjects before and after each treatment session for any indications of improvement in the areas of gross motor function [5], energy expenditure [6], posture [7], muscle symmetry [8], spasticity [12], and balance and coordination [11]. Other studies have been published linking hippotherapy to psychosocial improvements in subjects [9,10].

The American Hippotherapy Association (AHA), a section of the North American Riding for the Handicapped Association (NARHA), defines hippotherapy as "a term that refers to the movement of the horse as a tool by physical therapists, occupational therapists, and speech-language pathologists to address impairments, functional limitations, and disabilities in patients with neuromusculoskeletal dysfunction" [13]. The author also stated that hippotherapy is derived from the Greek root word 'hippos,' meaning horse. Patients receiving hippotherapy in their treatment programs do not typically control the horse's movement. The AHA goes on to describe hippotherapy as a

treatment that takes place in a controlled environment where graded sensory input can elicit appropriate adaptive responses from the patient [13]. The main objective of hippotherapy is to improve neurological function and sensory processing, as opposed to therapeutic riding, which focuses on the teaching of specific riding skills in conjunction with improving neurological dysfunctions [14].

Conditions Treatable Using Hippotherapy

Case studies have shown improvements in patients with Cerebral Palsy (CP), Down syndrome, developmental delays, traumatic brain injuries, spinal cord injuries, and Multiple Sclerosis (MS) using hippotherapy as part of an integrated treatment program to achieve specialized therapeutic functional outcomes [15]. Adults and children with mild to severe neuromuscular disabilities, developmental disorders or skeletal impairments are thought to benefit in the areas of the gross motor function, energy expenditure, postural alignment, muscle symmetry, spasticity, and balance and coordination [16]. Hippotherapy has also been said to improve speech, language, and cognitive function and may help the rider develop responsibility, self-esteem, self-confidence, and emotional self-control [15].

Cerebral Palsy

Most research completed regarding the effectiveness of hippotherapy has been performed on patients suffering from some form of CP [14]. CP is a term used for a heterogeneous group of disorders that are non-progressive but lead to permanent damage to the immature brain, resulting in varying degrees of delay in the patients' developmental milestones. Sayli et al. reports that the condition afflicts one to three

children every 1,000 births and can occur *in utero*, at birth, or within the first few months of life [17].

Neurologic lesions in the brain result in abnormalities of muscle tone, reflexes, and righting (to bring to an upright position) reactions, as well as impaired motor development and control [8]. Even though this injury is static, the "resultant dysfunction is often progressive" [8]. If the diagnosis can be made early and the subsequent treatment can be assessed at a young age, the child will have a greater chance of living a more normal life. According to Bleck, ambulation skills are reached by the age of seven due to the presence of postural and tonic reflexes in the child [18]. In children with some neuromusculoskeletal dysfunction, such as CP, development of correct postural reactions and equilibrium may be delayed or fail to occur [19].

The classifications of the condition are due to anatomical and pathophysiologic involvement. Spasticity is the most common type of pathology encountered, and children with spastic CP may have impaired walking ability due to lack of selective muscle control, poor equilibrium responses, agonist-antagonist imbalance, and excessive co-contraction [6].

Because children with CP have multiple symptoms for which no curative treatment exists, their families seek therapies from many sources. Some look for cures while others seek therapies that will improve the way their child functions or feels [20]. In addition, there is the potential for detrimental effects on vision, perception, cognition and social development. The result of these effects is a child who cannot perform many common daily activities and a family that must redirect substantial energies to his or her care [8].

Multiple Sclerosis

Hippotherapy has also been used to treat patients with MS, a condition which can be divided into a relapsing-remitting form and a progressive form. Treatment and help to overcome disability and handicap is primary in the management of MS patients. Hammer et al. concludes that, "Multiple Sclerosis presents us with a special challenge, partly because of the multiplicity of symptoms and functions that are affected, and partly because of the unpredictable and progressive course of the disease" [11]. Rehabilitation in MS must consequently be individually adapted.

History

Hippocrates was the first to describe the "health-giving rhythm" of the horse [21]. Documentation of the benefits of horses to health and well-being has existed since the fifth century BC, when Greek and Roman soldiers injured in battle were placed back on their mounts to facilitate recovery [8]. The first complete reference to the value of equitation as an effective method to promote and conserve health was made by Markurialis (1569) in the book "De Arte Gymnastica." Merkurialis makes reference to an observation by Galeno, whereby "equitation is by no means the most marginal of physical exercises inasmuch as it not only exercises the body, but also the senses" [21]. In 1782, J.C. Tissot was the first to define three forms of movement: the active kind, the passive kind, and a combination of active/passive movement which is typical of equitation [21].

Sterba et al. summarized the recent history of therapeutic horseback riding over the past century [14]. According to the authors, there were no further references in the literature to the use of horseback riding as a form of therapy until two serious epidemics

of Paralytic Poliomyelitis in Scandinavia in 1946. These events led to the founding of the first two centers of therapeutic horseback riding in Copenhagen, Denmark, and Oslo, Norway, for the treatment of children with neuromuscular disorders, most notably children with Poliomyelitis and CP. From 1953 onward, therapeutic horseback riding was actively promoted by the International Polio Fellowship in England. The first book published on the use of the horse for therapeutic means appeared in German in 1961, written by Ernst Durschky. Shortly thereafter, the development of the first therapeutic riding program in North America was established in Toronto, Canada in 1965 as the Community Association for Riding for the Disabled. The North American Riding for the Handicapped Association was then founded in 1969 to support riders from both the United States and Canada [14].

Mechanical Effects of Hippotherapy

Once placed on the back of a horse, the rider is placed in a position that inhibits extension spasticity of the legs and applies a long-lasting stretching of the hip adductors. These mechanisms can be useful in reducing abnormally high muscle tone. Balance can be improved if neuromuscular and vestibular mechanisms are affected. At least one study supports the idea that as the horse walks, its center of gravity is displaced three-dimensionally with a rhythmical movement very similar to that of the human pelvis during gait [11]. Millhouse-Flourie stated that the complex movement of the horse influences the rider by passive and active stretching and stimulation of the rider's balance and postural control [15]. Astride on the horse, the rider's pelvis, lumbar spine, and joints are mobilized; deep muscles that are not accessible in conventional physical therapy are stretched and strengthened. The horse's smooth and rhythmic gait elicits

motor responses in the rider that are similar to and essential for movement patterns of a human pelvis while walking. The rider's center of gravity shifts atop the moving horse, facilitating righting and equilibrium reactions that will stimulate improved trunk stability and posture. These may, in turn, generate improvement in respiratory, circulatory, and digestive functions [15].

Psychosocial Effects of Hippotherapy

The psychosocial benefits of hippotherapy are known to contribute to improvements in the overall quality of life [15]. Increases in self-confidence, self-image and self-esteem have been reported by the caregivers of the subject. The unique and memorable experience of the therapy can yield feelings of control and freedom that few activities in the rider's life can provide. For the patient who spends much time in medical and other clinical settings, a horseback riding facility with a natural environment can provide a welcome break from normal routine. The attitudes of a patient and his or her motivation toward engaging in therapy sessions may subsequently improve [15], but no statistical evidence can be found to verify these claims.

Case Studies

As stated previously, hippotherapy can be used to treat adults and children with a wide range of diagnoses and can benefit in the areas of the gross motor function, energy expenditure, postural alignment, muscle symmetry, spasticity, and balance and coordination [16]. There have also been studies conducted to test the positive benefits of hippotherapy on children who exhibit language-learning disabilities [9] and on children who are grieving [10].

The Gross Motor Function

Winchester et al. elaborated on the Gross Motor Function Measure (GMFM), an 88-item evaluative measure used to assess motor function in a quantitative manner without regard to the quality of performance [5]. They divided the measure into five dimensions: lying and rolling; sitting; crawling and kneeling; standing; and walking, running, and jumping. Each item is scored on a scale from zero to three as defined within the testing instructions. This test has been validated on children ages two to twelve to detect changes in gross motor function in children with developmental delays secondary to diagnosis, such as CP, brain injury, and Down syndrome [5].

Sterba et al. investigated the effect of horseback riding in children diagnosed with CP, specifically focusing on the effect of the gross motor function [14]. After 12 weeks of horseback riding therapy (i.e. one hour a week for a total of 12 hours) only the fifth dimension of GMFM (walking, running and jumping) was reported to have increased significantly by 8.7% after 12 weeks and by 8.5% after 18 weeks, and remained elevated by 1.8% six weeks after the treatment ended. In other words, the treatment persisted for weeks after the experiment ended. These results suggest that hippotherapy may improve gross motor function in children with CP, which in turn may reduce the degree of motor disability [14].

Using the gross motor function measure, Winchester et al. chose to analyze the effect of hippotherapy on seven participants, two of whom had CP, one with CP and Autism, two with Down syndrome, one with Spina Bifida, and one that suffered a traumatic brain injury at five years [5]. All five dimensions of the GMFM were analyzed. One pretest measurement was completed in the week preceding the

hippotherapy session (each session lasted for one hour a week for seven weeks). Two post-treatment measures were taken. The first post-test was administered one week after the program was completed to determine if the intervention of hippotherapy was effective. The second post-test administered taken seven weeks after the end of the hippotherapy program to determine if the changes observed during the program were maintained. It was found through statistical analysis that there was a significant difference in all of the GMFM raw scores between the pretest (60.2 $\pm$ 24.1%, mean $\pm$ s.d.) and the first posttest (71.0 $\pm$ 20.1%, mean $\pm$ s.d.), as well as a significant difference in all of the GMFM raw scores between the pretest and the second posttest (70.3 $\pm$ 18.9%, mean $\pm$ s.d.). These results imply that hippotherapy can be used as an adjunctive therapy in the ongoing rehabilitation of children with developmental motor delays. No statistical analysis was performed comparing the subjects, but all of the GMFM raw scores for each subject increased from pretest to each posttest [5].

Energy Expenditure

In a study completed at the Therapeutic Riding Center in Tucson, AZ, McGibbon et al. states that, “the primary pathophysiological factors related to CP that hinder effective and efficient walking are: velocity-dependent increased resistance to muscle stretch, hypoextensibility due to non-neural changes in the mechanical properties of the muscles and tendons, insufficient force generation of affected muscle groups, and impaired muscle recruitment and activation” [6]. The authors further state that the preceding factors, combined with compensatory movement strategies, may result in gait deviations, including increased energy expenditure during walking, which leads to decreased stride length, increased cadence, and decreased walking velocity. In

conclusion, they speculate that any one or a combination of the aforementioned factors may affect walking efficiency for a particular patient [6].

McGibbon et al. used a repeated measures experimental design consisting of two baseline measurements taken eight weeks apart, followed by an eight week intervention period (with two hippotherapy sessions held weekly), and then a posttest measurement [6]. Five children were used for the study, all of whom were diagnosed with CP. Energy expenditure was measured using the child's heart rate. It is possible to use the heart rate of an individual to determine the person's energy expenditure because the two are known to have a linear relationship under submaximal work conditions. All five children showed a statistically significant decrease in energy expenditure after the hippotherapy treatment compared to before the treatment. Multiple comparisons to test pair-wise differences showed that the posttest energy expenditure was significantly less than either pretest, suggesting that eight weeks of twice-weekly hippotherapy may result in decreased energy expenditure and increased efficiency during walking for children with CP [6].

Posture Control

According to a theory of postural control, "The task of postural control involves the body's position in space for (a) stability, defined as controlling the center of body mass within the base of support, and (b) orientation, defined as the ability to maintain an appropriate relationship between the body segments and between the body and the environment for a task" [7]. Placing a patient with some neuromuscular dysfunction on a horse provides numerous opportunities for the subject to respond to the movement of the horse while performing functional tasks like reaching and stretching. The participant

must maintain his/her head, arms and trunk (HAT), or body mass, over the base of support (the pelvis) when sitting on a horse. If this protocol is properly followed, it is presumed that the subject is practicing postural control in the sitting position. The rider is an active participant who makes continuous adjustments to maintain postural control on a dynamic surface. Responding to the movements of the horse requires both reactive and anticipatory postural adjustments, both of which can be impaired in people suffering from some neuromusculoskeletal dysfunction [7].

Hamill et al. studied the effect of hippotherapy on postural control for children diagnosed with CP [7]. Three children attended hippotherapy sessions that took place once a week for 10 weeks. The sitting dimension of the GMFM was administered every two weeks during the treatment and was used to establish a baseline of sitting abilities. The overall GMFM was administered before, after, and four weeks post-intervention. The only data presented were the results of questionnaires that reflected the parental perceptions of the hippotherapy intervention, which were reported to be very positive, with reported improvements in the range of motion and head control [7].

Muscle Symmetry

Muscle asymmetry, combined with the physical growth in the face of long-term sensory and motor impairments, often leads to increasingly severe disability [8]. Muscle imbalance may lead to uneven bone growth, contractures, spinal deformities, scoliosis, imbalances in weight bearing, hip dislocation, chronic pain, and increasing difficulty with performance of basic motor skills defined in the GMFM. It is reported that, "Conventional medical approaches designed to achieve improved left/right symmetry are invasive and potentially injurious, including tendon release surgical procedures, selective

dorsal rhizotomy, injection of botulinum toxin into the affected muscles, and systemic muscle relaxing drugs" [8].

Benda et al. chose to study the effects of hippotherapy on muscle activity of children with cerebral palsy utilizing surface electromyography (EMG) to determine changes in symmetry of postural muscle groups [8]. Objectives included determining if there were any changes in muscle activity after a short hippotherapy session and comparing the effects of symmetrical sitting practice on a stationary barrel to symmetrical sitting practice on a rhythmically moving horse. Each hippotherapy session lasted only eight minutes because of the clinical impression that hippotherapy patients with spastic CP typically show positive changes within the first five to ten minutes on a horse. Those children chosen to sit on the barrel watched a horse video for eight minutes. Absolute differences in mean microvolt readings between left- and right-side individual muscle groups during each task were calculated and recorded as asymmetry scores. The higher the asymmetry score, the greater the difference between left and right muscle activity for that particular muscle group and task for that child. The mean change in asymmetry scores was 55.5 for the children in the hippotherapy protocol, and 11.9 for the children in the barrel protocol. The mean change in percentage improvement from pretest to post-test was 64.6% for the children in the hippotherapy protocol, and -12.8% for the children in the barrel protocol [8]. This data clearly shows that the hippotherapy protocol was more effective on improving muscle symmetry compared to a static exercise.

Spasticity

Spasticity is an accompanying phenomenon of spinal cord injuries and is defined as, “a velocity-dependent increase in muscle tone elicited by passive stretching” [12]. For several years hippotherapy has been used in rehabilitation of spinal cord injury (SCI) patients. Lechner et al. stated that the rhythmical side flexion and extension of the patient’s trunk combined with trunk torsion have a beneficial effect on spasticity [12]. According to neurophysiological standards, an inhibition of the spasticity is achieved through the saddle position in a combination of hip flexion, hip abduction, and the external rotation of the hip. Spasticity is also thought to improve through the rhythmical and three-dimensional equine movements communicated to the patient’s pelvis and trunk [12].

Lechner et al. investigated 32 SCI patients for the level of spasticity before and after 11 hippotherapy sessions, with each session lasting 25-30 minutes [12]. Rating of spasticity was done directly before and after the hippotherapy session, with eight movement directions being rated: hip flexion and extension, abduction and adduction, knee flexion and extension, and ankle dorsi- and plantarflexion. The elicited spasticity was rated according to a scale between one and five, with five representing very high spasticity. The values of the eight movement directions of both sides of the body were recorded as a sum of 16 scores ranging from a minimum of 16 to a maximum of 80. The researchers discovered that 93% of the hippotherapy sessions led to a lower score immediately after the intervention as compared to before the intervention. In all, only 6% of the sessions did not lead to a change in score; these sessions were completed by ten patients with a low score (<24) prior to treatment. An increased value was measured in

only 1% of the hippotherapy sessions, but these patients entered the experiment with very low scores (<18). These results indicate that hippotherapy causes an immediate reduction of spasticity of the lower extremities of SCI patients experiencing moderate to severe spasticity. On average, the scores were significantly lower after the treatment than before. For example, the final values of the eight movement directions varied from 17.6 to 53.3 between each subject before hippotherapy was administered. After the treatment sessions, the values ranged from 16.6 to 42. The greatest before- and after-session differences were measured in patients with very high spasticity [12].

Balance and Coordination

The improvement in a subject's balance can be expected after participating in hippotherapy sessions since riding a horse is a balance-demanding task. The movements of the horse generate continuous vestibular input with the rider continually having to adjust to these movements. Equilibrium reactions are thus stimulated, which lead to the facilitation of the musculature of the trunk and extremities. Changes in the speed and direction of the horse are thought to increase the control of muscle fibers, thus improving balance [11].

Hammer et al. chose to use a single-subject experimental design to study the effects of hippotherapy in eleven patients with MS [11]. The therapy comprised ten weekly hippotherapy sessions, each lasting 30 minutes. The authors studied the following variables: five physical measures testing balance and coordination, gait velocity, spasticity, functional strength, and pain, and two self-related measures, including activities of daily living (ADL) and health-related quality of life. The ADL included one or two daily activities with which the subjects were experiencing

difficulties. The health-related quality of life measure included the categories of physical functioning, role-physical, bodily pain, general health, vitality, social functioning, role-emotional, and mental health. The results indicated that one or more positive changes were seen in ten out of the eleven subjects. Out of the eleven participants in this particular study, eight saw an overall balance improvement. However, only one of the eleven subjects saw an improvement in gait velocity and only one of the eleven subjects saw an improvement in the level of spasticity. No subject improved in functional strength. Three out of eleven subjects who initially reported pain reported some pain reduction related to the intervention. Four of the eleven subjects rated an improvement in the activities of daily living. In the health-related quality of life questionnaire, 28 positive and 16 negative changes were recorded. The role-emotional category contained the most positive changes (8), while the social-functioning category possessed the most negative changes (3). Overall, there were slightly more changes in the mental (24) than in the physical (20) dimensions [11].

Language-Learning Disabilities

After completing his research, Macauley et al. reported that, "Students with learning disabilities comprise 45.2% of the population with disabilities and 5.5% of the total population in pre-kindergarten through 12th grade, and students with speech or language impairments are the next largest group, comprising 17.2% of the population with disabilities and 2.1% of the total population" [9]. In addition, of the students experiencing learning disabilities, a large portion exhibits language-learning disabilities (LLD). It has been hypothesized that children with learning disabilities are at greater risk for experiencing negative emotions that, in turn, negatively affect their ability to

participate in and respond to therapy. These emotions include one's self-perceived state-of-being and mood which influence and shape one's behavior. The aforementioned negative emotions lead to a decreased desire to participate in therapy sessions and a dysphoric mood. The brain can produce chemicals that cause a negative mood. These chemicals include adrenaline, a hormone associated with increased heart rate, and neuropeptides, a group of neurotransmitters associated with such negative emotions as fear and anger. Positive emotions lead to an increased desire to participate and a euphoric mood. The brain can produce chemicals that cause a positive mood. These chemicals include endorphins, or natural opiate chemicals that lead to muscle relaxation and a sense of well-being. A person's emotional state influences how the brain processes information. If an activity is pleasant, it is easier to perform. If an activity is unpleasant, it is inherently more difficult to perform. Hippotherapy is one form of treatment that has tremendous potential for children with LLD [9].

Macauley et al. examined the effectiveness of hippotherapy versus traditional therapy for children with LLD [9]. Three different questions were addressed, "1) Will children with LLD and their parents report improvement in speech and language abilities following hippotherapy? 2) Will the children and their parents report improvement in the children's motivation to attend speech-language therapy following hippotherapy? 3) Will the children and their parents report improvement in the children's self-concept following hippotherapy?" [8]. A total of twelve questionnaires were sent to three children with LLD and their parents, six after the completion of traditional clinic-based therapy, and the same six after the completion of the hippotherapy. Each child and each set of parents completed the 21-item questionnaire. The responses from the two surveys were then

compared. Each questionnaire was divided into the three previously mentioned research questions. The first research question contained 10 items. The second research question contained 6 items. The third research question contained 4 items. Responses in the range of 1 to 3 were considered negative (a regression of skills), responses in the range of 4 to 6 were considered no improvement (maintenance of previously learned skills), and responses in the range of 7 to 10 were considered positive improvement (active learning and retention of new skills) [9].

For the first research question answered after the hippotherapy session, the overall average for the five parent questions in the surveys was 9.2, indicating that the parents strongly agreed that hippotherapy was effective in improving their children's speech and language abilities. The overall average for the children's responses was 8.0, indicating that the participants thought hippotherapy was effective in helping them improve their speech and language skills. For the second research question answered after the hippotherapy session, the parent's overall average was 9.9 and the participant's average was 9.5, indicating that both groups strongly agreed that the children were very motivated to attend the hippotherapy sessions. For the third research question answered after the hippotherapy session, both the parent's and participant's overall average was 8.5, indicating that both the parents and the participants agreed that hippotherapy improved the children's self-concept [9].

Finally, the differences in the 21-item questionnaires were compared for each child and set of parents across the post-traditional therapy and post-hippotherapy surveys. The results were then averaged. The authors used a scale as follows, "a difference less than 2 points was considered negligible, a difference between 2 and 4 points was

considered important, and a difference greater than 4 points was considered noteworthy" (Macauley, 2004). The scale was created specifically for this experiment. The parents' differences averaged 3.3, indicating to the researchers that hippotherapy was more effective than clinical therapy. The childrens' differences averaged 1.9, indicating to the researchers that the children believed that hippotherapy and clinical therapy were equally effective. The authors acknowledged the small number of participants and concluded that the study showed that hippotherapy was effective with a small sample size. This small sample size, along with the lack of statistical analysis in the difference in results, proved to be limitations of the study [9].

Grieving Children

Glazer et al. investigated the effects of hippotherapy on grieving children. Five subjects, all under the age of 14, participated in a six week hippotherapy program [10]. An increase in confidence building was observed, which included overcoming any fear of the horse and the development of a sense of independence. Children moved from hesitation to looking forward to coming to the sessions. Through the performance of tasks, such as learning the skills related to caring for a horse and learning the skills related to riding, the relationship with the horse was established. The trust and confidence levels in the children were related to self-esteem and self-confidence. Trust included a child's trust of self that he or she could learn the riding skills and trust that the horse would respond. One parent linked the openness of the children with the horses to a positive change in the parent-child relationship. Overall, the children gained in confidence, trust, and communication skills as measured by testimonials given by the children, parents, and volunteers at the riding center. The children were asked what they

learned and how their newly acquired skills could help them in life. The parents were asked how the riding program impacted their child and how the child acted during the sessions. The volunteer accompanying the child throughout the program was also asked to reflect on the childs' actions during the therapy sessions. The children's level of communication with others as well as with the horses increased, and there was evidence of transfer from the behaviors learned with the horses to behaviors practiced at home. The parents all saw the intervention as a positive experience and not only noted increases in communication but also increases in self-confidence and self-esteem [10].

Drawbacks

Because hippotherapy is used to treat patients with some type of neuromuscular dysfunction, an injury sustained during the therapy session is a real possibility. In a study completed by Sayli et al. hippotherapy was administered to spastic diplegics and hemiplegics with osteoporotic bones [17]. Each subject underwent lower extremity spasticity surgery prior to the rehabilitation. One patient suffered a non-displaced femoral neck fracture during hippotherapy, which healed without any intervention. Another patient had a supracondylar femoral fracture after a fall during the therapy, which was plated and healed without a problem [17]. These accidents suggest that hippotherapy is not an ideal rehabilitation method for patients with osteoporotic bones because falls and other injuries can occur, especially if the caregiver or physical trainer is not cognizant of the patient at all times.

Another drawback to hippotherapy is that many researchers have a limited number of candidates for a hippotherapy-related study, as several exclusion factors have to be considered: uncontrolled seizures, recent surgical procedures, animal allergies, and

musculoskeletal conditions that could be exacerbated by hippotherapy, such as atlantoaxial instability and severe hip subluxation [6].

Finally, there has also been little objective research offered to document the widespread clinical impression of benefit reported by therapists, parents, and pediatricians, particularly for children with CP [14]. One methodological dilemma is that each child presents with unique impairments and functional limitations, creating difficulties in gathering a homogeneous sample of the population being tested [16]. Another dilemma is the fact that a scientific study involving hippotherapy can create a potentially multifactorial experiment, making specific cause and effect relations difficult to discern [8].

Conclusion

Hippotherapy is one example of a treatment strategy used by physical and occupational therapists to improve the gross motor function (specifically walking, running, and jumping), energy expenditure, postural control, muscle asymmetry, spasticity, and balance and coordination in individuals with some neuromotor dysfunction. Hippotherapy also has numerous psychosocial benefits, including increases in the subject's self-confidence and self-esteem, as well as improvements in speech and language [16].

While the majority of the case studies concerning hippotherapy have been clinical in nature, there is scant research to date on objectively quantifying the mechanical effects of hippotherapy. The case studies present a solid baseline for whether hippotherapy is a valid treatment option and what symptoms the therapy treats. Comparing and quantifying the human pelvis kinematics during normal walking and while sitting astride

a walking horse will provide validity to previous case studies that presented patient improvement after hippotherapy sessions.

CHAPTER THREE

Background: Human Pelvic Kinematics During Gait

The purpose of this chapter is to introduce the role of the pelvis during normal human walking and explain why the pelvis is important in bipedal locomotion. The position of the pelvis is important in that it affects the alignment of the spine, head, and limbs [1]. The movement of the pelvis is involved with many activities such as walking. An understanding of how the human pelvis moves during normal gait can assist in the evaluation of human pelvis kinematics during riding.

Lamoreux stated that the process of normal walking demands an elaborate collaboration between the central nervous system (CNS) and the musculoskeletal system [22]. In order for the human body to implement such a smooth and relatively effortless motion, the body acts as a complex control system, with the CNS receiving and interpreting feedback signals from numerous sensory organs and simultaneously controlling and directing the activity of more than 200 muscles and 100 bones in the lower extremity and trunk [22]. It is the lower extremities, or legs, that effectively execute the main propulsive movements in human locomotion. The trunk interacts with limb movements and maintains body equilibrium [23].

History

Since the 1970s, most studies that have been conducted to determine pelvic kinematics during gait have used video cameras to capture the motion of the pelvis [24,25]. Before this period of time, many studies used different methods of data

collection to capture the kinematics of human gait. For example, in the pioneering work of Braune and Fischer [26] at the turn of the 20th century, the researchers required the subject to wear an experimental suit that included Geissler tubes attached to it. A camera that captured continuous exposures in the dark was used to track the motion of the subject. A tuning fork, "was used to make and break the electrical circuit thus ensuring accurate timing of the flashes of light" [26]. The suit also included thick rubber strapping to provide electrical insulation. The study was so elaborate and detailed that other researchers recognized the importance of the study and its results were widely used for the next 50 years [22].

Nearly 70 years later, Lamoreux studied the kinematics of human walking [22]. In his research, several methods were used depending on the body segment that was being measured during gait. For the pelvis, a "string-type pelvic motion transducer used on a treadmill" was used to measure linear and angular displacements. Parallel strings were attached to the subject to allow for the measurement of displacements and rotations, which were determined by two potentiometers. Each device could measure one displacement and one rotation, so three devices were used simultaneously to measure the displacements and rotations in all three planes [22].

There have been many previous studies that explored different permutations regarding pelvic motion during gait. One study investigated the pelvic kinematics of individuals who were of a different age and gender [27]. Another study focused on individuals who performed their gait at different cadences [28]. Finally, one study compared healthy individuals to those who experienced some neuromusculoskeletal dysfunction [29].

Gait Analysis of Human Walking

Gage et al. stated that when one performs a gait analysis, one evaluates a specific person's walking pattern [29]. Alternatively, one can systematically measure, describe and assess characteristics of human locomotion. One gait cycle can be defined as motion of the body from heel-strike on one limb to the next subsequent heel-strike of the same limb. Stance phase, or the beginning of the gait cycle, is initiated with the first contact of the heel (see figures 1 and 2). This phase is 60 percent of the cycle and consists of the loading response, in which plantar flexion occurs at the ankle so that the entire foot makes contact with the ground; mid-stance, in which the center of gravity of the body passes over the stable foot with dorsiflexion occurring at the ankle; and terminal stance, in which the heel looses contact with the ground, the foot plantar is flexed, and toe-off

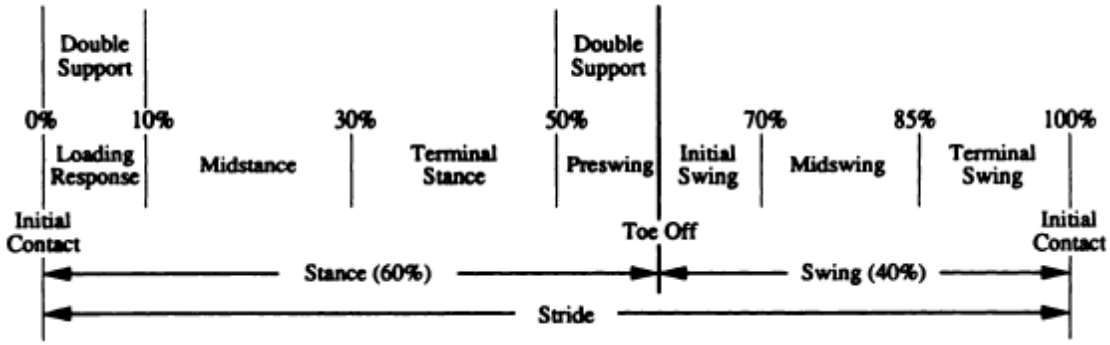


Figure 1: Components of the gait cycle [29]

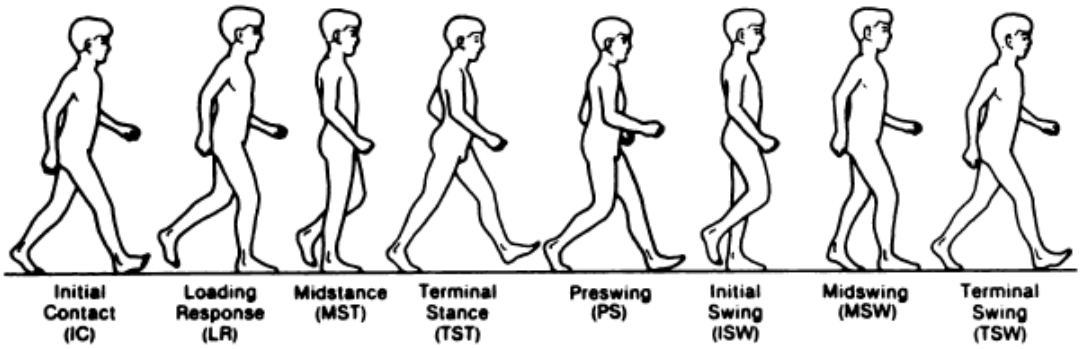


Figure 2: The movement of a subject through the gait cycle [29]

occurs. The last 40 percent of the gait cycle, the swing phase, is comprised of: the initial swing, in which specific muscles control cadence and separation between the foot and the ground; mid-swing, in which the center of gravity of the body shifts back over the contralateral foot; and terminal swing, which prepares the foot for contact with the ground before the next heel-strike. The cycle then begins again. Other characteristics of the gait cycle include the fact that heel-strike and contralateral toe-off are the instantaneous moments in the gait cycle. Furthermore, there are two periods of double support, or two periods in which both feet are in contact with the ground at the same time in the cycle. Each period is about 10 percent of the gait cycle [29].

Kinematics

The analysis of human movement can provide much detail regarding joint and segment kinematics through the use of video motion capture or through the use of other instruments, such as accelerometers or goniometers [30]. Lamoreux goes further to state that "any comprehensive description or analysis of locomotion must…implicitly [be] concerned with kinematics" [22]. Kinematics, a subdivision of mechanics, allows one to describe how an object moves without regard to the forces that caused the movement. These movements can include linear and angular displacements [29]. This branch of science is a fundamental area in the study of human locomotion since it is known that the human body is a complex mechanical structure capable of producing truly extraordinary movements.

Pelvic Kinematics During Gait

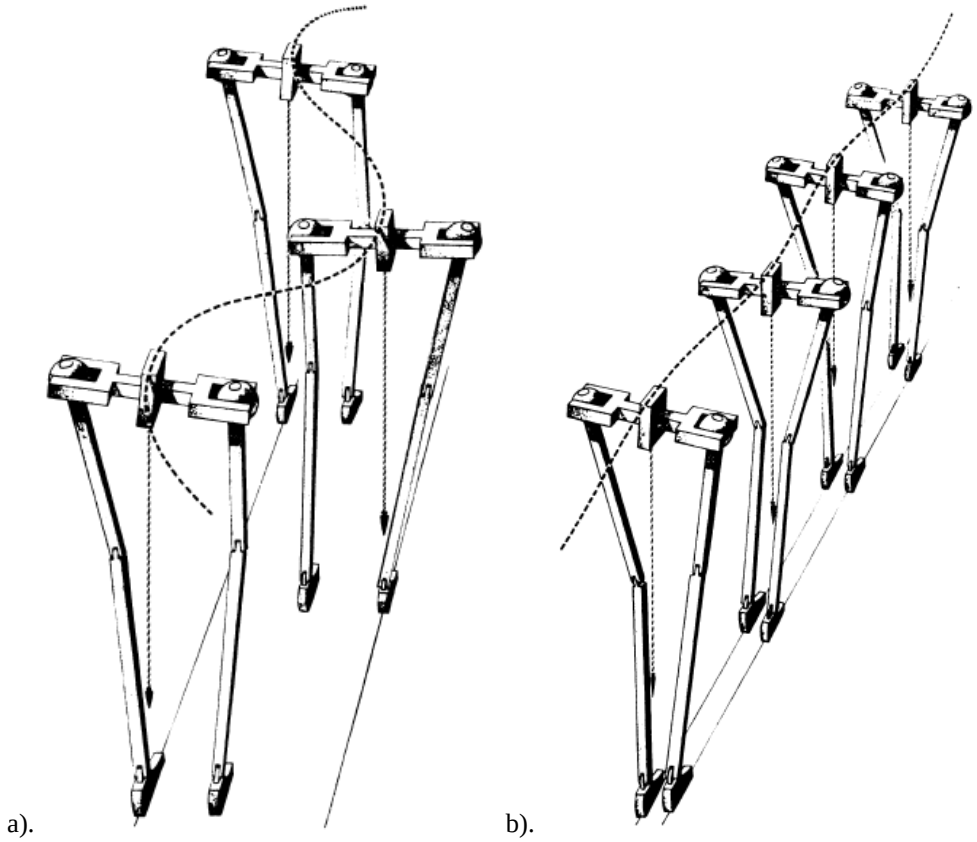
Since the pioneering work of Saunders et al., the pelvis has been recognized as a major contributor in the process of human locomotion [2]. The pelvis translates and rotates in all three planes throughout the gait cycle. One of the more comprehensive studies on linear displacements of the pelvis during gait was completed by Lamoreux [22]. Rotations of the pelvis in all three planes have been studied by numerous authors, starting with Saunders et al. and continuing to this day, with over 50 years of research.

Linear Displacements

Linear displacements of the pelvis in all three planes are one of many measurements that are of interest in the analysis of pathological gait and the design of prosthetic and orthotic devices that fit the lower-extremity [22]. Zhao et al. stated that the pelvis displaces in both the anterior and posterior direction with each step during ambulation [31]. When the body weight is transferred from one limb to the other, the pelvis moves in the upward vertical direction and experiences cyclic movements in both the medial and lateral directions [31].

Saunders et al. listed the major determinants of human gait, the sixth of which is side-to-side, or lateral, displacement of the pelvis relative to the ground [2]. This determinant is related to the center of gravity (COG) of the body and subsequently the vertical displacement of the pelvis. The COG of the human body shifts over the weight-bearing extremity twice during the gait cycle [29]. Saunders et al. stated that the COG not only shifts but is displaced laterally over the weight-bearing extremity twice [2]. Either a horizontal shift (with respect to the ground) of the pelvis or relative adduction at the hip causes this displacement. If, for example, the lower extremities were parallel to

each other, this lateral displacement would be equal to half the interval between the hip joint axes, or about three inches (see figure 3a). But, the existence of the tibiofemoral angle corrects any superfluous displacement and, with the influence of relative adduction at the hip, a reduction in lateral displacement of nearly two inches occurs, so that it approximates the vertical displacement of the hip (see figure 3b).



a). b).

Figure 3a): Parallel lower extremities; 3b): The lower extremities with the existence of the tibiofemoral angle and with the influence of relative adduction at the hip [2]

Therefore, the COG is centered in both of the vertical and horizontal planes. The deviations of the COG, "contribute to the establishment in the plane of progression of the spiral of approximately equal axes and add smoothness to the gait, since all sharp inflexions are obliterated and are replaced by a sinusoidal curve" [22].

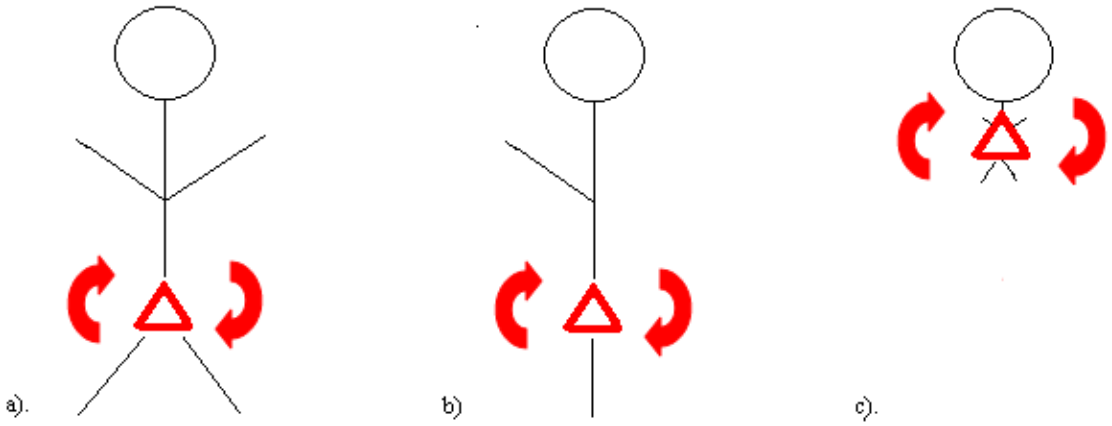


Figure 4: Rotation of the pelvis in the a) coronal plane - list (front view); b) sagittal plane - tilt (side view); c) transverse plane - twist (top view)

Rotations in the Coronal Plane

A rotation of the pelvis in the coronal plane, or about the anterior-posterior (horizontal, forward-pointing) axis, is termed pelvic list [32]. When the patient is viewed from the front, a negative pelvic list results in a clockwise rotation of the pelvis (see figure 4a).

The pelvis lists inferiorly toward the weight-bearing limb during gait. The angular displacement during gait of the pelvis in the coronal plane averages five degrees ($\pm$ 5°). In order for pelvic list to occur, the knee joint on the limb opposite to that of the weight-bearing-limb flexes, which allows clearance for the unloaded limb to swing through. Rotation transpires at the hip joint, "producing an equivalent relative adduction of the extremity in the stance phase and relative abduction of the extremity in the swing phase of the cycle" [2].

Watanabe et al. studied three-dimensional trunk and leg movements during walking using an electromagnetic tracking instrument and measured rotations of the pelvis in all three planes [33]. When analyzing rotations (see figure 5a) in the coronal

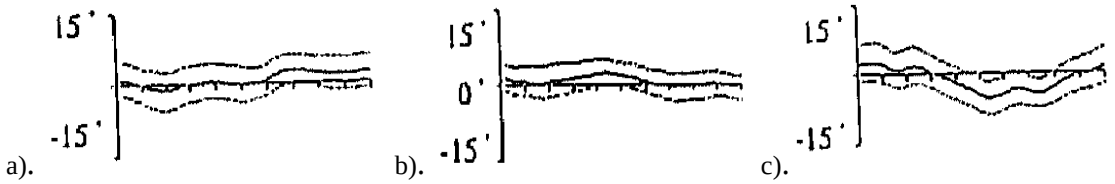


Figure 5: Measured rotation of the pelvis in the a) coronal plane; b) sagittal plane; c) transverse plane as given by Watanabe (mean ± s.d.)[33]

plane, the authors observed that maximum pelvic list (moving inferiorly and to the right) coincided with contralateral toe-off of the right limb with the pattern or curve of the graph inversely repeating itself [33].

Gage et al. described how the pelvis rises and falls during the gait cycle [29]. The authors mentioned that in healthy subjects, the pelvis rose about four degrees in the coronal plane during the loading response and the pelvis dropped during later stance in single-limb support during normal walking. The pelvis rose due to the eccentric contraction of the abductors at the hip [29].

Thurston et al. used a television and computer motion analysis system to capture the kinematics of the lumbar spine and pelvis during walking [34]. One of the measures included rotations in the coronal plane of the pelvis. The researchers observed that the graph representative of this rotation (see figure 6a) included a major minimum and a major maximum, each of which was followed by a minor wave. The amplitudes of both the major and minor waves varied, however, from subject to subject. The authors noticed from the graphs that the pelvis dropped on the swing phase side during normal gait thus leading to deflections in the wave pattern that coincide with toe off on each limb [34].

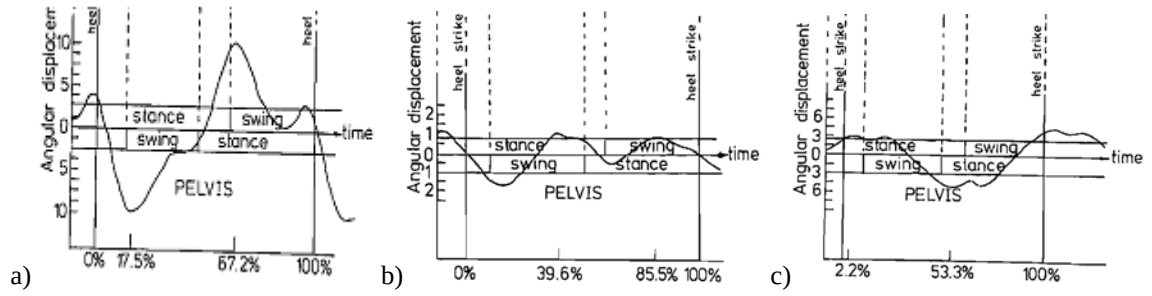


Figure 6: Rotations of the pelvis in the a) coronal plane; b) sagittal plane; c) transverse plane as given by Thurston [34]

Rotations in the Sagittal Plane

A rotation of the pelvis in the sagittal plane, or about the transverse axis, is termed pelvic tilt [32]. When viewed from the left side of the patient, a negative pelvic tilt results in a clockwise rotation of the pelvis (see figure 4b). Watanabe et al. observed that pelvic rotations in the sagittal plane (see figure 5b) revealed two smooth oscillations in one gait cycle [33]. The researchers added that, "The pelvis is most extended or horizontal at toe off and opposite toe off with maximum flexion in mid to late stance and terminal swing" [33].

Thurston et al. observed that the graph representative of the rotation in the sagittal plane (see figure 6b) also included two maximums and two minimums [34]. Little variation was present, however, in the shape and amplitude of the two maximums, as well as the two minimums. Each peak marked the point of maximum forward tilt of the pelvis, which occurred at the mid-swing phase of gait. Conversely, the valleys marked the point of maximum backward tilt, occurring at toe-off. In summation, the maximum tilt (anterior and posterior movement) of the pelvis occurred at contralateral toe-off on each limb. This, in turn, corresponded in an acceleration with the swing phase leg [34].

Rotations in the Transverse Plane

A rotation of the pelvis in the transverse plane, or about the superior-inferior (vertical) axis, is termed pelvic axial rotation [32] or pelvic twist. When the patient is viewed from above, a negative pelvic twist results in a clockwise rotation of the pelvis (see figure 4c). Another one of the major determinants of pathological gait as stated by Saunders et al. included the axial rotation of the pelvis. The magnitude of this rotation varied some eight degrees, or four degrees on either side of the line of progression. As the pelvis moves, rotation occurred alternately at each hip joint, internally then externally rotating during the stance phase of gait [2].

Watanabe et al. discovered that the graph of the pelvis rotating in the transverse plane (see figure 5c) exhibited one oscillation during one complete gait cycle [33]. As soon as left foot strike occurred in normal walking, the pelvis began to rotate in the right, forward direction, and peaked when the right foot struck the ground [33]. Another study found that the pelvis internally rotated in the transverse plane during early stance [29].

Thurston et al. noted that the graph representative of this rotation (see figure 6c) included one wave, including one maximum that coincided with heel strike and one minimum that corresponded with the instant just before contralateral toe-off [34]. Each maximum and minimum appeared dichotic in form due to a notch present at each feature. This notch marked the point of toe off on each limb. The researchers concluded that maximum pelvic axial rotation occurred at heel strike on each limb [34].

Conclusion

The normal gait cycle is measured from heel strike on one side to the next heel strike on the same side. For each limb, there is a stance phase and a swing phase in each

gait cycle [34]. One leg provides support while the other leg swings forward and prepares for its support role, which occurs in the next phase of gait [22]. Between heel strike on one side and toe off on the other side is the phase of double support [34]. At this point, there is a transfer of support from the trailing leg to the leading leg [22]. Human locomotion can provide much detail regarding kinematics, including pelvic kinematics. Without regarding forces, the movements of the pelvis can be studied. These movements include the translations and rotations of the pelvis in all three planes throughout the gait cycle. Measurements of the rotation of the pelvis can be found in literature and are included in studies published recently [25,28]. Measurements of translations of the pelvis and lower trunk are not as common but are found in older literature dating back several decades [22,23]. These studies are discussed in greater depth in chapter six. Lateral pelvic displacement data appears to be most pertinent to researchers studying pelvic displacement of walking adults and when mounted on a walking horse [3]. This is most likely because lateral displacement of the pelvis is one of the major determinants of pathological gait [2].

The study of gait analysis and, specifically the role of the pelvis during gait, helps one better understand the mechanics of normal human walking. Since the aim of this research was to evaluate the theory that movement patterns of the human pelvis during walking are similar to those during riding, the study of the pelvis and its role in gait analysis can be applied to the study of human pelvis kinematics of individuals sitting astride a walking horse.

CHAPTER FOUR

Methods and Materials

Six healthy children participated in a series of walking and riding trials at Camp Hope. Data from these trials was collected using an external marker system and video motion capture. The data was processed and a statistical analysis was performed on the results.

Human Subjects

A total of six human subjects (three males and three females) aged between eight and twelve years (see table 1) were tested. The subjects were tested three at a time, so

TABLE 1 SUBJECT PROFILES

Subject	Age	Gender
A	11	Female
B	11	Female
C	8	Male
D	10	Male
E	12	Male
F	10	Female

two different experiments (or sessions) took place, each on a different day. The protocols for each session only differed in human subject profile. In the first session, the subjects were all female, age ten to eleven years. In the second session, three males volunteered (ages eight to twelve), who were all siblings. All subjects included were healthy, experiencing no recent pain in the hip, back, or leg. None of the subjects reported any neurological or musculoskeletal illness, and none were using any prescribed medication at the time of the study. All subjects were required to be inexperienced riders since

actual patients in typical hippotherapy sessions suffer from some type of motor dysfunction and are thus inexperienced at riding. The experimental protocol was approved by the Baylor University Institutional Review Board (IRB). Informed consent was given by the parents of all of the subjects.

Horses

Three different horses were used in the study. All three horses assist with hippotherapy sessions at the REACH Therapeutic Riding Center (NAHRA certified) at Camp Hope in McGregor, TX.. The three horses (Bonnie, Bailey, and Dolly) each exhibited unique gait characteristics. Of the three horses used for the study, Bonnie possessed the smoothest gait. She is typically used for riders who exhibit poor postural control (i.e., floppy). She has very symmetrical and rhythmic movements that provide symmetrical postural responses in the rider. She also has an equal magnitude of movement produced in all three planes of motion, producing equal tilt, rotation, and anterior-posterior movement (flexion-extension) in the rider. She can also maintain her quality of smoothness regardless of speed.

Bailey is a very small horse and is also very smooth throughout her gait. She walks faster and has smaller vertical movements when she walks, thus is slightly more "choppy" than Dolly. She is best used for patients who have very little control of their upper body.

Dolly is slightly broader and possesses a faster cadence (speed) than Bonnie. Even though the two horses have similar three dimensional movements throughout one period of their gait cycle, the frequency is higher with Dolly. Thus, for a given time, a client will get more stimulation in the therapy session. Since Dolly is a horse that

exhibits larger movements than the other two horses, patients with a higher level of control, particularly in their upper body, are best suited for Dolly.

Data Collection

A video motion-capture system (Simi Motion; Reality Motion Systems, Unterschleissheim, Germany) was used to collect data. Subsequently, a three-dimensional kinematic analysis was performed on this data. Four video cameras (Canon model Optura XI) were used to record images from body markers of subjects walking at a sampling frequency of 60 frames/s and a shutter speed of 1/250 s. Six other video cameras (Canon model ZR950) were used to record images from markers placed on the rider and on the horse during simulated hippotherapy sessions at the same sampling frequency and shutter speed of the previously mentioned cameras. The observation space, or the area that is captured by the cameras, was 2 m long by 2 m high by 1.5 m wide with the x-axis aligned with the direction of forward progression, the y-axis aligned with the vertical axis, and the z-axis aligned perpendicular to the two aforementioned axes. Data was recorded on digital video cassettes (Sony Mini DV, Sony Electronics Inc, San Diego, CA) and uploaded to a computer workstation (Dell Precision™ Workstation 650, Dell Inc, Austin, TX). Processing of the data files utilized in-house and commercial software for data reduction and analysis.

Prior to collecting the data, both sets of cameras were calibrated using a 32-point rigid structure (Sputnik, Peak Performance Technologies, Englewood, CO) that contained eight "arms," expanding out into all three planes. It was necessary for all 32 markers to be visible to each camera. Results indicated average RMS measurement errors for each camera over each session between were 0.08% and 0.23% with a standard deviation

between 0.04% and 0.13%. No marker in any camera in any session contained an error greater than 0.40%. According to the software, any value greater than 1% would affect the accuracy of the results.

Protocol

Subjects were asked to wear skin-tight clothing, either in the form of leotards or swimsuits. This request was made to prevent interference between the clothing and the skin as possible. The location of the markers attached to the clothing would subsequently represent the same location on the body. Adhesive, skin-mounted markers were used in the study. The most widely used method of data collection in biomechanics uses skin-mounted markers [35-37] which are unquestionably safer and easier to use than pin-mounted markers [38].

Each marker emitted white light by way of a diode (LED) on its surface. The markers were designed and fabricated by a senior design team from Baylor University in the spring of 2008. In order to properly view the two markers (right and left) placed posterior to the pelvis, a 16-inch by 0.75-inch by 0.1-inch, custom-designed bar, attached to a 4-inch by 1.5-inch by 0.15-inch centerpiece was fabricated. An elastic belt that could be fit around the subject's pelvis was attached at the centerpiece (see figure 7).

Markers representing the anterior side of the pelvis (right and left) were placed directly on the belt, although in the final analysis these markers could not be used (see chapter six). The subjects wore a helmet during the riding sessions, and markers were placed on the front and back of the head protection. The helmets used in the study were the same helmets used by patients in hippotherapy sessions at Camp Hope. Other locations for markers placed on the subject's body (see figure 8) included the: left

Figure 7: Pelvis bar with elastic belt

acromion, right acromion, upper spine (process of C7), middle spine (process of T6), lower spine (process of L1), right knee (lateral side of the patella), left knee (lateral side of the patella), right ankle (lateral side of the joint), and left ankle (lateral side of the joint). A total of 15 markers were mounted on each subject. Ten markers were used in the following locations on each horse: left front saddle, right front saddle, left back saddle, right back saddle, left cranial pelvis, right cranial pelvis, left caudal pelvis, right caudal pelvis, left hind hoof, and right hind hoof. All of the markers were attached using double-sided foam tape. To firmly attach the markers on the body of the horse, a layer of duct tape was placed in between the markers and the skin of the horses. For the scope of this thesis, only the markers affixed to the pelvis belt were analyzed.

In order to properly organize the large amount of data collected, terms were defined to classify the data, according to the protocol setup:

Observation space – the area that is captured by the cameras (see figures 9 and 10)
Pass – each time a rider/walker passes into the observation space
Set – A collection of three passes for each rider/horse combination at one gait speed
Session – defined as the entire amount of time that was spent on one visit to Camp Hope. Each session contains four sets (three riding and one walking).

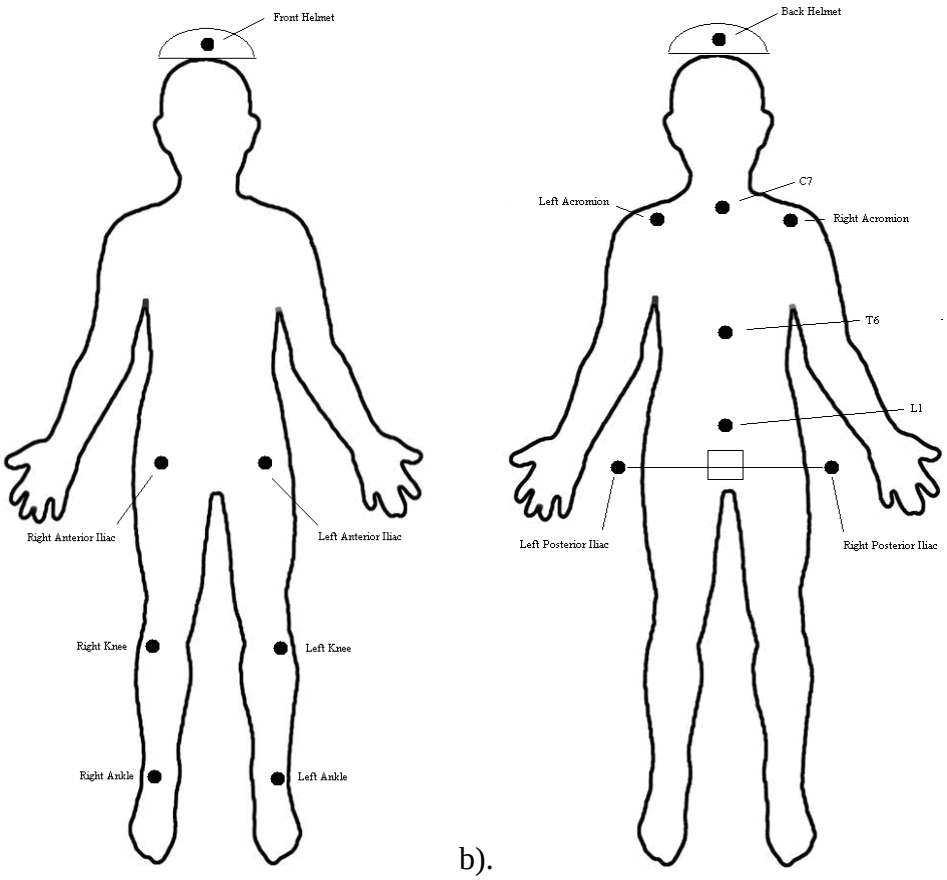


Figure 8a): Anterior view of subject with marker placement; b): Posterior view of subject with marker placement

Before each session began, the staff at Camp Hope smoothed the dirt in the arena to ensure that the horses would be walking on a level surface. Particular attention was paid to the observation space. Other preparations included resting the horses for a number of hours before the sessions began and making sure the equipment (helmets, saddles) was gathered and easily accessible.

To effectively simulate an actual hippotherapy session, subjects were asked to wear a helmet and sit on a therapeutic saddle when they sat astride the horse. Trained horse handlers were asked to lead the horse along a straight path through the observation space. In each session, each of the three subjects rode a total of three horses. Each horse

was led in a slow walking gait speed. The subjects subsequently performed walking trials at a self-selected slow gait speed. Each session contained three riding sets to account for all the permutations between the rider and the horse. The protocol for the rider and horse combinations that was followed for the first riding set during one session at Camp Hope was presented in table 2. The riders then dismounted and switched horses and repeated the process (see table 3). After the next two sets were completed, the riders dismounted again and switched horses one last time (see table 4).

Table 2 PROTOCOL FOR RIDING SET 1 IN SESSION 1

Set	Pass	Subject	Horse	Gait Speed
1	1	A	Dolly	Slow Walk
		B	Bailey	Slow Walk
		C	Bonnie	Slow Walk
	2	A	Dolly	Slow Walk
		B	Bailey	Slow Walk
		C	Bonnie	Slow Walk
	3	A	Dolly	Slow Walk
		B	Bailey	Slow Walk
		C	Bonnie	Slow Walk

Table 3 PROTOCOL FOR RIDING SET 2 IN SESSION 1

Set	Pass	Subject	Horse	Gait Speed
2	1	A	Bonnie	Slow Walk
		B	Dolly	Slow Walk
		C	Bailey	Slow Walk
	2	A	Bonnie	Slow Walk
		B	Dolly	Slow Walk
		C	Bailey	Slow Walk
	3	A	Bonnie	Slow Walk
		B	Dolly	Slow Walk
		C	Bailey	Slow Walk
		C	Bailey	Fast Walk

Table 4 PROTOCOL FOR RIDING SET 3 IN SESSION 1

Set	Trial	Subject	Horse	Gait Speed
3	1	A	Bailey	Slow Walk
		B	Bonnie	Slow Walk
		C	Dolly	Slow Walk
	2	A	Bailey	Slow Walk
		B	Bonnie	Slow Walk
		C	Dolly	Slow Walk
	3	A	Bailey	Slow Walk
		B	Bonnie	Slow Walk
		C	Dolly	Slow Walk

In the walking trials, a similar protocol was followed, as listed in Table 5.

Table 5 PROTOCOL FOR THE WALKING SET IN SESSION 1

Set	Pass	Subject	Gait Speed
1	1	A	Slow Walk
		B	Slow Walk
		C	Slow Walk
	2	A	Slow Walk
		B	Slow Walk
		C	Slow Walk
	3	A	Slow Walk
		B	Slow Walk
		C	Slow Walk

The second session followed the same protocol as the first session, but with three different subjects.

Six cameras were used to capture the motion of the subjects when sitting atop walking horses (see figure 9) and four cameras were used to capture the motion of the normal volunteers when walking normally (see figure 10). All cameras were pointed toward the center of the observation space. For the riding trials, cameras 1 and 4 were used to capture the posterior markers on the subject and the caudal markers on the horse while cameras 3 and 6 were used to capture the anterior markers on the subject and the

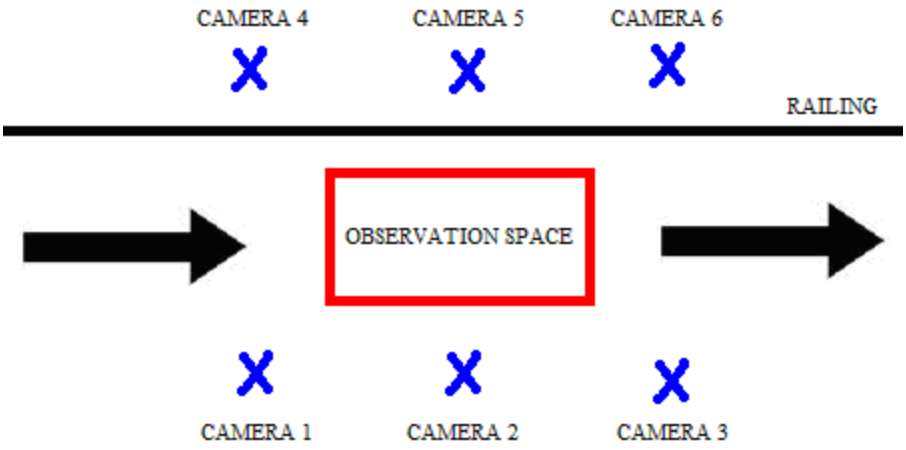


Figure 9: Camera position setup for the riding trials

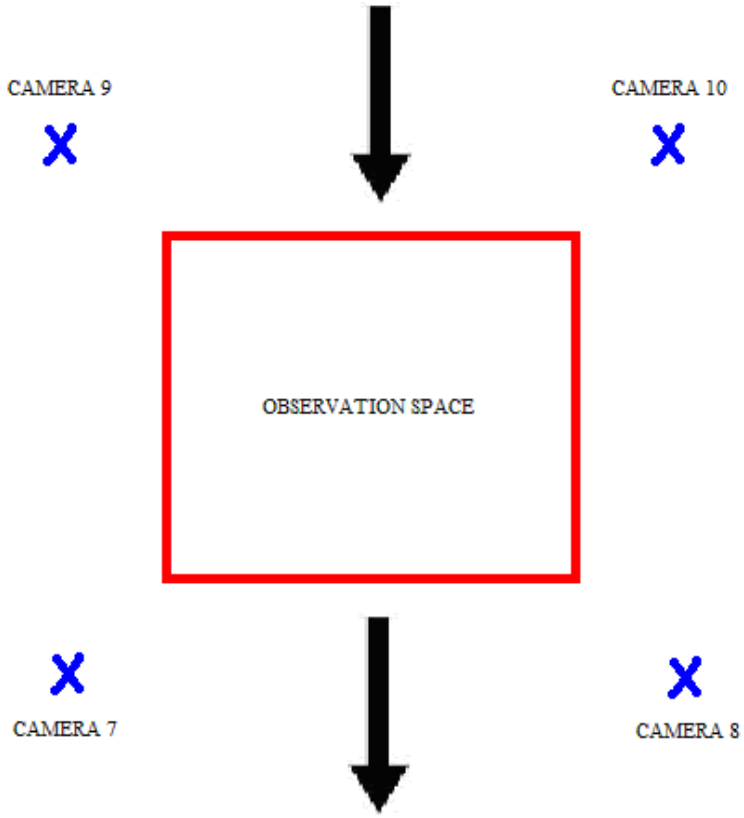


Figure 10: Camera position setup for walking trials

cranial markers on the horse. Cameras 2 and 5 were used mostly for timing, or when it was necessary to start and stop tracking markers in other cameras because the observation space fit perfectly into the entire frame in each camera.

In the walking trials, subjects walked single-file through the observation space in one direction. The subjects then turned around and walked back through the observation space, again single-file. The process was repeated until the sets were completed. Depending on which direction the subjects were walking through the observation space, cameras 7 and 8 viewed the back and front of the subjects. Conversely, cameras 9 and 10 viewed the back of the subject when cameras 7 and 8 captured the front.

Analysis

Data Processing

A coordinate axis was defined as follows: the forward movement of the horse/rider through the observation space represented motion along the positive x-axis, the upward movement represented motion along the positive y-axis, and side-to-side movement represented motion along the z-axis.

After the data was tracked using the SIMI Motion Software, drift was eliminated mathematically. Drift existed because the subjects did not always walk directly along the positive x-axis. To accomplish this, a linear regression equation (a first order polynomial) was fit to the xyz motion trajectory of each marker. The slopes of the line fits were averaged across all markers to define an overall, average linear trajectory of the subject. These slopes represented the overall drift in the data. All of the points were then rotated so that this drift line (the average linear trajectory) was aligned with the x-axis,

thereby effectively rotating the observation coordinate system so that forward subject motion was corrected to align with the x-direction.

The data was further analyzed to identify the gait cycle period for each pass. Because each pass through the observation space contained about one-and-a-half to two full gait cycles, the selection of a single gait cycle was desired, which then could be aligned with other single gait cycles selected for other passes and subjects. To identify a common gait cycle starting point in an objective way, the vertical acceleration of a center pelvis marker was calculated. Any time the vertical acceleration transitioned from positive to negative (passing through zero), that point in time was marked. This occurred near heel strike for both horse and subject. The first of these points occurring near left heel strike (identified by also looking at the z-axis motion) was defined as the starting point of a gait cycle. The next of these points occurring near the subsequent left heel-strike was defined as the end of the gait cycle, and the start of the next gait cycle. So, an entire gait cycle was assumed to span between two adjacent including zero-vertical-acceleration points occurring near left heel strikes.

Next, in order to reduce noise and ensure that the end trajectory of a gait cycle corresponded in space to the beginning of the next gait cycle, the data was smoothed and made periodic. To accomplish this, a 12th-order Fourier series equation was fit to each of the xyz marker trajectories versus time over the period of the gait cycle. Since a Fourier series is by definition periodic, the resulting data was periodic and smooth.

Finally, the forward motion of the data was subtracted out. As previously mentioned, lateral drift was corrected, but the actual motion of the horse/rider moving forward was not. The subtraction of the forward motion was completed by computing

the overall drift line (a linear line fit to all points). The average forward motion (x-displacement) was then subtracted out so that the periodic cycle of the point motions in three-dimensions "looped" back on itself, as if the subjects were walking on a treadmill.

Graphs

From the data supplied by the two back pelvis markers on each subject, the following kinematic measurements of the pelvis were made: x-translations, y-translations, z-translations, pelvic list, and pelvic twist. All of these measures were given in graphical form (see figures 13,15,17,19,21). Each graph represented one-and-a-half gait cycles, with the last half-cycle of data being duplicated from the first (for clear visualization). The vertical line at 1.0 was shown to indicate where the first complete gait cycle ends and the next half gait cycle begins.

The translations represented the translation of a center pelvis point. This point was found by averaging the data (at each instant in time) representing the right and left pelvis markers. Pelvic list and twist represented the rotations of the pelvis, calculated as the angle produced by the line connecting the right and left pelvis markers (at each instant). List was calculated relative to the horizontal plane, and twist relative to the frontal plane. For example, consider the angle produced by pelvis list. Each marker on the back pelvis allowed for data to be produced in the form of x, y, z trajectories. The difference was calculated in the data representing the z trajectories between the two back pelvis markers first. Then, the difference was calculated in the data representing the y trajectories between the same two markers. The inverse tangent was then found of the quotient of the two differences stated above. The translations of the pelvis were also plotted against each other and were plotted in the results (see figures 23-25).

Statistics

The averages of all five measures for each subject on each horse were first calculated. These averages are presented in appendix A (e.g. figure A.1). The maximum and minimum values were calculated for each of these sets of data to find a range. The mean and standard deviation for these ranges were then calculated according to each horse and to the walking data. So, for each measure (e.g. the x-translations of the pelvis), there were four averages and four corresponding standard deviations calculated. That is, these values were calculated for all of the subjects on Bailey, all of the subjects on Bonnie, and so on.

Then, for each measure, a one-way Analysis of Variance (ANOVA) was calculated using the means and standard deviations of the ranges. The null hypothesis was that there was no difference between the means. The alternative hypothesis was that there would be differences between the means. The significance level was set at $P=0.05$. If the null hypothesis was rejected, a Tukey-Kramer multiple comparisons test was performed to identify which groups were significantly different from each other.

CHAPTER FIVE

Results

The primary focus of the current research was on the pelvis due to its importance in human gait. Although markers were placed in multiple locations on the subjects and on the horses, only the data from the back pelvis markers (left and right) were analyzed. The data from the anterior pelvis markers could not be processed. Both markers were consistently obstructed from the view of the cameras by either the horse's head or the subjects themselves (e.g., swinging arms). The scope of the study was to compare and quantify the pelvic kinematics of able-bodied children during walking to that during riding.

During data analysis, female pelvic kinematics while riding were compared to those of male. It was determined that there was very little difference between the curves. Consequently, the curves representing the riding data were averaged across all subjects. The same comparison was made between genders for the walking data. Again, there were very few notable differences. The curve representing the walking data in each graph was therefore averaged across all subjects.

Six subjects and three horses were included in this study: five subjects (A, B, C, D, and E) rode Bailey, three subjects (C, D, and E) rode Bonnie (only present in session 2), and five subjects (B, C, D, E, and F) rode Dolly. Not all subjects rode Bailey and Dolly due to errors in data collection (see chapter six). Only the second two sets from the first session but all three sets from the third session were analyzed in this study (see protocol, chapter four).

The riding data in each graph represented the average pelvis data of all the subjects when they sat astride the particular horse. The walking data represented the average pelvis data of all the subjects when they performed the walking trials. These curves were calculated in several steps. For this example, consider the subject pelvis y-translation data. First, the data for all three passes (slow walk) for one particular subject atop Bailey were plotted against each other (see figure 11). The average of these curves was plotted in the same graph (see also figure 11). This process was repeated for all the subjects who rode Bailey. Then, the average curves for each subject were plotted against each other (see figure 12). The average of these curves was also plotted in figure 12. It was this curve (the average of the averages) that was plotted as "Bailey" in figure 13. Figures 11 and 12 are sample graphs plotted in this chapter. Similar figures for other horses and subjects can be observed in the appendix.

Pelvis Y-Translations vs. Gait Cycle

The data resulting from the translation of the subject's pelvis along the y-axis (vertical axis) was plotted in figure 13. The curves found in this graph appeared synchronized. The explanation for this synchronization, as stated in chapter four, was due to the definition of the beginning and the ending of the gait cycle based on the y-acceleration data. In this plot, similar shapes and magnitudes between the curves in the graph above were observed. The timing of the maximums among the riding curves and the walking curve was also similar.

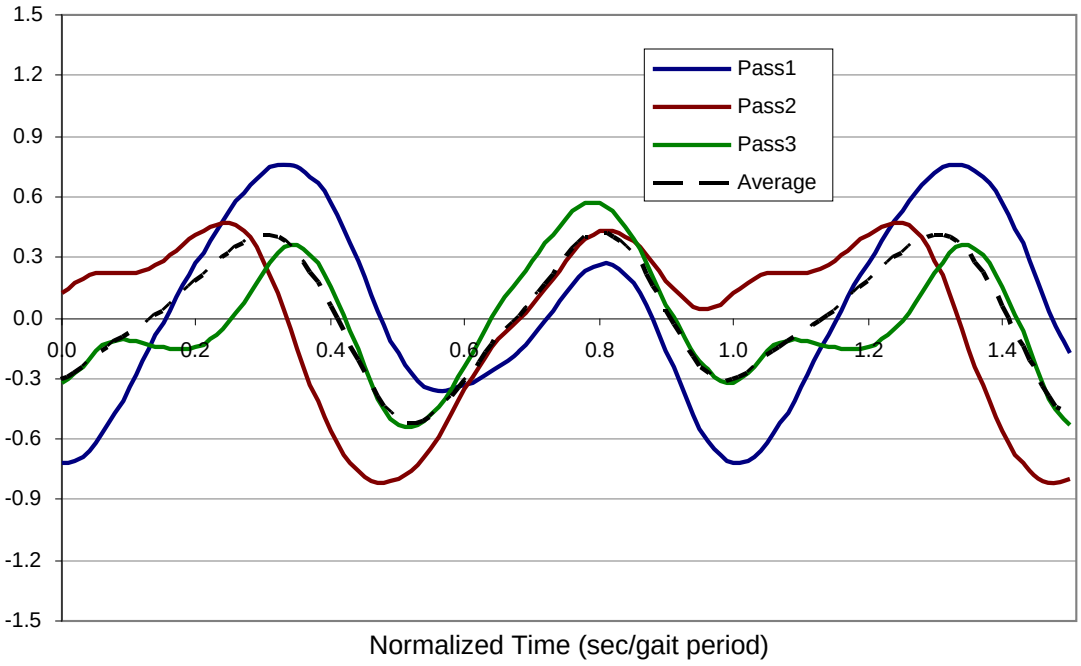


Figure 11: Pelvis y-translations for subject A on Bailey

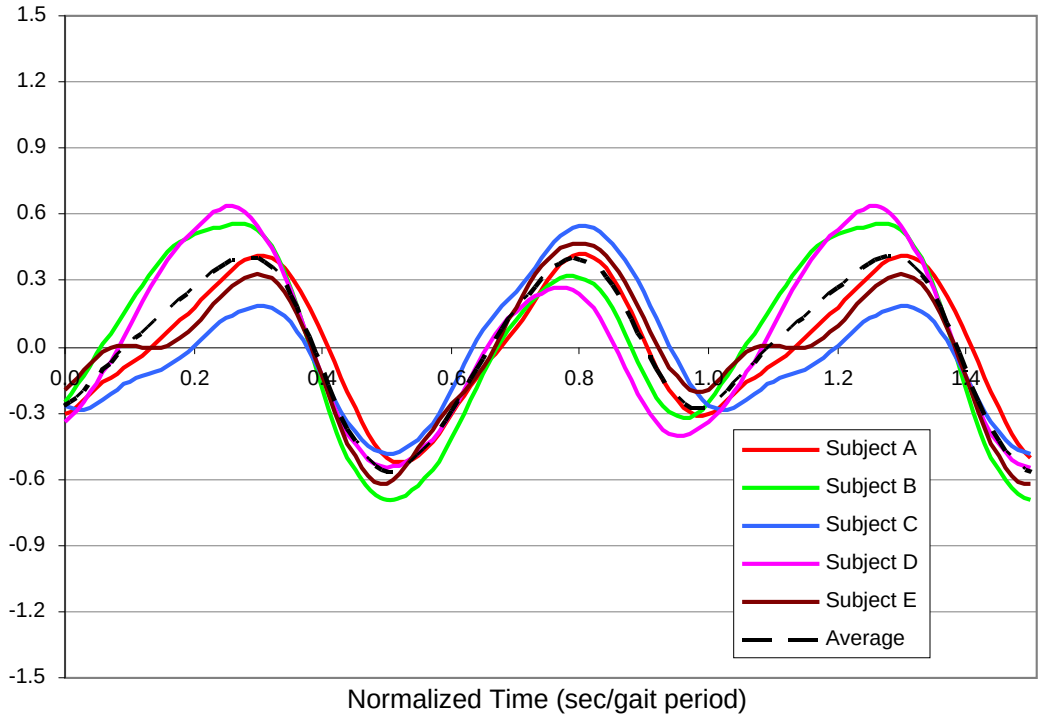


Figure 12: Pelvis y-translations for all subjects on Bailey

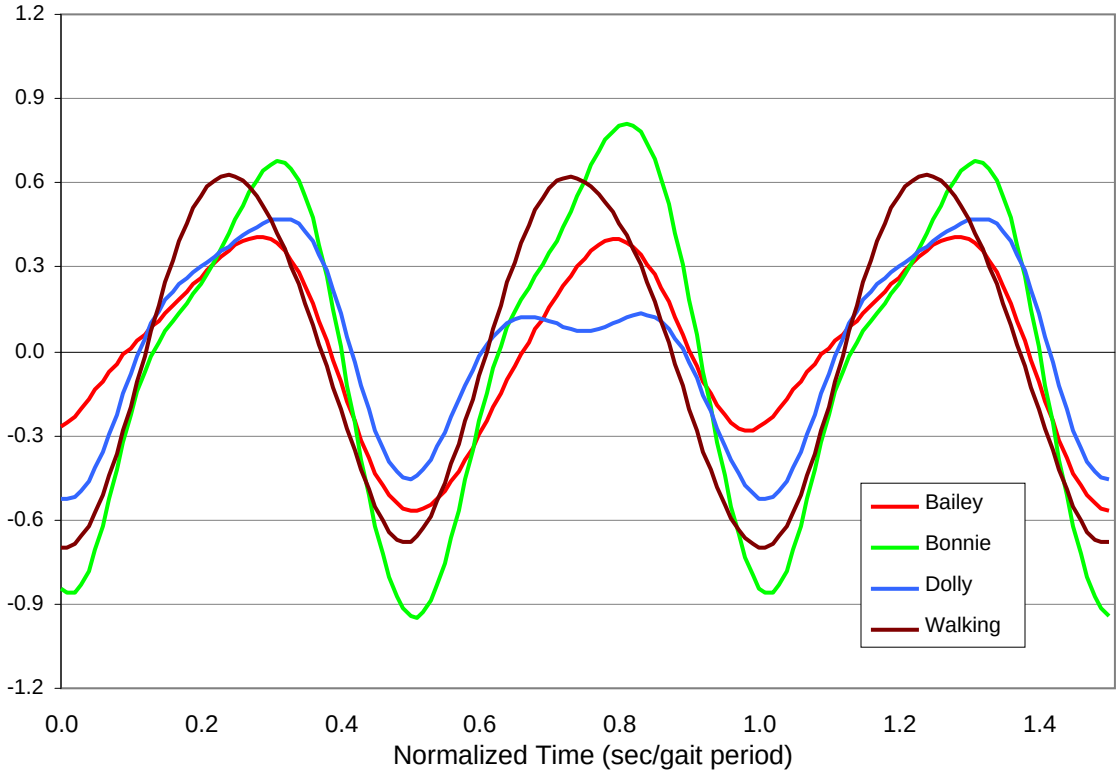


Figure 13: Y-translations of the pelvis

Statistics

The total ranges in the pelvis y-translation data for all subjects (mean $\pm$ s.d.) walking and riding Bailey, Bonnie, and Dolly were observed in figure 14. The ANOVA for the ranges just mentioned was given in the appendix, table E.1. Since P=0.01, the null hypothesis was rejected, and it can be inferred that there was a significant difference between at least two groups in figure 14. A more than two groups Tukey-Kramer multiple comparisons test was performed to test for significance among the groups in the same figure. It was observed that there was a significant difference in the subject's y-translation pelvis data among those who rode Bailey and Bonnie (labeled 'a' in figure

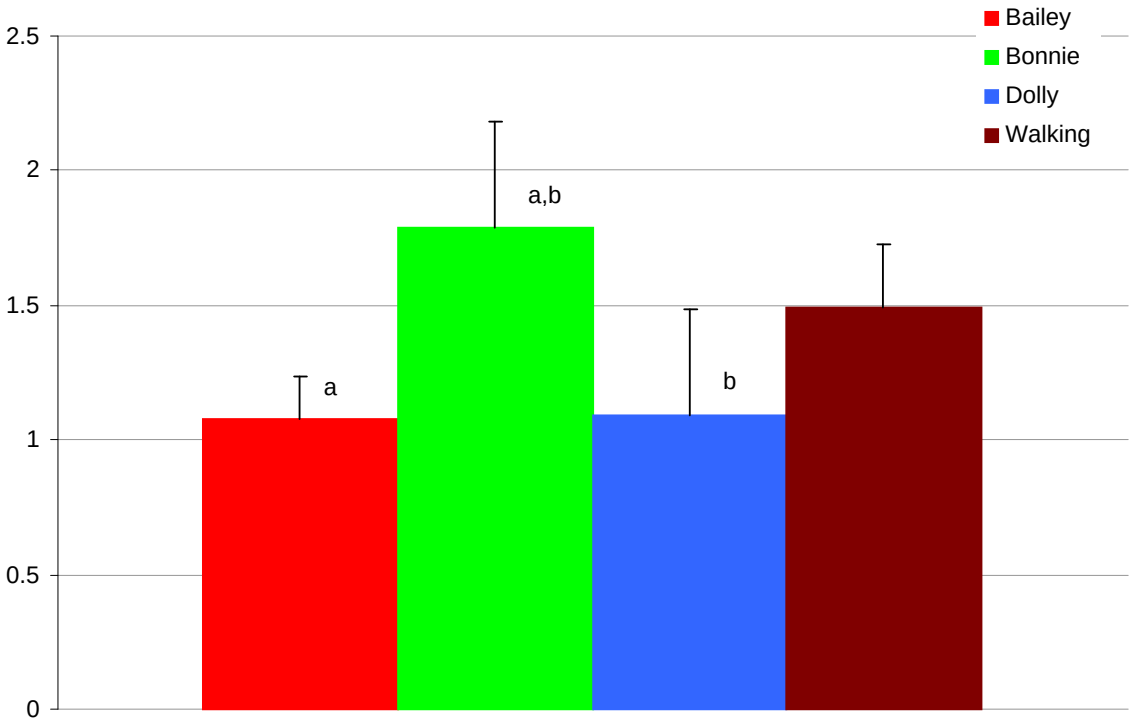


Figure 14: Multiple comparisons of the y-translation ranges (mean ± s.d.). A: P=0.08, B: P=0.07

14). There was also a significant difference among those who rode Bonnie and those who rode Dolly (labeled 'b' in figure 14). There was no evident trend in the data that was observed from figure 14. The range values for the walking data appeared to lay within the range values of the riding data.

Pelvis X-Translations vs. Gait Cycle

The data resulting from the translation of the subject's pelvis along the x-axis (forward axis) was plotted in figure 15. There was a noticeable timing issue between the walking and riding curves. The riding curves appeared to be synchronized while the walking data was out of phase with the riding data. This was thought to be due to the differences in the period of the gait cycles. Nevertheless, the walking data had a similar

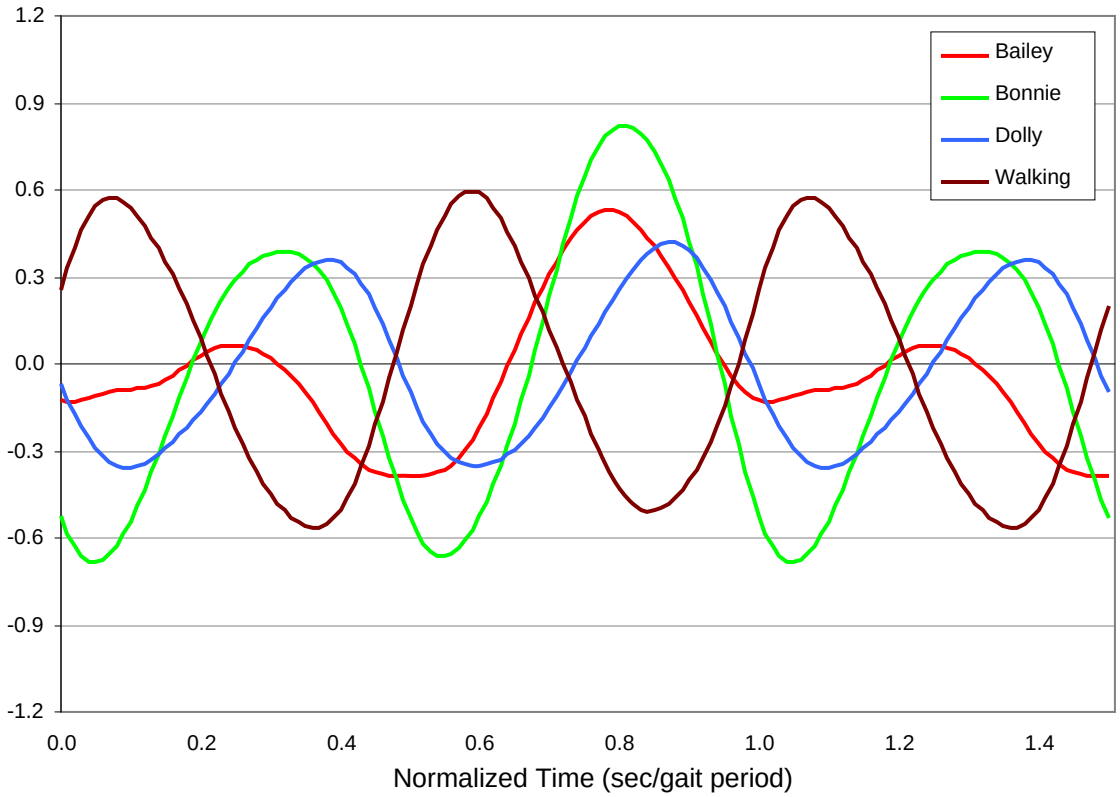


Figure 15: X-Translations of the Pelvis

shape and magnitude compared to the riding data. The timing of the maximums among the horse curves was similar.

Statistics

The total ranges in the pelvis x-translation data for all subjects (mean $\pm$ s.d.) walking and riding Bailey, Bonnie, and Dolly were observed in figure 16. The ANOVA for the ranges just mentioned was given in the appendix, table E.3. Since P was only slightly greater than 0.05 (P=0.051), the null hypothesis was rejected, and it was inferred that there was a borderline significant difference among at least two of the groups in figure 16. A more than two groups Tukey-Kramer multiple comparisons test was performed to test for significance among the groups in the same figure. There were no

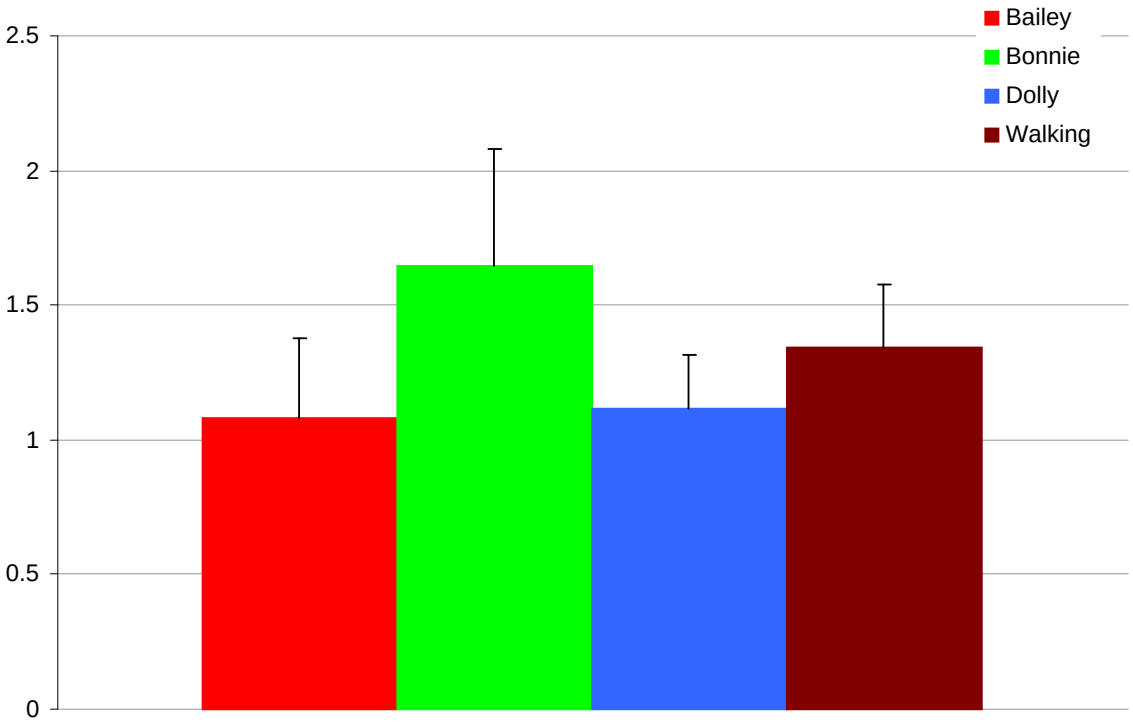


Figure 16: Multiple comparisons of the x-translation ranges (mean ± s.d.)

significant differences among any of the groups. The range values for the walking data appeared to lay within the range values of the riding data in figure 15.

Pelvis Z-Translations vs. Gait Cycle

The data resulting from the translation of the subject's pelvis along the z-axis (lateral axis) was plotted in figure 17. The riding data presented two maximums and two minimums in one period for each horse, while the walking data only presented one maximum and one minimum in one period. The maximum and minimum in the walking data, however, approximately corresponded to the second major maximum and the first major minimum in the riding data, respectively.

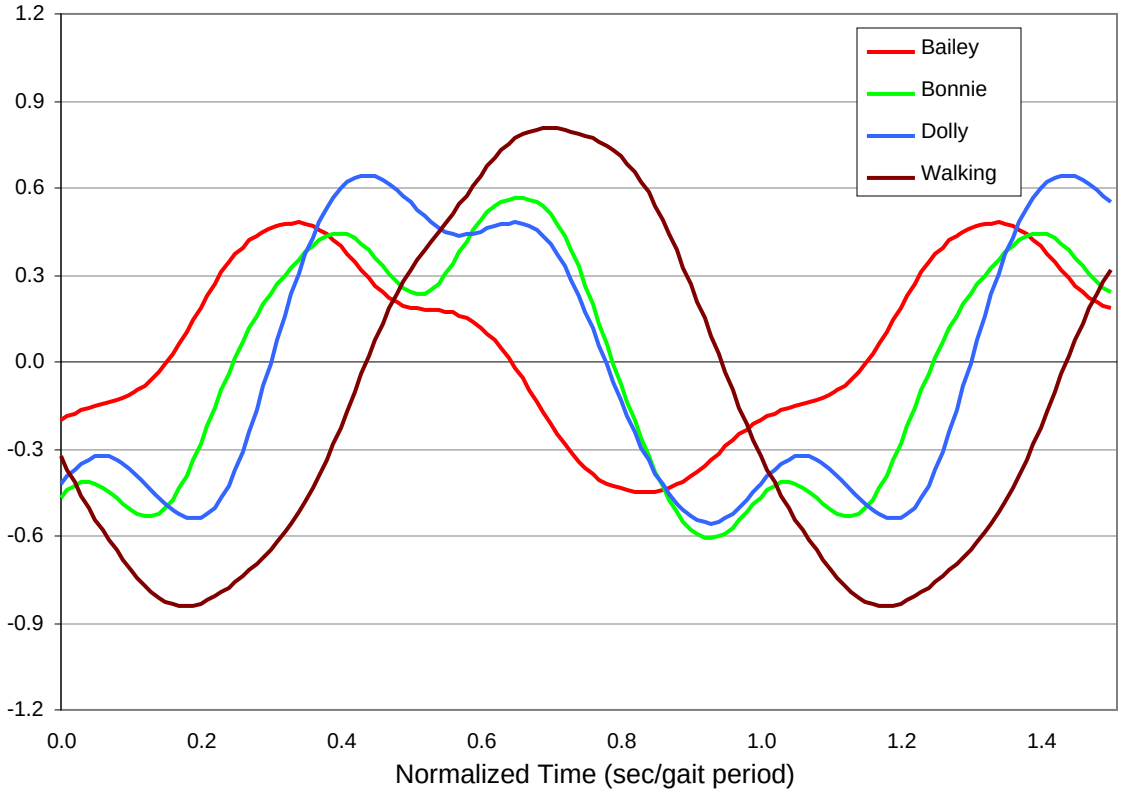


Figure 17: Z-translations of the pelvis

Statistics

The total ranges in the pelvis z-translation data for all subjects (mean $\pm$ s.d.) walking and riding Bailey, Bonnie, and Dolly were observed in figure 18. The ANOVA for the ranges just mentioned was given in the appendix, table E.5. Since P was only slightly greater than 0.05 (P=0.09), the null hypothesis was rejected, and it was inferred that there was a borderline significant difference among at least two of the groups in figure 18. A more than two groups Tukey-Kramer multiple comparisons test was performed to test for significance among the groups in the same figure. There were no significant differences in any of the data sets. The walking results appeared to possess a greater lateral motion compared to the riding results.

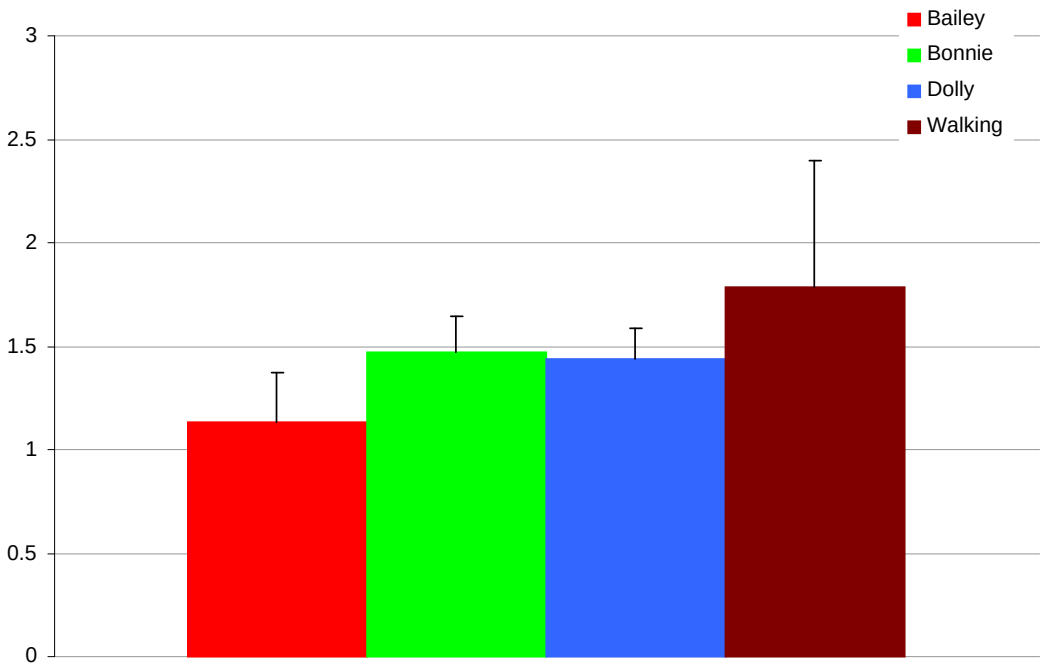


Figure 18: Multiple comparisons of the z-translation ranges (mean ± s.d.)

Pelvis List vs. Gait Cycle

The data resulting from the rotation of the subject's pelvis in the coronal plane (about the anterior-posterior axis) was plotted in figure 19. While the magnitude of the walking data was similar to the magnitude of Bailey, the shapes of the curves were different. The riding data presented at least one noticeable maximum and minimum in a period while the walking data presented two noticeable maximums and two minimums in each period. In the walking data, a minor maximum was present between the two minimums. This maximum corresponded to the maximums in the riding data. Likewise, in the walking data, a minor minimum was present between the two maximums. This minimum corresponded to the minimums in the riding data.

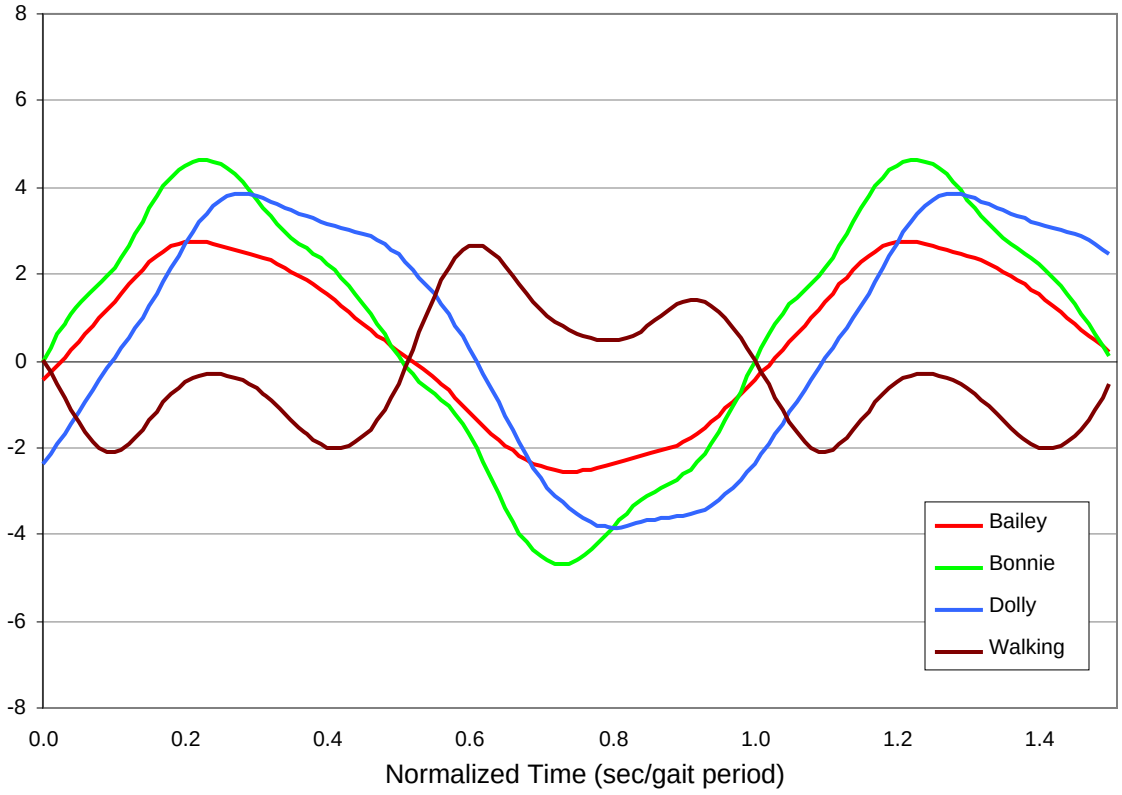


Figure 19: List angles of the pelvis

Statistics

The total ranges in the pelvis list data for all subjects (mean $\pm$ s.d.) walking and riding Bailey, Bonnie, and Dolly were observed in figure 20. The ANOVA for the ranges just mentioned was given in the appendix, table E.7. Since P=0.01, the null hypothesis was rejected, and it can be inferred that there was a significant difference among at least two of the groups in figure 20. A more than two groups Tukey-Kramer multiple comparisons test was performed to test for significance among the groups in the same figure. It was observed that there was a significant difference in the subject's pelvis list data among those who rode Bailey and Bonnie (labeled 'a' in figure 20) and those who rode Bonnie and those who performed the walking trials (labeled 'b' in figure 20). The statistical analysis revealed that, overall, when riding, a greater pelvic list angle was

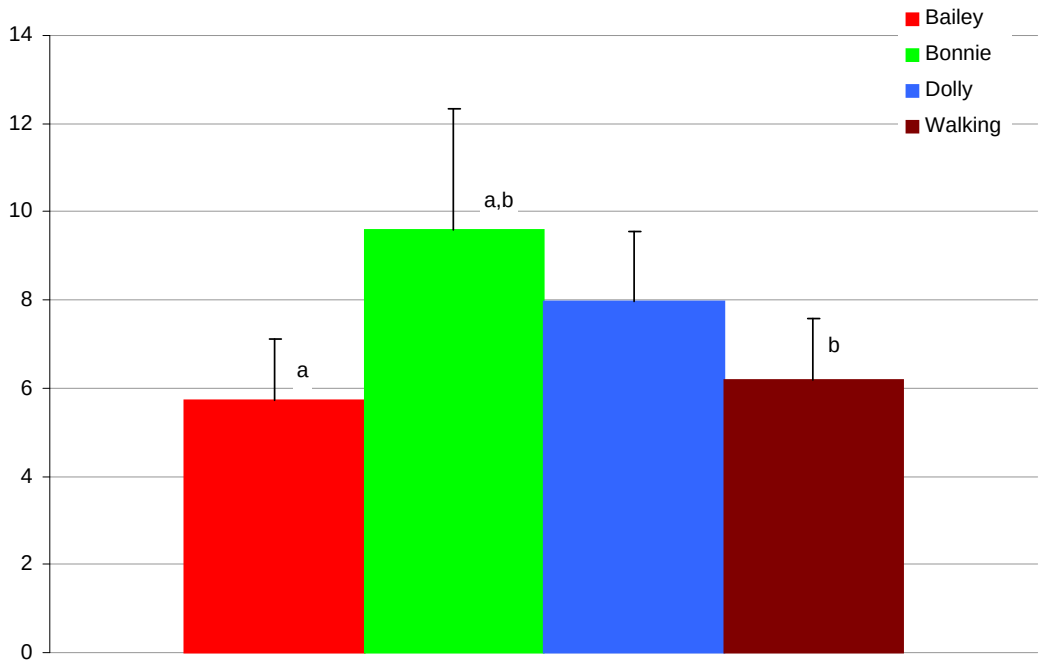


Figure 20: Multiple comparisons of the pelvis list ranges (mean ± s.d.). A: P=0.56, B: P=0.18

experienced in the subjects compared to the pelvic list angle in the same subjects when the walking trials were performed.

Pelvis Twist vs. Gait Cycle

The data resulting from the rotation of the subject's pelvis in the transverse plane (about the superior-inferior axis) was plotted in figure 21. The walking curve presented a similar shape and magnitude compared to the horse curves. Each curve possessed one noticeable maximum followed by a minor maximum, and one noticeable minimum followed by a minor maximum in each period. The timing of the noticeable maximums and minimums were similar between the riding data and the walking data.

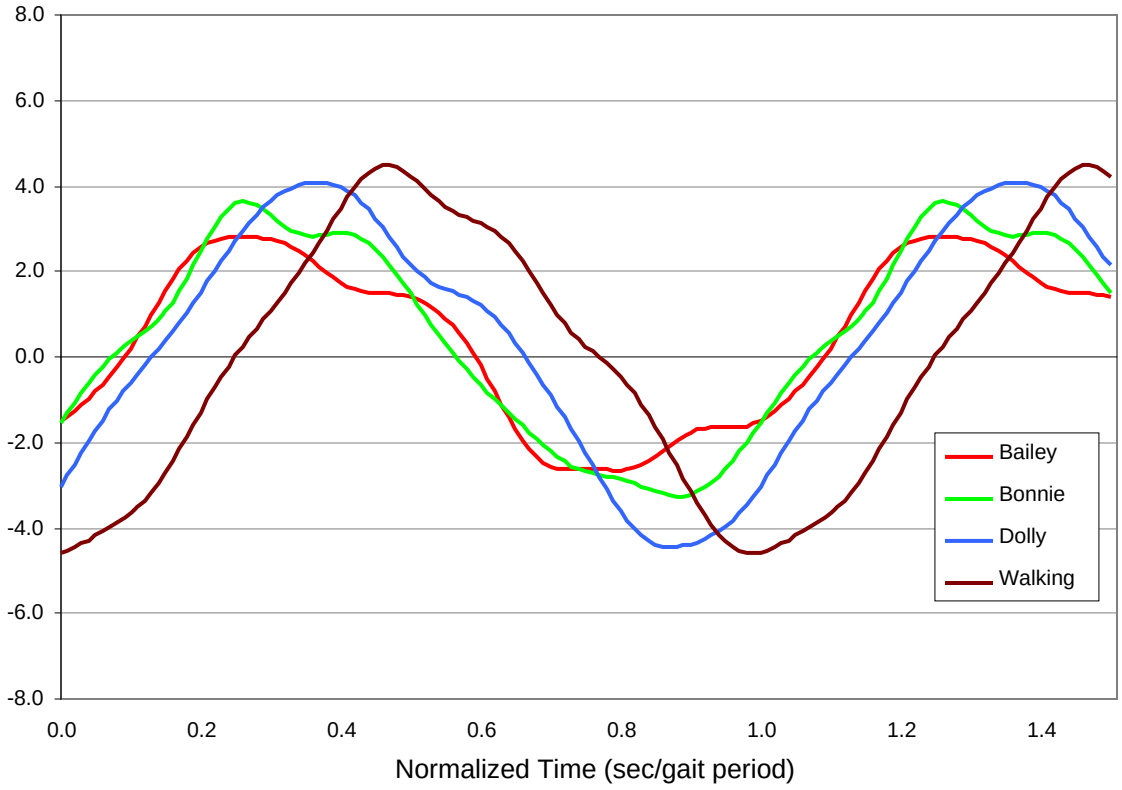


Figure 21: Twist angles of the pelvis

Statistics

The total ranges in the pelvis twist for all subjects (mean $\pm$ s.d.) walking and riding Bailey, Bonnie, and Dolly were observed in figure 22. The ANOVA for the ranges just mentioned was given in the appendix, table E.9. Since P was only slightly greater than 0.05 (P=0.08), the null hypothesis was rejected, and it was inferred that there was a borderline significant difference among at least two of the groups in figure 22. A more than two groups Tukey-Kramer multiple comparisons test was performed to test for significance among the groups in the same figure. There were no significant differences in any of the data sets. From the statistical analysis, the pelvic twist angle in the subjects while walking was greater than the pelvic twist angle in the same subjects while riding.

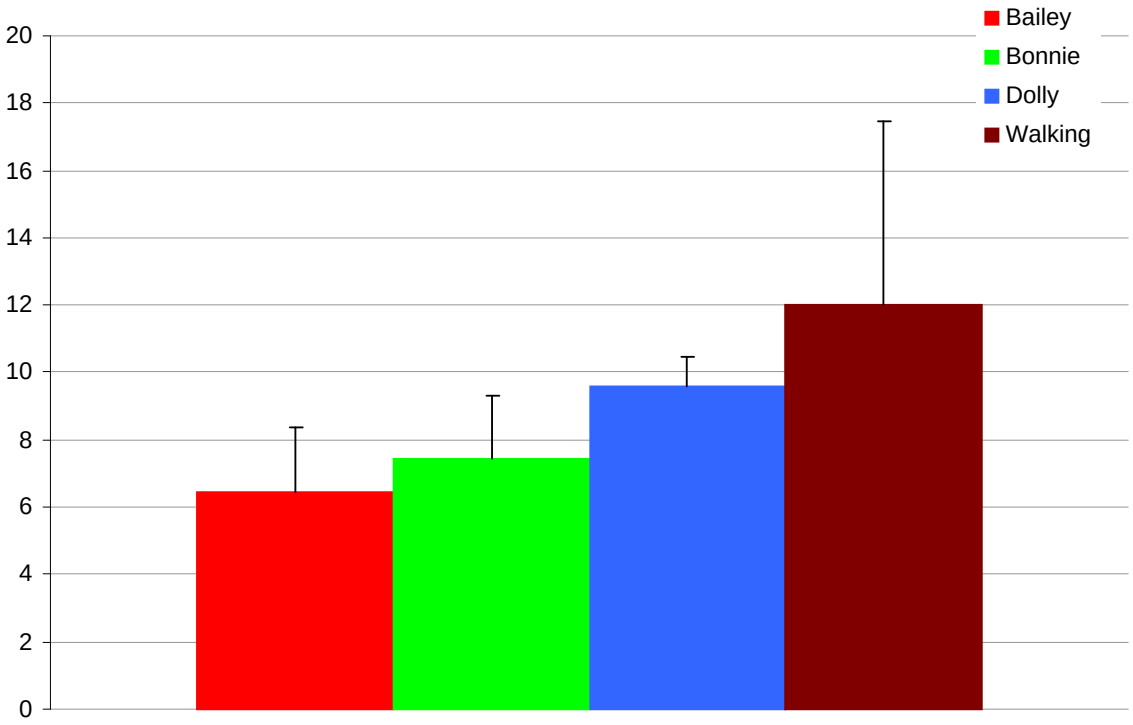


Figure 22: Multiple comparisons of the pelvis twist ranges (mean ± s.d.)

.

Pelvis Trajectories in the Principal Planes

The figures that represent the motion of the pelvis two-dimensionally were plotted in figures 23-25. These plots show how a marker, if placed halfway between the right and left back pelvis markers (that is, on L5), would move in three dimensions depending if the subject was sitting astride a horse or walking. In figure 23, the walking data exhibited a circular pattern because the maximums in the x-translation data corresponded to the minimums in the y-translation data and vice versa. This was not the case with the curves that represented the riding data, as the maximums and minimums corresponded to one another, resulting in a more linear, 45° angle pattern. In figures 24 and 25, there was a noticeable infinity shape, particularly in the walking data. The shape was stretched more upward in figure 25. Bailey had a slightly distorted infinity shape, but it followed

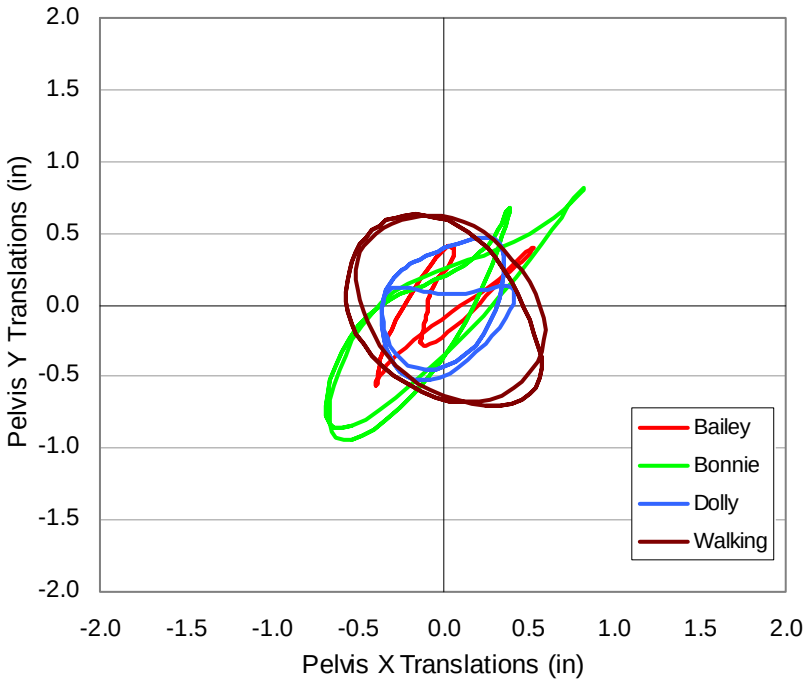


Figure 23: Translations of the pelvis (side view)

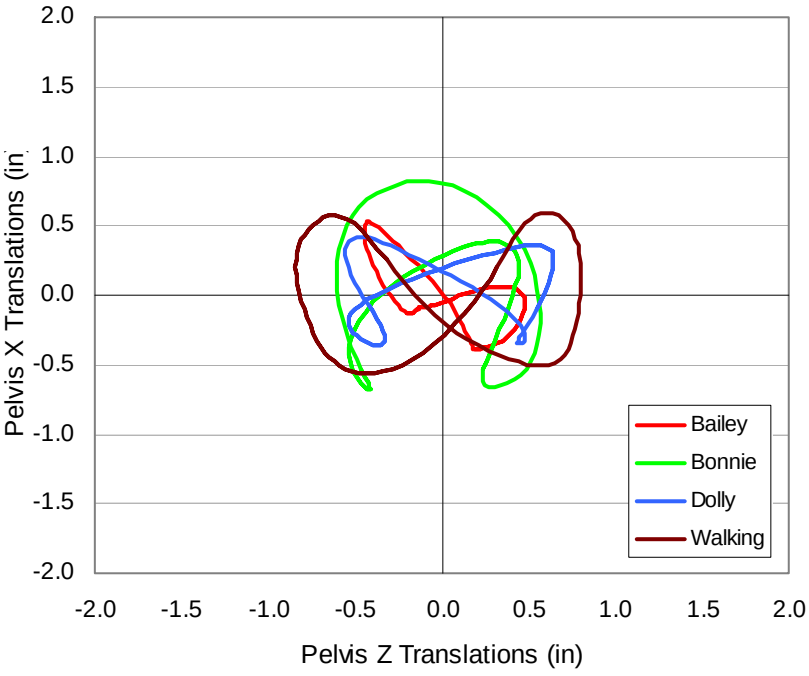


Figure 24: Translations of the pelvis (top view)

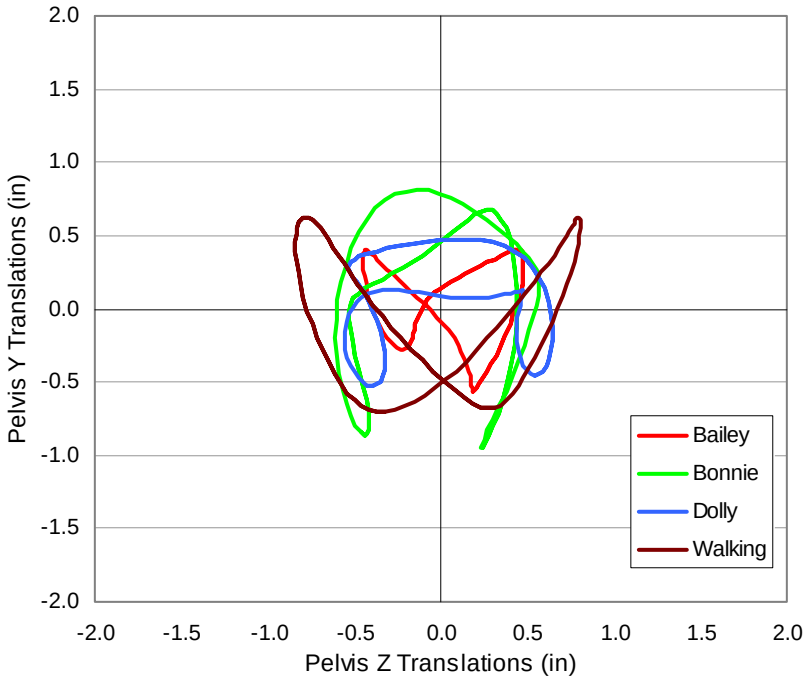


Figure 25: Translations of the pelvis (back view)

the same pattern in both graphs. The infinity shape for Bonnie projected in figures 24 and 25 exhibited an infinity shape distorted into the form of an upside-down "U." Patterns in the curves for Dolly were more difficult to identify. However, in figure 24, the curve for Dolly did exhibit an infinity pattern that was slightly distorted , downward on each side, with small additional loops at the "wings."

CHAPTER SIX

Discussion

The purpose of this study was to quantify and compare human pelvis kinematics during walking and when sitting astride a walking horse. As shown in figures 13, 15, 17, 19, and 21 in chapter five, many similarities were evident. Perhaps the most evident similarities were in the y-translations of the pelvis (figure 13). The synchronized curves presented similar shapes and similar magnitudes. Even though the walking data was not synchronized with the riding data in figure 15, similarities were seen between the curves in the plot. In the figures representing both the x- and z-translations of the pelvis (figures 15 and 17), similar shapes and magnitudes were also observed. The similarities in the three aforementioned plots were also summarized in this way: in figures 13 and 15, there were two oscillations each for the riding and walking data; in figure 17, there was one oscillation each for the riding and walking data. In the rotation data, the curves in figure 21 were nearly identical, with the walking curve slightly out of phase with the riding curves. The walking data for pelvis list (figure 19) was the most dissimilar to the riding data when compared to the previously mentioned plots in chapter five. However, the riding curves in figure 19 were very similar in shape and very similar in magnitude.

Significance

One previous study [3] compared pelvis kinematics for riding and walking. The present thesis was the first known study to investigate and compare the human pelvis kinematics (translations in three planes and rotations in two planes) of subjects sitting

astride a walking horse and the human pelvis kinematics of the same subjects walking. This study presented a foundation from which physical therapists may start investigating how hippotherapy is thought to be successful.

An Analysis of Data

The Translations

To better illustrate the characteristics of the gait cycle, figure 13, repeated here as figure 26, was the easiest to interpret. In this figure, the minimums corresponded to the moment reached just after heel-strike. Since the gait cycle began with a left foot heel-strike, the first minimum (see figure 26a) occurred very close to the beginning of the gait cycle. Toe-off of the right foot occurred near 10% of the gait cycle (see figure 26b), or where all of the curves intersected. The next heel strike (of the right foot) occurred just before the next minimum or at 50% of the gait cycle (see figure 26c). This implied that the right foot was in its swing phase for 40% of the gait cycle, a value that agreed with Gage et al. [29]. A toe-off by the left foot is represented in the moment about midway between the first minimum and second maximum, or at 60% of the gait cycle (see figure 26d). This implied that the left foot was in its swing phase for 60% of the gait cycle, a value that agreed also with Gage et al. [29]. The maximums represented the middle of the single support phase for each leg. So, the first maximum (see figure 26e) represented the point midway through the stance phase of the left leg, with the left leg supported by the ground and the right leg swinging through. The second maximum (see figure 26f) represented the same principle as the first maximum, but with the legs in opposite roles.

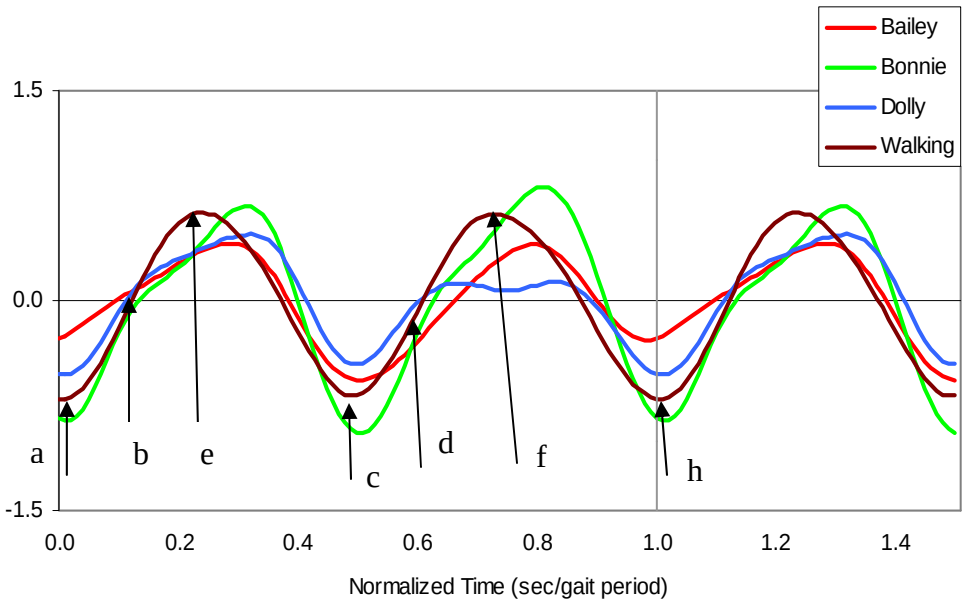


Figure 26: Y-translations of the pelvis with gait cycle landmarks

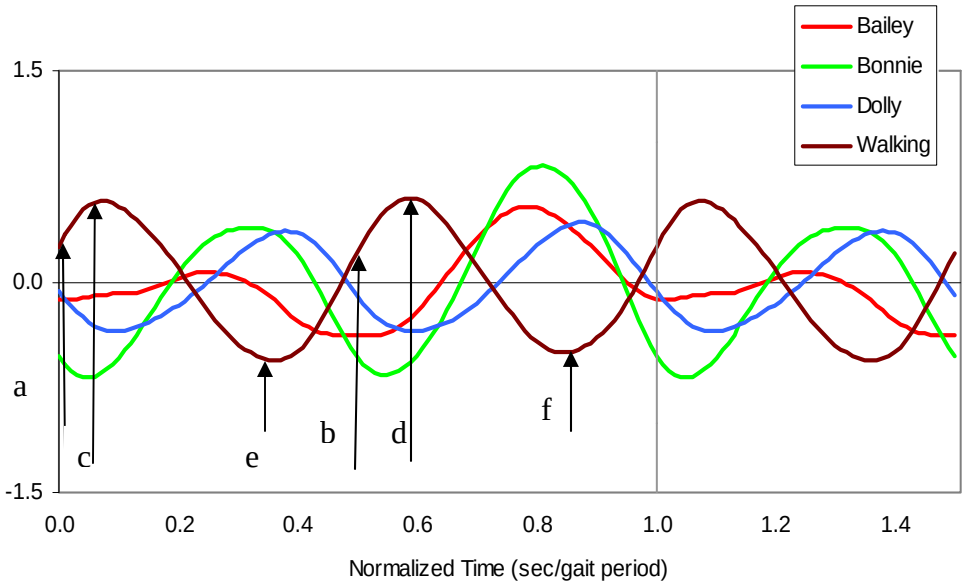


Figure 27: X-translations of the pelvis with gait cycle landmarks

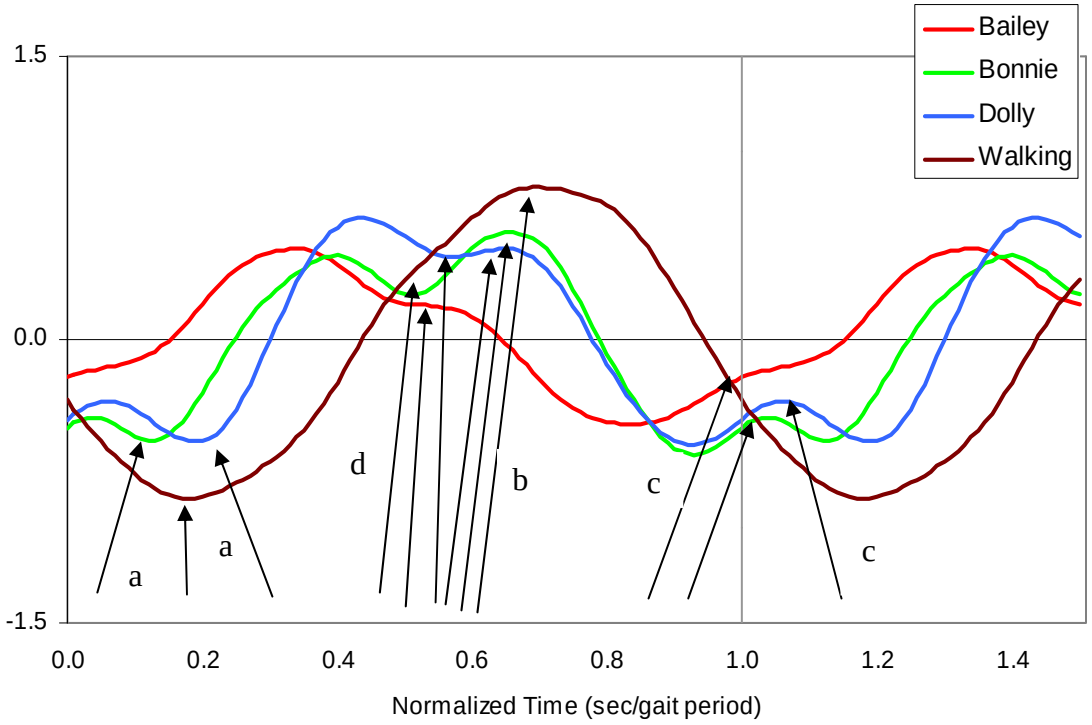


Figure 28: Z-translations of the pelvis with gait cycle landmarks

Then the process repeated itself with a left heel-strike (see figure 26h), the moment just before another minimum.

Figure 15, repeated here as figure 27, was difficult to interpret due to the timing issue mentioned in chapter five. It was obvious from the positive slope of the walking curve in this figure that the pelvis was moving forward faster than the average forward speed at the time of heel-strike of both feet (see figure 27a and 27b). The maximums represented the transition from double support to single support (see figure 27c and 27d) for each limb. The minimums represented the transition from midswing to terminal swing [29]. At 35% (see figure 27e) of the gait cycle, the right limb made the transition. At 85% (see figure 27f) of the gait cycle, the left limb made the transition. Again, all of these values agreed with Gage et al. [29]. The riding data would follow the same pattern

if the horse curves were synchronized with the walking data. However, figure 27 showed that the riding data were out of phase with the walking data, when the y-translations of figure 26 were in phase, by about 25% of the gait cycle.

Figure 17, repeated here as figure 28, was again a challenge to analyze but for different reasons than for figure 27. In this case, the horse curves presented a different shape compared to the walking curve. For example, there were two maximums and two minimums for the riding data for every period but only one maximum and one minimum for the walking data for every period. However, the minimum in the walking curve corresponded (see figure 28a) to minimums in two of the horse (Bonnie and Dolly) curves and the maximum in the walking curve corresponded (see figure 28b) to one of the maximums in all three of the horse curves. For Bailey and Dolly, this second maximum was of lesser magnitude compared to the first maximum. For Bonnie, however, this second maximum was of greater magnitude compared to the first maximum.

It was interesting to note that at 20% of the gait cycle, or where the aforementioned minimums meet, was the transition from initial swing to midswing [29] of the gait cycle for the right limb. Also, at 70% of the gait cycle, or where the aforementioned maximums meet, was the transition from initial swing to midswing [29] of the gait cycle for the left limb. Finally, in the riding data, there was a noticeable minor maximum in between the two minimums (see figure 28c) and a noticeable minor minimum in between the two maximums (see figure 28d). The minor maximum corresponded approximately to the heel-strike of the left foot while the minor minimum corresponded to the heel-strike of the right foot.

Comparison with Past Data – Translations

In a study published in the mid-1980s, Thorstensson et al. used LEDs glued to the skin on specific landmarks (the ankle, knee, hip, C7, L3, and 50% between the latter two) and an optoelectronic system recorded the trunk movements of ten healthy males walking and running [23]. The linear displacements of the trunk for one subject during consecutive gait cycles were plotted in figure 29. A comparison of the data obtained in this study and the data obtained from the Thorstensson et al. was given in table 6. The data obtained from Thorstennson et al. [23] was calculated in the same manner as the data obtained in this study. That is, the minimum-to-maximum displacements were the values listed.

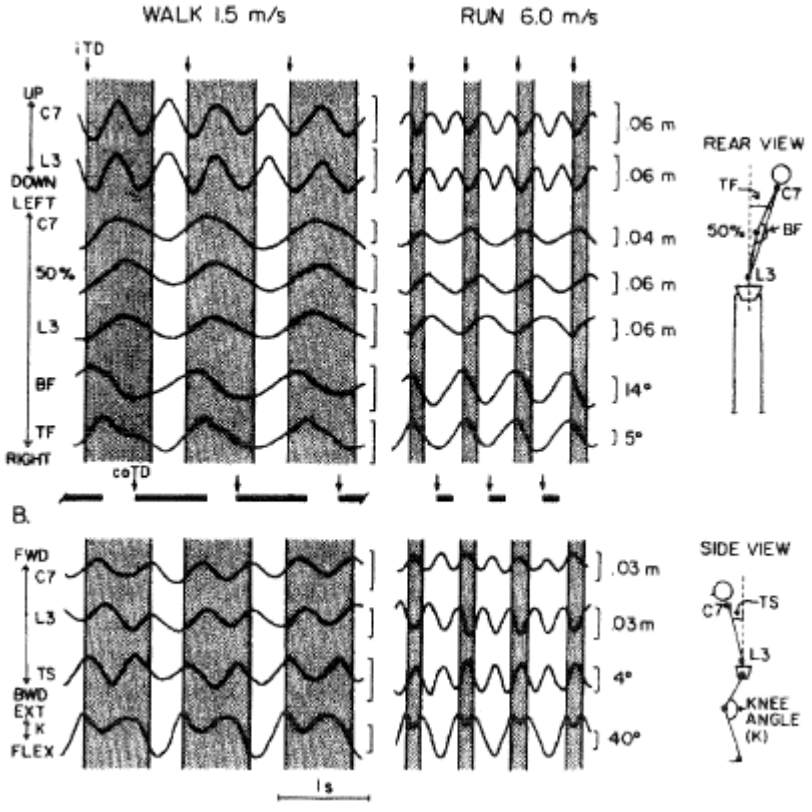


Figure 29: Translations and rotations of the trunk during consecutive gait cycles for one subject given by Thorstennson [23]

TABLE 6 OVERVIEW OF TRANSLATION RANGE DATA

	x-translations (in)	y-translations (in)	z-translations (in)
Bailey	0.90	0.90	0.95
Bonnie	1.50	1.75	1.20
Dolly	0.80	1.00	1.20
Walking	1.15	1.30	1.65
Thorstensson [23] – Adult pelvis walking	0.95	1.06	1.89
Lamoreux [22] – Adult pelvis walking	1.38	1.58	1.58
Fleck [3] – Child pelvis on walking horse	N/A	N/A	Mean: 2.21

When analyzing the y-translation of the data processed from the L3 marker on the trunk, the Thorstensson et al. once again found a pattern of two oscillations for every gait cycle [23]. They also observed that the first minimum followed a heel-strike and the maximums represented the middle of the single support phase [23]. These observations corresponded to the behavior of all of the curves in figure 30a.

When analyzing the x-translation of the data processed from the L3 marker on the trunk during a gait characterized by a slow cadence, Thorstensson et al. found a pattern of two oscillations for every gait cycle [23]. The authors also found that the L3 level of the trunk, which can be representative of the center pelvis marker calculated for this study, was moving forward at the heel-strike of each foot. The maximums also signaled the transition from double to single support [23]. These observations corresponded to the behavior of the walking curve in figure 30b.

Finally, when analyzing the z-translation of the data processed from the L3 marker on the trunk, Thorstensson et al. found a pattern of one full oscillation for every gait cycle [23]. At heel-strike, the L3 marker was moving towards that same limb. The

extremes represented periods of single support [23]. These observations corresponded to the behavior of the walking curve in figure 30c.

In the study conducted by Lamoreux, the average minimum-to-maximum displacements in all three planes lay in the ranges given by the data in this study (see table 6). Furthermore, the translations corresponded to the previously mentioned data from Thorstensson [23] and the data presented in this study. That is, there were two oscillations for every gait cycle in the x-translation data (see figure 31a), two oscillations for every gait cycle in the y-translation data (see figure 31b), and one complete oscillation for every gait cycle in the z-translation data (see figure 31c). The translation data from this study is given in figure 30. This data is scaled and the units have been changed to match the data from Lamoreux in figure 31.

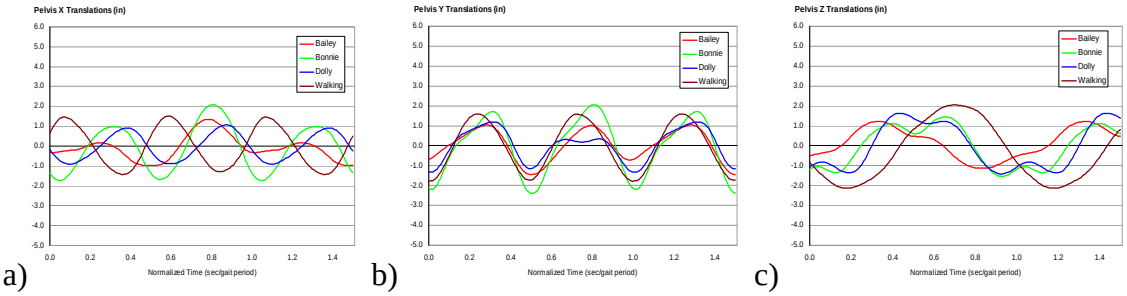


Figure 30: Translations of the pelvis along the: a) x-axis, b): y-axis, and c): z-axis

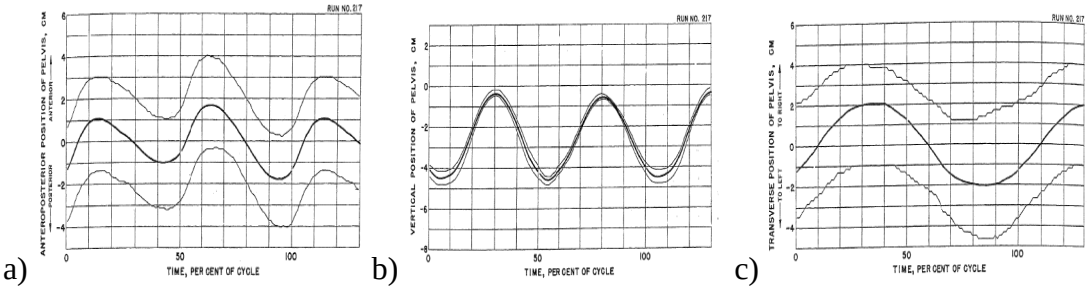


Figure 31: Translations of the pelvis along the: a): x-axis, b): y-axis, and c): z-axis as reported by Lamoreux [22]

A value for the z-translation of the human pelvis sitting astride a walking horse [3] was given in table 6. As stated in chapter one, the method by which this value was obtained was unclear. Only a numerical value was found and the original study could not be located.

The Rotations

Though analyzing the curves according to the phases of the gait cycle was beyond the scope of the current study, it was useful information and was interesting to investigate.

Figure 19, repeated here as figure 32, was most notably different from the data presented in chapter two from Thurston et al. (see chapter three, figure 6a). Minimum-to-maximum rotations in the coronal plane were found to be approximately 20 degrees in the latter data [34]. In the data presented for this study, the curve representative of the data produced by subjects atop Bonnie presented the greatest minimum-to-maximum value: 9.5 degrees. The curve representative of the walking data was even less (see table 6). Though the magnitudes were different, the walking data presented in this study did have a similar shape to the data presented in figure 6a. Both presented a minimum followed by second minimum and a maximum followed by a second maximum. In the data presented by Thurston et al., however, this second minimum and this second maximum were both minor compared to the landmarks that preceded them [34]. In this study, the two minimums were of equal magnitude in the walking data and the second maximum was only slightly less in magnitude compared to the first maximum. The two plots did share another common characteristic. The first minimum (see figure 32a) in each of the plots represented toe-off of the left foot while the major maximum (see figure

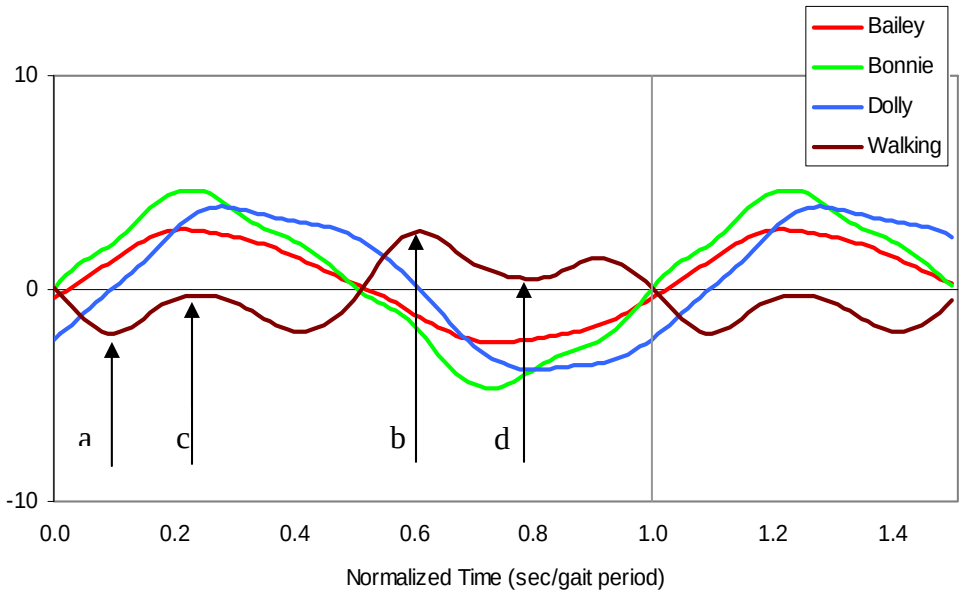


Figure 32: Pelvis list with gait cycle landmarks

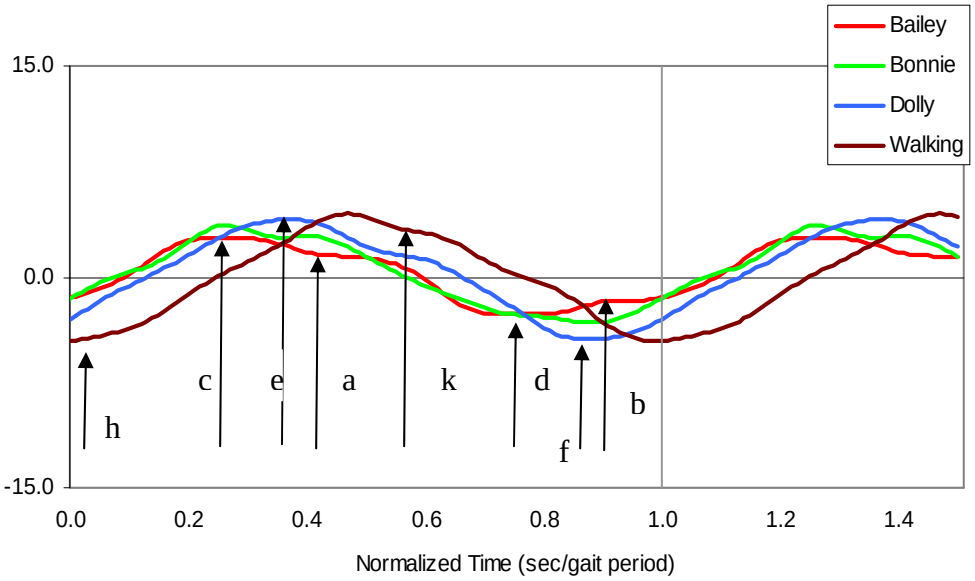


Figure 33: Pelvis twist with gait cycle landmarks

32b) represented toe-off of the right foot. The horse curves only presented one major maximum and one major minimum each. It was interesting to note that the notches

present in the walking data corresponded to the extremes of the riding data. For example, there was a notch present in the walking curve (see figure 32c) in between the first two minimums at 0.2. This corresponded to the location of the major maximum in the horse curves. There was another notch present in the walking curve (see figure 32d) in between the two maximums at 0.78. This corresponded approximately to the location of the minimum in the horse curves.

When analyzing figure 21, repeated here as figure 33, it appeared that the riding data more closely resembled the pelvic rotation in the transverse plane of a subject walking. If all of the data was shifted over to the left by 0.2, or 20%, then it would more closely have resembled the data reported by Thurston et al. (see chapter three, figure 6c). Nevertheless, there were some key graphical landmarks particularly in the riding data that were matched with the data presented in chapter two from Thurston et al. In each horse curve, there was a notch present following the major maximum and a notch present following the major minimum [34]. For example, in the curve for Bailey, this notch was present at 40% of the gait cycle (see figure 33a) and at 90% of the gait cycle (see figure 33b). In the data mentioned previously, the notches were also present after each the maximum and the minimum. These notches represented toe-off of each foot. Because the maximums and minimums preceded the notches closely, these graphical landmarks represented heel-strike at each foot. So, the curves for Bailey and Bonnie showed that heel-strike occurred at approximately 25% (see figure 33c) and 75% (see figure 33d) of the gait cycle and the curve for Dolly showed that heel-strike occurred at approximately 35% (see figure 33e) and 85% (see figure 33f) of the gait cycle. The hypothesis was that these points did represent heel-strikes, as a half of a period separated the strikes. The

walking curve presented very shallow notches at 5% (see figure 33h) and 55% (see figure 33k) of the gait cycle. These notches were not as pronounced as the notches present in the horse curves.

Comparison with Past Data – Rotations

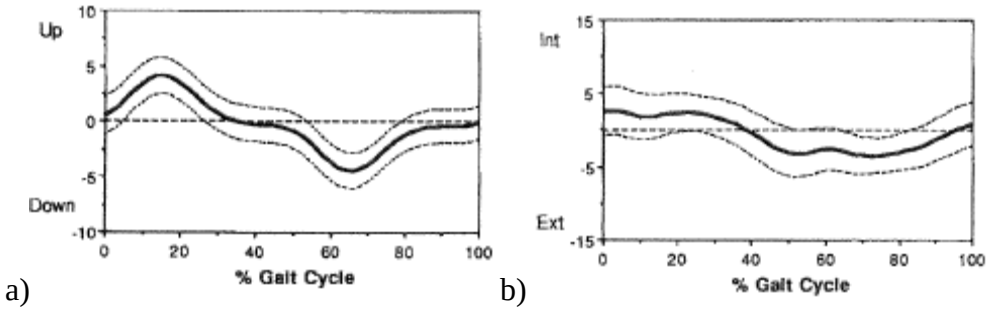
In a study conducted by Kadaba et al. in 1990, an external marker system and motion analysis software was used to obtain angular motion of the pelvis and other body landmarks on 40 normal young adults [28]. To achieve the necessary repeatability of the motion data, the subjects were tested on three different days within one week. The data was taken and averaged across all subjects. A limitation of the study included unknown errors in joint angle motion with the use of motion analysis. Naturally there was some "uncertainty in the construction of an embedded coordinate system" [28]. Values for minimum-to-maximum rotation values of the pelvis in [28] were given in table 7 while graphical representation of these values was plotted in figure 34.

TABLE 7 OVERVIEW OF ROTATION RANGE DATA

	Pelvic List (deg)	Pelvic Twist (deg)
Bailey	5.0	5.5
Bonnie	9.5	7.0
Dolly	8.0	8.5
Walking	4.5	9.0
Kadaba [28] – Adult pelvis walking	5.5	9.0
Whittle [25] – Adult pelvis walking	9.5	8.0
Fleck [3] – Adult pelvis on walking horse	10.08 $\pm$ 2.48 (mean $\pm$ s.d.) drop	N/A

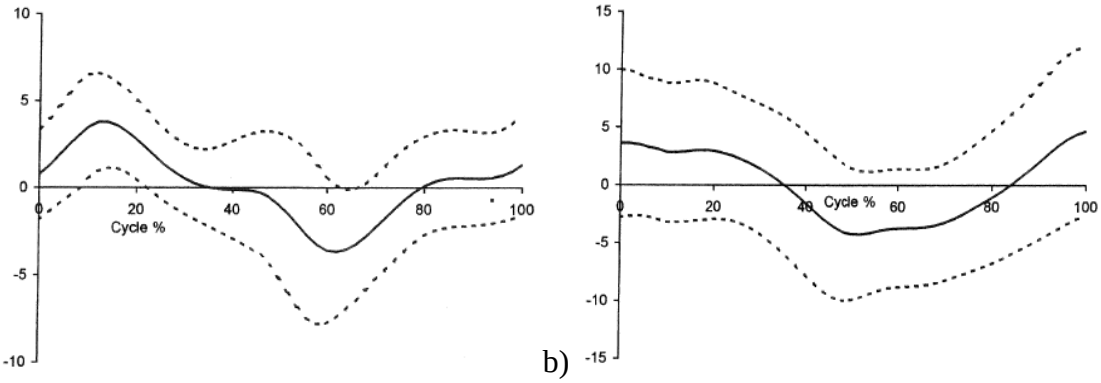
Nine years after the Kadaba study, Whittle et al. used reflective targets attached to lightweight rings that covered the throracolumbar junction and upper sacrum and an

optoelectronic system to measure the movements of the pelvis and lumbar spine [25]. The subjects consisted of 20 normal adult males who all were asked to walk normally. Each subject performed four walks. The data was taken and averaged across all subjects.



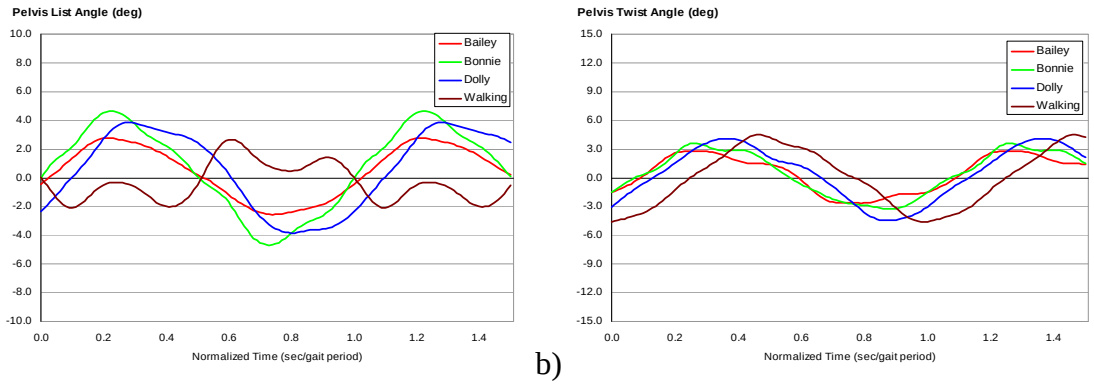
a) b)

Figure 34: Pelvic rotations in the a): coronal plane and the b): transverse plane as reported by Kadaba [28]



a) b)

Figure 35: Pelvic rotations in the a): coronal plane and the b): transverse plane as reported by Whittle [25]



a) b)

Figure 36: Pelvic rotations in the a): coronal plane and the b): transverse plane

Limitations of the study from Whittle et al. included the discarding of potentially valuable data from a number of taller subjects because the cameras could not capture the motion of the markers placed on the head of these subjects [25]. Values for minimum-to-maximum rotation values of the pelvis were given in table 7 while graphical representation of these values was plotted in figure 35. There was a striking similarity in the shapes of these plots. The minimum-to-maximum values were a bit different, but the data complemented the data found in this study. The pelvic rotations in the coronal plane in the figures above more closely resembled the horse curves in the pelvis list angle graph (figure 36a) than the walking curve in the same graph. The characteristic major maximum (presented in all the horse curves), followed by a minor maximum (presented most prominently in the curve representing Dolly), followed by a major minimum (presented in all of the horse curves), followed by another minor maximum (presented most prominently in the curve representing Bonnie) was observed in figures 34a and 35a above. The data in the pelvis twist angle graph (figure 36b) presented in this study was shifted compared to the data seen in figures 34b and 35b above. All of the plots in figure 36b had the same shape and were compared to the shape of the plots displaying pelvic rotations in the transverse plane in the graphs above.

A value for the list of the human pelvis sitting astride a walking horse [3] was given in table 7. As stated in chapter one, the method by which this value was obtained was unclear. Only a numerical value was found and the original study could not be located.

The Pelvis Trajectories in the Principal Planes

The three plots of the pelvis trajectories in the principal planes (or Lissajous figures) were created in this study to show how a marker, if placed halfway between the right and left back pelvis markers (that is, on L5), would move in three dimensions depending if the subject was sitting astride a horse or walking. Lissajous figures were

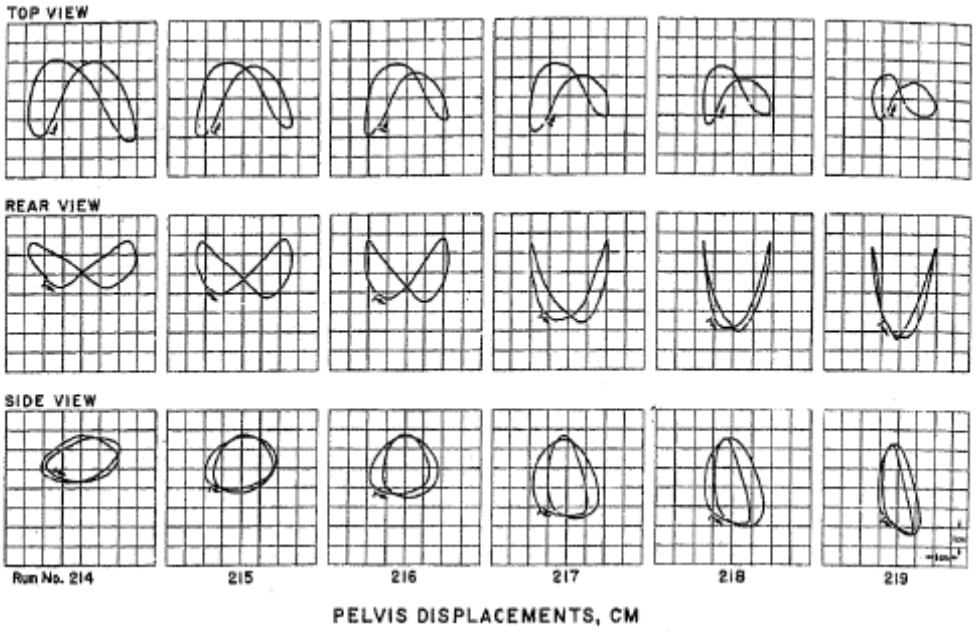
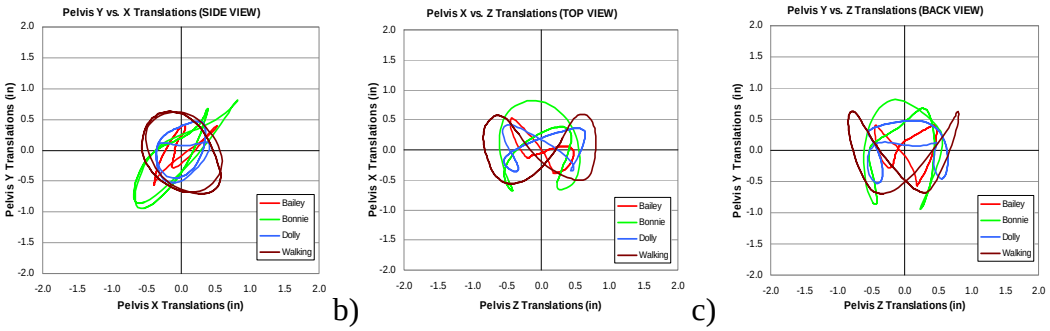


Figure 37: Lissajous figures displaying the translations of the pelvis as reported by Lamoreux [22]



a) b) c)

Figure 38: Pelvis trajectories viewed from the a): side; b): top; c): back

first created in the 19th century and combined "simple harmonic variables on orthogonal axes to study frequency, amplitude, and phase relationships" [39].

In his 1971 study, Lamoreux created Lissajous figures from the translation data of the pelvis (see figure 37). There were striking similarities between all of the walking curves found in figure 38 and the data from Lamoreux. The riding curves did not follow any type of pattern in figure 38a but all three riding curves in figures 38b and 38c showed the familiar infinity shape, but these plots had been distorted through compression and rotation.

Errors and Limitations

As mentioned in chapter five, all of the data from the second session and the data from the first set of session one was lost due to errors in camera settings. The cameras with the errors were programmed with an incorrect shutter speed and an improper focus. This caused the video to remain still for three frames then jump in the fourth frame. The process was repeated throughout the time-span listed above. The camera was also not blurred correctly, resulting in an untrackable video file once the information from the camera was imported into SIMI Motion.

Other errors might have occurred with marker placement. A major source of inaccuracy in kinematic analysis is the error introduced by skin motion, if the markers are placed directly on the skin [24]. However, not only might skin artifacts have introduced error in this study, but clothing artifacts most likely might have played a larger role in the occurrence of errors. The clothing was not always skin-tight on the subjects, so the location of the marker on the subject might not truly have represented the actual location of the subject's body segment. Markers placed on plates, however, showed smaller

artifacts compared to markers mounted directly onto the skin [40]. This was encouraging since the data analyzed in this study originated from markers on a plate.

Moreover, markers occasionally lost their adhesive backing and fell to the ground. This occurred with markers placed on both the horse and the subject. For some passes, markers would not be attached. Even when the markers were found to not be on the subject or horse, and the adhesive was reapplied, they were not placed in the exact same location as before the adhesive was lost. This may have caused errors in the tracking of the data, but would not have affected the pelvis data presented in this study.

Finally, there was most likely some error due to the patients themselves. Individuals consistently change their gait patterns [22]. Any person, particularly an adolescent, would have trouble with the repeatability in gait patterns, regardless of cadence. Add to this the fact that the subject was aware that he or she was part of an experiment. The gait pattern might then have changed from normal to a pattern that is abnormal Simply put, a subject's, "usual gait patterns may be altered still further by the conditions of the experiment, or by the instrumentation used to make measurements, or simply by the knowledge that his walking is being closely observed" [22].

There were also several limitations in the study. One limitation arose from the type of cameras and LED markers used. The markers could only be seen by the cameras in dark conditions, so all the experiments were conducted at night. This practice should not affect the results in any way. But, a camera and LED system capable of infrared lighting would make the experiments more convenient for researchers and subjects.

Another limitation that was encountered was the inability to obtain pelvis tilt, or the quantification of the rotation of the pelvis in the sagittal plane. This movement would

have been possible to measure if the data from the markers placed on the anterior side of the pelvis was processed. However, due to the consistent obstruction of the markers during data collection (see chapter five), the data could not be tracked in SIMI and therefore could not be processed.

The observation space was also very small, which presented a limitation in the study. In this small space, only the motion of one-a-half to two gait cycles could be captured by the cameras. The horses had to walk as normally as possible when passing through this small space (i.e. not trip, change gait speed). A larger observation space would allow for more gait cycles to be recorded and processed with a greater likelihood of capturing a single straight, smooth, and regular gait cycle in every pass.

Finally, another limitation arose in the statistical analysis of the data obtained in the study. Ideally, a repeated measures test, or a test in which multiple measurements are made on the same subjects, would have been performed. However, due to missing data and a limited number of subjects in the study, an ANOVA had to be performed instead. With more subjects and no missing data, it was probable that more or all of the data would have been statistically different.

Future Work

Subjects

Although the study consisted of six subjects, there were obvious limitations in subject profile. Aside from gender, all of the subjects were similar in age, health, and riding experience. Many permutations can be studied, including older subjects or those who suffer from some neuromusculoskeletal dysfunction.

Horses

The only horses that could be used were the few that were available for use in hippotherapy sessions at Camp Hope. Different horses could be used, characterized by different cadences or stride lengths. The physical attributes of different horses could be noted. For example, broad horses versus smaller horses.

Saddles

The study limited itself to the type of saddle used (therapeutic). Different saddles could have been used to examine the differences between them. For example, a rider could have used a Western saddle or could have ridden the horses bareback.

Subject Orientation on the Saddle

All of the subjects in the current study were facing forward on the horse at the time of data collection. Data collected with subjects sitting sideways or backwards on the saddle might give more insight into what exactly is occurring with the subject when sitting astride a horse, especially since the positions are used occasionally in hippotherapy sessions.

Gait Speed

Only one gait speed was analyzed in this study. Data showing faster cadences is desired to investigate any similarities between gait speeds. This data was collected in the study and remains to be analyzed in the future. However, the processing and analyzing of the fast walk data was beyond the scope of the current study.

Treadmill

A study involving a treadmill specifically designed for horses would provide valuable data. Cameras could be mounted permanently in the room that holds the treadmill. This would eliminate any further calibration of the cameras as the data would consistently be collected in the same space. The risk of the cameras being moved during data collection would also be eliminated. Moreover, the horse would walk at a constant gait speed and over a consistent terrain, allowing for smoother and easier processing.

Mechanical Horse

Another direction that this research might lead to was the construction of a more sophisticated mechanical horse. A prototype was designed and built by the Baylor senior design team in the spring of 2009. A mechanical horse would have a number of advantages over an actual horse: 1) it is possible to standardize and accurately reproduce the riding sessions; 2) the movement would be consistent and constant; 3) the speed can be finely altered; 4) it can be used indoors, enabling frequent sessions to be provided, regardless of weather, and eliminating the need to transport children to and from the riding stables; 5) it requires less manpower than conventional horse riding to maintain and operate, and thus is cheaper to run; 6) a child would benefit from hippotherapy when they could not otherwise due to some allergy to the horse [1].

At least one mechanically powered saddle has been developed and documented in literature, but only to study if the effects of pelvic mobility and postural control were similar to those experienced in an actual hippotherapy session [1]. The Brunel Active Balance Saddle (BABS) was primarily designed to measure pelvic rotation about the anterior-posterior axis of subjects. Thirteen children, all diagnosed with CP, took part in

the study and the researchers found that the BABS increased pelvic list in all subjects. Only a small number of BABSs were reproduced and were only distributed in Europe some ten years ago [1]. The saddle has not been reproduced since this time and finding one was a difficult task.

CHAPTER SEVEN

Conclusion

Hippotherapy has been shown in numerous clinical studies to provide stimulation to subjects suffering from some neuromusculoskeletal dysfunction [4-10,12,14,16,19,20]. This stimulation can have positive physical and emotional effects on the subject. The kinematics of the pelvis have been studied in a number of published papers [22,23,25,27,28,34] but only focus on subjects walking or running. Fleck had published values on the displacement and rotation of the pelvis in one plane of motion [3]. Only numerical values could be found for the latter study as locating the actual article is difficult. The interlibrary loan system at Baylor University could not locate the study.

The experiment completed in this study is the most comprehensive analysis of pelvic kinematics of human subjects sitting astride a walking horse (riding data) and walking (walking data). Overall, the curves representing the riding data and the curves representing the walking data were similar in shape and magnitude for five measures of pelvic motion. These measures included translations in all three planes of motion and rotations in two planes of motion (pelvis list and twist). Statistical analysis showed that only one important set of data (riding versus walking) was significantly different: the data represented by the subject's pelvis list angle when walking data and the pelvis list data represented by the subjects riding atop Bonnie. The results provide quantitative support for the validity of the prevailing theory about how hippotherapy may benefit disabled patients.

APPENDICES

APPENDIX A

Riding Data: Bailey

Subject A

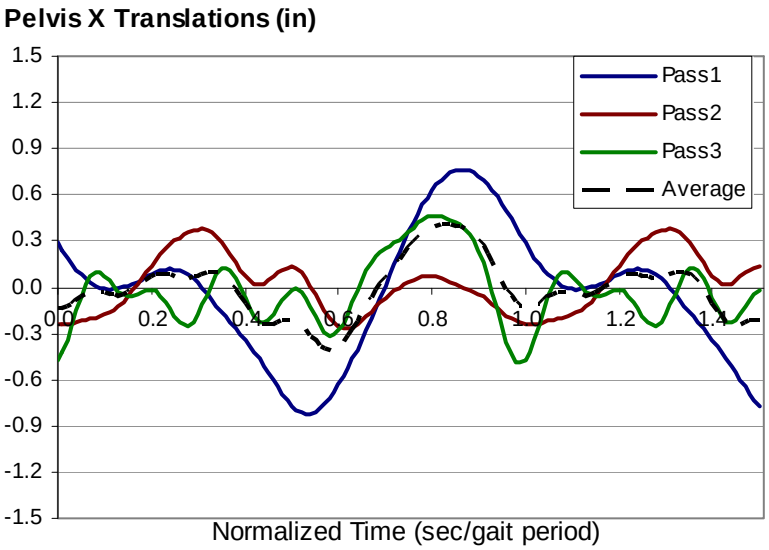


Figure A.1: Pelvis x-translations for subject A on Bailey

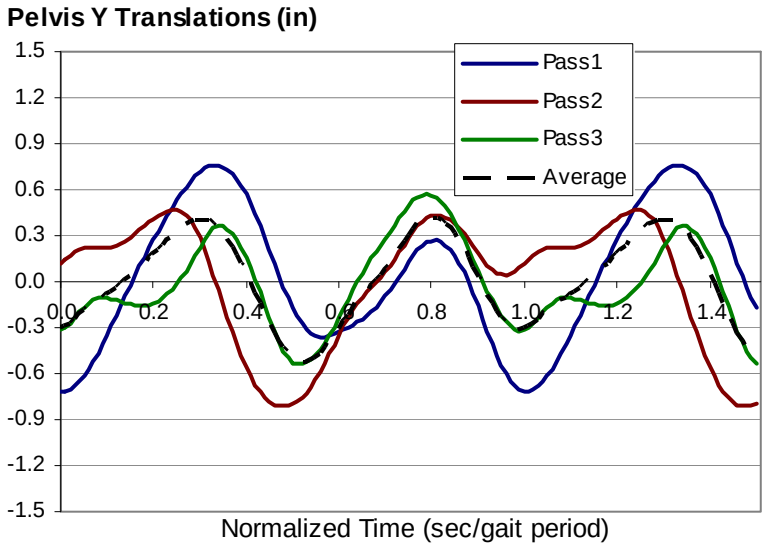


Figure A.2: Pelvis y-translations for subject A on Bailey

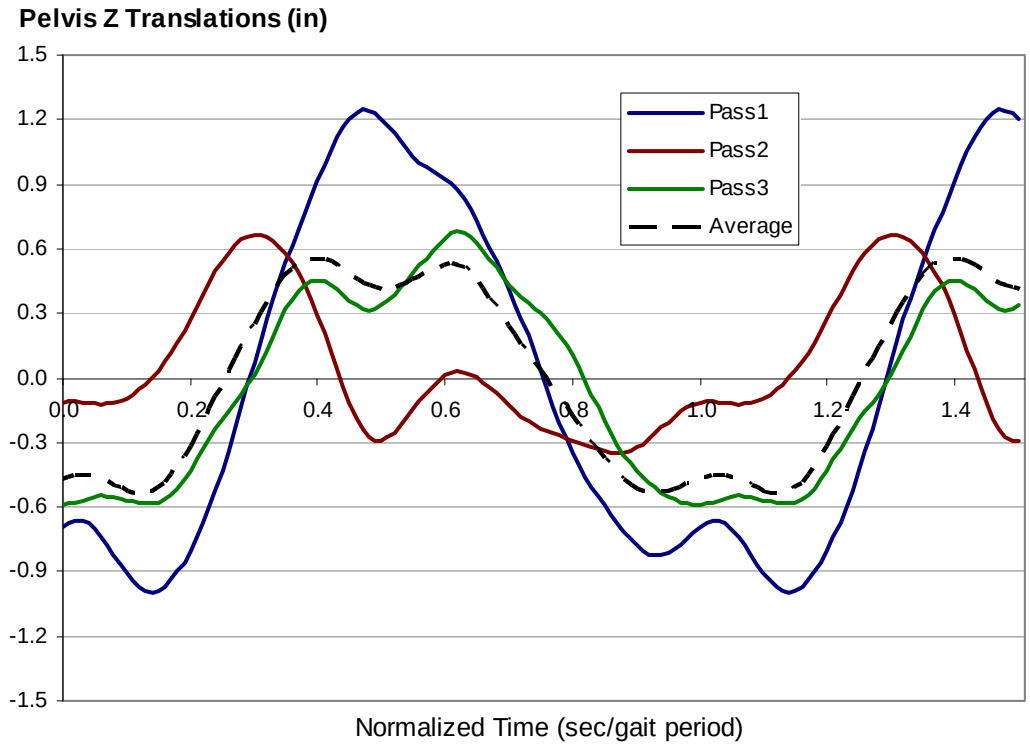


Figure A.3: Pelvis z-translations for subject A on Bailey

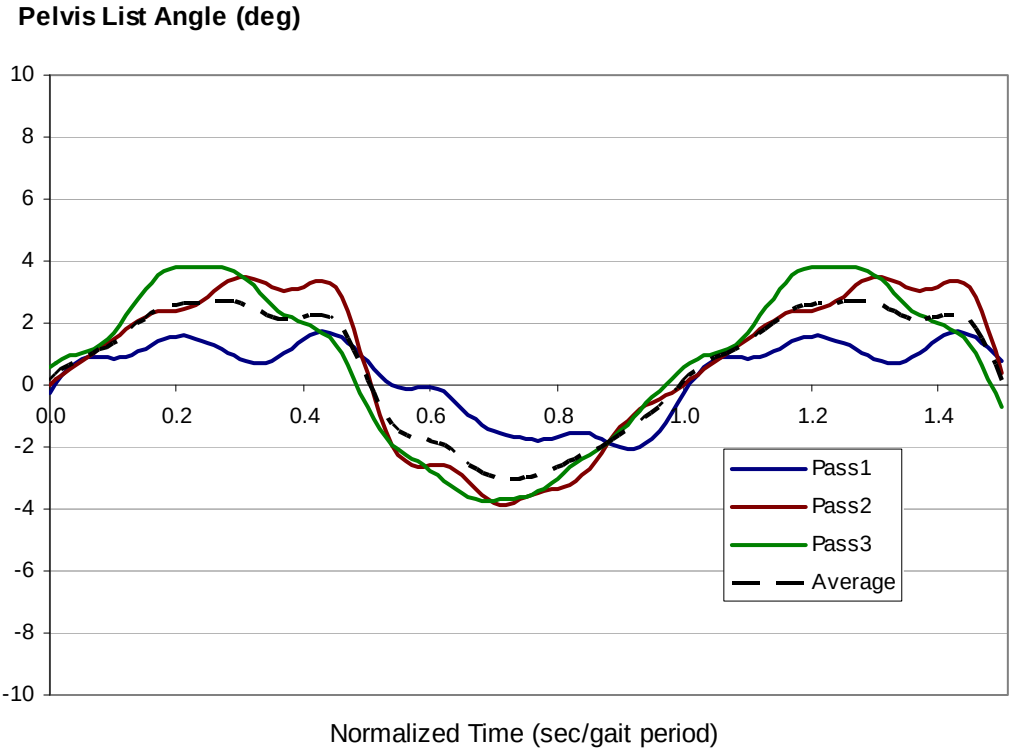


Figure A.4: Pelvis list angle for subject A on Bailey

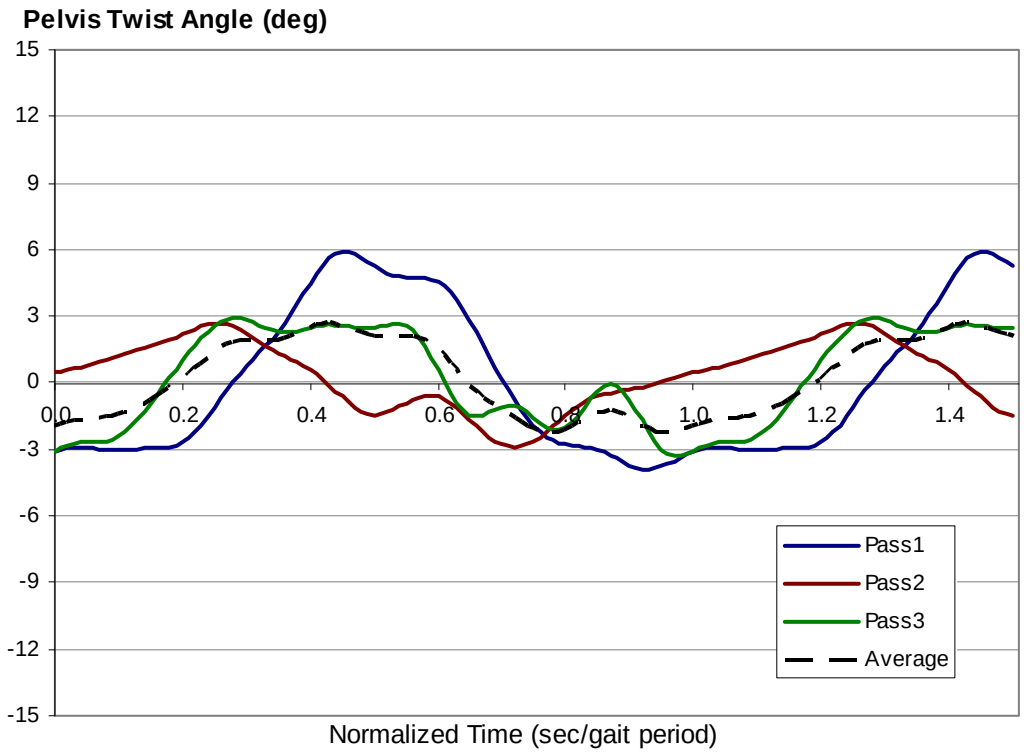


Figure A.5: Pelvis twist angle for subject A on Bailey

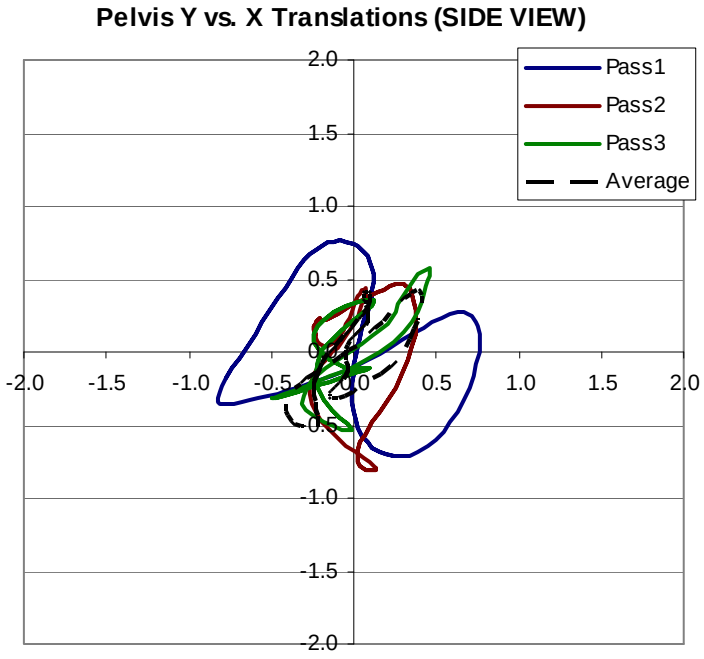


Figure A.6: Side view of pelvis for subject A on Bailey

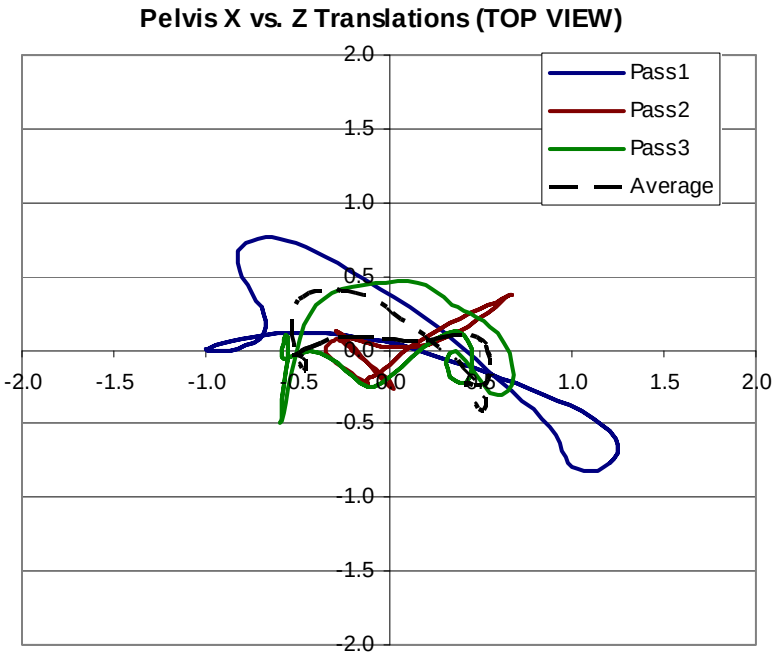


Figure A.7: Top view of pelvis for subject A on Bailey

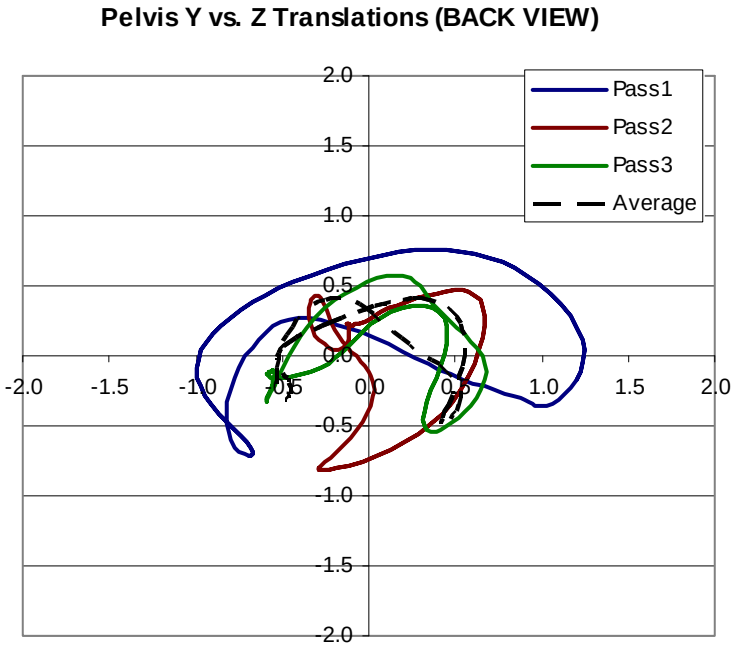


Figure A.8: Back view of pelvis for subject A on Bailey

Subject B

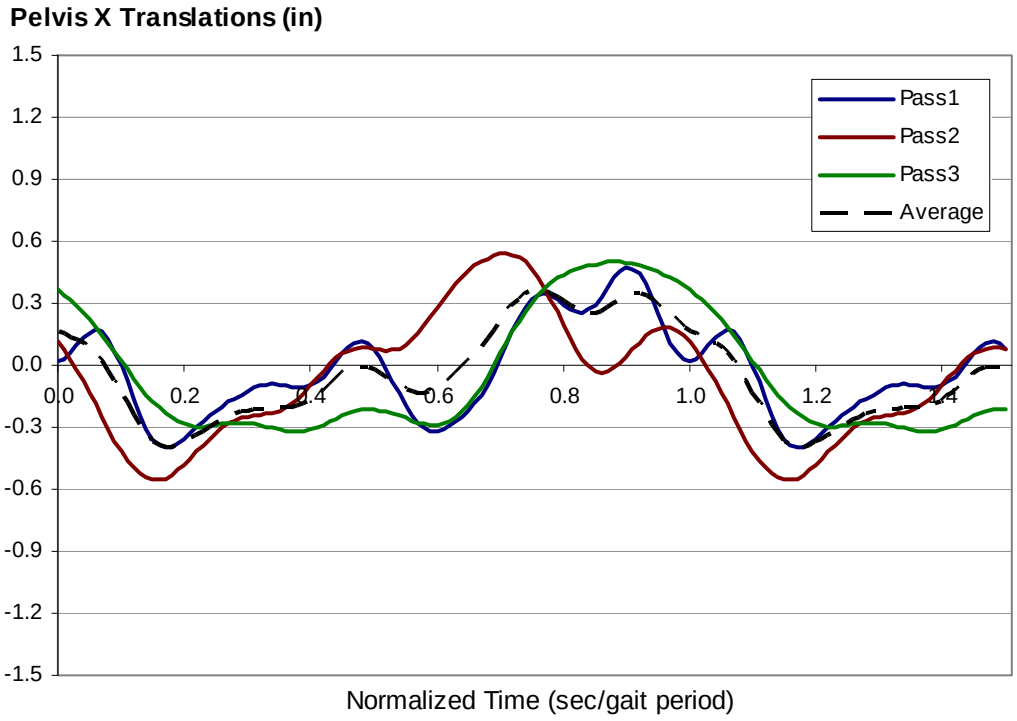


Figure A.9: Pelvis x-translations for subject B on Bailey

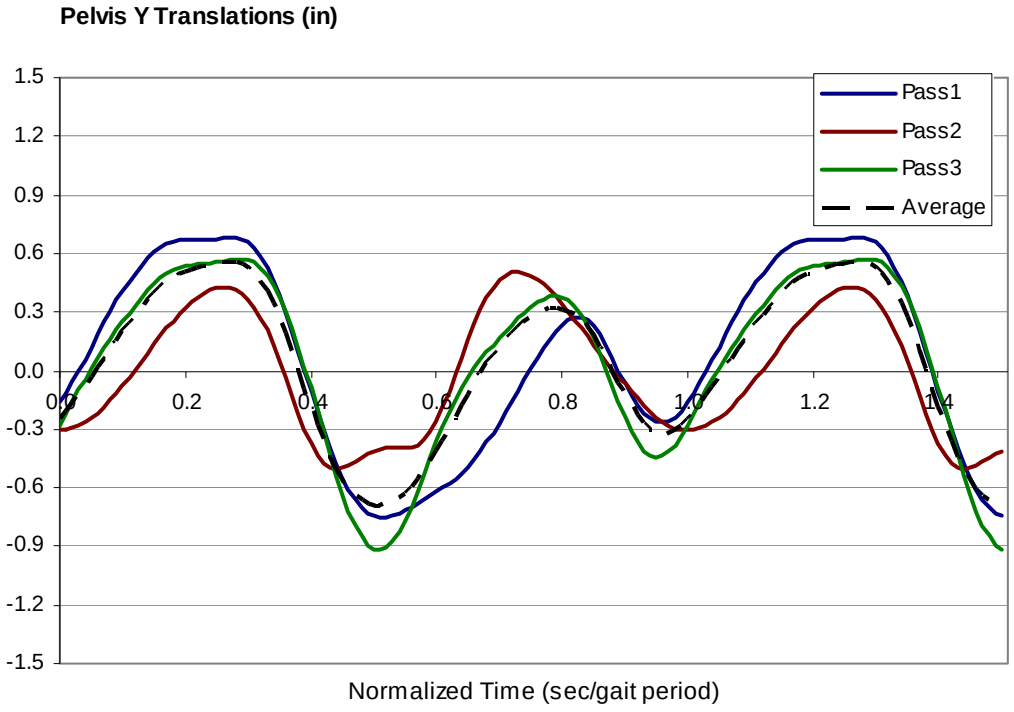


Figure A.10: Pelvis y-translations for subject B on Bailey

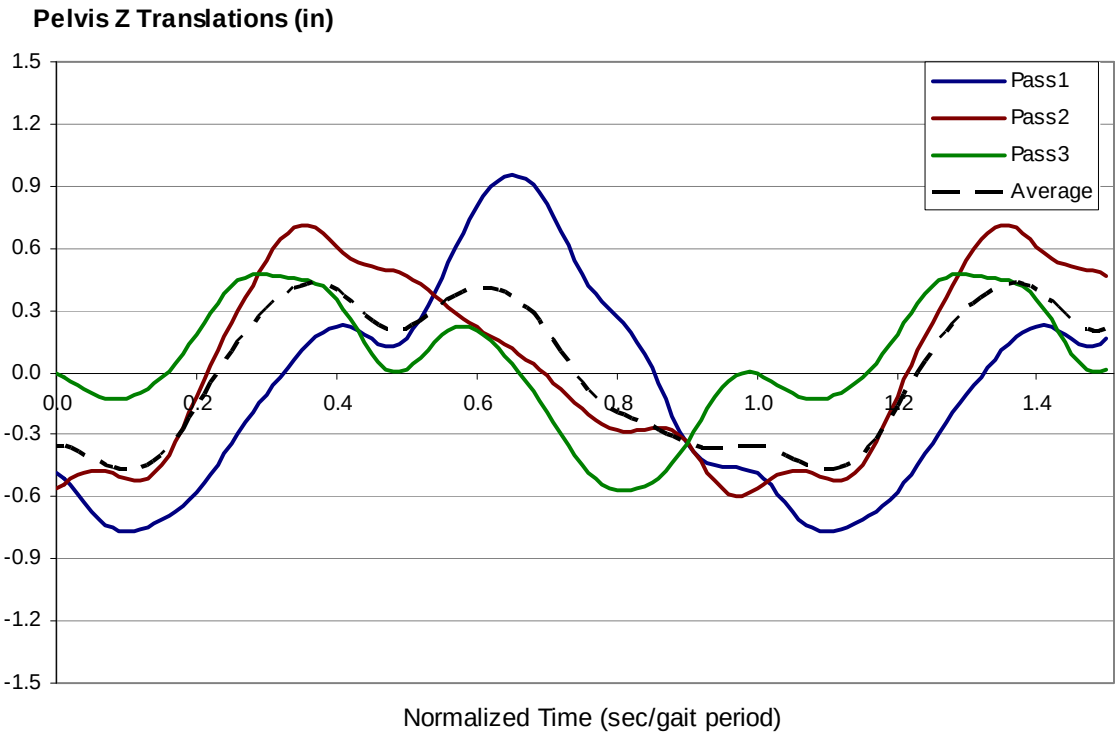


Figure A.11: Pelvis z-translations for subject B on Bailey

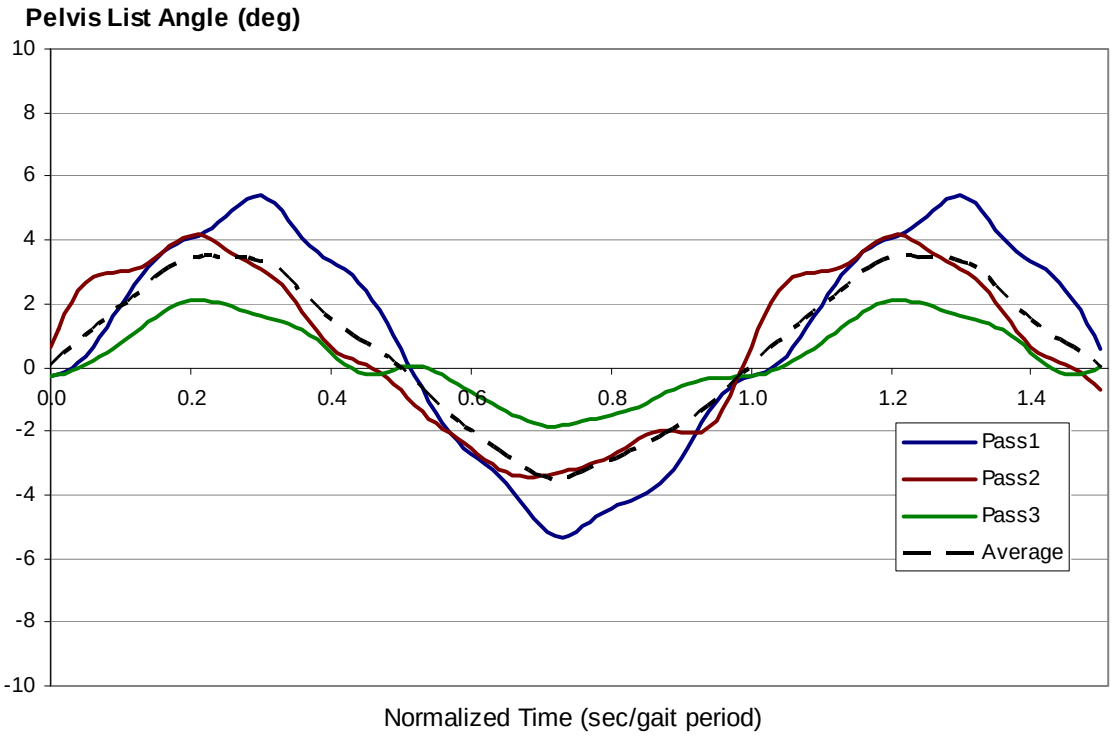


Figure A.12: Pelvis list angle for subject B on Bailey

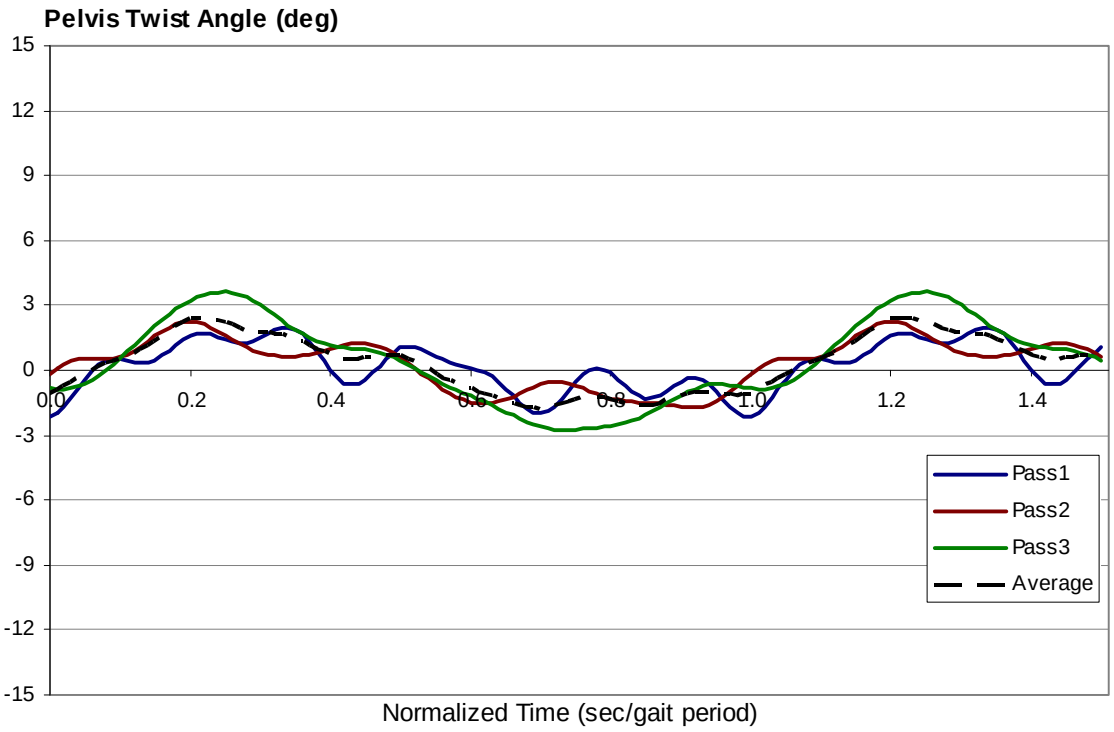


Figure A.13: Pelvis twist angle for subject B on Bailey

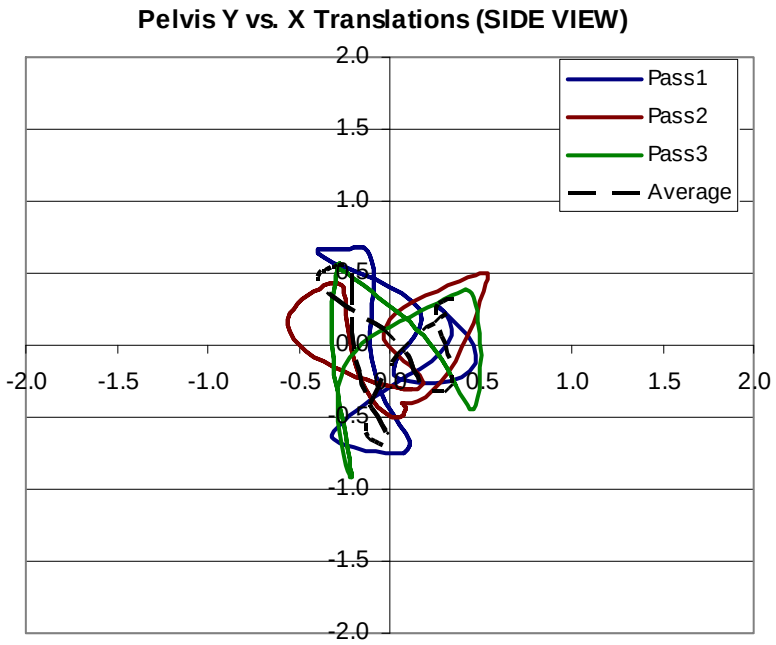


Figure A.14: Side view of pelvis for subject B on Bailey

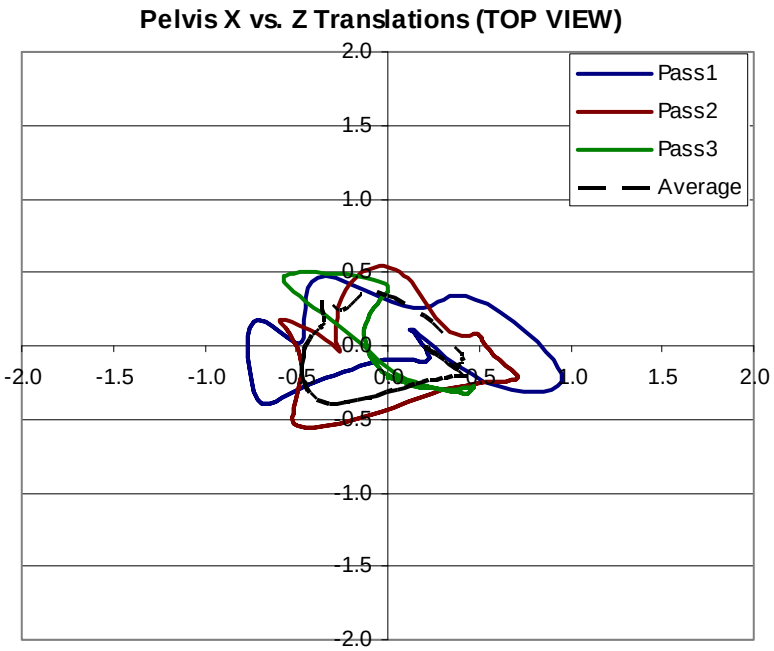


Figure A.15: Top view of pelvis for subject B on Bailey

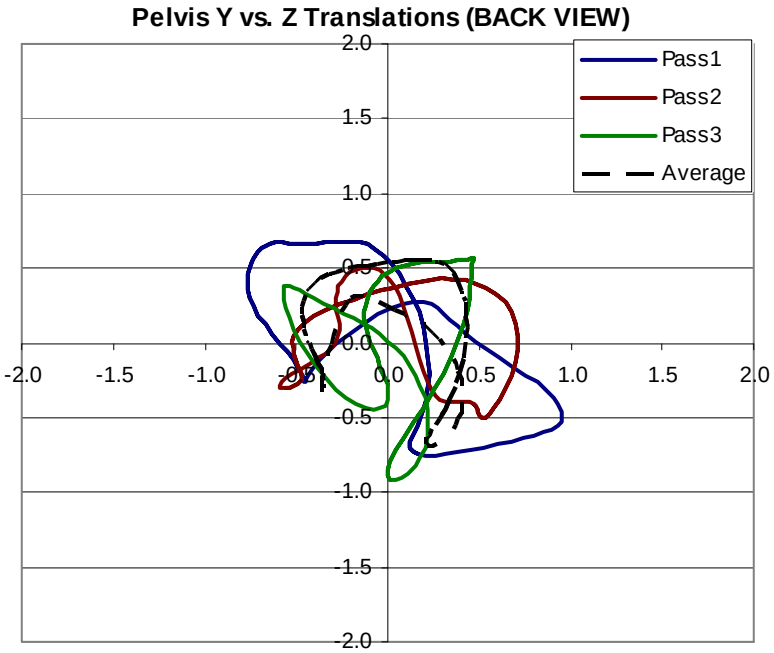


Figure A.16: Back view of pelvis for subject B on Bailey

Subject C

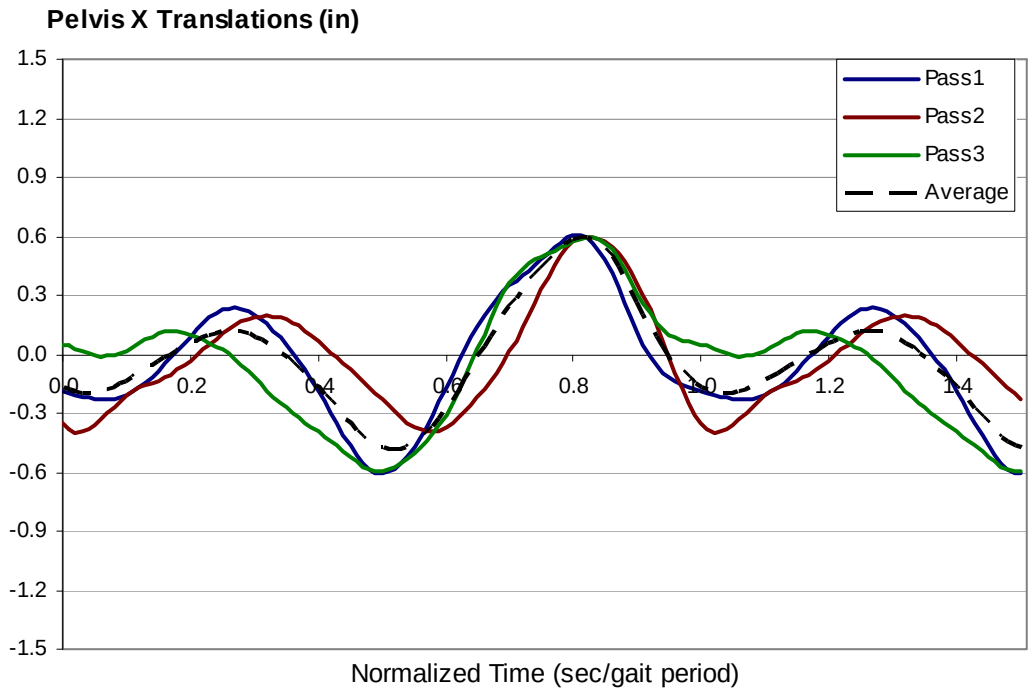


Figure A.17: Pelvis x-translations for subject C on Bailey

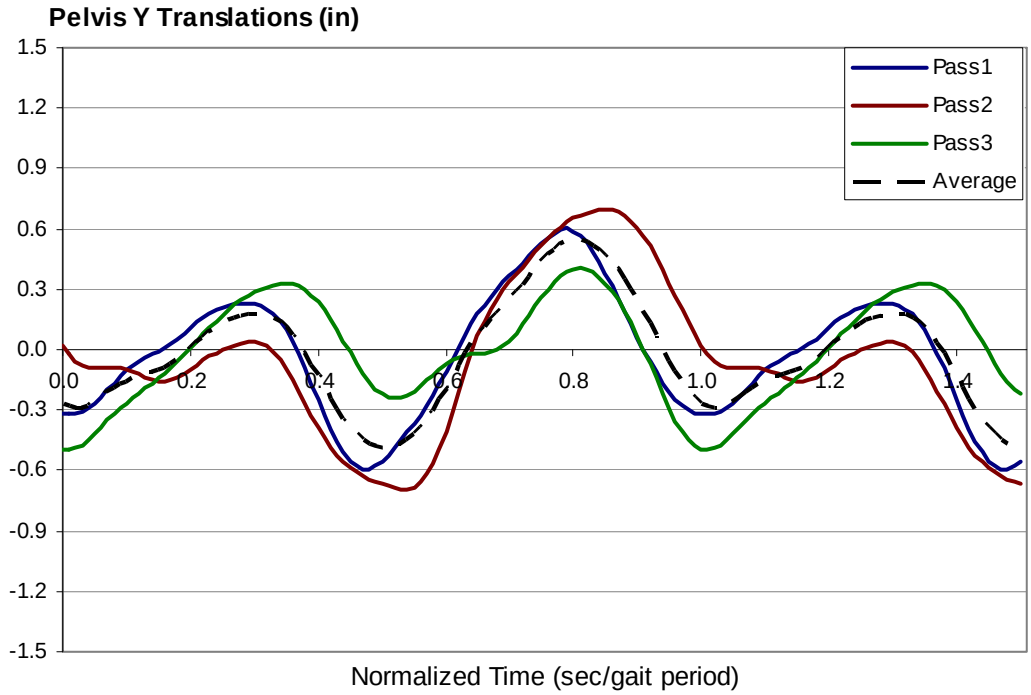


Figure A.18: Pelvis y-translations for subject C on Bailey

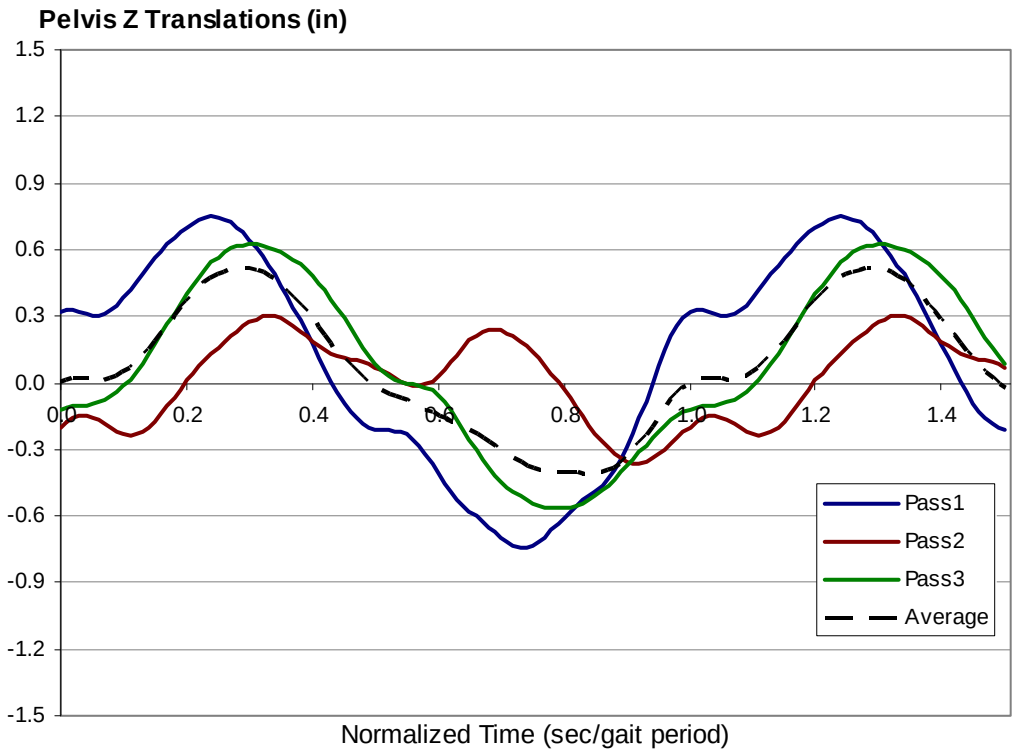


Figure A.19: Pelvis z-translations for subject C on Bailey

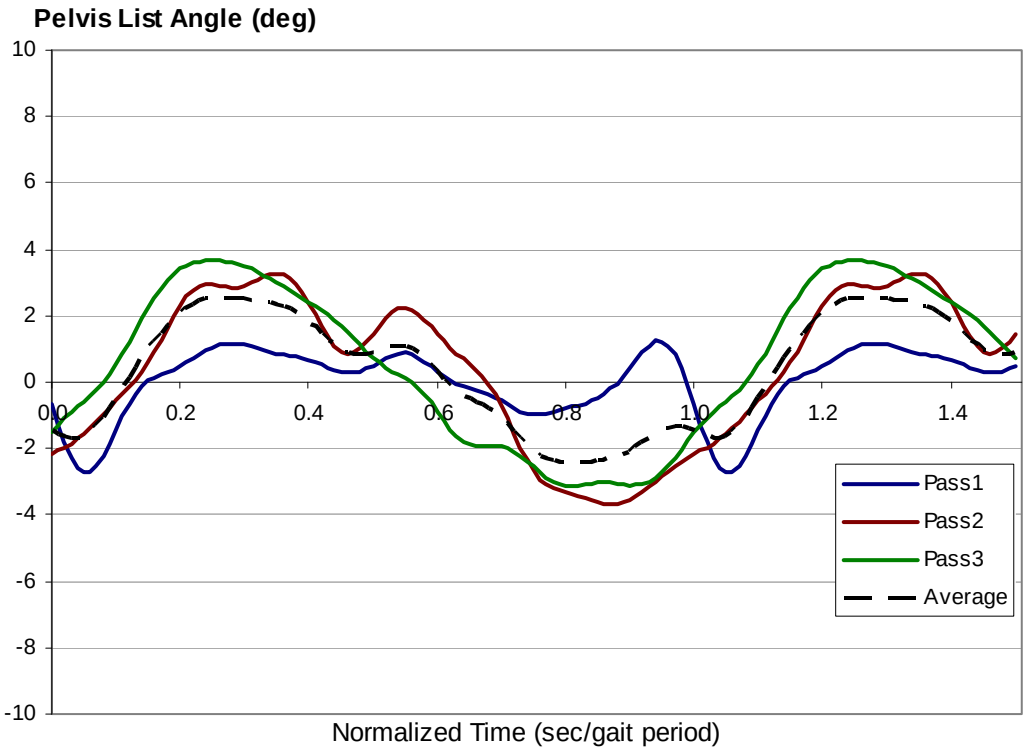


Figure A.20: Pelvis list angle for subject C on Bailey

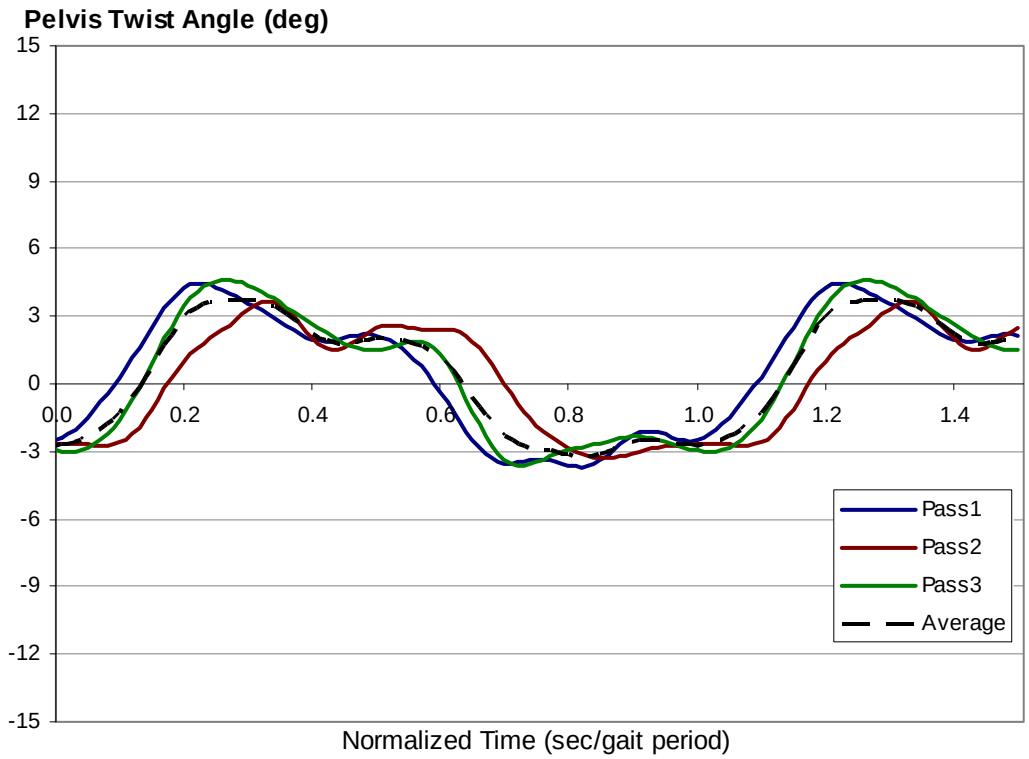


Figure A.21: Pelvis twist angle for subject C on Bailey

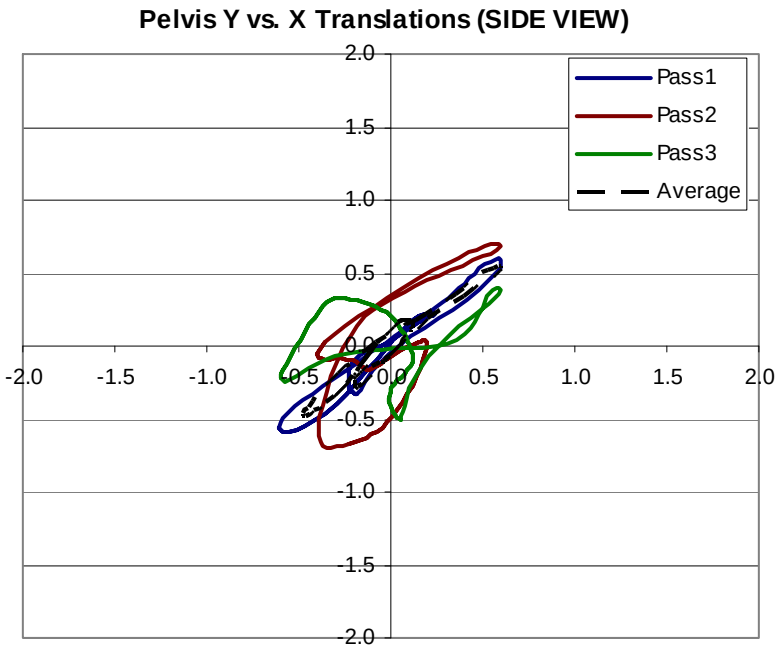


Figure A.22: Side view of pelvis for subject C on Bailey

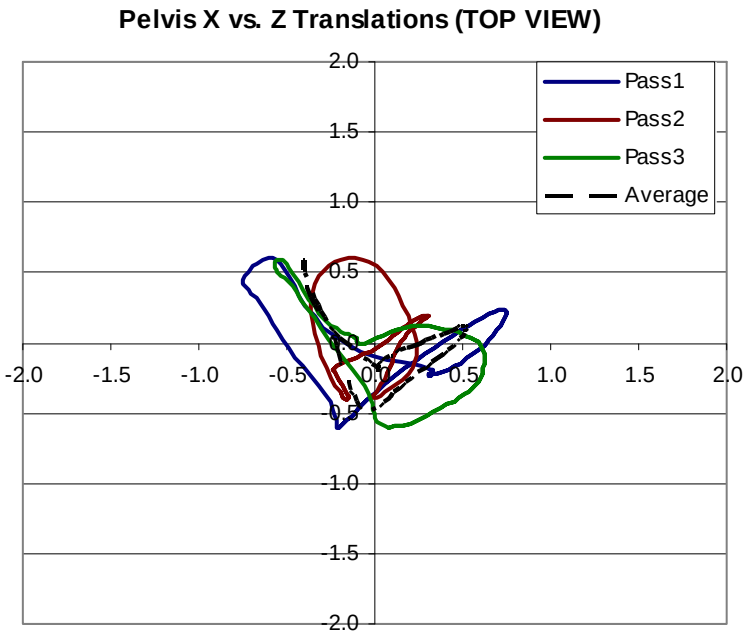


Figure A.23: Top view of pelvis for subject C on Bailey

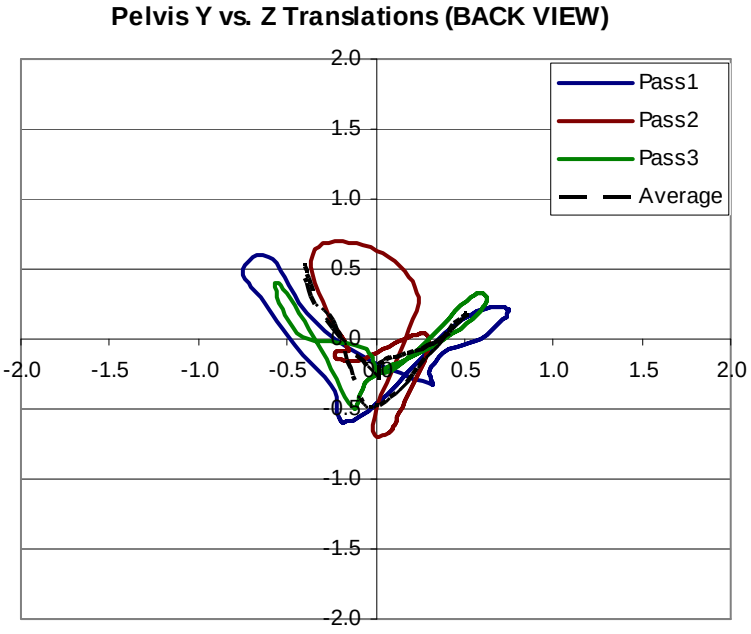


Figure A.24: Back view of pelvis for subject C on Bailey

Subject D

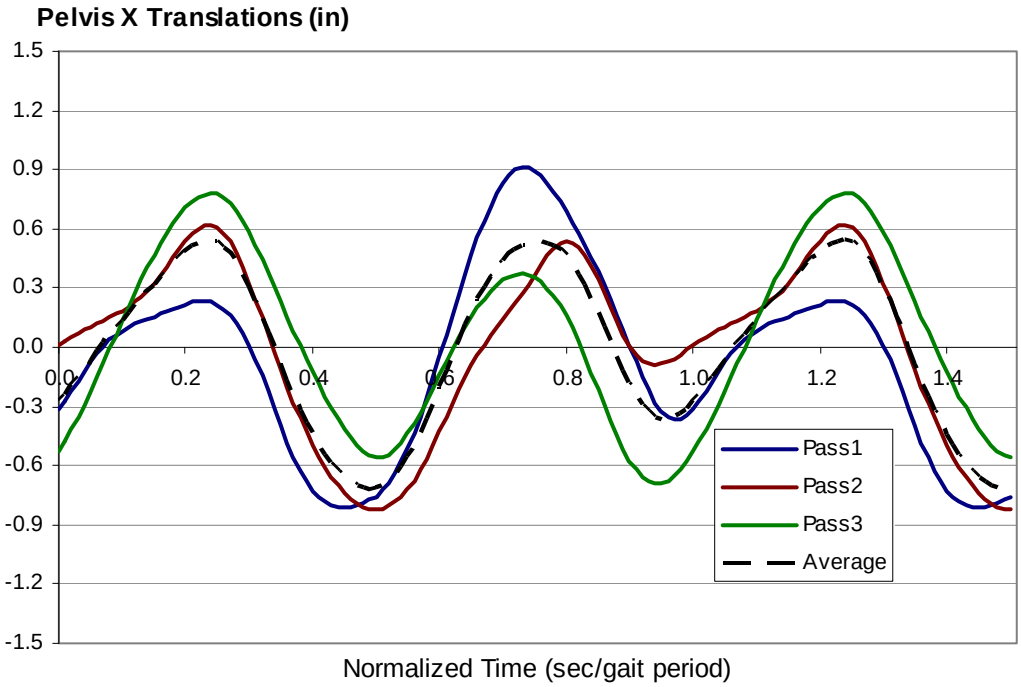


Figure A.25: Pelvis x-translations for subject D on Bailey

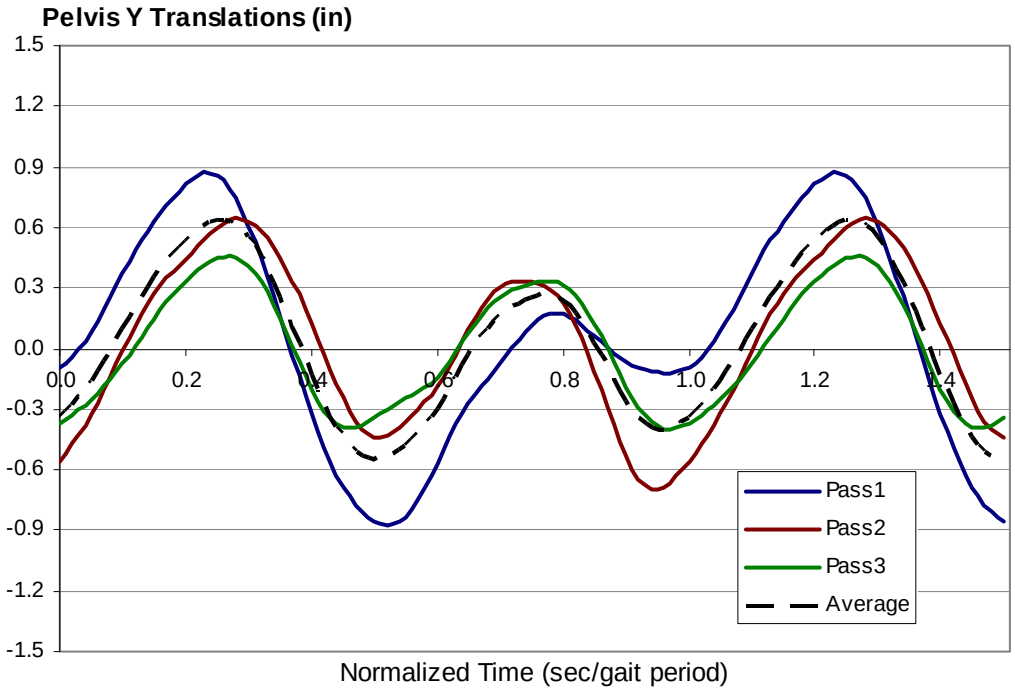


Figure A.26: Pelvis y-translations for subject D on Bailey

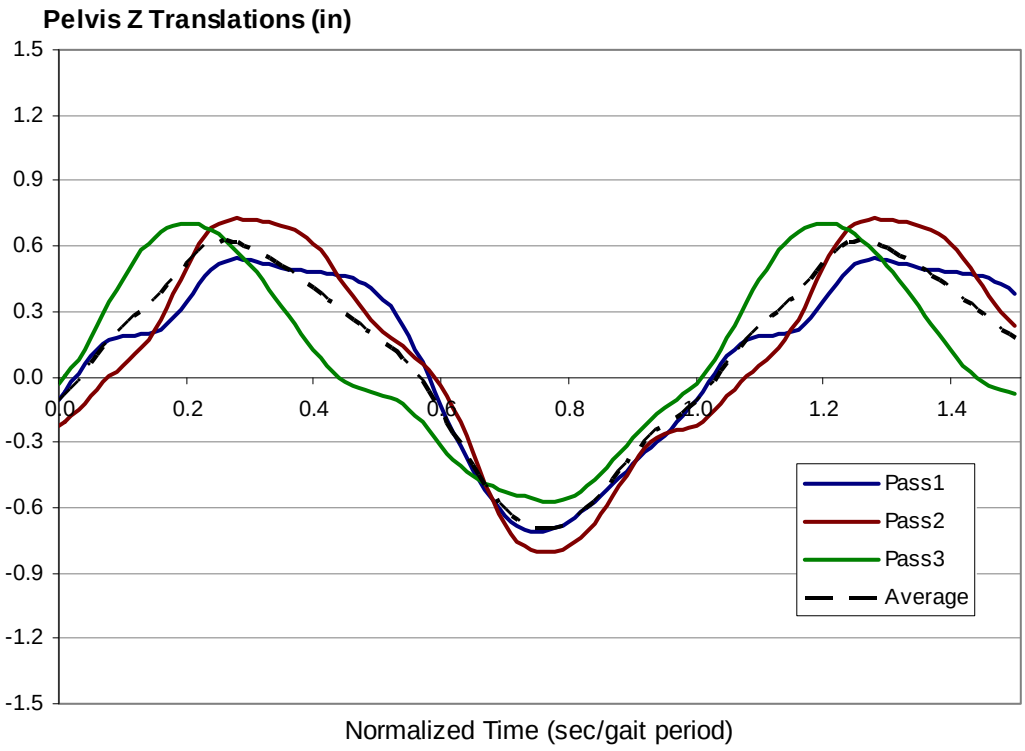


Figure A.27: Pelvis z-translations for subject D on Bailey

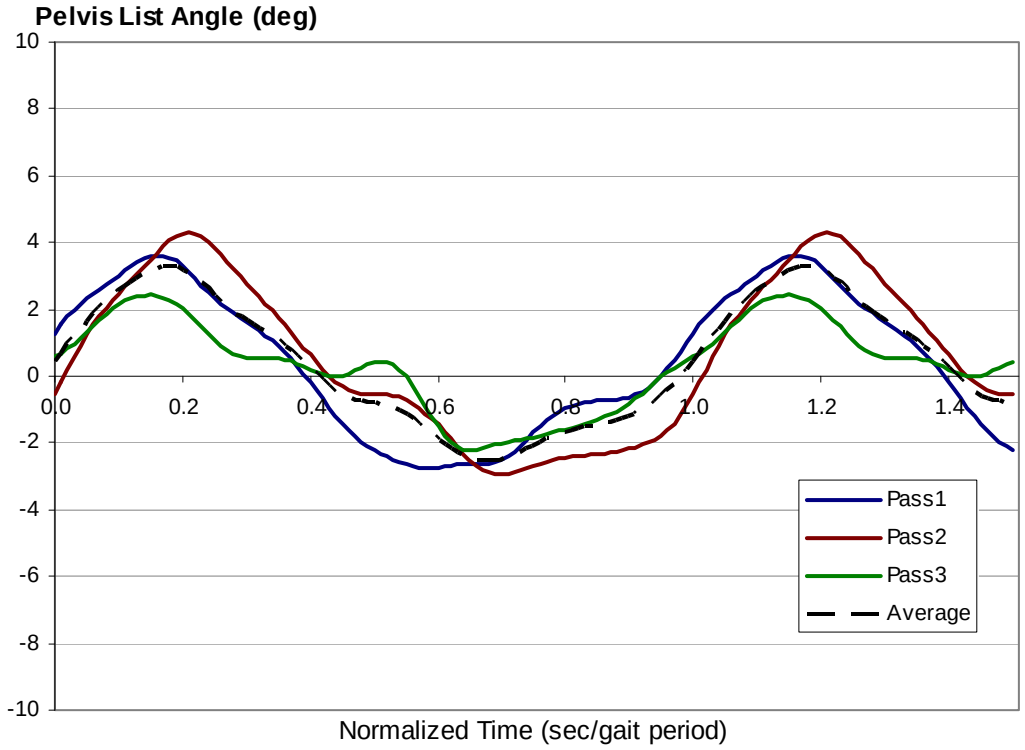


Figure A.28: Pelvis list angle for subject D on Bailey

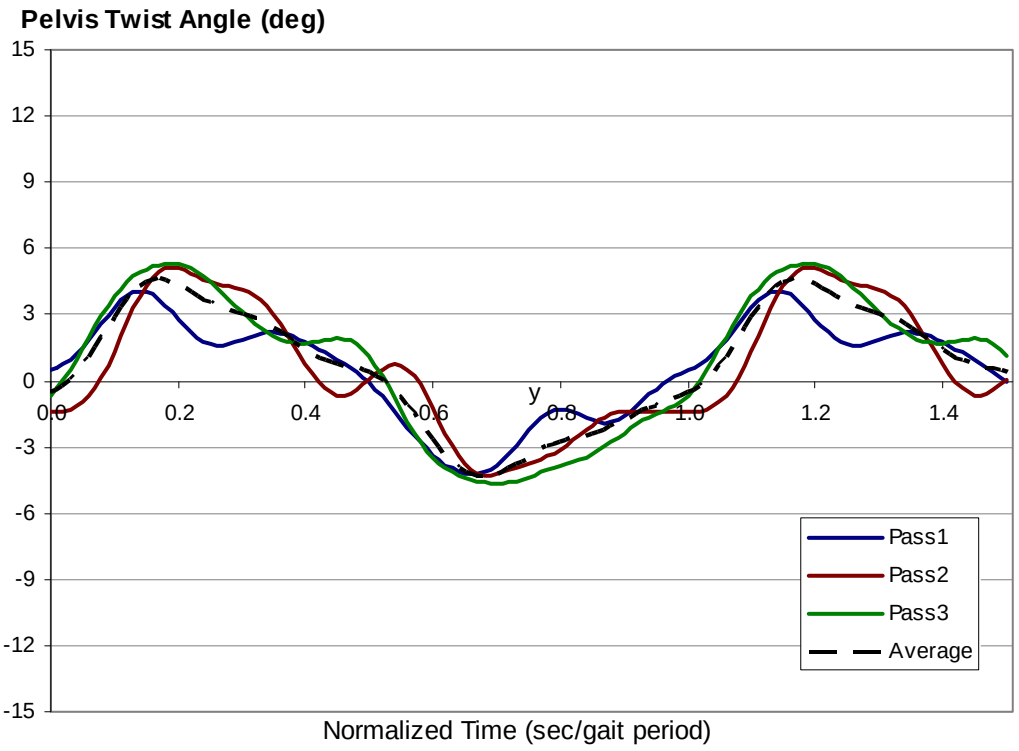


Figure A.29: Pelvis twist Angle for subject D on Bailey

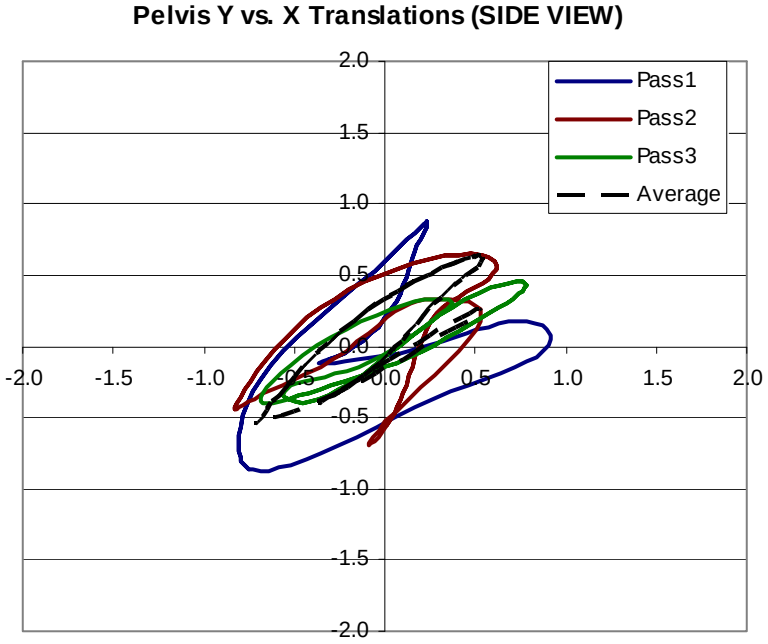


Figure A.30: Side view of pelvis for subject D on Bailey

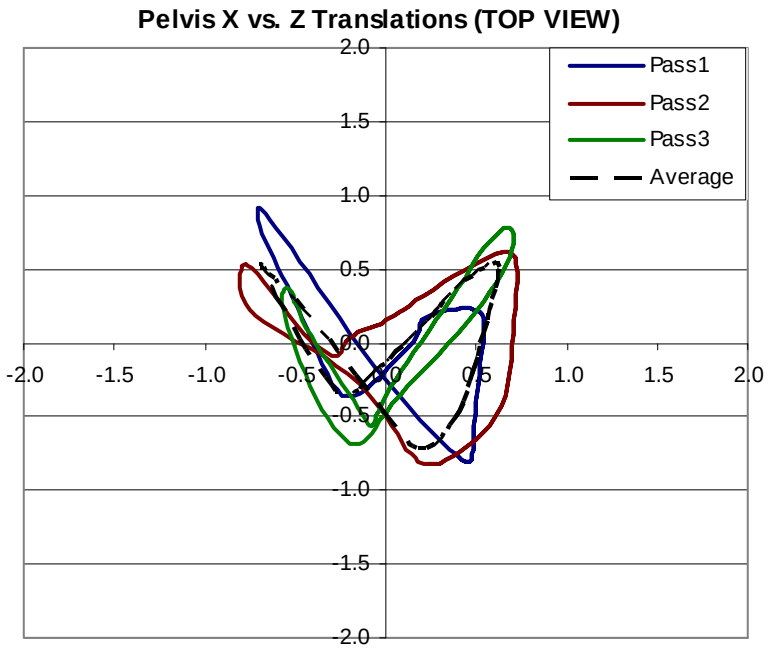


Figure A.31: Top view of pelvis for subject D on Bailey

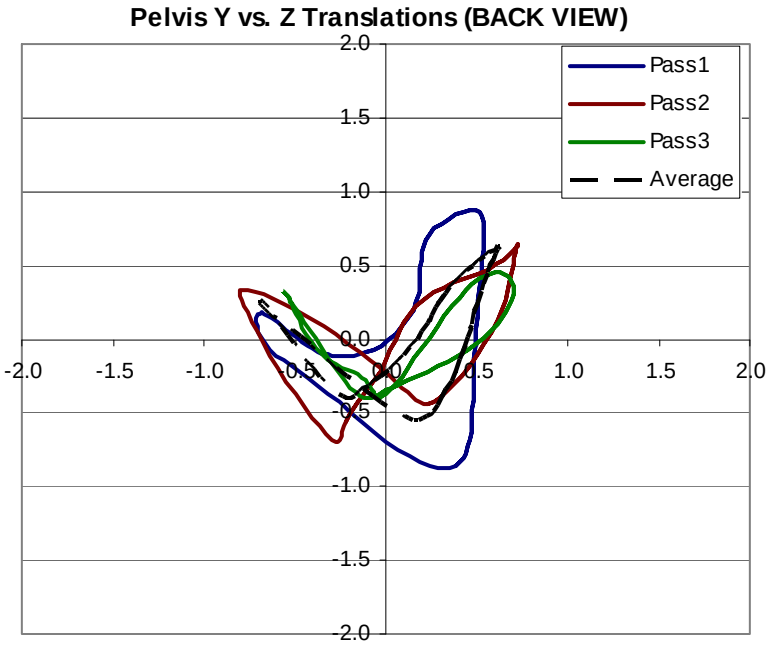


Figure A.32: Back view of pelvis for subject D on Bailey

Subject E

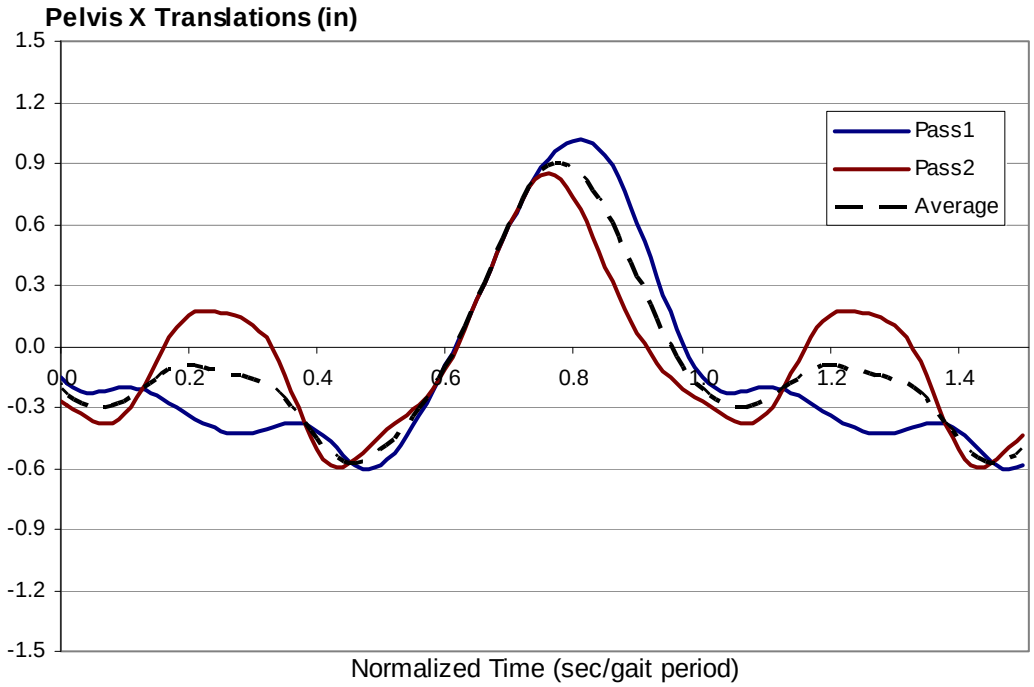


Figure A.33: Pelvis x-translations for subject E on Bailey

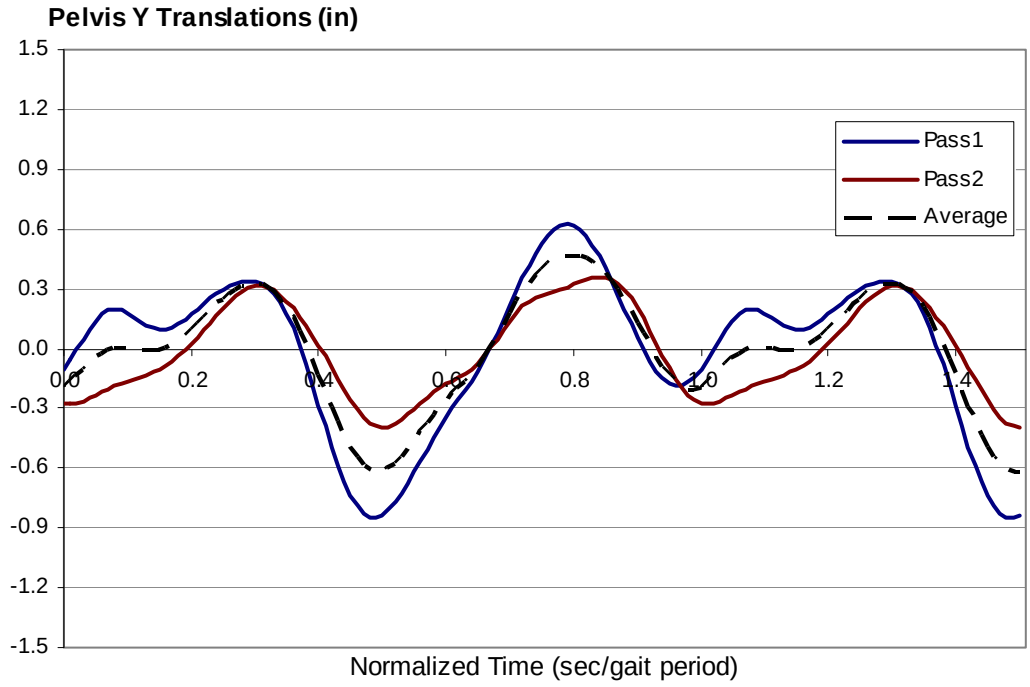


Figure A.34: Pelvis y-translations for subject E on Bailey

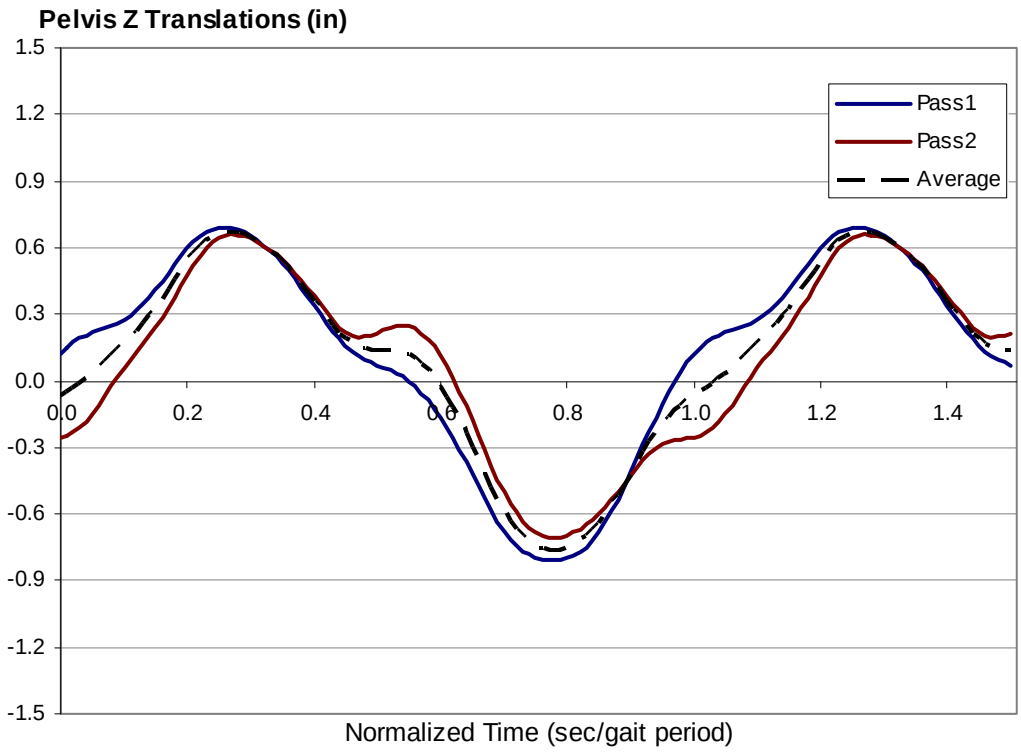


Figure: A.35: Pelvis z-translations for subject E on Bailey

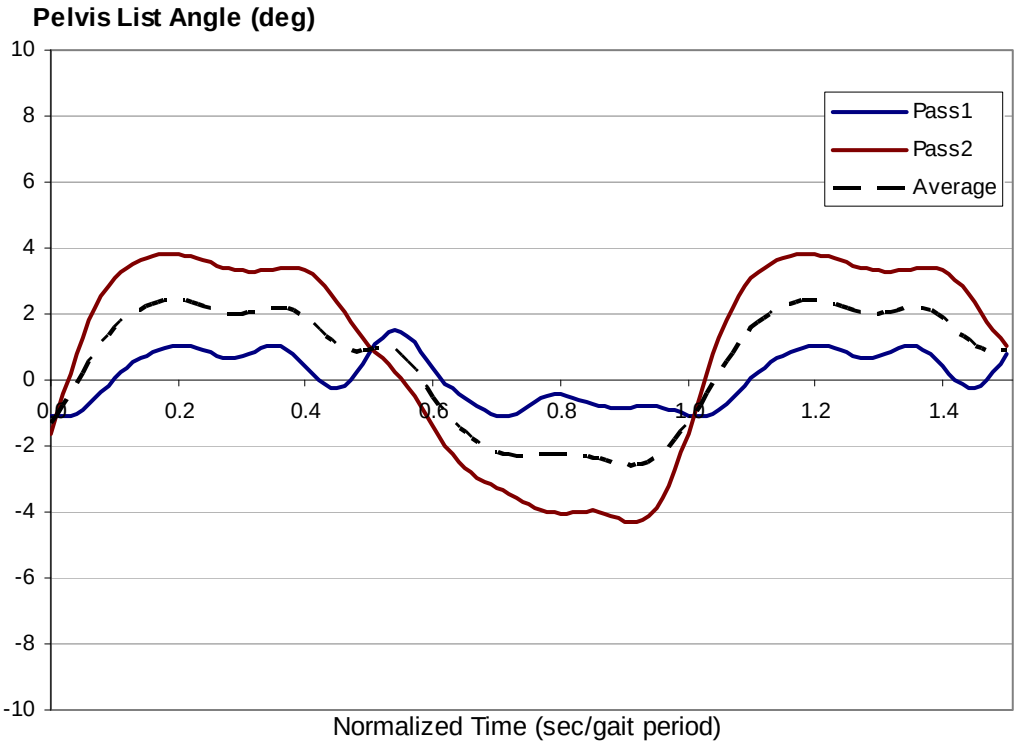


Figure A.36: Pelvis list angle for subject E on Bailey

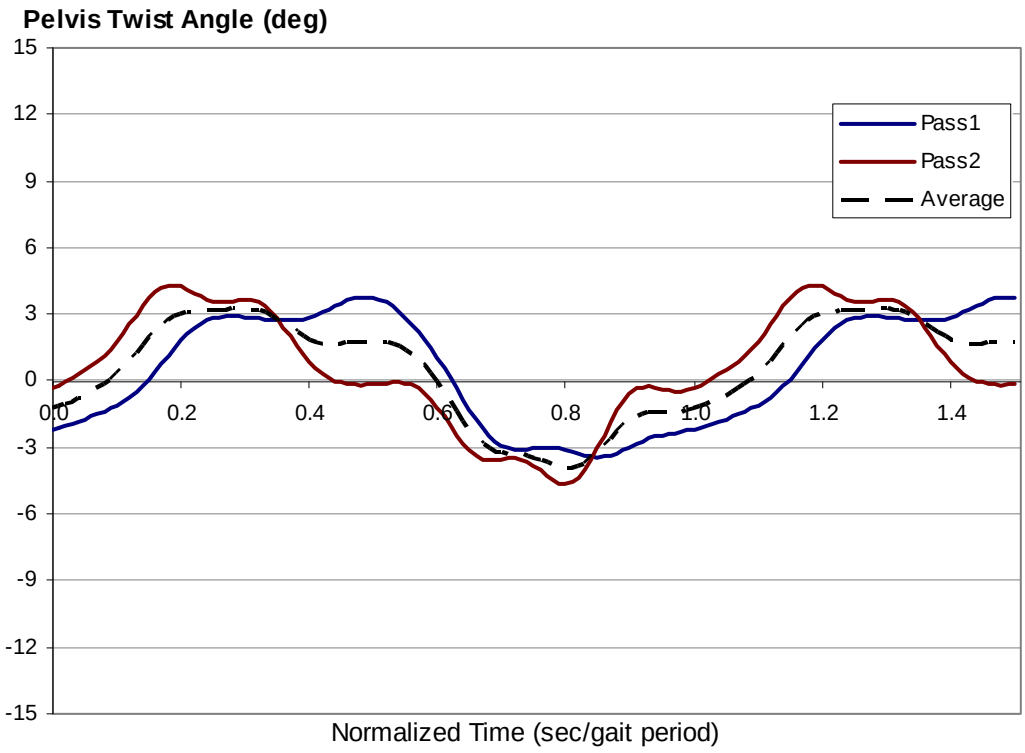


Figure A.37: Pelvis twist angle for subject E on Bailey

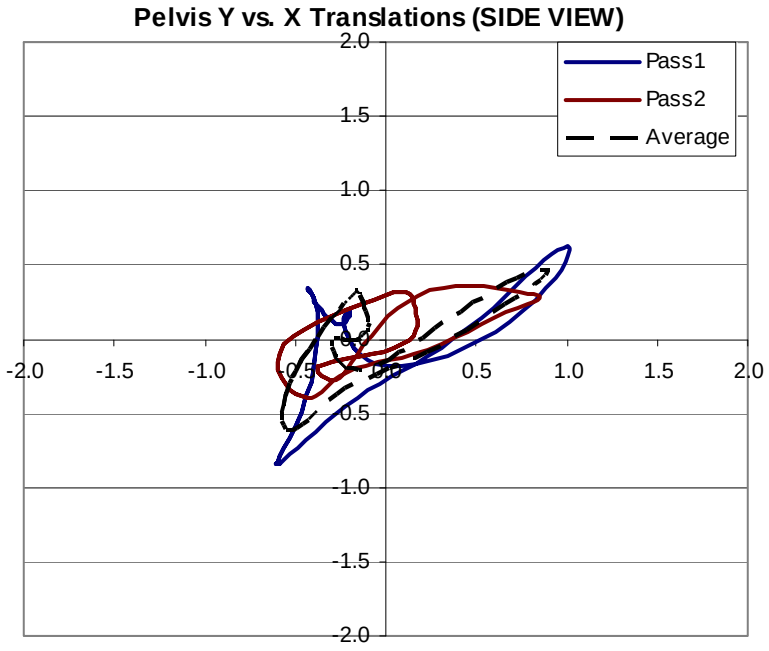


Figure A.38: Side view of pelvis for subject E on Bailey

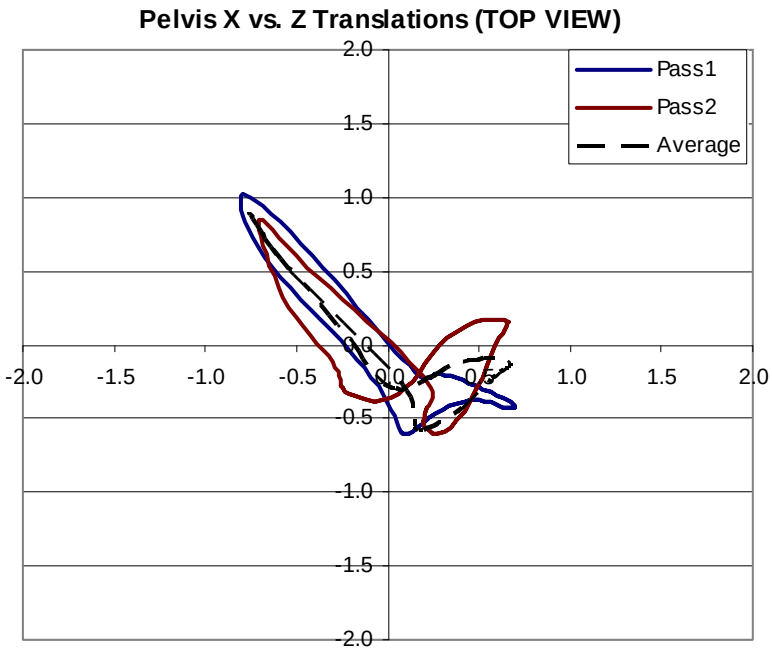


Figure A.39: Top view of pelvis for subject E on Bailey

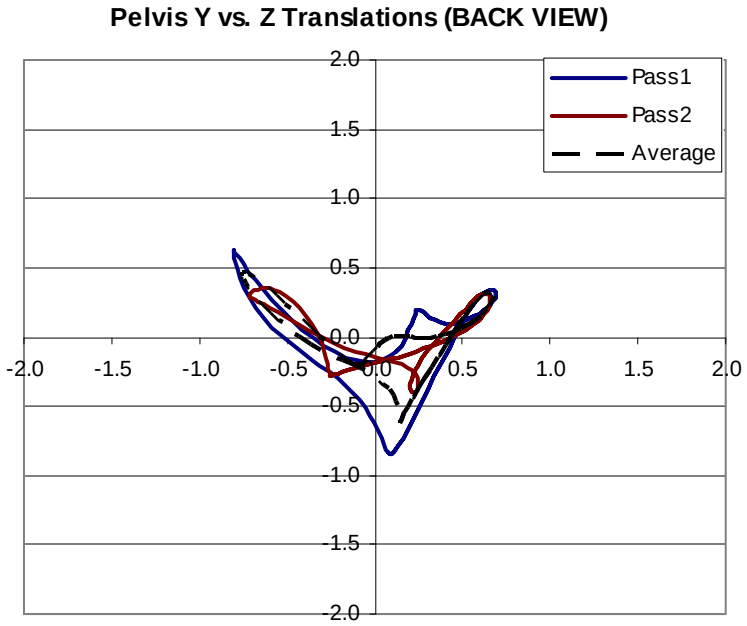


Figure A.40: Back view of pelvis for subject E on Bailey

Averages

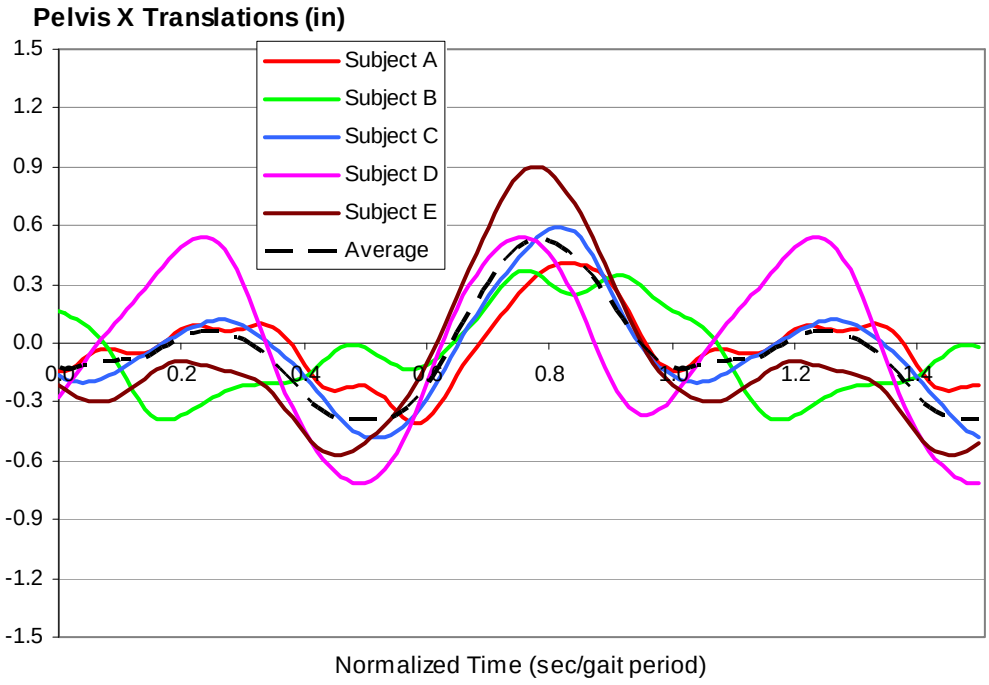


Figure A.41: Pelvis x-translations for all subjects on Bailey

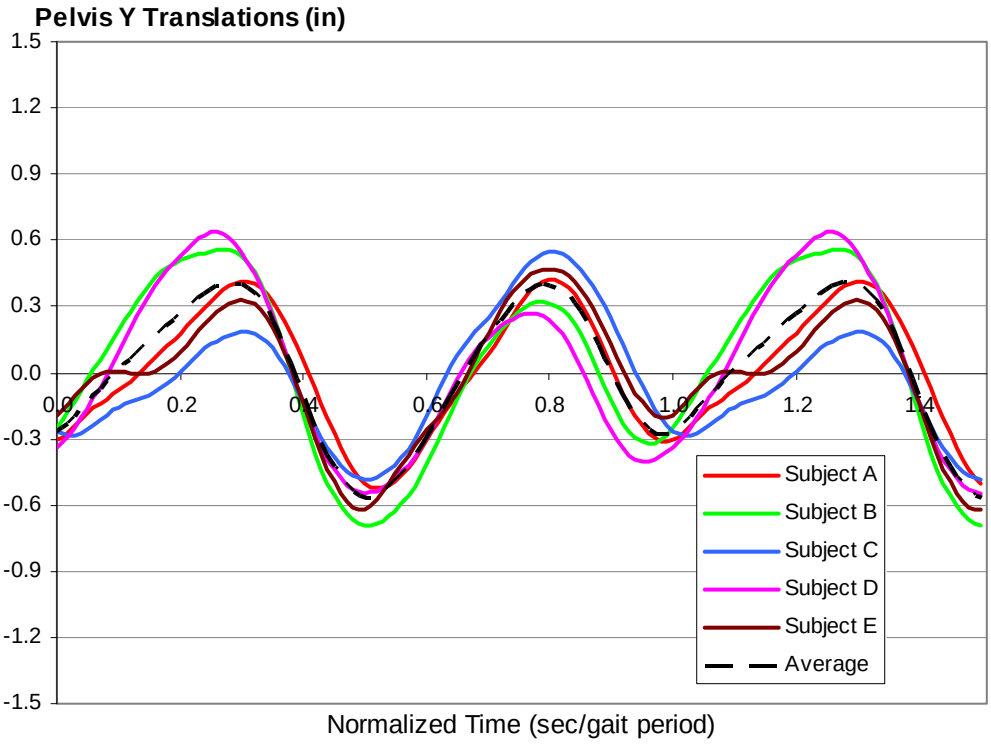


Figure A.42: Pelvis y-translations for all subjects on Bailey

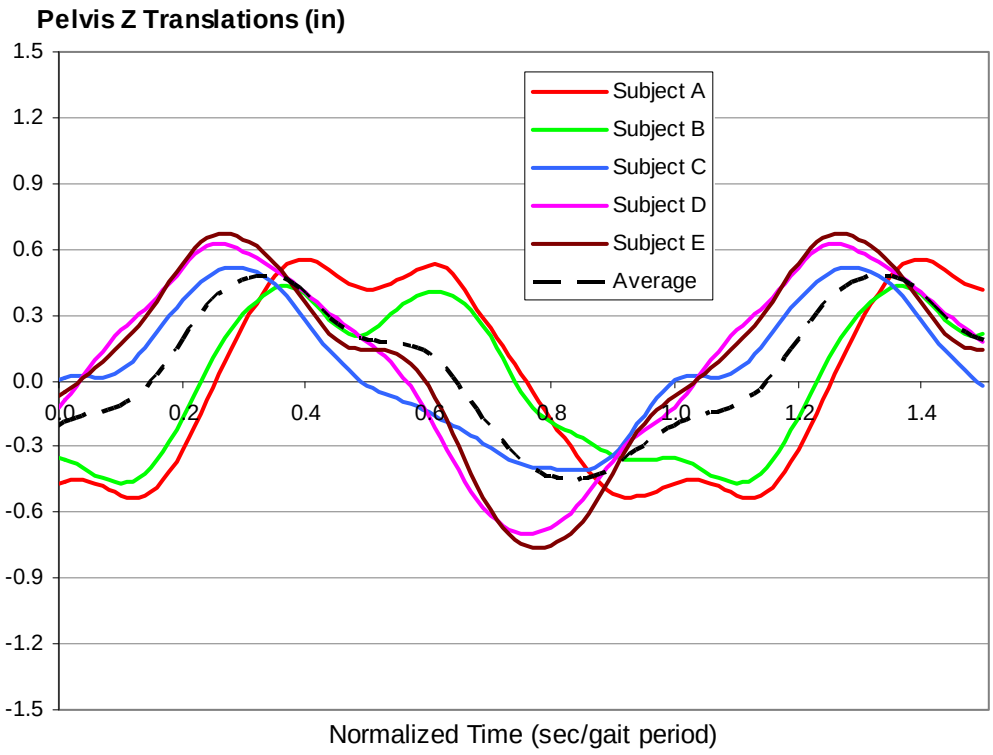


Figure A.43: Pelvis z-translations for all subjects on Bailey

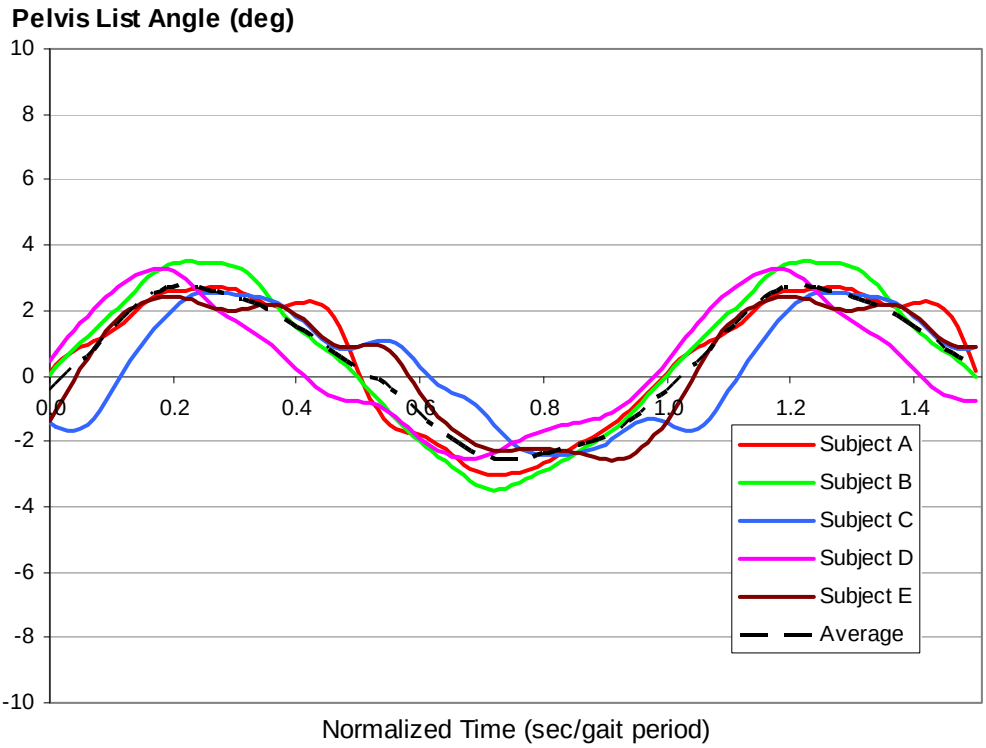


Figure A.44: Pelvis list angle for all subjects on Bailey

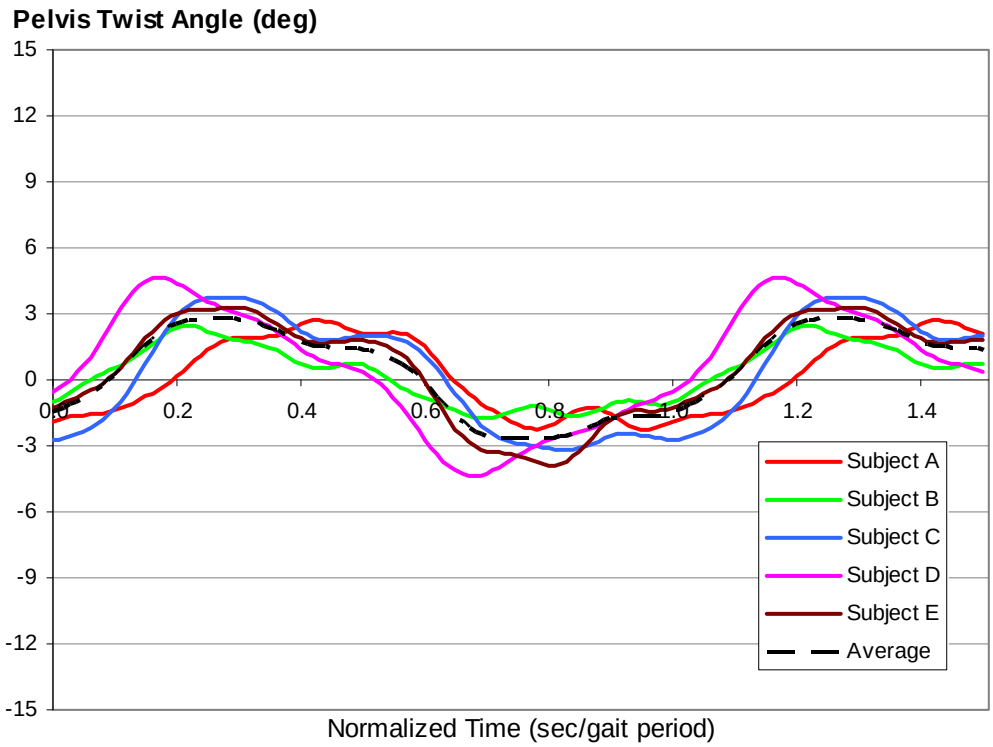


Figure A.45: Pelvis twist angle for all subjects on Bailey

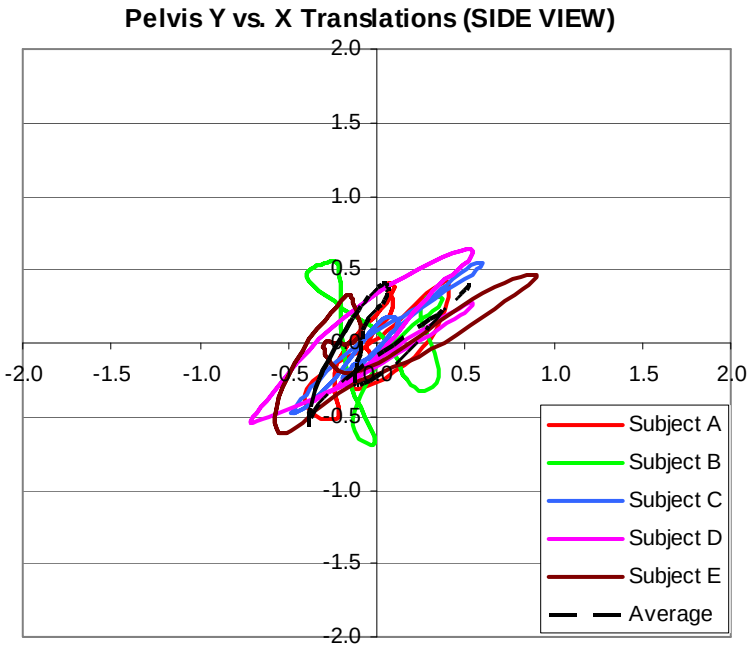


Figure A.46: Side view of pelvis for all subjects on Bailey

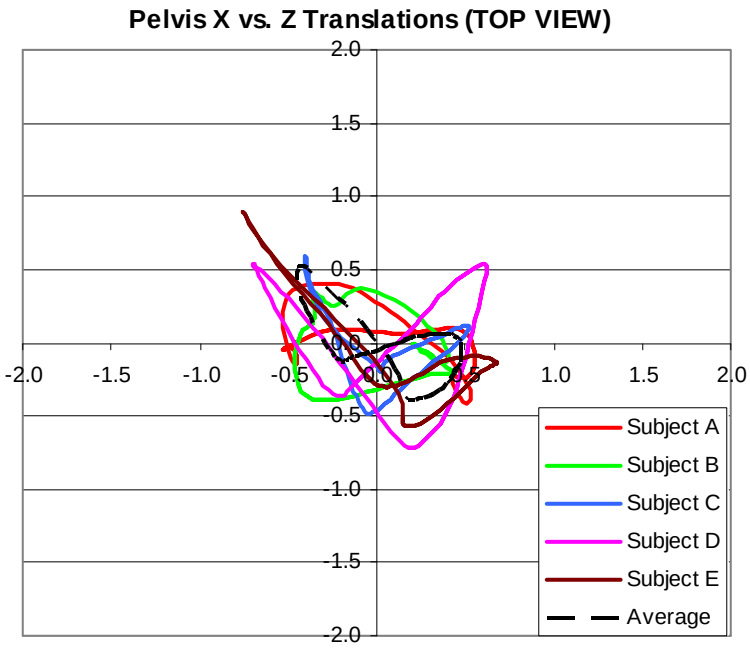


Figure A.47: Top view of pelvis for all subjects on Bailey

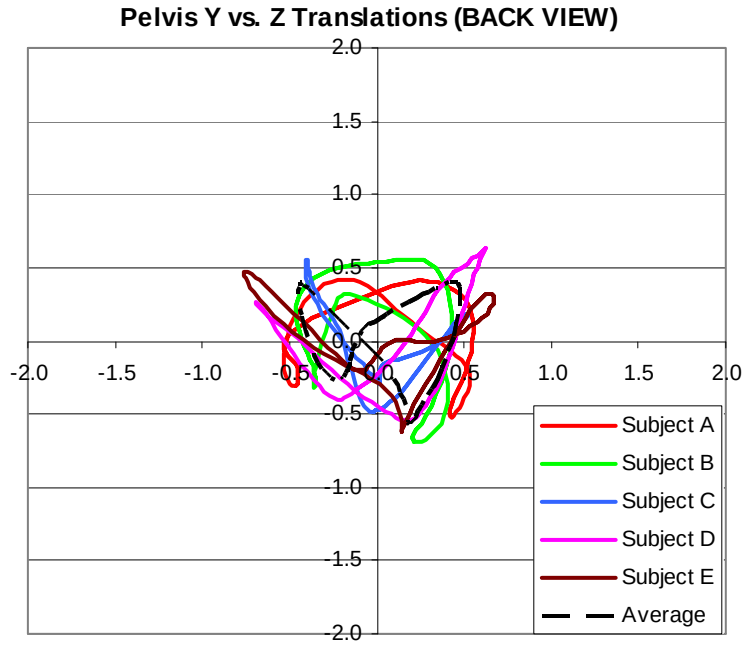


Figure A.48: Back view of pelvis for all subjects on Bailey

APPENDIX B

Riding Data: Bonnie

Subject E

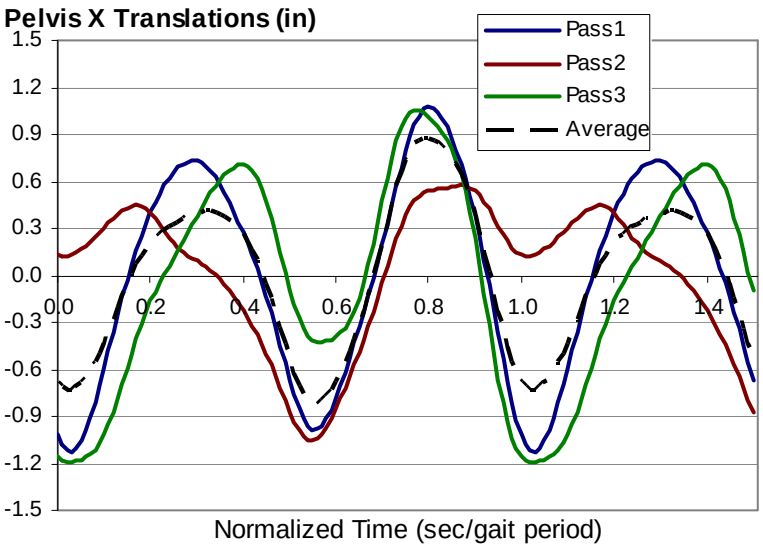


Figure B.1: Pelvis x-translations for subject E on Bonnie

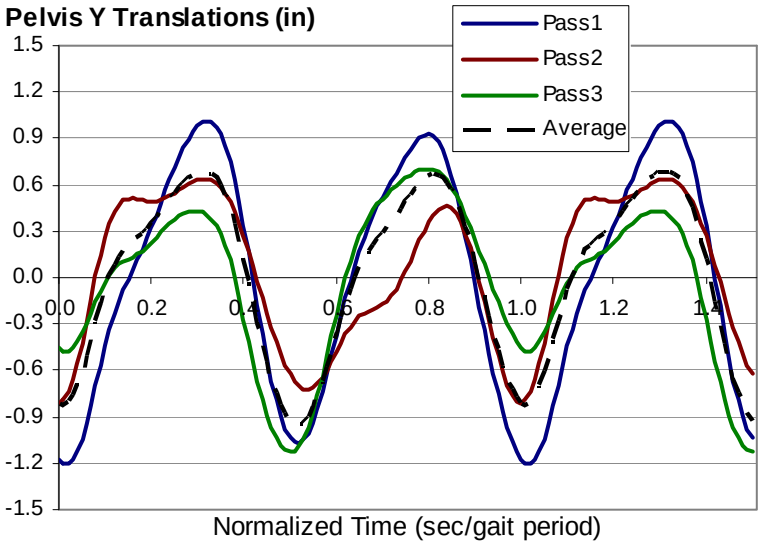


Figure B.2: Pelvis y-translations for subject E on Bonnie

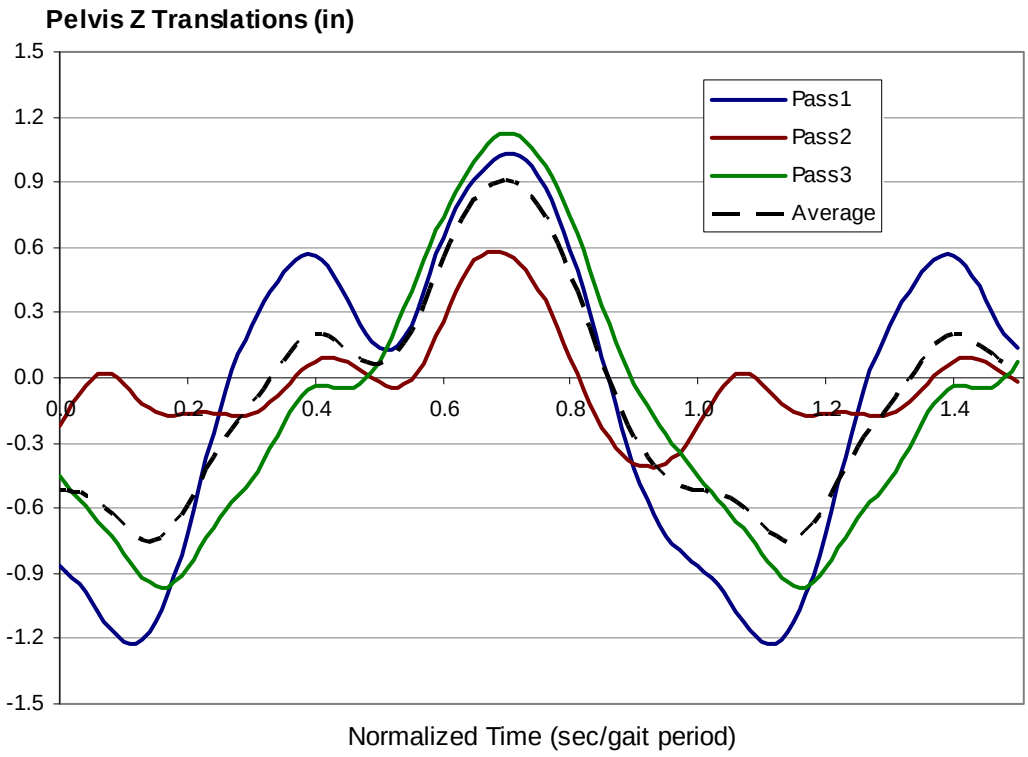


Figure B.3: Pelvis z-translations for subject E on Bonnie

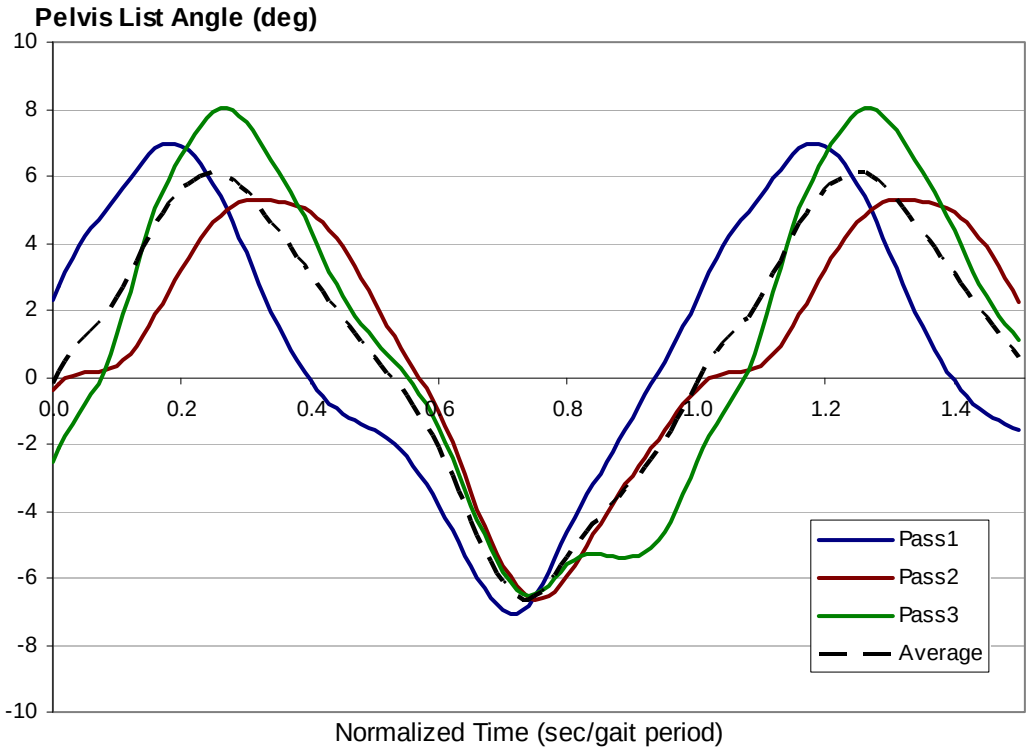


Figure B.4: Pelvis list angle for subject E on Bonnie

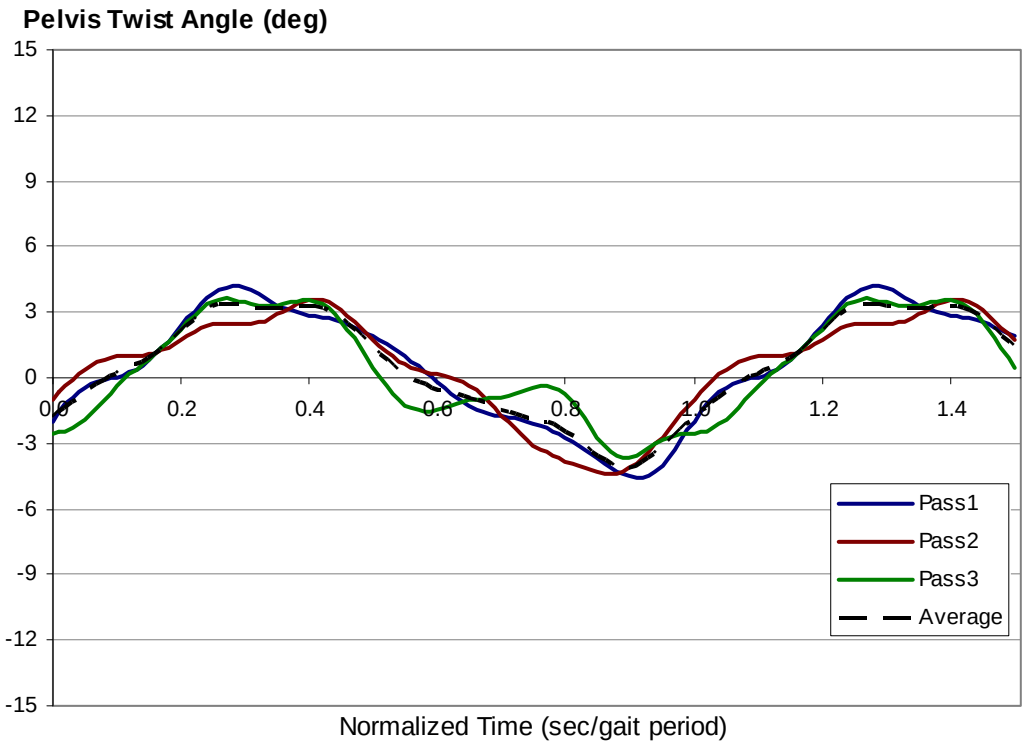


Figure B.5: Pelvis twist angle for subject E on Bonnie

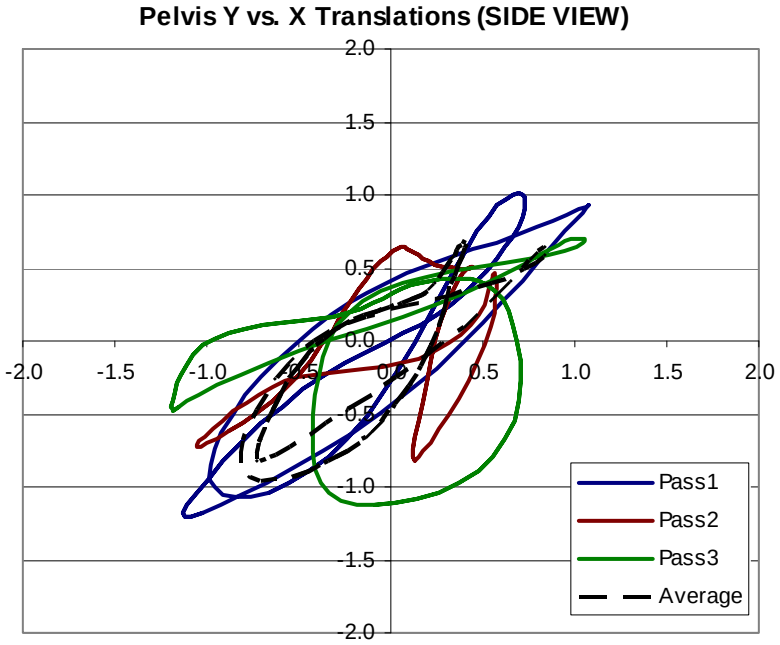


Figure B.6: Side view of pelvis for subject E on Bonnie

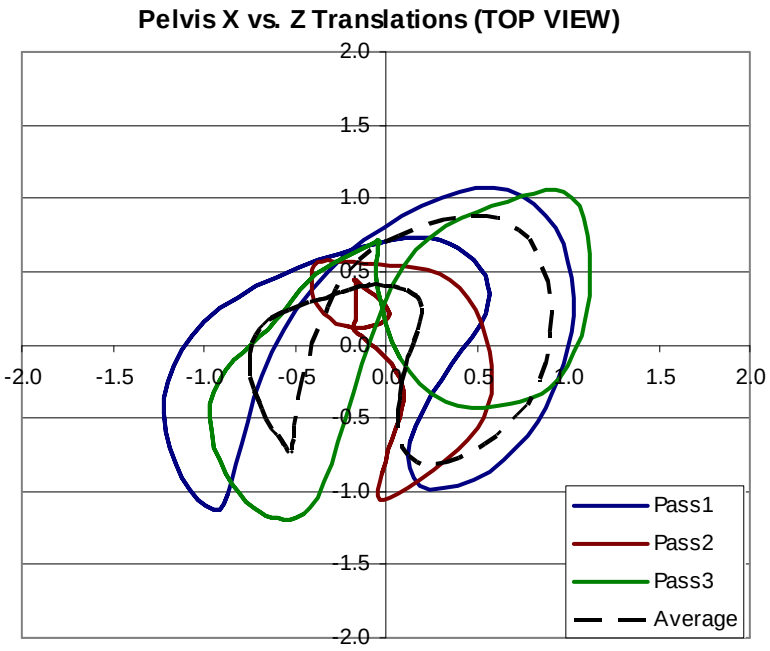


Figure B.7: Top view of pelvis for subject E on Bonnie

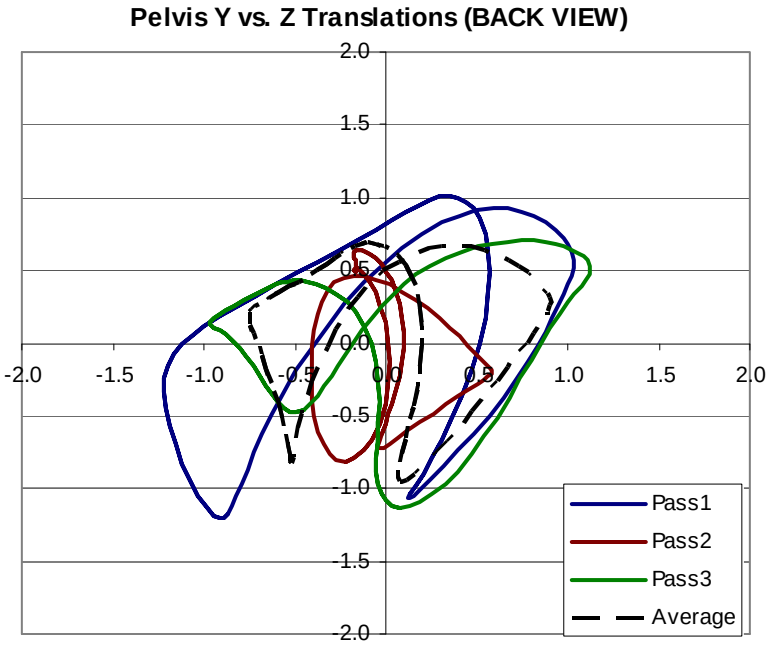


Figure B.8: Back view of pelvis for subject E on Bonnie

Subject C

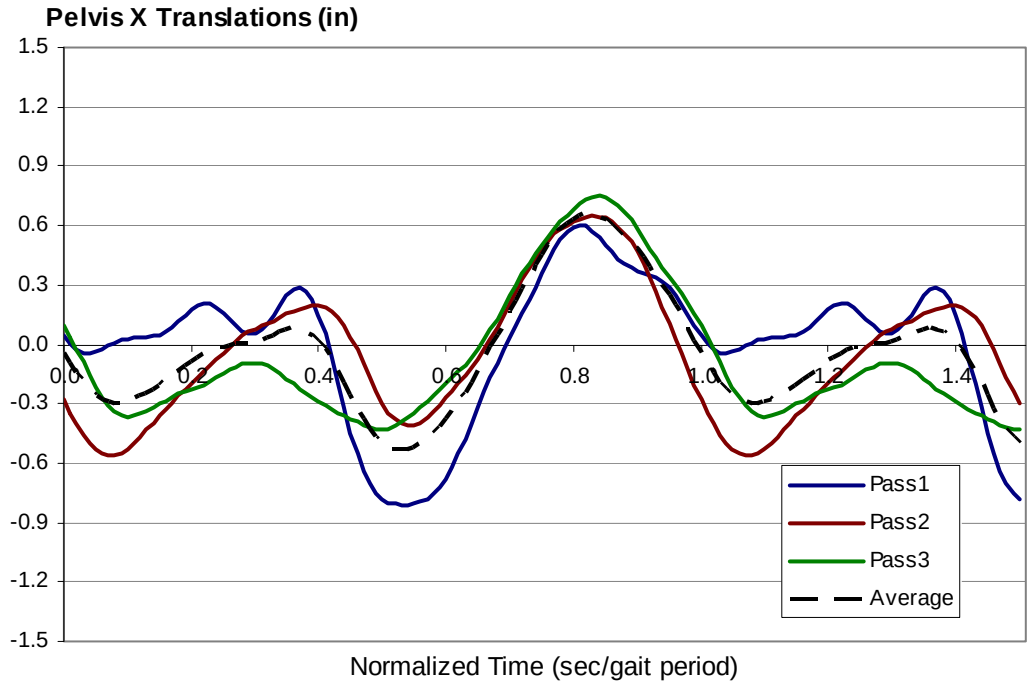


Figure B.9: Pelvis x-translations for subject C on Bonnie

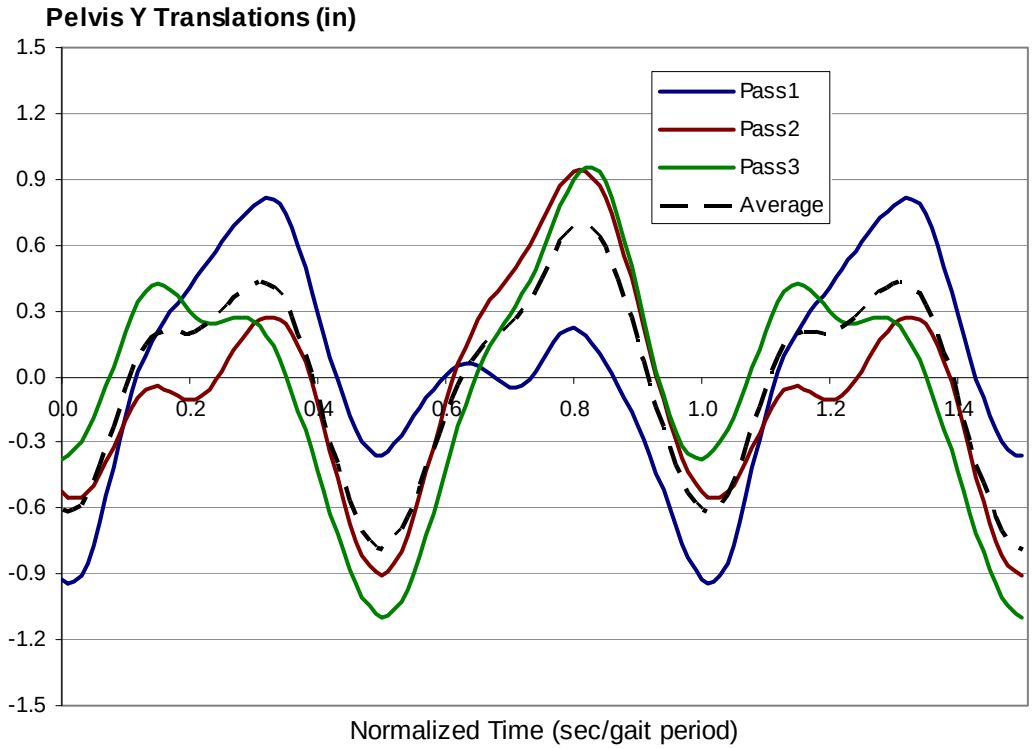


Figure B.10: Pelvis y-translations for subject C on Bonnie

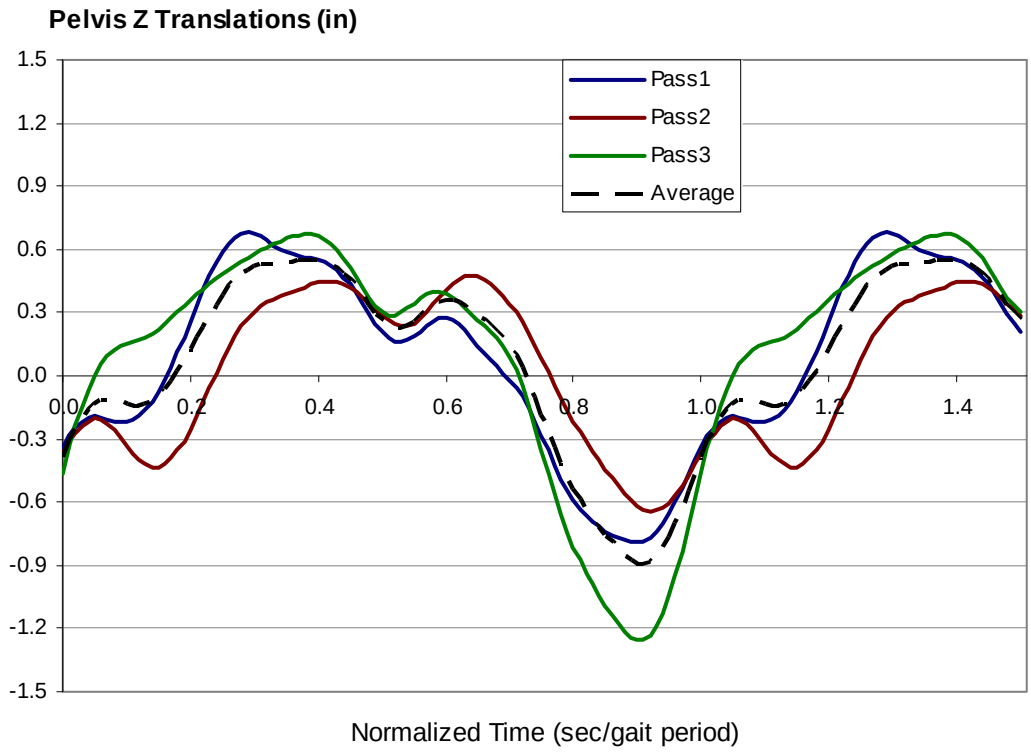


Figure B.11: Pelvis z-translations for subject C on Bonnie

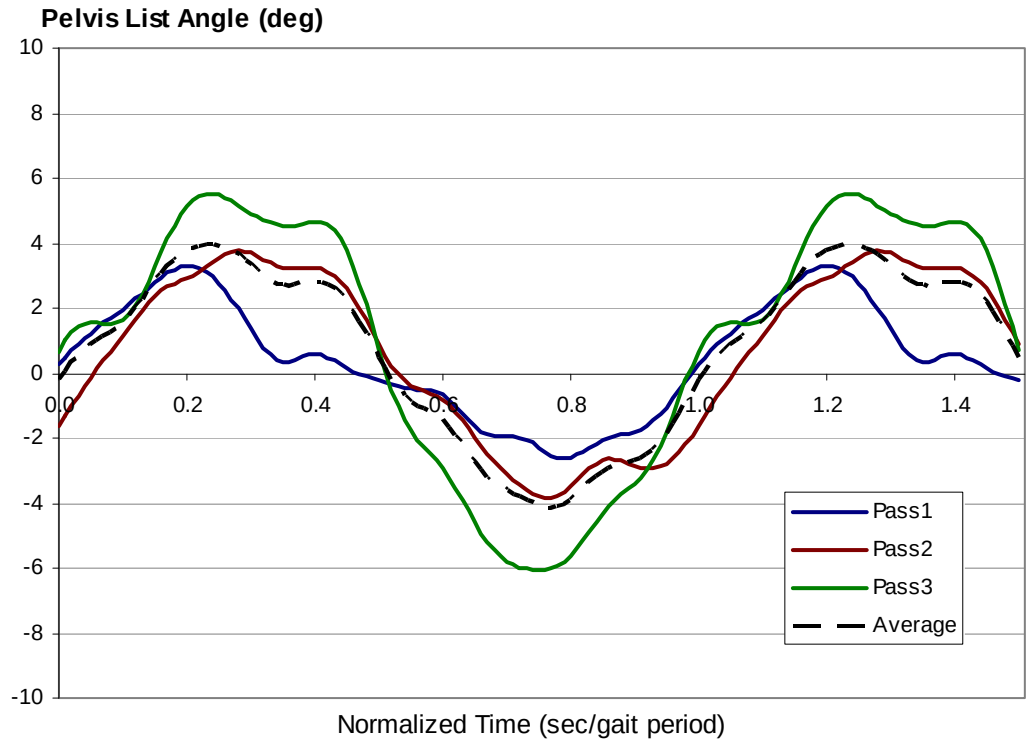


Figure B.12: Pelvis list angle for subject C on Bonnie

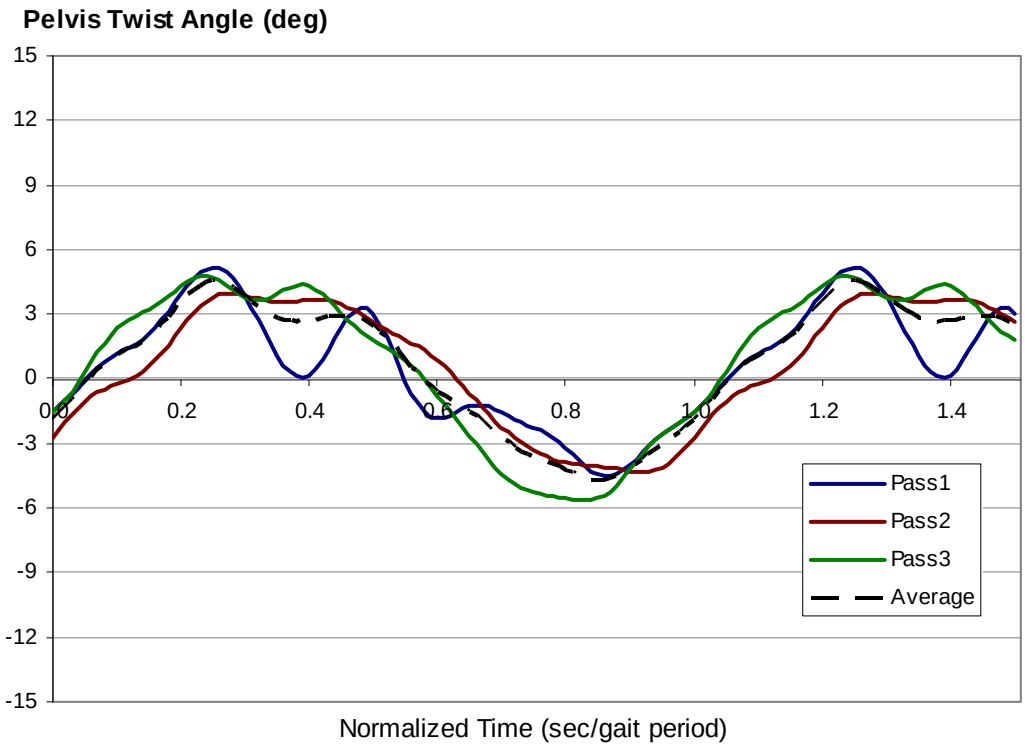


Figure B.13: Pelvis twist angle for subject C on Bonnie

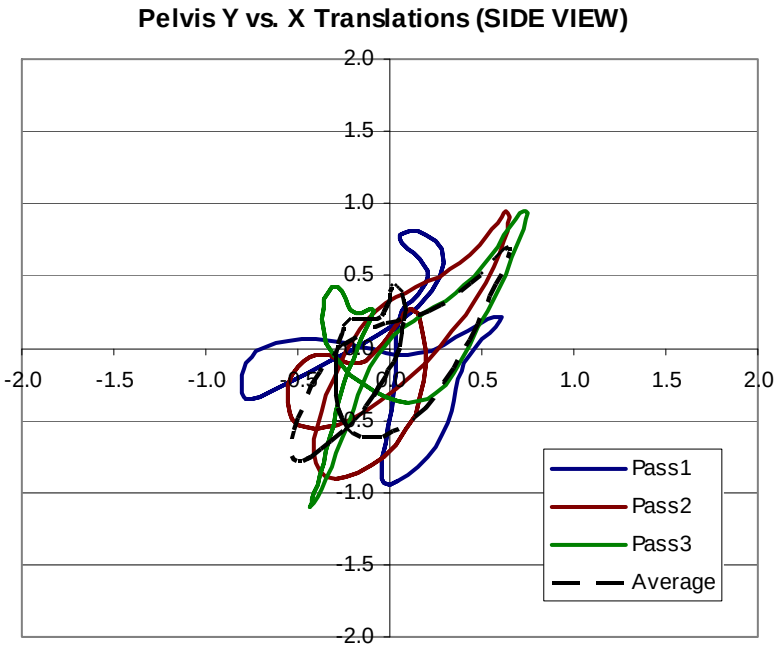


Figure B.14: Side view of pelvis for subject C on Bonnie

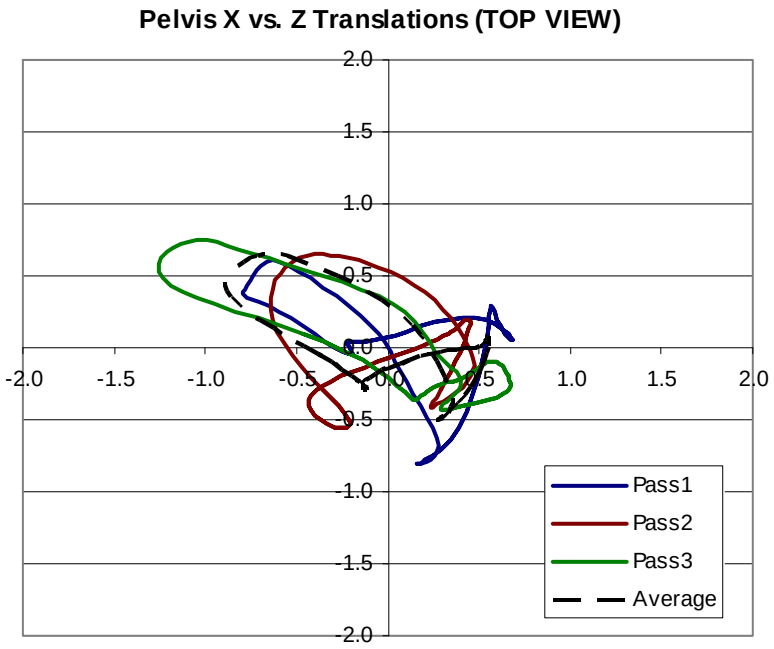


Figure B.15: Top view of pelvis for subject C on Bonnie

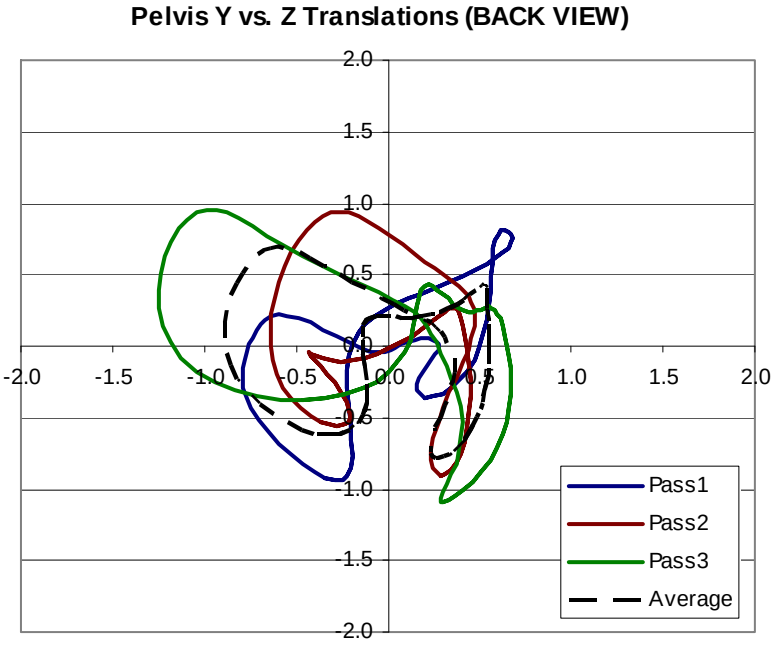


Figure B.16: Back view of pelvis for subject C on Bonnie

Subject D

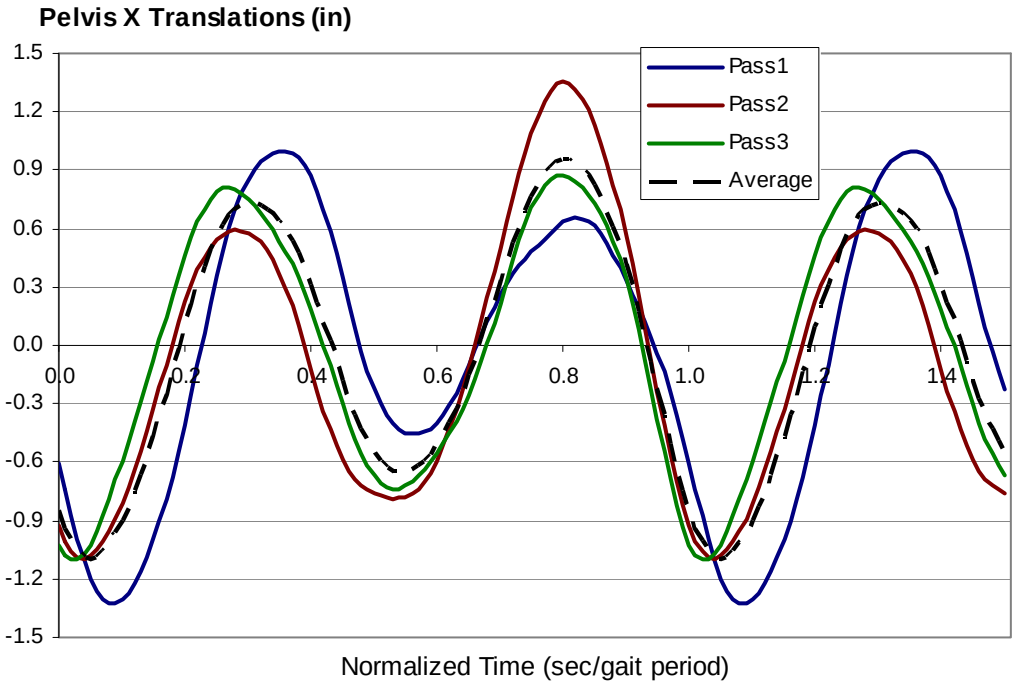


Figure B.17: Pelvis x-translations for subject D on Bonnie

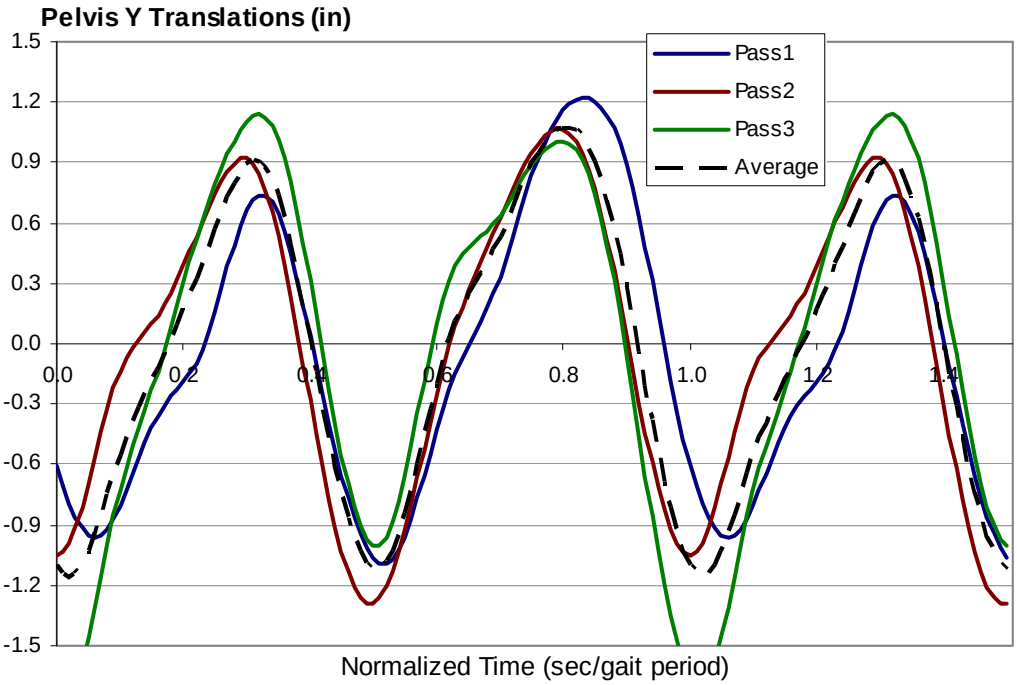


Figure B.18: Pelvis y-translations for subject D on Bonnie

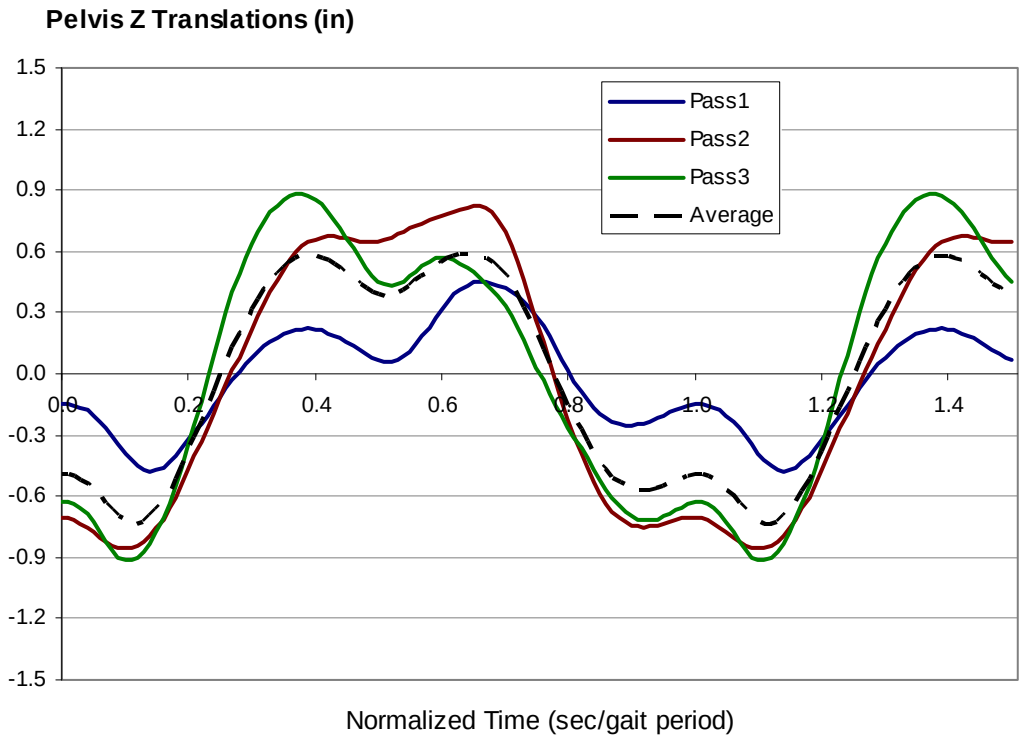


Figure B.19: Pelvis z-translations for subject D on Bonnie

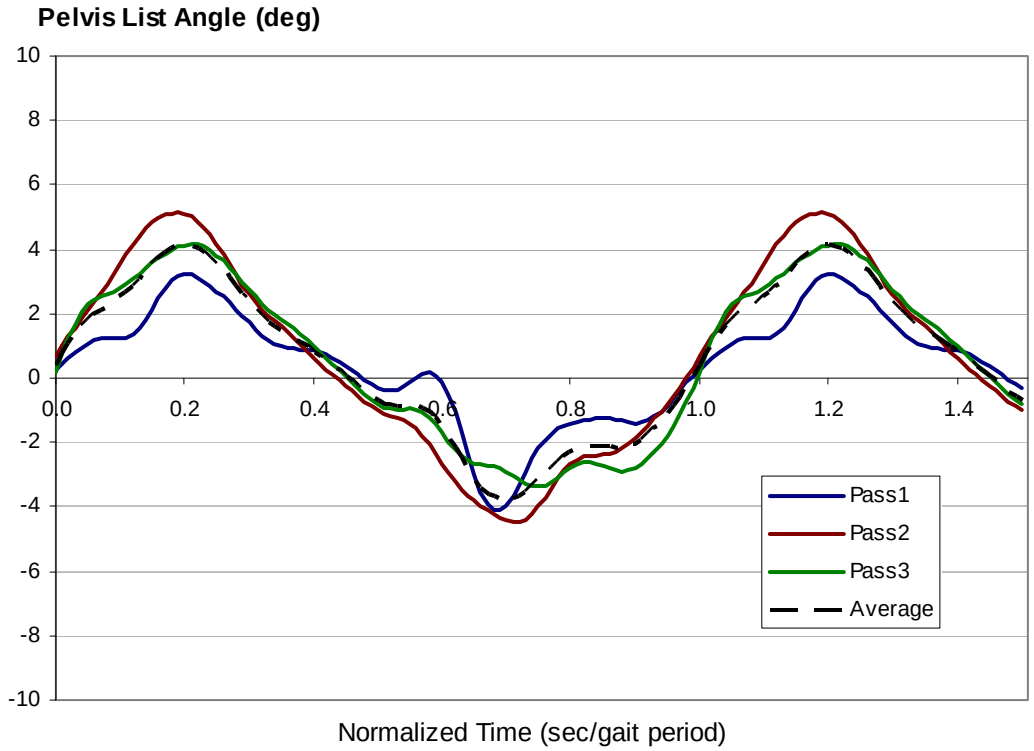


Figure B.20: Pelvis list angle for subject D on Bonnie

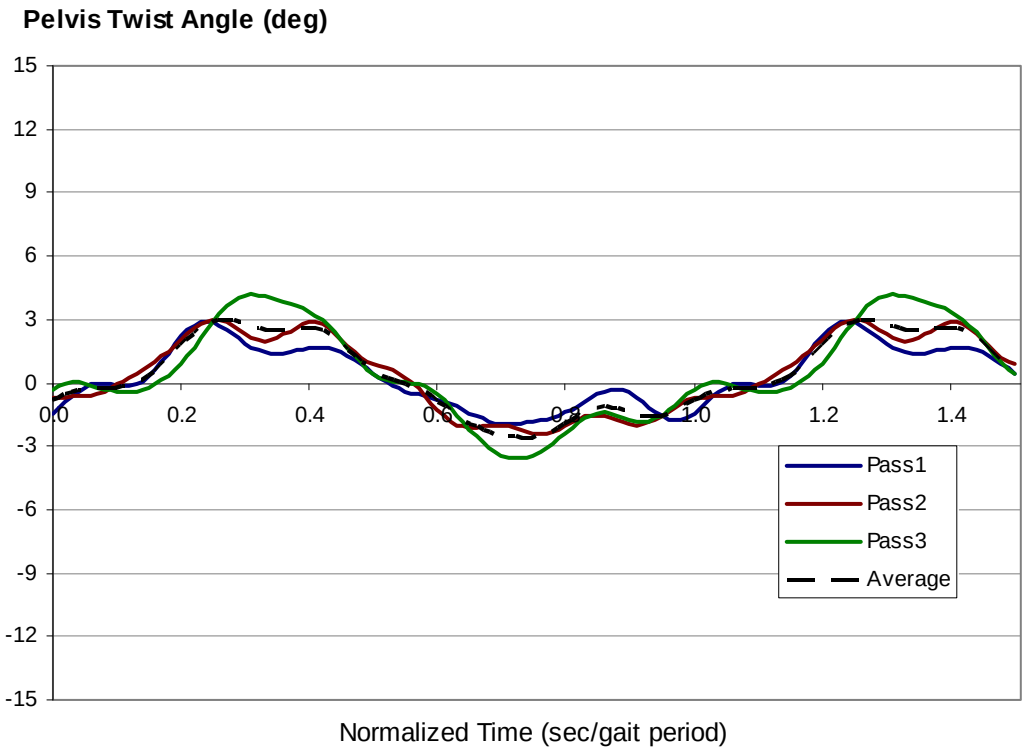


Figure B.21: Pelvis twist angle for subject D on Bonnie

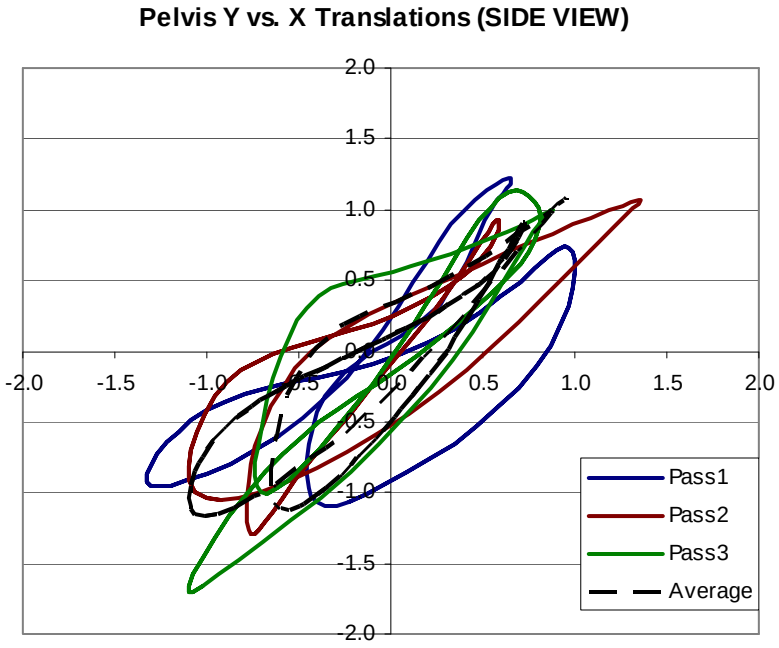


Figure B.22: Side view of pelvis for subject D on Bonnie

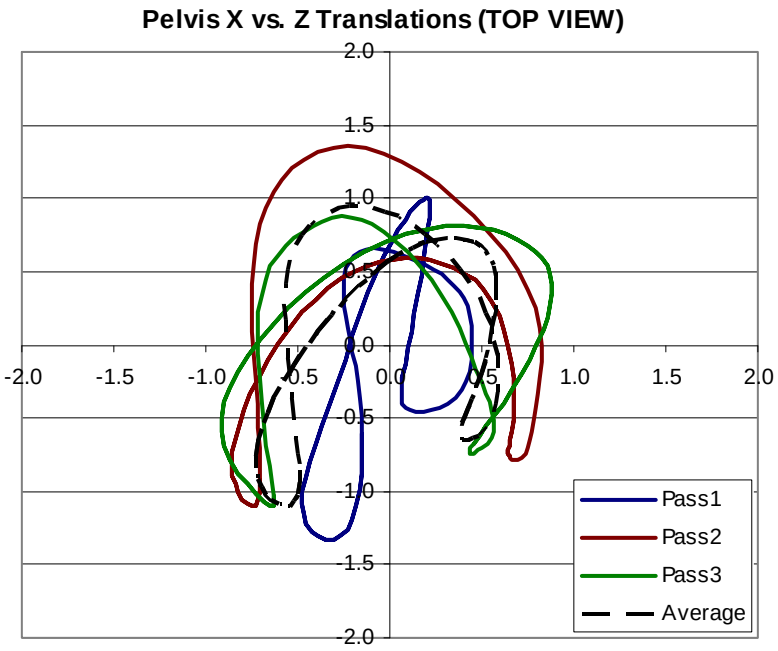


Figure B.23: Top view of pelvis for subject D on Bonnie

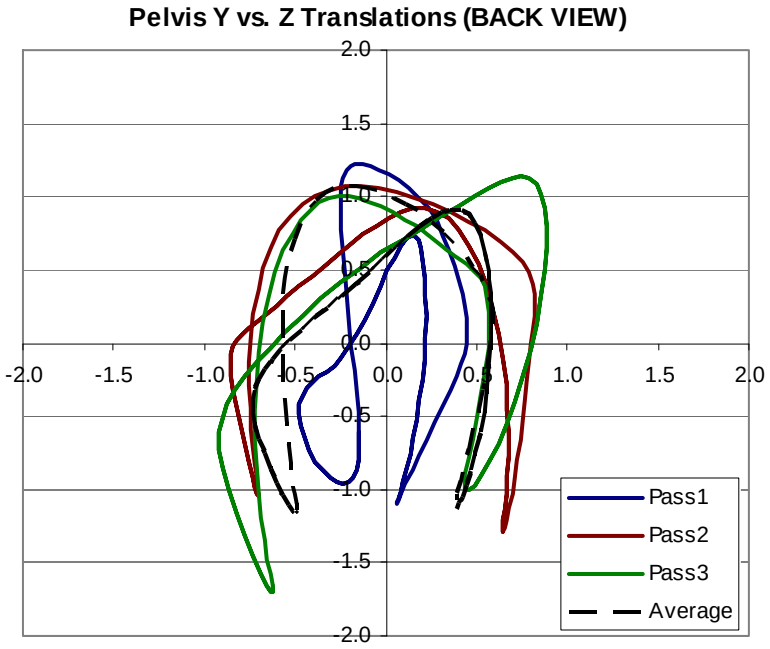


Figure B.24: Back view of pelvis for subject D on Bonnie

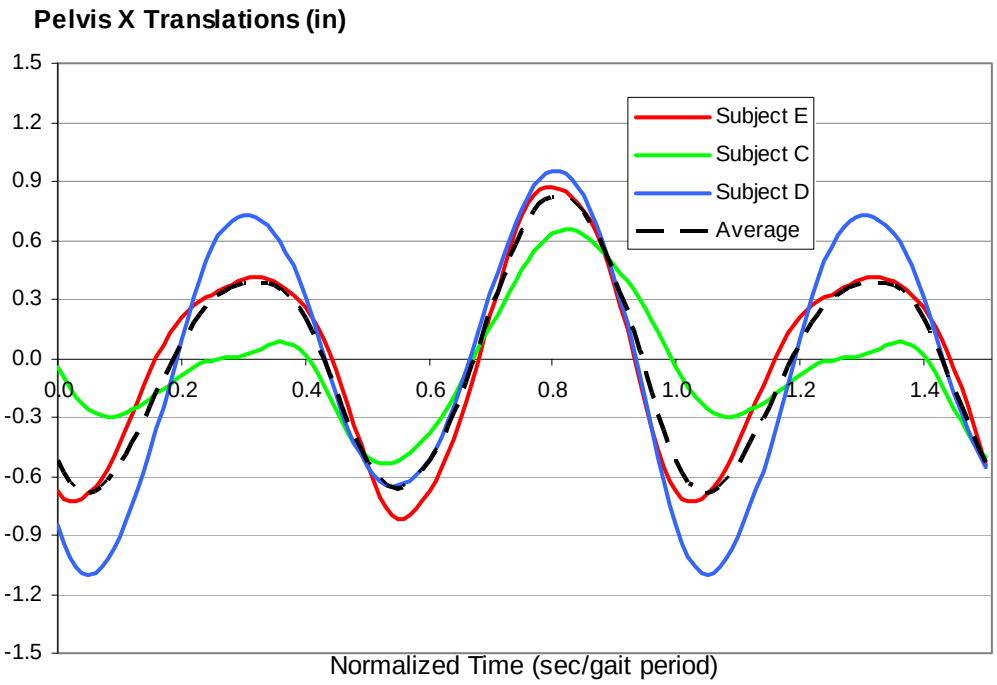


Figure B.25: Pelvis x-translations for all subjects on Bonnie

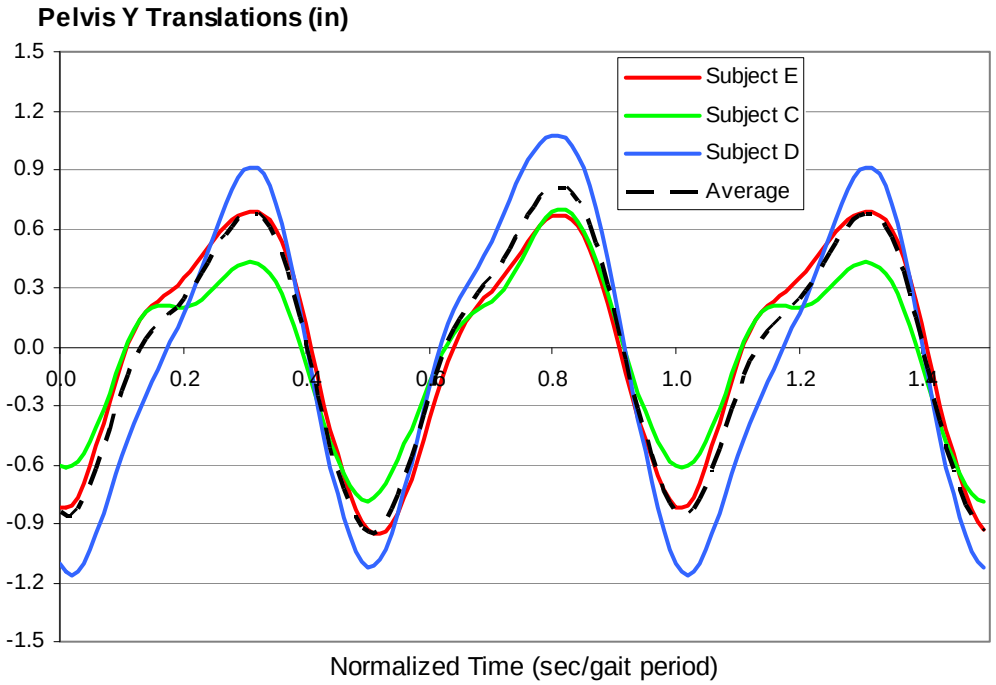


Figure B.26: Pelvis y-translations for all subjects on Bonnie

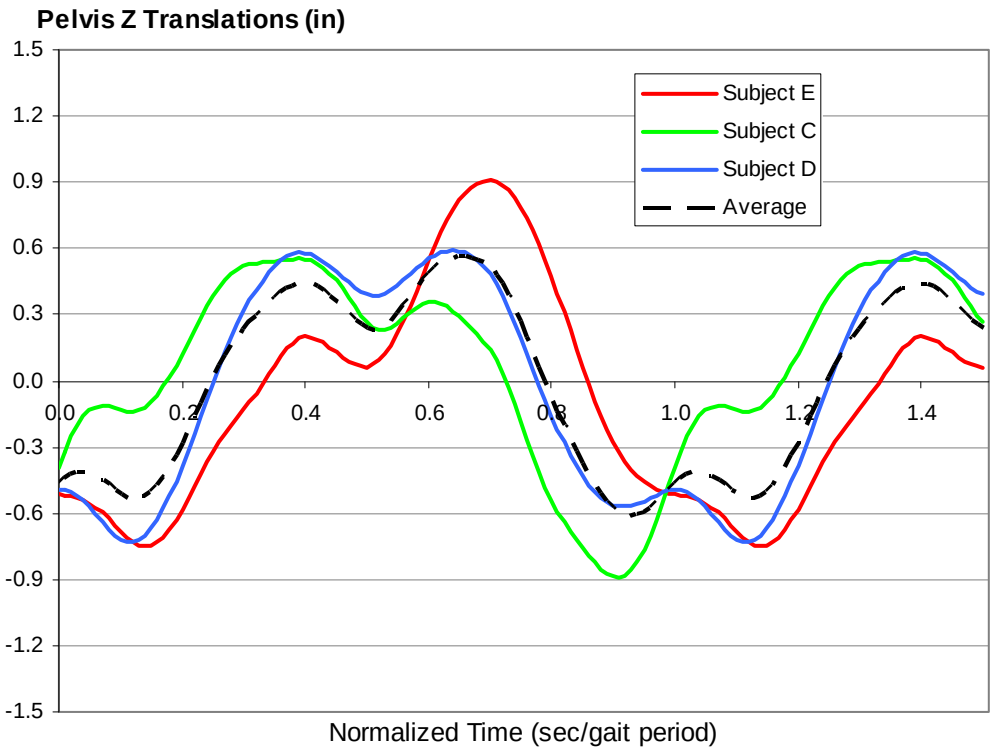


Figure B.27: Pelvis z-translations for all subjects on Bonnie

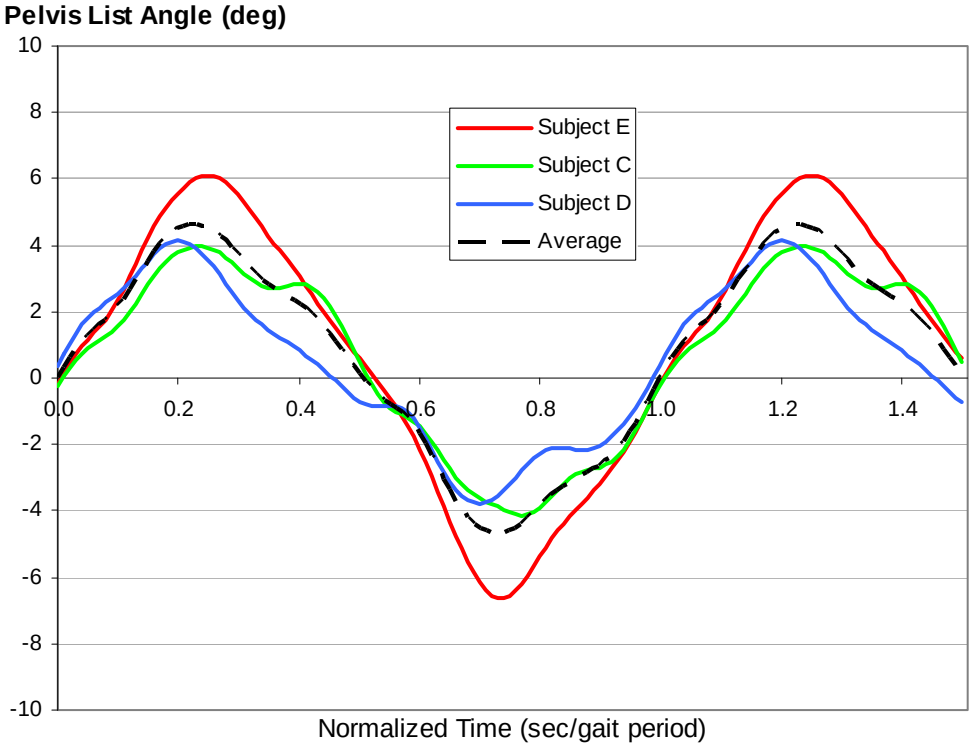


Figure B.28: Pelvis list angle for all subjects on Bonnie

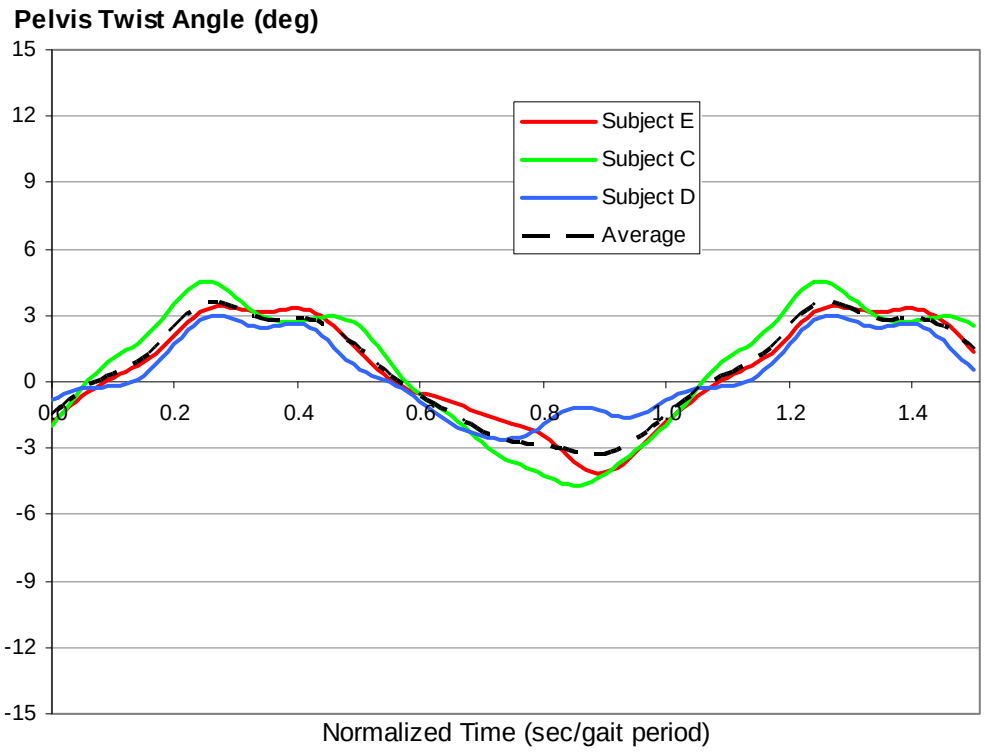


Figure B.29: Pelvis twist angle for all subjects on Bonnie

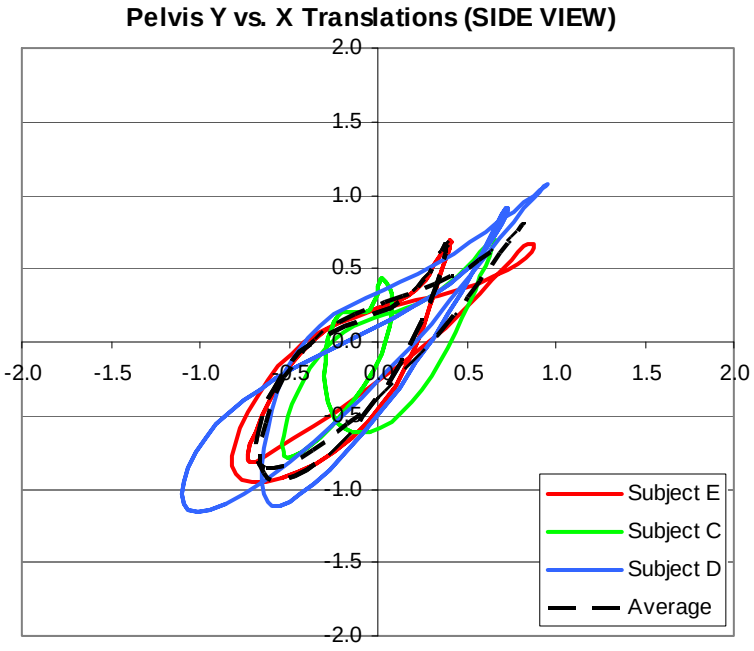


Figure B.30: Side view of pelvis for all subjects on Bonnie

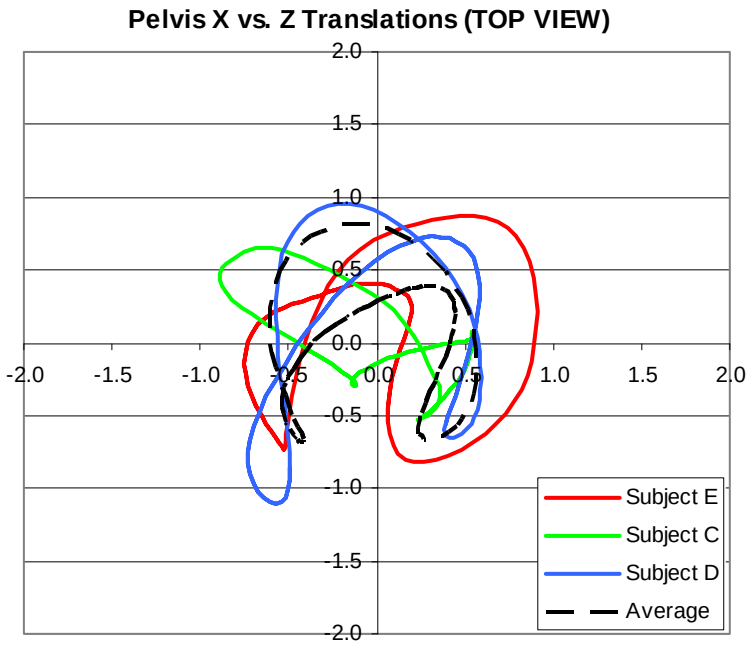


Figure B.31: Top view of pelvis for all subjects on Bonnie

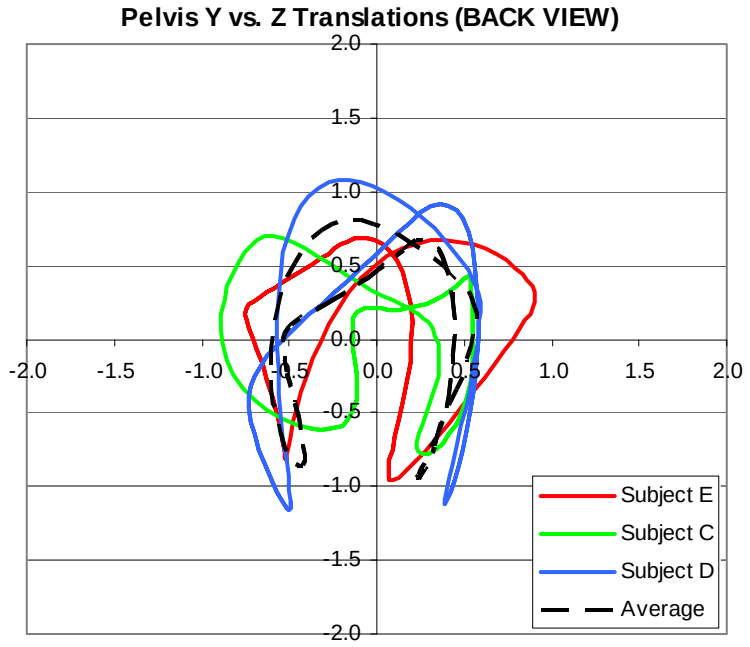


Figure B.32: Back view of pelvis for all subjects on Bonnie

APPENDIX C

Riding Data: Dolly

Subject B

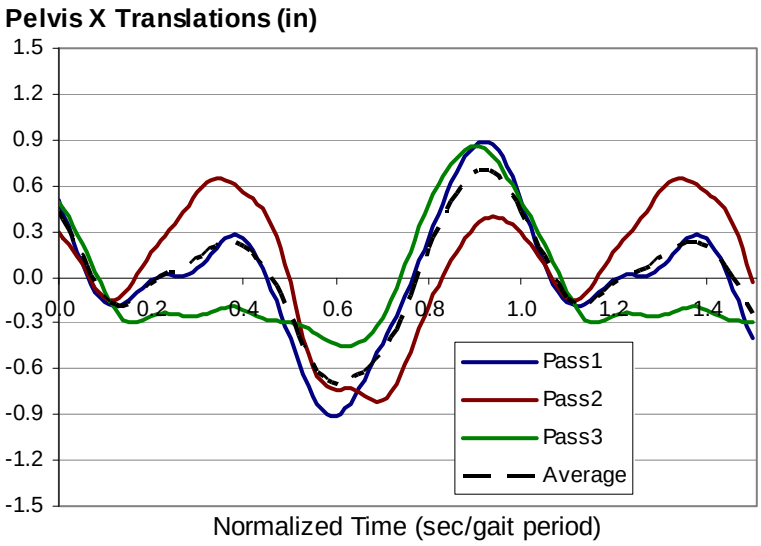


Figure C.1: Pelvis x-translations for subject B on Dolly

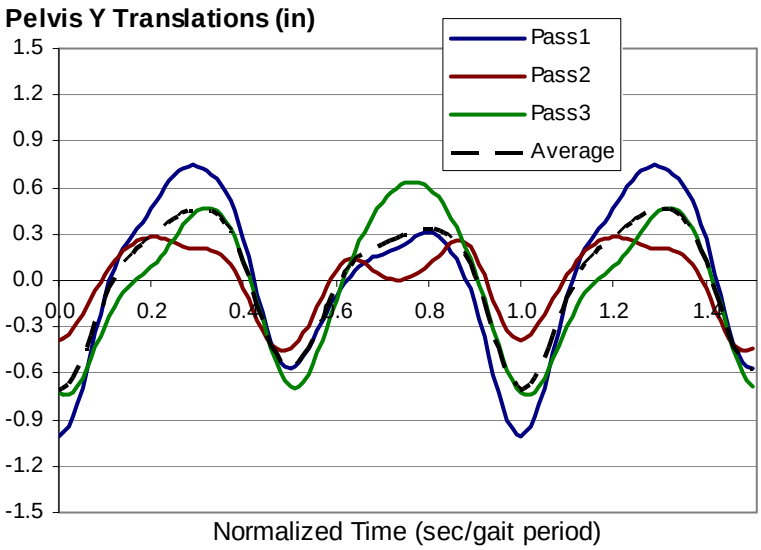


Figure C.2: Pelvis y-translations for subject B on Dolly

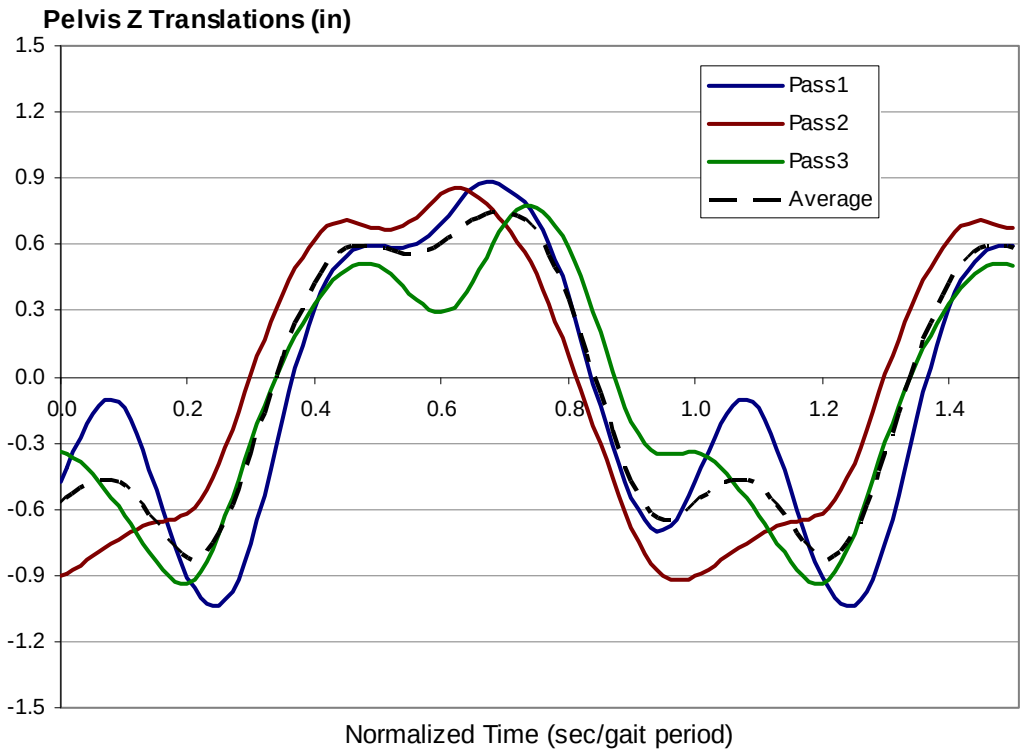


Figure C.3: Pelvis z-translations for subject B on Dolly

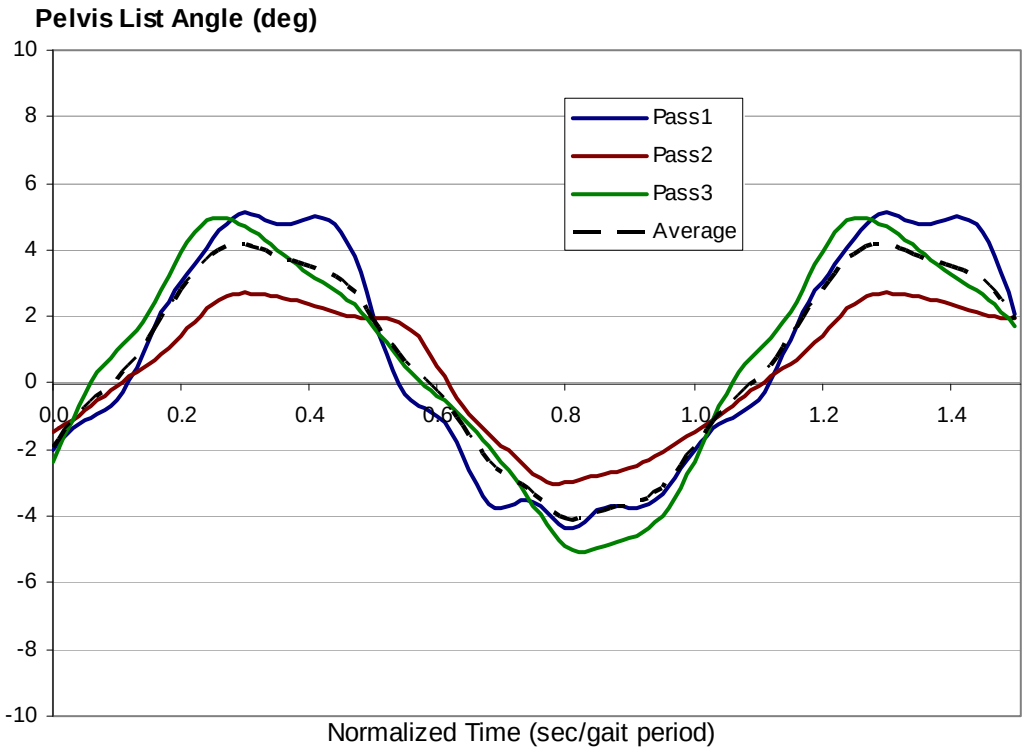


Figure C.4: Pelvis list angles for subject B on Dolly

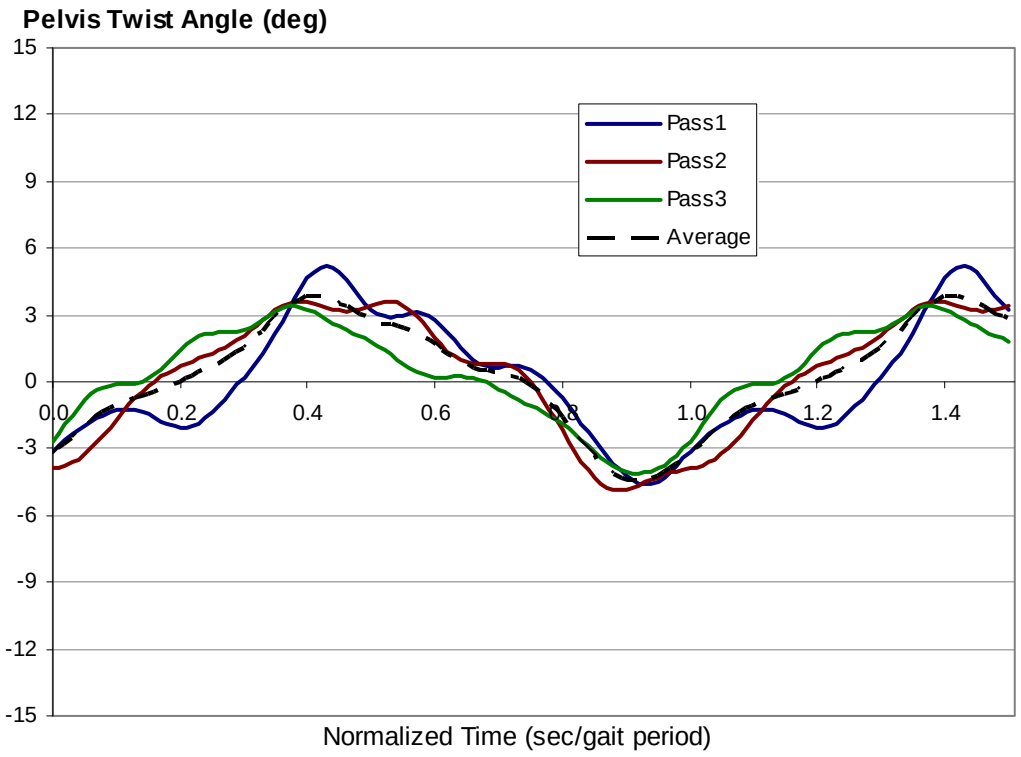


Figure C.5: Pelvis twist angles for subject B on Dolly

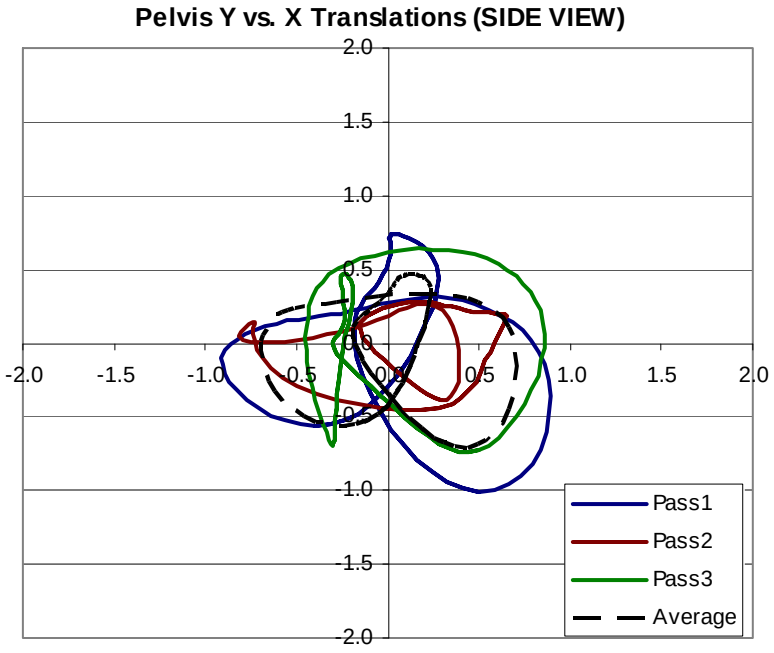


Figure C.6: Side view of pelvis for subject B on Dolly

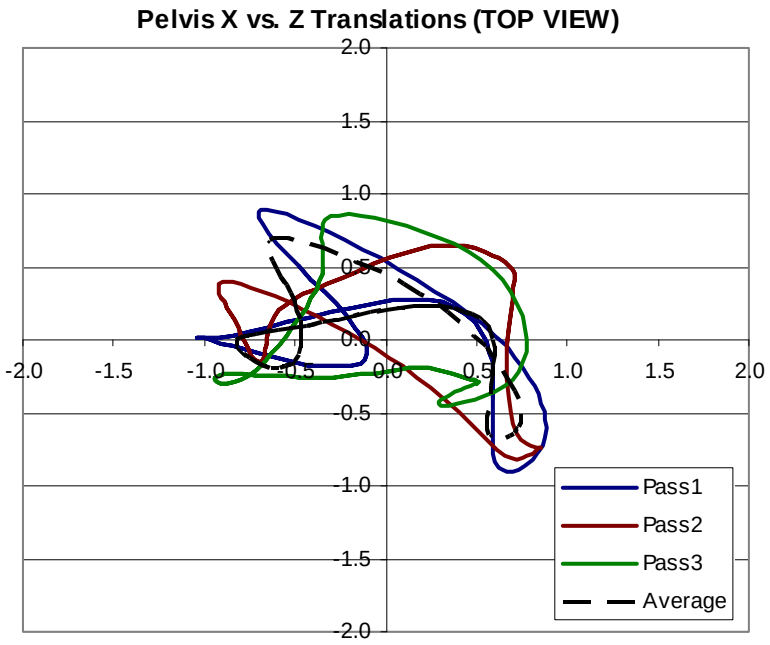


Figure C.7: Top view of pelvis for subject B on Dolly

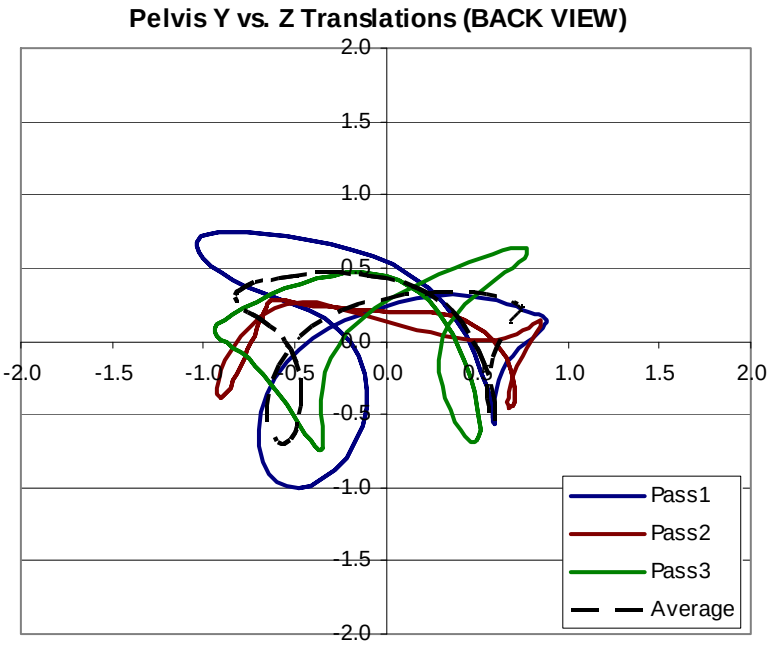


Figure C.8: Back view of pelvis for subject B on Dolly

Subject C

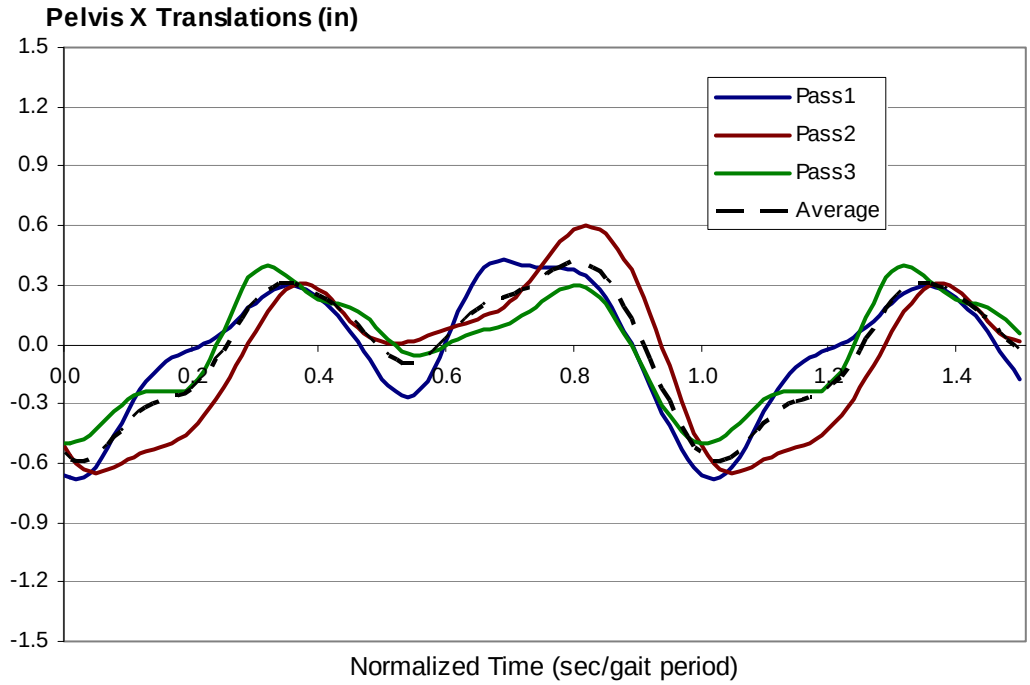


Figure C.9: Pelvis x-translations for subject C on Dolly

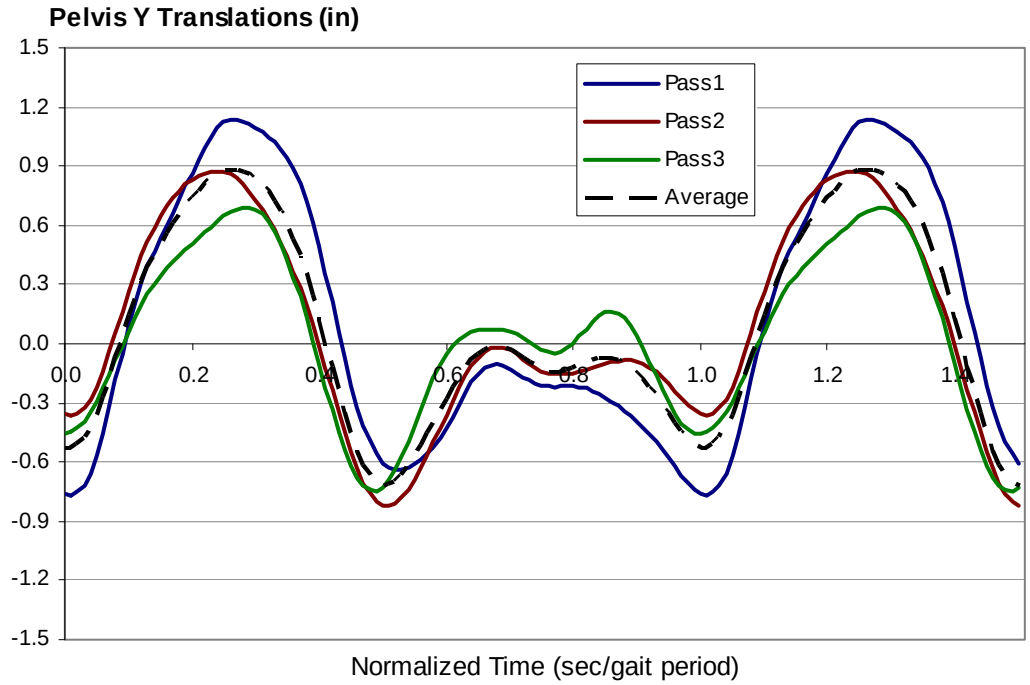


Figure C.10: Pelvis y-translations for subject C on Dolly

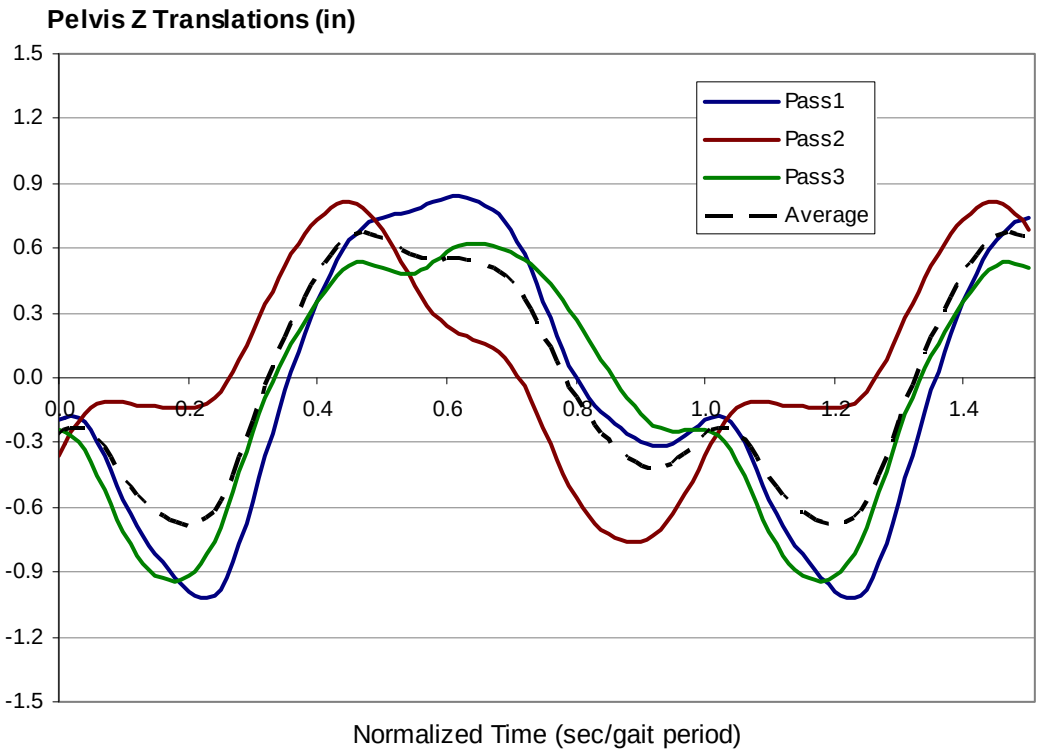


Figure C.11: Pelvis z-translations for subject C on Dolly

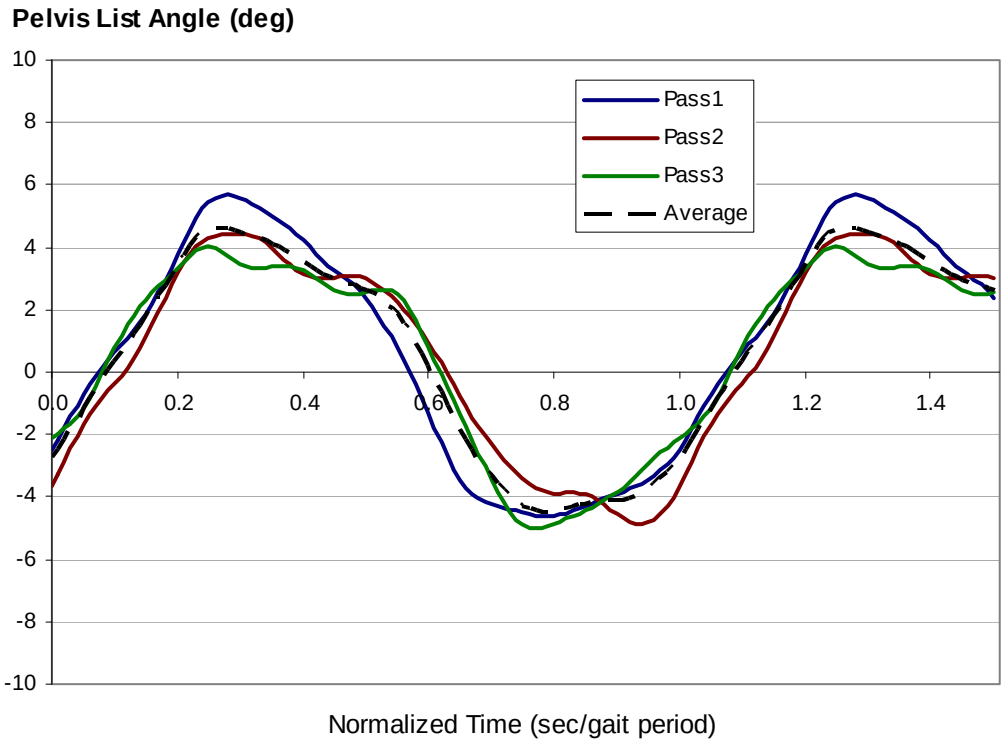


Figure C.12: Pelvis list angles for subject C on Dolly

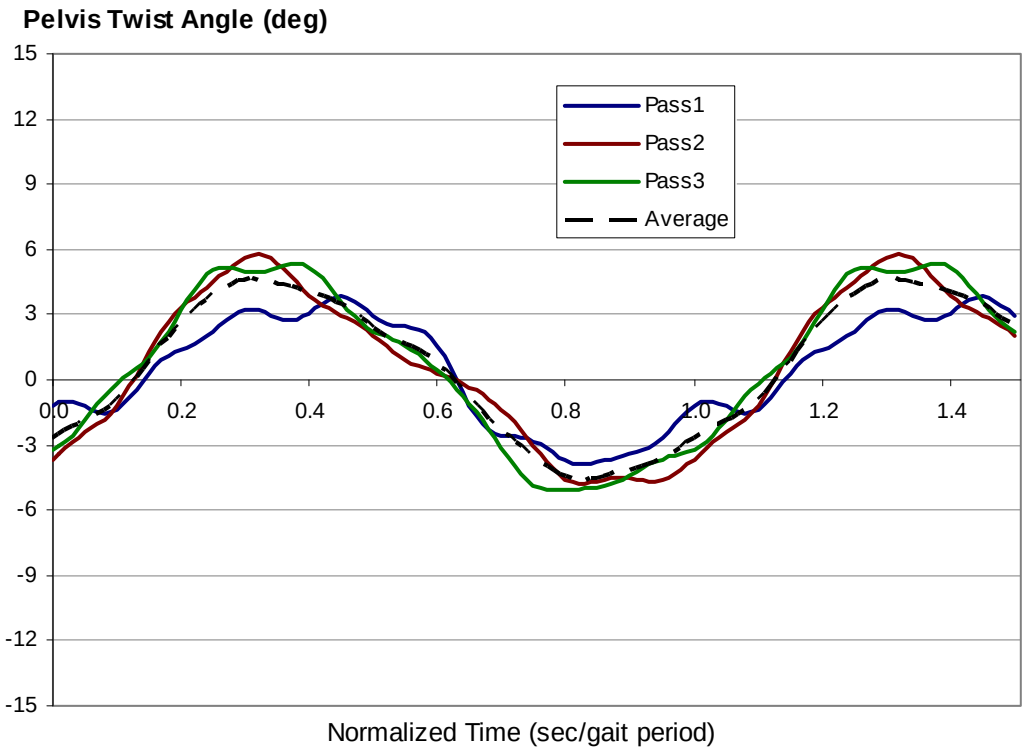


Figure C.13: Pelvis twist angles for subject C on Dolly

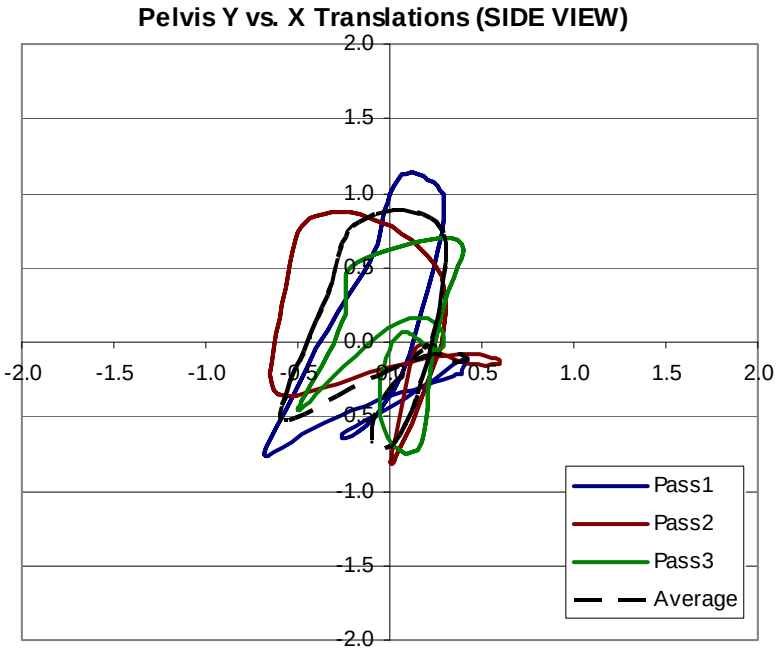


Figure C.14: Side view of pelvis for subject C on Dolly

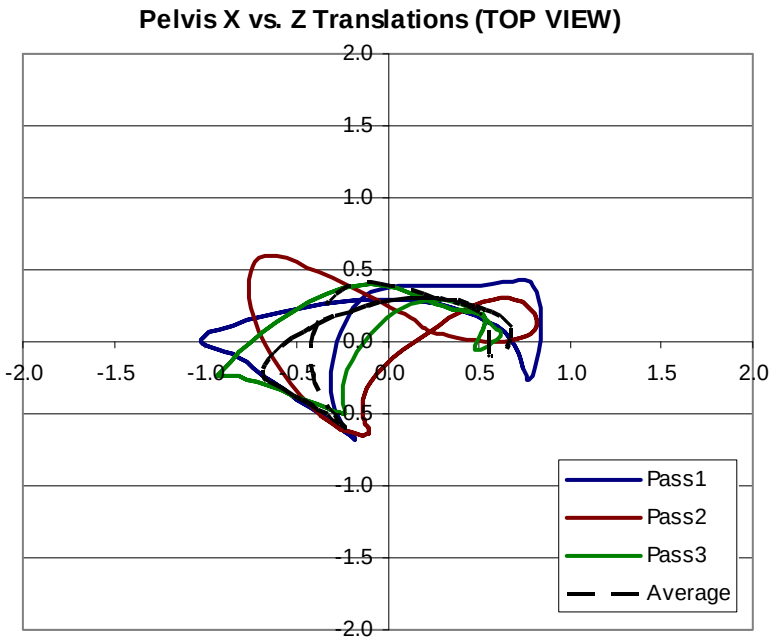


Figure C.15: Top view of pelvis for subject C on Dolly

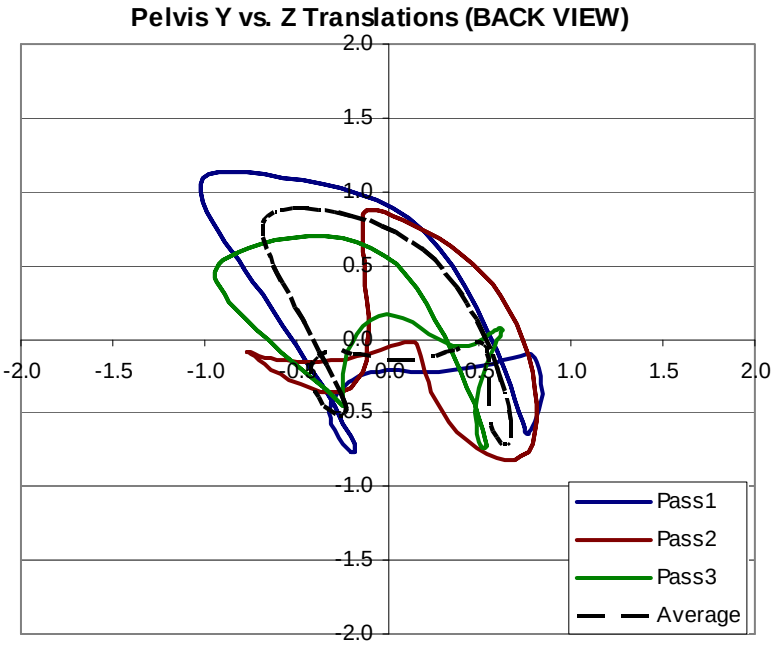


Figure C.16: Back view of pelvis for subject C on Dolly

Subject D

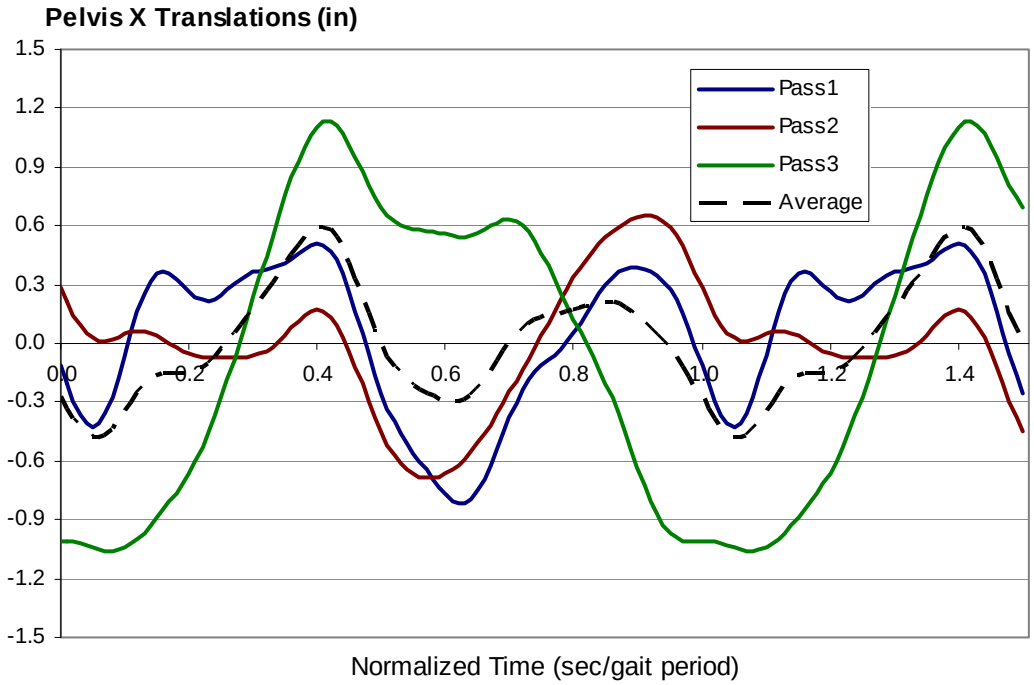


Figure C.17: Pelvis x-translations for subject D on Dolly

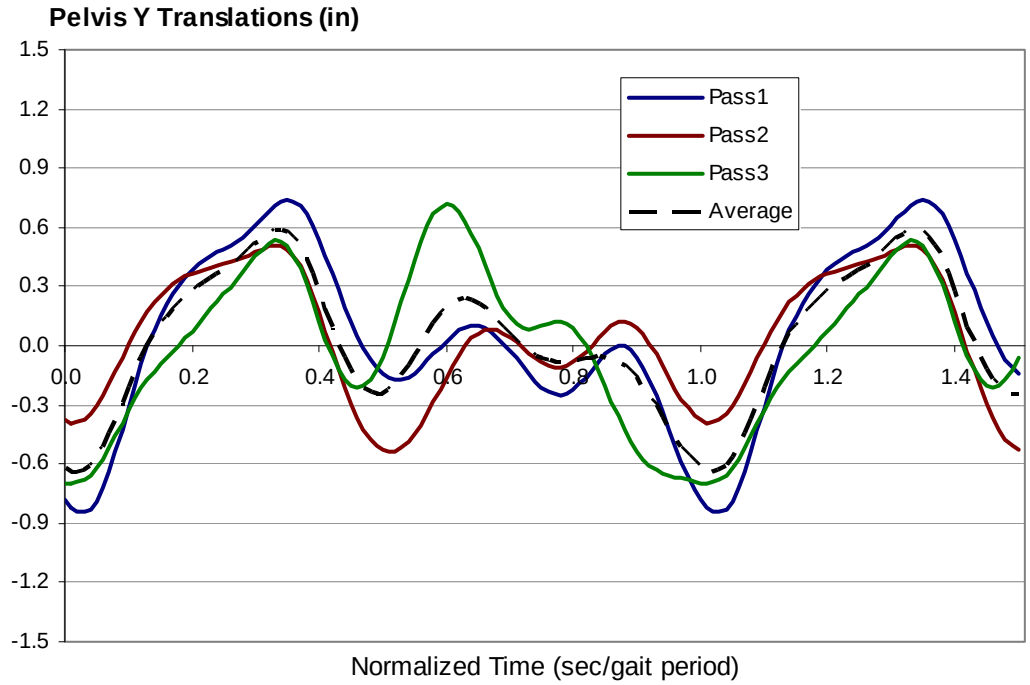


Figure C.18: Pelvis y-translations for subject D on Dolly

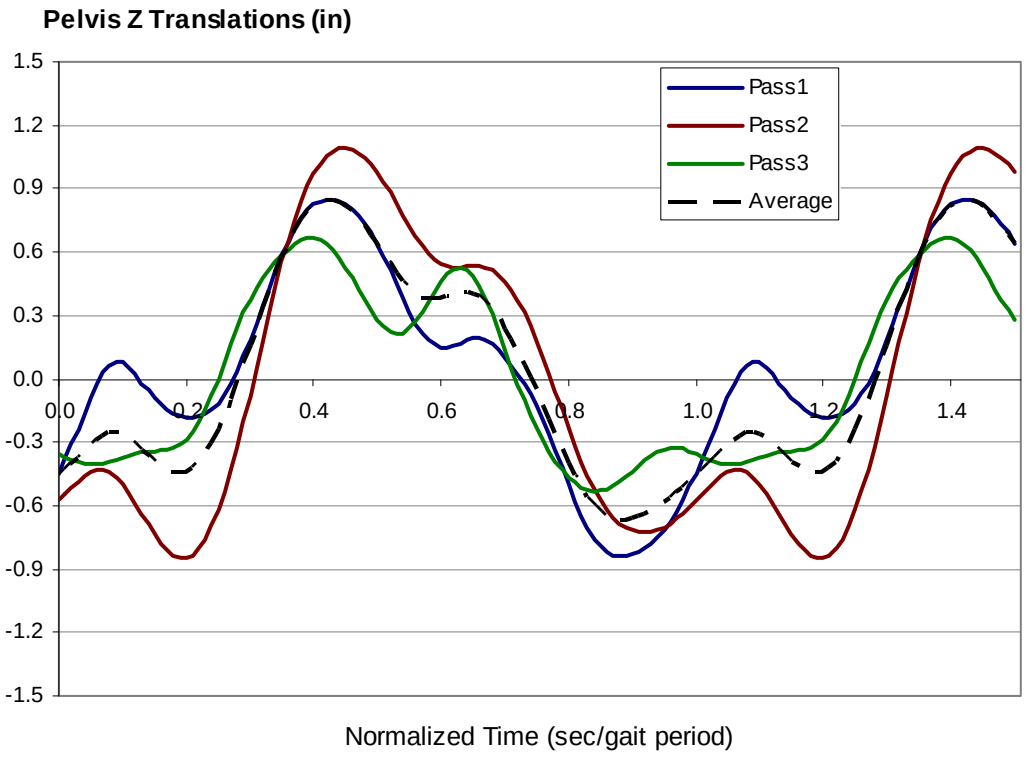


Figure C.19: Pelvis z-translations for subject D on Dolly

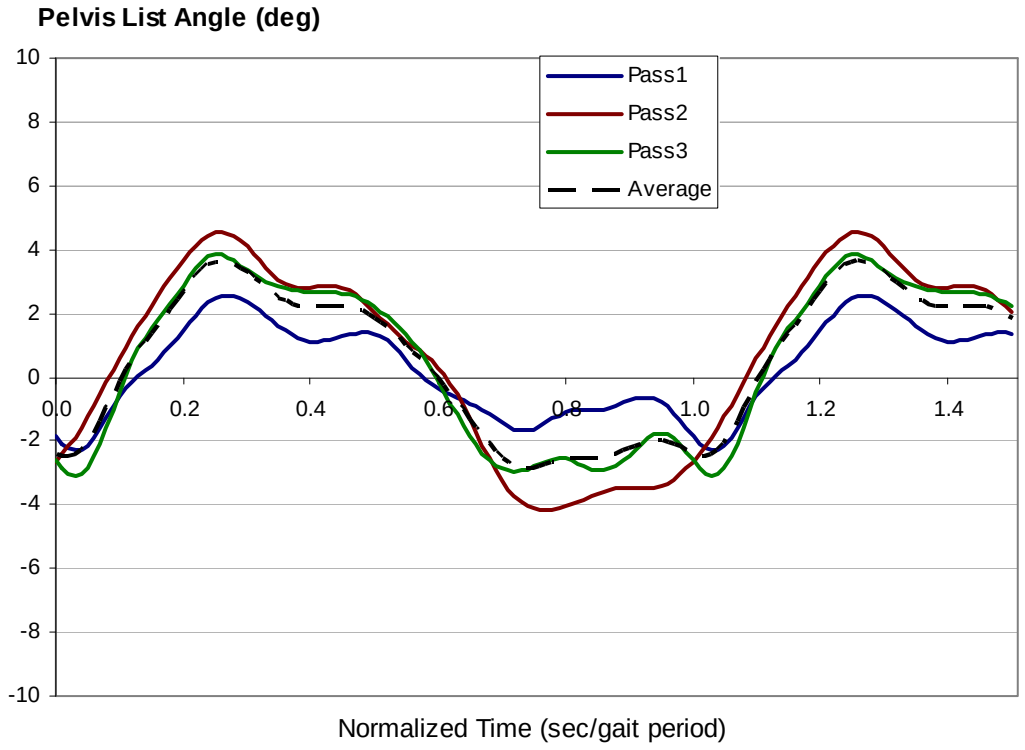


Figure C.20: Pelvis list angles for subject D on Dolly

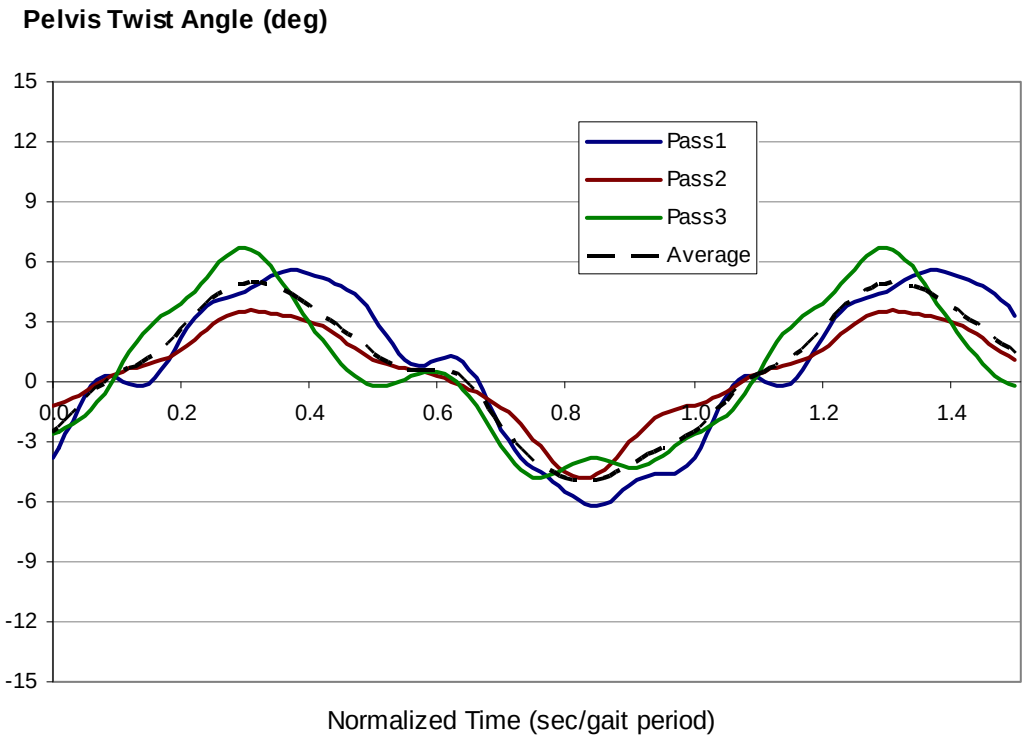


Figure C.21: Pelvis twist angles for subject D on Dolly

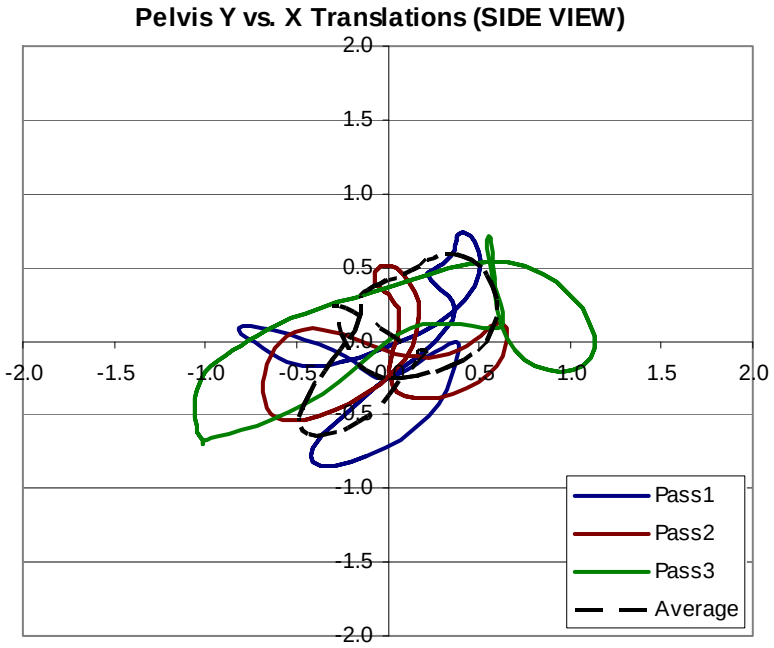


Figure C.22: Side view of pelvis for subject D on Dolly

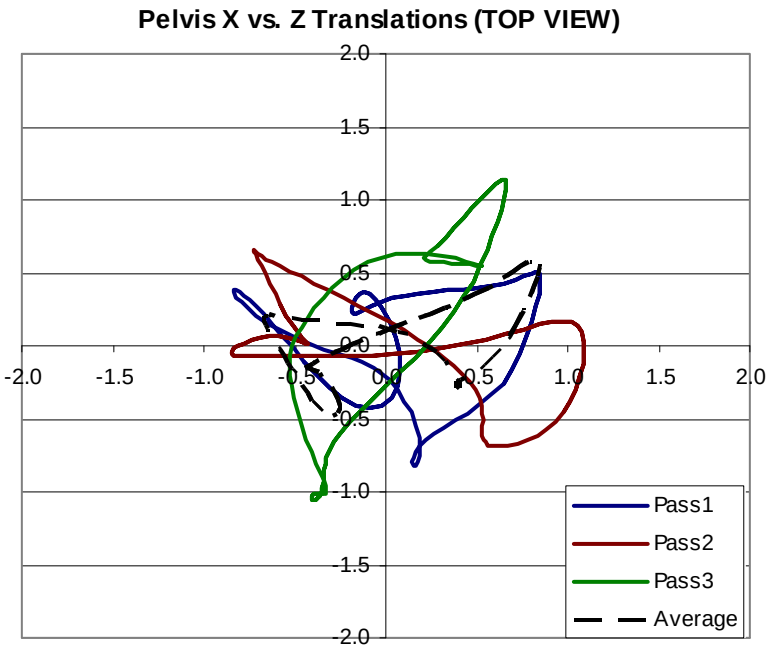


Figure C.23: Top view of pelvis for subject D on Dolly

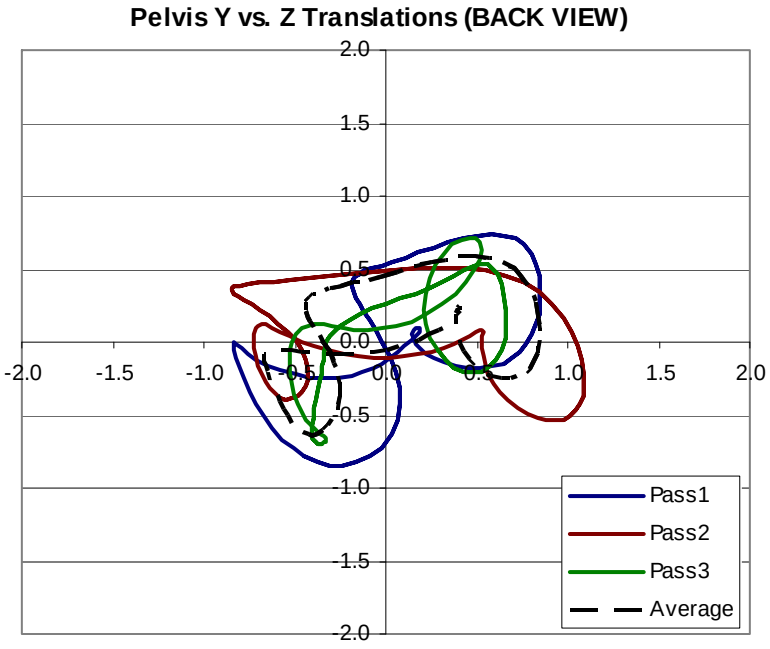


Figure C.24: Back view of pelvis for subject D on Dolly

Subject E

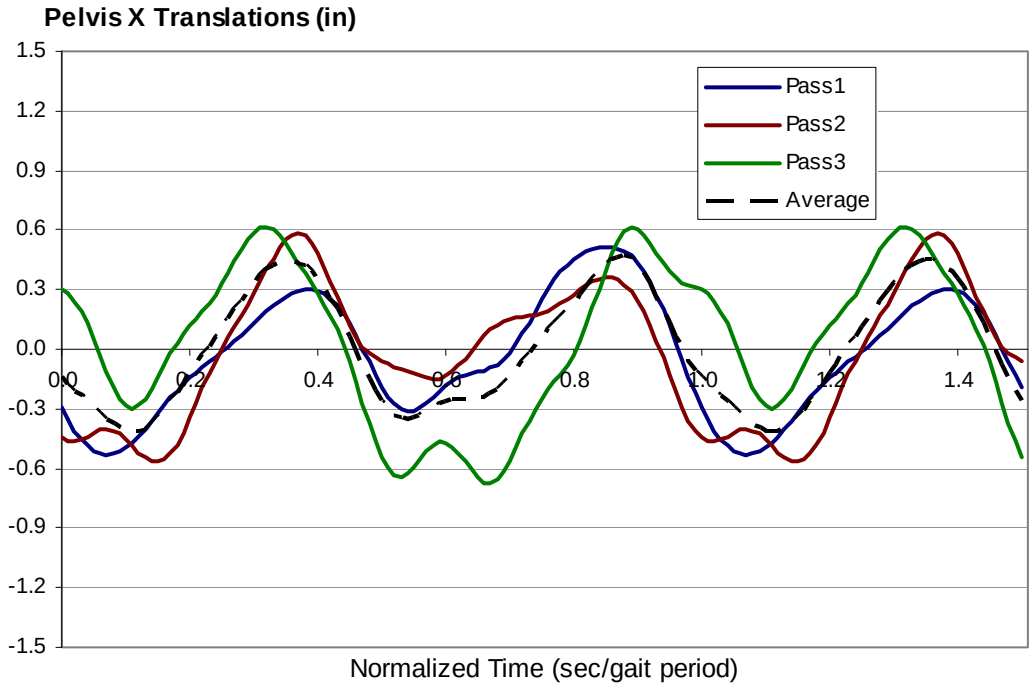


Figure C.25: Pelvis x-translations for subject E on Dolly

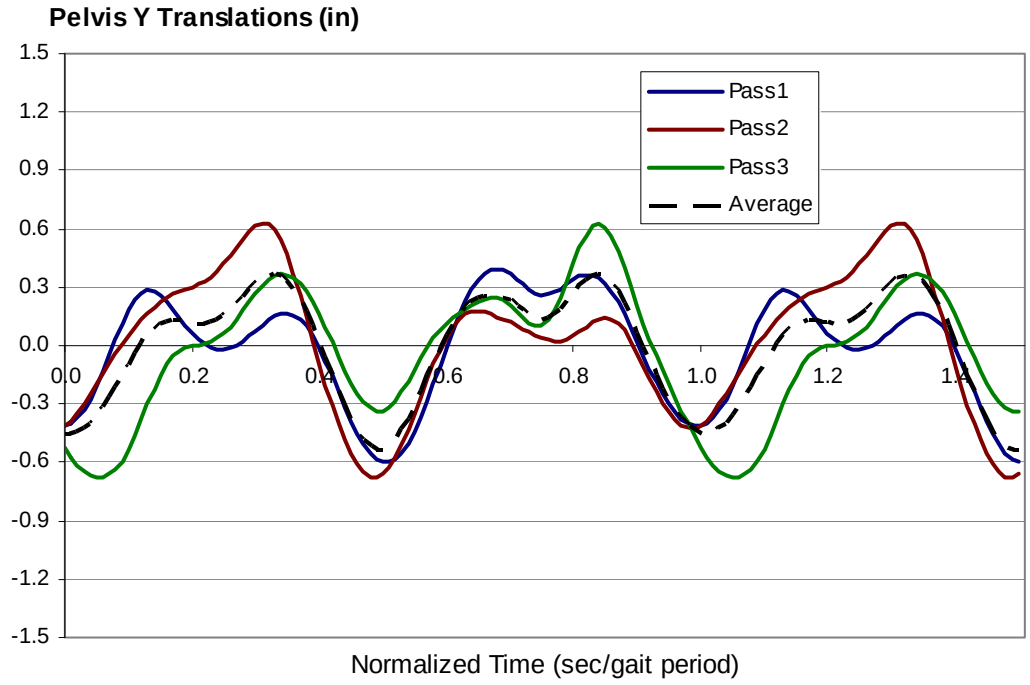


Figure C.26: Pelvis y-translations for subject E on Dolly

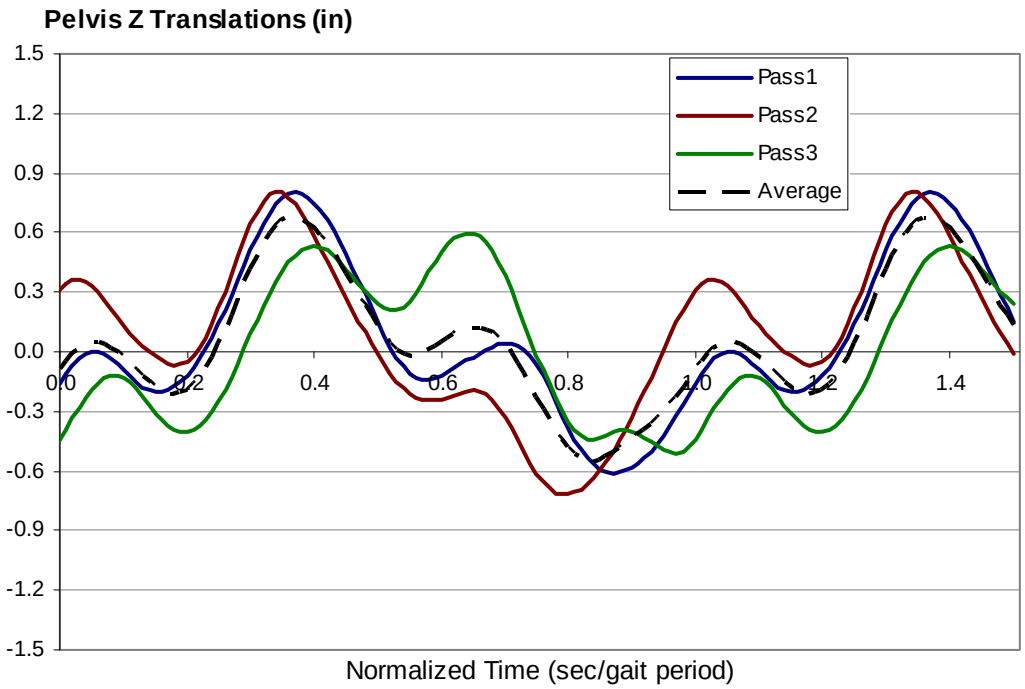


Figure C.27: Pelvis z-translations for subject E on Dolly

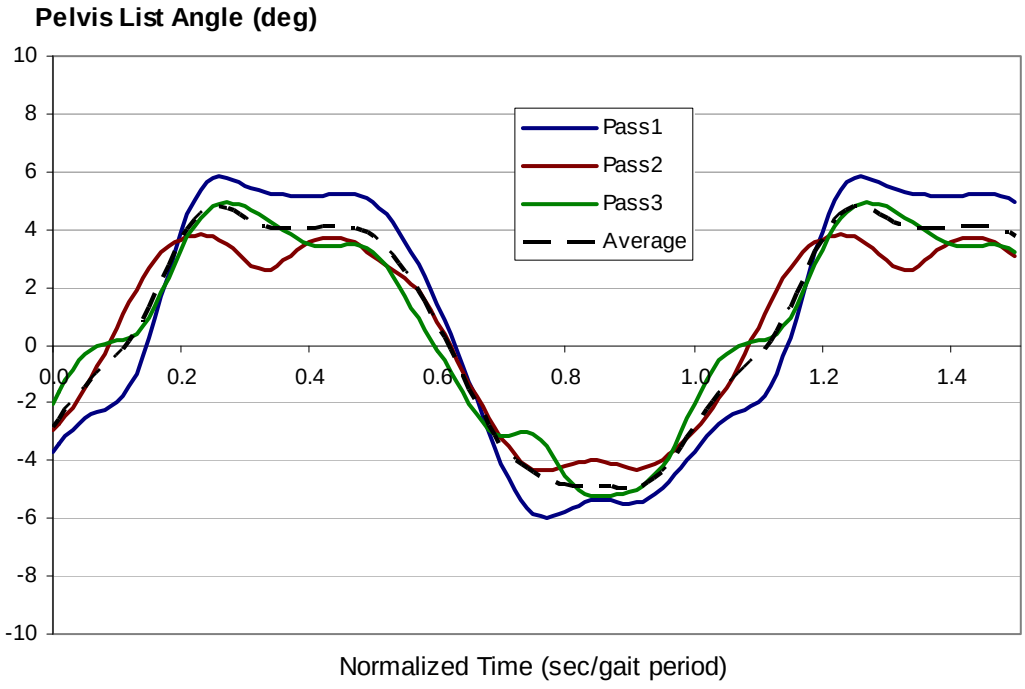


Figure C.28: Pelvis list angles for subject E on Dolly

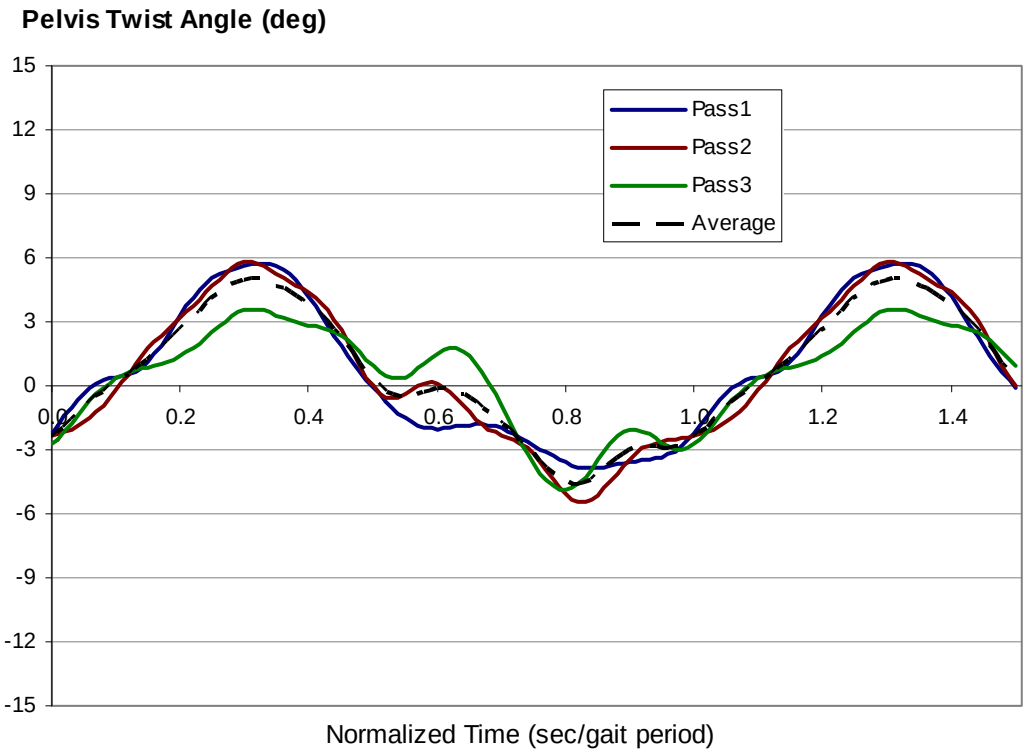


Figure C.29: Pelvis twist angles for subject E on Dolly

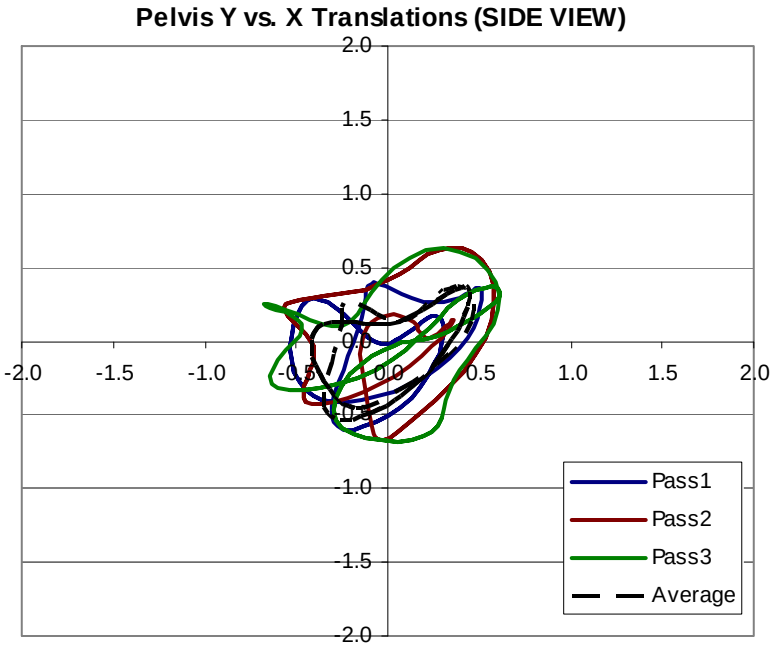


Figure C.30: Side view of pelvis for subject E on Dolly

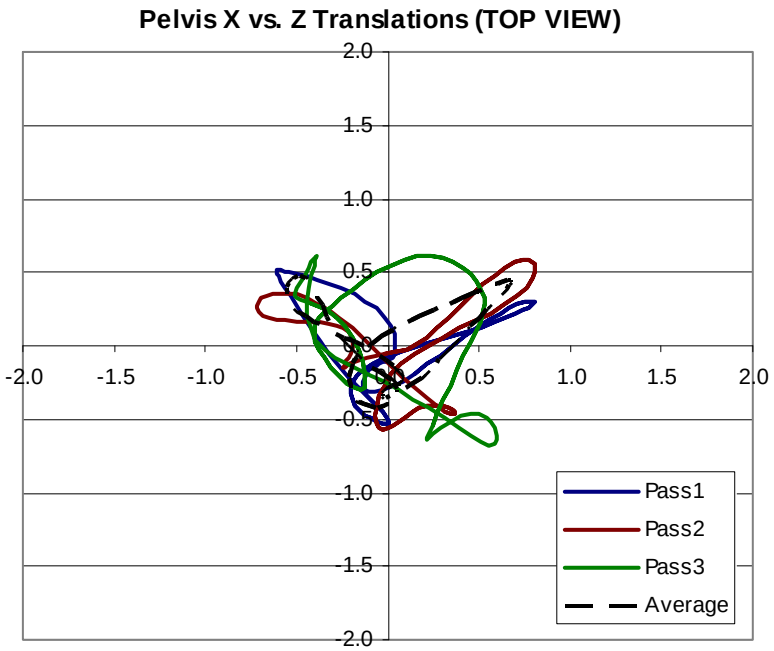


Figure C.31: Top view of pelvis for subject E on Dolly

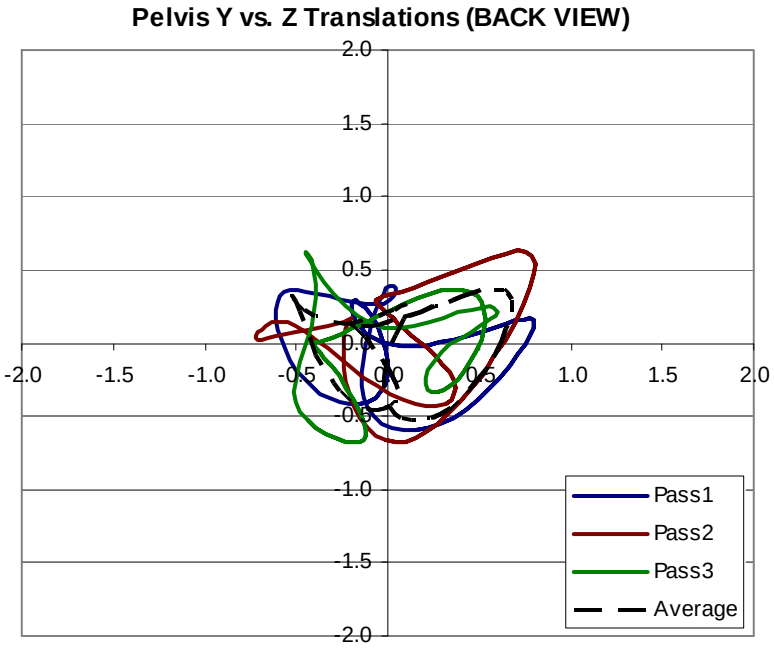


Figure C.32: Back view of pelvis for subject E on Dolly

Subject F

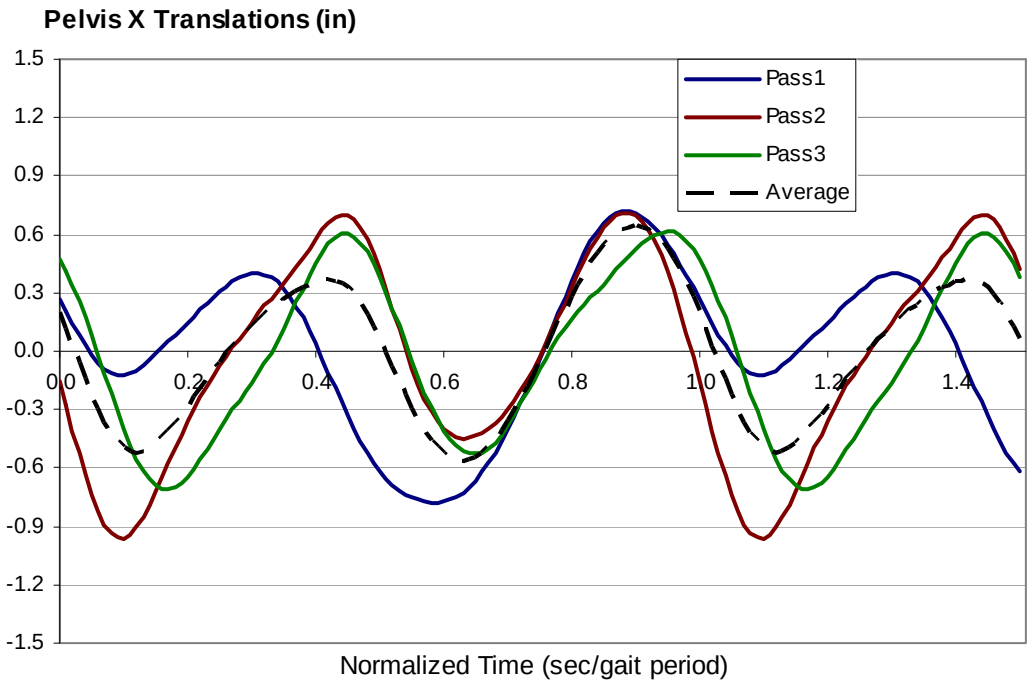


Figure C.33: Pelvis x-translations for subject F on Dolly

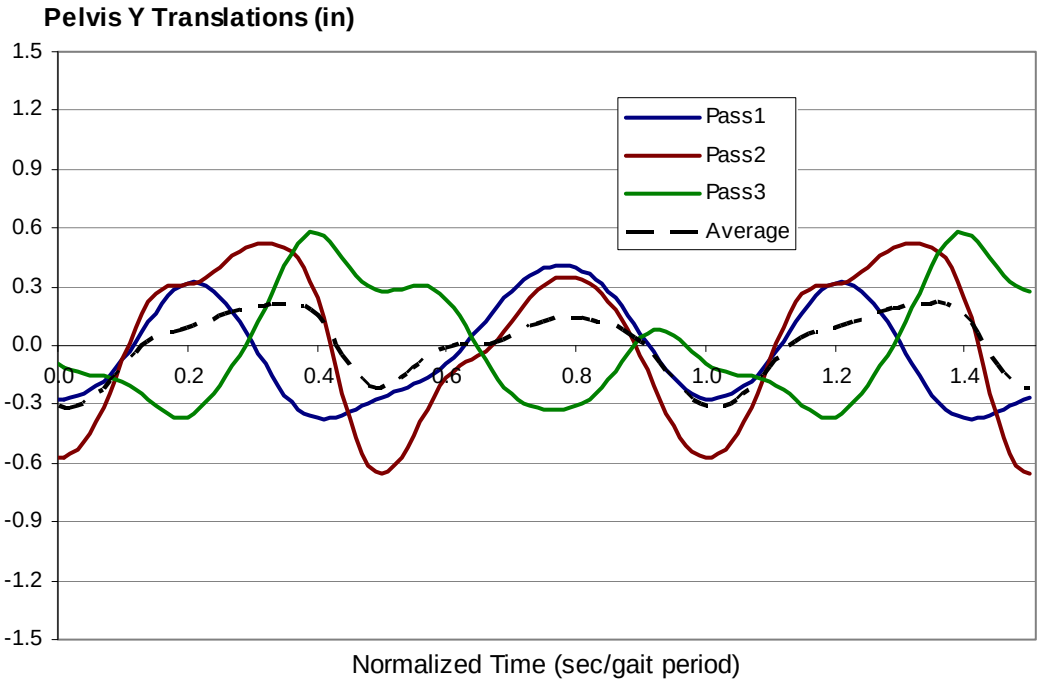


Figure C.34: Pelvis y-translations for subject F on Dolly

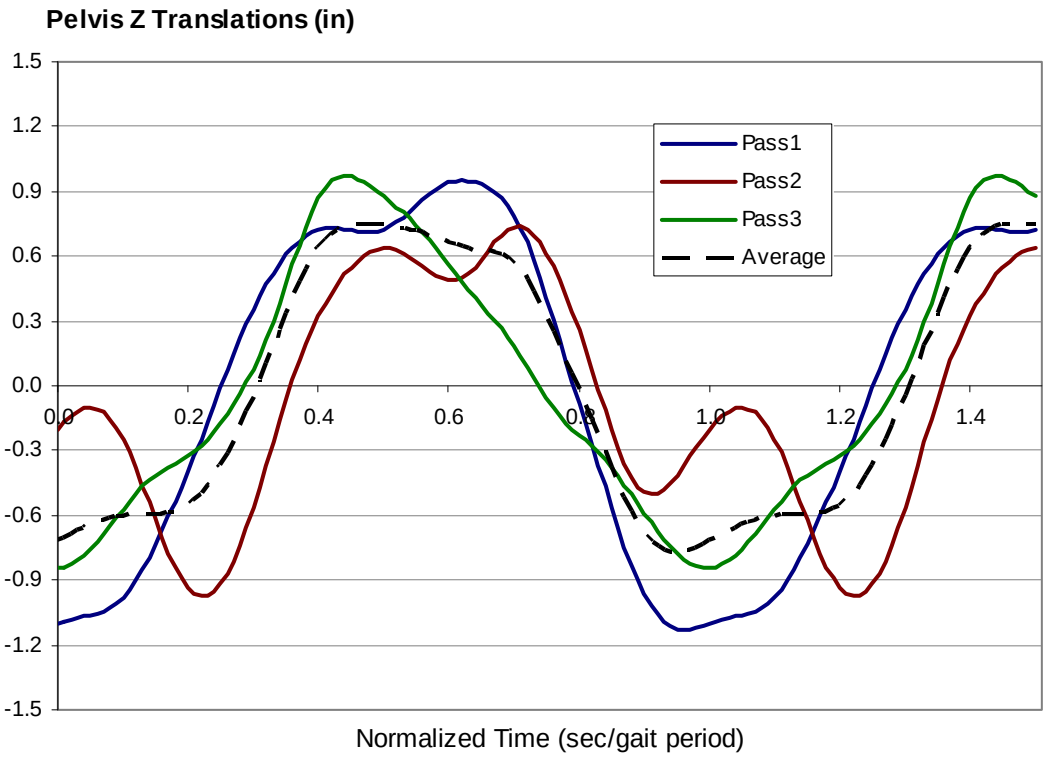


Figure: C.35: Pelvis z-translations for subject F on Dolly

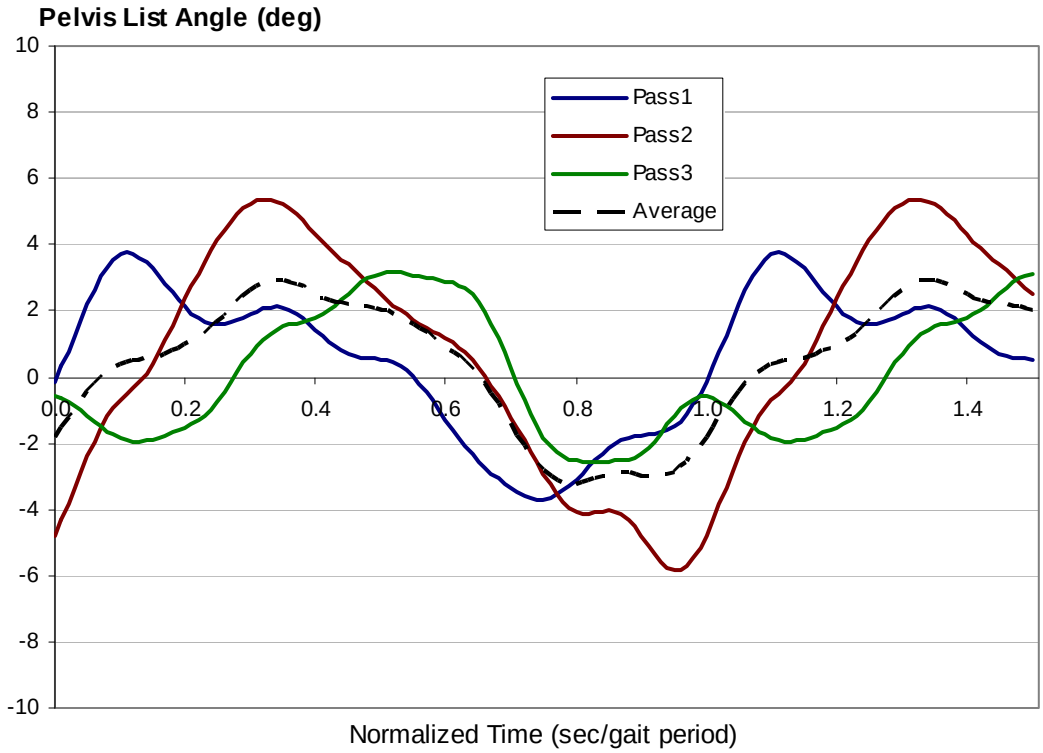


Figure C.36: Pelvis list angles for subject F on Dolly

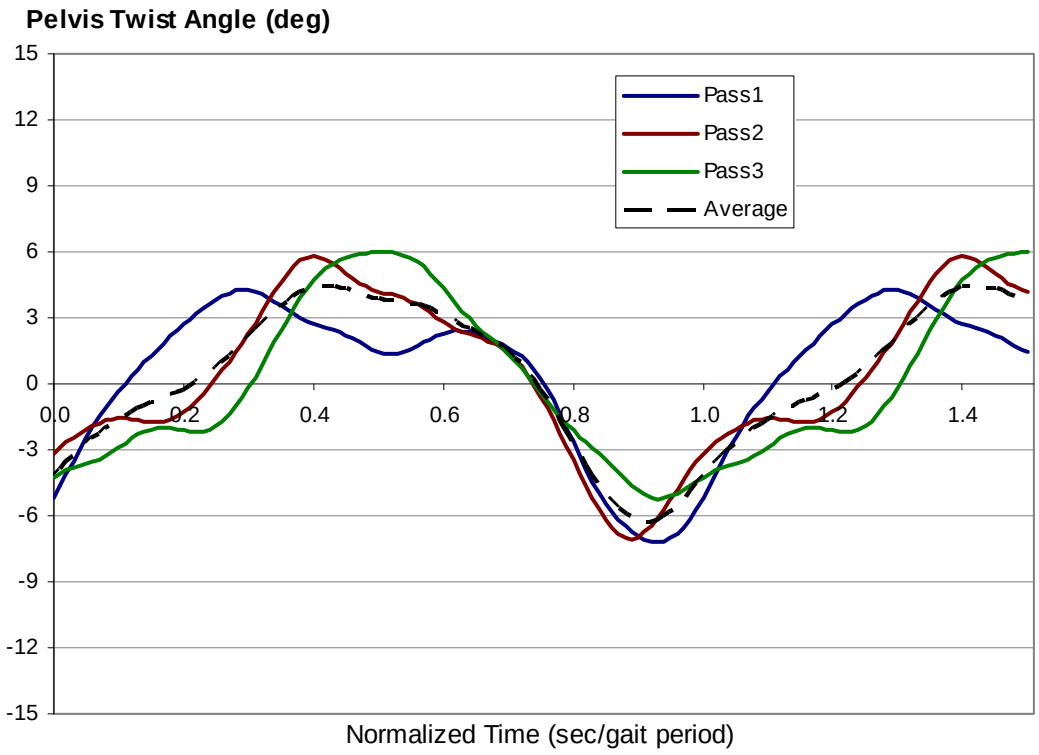


Figure C.37: Pelvis twist angles for subject F on Dolly

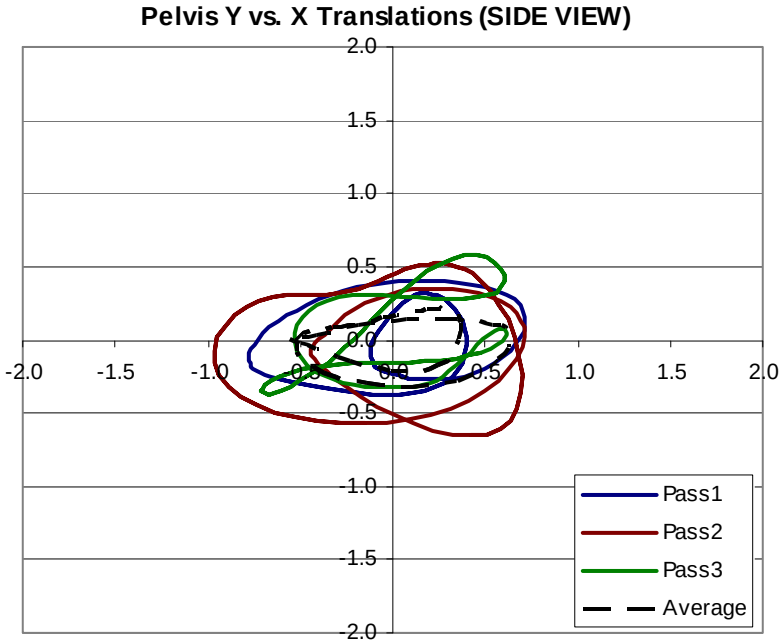


Figure C.38: Side view of pelvis for subject F on Dolly

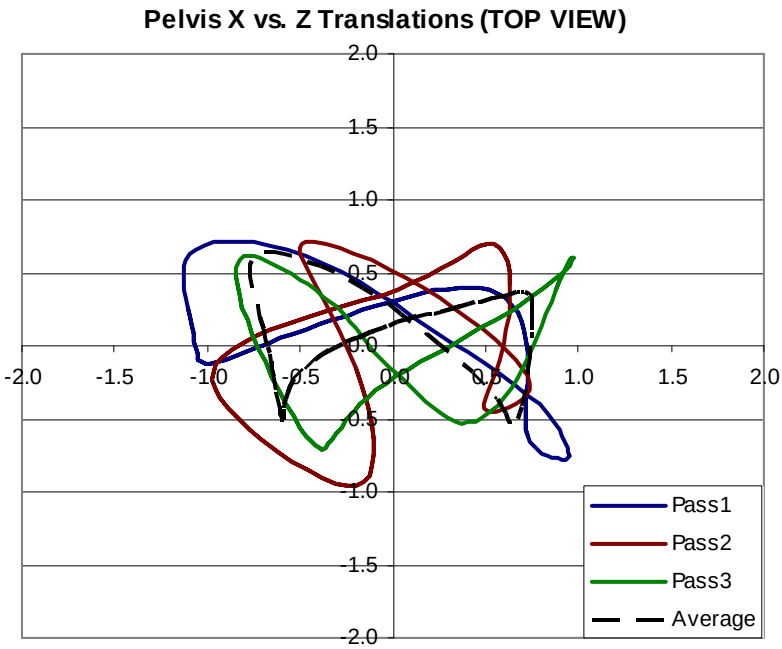


Figure C.39: Top view of pelvis for subject F on Dolly

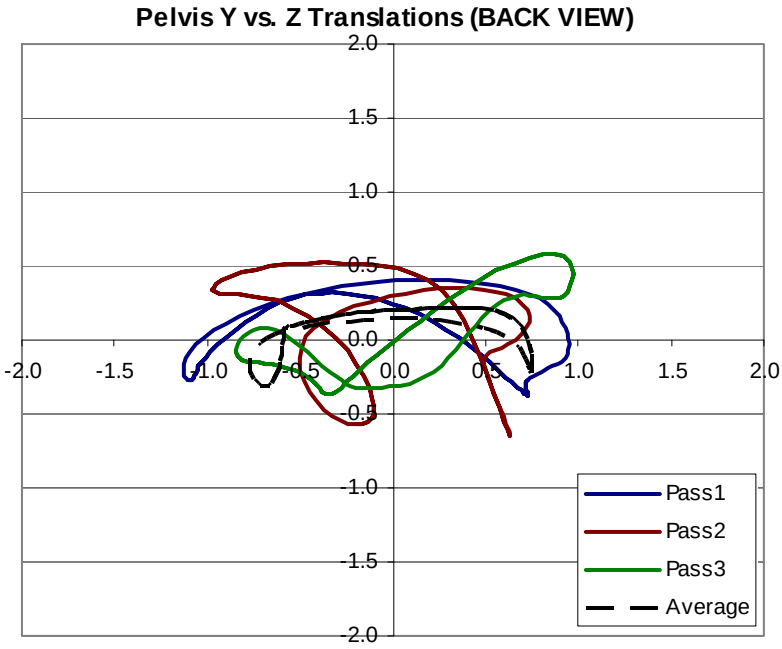


Figure C.40: Back view of pelvis for subject F on Dolly

Averages

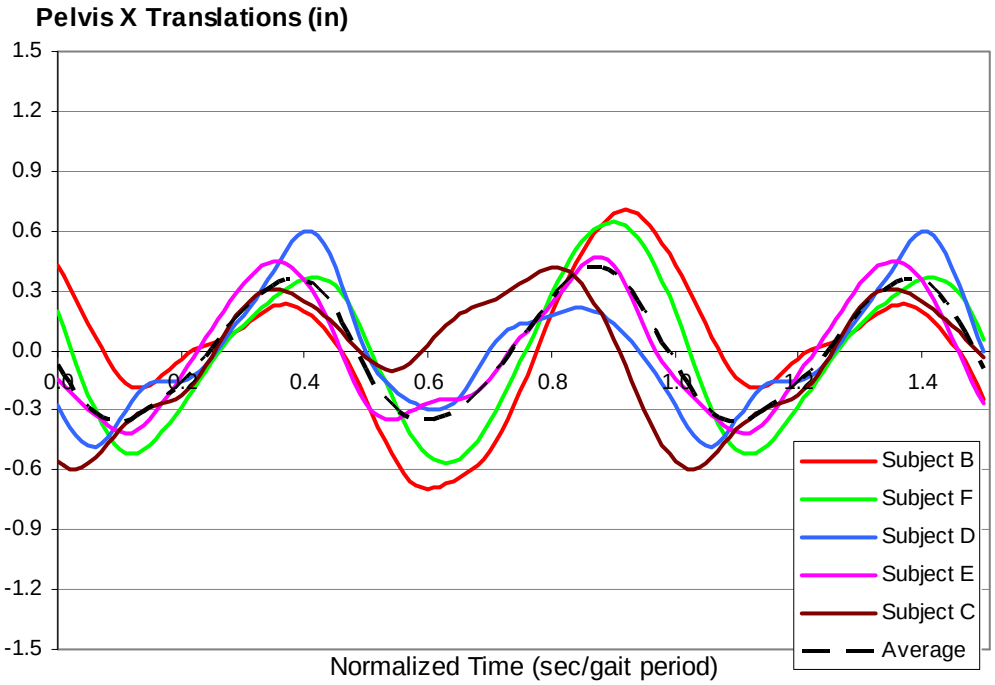


Figure C.41: Pelvis x-translations for all subjects on Dolly

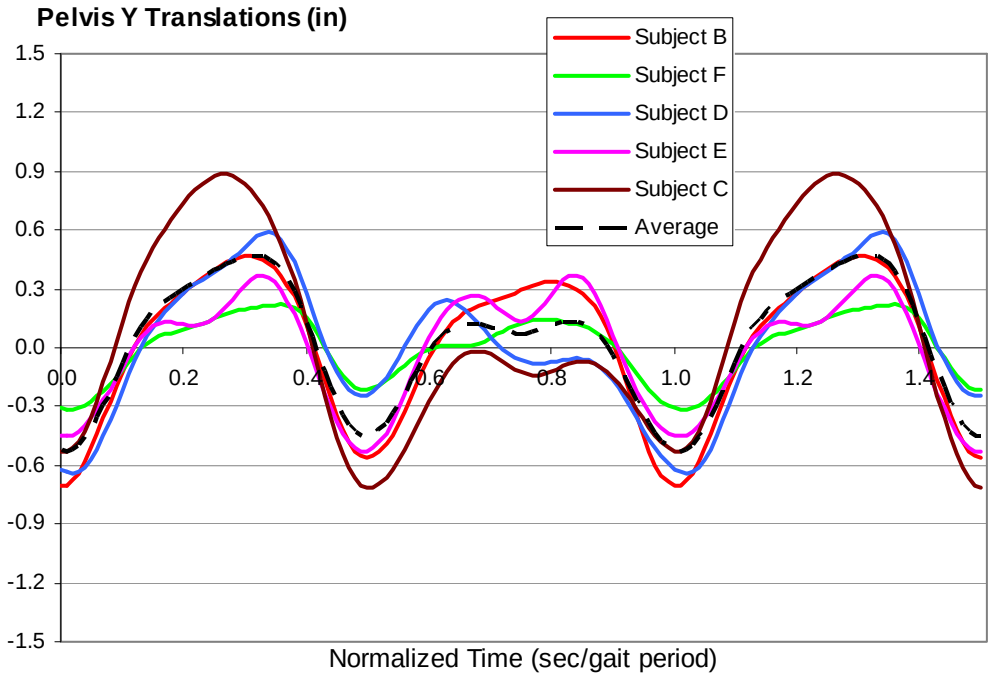


Figure C.42: Pelvis y-translations for all subjects on Dolly

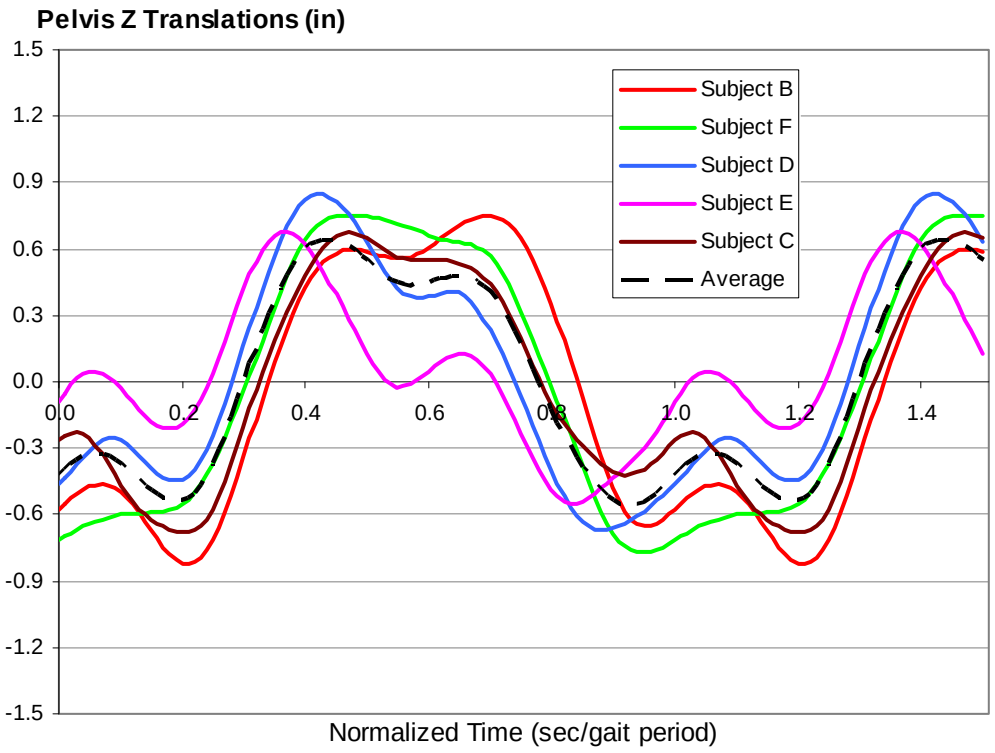


Figure C.43: Pelvis z-translations for all subjects on Dolly

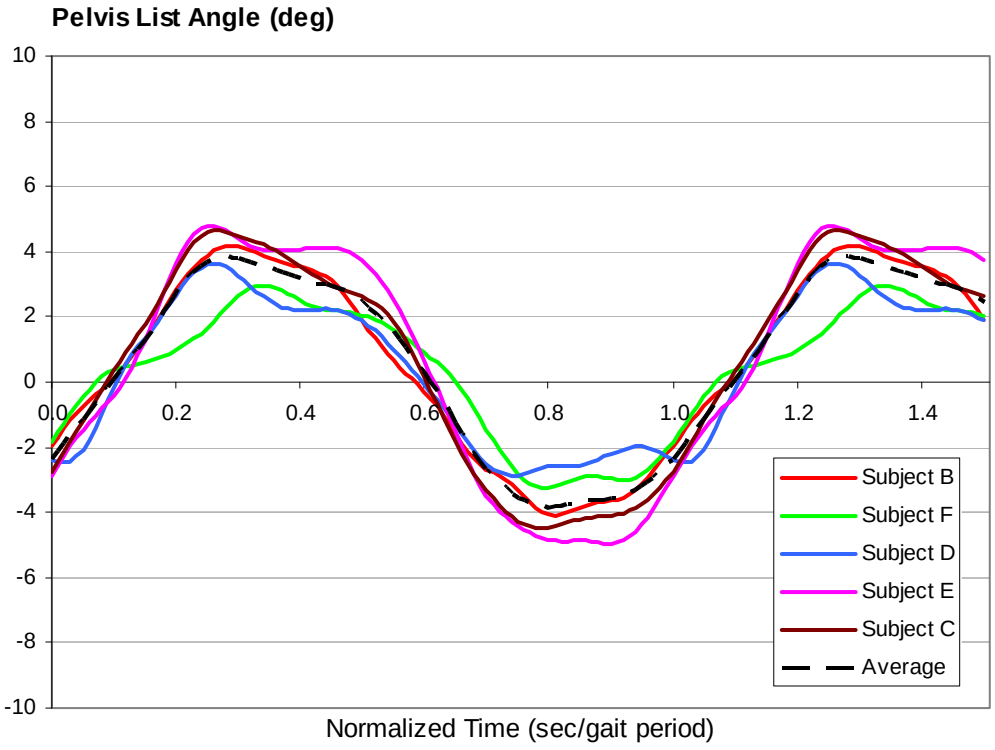


Figure C.44: Pelvis list angles for all subjects on Dolly

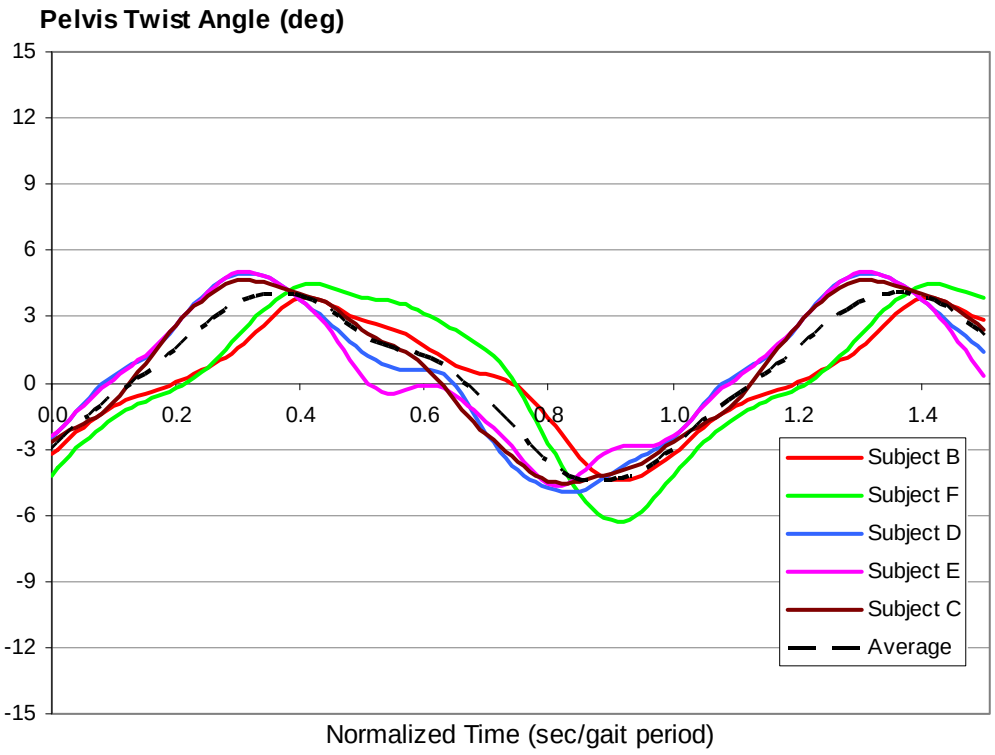


Figure C.45: Pelvis twist angles for all subjects on Dolly

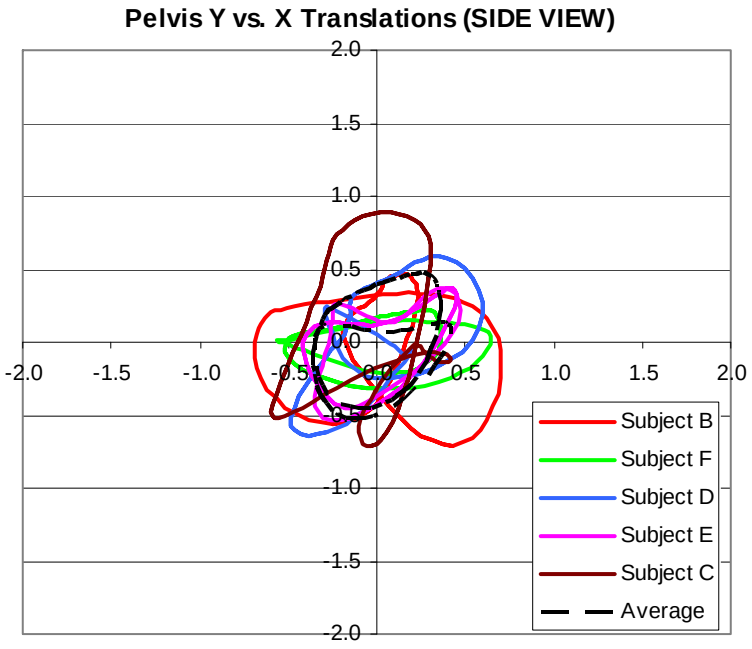


Figure C.46: Side view of pelvis for all subjects on Dolly

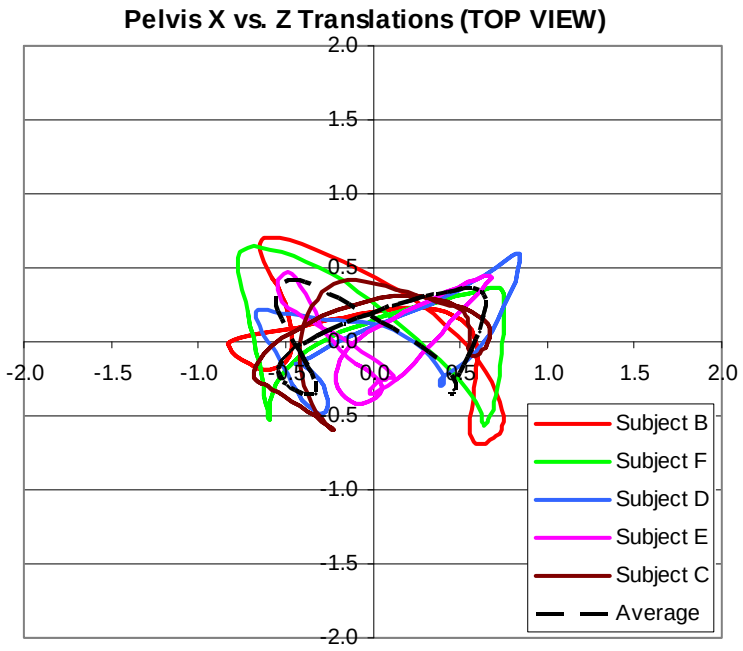


Figure C.47: Top view of pelvis for all subjects on Dolly

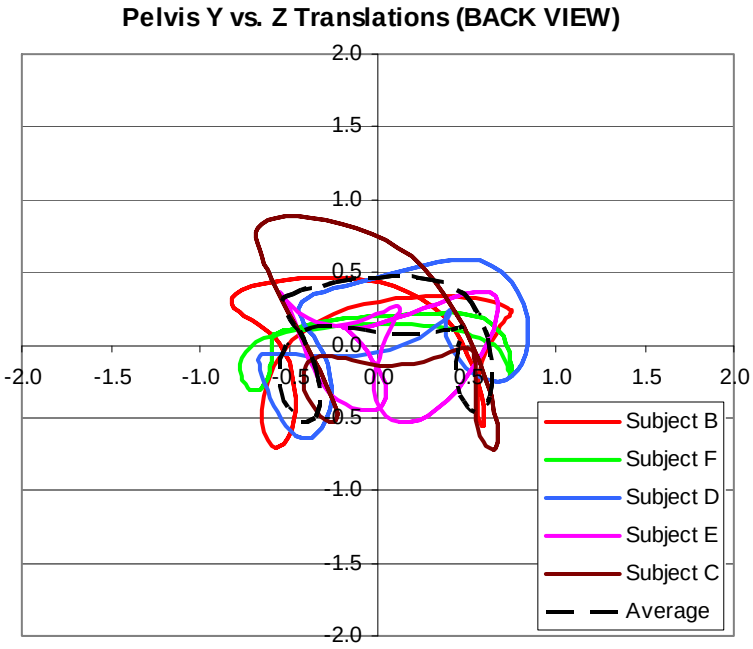


Figure C.48: Back view of pelvis for all subjects on Dolly

APPENDIX D

Walking Data

Subject A

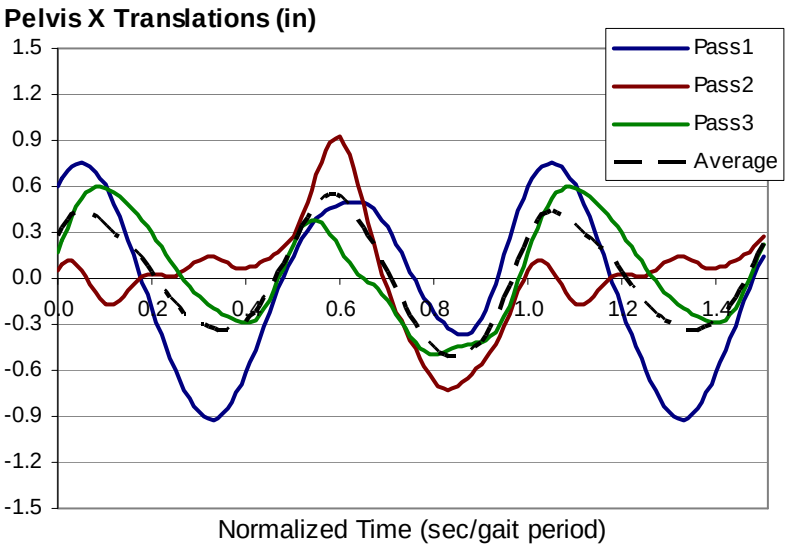


Figure D.1: Pelvis x-translations for subject A, walking

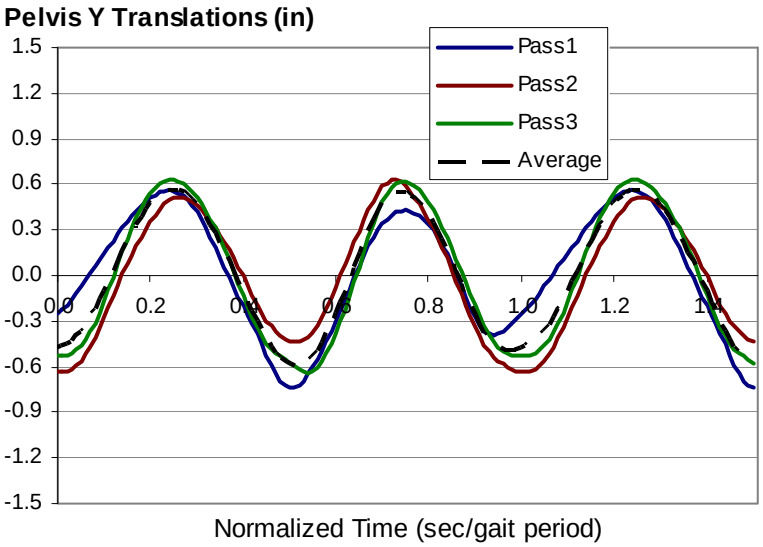


Figure D.2: Pelvis y-translations for subject A, walking

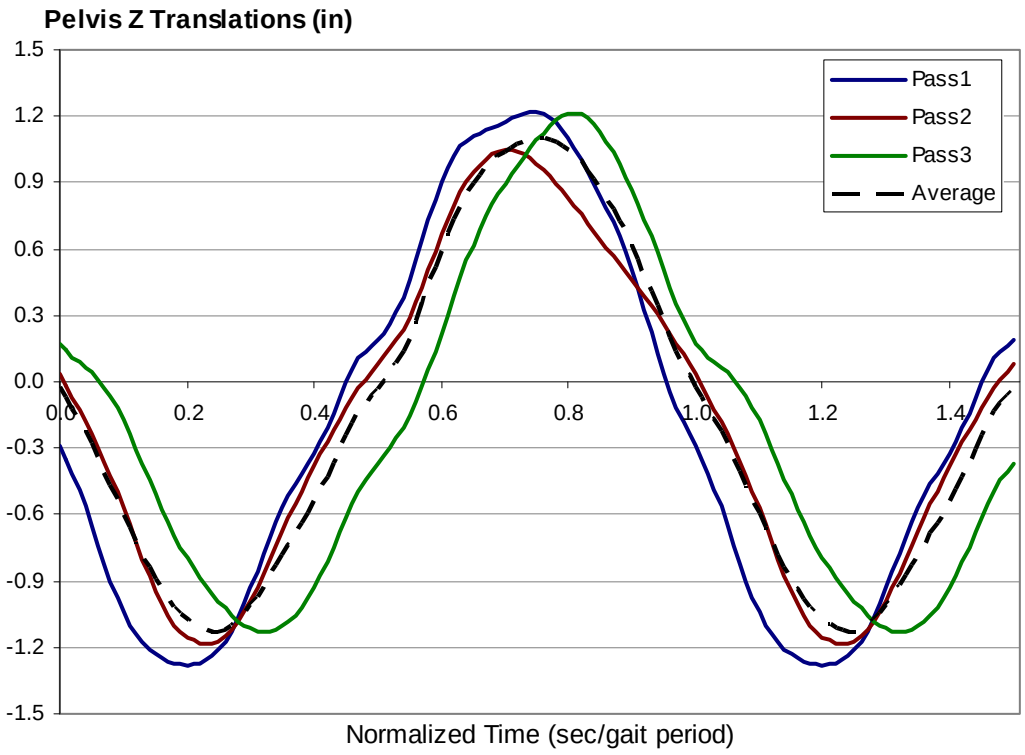


Figure D.3: Pelvis z-translations for subject A, walking

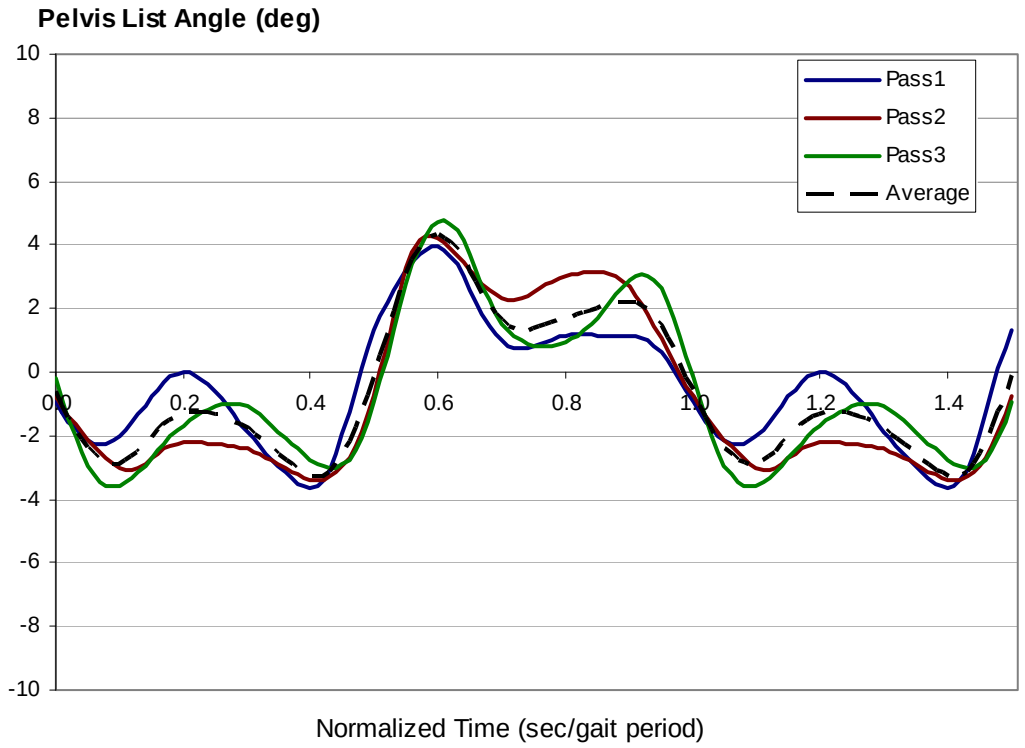


Figure D.4: Pelvis list angles for subject A, walking

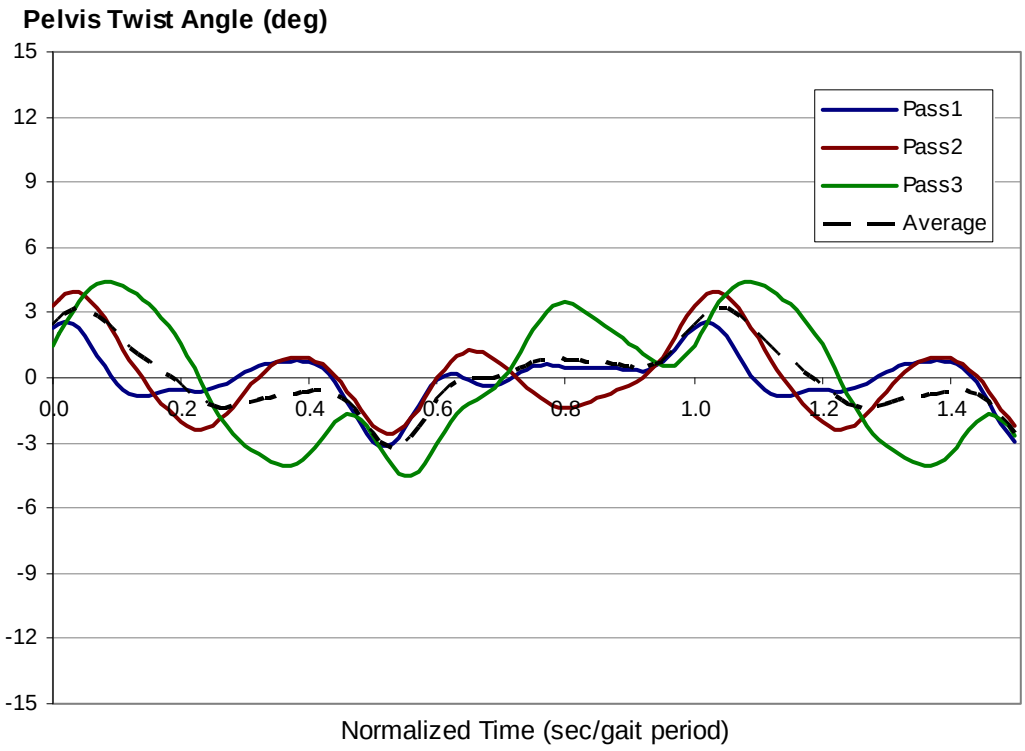


Figure D.5: Pelvis twist angles for subject A, walking

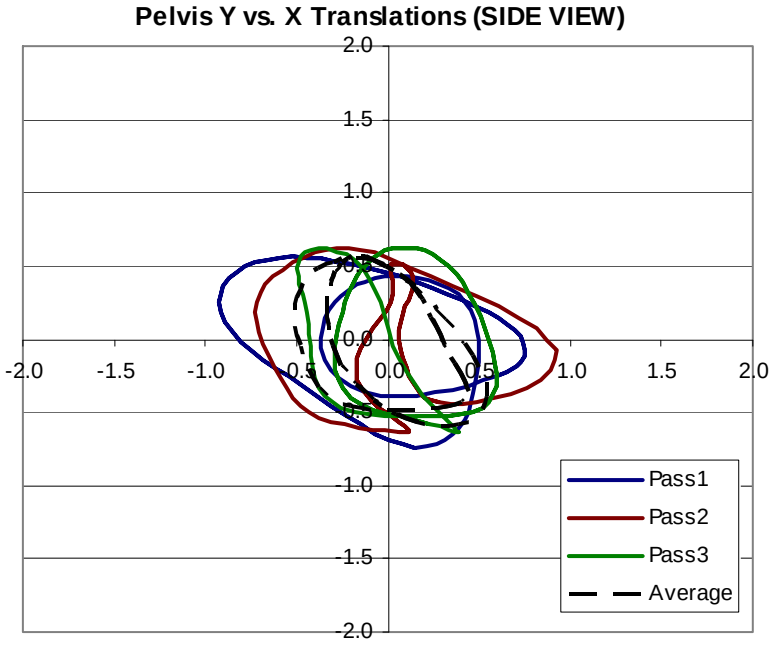


Figure D.6: Side view of pelvis for subject A, walking

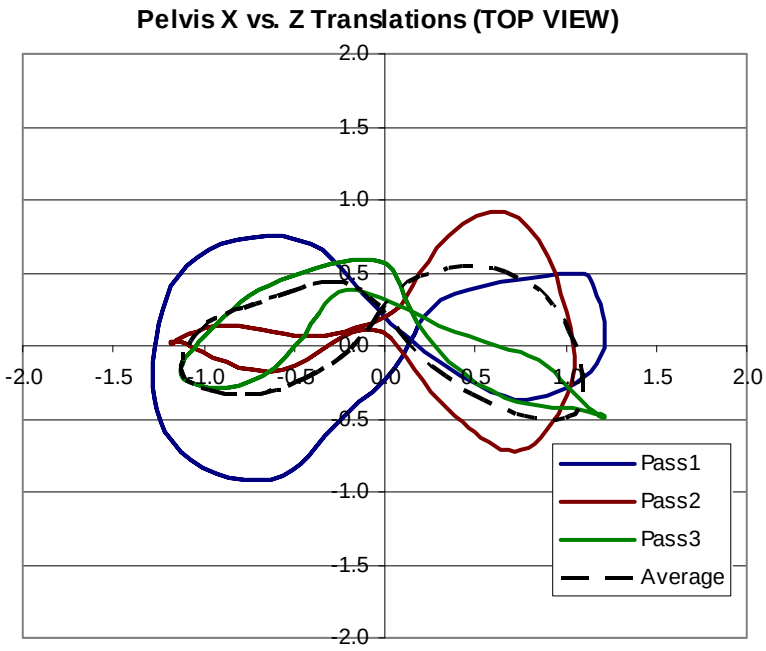


Figure D.7: Top view of pelvis for subject A, walking

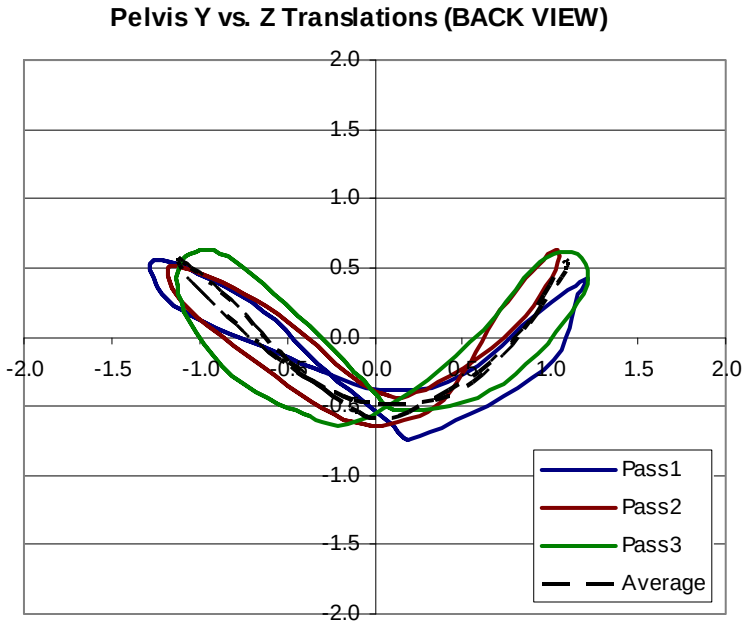


Figure D.8: Back view of pelvis for subject A, walking

Subject B

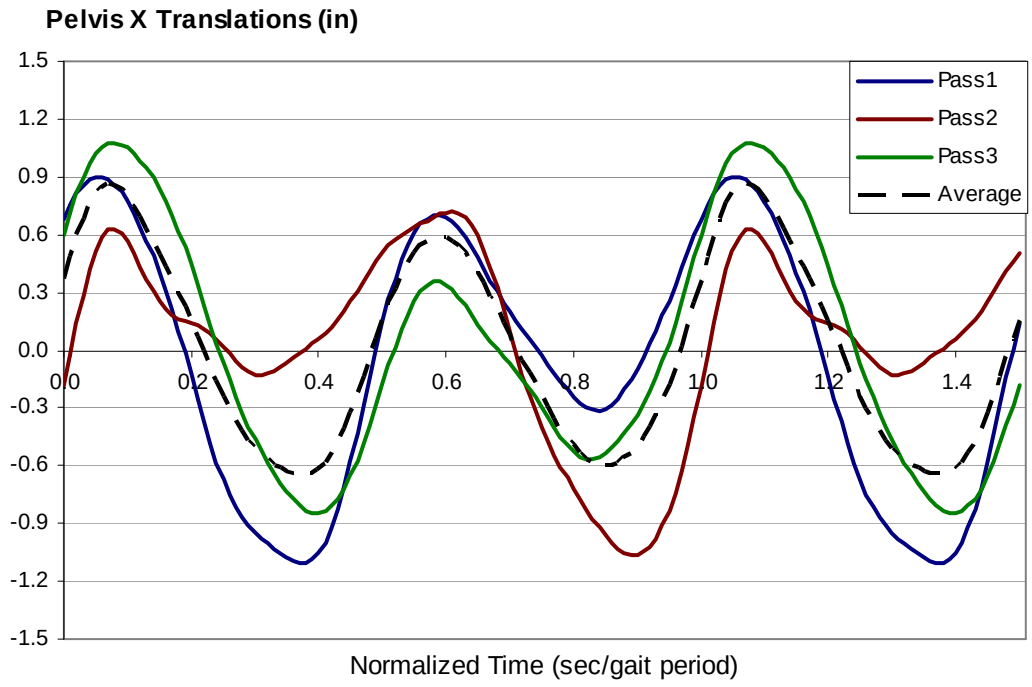


Figure D.9: Pelvis x-translations for subject B, walking

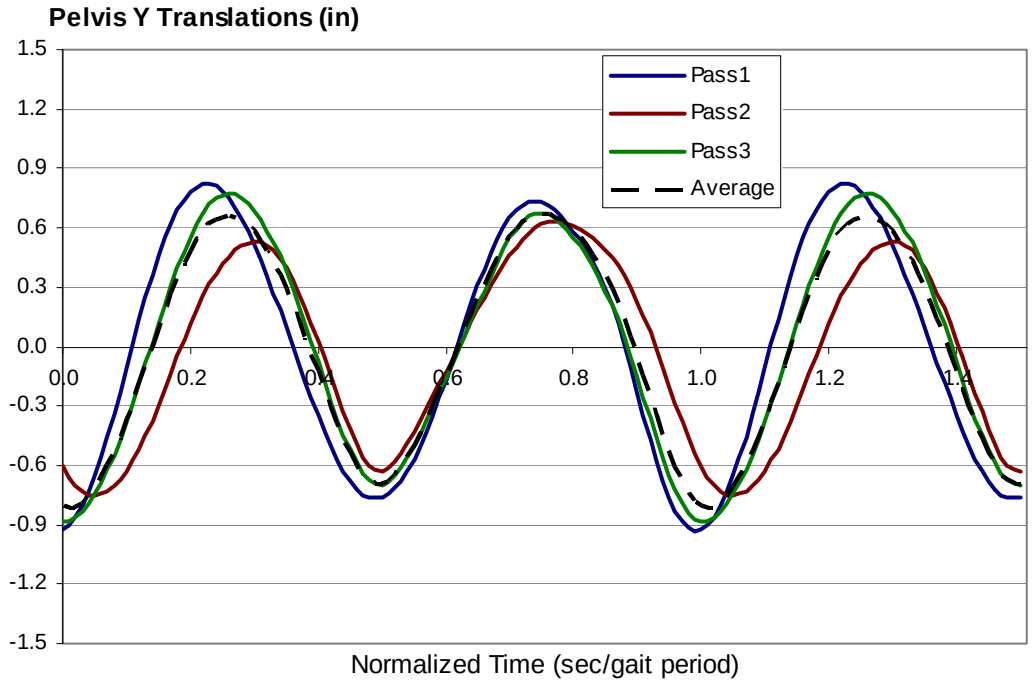


Figure D.10: Pelvis y-translations for subject B, walking

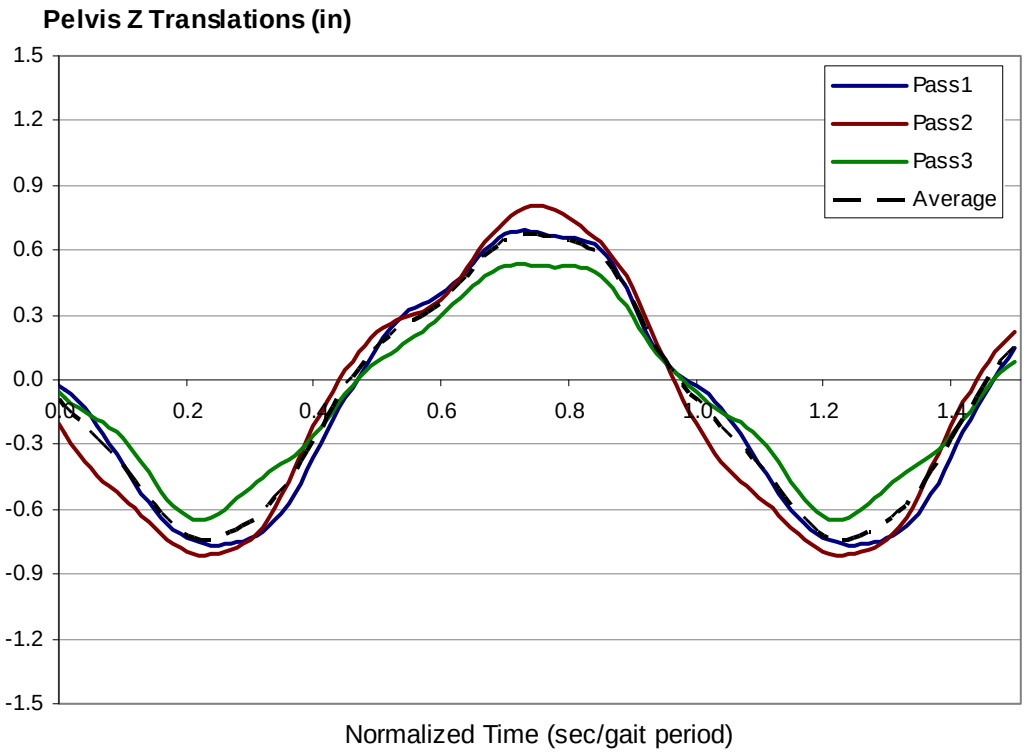


Figure D.11: Pelvis z-translations for subject B, walking

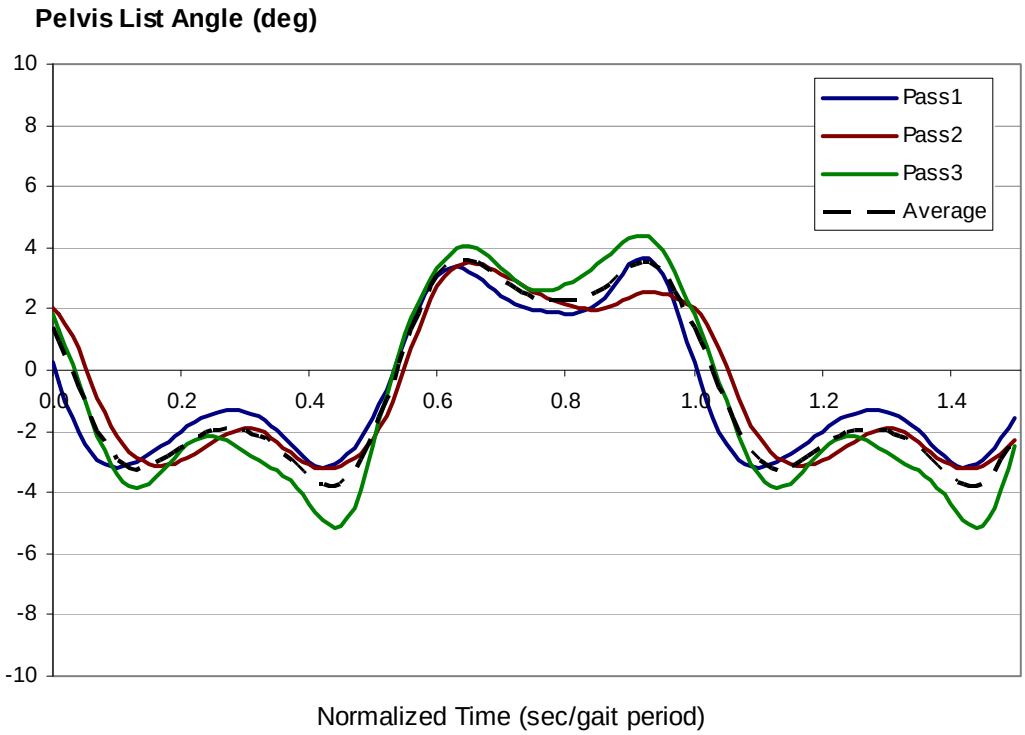


Figure D.12: Pelvis list angles for subject B, walking

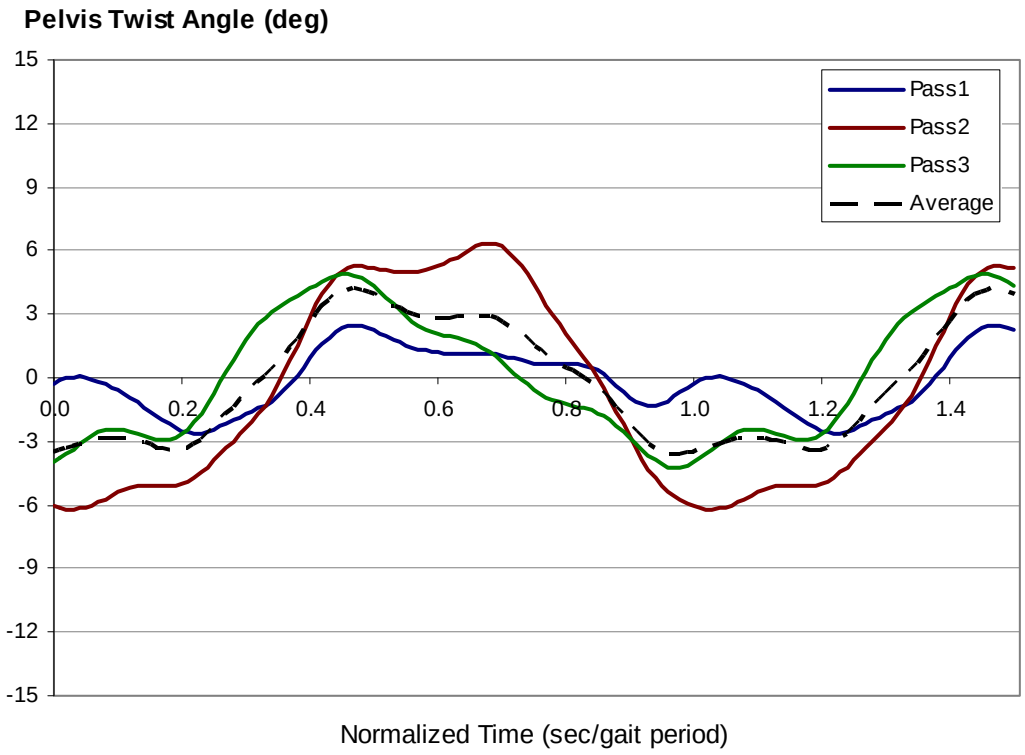


Figure D.13: Pelvis twist angles for subject B, walking

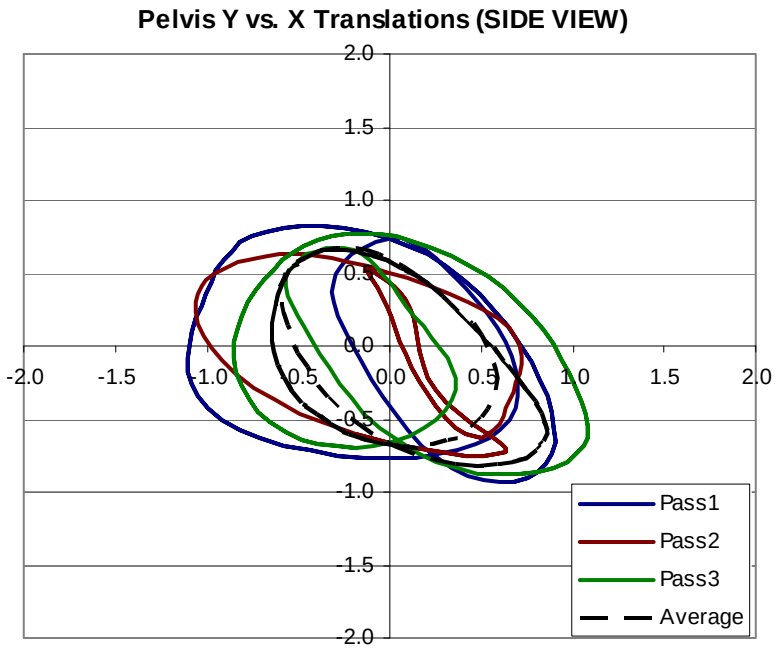


Figure D.14: Side view of pelvis for subject B, walking

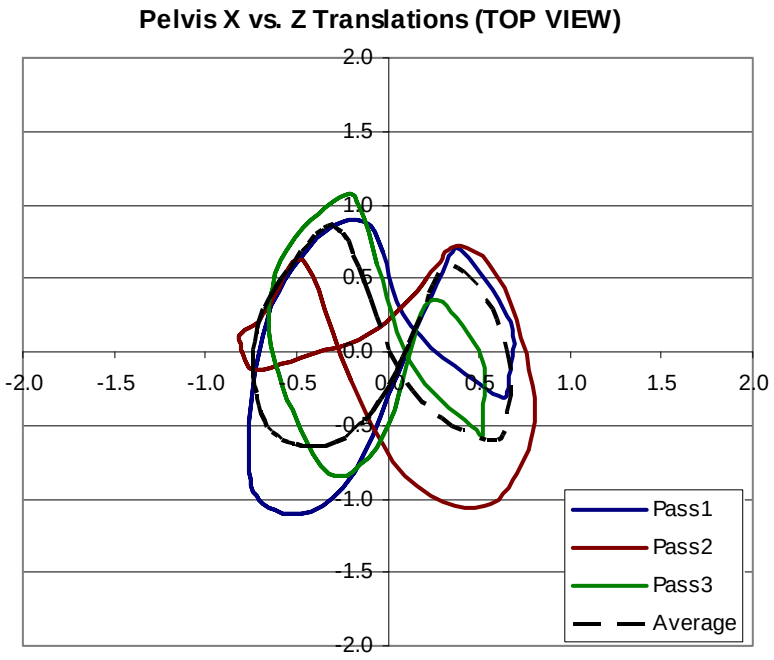


Figure D.15: Top view of pelvis for subject B, walking

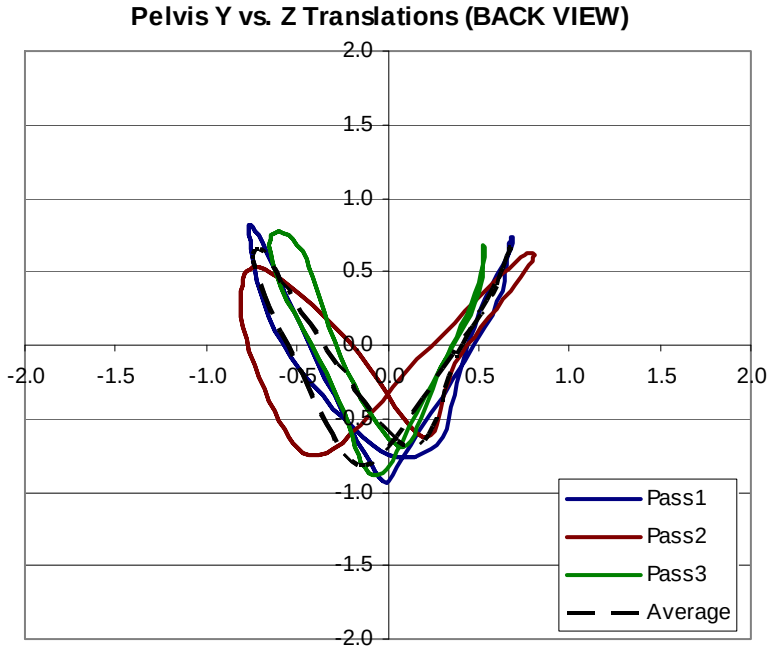


Figure D.16: Back view of pelvis for subject B, walking

Subject C

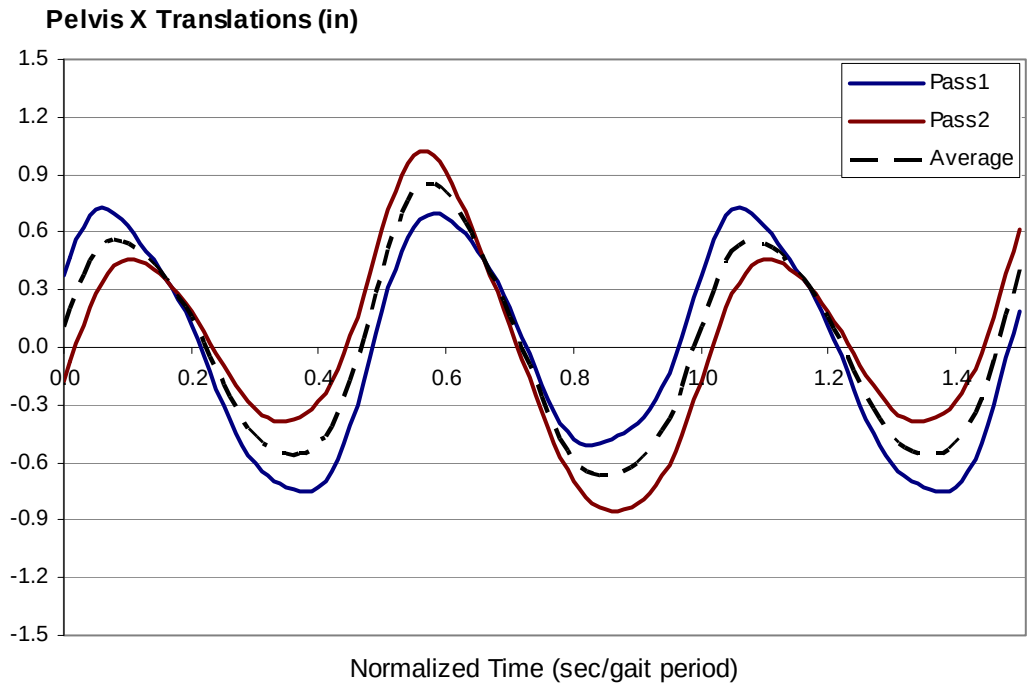


Figure D.17: Pelvis x-translations for subject C, walking

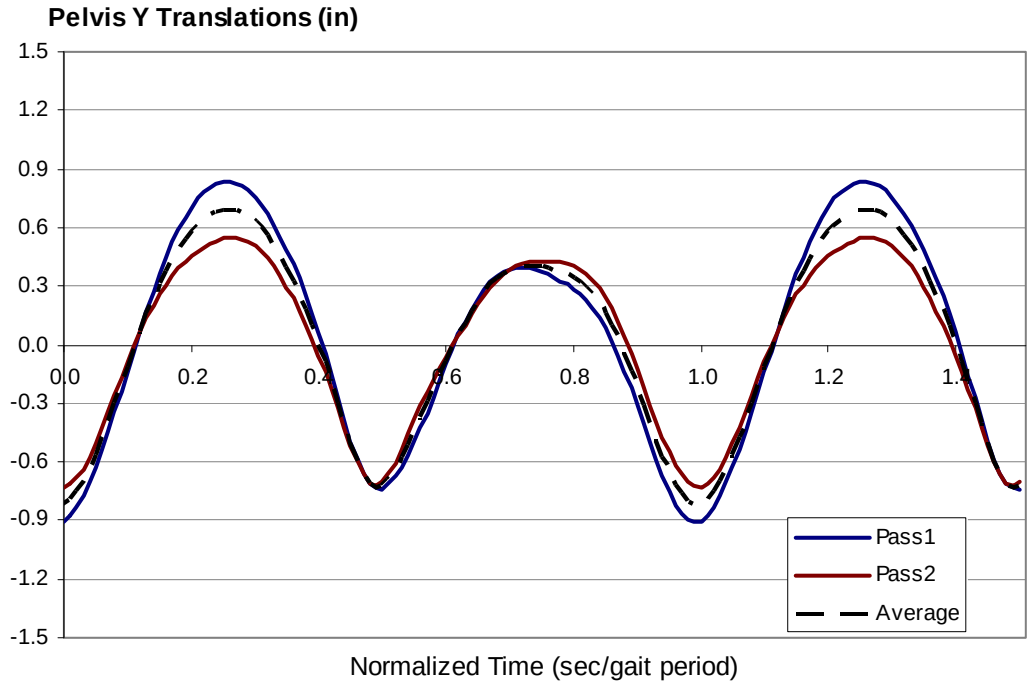


Figure D.18: Pelvis y-translations for subject C, walking

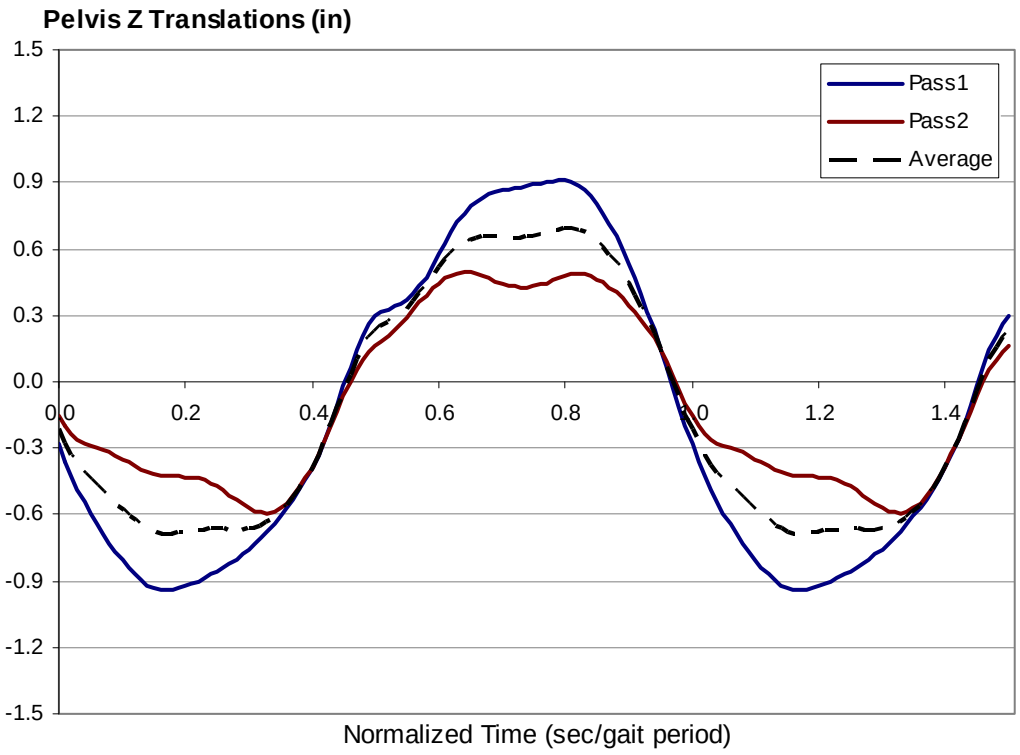


Figure D.19: Pelvis z-translations for subject C, walking

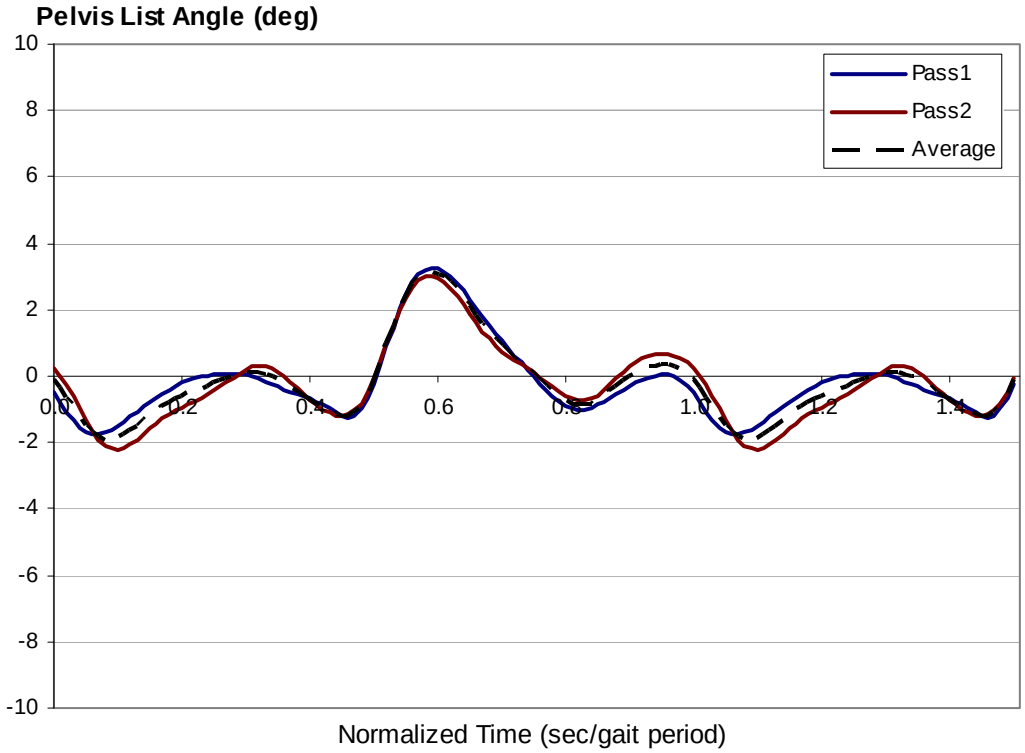


Figure D.20: Pelvis list angles for subject C, walking

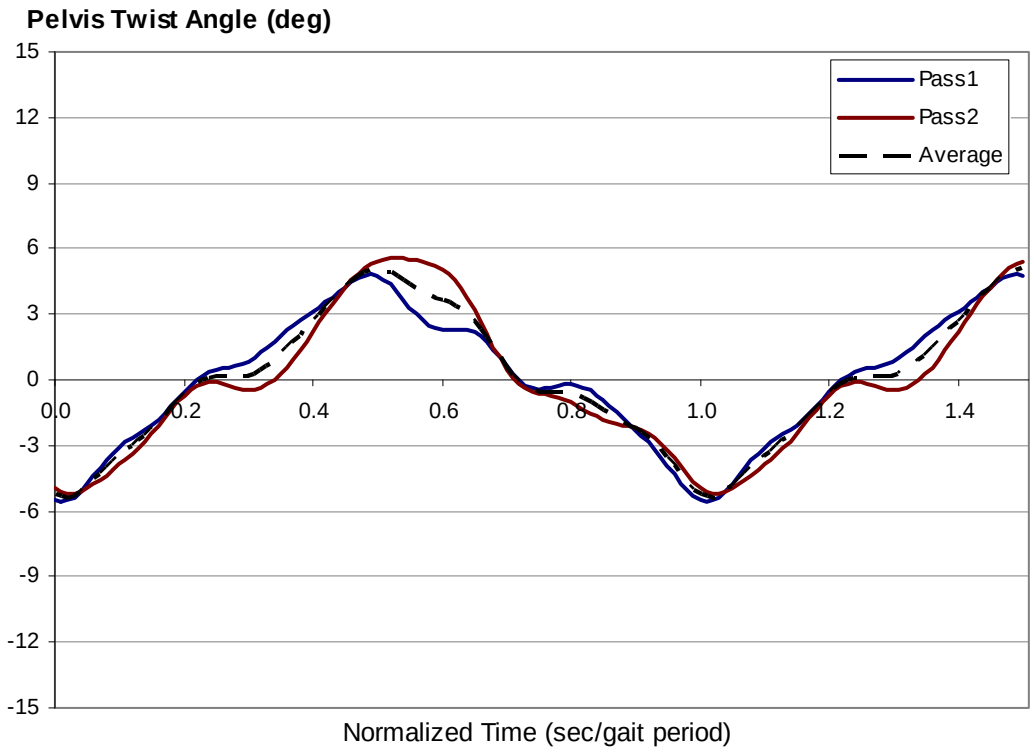


Figure D.21: Pelvis twist angles for subject C, walking

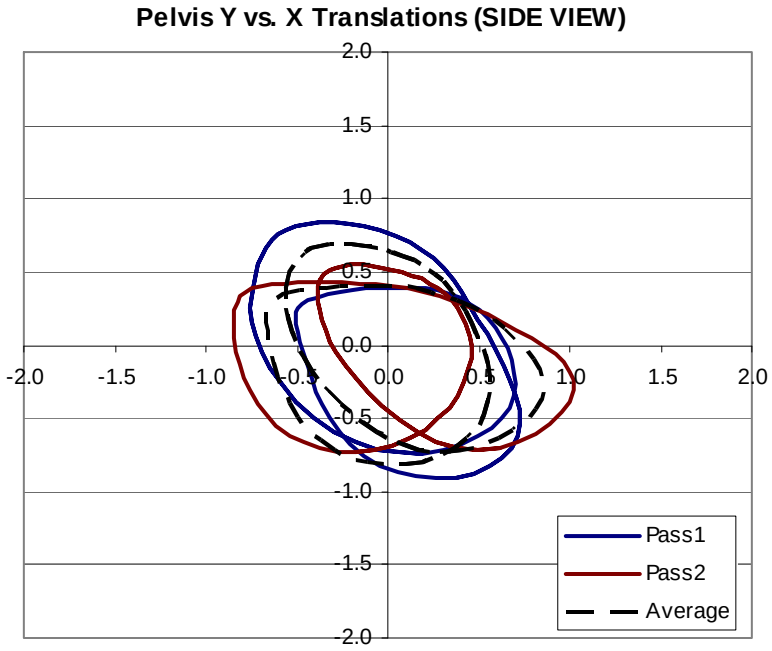


Figure D.22: Side view of pelvis for subject C, walking

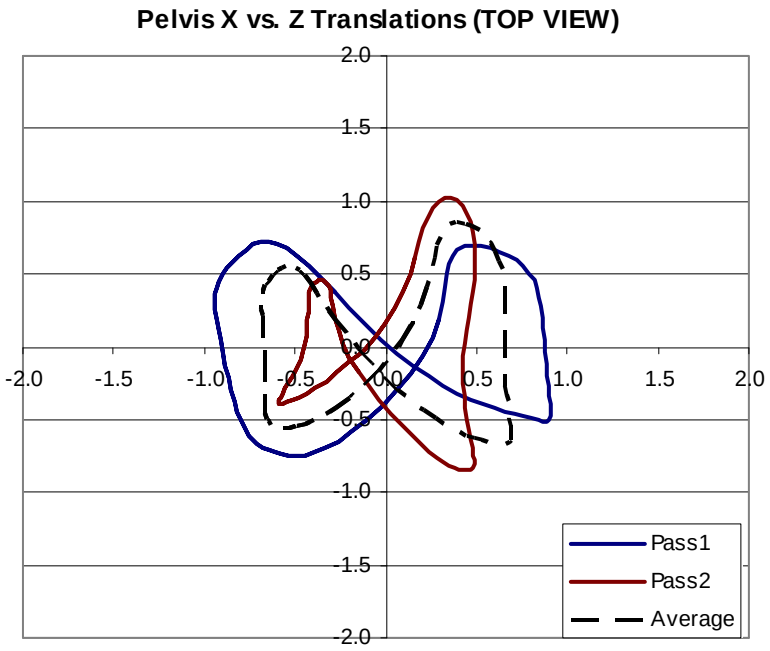


Figure D.23: Top view of pelvis for subject C, walking

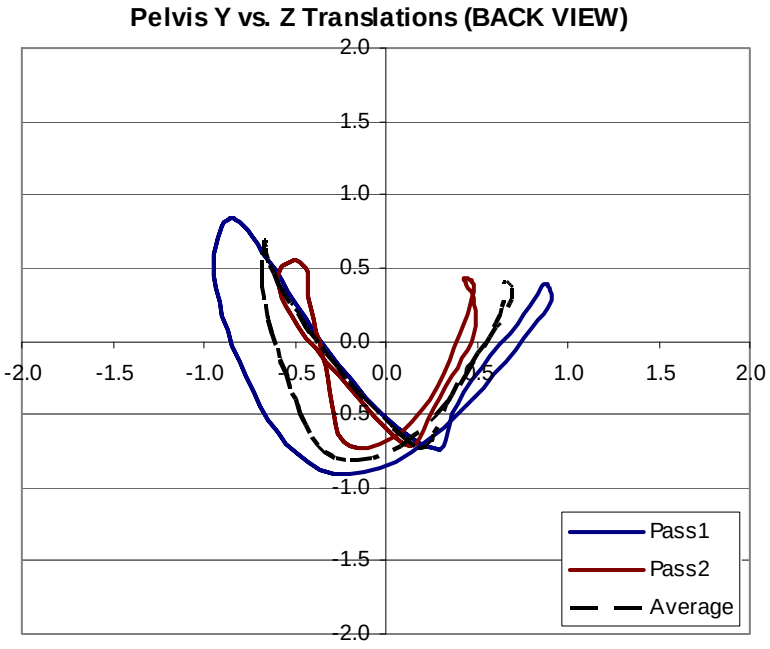


Figure D.24: Back view of pelvis for subject C, walking

Subject D

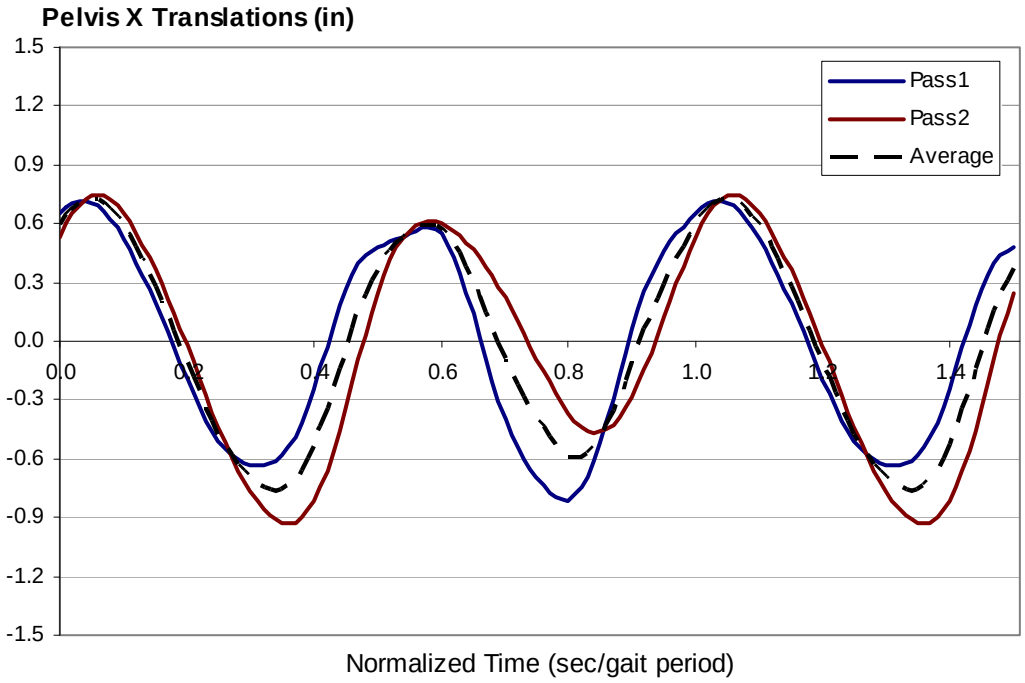


Figure D.25: Pelvis x-translations for subject D, walking

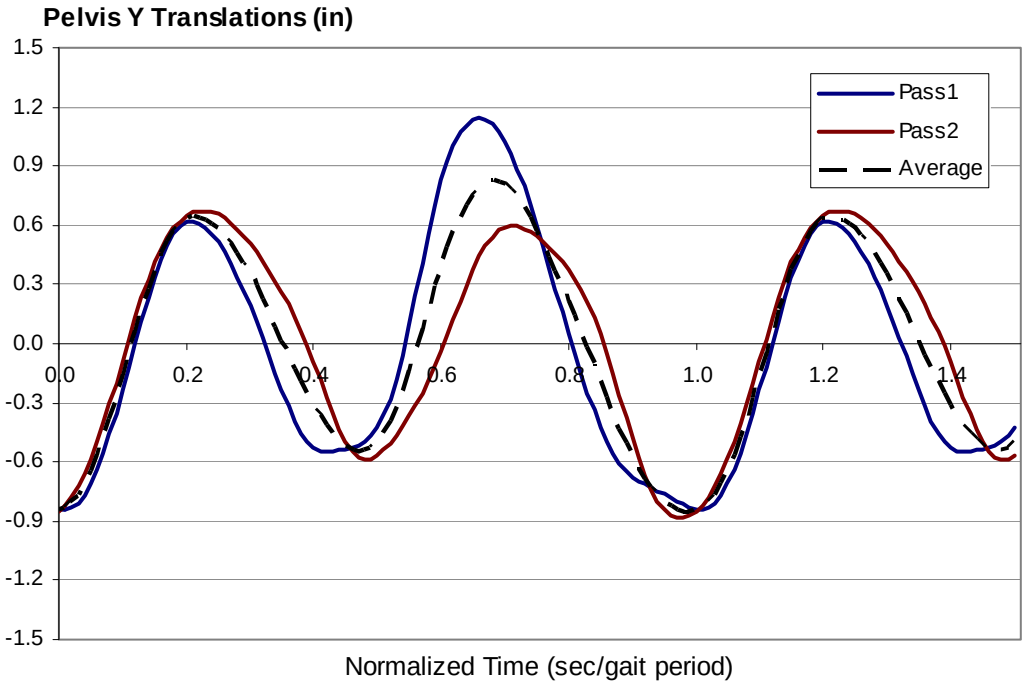


Figure D.26: Pelvis y-translations for subject D, walking

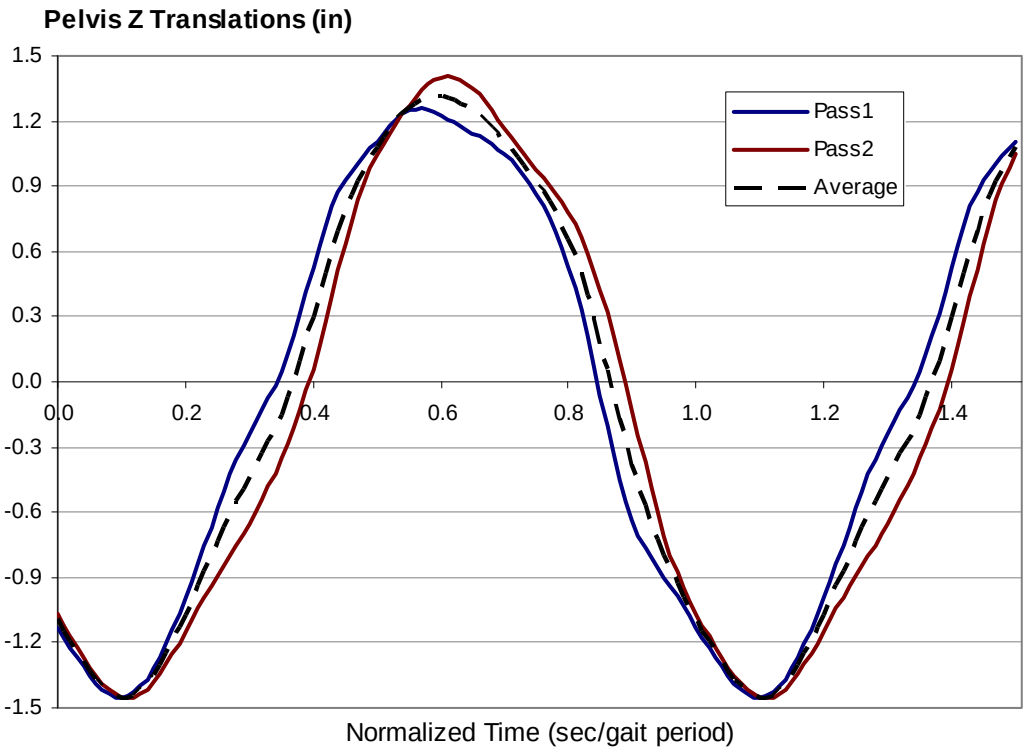


Figure D.27: Pelvis z-translations for subject D, walking

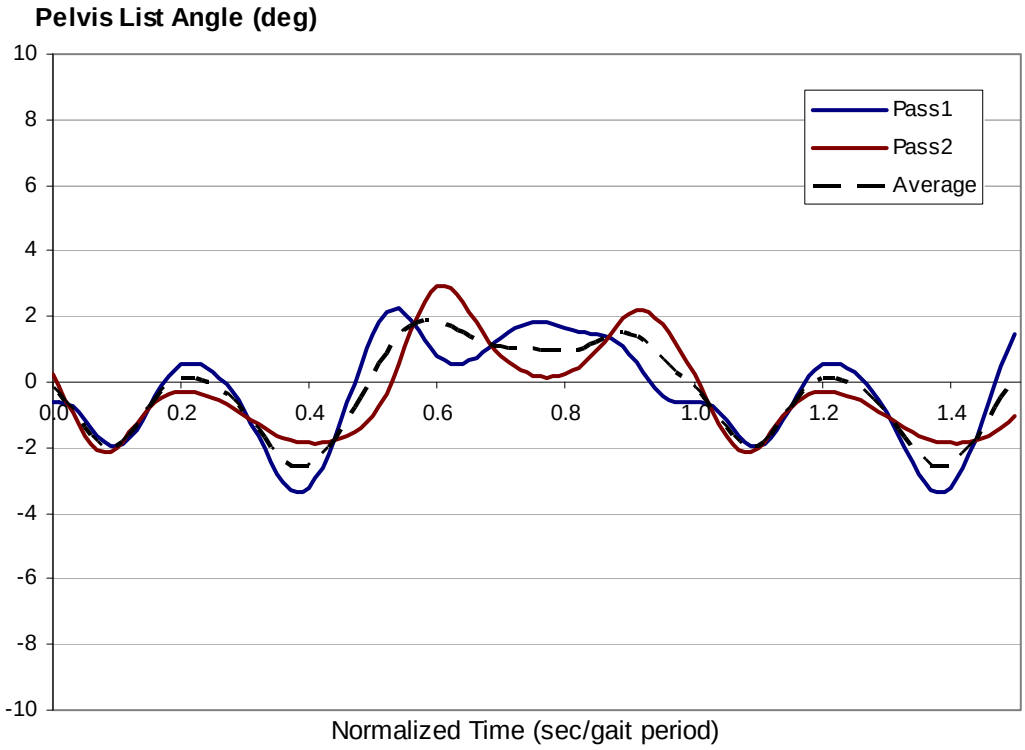


Figure D.28: Pelvis list angles for subject D, walking

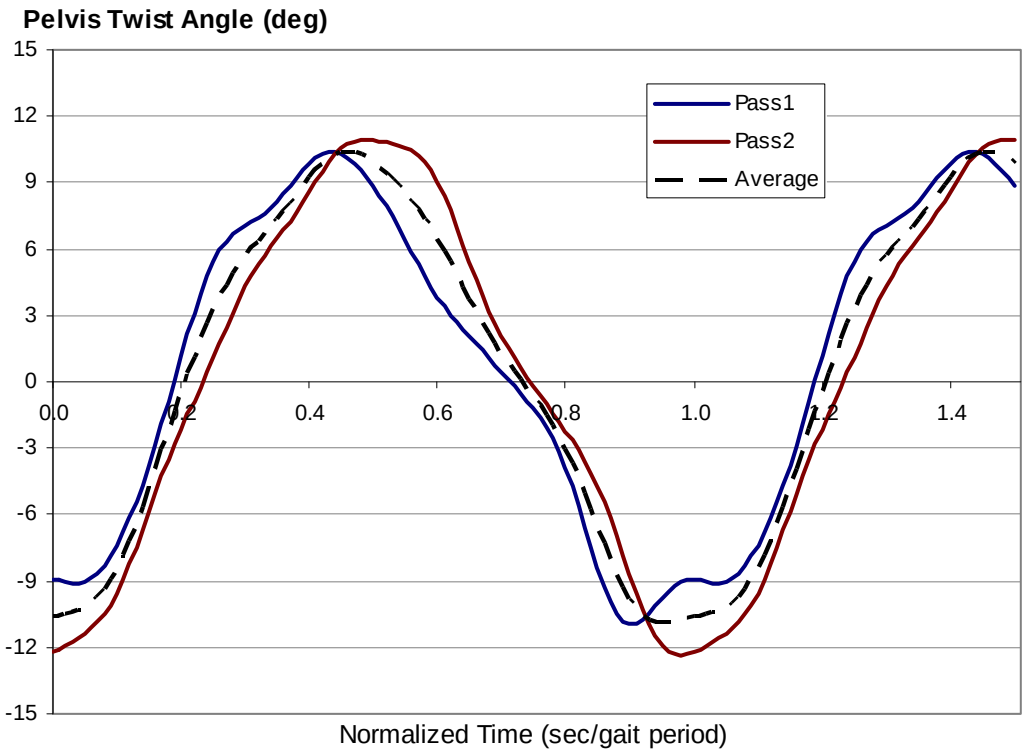


Figure D.29: Pelvis twist angles for subject D, walking

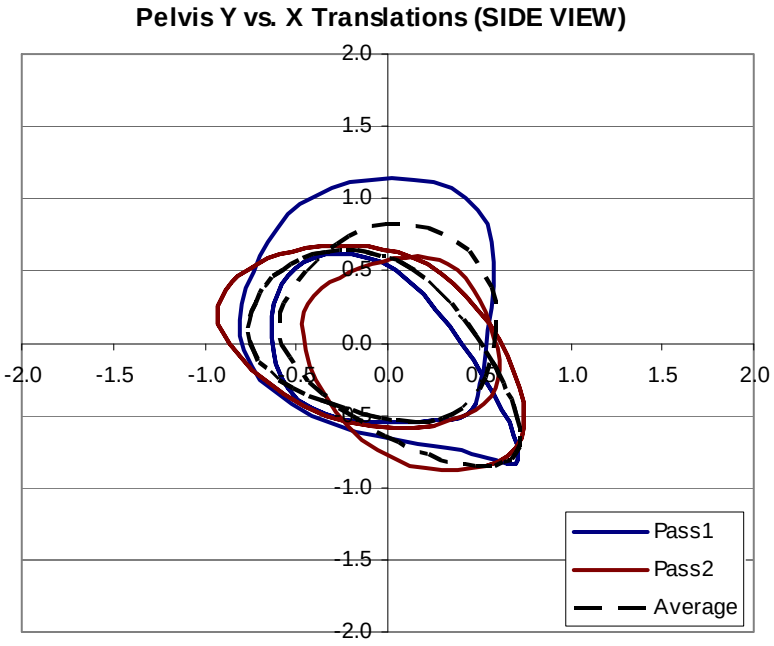


Figure D.30: Side view of pelvis for subject D walking

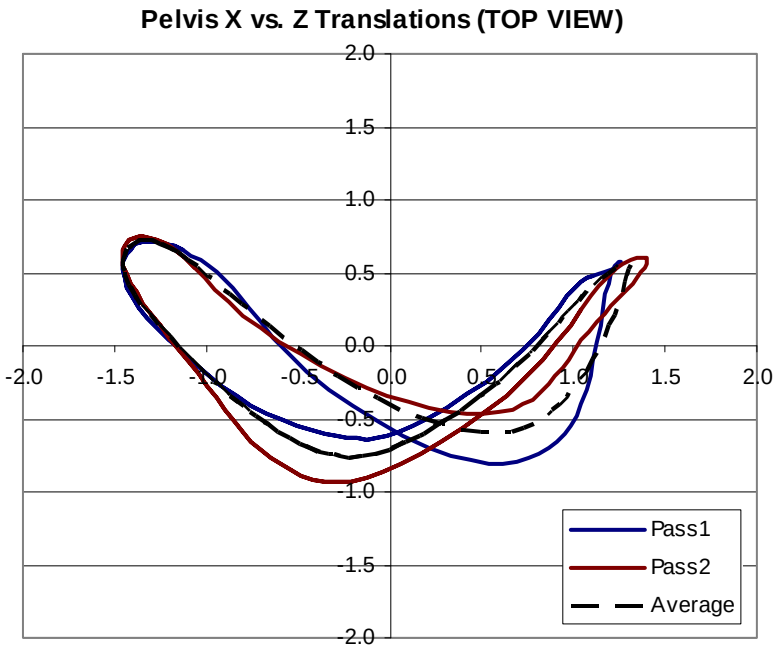


Figure D.31: Top view of pelvis for subject D, walking

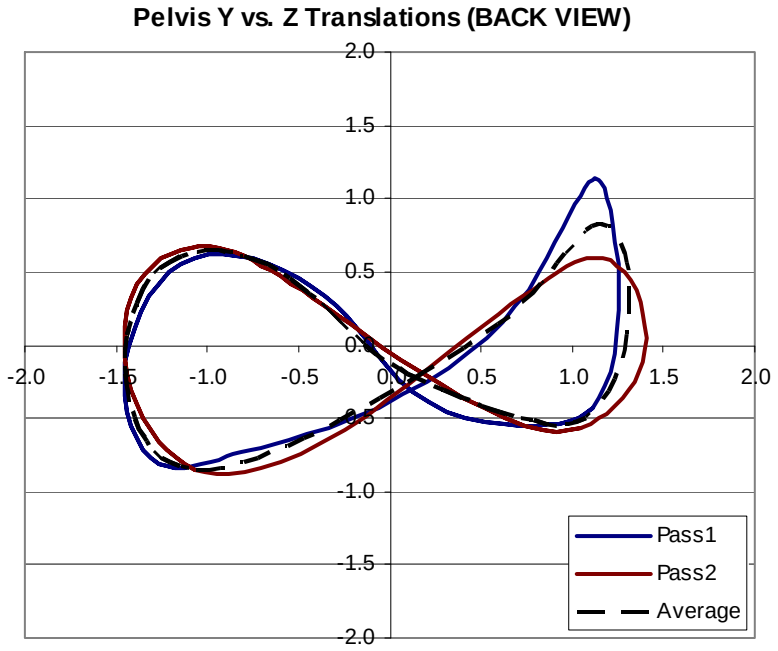


Figure D.32: Back view of pelvis for subject D, walking

Subject E

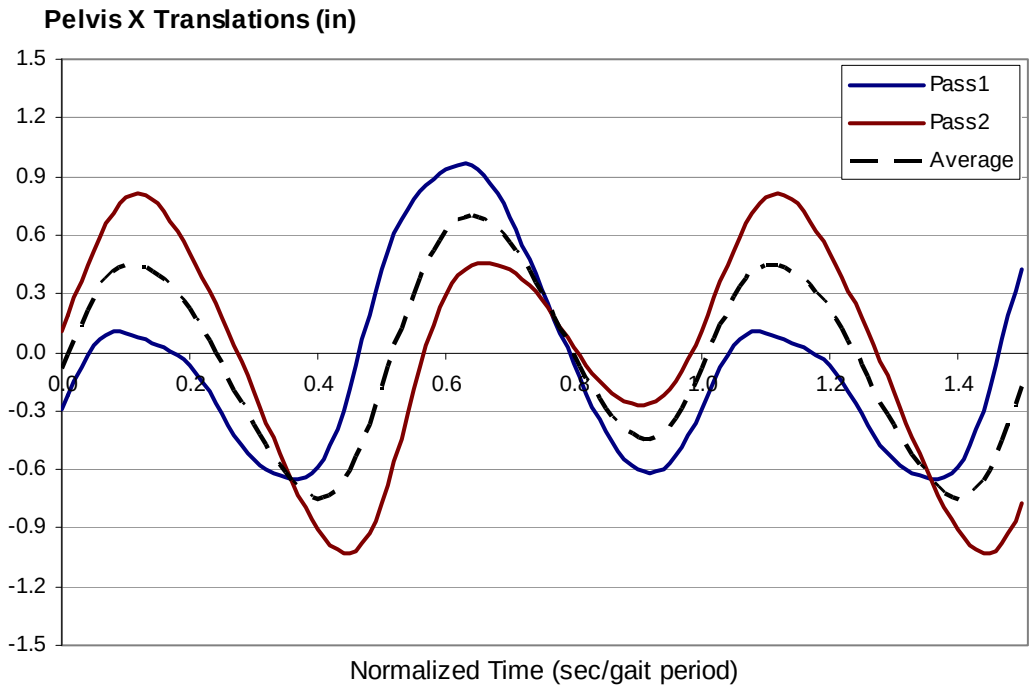


Figure D.33: Pelvis x-translations for subject E walking

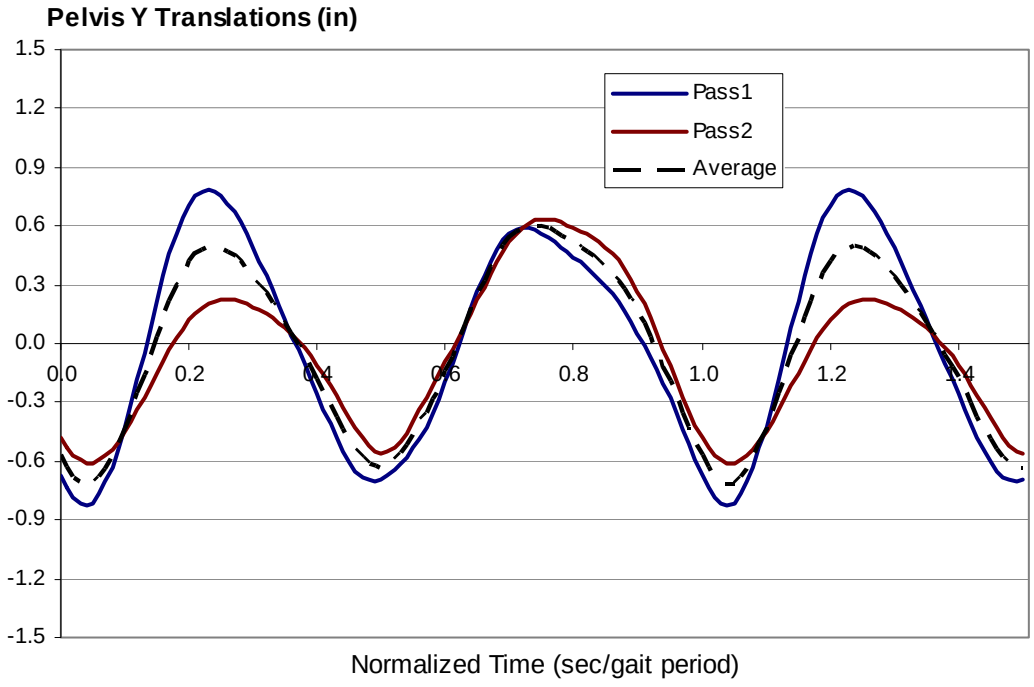


Figure D.34: Pelvis y-translations for subject E, walking

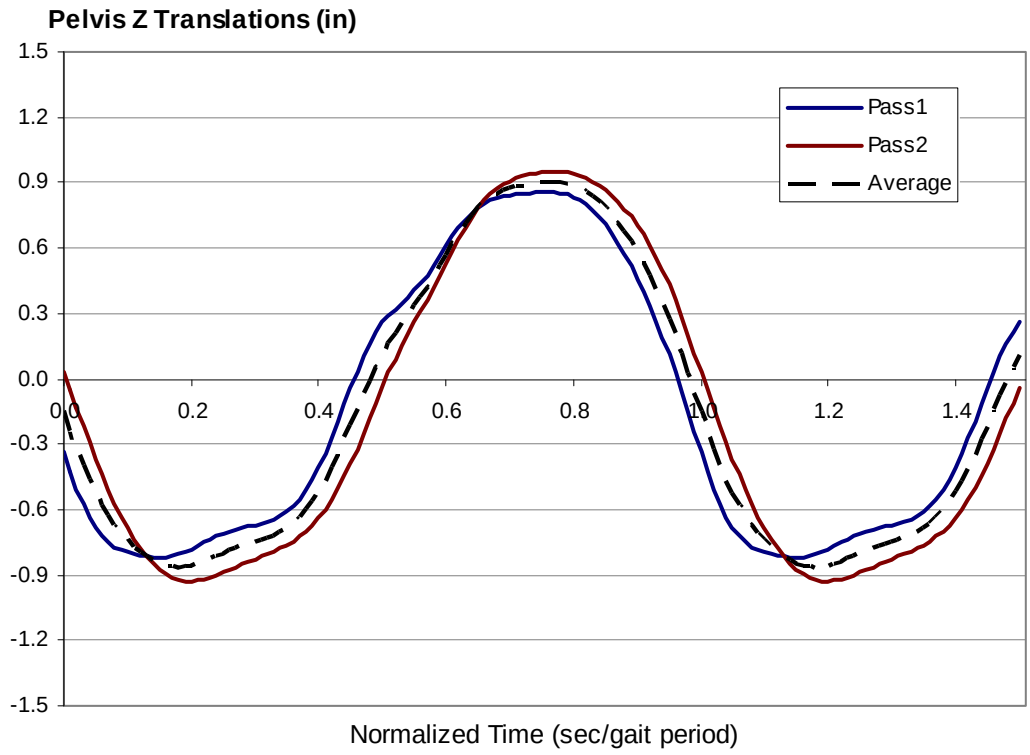


Figure: D.35: Pelvis z-translations for subject E, walking

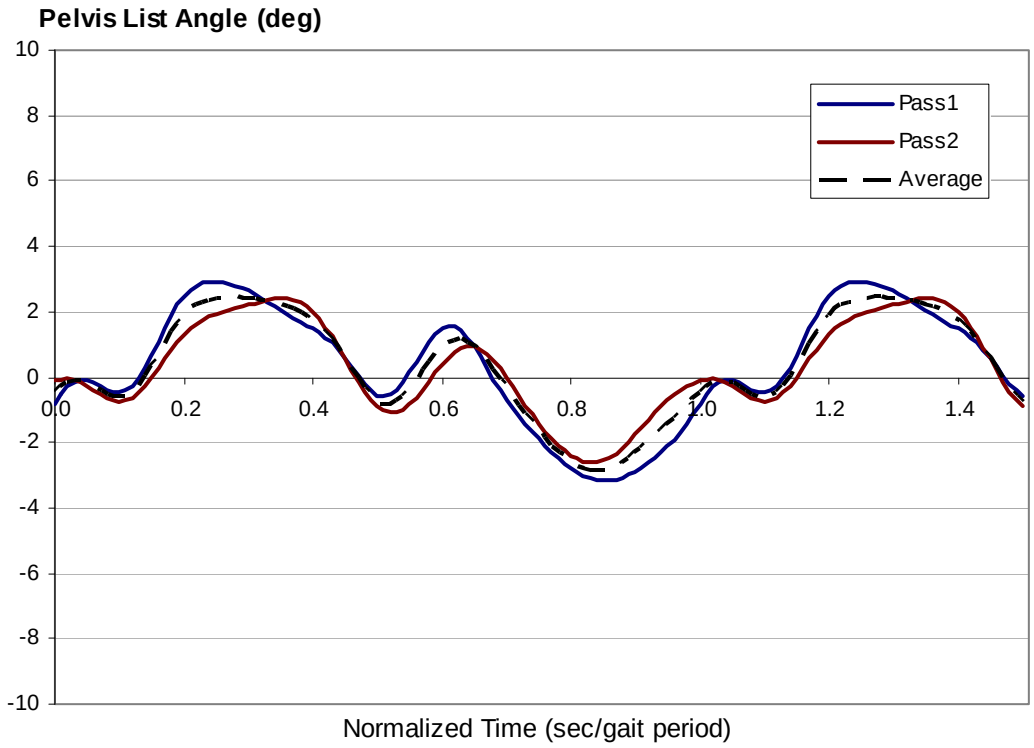


Figure D.36: Pelvis list angles for subject E, walking

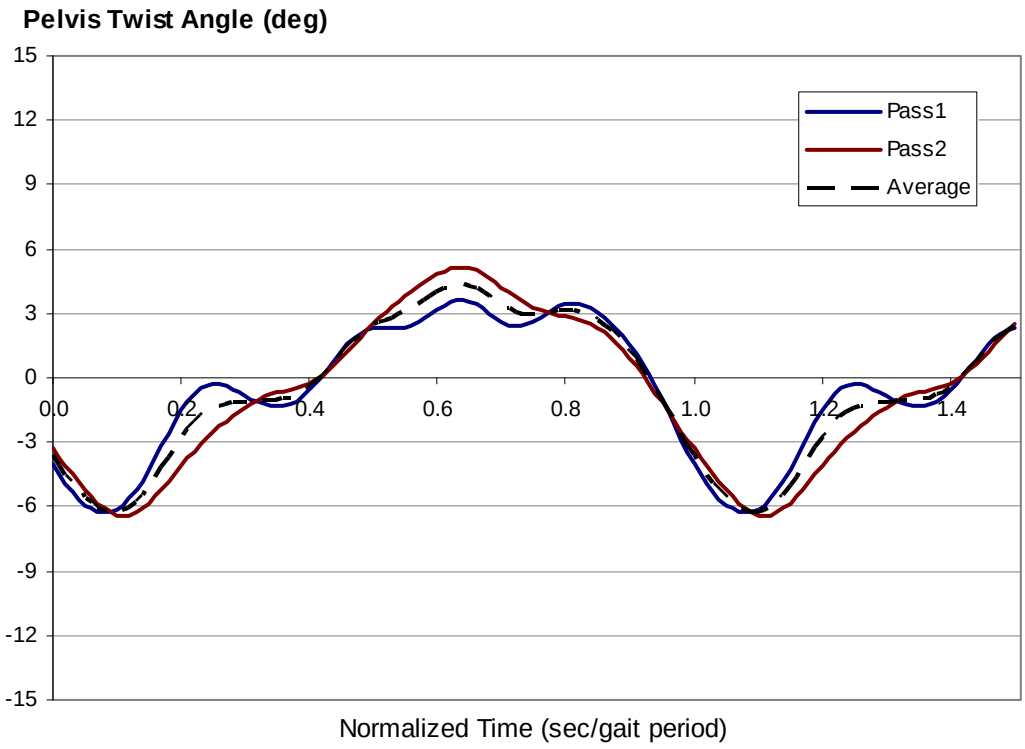


Figure D.37: Pelvis twist angles for subject E, walking

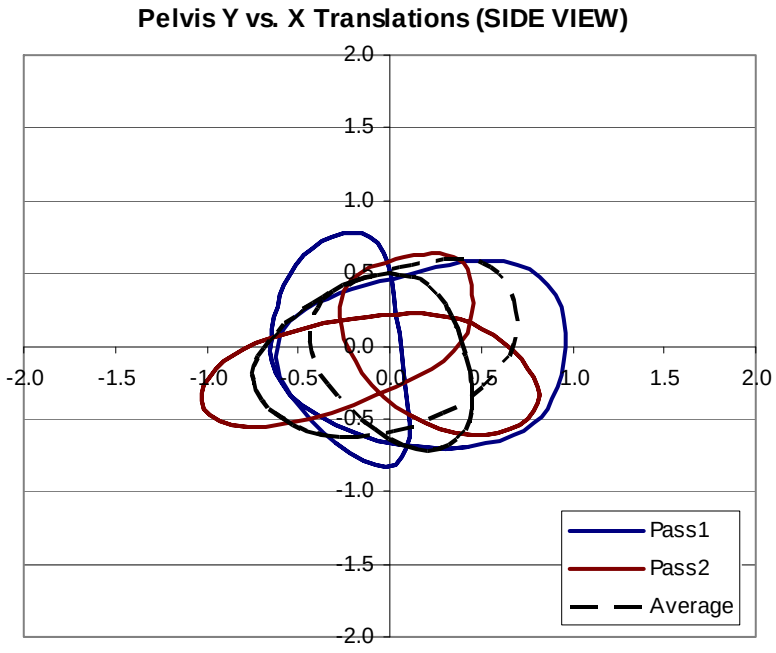


Figure D.38: Side view of pelvis for subject E, walking

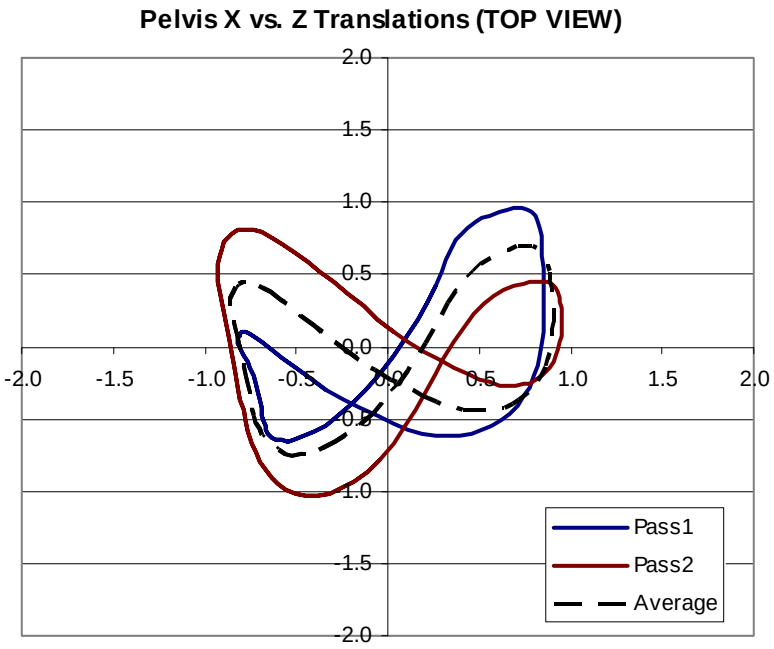


Figure D.39: Top view of pelvis for subject E, walking

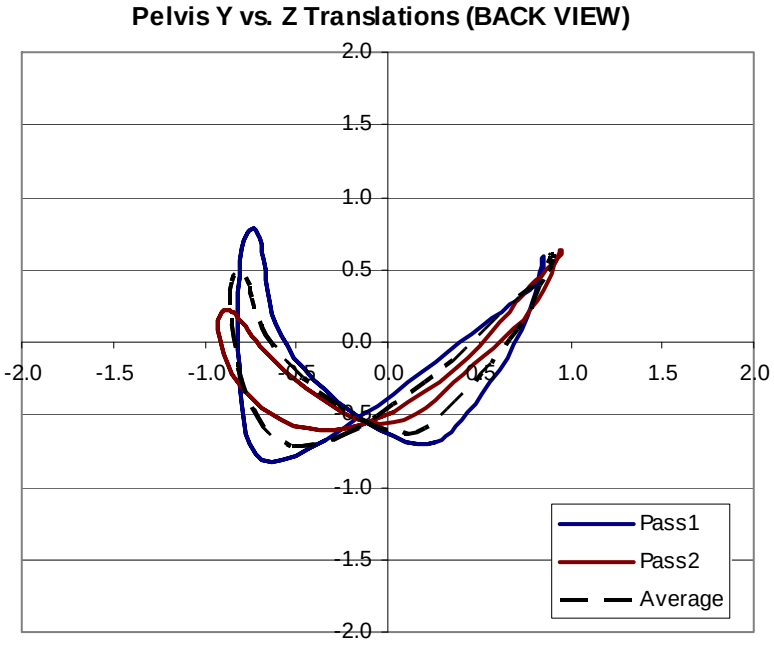


Figure D.40: Back view of pelvis for subject E, walking

Subject F

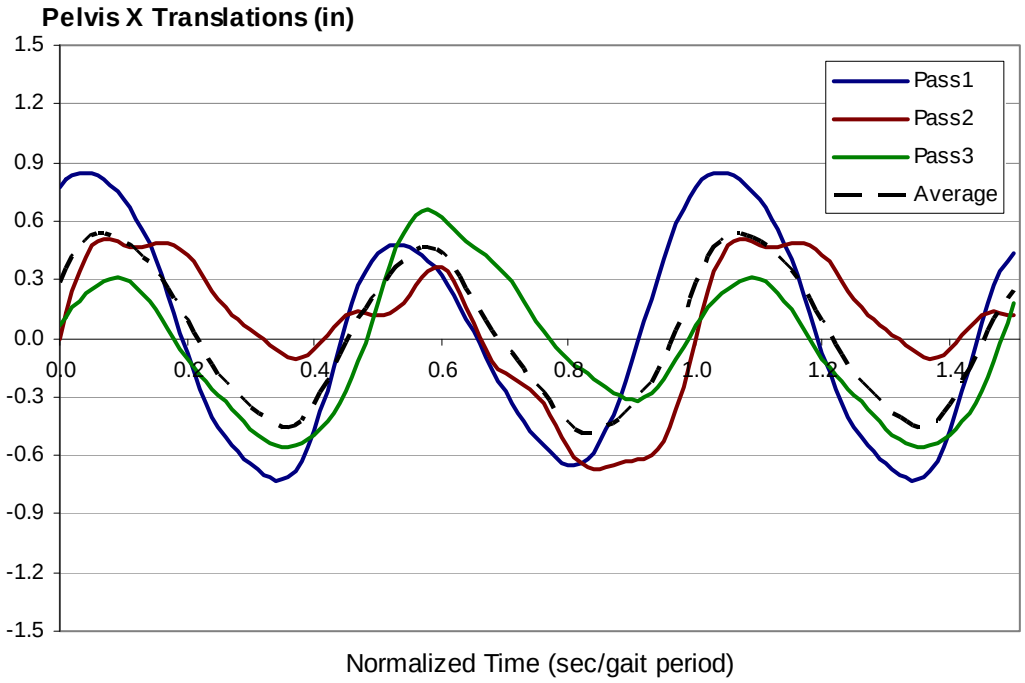


Figure D.41: Pelvis x-translations for subject F, walking

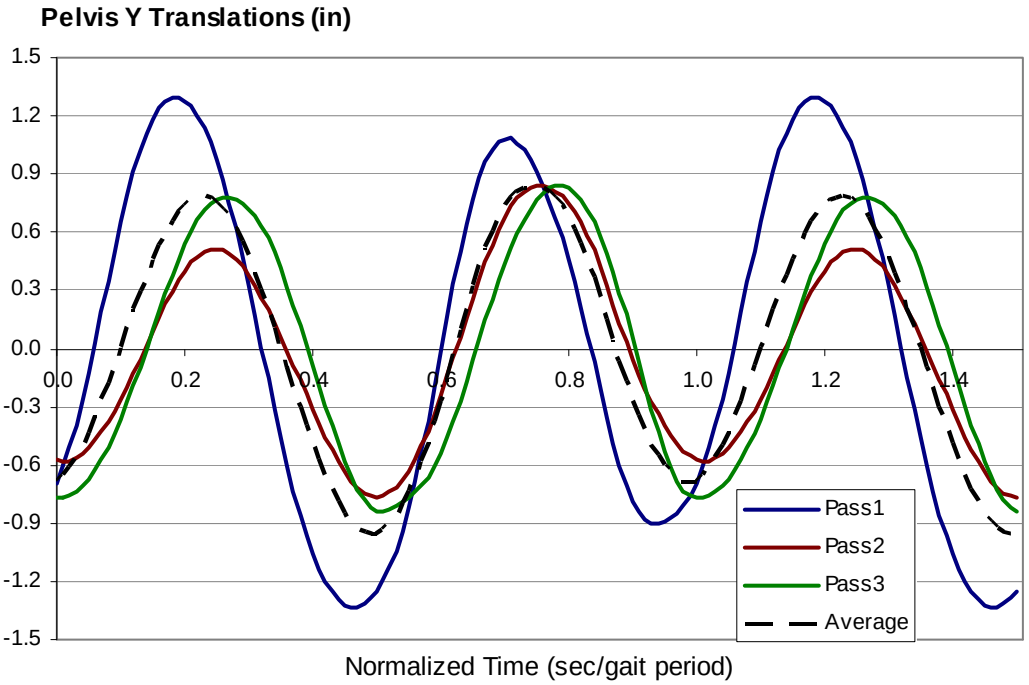


Figure D.42: Pelvis y-translations for subject F, walking

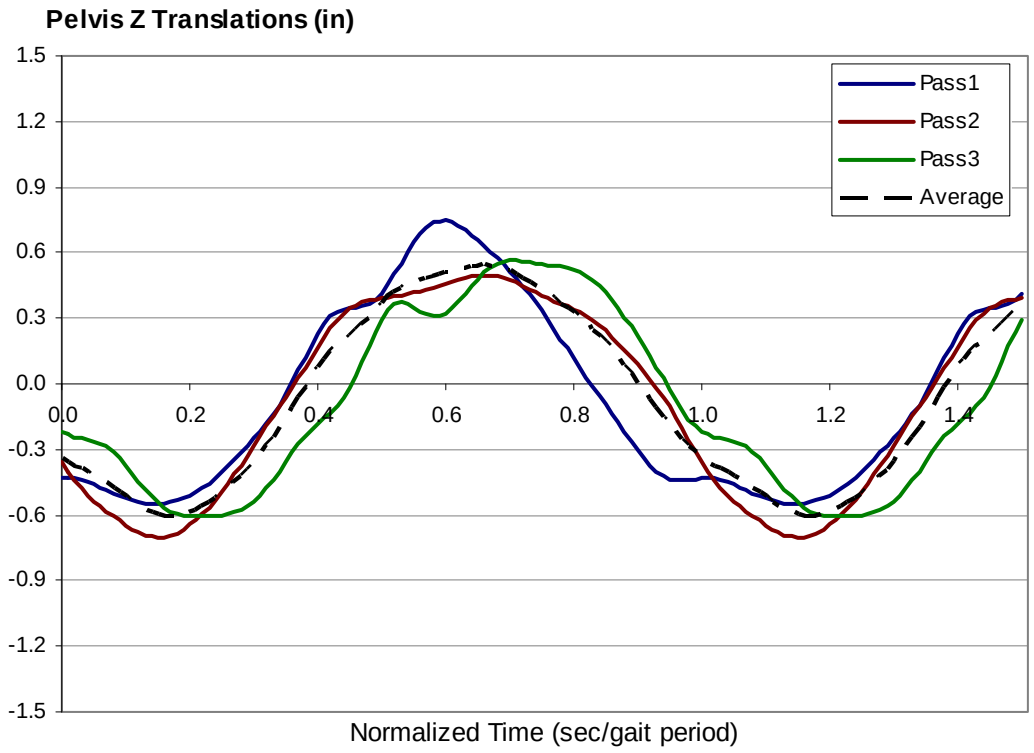


Figure: D.43: Pelvis z-translations for subject F, walking

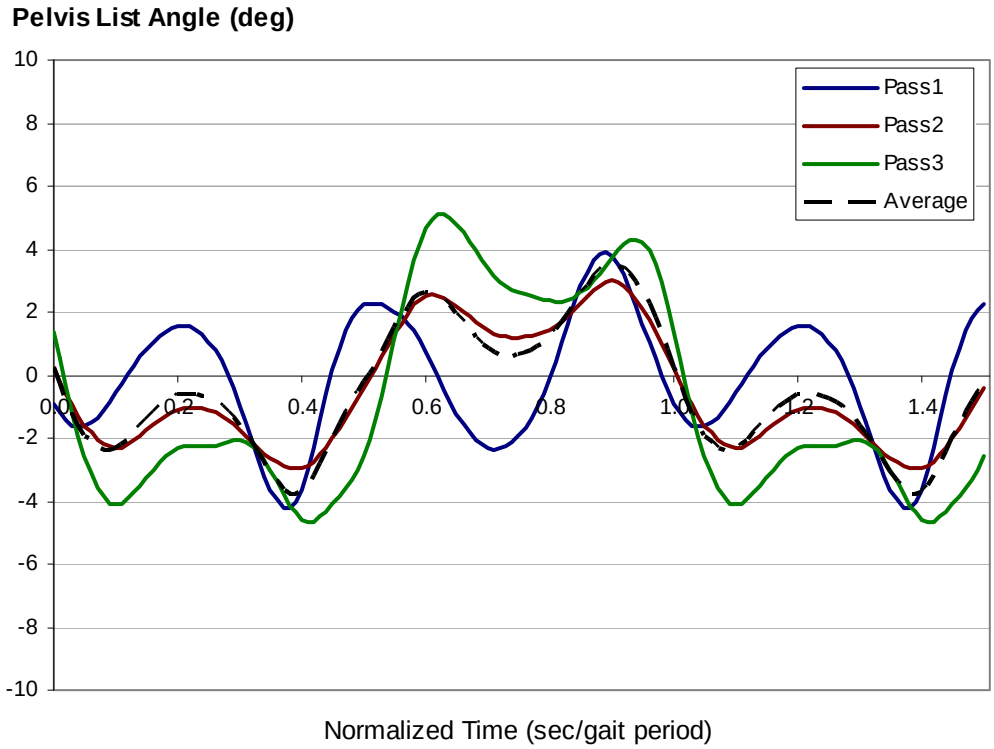


Figure D.44: Pelvis list angles for subject F, walking

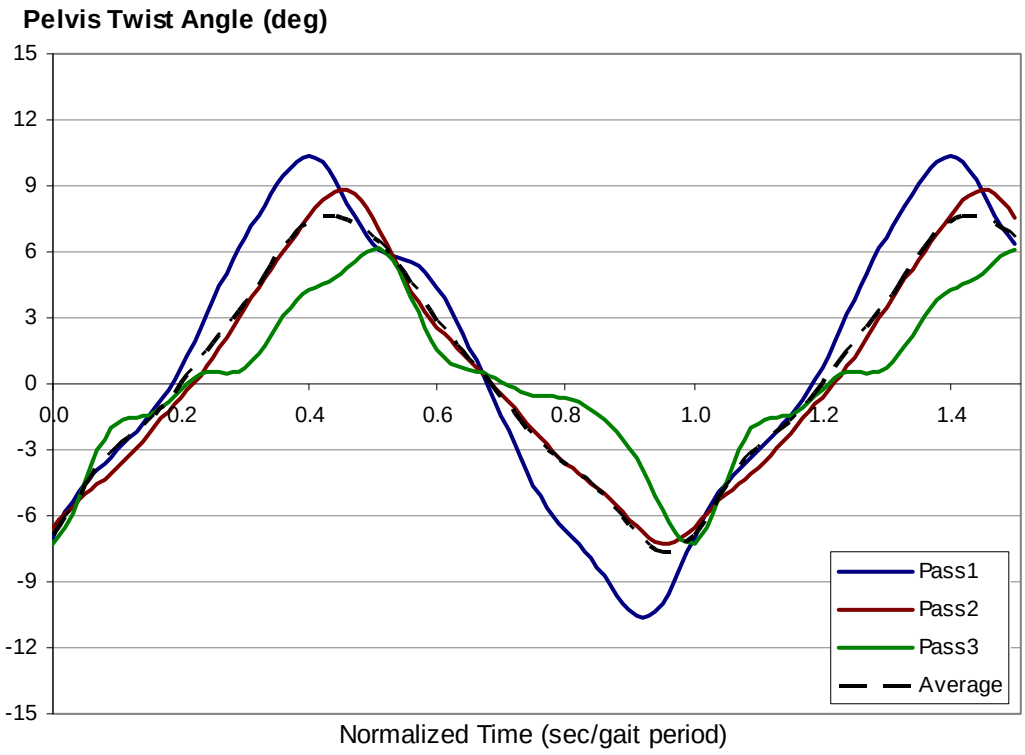


Figure D.45: Pelvis twist angles for subject F, walking

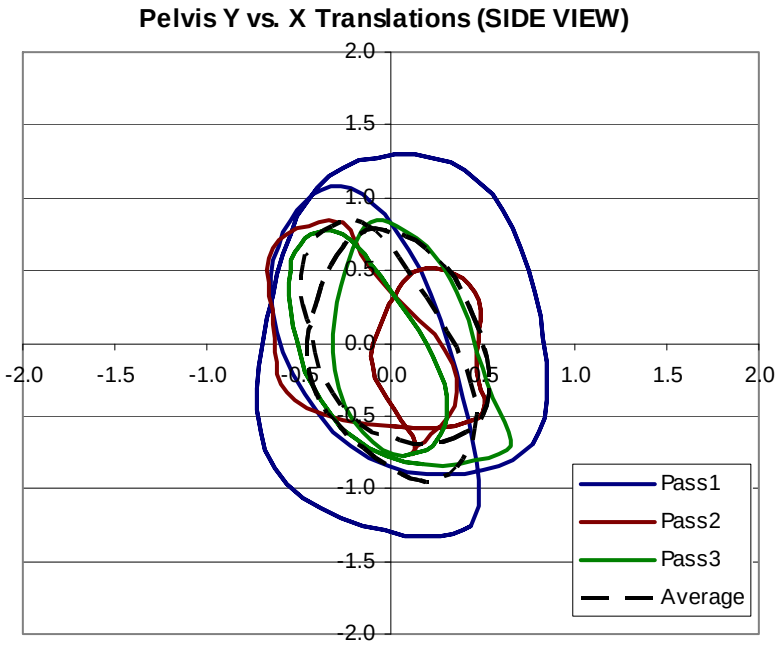


Figure D.46: Side view of pelvis for subject F, walking

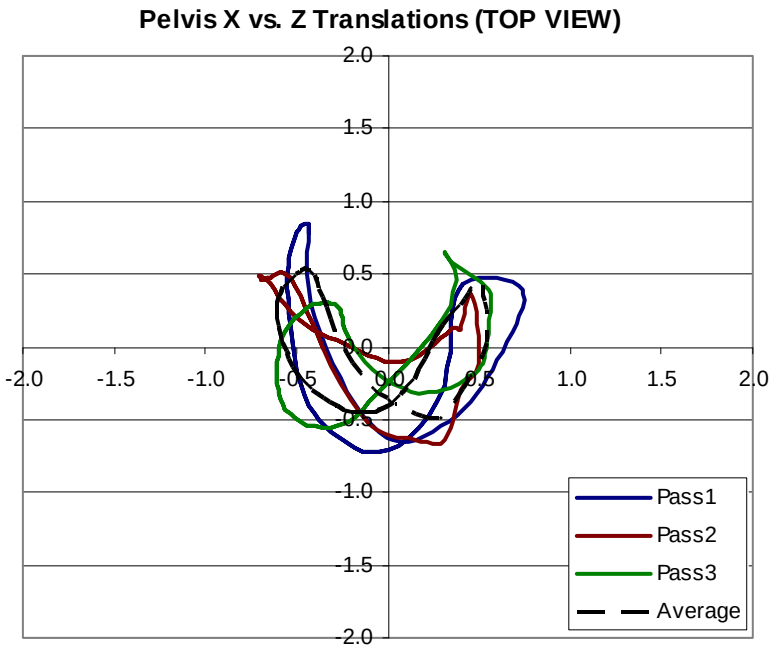


Figure D.47: Top view of pelvis for subject F, walking

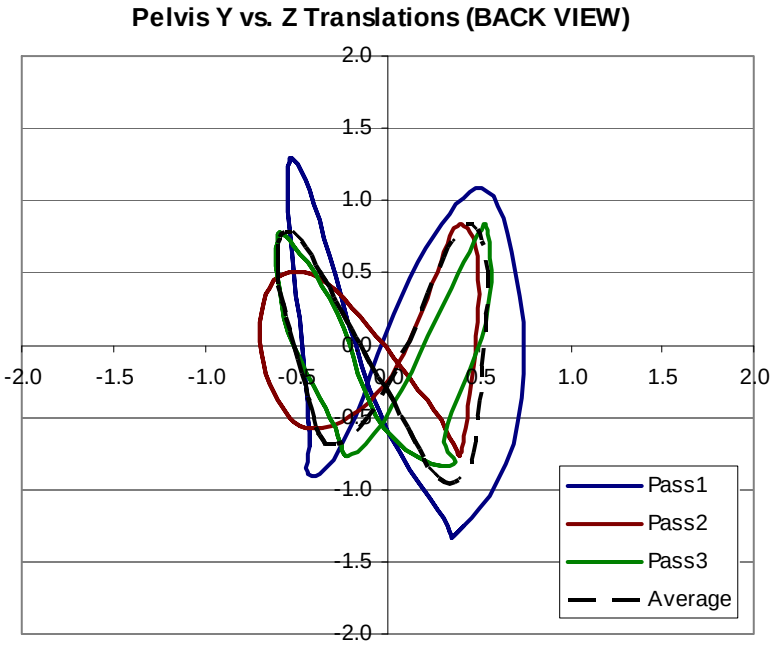


Figure D.48: Back view of pelvis for subject F, walking

Averages

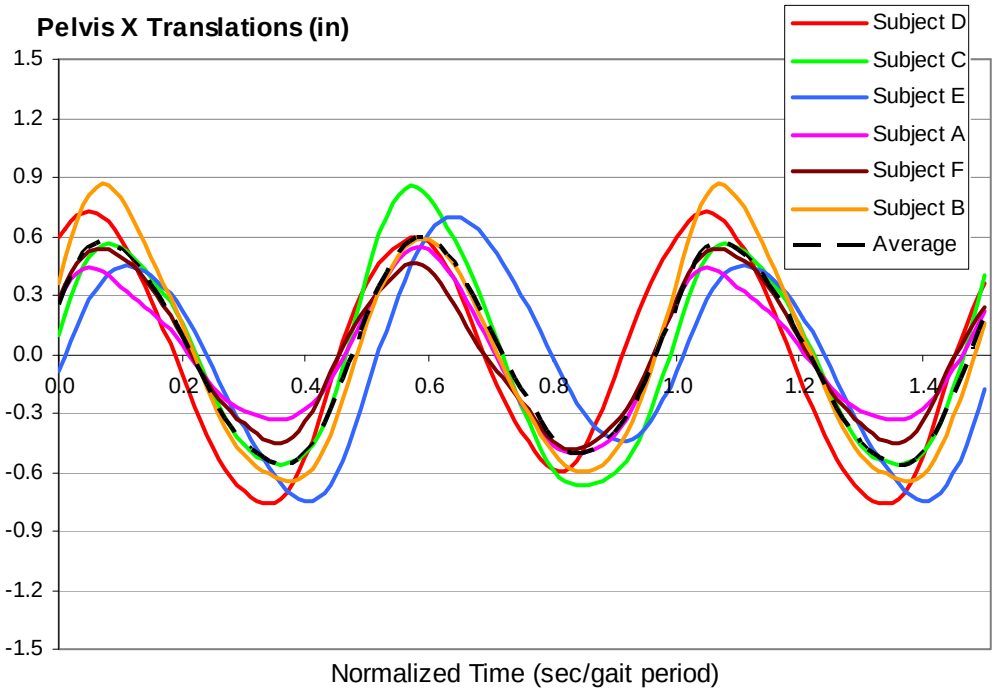


Figure D.49: Pelvis x-translations for all subjects, walking

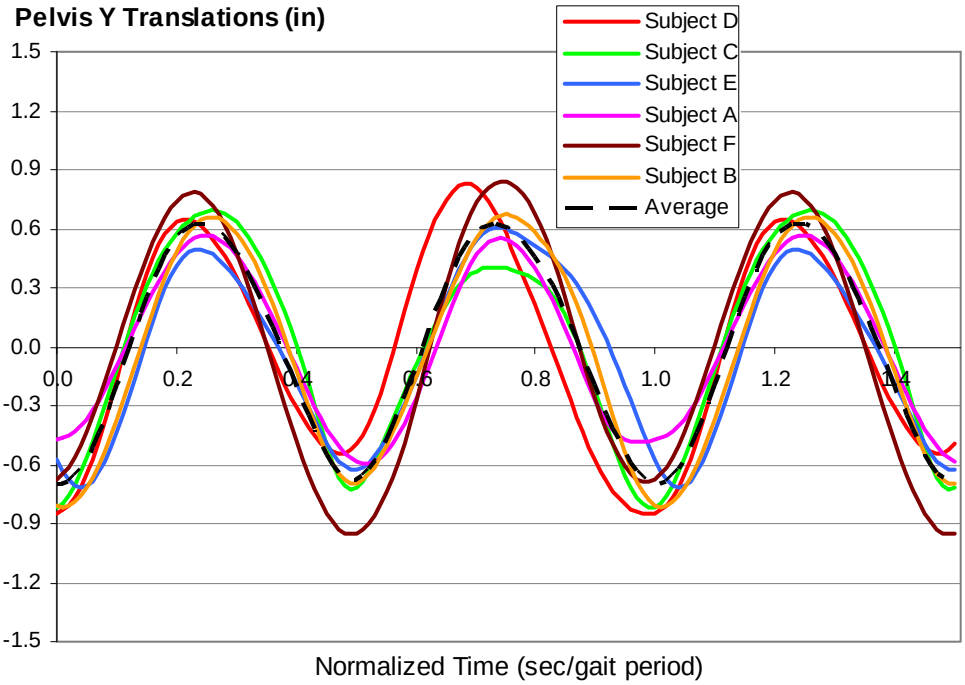


Figure D.50: Pelvis y-translations for all subjects, walking

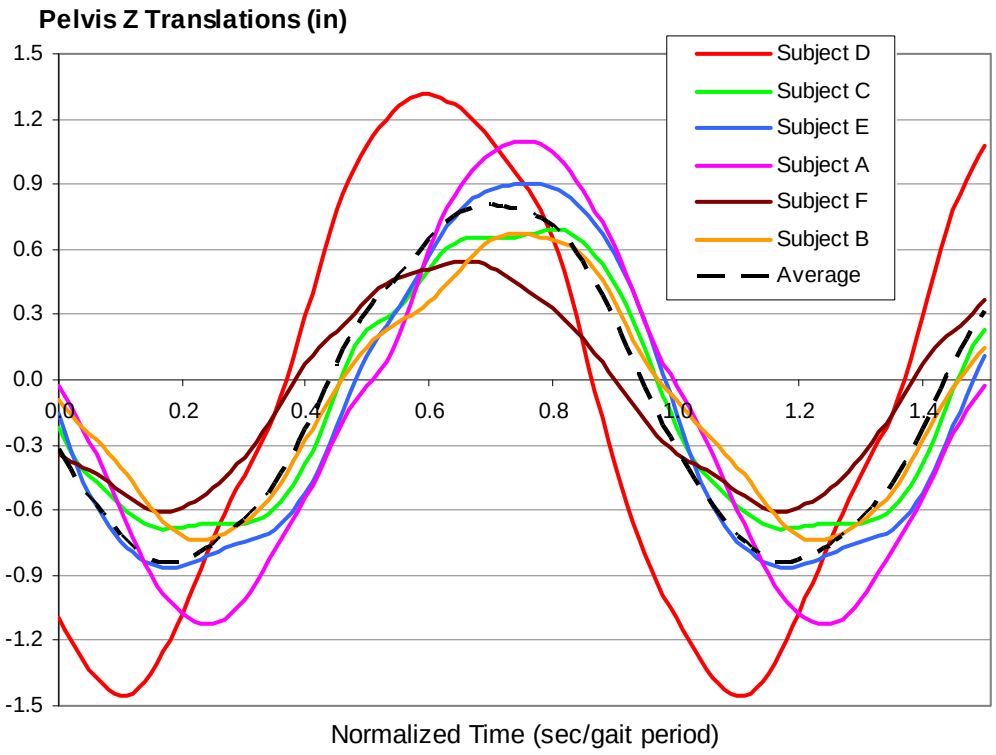


Figure D.51: Pelvis z-translations for all subjects, walking

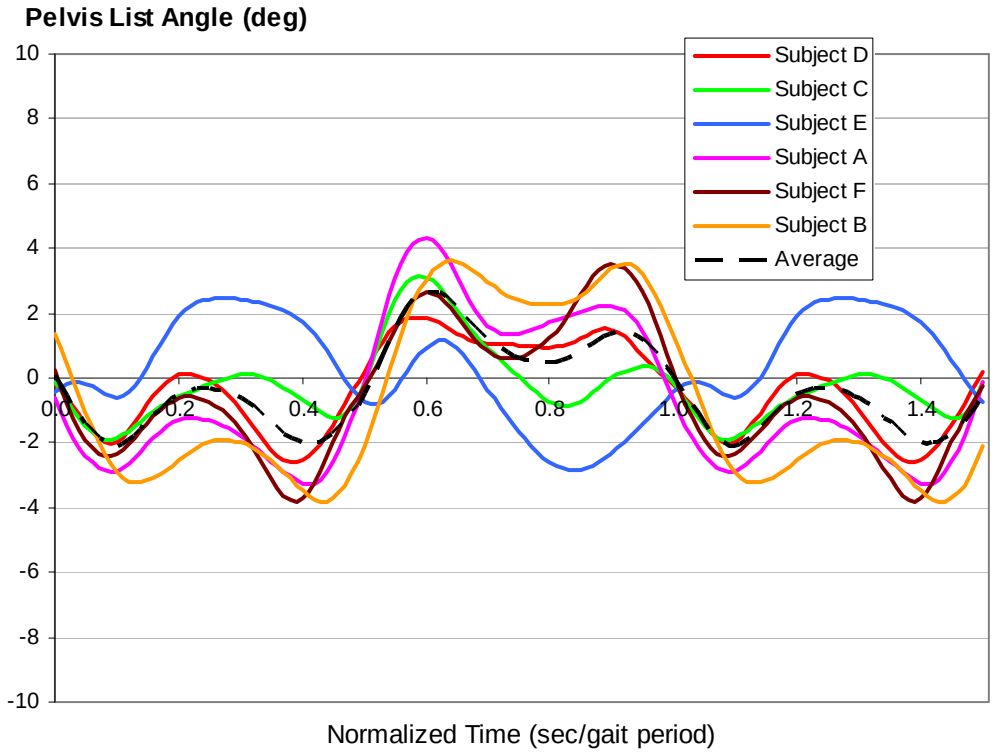


Figure D.52: Pelvis list angles for all subjects, walking

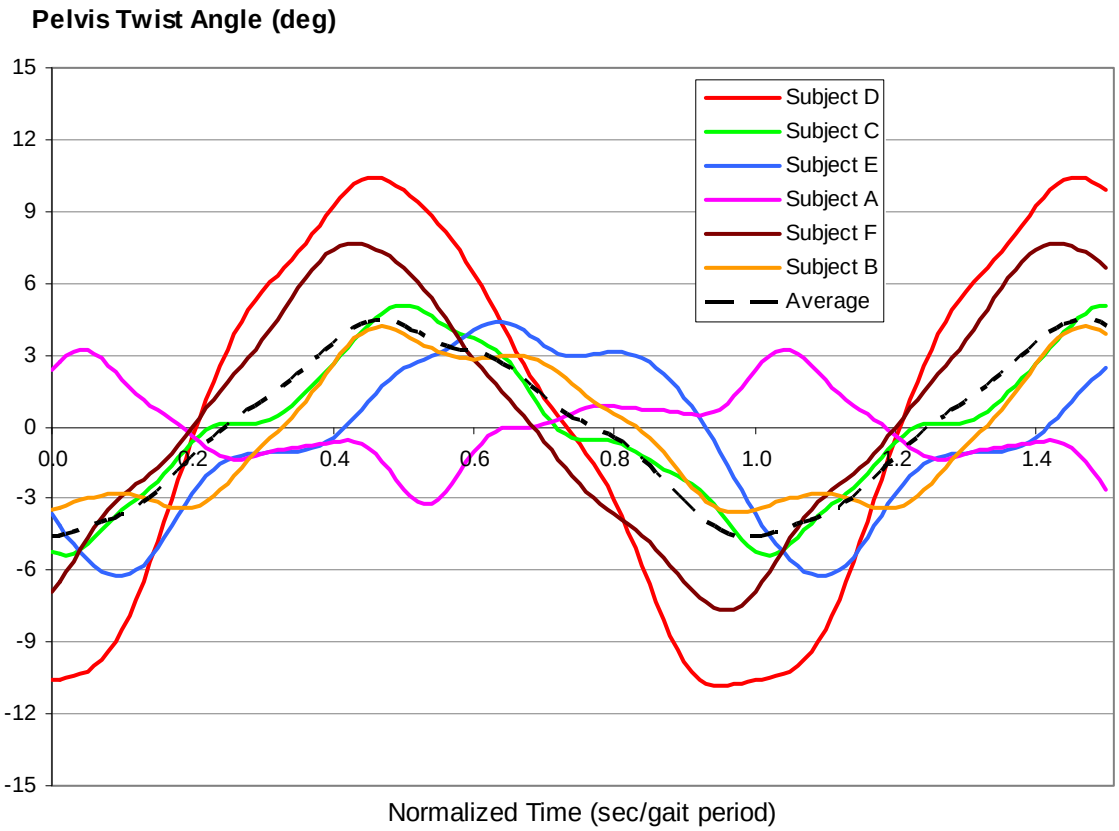


Figure D.53: Pelvis twist angles for all subjects, walking

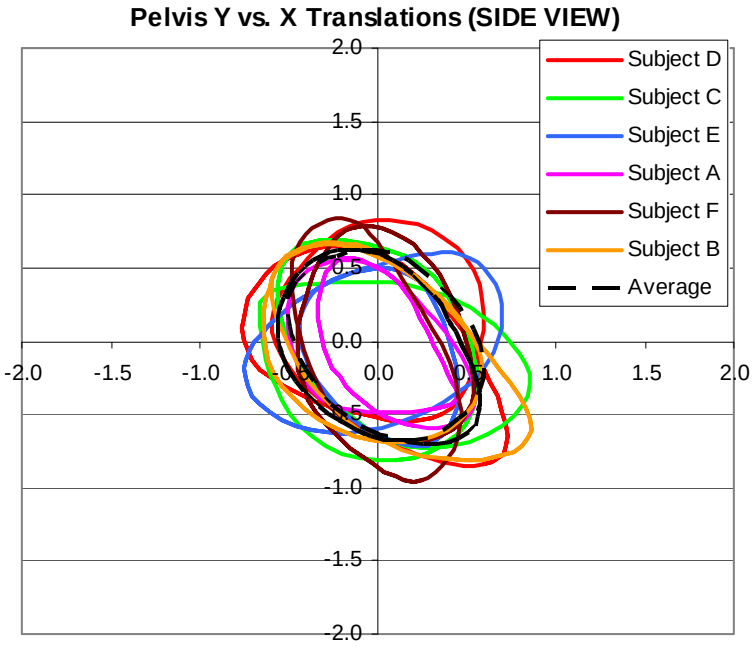


Figure D.54: Side view of pelvis for all subjects, walking

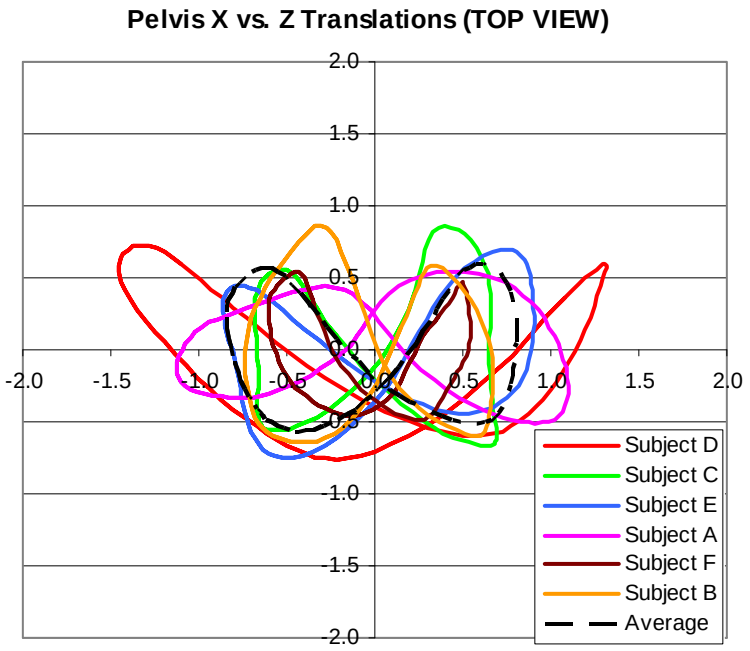


Figure D.55: Top view of pelvis for all subjects, walking

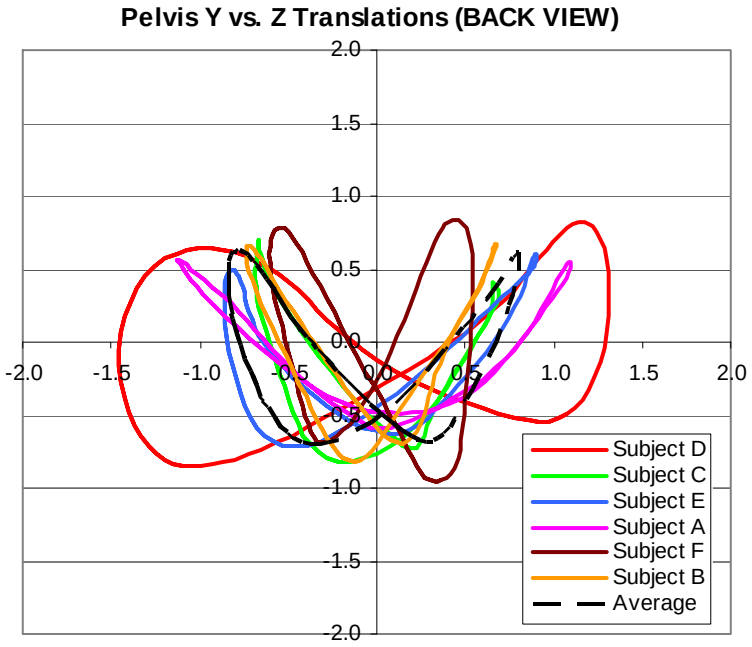


Figure D.56: Back view of pelvis for all subjects, walking

APPENDIX E

Statistics Tables

Pelvis Y-Translations

TABLE E.1 ANALYSIS OF VARIANCE (Y-TRANSLATIONS)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	1.3960789	0.465360	5.2816	0.0110
Error	15	1.3216380	0.088109		
C. Total	18	2.7177169			

TABLE E.2 COMPARISONS FOR ALL PAIRS USING THE TUKEY TEST (Y-TRANSLATIONS)

Abs(Dif)-LSD	Bonnie	Walking	Dolly	Bailey
Bonnie	-0.69853	-0.30994	0.07322	0.08622
Walking	-0.30994	-0.49393	-0.11504	-0.10204
Dolly	0.07322	-0.11504	-0.54108	-0.52808
Bailey	0.08622	-0.10204	-0.52808	-0.54108

Pelvis X-Translations

TABLE E.3 ANALYSIS OF VARIANCE (X-TRANSLATIONS)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.7550746	0.251692	3.2547	0.0514
Error	15	1.1599830	0.077332		
C. Total	18	1.9150576			

TABLE E.4 COMPARISONS FOR ALL PAIRS USING THE TUKEY TEST (X-TRANSLATIONS)

Abs(Dif)-LSD	Bonnie	Walking	Dolly	Bailey
Bonnie	-0.65441	-0.26074	-0.05632	-0.01632
Walking	-0.26074	-0.46274	-0.26233	-0.22233
Dolly	-0.05632	-0.26233	-0.50691	-0.46691
Bailey	-0.01632	-0.22233	-0.46691	-0.50691

Pelvis Z-Translations

TABLE E.5 ANALYSIS OF VARIANCE (Z-TRANSLATIONS)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	1.1569969	0.385666	2.5976	0.0908
Error	15	2.2270760	0.148472		
C. Total	18	3.3840729			

TABLE E.6 COMPARISONS FOR ALL PAIRS USING THE TUKEY TEST (Z-TRANSLATIONS)

Abs(Dif)-LSD	Bonnie	Walking	Dolly	Bailey
Bonnie	-0.64118	-0.47728	-0.32847	-0.02347
Walking	-0.47728	-0.90676	-0.77503	-0.47003
Dolly	-0.32847	-0.77503	-0.70237	-0.39737
Bailey	-0.02347	-0.47003	-0.39737	-0.70237

Pelvis List

TABLE E.7 ANALYSIS OF VARIANCE (PELVIS LIST)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	36.893434	12.2978	4.9342	0.0140
Error	15	37.385519	2.4924		
C. Total	18	74.278953			

TABLE E.8 COMPARISONS FOR ALL PAIRS USING THE TUKEY TEST (PELVIS LIST)

Abs(Dif)-LSD	Bonnie	Dolly	Walking	Bailey
Bonnie	-3.7152	-1.6989	0.1776	0.5561
Dolly	-1.6989	-2.8778	-0.9842	-0.6228
Walking	0.1776	-0.9842	-2.6270	-2.2712
Bailey	0.5561	-0.6228	-2.2712	-2.8778

Pelvis Twist

TABLE E.9 ANALYSIS OF VARIANCE (PELVIS TWIST)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	94.19507	31.3984	2.6948	0.0832
Error	15	174.77404	11.6516		
C. Total	18	268.96911			

TABLE E.10 COMPARISONS FOR ALL PAIRS USING THE TUKEY TEST (PELVIS TWIST)

Abs(Dif)-LSD	Bonnie	Dolly	Walking	Bailey
Bonnie	-5.6800	-3.5442	-2.4266	-0.4212
Dolly	-3.5442	-6.2221	-5.0677	-3.0991
Walking	-2.4266	-5.0677	-8.0327	-6.1787
Bailey	-0.4212	-3.0991	-6.1787	-6.2221

BIBLIOGRAPHY

[1] Quint, C., Toomey, M., 1998, "Powered Saddle and Pelvic Mobility: An Investigation into the Effects on Pelvic Mobility of Children with Cerebral Palsy of a Powered Saddle Which Imitates the Movements of a Walking Horse," Physiotherapy, **84**(8), pp. 376-384.

[2] Saunders, M., Inman, V., Eberhart, H., 1953, "The Major Determinants in Normal and Pathological Gait," Journal of Bone and Joint Surgery, **35-A**(3), pp. 543-558.

[3] Fleck, C., 1997, "Hippotherapy: Mechanics of Human Walking and Horseback Riding," In: Engel, B, 1997, *Rehabilitation with the Aid of the Horse: a collection of studies*, Barbara Engel Therapy Services, Durango CO.

[4] Bertoti, D., 1988, "Effect of Therapeutic Horseback Riding in Children with Cerebral Palsy," Physical Therapy, **68**, pp. 1505-1512.

[5] Winchester, P., Kendall, K., Peters, H., Sears, N., Winkley, T., 2002, "The Effect of Therapeutic Horseback Riding on Gross Motor Function and Gait Speed in Children Who Are Developmentally Delayed," Physical and Occupational Therapy in Pediatrics, **22**(3/4), pp. 37-50.

[6] McGibbon, N., Andrade, C-K., Widener, G., Cintas, H., 1998, "Effect of an Equine-movement Therapy on Gait, Energy Expenditure, and Motor Function in Children with Spastic Cerebral Palsy: A Pilot Study," Developmental Medicine & Child Neurology, **40**, pp. 754-762.

[7] Hamill, D., Washington, K., White, O., 2007, "The Effect of Hippotherapy on Postural Control in Sitting for Children with Cerebral Palsy," Physical and Occupational Therapy in Pediatrics, **27**(4), pp. 23-31

[8] Benda, W., McGibbon, N., Grant, K., 2003, "Improvements in Muscle Symmetry in Children with Cerebral Palsy After Equine-assisted Therapy (Hippotherapy)," The Journal of Alternative and Complementary Medicine, **9**(6), pp. 817-825.

[9] Macauley, B., Guiterrez, K., 2004, "The Effectiveness of Hippotherapy for Children with Language-learning Disabilities," Communication Disorders Quarterly, **25**(4), pp. 205-217.

[10] Glazer, H., Clark, M., Stein, D., 2004, "The Impact of Hippotherapy on Grieving Children," Journal of Hospice and Palliative Nursing, **6**(3), pp. 171-175.

[11] Hammer, A., Nilsagard, Y., Forsberg, A., Pepa, H., Skargren, E., Oberg, B., 2005, "Evaluation of Therapeutic Riding (Sweden) / Hippotherapy (United States). A Single-subject Experimental Design Study Replicated in Eleven Patients with Multiple Sclerosis," Physiotherapy Theory and Practice, **21**(1), pp. 51-77.

[12] Lechner, H., Feldhaus, S., Gudmundsen, L., Hegemann, D., Michel, D., Zach, G., Knecht, H., 2003, "The Short-term Effect of Hippotherapy on Spasticity in Patients with Spinal Cord Injury," Spinal Cord, **41**, pp. 502-505.

[13] Ries, E., 2001, "Passions for the profession," PT magazine, **6**, pp. 34-42.

[14] Sterba, J., Rogers, B., France, A., Vokes, D., 2002, "Horseback Riding in Children with Cerebral Palsy: Effect on Gross Motor Function," Developmental Medicine & Child Neurology, **44**, pp. 301-308.

[15] Millhouse-Flourie, T., 2004, "Physical, Occupational, Respiratory, Speech, Equine and Pet Therapies for Mitochondrial Disease," Mitochondrion, **4**, pp. 549-558.

[16] Haehl, V., Giuliani, C., Lewis, C., 1999, "Influence of Hippotherapy on the Kinematics and Functional Performance of Two Children with Cerebral Palsy," Pediatric Physical Therapy, **11**, pp. 89-101.

[17] Sayli, U., Avci, S., 2000, "Multiple Simultaneous Approach in Lower Extremity Spasticity Surgery," Journal of Musculoskeletal Research, **4**(3), pp. 221-229.

[18] Bleck, E., 1975, "Locomotor Prognosis in Cerebral Palsy," Developmental Medicine and Child Neurology, **17**, pp. 18-25.

[19] Casady, R., Nichols-Larsen, D., 2004, "The Effect of Hippotherapy on Ten Children with Cerebral Palsy," Pediatric Physical Therapy, **16**, pp. 165-172.

[20] Liptak, G., 2005, "Complementary and Alternative Therapies for Cerebral Palsy," Mental Retardation and Developmental Disabilities, **11**, pp. 156-163.

[21] Riede, D., 1987, "The Relationship Between Man and Horse with Reference to Medicine Throughout the Ages," People-Animals-Environment, **5**(2), pp. 26-28.

[22] Lamoreux, L., 1971, "Kinematic Measurements in the Study of Human Walking," Bulletin of Prosthetics Research, **10**(15), pp. 3-84.

[23] Thorstensson, A., Nilsson, J., Carlson, H., Zomlefer, M., 1984, "Trunk Movements in Human Locomotion," Acta Physiologica Scandinavica, **121**, pp. 9-22.

[24] Vogt, L., Portscher, M., Brettmann, K., Pfeifer, K., Banzer, W., 2003, "Cross-validation of Marker Configurations to Measure Pelvic Kinematics in Gait," Gait & Posture, **18**, pp. 178-184.

[25] Whittle, M., Levine, D., 1999, "Three-dimensional Relationships Between the Movements of the Pelvis and Lumbar Spine During Normal Gait," Human Movement Science, **18**, pp. 681-692.

[26] Baker, R., 2007, "The History of Gait Analysis Before the Advent of Modern Computers," Gait & Posture **26**, pp. 331-342.

[27] Crosbie, J., Vachalathiti, R., Smith, R., 1997, "Age, Gender, and Speed Effects on Spinal Kinematics During Walking," Gait & Posture, **5**, pp. 13-20.

[28] Kadaba, M., Ramakrishnan, H., Wootten, M., 1990, "Measurement of Lower Extremity Kinematics During Level Walking," Journal of Orthopaedic Research, **8**(3), pp. 383-392.

[29] Gage, J., Deluca, P., Renshaw, T., 1995, "Gait Analysis: Principles and Applications," Journal of Bone and Joint Surgery, **77-A**(10), pp. 1607-1623.

[30] Benedetti, M., Catani, F., Leardini, A., Pignotti, E., Giannini, S., 1998, "Data Management in Gait Analysis for Clinical Applications," Clinical Biomechanics, **13**(3), pp. 204-215.

[31] Zhao, L., Zhang, L., Wang, L., Wang, J., 2005, "Three-dimensional Motion of the Pelvis During Human Walking," Mechatronics and Automation, 2005 IEEE International Conference 1: 335-339.

[32] Crosbie, J., Vachalathiti, R., Smith, R., 1997, "Patterns of Spinal Motion During Walking," Gait & Posture, **5**, pp. 6-12.

[33] Watanabe, S., Kobayashi, K., 1996, "An Analysis of Three-dimensional Trunk and Leg Movements in Gait of Normal Subjects," Jikeikai Medical Journal, **43**(4), pp. 255-262.

[34] Thurston, A., Harris, J., 1983, "Normal Kinematics of the Lumbar Spine and Pelvis," Spine, **8**(2), pp. 199-205.

[35] Lafortune, M., Lake, M., 1991, "Errors in 3D Analysis of Human Movement," International Symposium on 3-D Analysis of Human Movement, Montreal, pp. 55-56.

[36] Kaufman, K., Moitoza, J., Sutherland, D., 1991, "Relation Between External Markers and Tibial Rotation Measurements," International Symposium on 3-D Analysis of Human Movement, Montreal, pp. 52-54.

[37] Macleod, A., Morris, J., 1987, "Investigation of Inherent Experimental Noise in Kinematic Experiments Using Superficial Markers, In: *Biomechanics X-B*, Champaign IL: Human Kinetics Publishers, Inc., pp. 1035-1039.

[38] Fuller, J., Liu, L.-J., Murphy, M., Mann, R., 1997, "A Comparison of Lower-extremity Skeletal Kinematics Measuring Using Skin- and Pin-mounted Markers," Human Movement Science, **16**, pp. 219-242.

[39] Gard, S., Knox, E., Childress, D., 1996, "Two-Dimensional Representation of Three-Dimensional Pelvic Motion During Human Walking: An Example of How Projections Can Be Misleading," Journal of Biomechanics, **29**(10), pp. 1387-1391.

[40] Angeloni, C., Cappozzo, A., Catani, F., Leardini, A., 1992, "Quantification of relative displacement between bones and skin- and plate-mounted markers," Proceedings of the VIIIth Meeting of the European Society of Biomechanics, Rome, pp. 279.