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Upper Extremity Kinematic and Kinetic Comparison of Anterior Versus Posterior Walkers During Functional Activities in Children with Cerebral Palsy

Chris Burckardt
University of Wisconsin-Milwaukee

UPPER EXTREMITY KINEMATIC AND KINETIC COMPARISON OF ANTERIOR VERSUS POSTERIOR WALKERS DURING FUNCTIONAL ACTIVITIES IN CHILDREN WITH CEREBRAL PALSY

by

Chris Burckardt

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ABSTRACT

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Chris Burckardt

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Under the Supervision of Professor Brooke Slavens, PhD

Introduction: Investigating the differences in upper extremity (UE) joint biomechanics between anterior and posterior walkers has been explored in limited contexts, even though research has shown that prolonged use of walking aids can lead to UE joint weakening or musculoskeletal injuries. Recent studies have investigated some of these differences in children with spastic diplegic cerebral palsy (CP) during gait; however, no research has been conducted that compare these UE joint biomechanical differences during functional activities or activities of daily living (ADLs). The aim of this study is to use motion analysis to compare kinematic and kinetic differences between anterior and posterior walker use during representations of ADLs at the glenohumeral (GH) joint.

Methods: Ten children ages 6-18 (mean age 13.27), 4 males and 6 females, were recruited to complete gait, reaching, and sit-to-stand/stand-to-sit tasks for kinematic analysis. One subject was chosen as a representative subject, and kinetic data was analyzed for gait and reaching tasks. Data was collected at Shriner's Hospital for Children (Chicago, IL) in the Motion Analysis Laboratory using a specially designed walker that could be switched between anterior and posterior styles.

Results: During gait, statistically significant differences were found in maximum flexion/extension angles at the dominant GH joint, with posterior walkers averaging greater minimum extension (-14.81 degrees +/- 20.83) compared to posterior walkers (-27.35 degrees +/- 13.60), as well as significant differences in the flexion/extension ROM in the dominant GH joint, with anterior walkers averaging 24.02 degrees +/- 15.95 versus 16..49 degrees +/- 8.26 for posterior walkers. During forward reaching, anterior walker usage resulted in an average reaching distance of 109.25mm +/- 76.65, which was statistically further than the 73.85mm +/- 37.34 average seen during posterior walker usage. For sit-to-stand, anterior walker use resulted in an average of 4.82 seconds +/- 3.02, which was statistically faster than with a posterior walker (15.08 seconds +/-6.47). For stand-to-sit, posterior walker use resulted in an average of 5.89 seconds +/- 2.40, which was statistically faster than with an anterior walker (10.41 seconds +/- 5.44). For kinetics during gait, the subject demonstrated a statistically significant increase in maximum anterior force (21.38 %BW +/- 3.54) and a greater maximum inferior force (-21.55 %BW +/- 2.65) for the dominant GH joint with an anterior walker versus a posterior walker. During forward reaching, peak anterior forces acting at the non-dominant GH joint (maximum 8.35 %BW +/- 0.21, minimum 5.68 %BW +/- 0.90) were significantly different between anterior and posterior walker usage. Also, a significantly different maximum medial force (-16.75 %BW +/- 1.85) was detected for posterior walkers. For moments, anterior walker usage resulted in a significantly greater minimum adduction moment (1.27 %BWxH +/- 0.04), and significantly greater peak internal rotation moments (maximum 1.56 %BWxH +/- 0.13, minimum 1.17 %BWxH +/- 0.03; Tables 8, 9; Figure 4). During lateral reaching, a significantly greater minimum medial force occurred at the non-dominant GH joint when using an anterior walker (11.29 %BW +/- 1.78). Anterior walker use resulted in significantly greater peak internal

rotation moments (maximum 1.70 %BWxH +/- 0.37, minimum 1.51 %BWxH +/- 0.31), whereas posterior walker use led to a significantly greater maximum flexion moment (1.63 %BWxH +/- 0.12).

Conclusion: Anterior and posterior walker use during gait and functional activities results in different kinematic and kinetic values in the GH joint, all of which should be considered during the walker prescription process.

I would like to dedicate this project to my amazing daughter, Sawyer. I know I wouldn't be here if it weren't for you. You have inspired me more than you will ever know.

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ACKNOWLEDGEMENTS

We would like to acknowledge the College of Health Sciences, Department of Occupational Science and Technology at UW Milwaukee and the Office of Undergraduate Research for their support of this work. We would also like to thank the Motion Analysis Team at Shriners Hospitals for Children-Chicago and Innovation Accelerator Research Lab Team for their contributions.

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I. Introduction

Over 4.8% of Americans aged 15 years and older (11.6 million) use assistive devices such as canes, crutches, and walkers for ambulation (Brault, 2012). Of these individuals, at least 1.8 million use walkers, including over 27,000 walker users under the age of 18 (Kaye, Kang, & LaPlante, 2000). Walkers can be prescribed in either anterior or posterior models based on a person's condition or preference. Although both types of walkers improve mobility and help maintain balance during activities of daily living (ADLs; Bateni & Maki, 2005), the two styles vary from one another and require a different set of skills and abilities to operate. The aim of this thesis is to quantify and compare the upper extremity (UE) joint kinematics and kinetics between anterior and posterior walkers during gait and components of ADLs.

Statement of the Problem

There are various factors that are taken into consideration when prescribing either an anterior or posterior walker (Low, Westcott, McCoy, Beling, & Adams, 2011; Greiner, Czerniecki, & Deitz, 1993; Logan, Byers-Hinkley, & Ciccone, 1990; Park, Park, & Kim, 2001). However, kinematic differences between walker styles such as UE joint angles have never been investigated and are therefore not considered during prescription, even though research has shown that certain joint angles are associated with higher risks of injury (Oyama, 2012). In addition, while essential for ambulation, walkers exert varying amounts of force on the joints of the UE during use, with studies showing that UE joint demands can reach as much as 20% body weight (McQuade, Finley, & Oliveira, 2011). This excessive force on UE joints, which are not designed to be weight-bearing joints, can often lead to joint weakening or musculoskeletal injuries. It has been reported that 19.1% of walker users suffer from osteoarthrosis, which is a

condition characterized by pain, aching, and/or stiffness of joints, muscle weakness, restricted active range of motion (AROM), or complete loss of joint function (Kaye et al., 2000). Even though walker use can result in harmful conditions in the UE, research relating to the differences in UE joint biomechanics between anterior and posterior walkers has been limited. Furthermore, any differences that have been investigated between walker styles have been confined to differences solely during gait, even though there is more to independence and performing ADLs than simply walking.

Purpose

The purpose of this study is to quantify and compare the UE kinematics and kinetics between anterior and posterior walkers during gait and functional activities. To achieve this goal, this study includes four tasks: 1) gait, 2) forward reaching, 3) lateral reaching, and 4) sit-to-stand/stand-to-sit. These functional tasks were inspired by existing, valid assessments, which are the Functional Reach Test (FRT), Lateral Reach Test (LRT), and the Timed Up and Go Test (TUG). Additionally, subjects are required to complete a pain-related assessment two times during testing in order to identify and correlations between pain and walker style. The results of this study could be used to make justifications during the walker recommendation/selection process, or to identify potentially harmful trends and develop training programs for proper walker use.

Hypothesis and Aims

Hypothesis 1: There will be a significant increase in peak shoulder extension angles with a posterior walker during gait.

Hypothesis 2: During the task of reaching, use of an anterior walker will result in significantly greater joint forces and moments at the GH joint of the upper extremity (UE) holding onto the walker than a posterior walker.

Hypothesis 3: During the task of reaching, the horizontal distance traveled of the reaching hand will be significantly greater while using an anterior walker versus a posterior walker.

Hypothesis 4: There will be no statistically significant differences in peak forces and moments between walkers during gait.

Hypothesis 5: Completion of the Timed Up and Go Test (TUG) will be significantly faster with an anterior walker than a posterior walker.

Significance to Occupational Therapy

The American Occupational Therapy Association (2014) defines independence as "self-directed state of being characterized by an individual's ability to participate in necessary and preferred occupations in a satisfying manner irrespective of the amount or kind of external assistance desired or required." In order to fully engage in many necessary and preferred occupations or ADLs, individuals often require the use of their upper extremities. If the UEs are either impaired or are needed to help support the entire body, the ability to perform these tasks could also be limited. In addition, since the body interacts with and manipulates anterior walkers differently than posterior walkers, investigation of any potential UE biomechanical difference

that exist between walker styles is important to promoting functionality, and could serve as a contributing factor for walker style prescription.

While the tasks of walking, reaching, and sitting/standing are not ADLs themselves, they make up a key component of many of the activities we do every day. These tasks are known as performance skills, which The American Occupational Therapy Association (2014) defines as features of what one does, not of what one has, related to observable elements of action that have implicit functional purposes, and can include motor skills, process skills, and communication/interaction skills. Similarly, an occupational therapist must analyze factors such as activity demands (the aspects of an activity, which include the objects, space, social demands, sequencing or timing, required actions, and required underlying body functions and body structures needed to carry out the activity), client factors (those factors that reside within the client and that may affect performance in areas of occupations including body functions and body structures), and quality of life (a person's dynamic appraisal of his or her life satisfactions, self-concept, health and functioning, and socioeconomic factors), all of which can directly be impacted by an ability or inability to perform these performance skills. Improvement in performance skills could lead to improvements in these factors as well.

An orthopaedic impairment is one type of condition that can negatively affect performance skills, and can be caused by a congenital anomaly, disease, or from other causes such as cerebral palsy (CP) (U.S. Department of Education, 2004). According to the Center for Disease Control (2013), CP is a neurological disorder that affects between 0.15 and 0.4% of newborns each year in the United States. It is the most common motor disability in childhood, with 11.3% of 8-year-old children with CP needing a hand-held mobility device, such as a walker, for ambulation (Center for Disease Control, 2013). Occupational therapists can work

with people with cerebral palsy in any setting, especially in schools or other PEDS settings. This study could have an impact on how these clients function when performing ADLs, which could change how OTs plan sessions and interact with them.

Literature Review

Shoulder Anatomy and Pain

Unlike the lower extremities, which play a role in locomotion and are designed to bear weight, the upper extremities (UEs) are built for large ranges of mobility (Goldstein, 2004). The most proximal part of the UEs, the shoulder, is comprised of multiple bones, joints, and ligaments. The bones that comprise the shoulder are the clavicle, scapula, and humerus. The clavicle articulates with the sternum and acts as a bony strut, and stabilizes the UE on the thorax. Joints and ligaments that play a role in shoulder mobility include the acromioclavicular joint, sternoclavicular joint, glenohumeral joint (GH), glenohumeral ligaments, coracoclavicular ligament, acromioclavicular ligament, and coracoacromial ligaments.

The GH joint is a ball-and-socket joint that links the humeral head to the glenoid fossa of the scapula, and is often thought of as "the shoulder". The composition and structure of this joint allows for the movement in every plane: flexion/extension, abduction/adduction, and internal/external rotation. This large range of motion allows the shoulder to position the rest of the upper extremity in a functional position to interact with the environment, such as maneuvering a walker. There are many different muscles that can contribute to the movements of the glenohumeral joint, including the deltoid, pectoralis major, latissimus dorsi, and rotator cuff muscles (Goldstein, 2004). While essential to movement and function, the glenohumeral

joint is unfortunately very unstable, and many disorders of the shoulder can occur due to this instability.

After low back pain and cervical pain, shoulder pain is the most common cause of musculoskeletal disorders in the United States (Goldstein, 2004). Disorders and symptoms that can cause shoulder pain include degeneration, infection, inflammation, arthritic changes, injury, neuropathic disorders, and more. Large amounts of shoulder pain can interfere with, or prevent completion of activities of daily living (ADLs).

The Visual Analog Scale (VAS) is a tool which allows users to assign a rating to a question within a range that has a clear, visual minimum and maximum. It has been described as useful for measuring a variety of subjective phenomena, especially in regards to research involving pain and mood (Wewers & Lowe). The VAS is most often depicted as a 100 millimeter horizontal or vertical line with dashes that range from 0 (representing no pain) to 100 (worst pain you can imagine), and is labeled in increments of 10. The VAS has been shown to be valid for children aged 8-17 (Bailey, Gravel, & Daoust). It is the standard pain assessment used at Shriner's Hospital for Children – Chicago, and readily available for this study.

Anterior versus Posterior Walkers: General

According to an extensive survey of physical therapists who work with children who use walkers, 65% of therapists agree that the position of the walker should be posterior to the child (4% disagree, 14% neutral, 17% no response), while 53% of therapists agree that the position of the walker should be used anterior to the child (12% disagree, 17% neutral, 18% no response (Low et al., 2011). For children with CP, the benefits of using a posterior walker have been well documented, and may explain the increase in agreement towards posterior walkers. Greiner et

al., (1993) mentions that the gait of children with CP is described as "crouch gait" because of an increase in trunk flexion, hip flexion, and knee flexion. This posture and gait pattern can increase the risk of developing hip and knee flexion contractures, which could result in the loss of independent ambulation (Sutherland & Cooper, 1978). Greiner et al. (1993) and Logan et al. (1990) both report that use of a posterior walker leads to a significantly decreased joint angles in the lower extremities and a more upright posture. Similarly, Park et al. (2001) notes that pelvic tilt angle, knee flexion angle at initial contact, and hip flexion angle during initial contact and midstance are significantly lower using a posterior walker.

In addition, research has found a significant increase in walking speed is a result of posterior walker use (Greiner et al., 1993). Logan et al. (1990) notes the gait velocity with posterior walkers was 40% greater than with anterior walkers. Noted reasons for this may be because use of a posterior walker results in a 41% greater stride length, as well as a 39% decrease in double-limb support (the time spent with both feet on the ground).

Energy expenditure is another factor that needs to be taken into consideration when using a walker, and recent studies have compared this between the two walker versions. Konop et al. (2009) used a heart rate monitor to investigate the energy expenditure index (EEI), and while anterior walkers are generally associated with a higher EEI, no statistically significant differences were found. However, Park et al. (2001) measured energy expenditure by using a portable metabolic measurement system (the KB1-C), and found there to be a statistically significant decrease in oxygen consumption, and therefore, energy expenditure, with posterior walkers. Not to be discounted, the preference of both the child and parents has been documented. According to Greiner et al. (1993), four of five parents preferred the posterior walker for their child, with the lone dissenter favoring the posterior walker outdoors and anterior

walker use indoors. Reasons why the posterior walker was favored by the parents include ease for navigating uneven terrain, perceived wobbliness of the walker, and ease of playing with other children. Mattsson and Andersson (1997) asked the children using the walkers which style they preferred; seven out of 10 kids preferred the posterior walker, two preferred the anterior walker, and one had no preference. A reason for this is that the preferred walker correlated to a lower score in perceived exertion for these children (perceived exertion not statistically significant).

Not every study finds evidence to support one style walker over the other. Mattsson and Andersson (1997) showed that spasticity (measured using a modified Ashworth scale), oxygen cost, perceived exertion, and walking velocity were not statistically significant between the two walkers. Park et al. (2001) and Logan et al. (1990) also failed to find statistically significant differences in walking speed between anterior and posterior walkers.

Anterior vs. Posterior Walkers: Upper Extremity

While the aforementioned research assessed a variety of differences between anterior and posterior walkers, the aim of this study is to investigate differences in UE joint demands, which include joint angles, forces, and moments. Studies have been completed that compare biomechanical differences in the UE when using anterior and posterior walkers. Konop et al. (2009b) sought to investigate these differences and compare UE kinetics in kids with CP by analyzing tri-axial forces (inferior/superior, medial/lateral, and anterior/posterior) and moments (internal/external rotation, flexion/extension, and medial/lateral bending) at the wrist, elbow, and glenohumeral (GH) joints. No significant differences were found in the kinetic joint parameters between anterior and posterior walkers, but several trends in which the p-value was <0.05 relating to forces and moments in the UE joints were observed.

Other studies echoed these results. A similar study by Strifling et al. (2008) analyzed UE kinematics of children with CP using both anterior and posterior walkers, and found "anterior and posterior walkers may be more statistically similar than different." This study found that the amount of torso tilt was not dependent upon walker type, as well as comparable joint patterns in motion and ranges of motion. However, this study noted that on average, posterior walkers led to a decrease in anterior torso tilt, torso rotation, ulnar deviation, as well as an increase in shoulder extension, elbow flexion, and forearm pronation.

Another study by Konop, Strifling, & Harris (2009) looked specifically at GH joint moments between the two walker types in children with CP. No significant differences were found between anterior and posterior walkers at the maximum, minimum, or range of the moments. However, the range of moments in the right GH joint tended to be greater in posterior walker use (1.228% Body weight x Height (BW*H) for posterior, 0.668% BW*H for anterior, $p = 0.0625$). In addition, the maximum Joint reaction moment (JRM) in the left side tended to be greater with anterior walker use (1.67% BW*H) than posterior walker use (1.39% BW*H), $p = 0.0625$.

One final study that compared these UE biomechanical differences in children with CP characterized wrist, elbow, and GH joint dynamics including position, joint reaction forces (JRFs), and JRMs. Similarly, the results showed no statistically significant differences in UE dynamics between walker styles (Konop, Strifling, Krzak, Graf, & Harris, 2011).

Functionality, ADLs, and Walkers

While many studies exist that make comparisons between anterior and posterior walker use, one type of comparison that is lacking in research is the comparison of functional activities

or areas of daily living (ADLs) between the walker types. Greiner et al. (1993) states "further investigation of walker use and performance of self-care skills may yield valuable clinical information." One of the main performance skills necessary to complete self-care activities or ADLs is the ability to manipulate and use one's UEs within their environment. Requiring a walker to stand or walk poses a challenge to performing ADLs because often at least one hand must remain on the walker at all times for stabilization, but also because the walker poses a physical barrier by being in the way from time to time. It has been reported that 72.1% of walker users are limited in ADLs, while 50% report needing assistance with completing ADLs (Kaye et al., 2000). Having the ability to maneuver one's UEs, as well as reach beyond the walker is critical for walker users to perform ADLs.

The ability to rise from a chair is one of the most common movements and a central component to upright mobility and many daily living tasks; it is more difficult for children with CP who often need to use compensatory patterns to stand from a seated position (Park et al., 2002). For children with CP who are not able to complete the sit-to-stand independently, a walker improves their point of stability to attain the task (Thanapan, Prasertsukdee, & Vachalathiti, 2013). In general, sit-to-stand transitions are not as smooth as children as they are in adults, who have refined their body mechanics over time. Due to changes in body morphology during adolescence, children have additional control problems of intrinsic dynamics (Guarrera-Bowlby & Gentile, 2004). The TUG incorporates sit-to-stand, walking, turning, and stand-to-sit phases; this diversity is why it has been chosen as a functional assessment. It has proven to be a reliable measure with children with CP, demonstrating high test-retest reliability (Dhote, Khatri, & Ganvir, 2012) and high within-sessions reliability (Williams, Carroll, & Reddihough, 2005; Katz-Leurer, Rotem, Lewitus, Keren, & Meyer, 2008). Investigating the

differences between timing it takes to complete the TUG and individual components of the TUG has not been previously explored.

In order to interact with many items that are part of ADLs, one must extend his or her UEs and reach for them. However, for children with cerebral palsy impaired hand function can be a disabling symptom in relation to the completion of ADLs (Ronnqvist & Rosblad, 2007). Ronnqvist and Rosblad (2007) also state that "the gravitational force during reach-to-grasp movement to an elevated object may also be particularly challenging for a child with moderate hemiplegic cerebral palsy and thus, would require compensations such as alerted muscle activation." Because the interaction between the body and a posterior walker differs from that of the body and an anterior walker, the ability to reach could vary between walker styles. "The child's balance deficit should be considered when selecting the type of walker. Children with ataxia or involuntary movements may benefit from the use of an anterior walker with added weights for additional stability. Children with better postural control can use a posterior walker" (Braga & de Paz Jr, 2006). The ability to reach forward and laterally with an outstretched arm while keeping a fixed base of support have shown to be reliable and valid measures of performance in older adults who are physically impaired (Netz et al., 2007). Brauer, Burns, and Galley (1999) state that the Lateral Reach Test (LRT) was found to be an accurate measure of lateral reaching ability, has high test-retest reliability, and is a valid indicator of lateral stability limits. Gan, Tung, Tang, and Wang (2008) investigated the Functional Reach Test (FRT) in children with CP and found it to be a simple, valid, and reliable method, and suitable for clinical practice.

II. Kinematics

Special Note – A version of the following chapter will be submitted to the American Journal of Occupational Therapy.

1. Introduction

There are more than 1.8 million walker users in the United States (U.S.), including over 27,000 users under the age of 18 (Kaye, Kang, & LaPlante, 2000). Cerebral palsy (CP) is one of the leading populations that use walkers for ambulation. An estimated 11.3% of all eight-year-old children with CP use a hand-held mobility device such as a walker for ambulation (Center for Disease Control, 2013). Posterior walkers are more frequently recommended for children with CP (Low, Westcott, McCoy, Beling, & Adams, 2011). Many benefits have been established for using posterior walkers, such as improved posture and increased walking speed (Greiner, Czerniecki, & Deitz, 1993, Sutherland & Cooper, 1978, Logan, Byers-Hinkley, & Ciccone, 1990, Park, Park, & Kim, 2001). However, studies comparing the upper extremity (UE) biomechanical differences between anterior and posterior walkers have been limited.

Walker users are at risk for developing UE musculoskeletal injuries later in life due to the physical demands placed on the shoulder, elbow, and wrist, which can reach as much as 20% body weight (McQuade, Finley, & Oliveira, 2011). This excessive force on UE joints, which are not designed to be weight-bearing, can often lead to joint weakening or musculoskeletal injuries. It has been reported that 19.1% of walker users suffer from osteoarthrosis, which is a condition characterized by pain, aching, and/or stiffness of joints, muscle weakness, restricted active range of motion (AROM), or complete loss of joint function (Kaye et al., 2000). In addition, 72.1% of

walker users report being limited in their activities of daily living (ADLs), while 50% report needing assistance with completing ADLs (Kaye et al., 2000). Even though it's been shown that different UE joint angles lead to increased amounts of joint loading, which can be associated with higher risks of injury (Oyama, 2012), kinematics of functional tasks during walker usage have not been investigated. Previous studies have been limited to differences solely during gait (Strifling et al., 2008), even though there is more to independence and ADLs than simply walking.

This study compares differences in joint biomechanics between anterior and posterior walker usage during performance skills. These skills are features of what one does, not of what one has, and are related to observable elements of action that have implicit functional purposes (American Occupational Therapy Association, 2014). Performance skills can include motor skills, process skills, and communication/interaction skills, and are a key component to the completion of ADLs. The performance skills investigated in this study include gait, forward and side reaching, sit-to-stand, and stand-to-sit movements.

In order to interact with items to perform ADLs, one must use their UEs and reach for the item. However, for children with CP, impaired hand function can be a disabling symptom in relation to the completion of ADLs, and often requires compensations such as altered muscle activation (Ronnqvist & Rosblad, 2007). The ability to rise from a chair is one of the most common movements and a central component to upright mobility and many daily living tasks; it is more difficult for children with CP who often need to use compensatory patterns to stand from a seated position (Park et al., 2002). Due to changes in body morphology during adolescence, children also have additional control problems of intrinsic dynamics (Guarrera-Bowlby & Gentile, 2004). For children with CP who are not able to complete the sit-to-stand

independently, a walker improves their point of stability to attain the task (Thanapan & Vachalathiti, 2014). These performance skills were chosen because of the frequency they occur throughout the day, and because of the additional time and effort required in order for walker users to complete.

2. Methods

2.1 Subjects. Ten (10) pediatric walker users with diplegic CP, 4 males and 6 females, aged 6 – 18 (mean age 13.27) participated in the study (Table 1). Subjects with other neurological conditions or those who had undergone orthopaedic surgery during the past year were excluded from this study. Subjects with UE joint contractures or who had received botulinum toxin type-A in the past 6 to 12 months were also excluded. Participants who used either anterior or posterior walkers were included in this study.

Table 1 - Subject Demographics

Subject #	Age (years)	Limb dominance	Gender	Height (m)	Weight (kg)
1	17.08	Right	Male	1.77	51.26
2	6.58	Left	Male	1.19	25.85
3	12.17	Right	Female	1.47	41.28
4	12.25	Right	Female	1.30	36.74
5	13.17	Left	Male	1.48	30.39
6	7.92	Right	Female	1.12	25.85
7	18.08	Right	Male	1.64	60.78
8	14.00	Left	Female	1.51	57.61
9	17.75	Left	Female	1.52	38.10
10	13.67	Right	Female	1.50	44.91
Mean	13.27	---	---	1.45	41.28
SD	3.86	---	---	0.29	12.41

Approval for this study was obtained from the Institutional Review Board (IRB) in accordance with the policies at the University of Wisconsin-Milwaukee, Marquette University, and Shriners Hospital for Children-Chicago. Informed consent was obtained from each subject and their legal guardian (as appropriate) prior to data collection. Please see Appendices A and B for consent and assent forms.

2.2 Data Collection. Data was collected at Shriners Hospitals for Children – Chicago (Chicago, IL) in the Motion Analysis Laboratory. Motion capture data was recorded by placing reflective surface markers on the subjects' upper and lower extremities based on an established marker set (Schnorenberg et al., 2014; Figure 1). Kinematic data was collected at 100 Hz using a 14-camera Vicon MX motion analysis system (Oxford Metric Group, Oxford, UK). A specially designed walker (AMTI, Model MCW-6-500, Watertown, MA) which could be switched

between anterior and posterior styles was used for all subjects (Figure 2). The height of the walker was adjusted similarly to the subject's personal walker, as set by their therapist. Prior to data collection, the Visual Analog Scale (VAS) was administered and initial pain outcomes were collected (Figure 3). Due to their varying abilities, the subjects were allowed to take breaks as needed throughout data collection. Subjects were requested to complete a minimum of three trials for each task, however, not all subjects could complete all trials due to fatigue. The order of trials was consistent between all subjects and not randomized, as randomization would mean constantly switching between anterior and posterior walker styles, which would result in a substantial increase in time for subject testing.

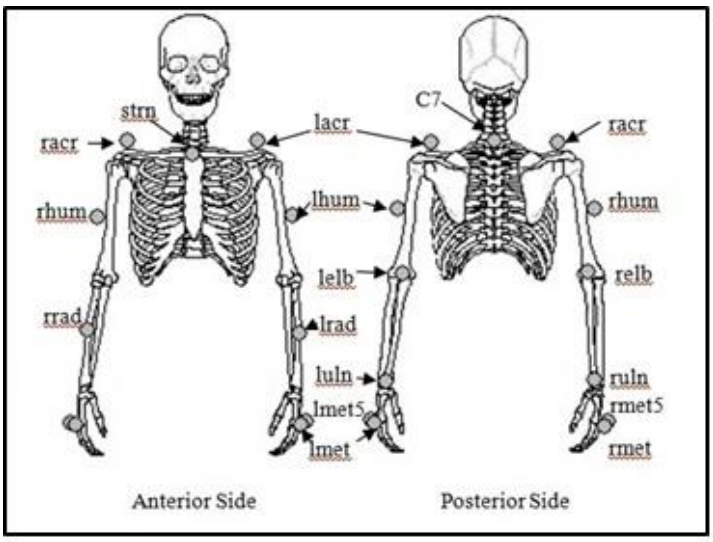


Figure 1: Upper extremity marker set. Markers for left and right side are as follows: 3rd metacarpal (met), 5th metacarpal (met5), ulna (uln), radius (rad), elbow (elb), humerus (hum), acromion process (acr), sternum (strn), and C7.

Figure 2: Reversible walker.

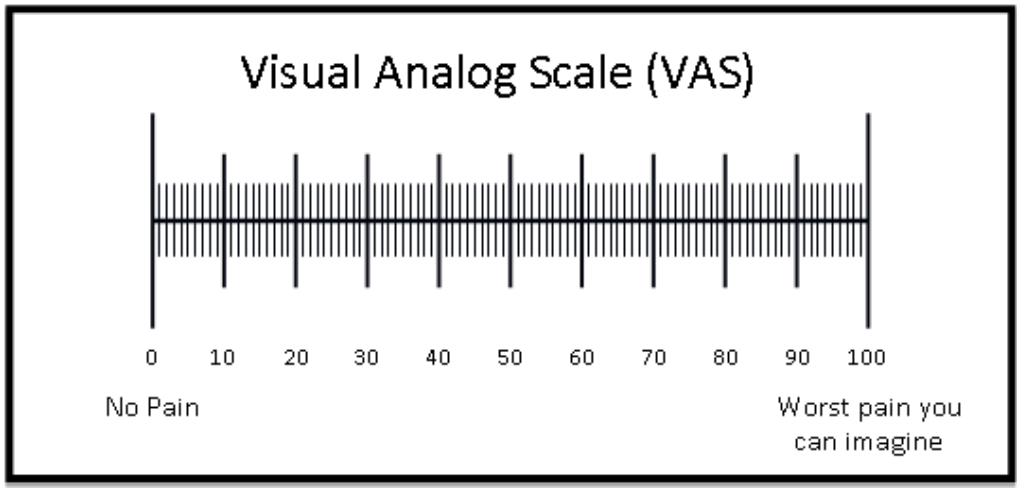


Figure 3: Visual analog scale (VAS) for pain (Wewers & Lowe, 1990). Subjects were asked to mark their average daily pain with 0 being no pain at all and 100 being the worst pain they could imagine.

Gait. Subjects began with the instrumented walker oriented to their preferred style, either anterior or posterior. The subjects performed a gait trial by walking from one side of the room to the other at a self-selected speed. The subjects completed three to five gait trials and three were analyzed (Table 2).

Reaching. Subjects participated in reaching trials simulated after the Functional Reaching Test (FRT; Duncan, Weiner, Chandler, & Studenski, 1990) and Lateral Reach Test (LRT; Brauer, Burns, & Galley 1999). For the FRT, subjects stood with their preferred walker and were asked to raise the shoulder of their preferred reaching arm to the starting position: 90-degrees flexion (or as close to 90-degrees as they could), and with the elbow of the outstretched arm extended and in either neutral position or in pronation, with fingers extended. A target was held at the same height of their reaching shoulder (but out of their reach) so the subjects could aim at a level object. The subjects were instructed to "reach as far as you can forward without

taking a step or moving the walker, and hold for three seconds." The subjects were allowed to flex at the hips as needed. After three seconds, the subjects returned to the starting position and relaxed, which constituted one trial (Figure 4).

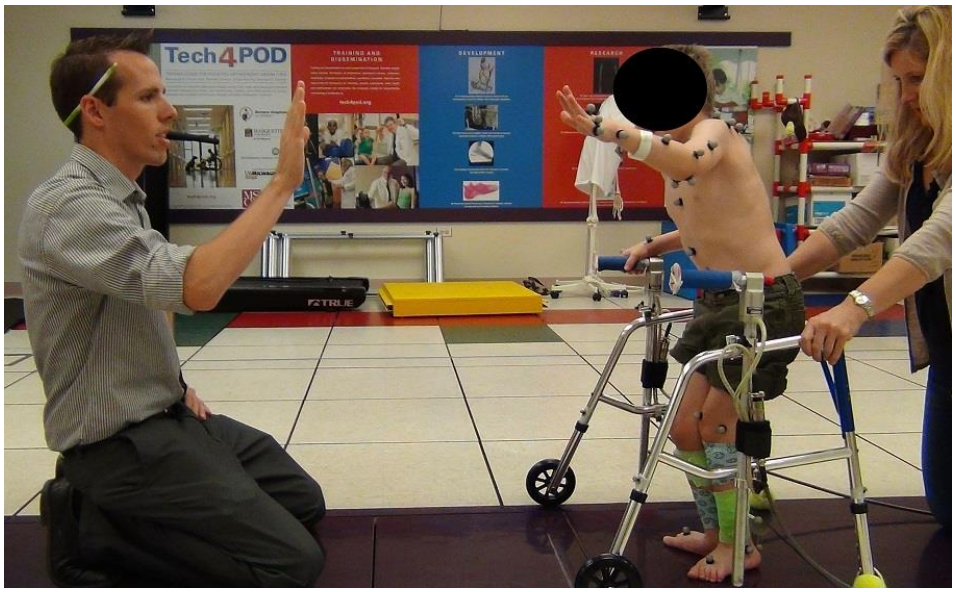


Figure 4: Subject performing Functional Reach Test.

Subjects used the same preferred walker and same standing position for the LRT but were instructed to place the shoulder of their preferred reaching arm into 90-degree abduction (or as close to 90-degrees as they can) with the elbow extended and in either neutral position or pronation, with fingers extended. Subjects were instructed to "reach as far as you can to the side without taking a step or moving the walker, and hold for 3 seconds." Subjects could laterally flex at the hips as needed. After the three seconds the subjects returned to starting position and relaxed, which constituted one trial. Subjects performed up to five trials for both the FRT and LRT (Table 2).

Table 2 - Number of Gait & Reaching Trials performed/analyzed

Subject #	Anterior Gait	Posterior Gait	Anterior Forward Reach	Posterior Forward Reach	Anterior Lateral Reach	Posterior Lateral Reach
1	3	3	3	3	3	3
2	3	3	1	3	0	0
3	3	3	0	0	0	0
4	3	3	3	3	3	1
5	3	3	0	0	0	0
6	3	3	3	3	3	3
7	3	3	3	3	3	3
8	3	3	3	2	3	3
9	3	3	3	3	0	0
10	3	3	3	3	3	3
Total	30	30	22	23	18	16

Sit-to-Stand/Stand-to-Sit. Subjects performed the Timed Up and Go (TUG) test (Podsiadlo & Richardson, 1991) to capture sit-to-stand and stand-to-sit activities within the context of walking to or from a task. The TUG test is a performance-based tool used on populations with various diagnosis to assess balance, mobility performance, and turning ability (Manaf, Justine, & Omar, 2014). Subjects began by sitting on a padded bench with their hips and knees at 90-degrees flexion (or as close as possible) (Eekhof, De Bock, Schaapveld, & Springer, 2001, Janssen, Bussmann, & Stam, 2002) with the walker positioned within arm's reach in front or next to them, as preferred. A cone was placed on the floor 3 meters in front of the starting bench. The subjects were instructed to "please get up on the word go, stand upright within your walker and walk as quickly and safely as possible to the marker on the floor, turn around the object, return to the chair, and sit down." The trial ended upon the subject sitting back down, with three trials being performed (Table 3).

Table 3 - Number of TUG/Sit-to-Stand (STS)/Stand-to-Sit (StTS) Trials performed/analyzed

Subject #	Anterior TUG	Posterior TUG	Anterior STS	Posterior STS	Anterior StTS	Posterior StTS
1	2	3	2	3	3	3
2	2	1	3	1	2	2
3	0	0	0	0	0	0
4	2	0	2	1	2	1
5	0	0	0	0	1	1
6	0	0	0	0	0	0
7	2	2	2	3	3	3
8	3	3	3	3	3	3
9	0	0	0	0	0	0
10	0	0	0	0	0	0
Total	11	9	12	11	14	13

Non-preferred Walker. After completing all trials with their preferred walker, the subjects were given a break as the instrumented walker was switched to their non-preferred style. Once ready, subjects were given an acclimation period to walk with the new walker until they felt comfortable to resume testing, which usually lasted less than 3 minutes. Subjects performed the same gait, reaching, and TUG trials as they did previously, this time with their non-preferred walker style.

2.3 Data Analysis. Data was labeled in Vicon Nexus 2.1.1 (Figure 5), and raw data was filtered with a Woltring filter (mean square error = 20; Woltring, 1986). A custom kinematics model, which was previously developed and validated to allow calculation of 3-D joint angles was applied (Strifling et al., 2008). This model is compliant with the International Society of Biomechanics (ISB) UE coordinate system definition (+x axis forward, +y axis superior, and +z axis right) (Wu et al., 2005; Table 4), and used a ZXY Euler rotation sequence method (sagittal-coronal-transverse sequence) to determine the joint angles. There angles were defined as the angle of the distal segment relative to the proximal segment.

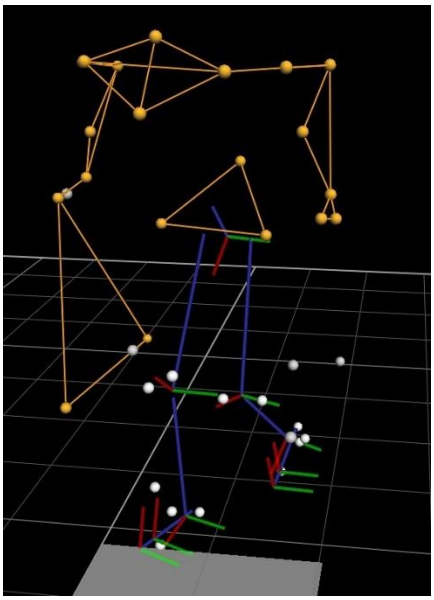


Figure 5: Labeled subject in Vicon.

Table 4 - Glenohumeral joint system axes directions

+X	Adduction
-X	Abduction
+Y	Internal Rotation
-Y	External Rotation
+Z	Flexion
-Z	Extension

Data from left and right side of body have been matches within the model so that directionality is the same (i.e. the left side is "negated" so that adduction and internal rotation are positive on both sides). Joint angles, timing, and distances between anterior and posterior walkers were compared using a two-tailed paired t-test analysis. A p-value of ≤ 0.05 is considered statistically significant. Data was processed via MATLAB (MathWorks, Natick, MA; Figure 6) and Microsoft Excel (Microsoft, Redmond, WA). Group means, standard deviations, peak joint angles (maximum and minimum), and range of motion (ROM) were calculated during gait tasks. The horizontal distance traveled of the 3rd metacarpal marker during forward and lateral reaching tasks, and timing for sit-to-stand, stand-to-sit, and TUG activities were determined.

```
        filename = strcat(filepathout,'\','Right Wrist Angle.jpg');
        h=gcf;     saveas(h,filename);

%Left Wrist Angular Plot
  figure('Position',[100,200,1350,370]);
  subplot(1,3,1)
  plot(lwx_Avg,'r'); hold on; plot(lwx_Avg+lwx_Std,':b'); hold on; plot(lwx_Avg-lwx_Std,':b');
  xlabel('Percent Task (%)');
  ylabel({'Left Wrist Angle';'Ulnar Dev + / Radial Dev - (deg)'});
  axis tight;
  subplot(1,3,2)
  plot(lwy_Avg,'r'); hold on; plot(lwy_Avg+lwy_Std,':b'); hold on; plot(lwy_Avg-lwy_Std,':b');
  xlabel('Percent Task (%)');
  ylabel({'Left Wrist Angle';'Pronation + / Supination - (deg)'});
  axis tight;
  subplot(1,3,3)
  plot(lwz_Avg,'r'); hold on; plot(lwz_Avg+lwz_Std,':b'); hold on; plot(lwz_Avg-lwz_Std,':b');
  xlabel('Percent Task (%)');
  ylabel({'Left Wrist Angle';'Flex + / Ext - (deg)'});
  axis tight;
      %Save the Plot
        filename = strcat(filepathout,'\','Left Wrist Angle.fig');
        h=gcf;     saveas(h,filename);
        filename = strcat(filepathout,'\','Left Wrist Angle.jpg');
        h=gcf;     saveas(h,filename);
```

Figure 6: Sample Matlab code.

Gait. Gait analysis data was normalized to percentage of gait cycle. One gait cycle was defined as heel-strike to heel-strike of the dominant side of the participants.

Reaching. The beginning of the FRT and LRT tasks were visually identified as the time when the acromion process of the outstretched arm began moving horizontally away from the body after maximum shoulder flexion was achieved. The ending of the FRT and LRT tasks occurred when the acromion process of the outstretched arm moved towards the body, or when the shoulder began extending towards neutral (Gan, Tung, Tang, & Wang, 2008, Weiner, Duncan, Chandler, & Studenski, 1992, Brauer et al., 1999). The horizontal distance traveled during the task was defined as the starting position of the 3rd metacarpal marker subtracted from the maximum horizontal distance the marker traveled during the defined start/end points. All subjects reached with their dominant UE (Table 1).

Sit-to-Stand. Sit-to-stand tasks included two phases: (1) the preparation/rising phase, and (2) the turning phase (Pavao, Neves dos Santos, Beatriz de Oliveira, Cicuto, & Rocha 2014). The turning phase is essential when using a walker, as both the walker and user must be oriented

in the proper direction before walking can begin. The preparation/rising phase began when the sacrum marker ascended 5 mm from its starting position without retreating back within 5 mm of the starting position, and ended when the back-walker marker moved 50 mm from its starting position in any one direction. The turning phase, which applied to posterior walkers only, began at the end point of the preparation/rising phase, and ended when the back of the walker moved 100 mm forward from the original starting position and when both toe markers were positioned in front of both heel markers.

Stand-to-Sit. Stand-to-sit tasks were also divided into two phases: (1) the turning phase, and (2) the descent phase (Agrawal, O'Toole, Gaunaurd, & Gailey, 2015). The turning phase, which applied to anterior walkers only, began when either marker from the back of the walker moved in front of (closer to the starting bench) one marker from the front of the walker, and ended when the sternum began descending towards the chair. The descent phase started when the sternum marker began to descend, and ended when the sacrum marker stopped descending, signaling the subject was now seated.

Timed Up-and-Go. The TUG incorporates the phases from the sit-to-stand and stand-to-sit movements, but also additional stages of straight walking and turning (Porciuncula, Rao, & McIsaac, 2015). The overall timing of the TUG was measured from the moment the sacrum marker ascended 5 mm from its starting position without retreating back within 5 mm of the starting point, and ended when the sacrum marker stopped descending, signaling the subject was now seated.

3. Results

Visual Analog Scale. Eight subjects reported no pain prior to data collection. Two subjects reported having some pain, but nothing more than mild. Patient #10, specifically, reported having pain in his right hip.

Table 5 - VAS Results

Subject #	VAS rating	Pain location
1	0	-
2	30	General
3	0	-
4	0	-
5	0	-
6	0	-
7	0	-
8	0	-
9	0	-
10	10	R. hip

Gait. During gait, anterior walker usage led to higher mean peak abduction and internal rotation angles at the GH joint of the dominant shoulder, but not enough to be statistically significant. Both anterior and posterior walker use resulted in shoulder extension. However, a statistically significant difference in mean minimum extension angles was discovered at the dominant GH joint (Tables 6, 7; Figures 7, 8), with posterior walkers averaging more minimum extension (-27.35 +/- 13.60 degrees) compared to anterior walkers (-14.81 +/- 20.83 degrees). There were no statistically significant differences in maximum joint extension averages between anterior and posterior walkers.

Similarly, the differences in GH joint ROM were found to be statistically significant in the sagittal plane for flexion/extension (p-value = 0.03), with the dominant GH joint ROM averaging 24.02 +/- 15.95 degrees for anterior walkers, versus 16.49 +/- 8.26 degrees for

posterior walkers (Table 8; Figure 9). There was no statistically significant difference in the coronal plane for adduction/abduction (p-value = 0.50) or transverse plane for internal/external rotation plane (p-value = 0.45).

Table 6 - GH Joint Angle Peaks During Gait - Anterior Walker

Trial #	Max GH Joint Angle (degrees)			Min GH Joint Angle (degrees)		
	X	Y	Z	X	Y	Z
1	-11.50	18.48	-8.90	-26.90	-19.84	-27.40
2	-8.60	7.57	-8.00	-20.20	-17.50	-19.70
3	-7.80	16.30	-6.00	-31.00	-44.19	-20.20
4	-22.90	22.69	25.58	-51.10	-33.88	-40.40
5	-26.04	48.80	13.65	-48.30	-32.30	-39.60
6	-33.83	30.40	35.20	-47.58	-33.40	-30.90
7	-1.90	32.23	-17.00	-14.30	-2.09	-33.00
8	-2.20	38.96	-12.20	-28.57	13.84	-35.89
9	-1.40	50.20	-20.80	-8.10	8.43	-34.90
10	19.00	53.70	-51.20	2.30	30.00	-63.00
11	9.10	48.16	-48.30	-2.60	29.83	-63.84
12	12.80	51.20	-51.30	-10.20	30.20	-71.80
13	0.80	45.10	-35.50	-3.20	37.60	-43.10
14	1.80	45.56	-35.24	-8.80	33.30	-44.87
15	0.48	37.30	-32.10	-5.60	27.60	-42.80
16	-5.10	38.20	-27.00	-15.70	19.40	-45.10
17	-19.90	9.30	-25.50	-33.00	-8.00	-35.80
18	-15.40	10.30	-24.20	-26.50	-10.46	-54.70
19	-17.20	14.23	12.00	-27.20	-47.69	-11.80
20	-19.73	8.70	0.20	-29.20	-50.80	-17.50
21	-13.80	-1.20	3.08	-27.29	-44.80	-13.30
22	-21.80	16.50	-25.00	-29.70	-5.30	-46.90
23	-14.92	10.50	-2.10	-28.19	-8.42	-55.90
24	-14.20	19.30	-23.70	-29.70	-12.30	-56.80
25	-26.90	-13.20	5.43	-31.80	-35.70	-23.50
26	-18.37	3.30	-20.61	-32.40	-14.40	-51.10
27	-32.00	4.20	-9.50	-43.20	-25.30	-38.90
28	4.00	32.96	-22.11	-8.50	12.60	-37.40
29	-4.70	31.00	-20.10	-10.70	14.20	-32.80
30	0.60	42.40	-13.10	-8.90	2.55	-32.10
Mean	-9.72	25.77	-14.81	-22.87	-6.22	-38.83
SD	13.07	18.28	20.83	14.45	27.03	15.11

Mean maximum and minimum joint angles in adduction/abduction (X), internal/external rotation (Y) and flexion/extension (Z) axes reported in degrees. Trials 1-3 were completed by subject #1, trials 4-6 were completed by subject #2, etc.

Table 7- GH Joint Angle Peaks During Gait - Posterior Walker

Trial #	Max GH Joint Angle (degrees) X	Y	Z	Min GH Joint Angle (degrees) X	Y	Z
1	-12.40	9.23	-16.50	-21.00	-12.50	-25.50
2	-12.50	21.60	-23.70	-20.60	-13.90	-33.60
3	-11.40	16.50	-18.90	-21.10	-21.00	-34.20
4	-7.10	40.73	-17.20	-31.50	-12.10	-46.80
5	7.20	34.83	-20.52	-28.46	-11.20	-56.20
6	1.24	37.07	-19.00	-22.00	-7.14	-48.60
7	12.80	59.00	-24.30	7.30	33.00	-33.30
8	7.10	66.05	-17.70	-12.10	32.05	-30.50
9	-0.53	37.12	-18.62	-21.29	-0.32	-35.10
10	21.40	50.40	-51.30	9.50	31.40	-59.60
11	12.20	58.43	-50.00	8.40	30.82	-60.00
12	43.40	56.60	-57.80	9.20	36.13	-68.90
13	-13.07	39.30	-29.80	-19.40	22.62	-39.50
14	-7.30	26.50	-22.90	-24.20	12.20	-32.70
15	-12.00	-142.28	-29.00	-22.80	-150.30	-40.60
16	-41.60	-2.43	-11.70	-55.00	-38.29	-31.60
17	-35.70	11.06	-6.60	-50.10	-30.60	-38.00
18	-36.00	-8.90	-2.10	-47.90	-43.60	-26.30
19	-16.50	6.70	-26.40	-34.00	-28.30	-41.10
20	-21.90	-9.81	-19.50	-32.10	-31.30	-30.96
21	-20.00	7.05	-9.40	-39.60	-44.10	-23.90
22	-14.50	27.20	-42.50	-28.40	8.60	-61.00
23	-18.20	24.29	-29.10	-30.56	-7.70	-62.30
24	-19.50	27.00	-39.20	-30.20	7.43	-56.80
25	-14.00	13.40	-35.10	-29.60	-10.10	-56.90
26	-14.02	30.90	-46.60	-28.80	0.40	-57.00
27	-10.30	21.70	-39.60	-20.98	5.25	-58.70
28	16.60	34.10	-34.00	8.00	5.60	-47.20
29	17.60	36.60	-29.60	2.20	11.53	-41.50
30	9.00	33.50	-31.90	6.10	20.40	-36.97
Mean	-6.33	22.12	-27.35	-20.70	-6.83	-43.84
SD	18.53	36.65	13.60	18.21	35.84	12.96

Mean maximum and minimum joint angles in adduction/abduction (X), internal/external rotation (Y) and flexion/extension (Z) axes reported in degrees. Trials 1-3 were completed by subject #1, trials 4-6 were completed by subject #2, etc.

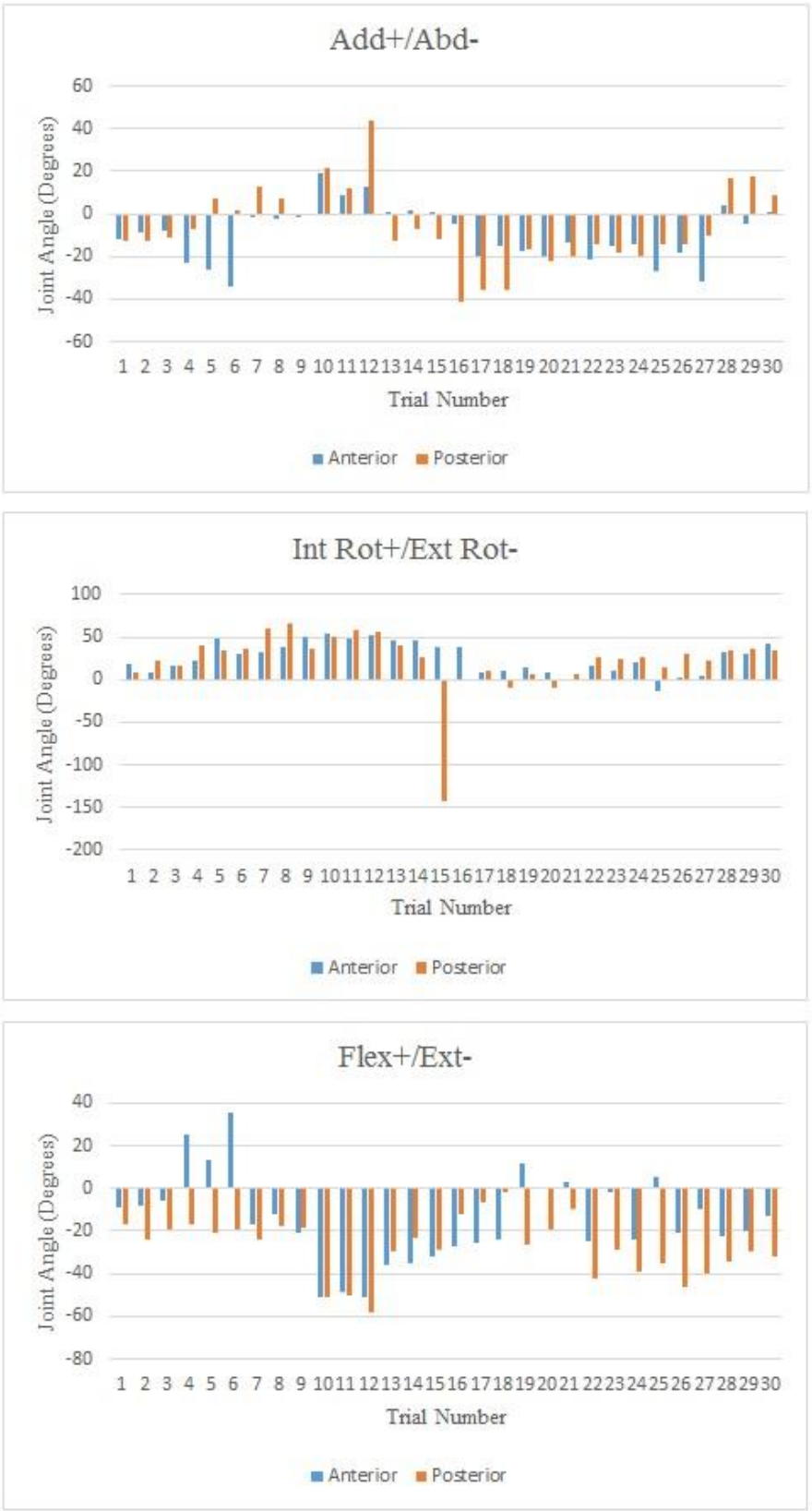


Figure 7. Maximum joint angles in the dominant GH joint during gait. P-values = 0.42, 0.63, & 0.008, respectively.

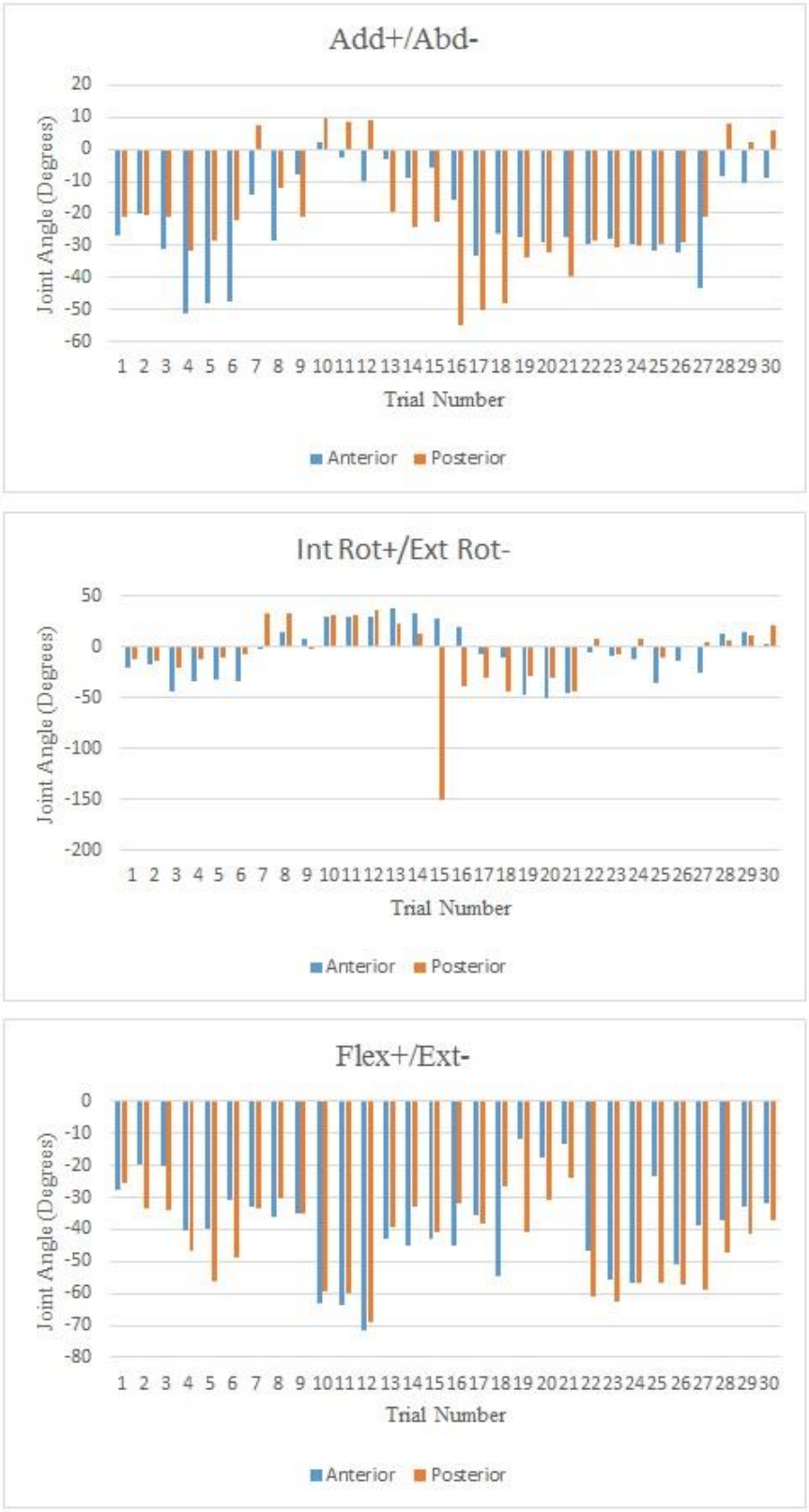


Figure 8. Minimum joint angles in the dominant GH joint during gait. P-values = 0.61, 0.94, & 0.17, respectively.

Table 8 - GH Joint ROM During Gait

Trial #	Anterior Walker ROM (degrees) X	Y	Z	Posterior Walker ROM (degrees) X	Y	Z
1	15.40	38.32	18.50	8.60	21.73	9.00
2	11.60	25.07	11.70	8.10	35.50	9.90
3	23.20	60.49	14.20	9.70	37.50	15.30
4	28.20	56.57	65.98	24.40	52.83	29.60
5	22.26	81.10	53.25	35.66	46.03	35.68
6	13.75	63.80	66.10	23.24	44.21	29.60
7	12.40	34.32	16.00	5.50	26.00	9.00
8	26.37	25.12	23.69	19.20	34.00	12.80
9	6.70	41.77	14.10	20.76	37.44	16.48
10	16.70	23.70	11.80	11.90	19.00	8.30
11	11.70	18.33	15.54	3.80	27.61	10.00
12	23.00	21.00	20.50	34.20	20.47	11.10
13	4.00	7.50	7.60	6.33	16.68	9.70
14	10.60	12.26	9.63	16.90	14.30	9.80
15	6.08	9.70	10.70	10.80	8.02	11.60
16	10.60	18.80	18.10	13.40	35.86	19.90
17	13.10	17.30	10.30	14.40	41.66	31.40
18	11.10	20.76	30.50	11.90	34.70	24.20
19	10.00	61.92	23.80	17.50	35.00	14.70
20	9.47	59.50	17.70	10.20	21.49	11.46
21	13.49	43.60	16.38	19.60	51.15	14.50
22	7.90	21.80	21.90	13.90	18.60	18.50
23	13.27	18.92	53.80	12.36	31.99	33.20
24	15.50	31.60	33.10	10.70	19.57	17.60
25	4.90	22.50	28.93	15.60	23.50	21.80
26	14.03	17.70	30.49	14.78	30.50	10.40
27	11.20	29.50	29.40	10.68	16.45	19.10
28	12.50	20.36	15.29	8.60	28.50	13.20
29	6.00	16.80	12.70	15.40	25.07	11.90
30	9.50	39.85	19.00	2.90	13.10	5.07
Mean	13.15	32.00	24.02	14.37	28.95	16.49
SD	6.14	18.80	15.95	7.71	11.50	8.26

Mean range of motion (ROM) in adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) axes reported in degrees. Trials 1-3 were completed by subject #1, trials 4-6 were completed by subject #2, etc.

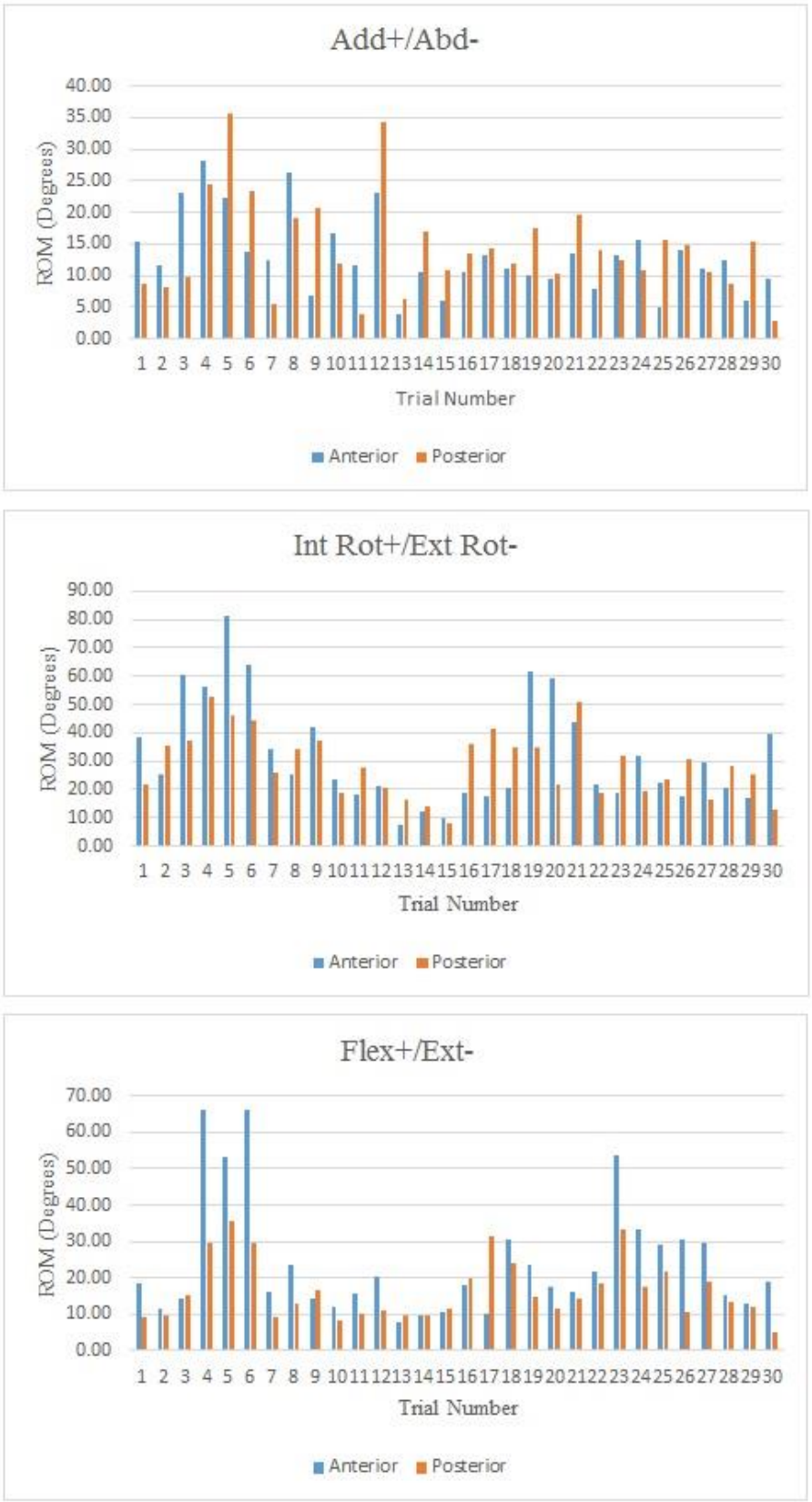


Figure 9: ROM in the dominant GH joint during gait. P-values = 0.50, 0.45, & 0.03, respectively.

Forward and Lateral Reaching. During forward reaching, anterior walker users could reach an average distance of 109.25 mm +/- 74.65 mm, whereas posterior walker users could reach an average of 73.85 mm +/- 37.34 mm, which was statistically significant ($p = 0.05$). Lateral reaching did not yield a significant difference ($p = 0.59$), as anterior walker usage led to an average reaching distance of 58.84 mm +/- 35.76 mm, whereas posterior walkers led to an average reaching distance of 70.13 mm +/- 76.09 mm (Table 9, Figure 10).

Table 9 - Reaching Distances

FRT Distances (mm)				LRT Distances (mm)			
Subject #	Anterior	Subject #	Posterior	Subject #	Anterior	Subject #	Posterior
1	104.8	1	81.4	1	63.6	1	7.1
1	93.5	1	50.5	1	34.9	1	4.5
1	48.9	1	33.2	1	24.3	1	5.3
2	37.7	2	69.2	4	89.3	4	122.7
4	171.9	2	93.1	4	26.5	6	41
4	87.3	2	22.1	4	55.6	6	37.2
4	56.7	4	76.2	6	39.9	6	56.4
6	88.8	4	51.5	6	74.6	7	170.6
6	53.5	4	109.5	6	108.5	7	180.4
6	81.9	6	66.2	7	102.7	7	269.6
7	213.7	6	73.6	7	113.1	8	25.9
7	262.4	6	56.6	7	124.8	8	59.2
7	298.1	7	162.5	8	20.5	8	42.8
8	137.4	7	90.7	8	41.1	10	23.4
8	143.3	7	111	8	67.8	10	24.4
8	133.1	8	145.2	10	33.3	10	51.5
9	57.5	8	110.7	10	23.9		
9	68.2	9	22.2	10	14.8		
9	160.3	9	75				
10	51.3	9	46.5				
10	29	10	83.7				
10	24.2	10	50.5				
		10	17.4				
Mean	109.25		73.85	Mean	58.84		70.13
SD	74.65		37.34	SD	35.76		76.09

Individual trial and mean reach distances for Functional Reach Test (FRT) and Lateral Reach Test (LRT) reported in mm. Subject's ability to participate varied among tasks.

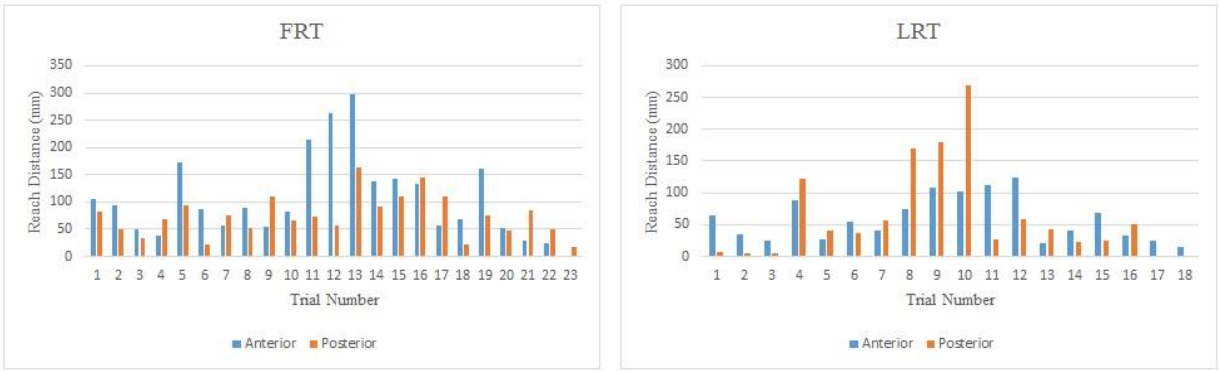


Figure 10: Anterior/posterior Functional Reach Test (p = 0.05) & Lateral Reach Test (p = 0.59) distances.

Timed Up-and-Go, Sit-to-Stand, and Stand-to-Sit. The overall timing of the TUG was similar between anterior and posterior walkers: 44.04 seconds +/- 18.72 for anterior walkers, and 46.62 seconds +/- 31.46 for posterior walkers (p = 0.83). However, the individual sit-to-stand and stand-to-sit trials were significantly different in their timing. For sit-to-stand, anterior walker users averaged 4.82 seconds +/- 3.02 to complete the task, whereas posterior walker users averaged 15.08 seconds +/- 6.47. This was significantly different (p = 0.0003). For stand-to-sit, anterior walker users averaged 10.41 seconds +/- 5.44 to complete, compared to 5.89 seconds +/- 2.40 for posterior walker users (p = 0.01; Table 10, Figure 11).

Table 10 - TUG, sit-to-stand, and stand-to-sit timing

TUG Timing (seconds)				Sit-to-stand Timing (seconds)				Stand-to-sit Timing (seconds)			
Subject #	Anterior	Subject #	Posterior	Subject #	Anterior	Subject #	Posterior	Subject #	Anterior	Subject #	Posterior
1	29.07	1	44.51	1	4.80	1	19.16	1	7.37	1	4.34
1	23.72	1	29.11	1	3.45	1	10.99	1	6.40	1	3.85
2	65.99	1	24.47	2	6.97	1	7.85	1	7.52	1	4.83
2	80.99	2	125.19	2	2.04	2	29.58	2	14.86	2	7.42
4	52.30	7	23.17	2	3.97	4	22.16	2	14.92	2	7.69
4	35.11	7	27.12	4	13.56	7	9.14	4	12.39	4	4.54
7	25.62	8	48.72	4	4.16	7	11.82	4	12.92	5	10.15
7	25.62	8	48.25	7	3.41	7	10.03	5	24.64	7	2.51
8	57.72	8	49.03	7	2.77	8	16.00	7	4.98	7	3.28
8	46.06			8	4.32	8	14.67	7	4.33	7	4.18
8	42.28			8	5.01	8	14.44	7	5.44	8	9.09
				8	3.40			8	10.35	8	7.09
								8	11.61	8	7.61
								8	7.99		
Mean	44.04		46.62	Mean	4.82		15.08	Mean	10.41		5.89
SD	18.72		31.46	SD	3.02		6.47	SD	5.44		2.40

Individual trial and mean times for TUG, sit-to-stand, and stand-to-sit tasks reported in seconds. Subject's ability to participate varied among tasks.

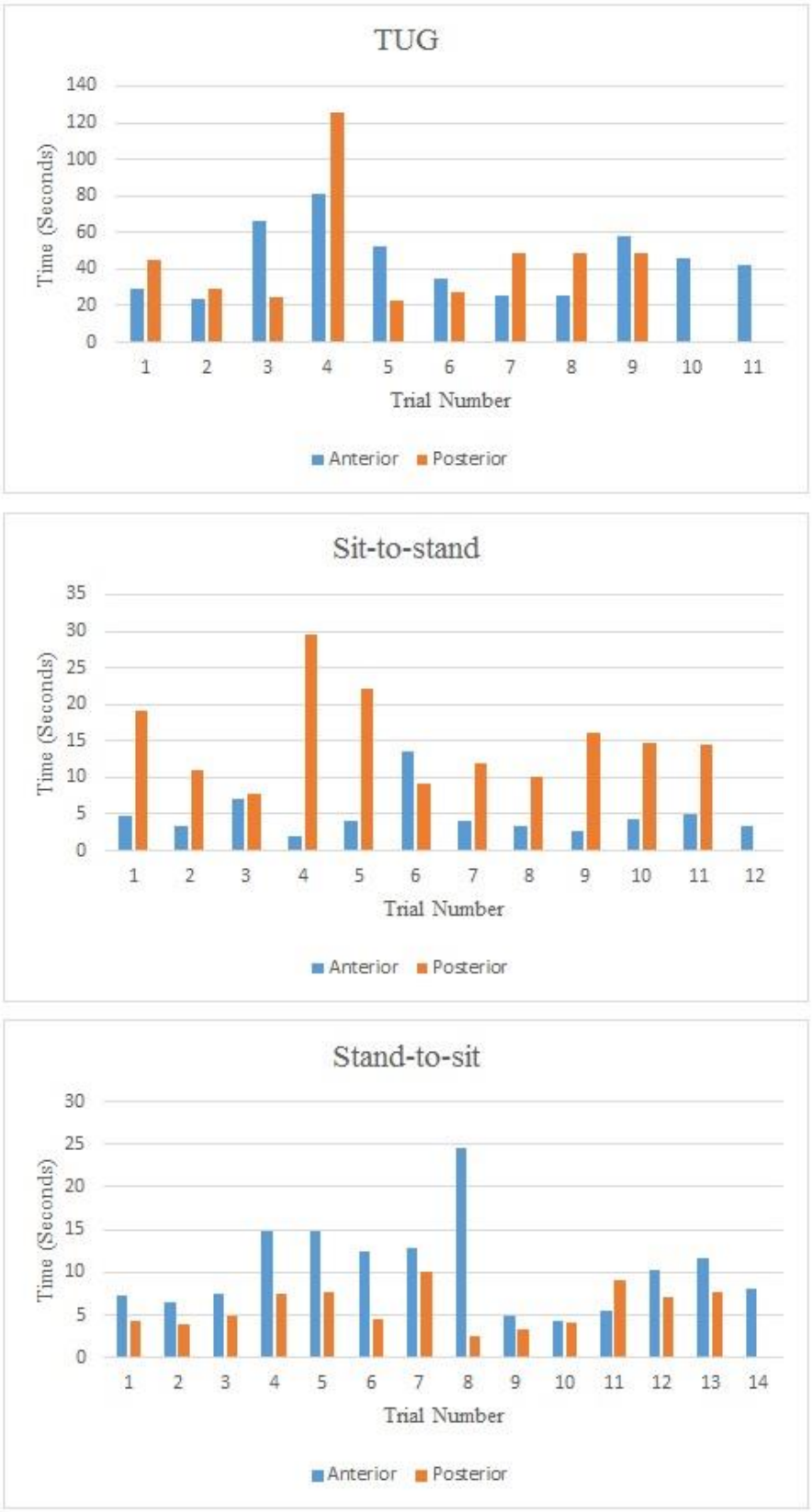


Figure 11: Timing during TUG (p = 0.83), sit-to-stand (p = 0.0003), and stand-to-sit (p = 0.01) tasks for anterior and posterior walkers.

4. Discussion

This study quantifies shoulder kinematics and timing of tasks during anterior and posterior walker usages. This is the first study to investigate kinematics of the UEs during performance skills and functional activities during walker usage. While posterior walkers are generally recommended for reasons that pertain to effectiveness of gait and posture, this study shows that anterior walkers may be better in terms of functionality and preventing UE injuries.

The results from the VAS show no correlation between pain and functional performance skills or quality of life. Of the two subjects to report pain, subject two (who reported a VAS score of 30) and subject 10 (who reported a VAS score of 10) were able to complete the fourth-most and seventh-most trials among the 10 participants. Two subjects who reported a VAS score of zero completed less than 10 trials each. Similarly, the two subjects who completed the most trials (more than 20 each) also reported a VAS score of zero. The UE strength limitations of several of the subjects appeared to affect trial completion and usability more than any reports of pain.

This study contributes to the knowledge base of UE shoulder kinematics during gait. Different joint angles result in different amounts of joint loading, and excessive joint loading leads to injury, such as greater maximum external rotation leading to higher shoulder moments (Oyama, 2012). Although there was not a significant difference in GH rotation in anterior and posterior walker usage, there was a significant difference in the flexion/extension axis. While both anterior and posterior walker usage results in GH extension, extension from posterior walker use was determined to be greater, as was the extension ROM between walker styles. The greater GH extension caused by a posterior walker could lead to injury, as anterior shoulder dislocation is widely believed to occur, in part, when the shoulder is in extension (Tanaka,

Koizumi, Kakiuchi, & Hayashida, 2012). This study could be used to help determine whether one walker style is more likely to lead to injury during gait, which is one of the most frequently occurring performance skills.

Reaching is an essential component of many ADLs, and as this study shows, there is a difference in reaching ability between walker styles. Anterior walker users were able to reach an average of 35.4 mm further, which is a 32.5% increase over posterior walker usage. We have shown that by having the body of the walker in front of a person, as with an anterior walker, it can allow for increased reaching distances up to 57.8% further within the same subject. An increased reaching distance has an impact on how walker users interact with their environment, as a larger reach means more accessibility, and more independence.

There was not a significant difference in TUG timing between anterior and posterior walkers. This is likely due to the fact that both walker styles require a turning phase at some point during completion of the TUG; anterior walker usage requires a turning phase during the stand-to-sit portion of the TUG, while posterior walker usage requires a turning phase during the sit-to-stand portion. However, when looking closer we find that the difference between the anterior and posterior walker sit-to-stand task is 10.26 seconds, while the difference during stand-to-sit is 4.52 seconds. When sit-to-stand and stand-to-sit values are combined for both anterior and posterior walkers, the timing breakdown becomes 7.83 seconds for anterior walker tasks, versus 10.1 seconds for posterior walker tasks. While these results are not statistically significant ($p = 0.19$), the edge for timing effectiveness favors anterior walkers. Children spend a large portion of their time engaging in school-based activities (getting up from a desk, transitioning from the classroom to the cafeteria, etc.) or completing ADLs in the home (sitting at the table for meals, playing on the computer, using the bathroom etc.). Transitioning from

standing to sitting and vice versa is a reoccurring component during these activities, and based on the results of this study, anterior walkers could be seen as a more effective facilitator of occupations in that regard.

5. Conclusions

This work presented a quantitative comparison of anterior and posterior walker usage in children with CP. We were able to measure joint motions and timing during gait, reaching, sit-to-stand, and stand-to-sit tasks. This work and methodology may aid clinicians in the decision-making process for walker prescription. Future directions of this research should investigate joint forces and moments of the UEs during gait and functional activities. Combined with the kinematic data from this study, kinetic data could help explain a more complete picture of shoulder biomechanics during walker use.

III. Three-Dimensional Glenohumeral Joint Kinetics

1. Introduction

While joint kinematics play an important role in determining how a person moves and interacts with a walker, joint kinetics is also needed to fully understand how the body acts together with a walker during mobility. Three-dimensional (3-D) glenohumeral (GH) joint kinetic data was collected concurrently with the kinematic trials from Chapter II. Kinetics from one representative human subject are described in this Chapter, with specific focus on methods of joint dynamics and analyses.

2. Methods

Subject: Of the ten subjects recruited for this study, one subject was selected to be a representative subject for investigating 3-D glenohumeral joint kinetics. The subject was a female of 7 years and 11 months old, weighed 25.85 kg, and measured 1.12 m tall. She was right-hand-dominant and owned and used an anterior walker.

Data Collection: Kinetic data was collected at 2000 Hz using a specially designed walker instrumented with a six-axis force transducer in each handle (AMTI, Model MCW-6-500, Watertown, MA) which could be switched between anterior and posterior walker styles. Kinetic and kinematic data collection was synchronized throughout testing. The subject completed three gait trials, three Functional Reach Tests (FRT), and three Lateral Reaching Tests (LRT) with both anterior and posterior walkers.

Data Analysis: Data was processed via MATLAB (MathWorks, Natick, MA) and Microsoft Excel (Microsoft, Redmond, WA), as described in Chapter II. Maximum and minimum forces and moments were calculated for the dominant (right) GH joint three-dimensionally using the UE inverse dynamics model developed by Schnorenberg et al. (2014) for gait. Since the subject reaches with her dominant hand and uses her non-dominant hand to hold onto the walker, the UE inverse dynamics model was used to calculate maximum and minimum forces and moments for the non-dominant (left) GH joint for all reaching tasks. This model is compliant with the International Society of Biomechanics (ISB) for UE coordinate systems (+X forward, +Y superior, and +Z right) (Wu, 2005; Table 11). Comparisons between anterior and posterior walkers were made.

Table 11 – Glenohumeral joint system axes directionality

Forces	Axis & Sense	Moments	About Axis & Sense
Anterior	+X	Adduction	+X
Posterior	-X	Abduction	-X
Superior	+Y	Internal Rotation	+Y
Inferior	-Y	External Rotation	-Y
Lateral	+Z	Flexion	+Z
Medial	-Z	Extension	-Z

3. Results

Gait. During gait, the subject demonstrated a statistically significant increase in maximum anterior force (21.38 %BW +/- 3.54) and a greater maximum inferior force (-21.55 %BW +/- 2.65) for the dominant GH joint with an anterior walker versus a posterior walker. There was almost a statistically significant difference for greater minimum anterior force ($p = 0.08$) with an anterior walker, as well. (Tables 12, 13; Figures 12, 13, 14). There was no

significant differences in the medial/lateral axis, nor a significant difference in any GH joint moments during gait (Tables 14, 15; Figures 15, 16, 17).

Table 12 - Maximum Dominant GH Joint Forces During Gait

	Anterior Walker Force (%BW)			Posterior Walker Force (%BW)		
Trial	X	Y	Z	X	Y	Z
1	24.22	-4.87	-3.89	13.55	-3.71	-5.96
2	22.51	-7.74	-5.53	6.99	10.01	1.03
3	17.41	-0.62	-1.92	11.52	-0.78	-0.65
Mean	21.38	-4.41	-3.78	10.69	1.84	-1.86
SD	3.54	3.58	1.81	3.36	7.23	3.65

Maximum GH forces in anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes reported in % body weight.

Table 13 - Minimum Dominant GH Joint Forces During Gait

	Anterior Walker Force (%BW)			Posterior Walker Force (%BW)		
Trial	X	Y	Z	X	Y	Z
1	12.68	-18.50	-12.14	-1.02	-9.12	-11.41
2	8.30	-22.91	-11.20	-9.89	-7.48	-4.47
3	0.70	-23.24	-8.92	-0.03	-13.79	-7.05
Mean	7.23	-21.55	-10.75	-3.65	-10.13	-7.64
SD	6.06	2.65	1.66	5.43	3.27	3.51

Minimum GH forces in anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes reported in % body weight.

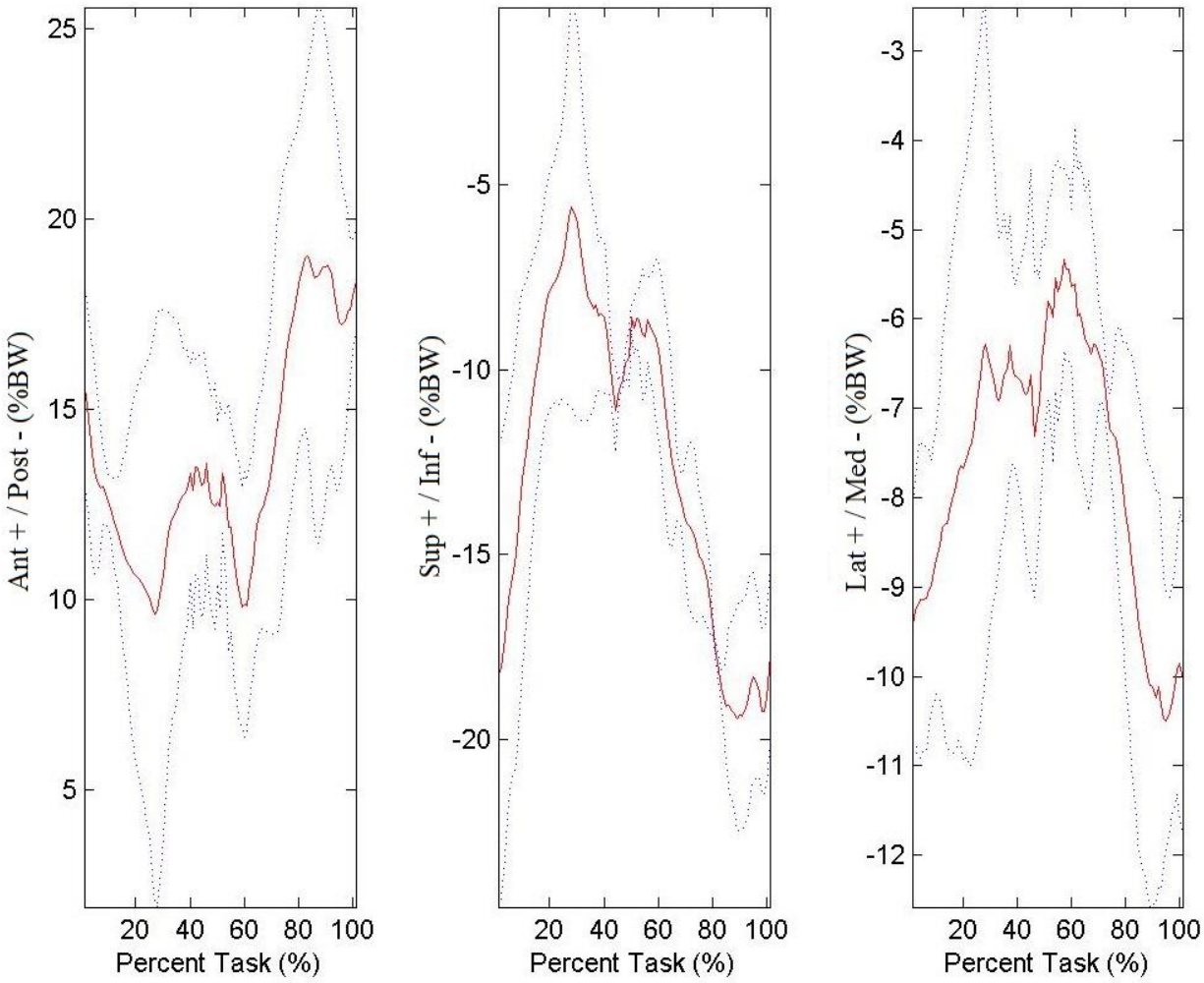


Figure 12. Mean +/- 1 standard deviation forces of the dominant shoulder during gait using an anterior walker in the anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes, reported in % body weight.

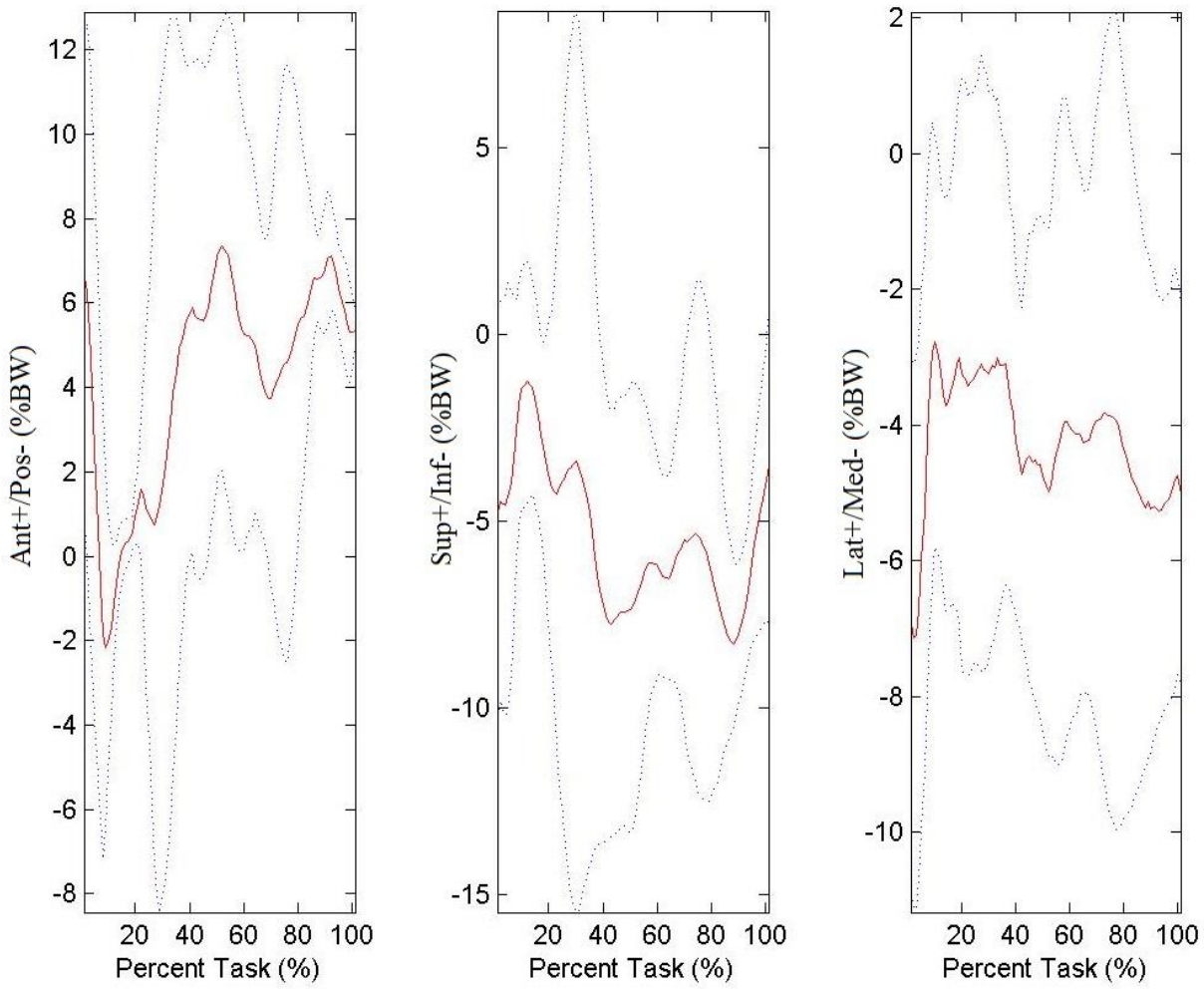
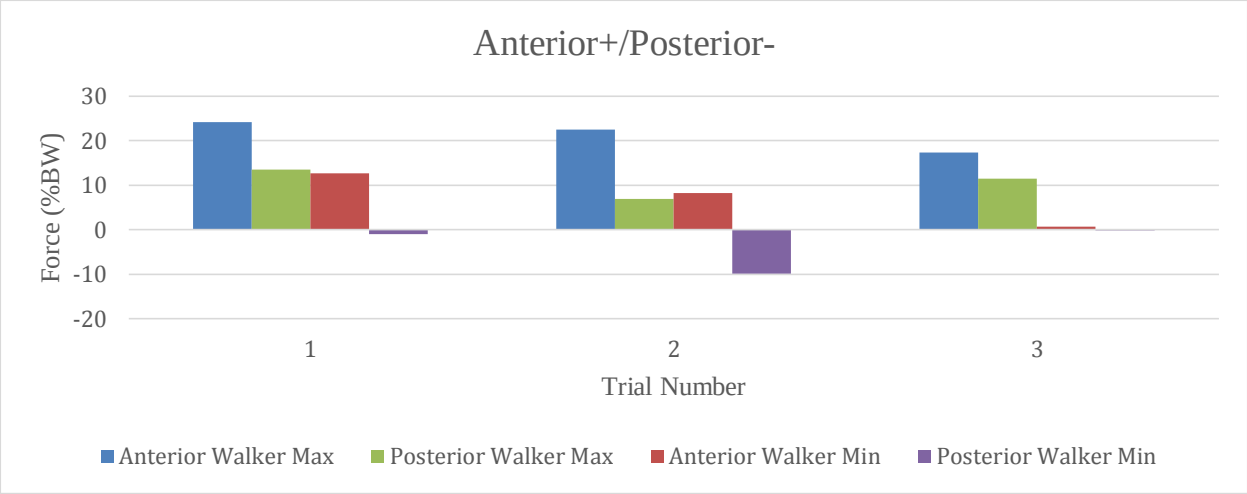
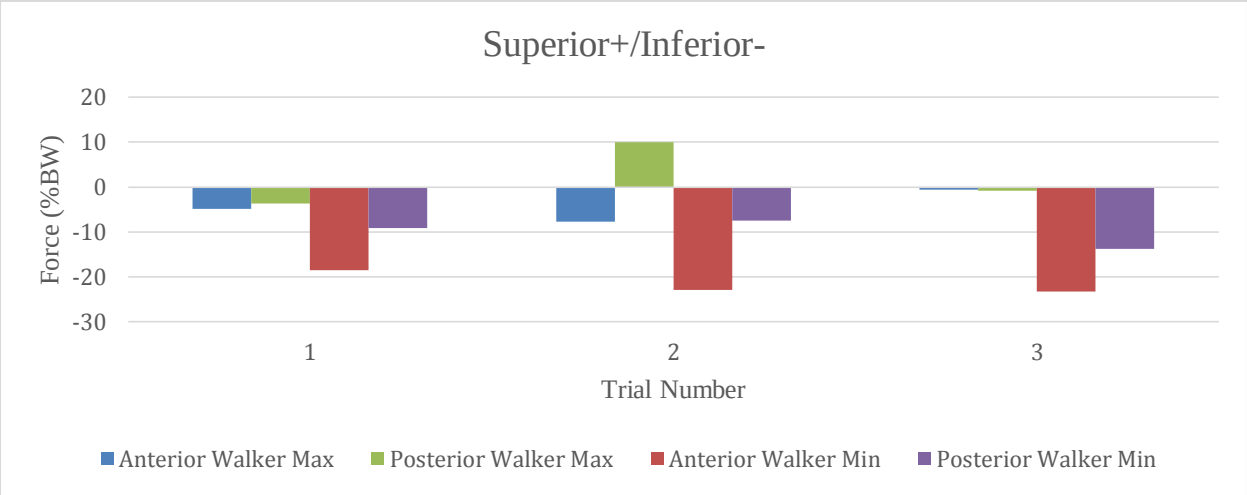


Figure 13. Mean +/- 1 standard deviation forces of the dominant shoulder during gait using a posterior walker in the anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes, reported in % body weight.





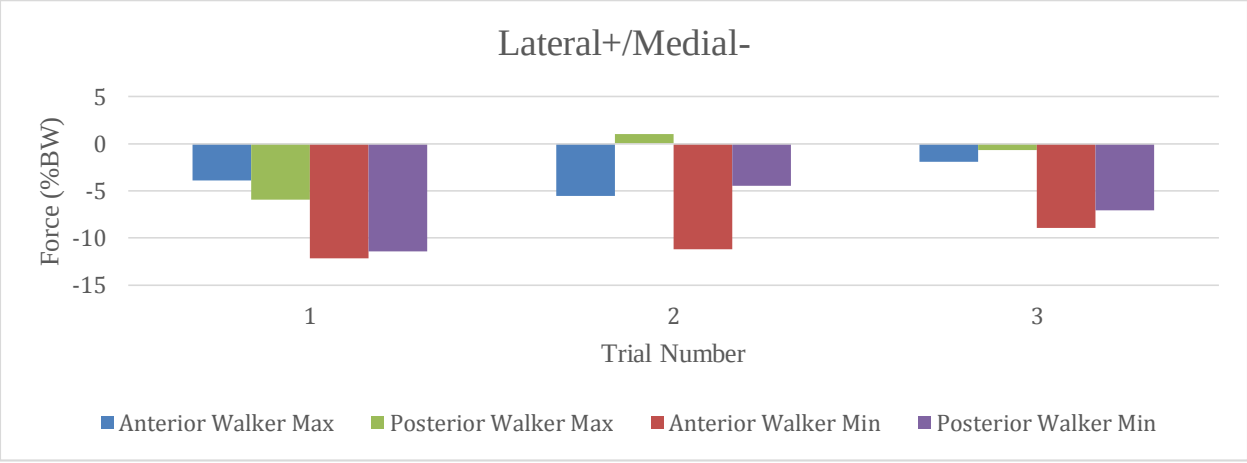


Figure 14. Peak anterior and posterior walker forces in the dominant GH joint during gait, reported in % body weight. Statistically significant p-values = 0.02 (maximum anterior force) & 0.01 (maximum inferior force).

Table 14 - Maximum Dominant GH Joint Moments During Gait

	Anterior Walker Moments (%BWxH)			Posterior Walker Moments (%BWxH)		
Trial	X	Y	Z	X	Y	Z
1	2.68	2.43	1.97	3.74	2.70	2.42
2	2.32	1.77	0.79	0.85	0.35	1.15
3	2.12	1.75	0.92	1.34	1.27	1.27
Mean	2.37	1.98	1.23	1.98	1.44	1.61
SD	0.28	0.39	0.65	1.55	1.18	0.70

Maximum GH adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) moments reported in % body weight x height.

Table 15 - Minimum Dominant GH Joint Moments During Gait

	Anterior Walker Moments (%BWxH)			Posterior Walker Moments (%BWxH)		
Trial	X	Y	Z	X	Y	Z
1	1.04	1.20	-0.08	1.16	0.26	-1.05
2	1.05	0.88	-1.12	-1.49	-1.60	-1.52
3	0.28	0.07	-1.91	-0.23	-0.40	-0.76
Mean	0.79	0.72	-1.04	-0.19	-0.58	-1.11
SD	0.44	0.58	0.92	1.33	0.94	0.38

Minimum GH adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) moments reported in % body weight x height.

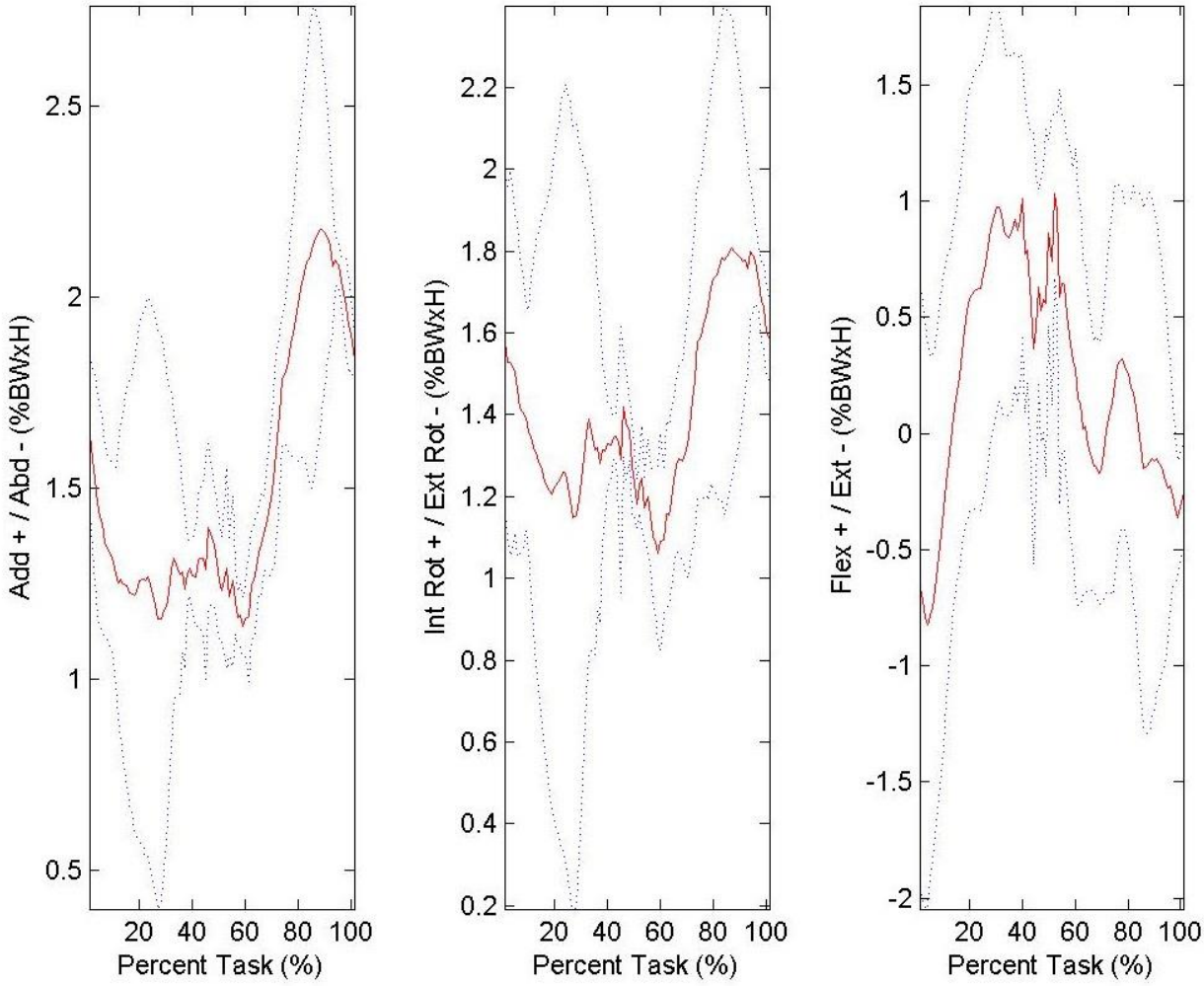


Figure 15. Mean +/- 1 standard deviation moment of the dominant shoulder during gait using an anterior walker in the adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) axes, reported in % body weight x height.

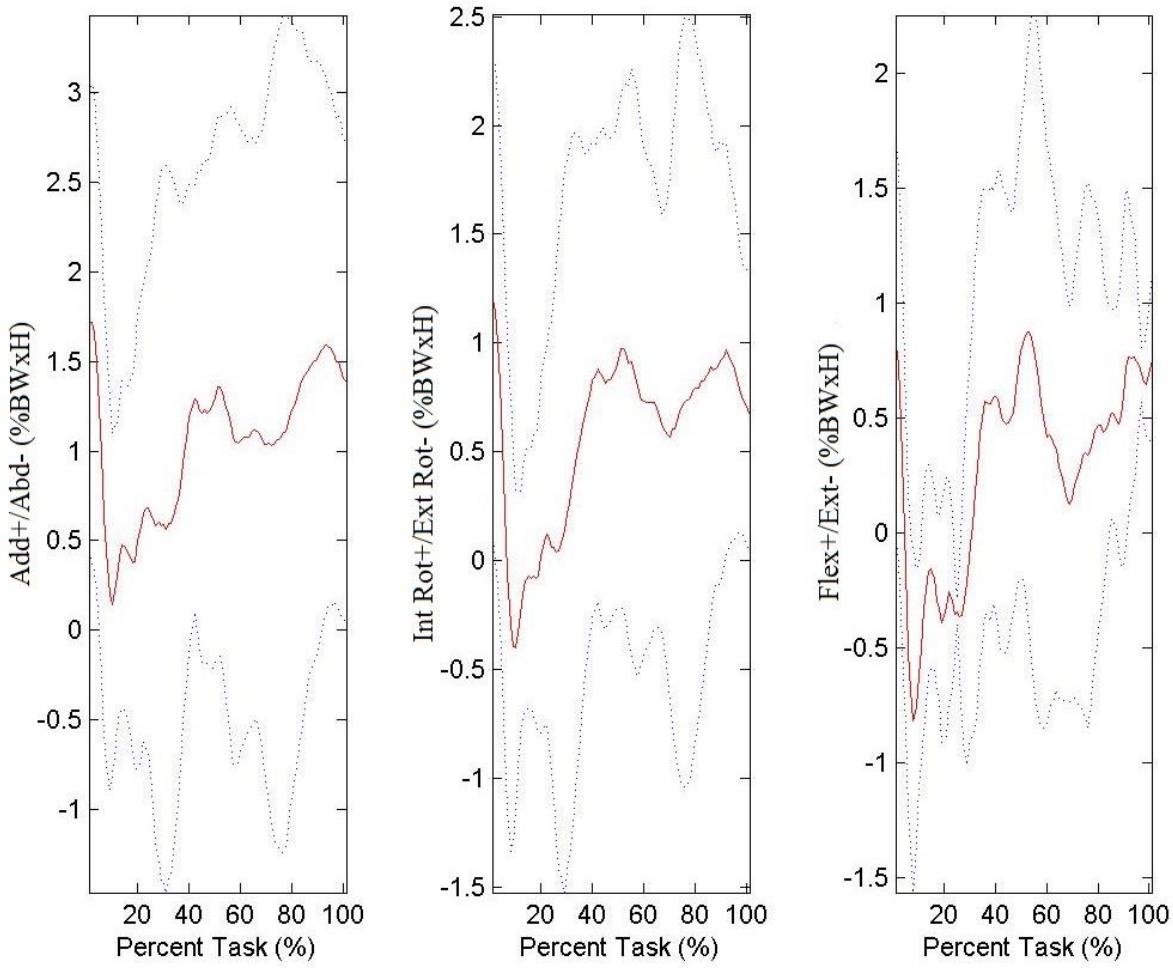


Figure 16. Mean +/- 1 standard deviation moment of the dominant shoulder during gait using a posterior walker in the adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) axes, reported in % body weight x height.

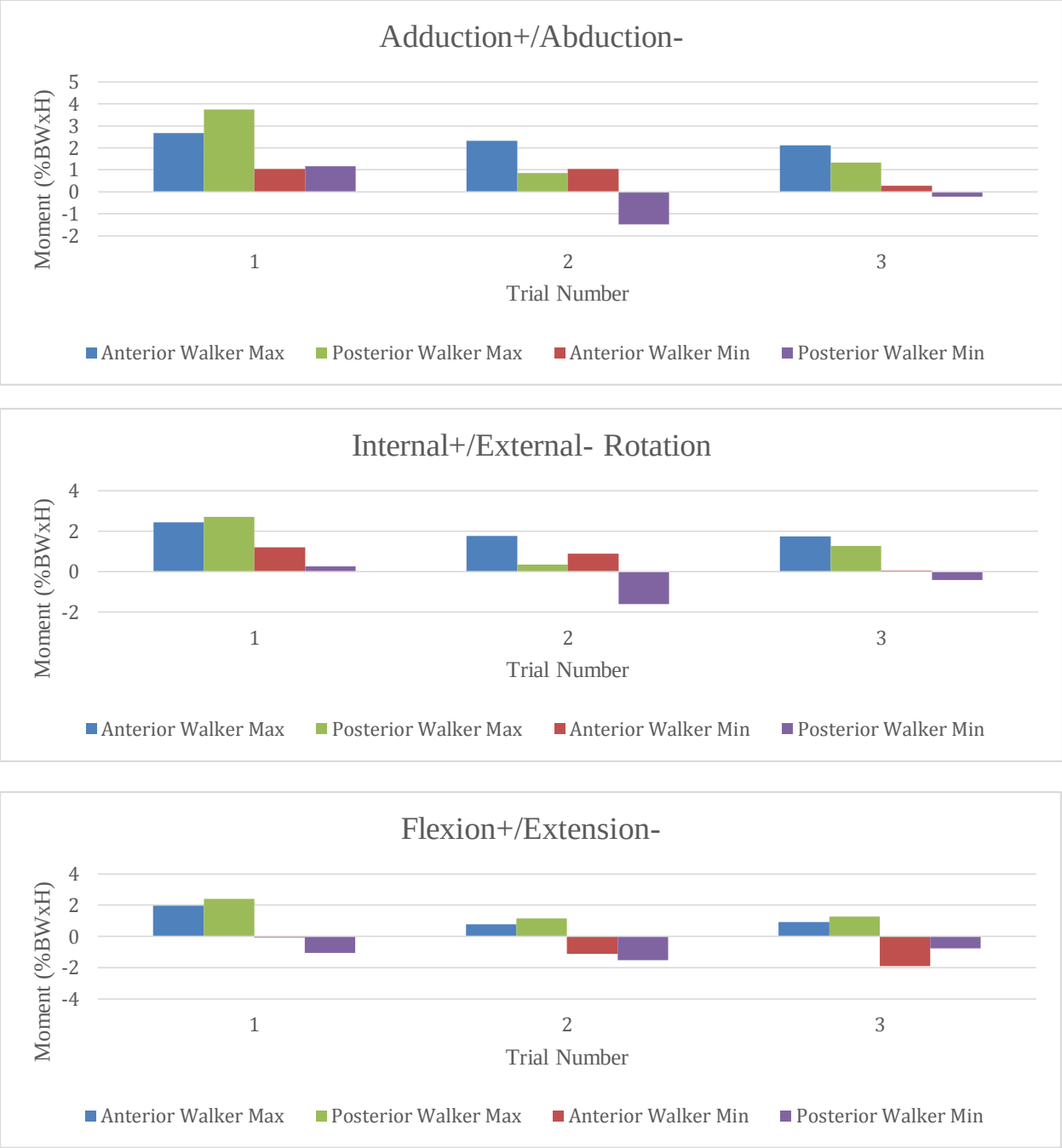


Figure 17. Peak anterior and posterior walker moments in the dominant GH joint during gait, reported in % body weight x height.

Functional Reach Test. Peak anterior forces acting at the non-dominant GH joint (maximum 8.35 %BW +/- 0.21, minimum 5.68 %BW +/- 0.90) were significantly different between anterior and posterior walker usage. Also, a significantly different maximum medial force (-16.75 %BW +/- 1.85) was detected for posterior walkers (Tables 16, 17; Figure 18). For moments, there were several different significant differences found between walker styles at the non-dominant GH joint. Both walker styles produced an adduction moment; however, anterior walker usage resulted in a significantly greater minimum adduction moment (1.27 %BWxH +/- 0.04). Anterior walker usage also led to significantly greater peak internal rotation moments (maximum 1.56 %BWxH +/- 0.13, minimum 1.17 %BWxH +/- 0.03; Tables 18, 19; Figure 19).

Table 16 - Maximum Non-Dominant GH Joint Forces During FRT

	Anterior Walker Force (%BW)			Posterior Walker Force (%BW)		
Trial	X	Y	Z	X	Y	Z
1	8.29	-5.58	-10.41	6.55	-12.34	-9.21
2	8.17	-8.93	-10.94	5.18	-7.46	-7.97
3	8.58	-8.18	-9.29	5.25	-7.19	-10.68
Mean	8.35	-7.56	-10.21	5.66	-9.00	-9.29
SD	0.21	1.76	0.84	0.77	2.90	1.36

Maximum GH forces in anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes reported in % body weight.

Table 17 - Minimum Non-Dominant GH Joint Forces During FRT

	Anterior Walker Force (%BW)			Posterior Walker Force (%BW)		
Trial	X	Y	Z	X	Y	Z
1	4.70	-9.73	-13.85	3.60	-15.35	-15.06
2	5.89	-10.74	-13.73	1.72	-12.14	-16.47
3	6.46	-8.82	-11.71	2.55	-10.60	-18.73
Mean	5.68	-9.76	-13.10	2.62	-12.70	-16.75
SD	0.90	0.96	1.20	0.94	2.42	1.85

Minimum GH forces in anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes reported in % body weight.

Table 18 - Maximum Non-Dominant GH Joint Moments During FRT

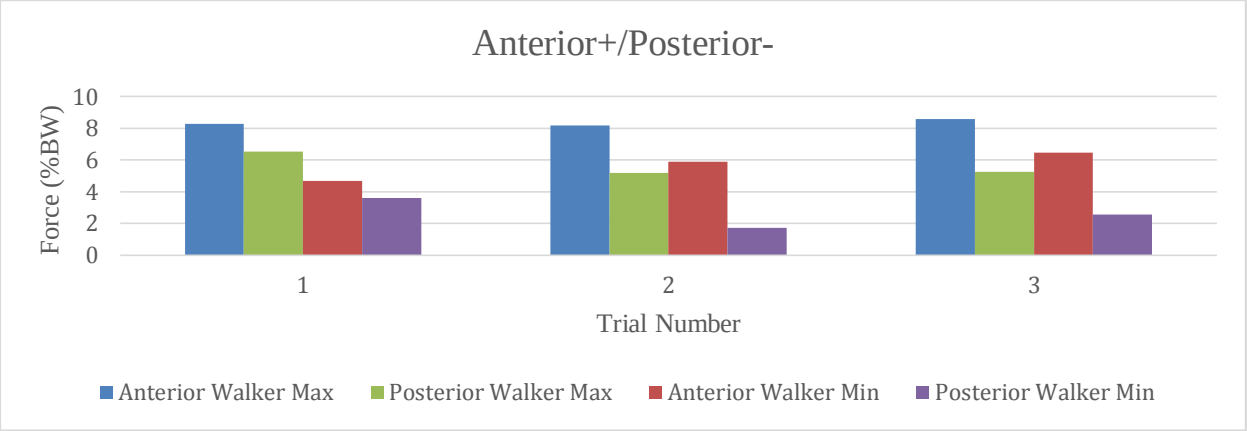
	Anterior Walker Moments (%BWxH)			Posterior Walker Moments (%BWxH)		
Trial	X	Y	Z	X	Y	Z
1	1.70	1.68	0.21	1.59	0.91	-0.39
2	1.61	1.59	-0.10	1.96	1.15	-0.01
3	1.45	1.42	0.01	2.69	1.27	0.40
Mean	1.59	1.56	0.04	2.08	1.11	6.83
SD	0.13	0.13	0.16	0.56	0.18	0.40

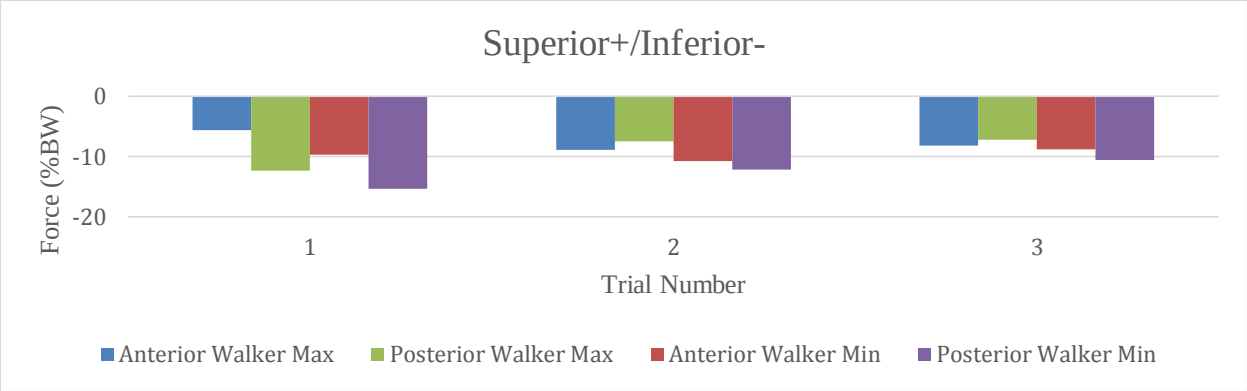
Maximum GH adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) moments, reported in % body weight x height.

Table 19 - Minimum Non-Dominant GH Joint Moments During FRT

	Anterior Walker Moments (%BWxH)			Posterior Walker Moments (%BWxH)		
Trial	X	Y	Z	X	Y	Z
1	1.27	1.21	-0.43	0.94	0.51	-0.77
2	1.23	1.15	-0.56	0.86	0.46	-0.67
3	1.31	1.16	-0.16	1.12	0.64	-0.46
Mean	1.27	1.17	-0.38	0.97	0.54	-0.63
SD	0.04	0.03	0.20	0.13	0.09	0.16

Minimum GH adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) moments, reported in % body weight x height.





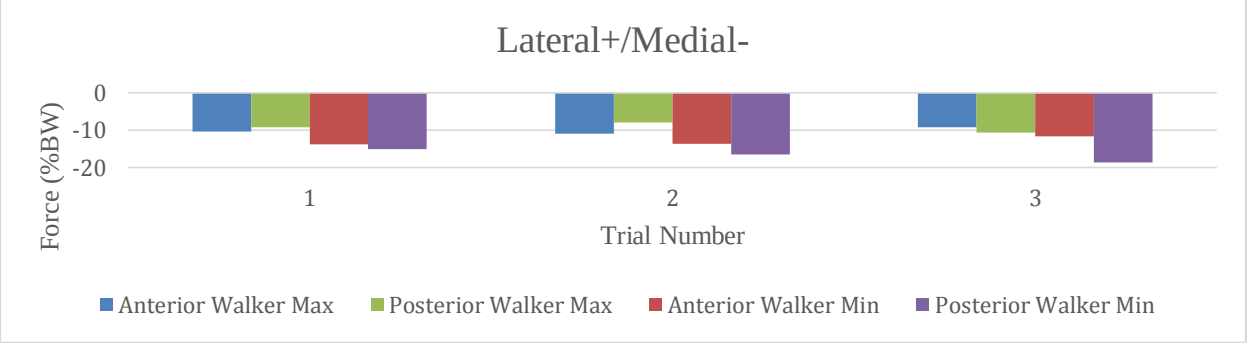
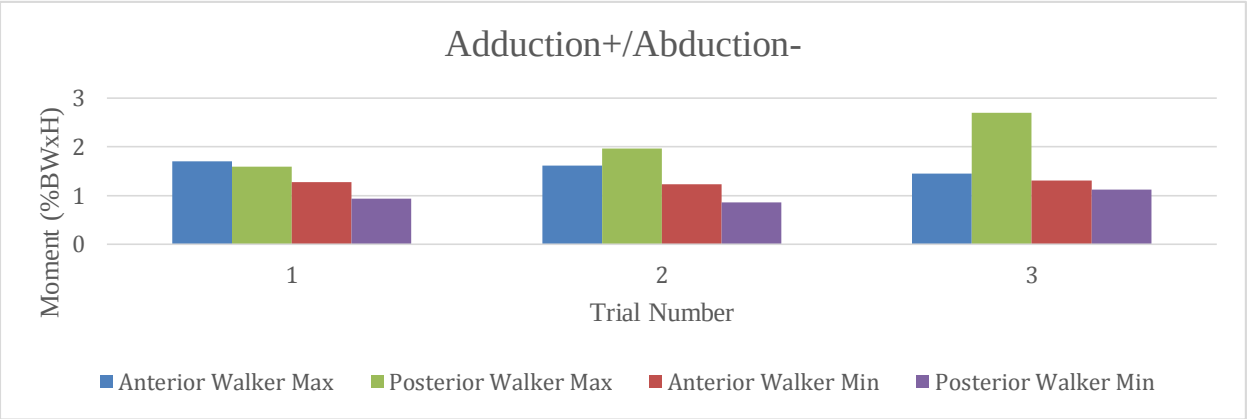
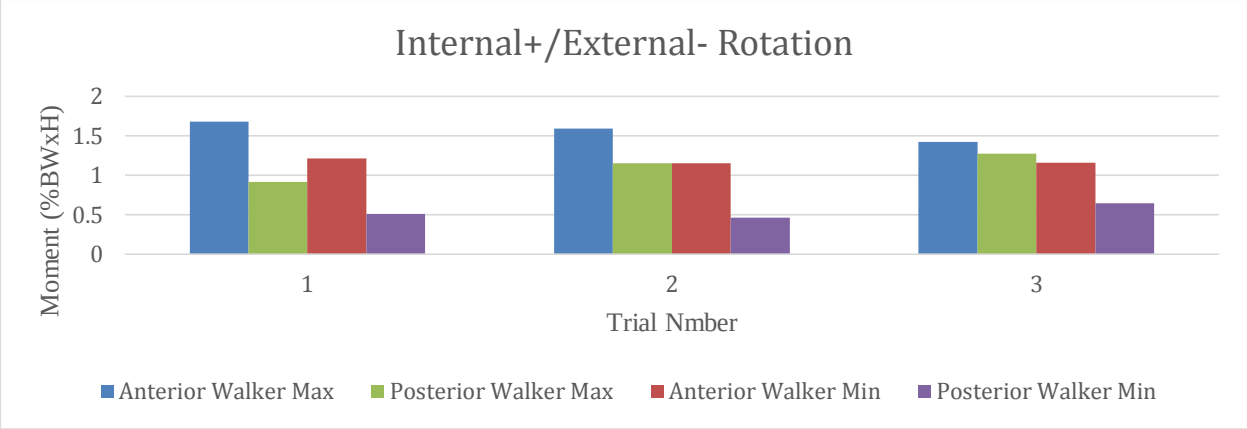


Figure 18. Peak anterior and posterior walker forces in the non-dominant GH joint during FRT, reported in % body weight. Statistically significant p-values = 0.02 (maximum anterior force), 0.02 (minimum anterior force) & 0.05 (maximum medial force).





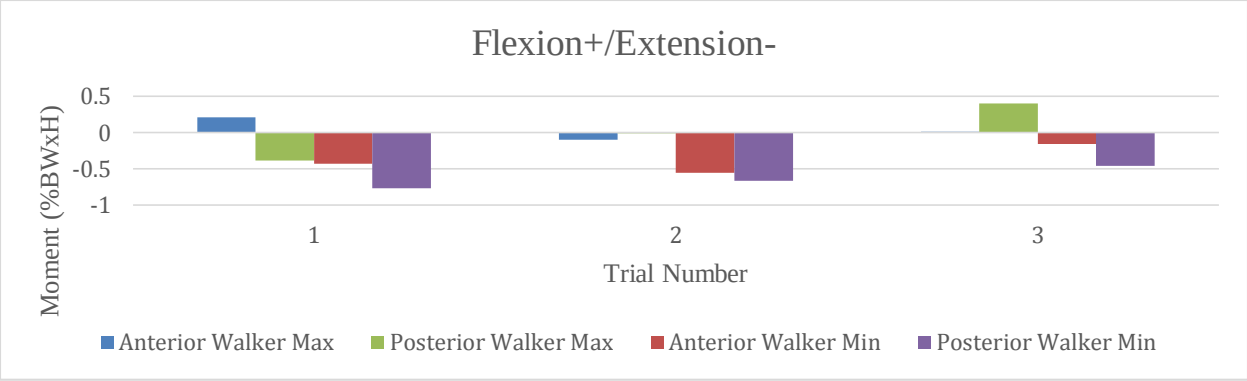


Figure 19. Peak anterior and posterior walker moments in the non-dominant GH joint during FRT, reported in % body weight x height. Statistically significant p-values = 0.05 (minimum adduction moment), 0.03 (maximum internal rotation moment), & 0.004 (minimum internal rotation moment).

Lateral Reach Test. A significantly greater minimum medial force occurred at the non-dominant GH joint when using an anterior walker (11.29 %BW +/- 1.78), as well as almost a significantly greater maximum medial force (p = 0.08; Tables 20, 21; Figure 20). Anterior walker use resulted in significantly greater peak internal rotation moments (maximum 1.70 %BWxH +/- 0.37, minimum 1.51 %BWxH +/- 0.31), whereas posterior walker use led to a significantly greater maximum flexion moment (1.63 %BWxH +/- 0.12), and almost a significantly greater minimum flexion moment (p = 0.07; Tables 22, 23; Figure 21).

Table 20- Maximum Non-Dominant GH Joint Forces During LRT

	Anterior Walker Force (%BW)			Posterior Walker Force (%BW)		
Trial	X	Y	Z	X	Y	Z
1	12.30	-3.05	-11.60	8.43	-2.68	-7.98
2	7.51	-4.33	-9.38	8.63	-2.66	-6.89
3	11.73	-4.60	-12.90	8.26	-5.20	-6.57
Mean	10.51	-3.99	-11.29	8.44	-3.51	-7.15
SD	2.62	0.83	1.78	0.19	1.46	0.74

Maximum GH forces in anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes reported in % body weight.

Table 21 - Minimum Non-Dominant GH Joint Forces During LRT

	Anterior Walker Force (%BW)			Posterior Walker Force (%BW)		
Trial	X	Y	Z	X	Y	Z
1	5.84	-7.54	-13.17	6.88	-4.32	-9.32
2	5.75	-7.67	-9.95	6.72	-4.58	-7.81
3	8.91	-5.71	-14.00	6.20	-6.63	-8.65
Mean	6.83	-6.97	-12.37	6.60	-5.18	-8.59
SD	1.80	1.10	2.14	0.36	1.27	0.76

Minimum GH forces in anterior/posterior (X), superior/inferior (Y), and lateral/medial (Z) axes reported in % body weight.

Table 22 - Maximum Non-Dominant GH Joint Moments During LRT

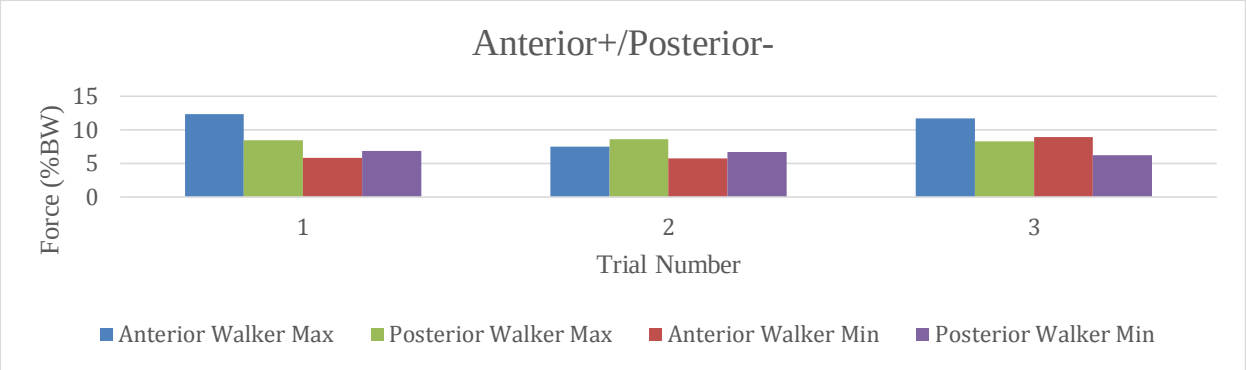
	Anterior Walker Moments (%BWxH)			Posterior Walker Moments (%BWxH)		
Trial	X	Y	Z	X	Y	Z
1	2.27	1.92	1.31	1.93	1.07	1.65
2	2.03	1.27	0.79	1.80	0.80	1.74
3	2.01	1.91	1.04	1.94	0.87	1.50
Mean	2.10	1.70	1.05	1.89	0.91	1.63
SD	0.14	0.37	0.26	0.08	0.14	0.12

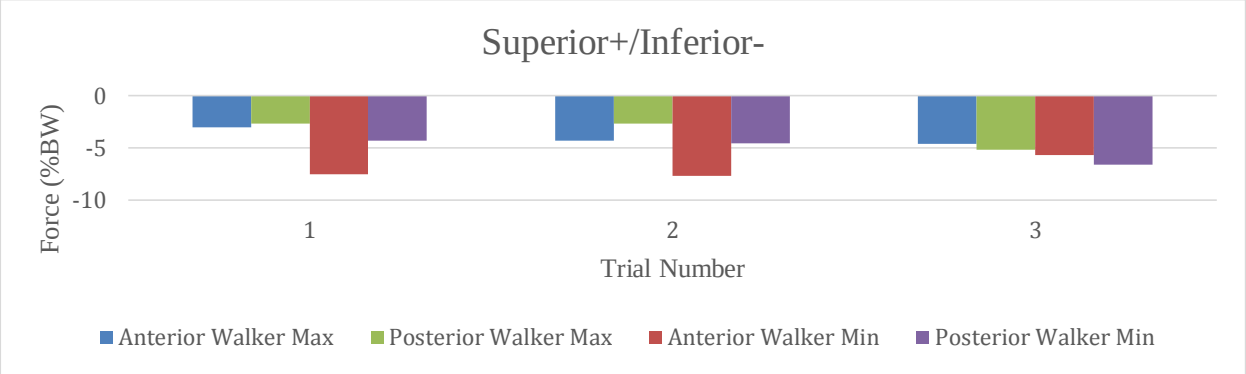
Maximum GH adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) moments, reported in % body weight x height.

Table 23 - Minimum Non-Dominant GH Joint Moments During LRT

	Anterior Walker Moments (%BWxH)			Posterior Walker Moments (%BWxH)		
Trial	X	Y	Z	X	Y	Z
1	1.75	1.63	0.28	1.70	0.80	0.98
2	1.48	1.16	0.14	1.55	0.67	1.07
3	1.74	1.74	0.73	1.48	0.49	0.96
Mean	1.66	1.51	0.38	1.58	0.65	1.00
SD	0.15	0.31	0.31	0.11	0.16	0.06

Minimum GH adduction/abduction (X), internal/external rotation (Y), and flexion/extension (Z) moments, reported in % body weight x height.





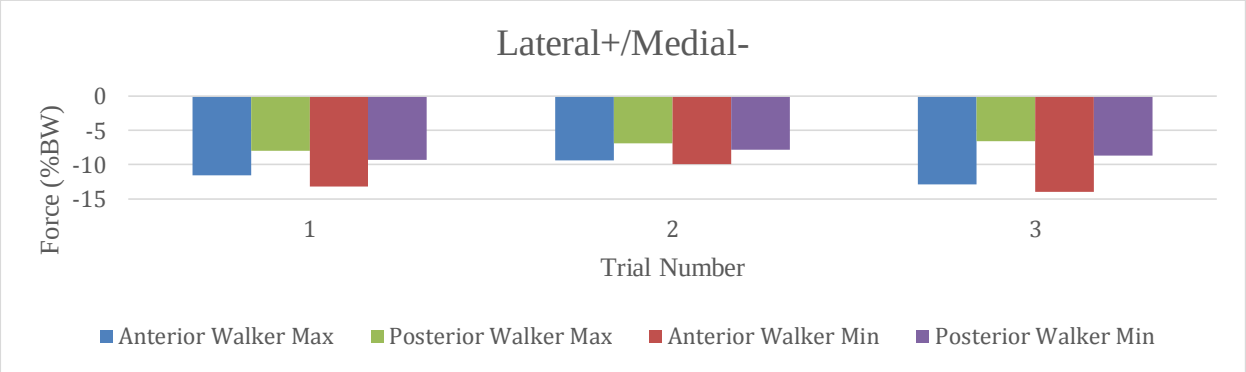
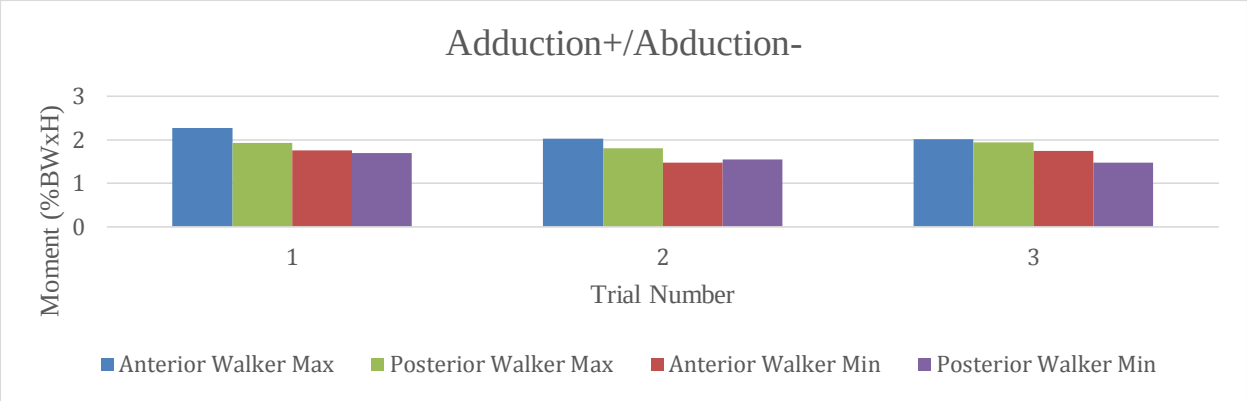
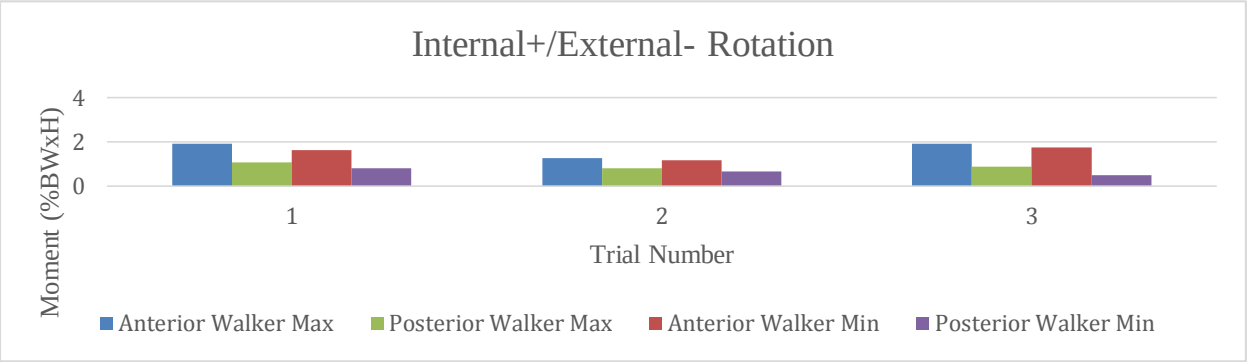


Figure 20. Peak anterior and posterior walker forces in the non-dominant GH joint during LRT, reported in % body weight. Statistically significant p-value = 0.04 (minimum medial force).





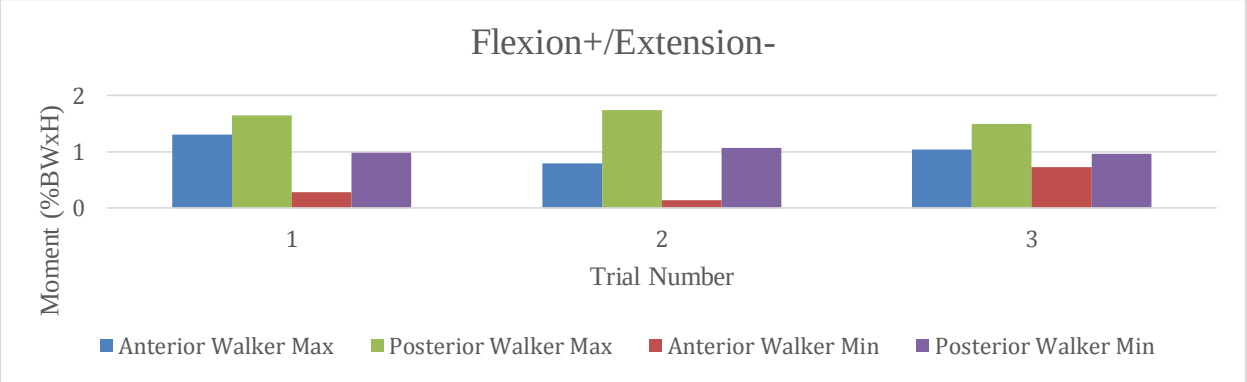


Figure 21. Peak anterior and posterior walker moments in the non-dominant GH joint during LRT, reported in % body weight x height. Statistically significant p-values = 0.05 (maximum internal rotation moment), 0.02 (minimum internal rotation moment), & 0.04 (maximum flexion moment).

4 Discussion

This study presents kinetic data of the glenohumeral joint for one representative subject. A comparison of GH joint kinetic metrics of maximum and minimum joint forces and moments was completed between anterior and posterior walkers of the dominant and non-dominant UEs. For this subject, anterior and posterior walkers each produced significantly greater forces and moments during different tasks. However, anterior walker usage resulted in more instances of significantly higher forces, as well as more instances of significantly greater moments.

While this study shows that a posterior walker would lead to reduced forces and moments for this subject, the kinematic findings from Chapter II also need to be considered before a walker recommendation can be made. For this subject, posterior walker usage resulted in significantly greater peak abduction angles ($p = 0.02$ for both maximum and minimum), a significantly greater minimum external rotation angle ($p = 0.04$), and a significantly smaller extension angle ($p = 0.01$). The larger extension angle when using an anterior walker suggests that the subject's body is very close to the frame during use. When combined with the increased forces and moments that anterior walker usage produces, we can infer that the subject leans over the walker during gait, and relies on her UEs to support her more than when using a posterior walker. During reaching tasks, the subject could reach and average of 9.27 mm further in front of her when using an anterior walker (the combined average of all 10 subjects resulted in a 35.41 mm reaching advantage for anterior walkers). The difference of 9.27 mm is not statistically significant, so that does not need to be considered when making a recommendation. Since this subject owns and uses an anterior walker outside the clinic, postural changes when using a walker should be recommended to the subject in order to reduce the risk of injury. If the subject

has difficulty implementing those changes, a posterior walker should instead be recommended to reduce the chance of developing UE impairments.

The authors of this study chose to investigate differences at the GH joint (as opposed to other joints) due to the large ROM of the GH joint, which is needed to engage in many functional tasks. It is also the most proximal joint of the UE, and any large movements, such as reaching or using a walker, must first begin with motion at the GH joint. The authors chose to specifically investigate the dominant GH joint during gait because it is the preferred side of the subject, and presumed to be the more heavily used. Previous studies have found a consistent pattern of greater strength in the dominant shoulder versus the non-dominant shoulder (Ivey, Calhoun, Rusche, & Bierschenk, 1985). During the reaching tasks of this study, the subject chose to reach with her dominant hand; because of this, one can infer that the subject prefers to do the majority of her unilateral activities using her dominant hand, which warranted investigation in this study.

Even though this was a representative study with only one subject, it proves to be capable of determining significant kinetic differences between the two walker styles. Doctors and therapists should be aware that anterior and posterior walkers can produce significantly different forces and moments in the UEs. Continued work in this field will allow for better understanding of forces and moments during walker use, which may lead to reducing UEs through better walker recommendations.

IV. Conclusions

This study quantifies shoulder kinematics of 10 subjects and presents kinetic data for one representative subject during gait and performance skills. It is the first study to look specifically at comparisons between anterior and posterior walker usage during performance skills. Anterior walkers are not as highly prescribed to children with CP as posterior walkers, but the results from this study suggest anterior walker use leads to improved functionality and engagement in the environment.

Understanding that walker use goes beyond gait is essential to better walker prescription. Because of the significant differences found in this study, it is important to include the effects a walker has on the UEs when prescribing a walker. An occupational therapist should also be included in the walker prescription process, as they can lend their expertise on whether one type of walker would be best for their client in order to interact with their environment. An occupational therapist could also work with the walker user in the event that multiple walkers are needed, such as having an anterior walker for use at home, where more functional activities take place, and a posterior walker for use outside the home in the community, where more mobility and gait take place.

Previous studies have been conducted that make kinetic and kinematic walker comparisons during gait, and the findings from this study drew similar and different results from those studies. Shoulder kinematics were investigated by Strifling et al. (2008), who found that both anterior and posterior walker usage results in shoulder extension and internal rotation. This is partly consistent with this study, which determined posterior walkers led to large peak extension angles (a significantly larger minimum extension angle). However, this study found that peak rotation angles for both walkers varied, as mean maximum angles (25.77 degrees for

anterior walkers, 22.12 degrees for posterior walkers) were in internal rotation, whereas mean minimum angles (-6.23 degrees for anterior walkers, -6.83 degrees for posterior walkers) were in external rotation.

Konop, Strifling, and Harris (2009) examined shoulder moments during gait with anterior and posterior walkers, but found no statistically significant differences. These findings are consistent with this study, which showed no statistical differences between walker styles for moments during gait. However, differences in minimum adduction moments and peak internal rotation moments between walker styles was noted in forward reaching, as well as statistical differences in peak internal rotation moments and maximum flexion moments during lateral reaching.

Konop et al. (2009b) determined that a posterior walker tended to produce greater dynamic ranges of force in the anterior/posterior and medial/lateral directions. This is consistent with the results from this study; however, the subject from this study also demonstrated a greater range in superior/inferior forces as well.

Children who use either an anterior or posterior walker for mobility are prescribed their walker for one of several reasons, which include performance during gait, energy expenditure, personal preference, etc. This study illustrates that there is another factor to consider when assigning walkers to children with CP, and determining how the UEs interact with a walker should be considered. This interaction can greatly vary between anterior and posterior walkers, as the findings of this study show:

Hypothesis 1:

There will be a significant increase in peak shoulder extension angles with a posterior walker during gait.

Findings:

Posterior walkers led to a significantly greater minimum extension angle, but not a significant difference in maximum extension angle.

Hypothesis 2:

During the task of reaching, use of an anterior walker will result in significantly greater joint forces and moments at the GH joint of the upper extremity (UE) holding onto the walker than a posterior walker.

Findings:

Findings varied within the single subject, but overall anterior walker use led to a greater number of forces and moments. During forward and lateral reaching, anterior walker use resulted in three significantly greater forces (peak anterior forces for forward reaching and minimum medial forces for lateral reaching), versus one significantly greater force in posterior walkers (maximum medial force for forward reaching). The ratio was even higher for moments, with anterior walker use leading to five significantly greater moments (minimum adduction and peak internal rotation moments for forward reaching, and peak internal rotation moments for lateral reaching), versus one significantly greater moment in posterior walkers (maximum flexion moment in lateral reaching.

Hypothesis 3:

During the task of reaching, the horizontal distance traveled of the reaching hand will be significantly greater while using an anterior walker versus a posterior walker.

Findings:

Anterior walker use allowed for a significantly further reach during forward reaching, but no significant difference was found during lateral reaching.

Hypothesis 4:

There will be no statistically significant differences in peak forces and moments at the dominant GH joint between walkers during gait.

Findings:

A statistically significant increase in maximum anterior force and maximum inferior force occurred with an anterior walker.

Hypothesis 5:

Completion of the Timed Up and Go Test (TUG) will be significantly faster with an anterior walker than a posterior walker.

Findings:

There was no significant difference in timing between walkers during the TUG. However, anterior walkers resulted in a significantly faster sit-to-stand time, whereas posterior walkers resulted in a significantly faster stand-to-sit time.

These hypotheses were established by watching walker users and by experimenting with the different styles of walkers. The accuracy of the hypotheses varied from very accurate, to not accurate at all. This proves the importance of the experiment, as it shows that conclusive evidence cannot be obtained simply by viewing and by tinkering. By using a motion capture

system and custom model set, this experiment was able to demonstrate the differences in upper extremity joint biomechanics between anterior and posterior walkers.

Limitations and Future Directions:

This study is limited by the number of participants recruited (10 for the kinematics portion, one for kinetics). However, since this study exists to raise awareness to, and determine any angle, force, and moment differences between anterior and posterior walkers, it serves its purpose as the first study of its kind. Future studies should look to include more participants to strengthen the results, which will bring even more focus to UE considerations when choosing a walker. This is especially true when analyzing joint kinetics, as the single subject in this study is not enough to draw significant clinical conclusions in regards to joint forces and moments.

This study was also limited by the variability between the subjects. Both stronger and weaker subjects participated in the study and the results included all 10 subjects regardless of abilities. Future studies should gather more information on each of the subjects and stratify the data into subsets, such as those based on type of CP or strength. This way, better conclusions could be made if there is a difference between the abilities of weaker and stronger subjects. Data collected from the VAS was also limited, as it was only conducted at the beginning of data collection. Further research on pain, as well as oxygen consumption or heart rate, could be beneficial as well to understand the optimal walker for a specific subject.

In addition to continuing research with children with CP, other orthopaedic impairments should also be investigated. This can include children with myelomeningocele (a form of spina bifida), osteogenesis imperfecta, and spinal cord injuries. Myelomeningocele (MM), a form of spina bifida, is a major birth defect of the spine where the spinal cord, meninges, and vertebral

arches develop abnormally and has a prevalence of about 6/10,000 (Liptak & Dosa, 2010). According to the Center for Disease Control, over 1,500 new cases of spina bifida are reported each year in the United States (Center for Disease Control, 2014). Osteogenesis imperfecta, (OI) also known as brittle bone disease, is an inherited bone disorder characterized by fragile bones that can easily break. The incidence rate for OI is 1/30,000 for Type I, 1/60,000 for Type II (which is fatal), 1/70,000 for Type III, and extremely rare for Type IV (National Institute of Health, 2009). Spinal cord injuries (SCIs), unlike CP, MM, and OI, occur due to external factors, such as automobile accidents. Approximately 12,000 new cases of SCI are reported annually in the United States; of those; of those cases, nearly 50% were in patients between the ages of 16 - 30 (National Spinal Cord Injury Statistical Center, 2013). Due to the different body morphology between pathologies, the results from this study or other studies involving children with CP cannot be applied to other pathologies. Future research into different orthopaedic impairments is needed.

Future studies should also be aware of difficulties that can take place with a study of this scope. Proper equipment checks and prompt data verification is essential to the data collecting process. Data analysis requires proper communication between programs, so additional time may be needed to get all systems up and functional. Subject recruitment can also be more time consuming than anticipated, and subject testing can also run long, resulting in tired subjects.

Future studies should continue to explore gait, reaching, and sit-to-stand/stand-to-sit, as these are all essential to many daily activities. However, since these are performance skills, additional research should also be conducted on actual ADLs as well. Occupational therapists operate in the world of daily living skills, and additional research on specific ADLs with walker users could lead to improved treatments plans to help maximize independence for their clients.

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Appendix A: Consent Form

SHRINERS HOSPITALS FOR CHILDREN-CHICAGO

INFORMED CONSENT TO PARTICIPATE IN RESEARCH PROJECT OR STUDY

Participant Name _____ Date: _____

Co-PIs: Gerald Harris, PhD, Peter Smith, MD

Investigators/Key Personnel:, Brooke Slavens, PhD, Sahar Hassani, MS, Adam Graf, MS, Joseph Krzak, PT, Kathryn Reiners

Title of Project or Study: R4 - Advanced Mobility Modeling to Improve Function and Longer Term Transitional Care of Children with Orthopedic Disabilities

If you are the parent/guardian of a minor, when we refer to "you" and "your," we mean either you or your child.

You have been invited to join this research study. Before you agree to join, it is important that you read and understand the following information. It tells how and why the study will be done. It also tells about the good things that could be learned from the study. Possible risks or things that may hurt or be uncomfortable are described and the different kinds of medical treatment that may also help you are explained.

It is important to know that no promises can be made about the results of the study. You can drop out of the study at any time without penalty.

Please ask questions about anything that you do not understand before deciding whether or not to participate.

The National Institute on Disability and Rehabilitation Research (NIDRR) is sponsoring this study through Marquette University. Shriners Hospital for Children – Chicago is one of the performance sites participating in this study.

1. **PURPOSE:**

I agree to the participation of _____ in this research study being conducted by Gerald Harris, PhD, Peter Smith, MD and/or their assistants.

There are 3 groups in this study. The first group includes children up to 21 years of age with cerebral palsy (CP), myelomeningocele (MM), spinal cord injury (SCI), and osteogenesis imperfecta (OI). We want to study how these children are able to move their bodies to get around. This may be with a wheelchair, walker or crutches. We want to understand how they use their arms and upper body to help them move and how we can make it easier for them.

The second group includes children with certain foot conditions who are going to have surgery. We will study their legs and lower body so we can improve the ways we treat them.

The third group consists of typically developing children up to 21 years of age with no orthopaedic disabilities or conditions which would prevent them from using both arms to freely propel a wheelchair.

2. **PROCEDURE:**

The study will be done at Shriners Hospital for Children in Chicago, IL. You will need to be screened by a physician and have his/her approval to participate in this study.

If we are studying your arms and upper body, you will come to the hospital for one visit. You will be asked to do activities that measure your arm strength and look at how you walk or use a wheelchair, crutches or walker. We will do this by having you sit in a special chair that has an arm rest that can measure how hard you push against it. We will also be measuring how you move using a special camera system in our lab. To do this, we will place reflective markers on your body using stickers that go on your shoulders and arms. We will also record your muscle activity by placing small electrodes on the surface of your skin that can "listen" for when your muscles are on or off. These will be taped onto the skin on top of a muscle on your arm or shoulder. You will be wearing shorts and a tank top that we will provide to you. We will also ask you questions about your level of pain, activity and participation in everyday activities using questionnaires

called the Visual Analog Scale (VAS) and the Short Form-12 (SF-12).

If we are studying your legs and lower body, you will come to the hospital for three visits: one before your surgery, one a year after your surgery, and one 2 years after your surgery. The surgery is not part of this study. We are studying the results from your surgery. You will be asked to sign a separate consent for the surgery. At each visit we will ask you to walk in the Motion Analysis Laboratory, take x-rays of your feet while you are standing still or walking, and ask you to fill out the following questionnaires:

- AOFAS midfoot and hindfoot scales
- Child Health Questionnaire (CHQ)
- Foot Function Index-Revised (FFI-Revised)
- Pediatric Outcomes Data Collection Instrument (PODCI).

Also, we will ask your parent or guardian to answer some questions about you.

3. **EXPERIMENTAL PROCEDURES:**

There are no experimental procedures used in this study. We are only gathering and studying information.

4. **RISKS:**

The risks or discomforts that we know about that you might experience as a result of participating in this research study are:

(1) The inconvenience of evaluation and travel.

(2) Time and energy of being tested.

(3) The risk of mechanical malfunction, electric shock from the walkway force plates, force transducers, and gait laboratory walkway hazards (for example, falling).

(4) Not feeling comfortable answering questions.

(5) Falling.

(6) Radiation exposure from x-rays.

What we do to keep you safe:

(1) All evaluations or tests performed are entirely non-invasive and performed by trained professionals.

(2) You will have contact with low voltage devices and biomedically approved instruments only.

(3) Routine electrical safety inspection.

(4) We will try to make sure that you are comfortable during testing.

(5) Mechanical design of measurement systems and examinations to provide comfort, to prevent tripping and/or loss of balance.

(6) Staff supervision.

(7) A psychologist at our hospital is available to consult with you.

(8) You do not have to answer any question that makes you feel uncomfortable.

(9) A trained radiologist will perform all x-rays and ensure that radiation exposure is kept to a minimum and be within the established standards.

If you are pregnant, it is possible that the x-ray radiation could pose risks to your unborn child and you cannot participate if you are in the leg/lower body group. If you are pregnant or if it is possible that you are pregnant, it is important that you tell one of the investigators immediately.

Since this is a research study, there may be additional risks or side effects that we do not know about at this time, but which might occur during the study or later.

5. **DURATION:**

If you are in the arm/upper body group, you will be in this study for one day. If you are in the leg/lower body group, you will be in this study for about two years.

6. **ALTERNATIVES:**

You can choose not to participate in this study.

7. **BENEFITS:**

No promises are being made that you personally will benefit from this study, but you and other patients may benefit later from what we learn.

8. **CONFIDENTIALITY/HIPAA PRIVACY**

Your participation in this study and your medical records will be kept confidential in accordance with applicable state and federal laws. No information identifying you will be released without your permission unless it is subject to a subpoena or court order.

Your information will be combined with information from other people taking part in the study. A statistical report of this research project or study, which may include slides or photographs that do not identify you (your head and face will be excluded) may be printed in a scientific paper or presented at a professional meeting.

Participants in this study will not be identified by name. Confidentiality in all record keeping will be maintained by assigning a unique number to each study participant. All data will be stored in a locked office in the research department and will only be accessible to research personnel.

Authorization to Use and Disclose Protected Health Information for Research Purposes

The privacy law, Health Insurance Portability & Accountability Act (HIPAA), protects your individually identifiable health information (*protected health information). The privacy law requires you to sign an authorization (or agreement) in order for researchers to be able to use or disclose your protected health information for research purposes for this study.

You authorize investigators for this study and their research staff to use and disclose your protected health information for the purposes described below. You also permit your doctors and other health care providers to disclose your protected health information for the purposes described below.

Your protected health information* that may be used and disclosed includes:

Age (birth date), height, weight, clinical history (including: full diagnosis, date of injury and/or diagnosis, time of assistive device use, information regarding assistive device training) initials, whole body pictures, body composition, motion (arm and leg movement) data including joint angles and forces, physical exam measures including range of motion and strength, and outcome/psychological questionnaires results.

Your protected health information will be used for:

Helping to improve the technology used to assess the functional ability of children with orthopedic disabilities. This will be done by improving the mathematical models used to evaluate the motion of the upper extremities (arms) using assistive devices and the lower extremities while walking. We will establish the relationship among joint forces, pathology, assistive device, function, and pain.

The data that does not have your name or any information that could identify you will be stored in a password protected electronic database. The clinical investigator, patient physicians, study coordinator and researchers, physical therapists, and motion lab staff will have access to the collected data, both locally and through secured remote desktop access.

The Researchers may use and share your health information with the following, but they are all required to keep your records confidential:

- The Institutional Review Board at RUSH University Medical Center
- Shriners Hospitals for Children – Chicago
- Medical College of Wisconsin
- Orthopaedic Rehabilitation and Engineering Center (OREC)
- University of Wisconsin – Milwaukee
- RUSH Medical Center
- Government representatives, when required by law
- Hospital representatives if applicable

The researchers agree to protect your health information by using and disclosing it only as permitted by you in this Authorization and as directed by state and federal law.

Some of these people may share your health information with someone else. If they do, the same laws that this hospital must obey may not protect your health information.

You do not have to sign this Authorization. If you decide not to sign the Authorization:

- You will not be allowed to participate in the research study.

After signing the Authorization, you can change your mind and:

- Not let the researchers disclose or use your protected health information (revoke the Authorization).
- If you revoke the Authorization, you must send a written letter to: Peter Smith, MD, Shriners Hospitals for Children-Chicago, 2211 North Oak Park Ave, Chicago, IL 60707 to inform him of your decision.
- If you revoke this Authorization, researchers may only use and disclose the protected health information **already** collected for this research study.
- If you revoke this Authorization, your protected health information may still be used and disclosed should you have an adverse event (a bad effect).
- If you change your mind and withdraw the authorization, you may not be allowed to continue to participate in the study.

You will not be allowed to review the information collected for the research until after the study is completed. When the study is over, you will have the right to access the information.

If you have not already received a copy of the Privacy Notice, you may request one. If you have any questions or concerns about your privacy rights, you should contact

the Privacy Manager at Shriners Hospitals for Children-Chicago, Delphine Brown, at 773-385-5489.

9. **QUESTIONS:**

If you have any questions, please ask us. If you have any questions later, please call Dr. Gerald Harris at 773-385-5457.

You can contact Arlette Grubbe at 773-385-5449 for answers to questions you might have about research and about your rights as a research participant.

In the event of an undesirable reaction or research-related injury, please call Peter Smith, MD at 773-622-5400.

10. **COMPENSATION:**

For each visit in this study that you complete, Marquette University will mail you a check to your home in the amount of $50.

Any physical injuries or adverse reactions arising from participation in the research project can be treated either by providing those medical services that are customarily available at the Shriners Hospitals for Children or by a combination of medical services

at the Shriners Hospitals for Children and any other hospital you choose. To the extent the Shriners Hospitals for Children provides medical services at its facility, those will be at no cost, while the cost at the other hospital will be based on your personal insurance coverage. Shriners Hospitals for Children has no program for financial compensation or other forms of compensation for any injury or undesirable reaction which you may experience as a result of participating in this study. By signing this form, you are not giving up any legal rights that you may have.

11. **WITHDRAWAL FROM THE STUDY:**

Your participation in this research study is voluntary. If you decide not to participate, there will be no penalty and you will not lose any benefits you would otherwise receive. If you change your mind after you volunteer for this study, you may withdraw from this study and stop participating at any time without penalty or loss of benefits you would otherwise receive. If you currently receive treatment you will continue to receive your usual care at Shriners Hospitals for Children-Chicago.

There are no consequences if you decide to withdraw from this research study.

If you wish to withdraw from this study, please contact Dr. Gerald Harris at 773-385-5457.

12. **COMMERCIAL PRODUCTS:**

Information and data gathered during this study may be used for research and development purposes. You will not have any property rights or ownership interest in products or data which may result from your participation in this study.

13. **GENERAL INFORMATION:**

If the investigator feels that this study is not appropriate for you or that you have not followed directions, you will be dropped from the study.

You will be advised if significant information is developed during the course of this research that may affect your willingness to continue to participate.

There will be 240 participants involved in this study.

Your signature, below, will indicate that you have decided to volunteer as a research participant, that you have had an opportunity to ask questions and all of your questions have been answered, and that you have read and understood the information provided above. You will be given a signed copy of this informed consent form which is yours to keep. This Authorization does not have an expiration date.

_____	_____	_____	_____
Signature of Witness	Date	Signature of Participant	Date
_____	_____	_____	_____
Signature of Witness	Date	Signature of Parent/Legal Guardian	Date
_____	_____	_____	_____
Signature of Witness	Date	Signature of Parent/Legal Guardian	Date

(Signature of both parents should be obtained where possible and signature of patient should be requested if 14 years of age or over).

.....

.....

Using language that is understandable and appropriate, I have discussed this project and the items listed above with the participant.

_____ _____

Signature of Principal Investigator or Co-Investigator Date

The undersigned interpreted, to the best of my ability, the informed consent discussion between the investigator and the patient and/or the patient's parent(s) or legal guardian(s).

_____ _____

Signature of Interpreter Date

_____ _____

Printed Name Title

Appendix B: Assent Form

Shriners Hospitals for Children-Chicago
Assent Form
(For Children Ages 7-13)

Study Title:

R4 - Advanced Mobility Modeling to Improve Function and Longer Term Transitional Care of Children with Orthopedic Disabilities

Who we are and why are we meeting with you?

Our names are Drs. Peter Smith and Gerald Harris. We work at Shriners Hospitals for Children-Chicago. Our research associates and I want to tell you about a research study that involves children like yourself. We want to see if you would like to participate in this research study.

Why are we doing this study?

This study is to learn more about how children with cerebral palsy (CP), myelomeningocele (MM), spinal cord injury (SCI), and osteogenesis imperfecta (OI) are able to move their bodies to get around. This may be with a wheelchair, walker or crutches. We want to understand how you use your arms and body to help you move and how we can make it easier for you.

We also want to study the legs and lower body of children with certain foot conditions so we can improve the ways we treat them.

What will happen to you if you are in the study?

The study will take place at the Shriners Hospitals for Children-Chicago.

If we are studying your arms and upper body, you will come to the hospital for one visit. You will be asked to do activities that measure your arm strength and look at how you walk or use a wheelchair, crutches or walker. We will do this by having you sit in a special chair that has an arm rest that can measure how hard you push against it. We will also be measuring the way you move by using special cameras in our lab. To do this we will place reflective (shiny) markers on your body using stickers that go on your shoulders and arms. We will also place some small "muscle microphones" on your skin that tell us when your muscles are on or off. These microphones will also be placed on your arms and shoulders using tape. You will be wearing shorts and a tank top that we will provide to you. We will also ask you questions about your level of pain, activity and participation in everyday activities using questionnaires.

If we are studying your legs and lower body, you will come to the hospital for three visits: one before your surgery, one a year after your surgery, and one 2 years after your surgery. At each visit we will take x-rays of your feet while you are standing still or walking and ask you to fill out questionnaires.

Also, we will ask your parent or guardian to answer some questions about you.

Will any part of the study hurt?

No part of this study should hurt. You may get tired during testing, but you can rest. A staff person will help you if you are not feeling well.

Who will know that you are in the study?

There are only a few people that will know you are in the study. Including us, they are people helping with the study who are researchers at the hospital.

Do you have to be in this study?

No, you don't. We hope this study will help us do a better job in taking care of children who come to the hospital. You don't have to participate, and no one will get angry or upset if you don't want to be in the study. And remember, you can change your mind later if you decide you don't want to be in the study anymore.

Do you have any questions?

You can ask questions any time. You can ask now or later. You can talk to any one of us at the hospital. Here are our phone numbers:

Peter Smith, MD, Principle Investigator (773) 622-5400

Sahar Hassani, MS, Co-Investigator (773) 622-5400

Gerald Harris, PhD, PE Co-Investigator (773) 622-5400

_____ _____

Sign Your Name Date

_____ _____

Principal Investigator/Co-Investigator Date

_____ _____

Translator Date

Appendix C: Walker Protocol

SETUP PROCEDURES (before subject arrives)

In Nexus, ALL the amplifier settings (gains and excitation voltages) have to be the SAME.

____ 1. Open amplifiers 5 & 6 and set **ALL** the jumpers to the gains and excitation voltages given below:

	Right (Amp 5)				Left (Amp 6)		
	Gain	**Excitation Volt.**	**Check**		**Gain**	**Excitation Volt.**	**Check**
Fx	4000	10		Fx	4000	10	
Fy	4000	10		Fy	4000	10	
Fz	4000	10		Fz	4000	10	
Mx	4000	10		Mx	4000	10	
My	4000	10		My	4000	10	
Mz	4000	10		Mz	4000	10	

Note: Nexus requires that all the gains and excitation voltages be set to the same value for each individual load cell. Differentiations can NOT be made between individual load cell channels.

____ 2. Close the amplifiers.

____ 3. Connect the transducers to the amplifiers as shown below.

Sensor	Amplifier #	Description	Check
Right Handle	5	Connect analog output cord #3 (from FP3) to Amp #5	
Left Handle	6	Connect analog output cord #4 (from FP4) to Amp #6	

____ 4. Turn on the Vicon system and amplifiers and allow the transducers to **warm up for at least 1 hour**.

____ 5. Create new session in VICON Nexus Data Management under appropriate folder structure

____ 6. Select the appropriate System Set-up

a. In the Resource Pane, in the System tab's pull down menu: choose Walker Testing
b. Check that all cameras appear green in the Vicon Cameras list and make sure both walker load cells appear in the force plates list.
c. Check the correction factor for each walker load cell. The calculation follows:
    1. Correction Factor = (1,000,000) / (Amplifier Gain * Excitation Voltage)
    2. For the above recommended settings (G = 4000 and E = 10) the Correction Factor will be equal to 25.

____ 7. Set up the walker for the subject's usual walker type

a. Anterior walker goes in front of subject. Wheels are at the front.

b. Posterior walker goes in back of subject. Wheels are at front.
c. Right handle is M3660/Amp 5; Left handle is M3661/Amp 6 for both walker types. **Wheels may need to be switched.**
d. Make sure handles are straight vertically and horizontally.

____ 8. Set up *14 mm* markers and tape for the subject.

____ 9. Get out calipers, tape measure, and goniometer.

____ 10. Calibrate the VICON cameras.

____ 11. Set up video camera (and sync up camera with Vicon system).

____ 12. Set up camera for pictures.

After an hour

____ 13. Hardware Zeroing:

a) While the walker remains untouched in the center of the capture volume, zero the force transducers by pressing and holding the zero button on each amplifier for a couple seconds.
b) If you have the analog graph for a load cell visible in Nexus as you do this, you should see the signal shift to zero for each load cell channel.

____ 14. Software Zeroing:

a) In the Resource Pane, under the System tab, expand the force plate list so that both load cells are listed.
b) Right click on one of the listed load cells and choose “zero level”.
c) Do this for each of the walker load cells listed.

_____15. Collect a 3 sec trial while the walker remains untouched and check for zero line on all of the analog channels for both the transducers.

_____ 15a. If there is no consistency or the baseline is not zeroed, repeat steps 13-15.

_____16. Check for Drift in the load cell signals

_____16a. **BEFORE** trials begin ff you see values greater than 4.5N in Fz AND/OR 310Nmm in Mx, re-zeroing is needed following steps 13-15.

_____16b. **AFTER** trials have begun, if drift is noticed greater than 9.0N in Fz AND/OR 620Nmm in Mx, STOP testing and re-zero the walker following steps 13-15.

NOTE: The calibration matrices and correction factors should be saved in the “Walker Testing” System Set-up and do not need to be altered unless the amplifier jumpers are changed from the settings in Step 1.

SET-UP PROCEDURES (once subject arrives)

____ 1. Make sure the informed consent/assent forms have been read, explained, and signed

   a. Explain all procedures performed to patient and/or parent
   b. Explain that all procedures are for investigational purposes
   c. Option of withdrawing from study is always open
   d. Answer any questions
   e. Sign consent/assent forms, including medical photography

____ 2. Have subject change into appropriate clothes (e.g. tank top and shorts)

____ 3. **Remove** subject's shoes and orthotics

____ 4. Take subject measurements (See the Subject Information Form)

____ 5. Place **14 mm** markers on subject (See the Subject Information Form)

____ 6. Adjust walker handles to reach subject's ulnar/styloid process with arms resting at their sides. Make sure handles are **straight vertically and horizontally**.

____ 7. Take still pictures of the subject with upper extremity markers

   a. Front view
   b. Back view
   c. Right and left side view

TEST PROCEDURES (during motion analysis)

Static & Dynamic Gait

____ 1. Collect baseline trials (at least 3 seconds)

   a. Preferred Walker only—**verify analog data collected**. Data should be at or near zero.
   b. Subject with walker and KADs, for LE processing

____ 2. Collect at least 5 good walking trials

____ 3. Check after every trial for marker dropout in the upper extremity. If there are more than 15 frames of dropout recollect trial.

____ 4. Check each of the transducers force and moment analog channels to verify data was collected.

____ 5. Verify at least 3 trials meet requirements 3 and 4.

____ 6. Take video and pictures of the upper extremities and the walkers during the session.

____ 7. Switch walker position to non-preferred configuration (anterior vs posterior). Repeat steps 2-6.

Functional & Lateral Reach Tests

____ 1. With walker in preferred position, have subject stand with both hands on handles.

____ 2. Have subject flex shoulder of dominant arm to 90-degrees flexion (or as close to 90-degrees as they can). Forearm can be in neutral position or in pronation with fingers extended.

____ 3. Instructor holds their hand in front of subject's outstretched arm, but out of reach. Give instructions "reach as far forward as you can and try to touch my hand without taking a step or moving the walker, and hold for three seconds. You won't actually touch my hand, just reach towards it. You are allowed to bend as much as needed." Record five trials of Functional Reach Test (FRT).

____ 4. Repeat step 2, but subject will abduct their dominant shoulder to 90-degrees, or as close to 90-degrees as they can instead of flex. Forearm can be in neutral position or in pronation with fingers extended.

____ 5. Give instructions "reach as far to the side as you can and try to touch my hand without taking a step or moving the walker, and hold for three seconds. You won't actually touch

my hand, just reach towards it. You are allowed to bend your body as much as needed." Record five trials of Lateral Reach Test (LRT).

____ 6. Switch walker to non-preferred configuration and allow one minute of acclimation. Then repeat steps 2-5.

Timed Up & Go (TUG) Test

____ 1. Place a chair or bench in center of the room. Measure 3 meters from the front of the seat and place a 3-dimensional object (cone, book, etc.) on the floor at that spot.

____ 2. Have subject sit on the seat with their preferred walker in front of them (or wherever subject normally places walker so it is ready to help them stand up).

____ 3. Give instructions "Please get up on the word go, stand upright within your walker and walk as quickly and safely as possible to the marker on the floor, turn around the object, return to the chair, and sit down".

____ 4. Record 5 trials of TUG with preferred walker.

____ 5. Switch walker to non-preferred configuration and give subject 3 practice attempts using it to help them sit-to-stand and stand-to-sit.

____ 6. Repeat steps 2-4.

POST TEST PROCEDURES (after motion analysis)

____ 1. Remove markers

____ 2. Administer necessary outcome tools (VAS and SF12).

____ 3. Scan/post all session data to ftp.orec.org**.**

Including:

a. Subject forms
b. Subject measurements
c. Vicon files, unprocessed and processed
d. Outcomes forms
e. Outcomes processed results
f. Subject photos
g. Subject videos

____ 4. Notify UWM, Brooke, Alyssa and Chris, when data is posted to the FTP site.