Abstracts of the 26th Annual Meeting of the Gait & Clinical Movement Analysis Society

June 7-9, 2021

https://gcmas2021.org
# Schedule

[https://gcmas2021.org/program/](https://gcmas2021.org/program/)

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We’d like to thank all our sponsors and exhibitors for their contributions to GCMAS2021. Without them, this conference would not have been possible.
Welcome!

Greetings GCMAS Members and Supporters! With the COVID 19 pandemic it’s been a challenging year. Keeping our patients, students, and staffs safe has meant that business has not gone on as usual. Due to lockdowns across the country and the world, GCMAS2020, originally planned to be held at West Chester University, was canceled. Although we briefly entertained the notion of trying to go online, perhaps later in the year, there was a great deal of uncertainty about whether we should just push the conference back and if an online conference would be worthwhile or not. It was not unlike the uncertainty one may have felt while riding the mechanical bull during the 2019 GCMAS banquet (Figure 1). Since then, most conferences have gone online with varying degrees of success, and in the depths of winter as we were looking ahead to this year, it was not at all certain that vaccinations would be as available as they are now, at least in the US. So we decided that this year would be online, and next year would usher in a return to normal for our annual meeting.

Many of us were impacted in our abilities to continue to do our research. The challenges were unprecedented. Those of us in the teaching world found our responsibilities multiplied whilst our labs were simultaneously shut down leaving us to do retrospective research. Some labs were allowed to continue to operate on a reduced basis, but despite all this, a number of fine abstracts were submitted this year. Two papers in this year’s meeting directly address the impact of COVID on physical activity in American youth. We have also allowed authors of ten of the top papers from last year to present their work to spotlight their contributions to the field.

The conference presentations this year will span two days, with a bit extra happening on Monday night for the students. Rather than starting the conference with keynotes, we have opted to have these in the afternoon so as to be able to give our west-coast members a chance to wake up. Similarly, our breakfast sessions don’t start until 9am EDT. All times are

GCMAS2021 - Tuesday, June 8, 2021 – 8.45-9.00am
EDT (Eastern Daylight Time) which is UTC-4 hours. We will reflect this as best as possible from the schedule.

We have two Zoom rooms active this year, one in webinar format for the podiums, tutorials, and keynotes, and the other in meeting format for posters and casual meetings. Zoom rooms will be accessible from the meeting website (gcmas2021.org), and are best accessed by laptop or computer. Given the content, while cell phones and smaller devices may be used, it was difficult to optimize the presentations so your results may be unpredictable. While the posters are not being presented, you are welcome to enter the second Zoom room with colleagues, ask to be assigned to a breakout room, and then chat away to do your networking as needed. All podium sessions in Zoom Room 1 are being recorded, and registered conference attendees will have access to these recordings over the next year.

In lieu of our banquet and welcome social, we have invited a comedy improv group to entertain those who wish to remain on Tuesday night. The group “Better Than Bacon” plays in the Southeastern Pennsylvania area at local arts centers, and over the pandemic, has been performing live via Zoom. We hope that you will grab your favorite drink, kick back and enjoy the show!

Despite the format, we are excited about the conference, and we are looking forward to seeing everyone online on June 7-9*.

All the best,
Tim Niiler
GCMAS2021 Conference Chair

*June 7th is for the student social only  
** Figure 2 is a snap of your conference chair before the controller shut the bull down so that he didn’t fly off.
Student Mixer

Date/Time: Monday, June 7: 6-7pm (UTC-4)
Login via https://gcmas2021.org and go to the “Meeting Rooms”

This year's student event will be a presentation/Q&A with Dr. Kristen Nicholson from Wake Forest.

(Dr. Kristen Nicholson - Biomechanist - Baseball Support Staff - Wake Forest University Athletics, Kristen Faith Nicholson | Wake Forest School of Medicine).

She will be talking a little bit about a few topics, including how to make connections at conferences, how to build a career, and how she balances work and her personal life. We would like to keep this pretty open-ended, and are hoping for a nice discussion/Q&A session following a short presentation. If you have any questions you would like to have her answer, feel free to submit them using this Google form, or you will be able to ask them live.
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*Papers so marked were “best of 2020” conference and had not been presented live*

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1. **Step Activity in Persons with Chronic Stroke**  
   Darcy Reisman

**Tutorial 1**

2. **Gait and Functional Outcomes of Adults with Cerebral Palsy**  
   M Wade Shrader, Nancy Lennon, Chris Church, Freeman Miller, John Henley, Faithe Kalisperis

**Poster Session 1**

4. **Kinetic and kinematic repercussion of the hip during knee hyperextension gait in hemiplegic cerebral palsy**  
   Lauro Machado Neto, Guilherme Auler Brodt, Carolina Panizzon Santini

5. **Split tendon transfer of the posterior tibialis for spastic equinovarus foot deformity: does tendon routing impact post-operative ankle kinematics?**  
   Frances Scheepers, Tim Bhatnagar, Karen Davies, Diane Wickenheiser, Alec Black, Christine Alvarez, Kishore Mulpuri, Lise Leveille

7. **Gait Profile Score of Children with Cerebral Palsy Can Differ Based on Normative Data from Different Institutions**  
   Justine Borchard, Wilshaw Stevens, Kelly Jeans, Kirsten Tulchin-Francis, Lane Wimberly

9. **Effect of Split Posterior Tibialis Tendon Transfer on Foot Progression Angles in Children with Cerebral Palsy**  
   Austin Skinner, Alex Tagawa, Wade Coomer, Jason Koerner, Lori Silveira, Sayan De, Jason Rhodes

11. **Perioperative management of a case of lower extremity torsional abnormalities undergoing derotational osteotomies**  
    Marianne Gagnon, Louis-Nicolas Veilleux, Mitchell Bernstein

13. **Impact of the COVID-19 Pandemic on Walking Activity in Individuals with Cerebral Palsy**  
    Eva Ciccodicola, Henry Lopez, Adriana Conrad-Forrest, Tishya Wren

15. **Kinematics evaluation of a 3d printed prosthetic hand**  
    Ivett Quinones-Uriostegui, Virginia Bueyes-Roiz, Jose Luis Zavaleta-Ruiz, Gerardo Rodriguez-Reyes

17. **1-segment to 2-segment foot model with one marker**  
    Kyle P. Chadwick, Susan A. Rethlefsen, Alison M. Hanson, Tishya A. L. Wren

19. **2-segment foot model: refining evaluation of club feet**  
    Alison Hanson, Susan Rethlefsen, Kyle Chadwick, Tishya Wren

21. **Effect of initial foot position on postural responses to lateral perturbations during standing in younger and older adults**  
    Woohyoung Jeon, Lisa Griffin, Megan Bell, Hao-Yuan Hsiao

23. **Impact of tendon transfers on shoulder motion in children with brachial plexus injuries**  
    Ross Chafetz, Stephanie Russo, Ross Chafetz, Spencer Warshauer, James Richards, Jamie Landgarten, Dan Zlotolow, Kozin Scott

25. **A Simple Neural Reward Circuit May Motivate Human Gait Development and Even Explain Cerebral Palsy Gaits**  
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35 Data Collection Settings Influence Spatiotemporal Walking Parameters: Effects of Walking Speed and Participant Sex
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37 Comparing the reliability of assessments of anterior cruciate ligament (ACL) pathology
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Breakfast Session 1

Step Activity in Persons with Chronic Stroke

Date/Time: Tuesday, June 8: 9-10am EDT (UTC-4)

Presenter:

- Darcy Reisman, Ph.D. - University of Delaware

Objectives:

1. The learner will describe the latest updates in potential treatments for improving walking activity after stroke
2. The learner will identify factors that impact walking activity after stroke
3. The learner will identify primary and secondary outcomes that reflect walking activity recovery after stroke

Description:

As a group, stroke survivors are more physically inactive than even the most sedentary older adults. Lack of physical activity has serious consequences in persons with stroke, including an increased risk of recurrent stroke, developing other diseases and mortality. Current rehabilitation interventions do little to improve real-world walking activity after stroke, suggesting that simply improving walking capacity is not sufficient for improving daily physical activity after stroke. Recent meta-analyses suggest that there are multiple factors influencing walking activity after stroke that likely need to be addressed to improve real-world walking in this population. This talk will review the latest evidence on factors influencing walking activity after stroke and potential interventions to address these factors.
Gait and Functional Outcomes of Adults with Cerebral Palsy

M. Wade Shrader, MD, Chris Church, MPT, Nancy Lennon, MS, PT, DPT Faith Kalisperis, MPT, John Henley, PhD, and Freeman Miller, MD

Purpose: Advances in pediatric orthopedic care over the past three decades have improved mobility, function, and quality of life for children and youth with cerebral palsy (CP). The long-term effectiveness of this care into adulthood has not been widely reported. Some studies demonstrate gait outcomes in young adults with cerebral palsy (CP) that show walking mechanics are largely unchanged from adolescence, but the relationship of gait outcomes to participation and pain in adulthood is unknown. Walking with persistent gait deviations increases energy cost, produces fatigue, and may lead to joint pain and degenerative joint disease in the long-term.

The purpose of this course is to review the relevant literature of gait and functional outcomes of adults with cerebral palsy, to discuss the difficulties and challenges of long-term follow-up studies in this population, and to describe in detail a recent investigation that measures long-term outcomes of outcomes of physical function, mental well-being, participation and pain in a cohort of adults with CP who received specialized pediatric orthopedic care as children and adolescents.

Course Format:
Introduction, Overview of Course Objectives:
M. Wade Shrader, M.D. (5 minutes)

Review of Previous Literature of Gait and Functional Outcomes of Adults with CP:
Faith Kalisperis, M.P.T. (15 minutes)
- Long-term gait follow-up studies
- Longitudinal assessment of function in adults with CP
- Identification of current gaps of knowledge

Design of a Call-Back Study: Who do our pediatric patients grow up to be?:
John Henley, Ph.D. (10 min)
- Purpose and need for long-term follow up study
- Study design
- Logistics of adult patient follow-up, contacting, and recruitment

Gait and Functional Outcomes of 130 adults with CP followed for 13 years
Chris Church, M.P.T. (15 min)
- Discussion of Methods and Subjects
- Adult kinematics and kinetics compared to adolescence
- Can we predict in adolescence who will decline in function as adults?

Pain in Adults with Cerebral Palsy: Review of the Literature and Results of our Call-Back Study
M. Wade Shrader, M.D. (10 min)
- Review of current literature of adults with CP
- Does high quality pediatric orthopedic care impact the prevalence of pain in adults with CP?

Functional Outcomes: Patient Reported Quality of Life and Activity
Nancy Lennon, M.S., P.T. (15 min)
PROMIS patient reported outcomes of pain, participation, and life-satisfaction
Community activity monitoring
Implications for further study

**Case Examples of Expected Adult Outcomes**
Freeman Miller, M.D. (20 min)
Interactive case review

**Question & Answer and Discussion Panel**: All speakers (30 minutes)

**Target Audience**: Physicians, Occupational and Physical Therapists, Engineers

**Prerequisite Knowledge**: Basic knowledge of quantitative gait analysis and pathophysiology of cerebral palsy

**Learning Objective**: After completion of this course, participants will be able to explain the current level of evidence of long-term outcomes of gait and physical function and their correlations with patient reported outcomes of mental well-being, participation, and pain in adults in cerebral palsy.
Kinetic and kinematic repercussion of the hip during knee hyperextension gait in hemiplegic cerebral palsy

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¹Hospital Moinhos de Vento, Porto Allegro, Brasil,
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INTRODUCTION
The knee hyperextension during stance phase is a pattern found in many pathologies and it is common in spastic hemiplegic cerebral palsy. This is not a simple gait pattern because produces an external extensor moment in knee, what can damage capsular structures and ligaments causing pain, ligament laxity and even bony deformities. This pattern also is related with high energy consumption during gait.

CLINICAL SIGNIFICANCE
The aim of our study is to verify the effect of the exacerbation of the plantar flexion/knee extension couple (PF/KE) and the hyperextension of the knee with its kinetic and kinematic repercussion on the hip joint in hemiplegic cerebral palsy.

METHODS
We evaluated 50 patients with hemiplegic cerebral palsy, from July 2014 to December 2019, 25 patients presented gait with hyperextension, 14 boys and 11 girls. The age varied between 5 and 32 years, with an average of 10,2 years. Sixteen patients were classified as GMFCS I, 8 as GMFCS II, and 1 GMFCS III. Two patients presented spasticity classified as Ashworth 1 on triceps suralis, 9 patients as Ashworth 2, and 14 as Ashworth 3.

RESULTS
All patients had typical kinetic changes of gait in hyperextension in the ankle and the knee (increased knee flexor moment and ankle plantar flexion moment). For data analysis, the patient with GMFCS III was excluded. Fifteen patients had an increase in hip flexion in the stance phase while 9 patients did not. Fourteen patients had increased hip flexor moment in stance phase while 10 patients did not. No association was found between hip parameters and ankle kinematics during physical examination.

The increase in hip extension in gait kinematics had no statistical association with the GMFCS, however there was an association with spasticity of the triceps suralis (p = 0.037) that was 0% in Ashworth 1, 88.9% in Ashworth 2 and 53 % in Ashworth 3. The increase in hip flexor moment was statistically associated with GMFCS (p = 0.019) being 75% in GMFCS I and 25% in GMFCS II, and we also found association with spasticity of the triceps suralis (p = 0.029) that was 0% in Ashworth 1, 88.9% in Ashworth 2 and 46.2% in Ashworth 3.

DISCUSSION
We lean heavily on 3D Gait Analysis dynamic data and so this study allows us to conclude that when the patient with spastic hemiplegic cerebral palsy has knee hyperextension gait and Ashworth 1, there will be no changes in gait kinematics. However, there is an association between Ashworth 2 and 3 and hip kinematics and kinetics and an association between hip kinetics and GMFCS.
Split tendon transfer of the posterior tibialis for spastic equinovarus foot deformity: does tendon routing impact post-operative ankle kinematics?

Authors: Frances Scheepers\textsuperscript{a,b}, Tim Bhatnagar\textsuperscript{a,b}, Karen Davies\textsuperscript{a}, Diane Wickenheiser\textsuperscript{a}, Alec Black\textsuperscript{a,b}, Christine Alvarez, MD\textsuperscript{a,b}, Kishore Mulpuri, MD\textsuperscript{b}, Lise Leveille, MD\textsuperscript{a,b}

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Introduction: Equinovarus foot deformity is commonly seen in children with cerebral palsy\textsuperscript{1}. The initial description of the split tendon transfer of the posterior tibialis (SPOTT) procedure routes the transferred portion of the tendon posterior to the fibula\textsuperscript{2}. An alternate routing through the interosseous membrane has subsequently been described. The purpose of this study is to determine if routing of the split tendon transfer through the interosseous membrane (IO group) improves ankle dorsiflexion in swing compared to routing posterior to the fibula (Posterior group), and to determine if either surgical approach results in changes in the coronal plane kinematics of the foot.

Clinical Significance: The described variation in surgical technique to address equinovarus foot deformity has an additional potential benefit of augmenting ankle dorsiflexion in swing.

Methods: Patients with a diagnosis of cerebral palsy (CP) and history of a SPOTT procedure for equinovarus foot deformity were identified from surgeon procedure logs. Patients with pre-operative and post-operative computerized gait analysis were included for review. A retrospective chart review was completed to determine surgical technique and identify concurrent surgical interventions performed at the ankle. A randomly selected single side was included for patients with bilateral procedures. Pre-operative and post-operative comparisons were determined for foot and ankle metrics: sagittal and coronal plane ankle kinematics, sagittal plane ankle kinetics, and coronal plane hindfoot kinematics. A Chi-squared / Wilcoxon Sum of ranks approach was used with a mixed effects model to determine if the type of surgical method had different effects on the foot gait metrics selected. Significance was observed at \( p < 0.05 \).

Results: Thirty-eight patients met the inclusion criteria. Average patient age was 10.3 years (range, 5-19 years). All patients were GMFCS level one or two. Thirty-one patients (82\%) had either a gastrocnemius recession (GR) (13 patients, 34\%) and/or tendoachilles lengthening (TAL) (18 patients, 47\%) performed concurrently with the SPOTT procedure. In twenty-seven patients the split tendon was transferred posterior to the fibula and in eleven patients it was transferred through the interosseous membrane. Both surgical approaches resulted in significantly greater maximum ankle dorsiflexion during stance and swing (9° increase, \( p=0.014 \), and 8° increase, \( p=0.027 \), respectively). However, there was no significant difference in this metric between surgical approaches. In the coronal plane, both surgical approaches resulted in significantly increased ankle and hindfoot varus, in terms of both average stance (17° increase, \( p=0.000 \), and 15° increase, \( p=0.004 \), respectively) and average
swing (13° increase, p=0.001, and 12° increase, p=0.002, respectively). Although there was no significant difference between surgical approaches for the hindfoot metrics, the IO approach resulted in a post-surgical increase in ankle varus, in both average stance and average swing, significantly greater than the Posterior approach, with an estimate of a 13° increase in ankle varus averaged over stance (p=0.009) and a 12° averaged over swing (p=0.02), relative to the post-operative ankle varus changes observed when the Posterior approach was used.

Discussion: The SPOTT procedure significantly increased ankle dorsiflexion in swing in both the Posterior and IO groups. However, the majority of patients were treated with concurrent tendon lengthening procedures (GR or TAL). The SPOTT procedure utilized for correction of spastic equinovarus foot deformity, can improve max ankle dorsiflexion in swing with routing of the tendon through the IO membrane or posterior to the fibula if performed concurrently with appropriate tendon lengthening to address equinus contracture. While both surgical approaches also resulted in increased ankle and hindfoot varus over stance and swing, the IO approach resulted in significantly greater ankle varus over stance and swing, indicating that the modified tendon routing in the IO approach could potentially be utilized to effect larger changes in the coronal plane kinematics of the foot, while simultaneously addressing sagittal plane deficits of the equinovarus foot deformity.

References:


Acknowledgements: None

Disclosure Statement: The authors of this study have no conflicts of interest to disclose.
Gait Profile Score of Children with Cerebral Palsy Can Differ Based on Normative Data from Different Institutions

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INTRODUCTION

The Gait Profile Score (GPS) is a single, raw measure of gait ‘quality’ based on nine Gait Variable Scores (GVS) which are root mean square (RMS) differences between kinematic time-series variables across a gait cycle and averaged data from those without gait pathology [1-3]. This index and others commonly used, such as the Gait Deviation Index (GDI), are useful for assessment of treatment outcomes. The GPS has been validated and used in children with cerebral palsy and other pathologies [2-3].

While the GPS requires averaged normative data for computation, kinematics and kinetics of typically developing children can vary depending on a number of factors including but not limited to age, speed, laboratory setting, hardware system, marker placement and the biomechanical model used to process marker trajectories [4-5]. Previous work has assessed the difference in normative data between sites as well as the influence of normative data’s walking speed on the computation of gait indices, proposing a method to correct for differences [3,6]. However, to our knowledge, the influence of normative data from different institutions of children walking at a self-selected speed, on the GPS of children with cerebral palsy, has not been investigated.

Thus, this study aimed to quantify the influence of modifying the normative reference data on the GPS and GVS scores in patients with cerebral palsy (GMFCS levels I-III).

CLINICAL SIGNIFICANCE

As clinical outcomes are typically presented relative to normative data, differences in normative data could influence cumulative gait indices. The impact of variation in reference data in children with cerebral palsy is understudied.

METHODS

Seventy patients (Avg. age: 12.1 ± 2.9; 27 F) diagnosed with cerebral palsy underwent 3D gait analysis during walking at a self-selected speed at Scottish Rite for Children (SRC) for at least one visit (N= 168 sided sessions; n=38 GMFCS level I, n=102 level II, n=28 level III). Sided GPS and GVS scores were determined using averaged control kinematic data at a self-selected speed from 83 typically developing subjects ages 4-17 from Gillette published by Schwartz et al. in 2008, released in May 2020 by Vicon in Polygon version 4.4.6, and using kinematic data from 83 typically developing children ages 4-17 from SRC. Average normalized speed \(v* = \frac{v}{\sqrt{gL_{leg}}}\) of Gillette’s free speed group was compared to SRC’s average normalized speed [4]. To determine the difference in GPS and GVS scores using each institution’s data, signed rank tests were performed within GMFCS level. Spearman’s correlations between scores using SRC and Gillette were determined within GMFCS level. Alpha was set to 0.05 for all tests.
RESULTS

Typically developing children from Gillette’s free speed group, walked with a comparable average normalized speed to SRC’s age-matched cohort (0.43 ± 0.07 vs. 0.47 ± 0.07) [4].

Median and interquartile ranges (IQR) for GPS and GVSs by GMFCS level, utilizing Gillette’s and SRC’s control data with signed rank test results are shown in Table 1. Within each level, significant differences when using SRC vs. Gillette were found in most scores, with GMFCS level II revealing GPS and all 9 GVSs to be significantly different (p<0.05).

Within GMFCS level I, hip abduction GVS between Gillette and SRC was not correlated (ρ=0.308, p=0.06), but GPS and all other GVSs were strongly correlated (range ρ= 0.600–0.981, p<0.001). Within GMFCS level II, all scores were strongly correlated (range ρ= 0.621–0.991, p<0.001), and within GMFCS level III, a moderate correlation was found in hip abduction (ρ=0.448, p=0.017) and all other scores were strongly correlated between sites (range ρ= 0.758–0.998, p<0.001).

DISCUSSION

Significant statistical differences were found when utilizing normative data from both sites, suggesting caution when using different normative datasets. However, within GMFCS level, almost all scores were moderately to strongly correlated to one another, as expected. The only non-significant, weak correlation was in hip abduction GVS within GMFCS level I, yet it was trending towards significance (p=0.06). While many of the average absolute differences between Gillette and SRC scores were larger than the previously determined MCID of 1.6° for the GPS, inherent variability in normative data due to factors like speed and different standardized protocols especially due to examiner marker placement cannot be ignored [2–5]. As such, the range in differences between institution median GVS scores across all patients (range=0.49° pelvic obl – 10.3° hip rot), were within the magnitude of previously reported variation across multiple examiners and sites [5]. Further investigation is needed to determine the impact of normative data on clinically relevant changes in gait indices.

REFERENCES


DISCLOSURE STATEMENT

Co-author K. Tulchin-Francis is on the GCMAS executive board. All other authors have no conflicts of interest to disclose.
Effect of Split Posterior Tibialis Tendon Transfer on Foot Progression Angles in Children with Cerebral Palsy

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Introduction: A common orthopedic issue for patients with spastic cerebral palsy (CP) is a hindfoot varus deformity. This deformity is often caused by over activation of the tibialis posterior and has an incidence of 8-27% in CP. One method of treatment is the split posterior tibialis tendon transfer (SPOTT). However, there is limited literature and variable results on the effect of SPOTT on foot progression angle (FPA) in children with CP who have equinovarus deformities.

Clinical Significance: The objective of our study was to evaluate the change in FPA after SPOTT, and determine if this procedure alone can correct a hindfoot varus deformity to assist orthopedists planning single event multi-level surgeries.

Methods: After IRB approval, a retrospective analysis of all ambulatory children with a diagnosis of CP who underwent SPOTT at Children’s Hospital Colorado between 2003 and 2019 was performed. Only patients with both pre- and post-operative gait analyses were included. Patients with concurrent rotational procedures were excluded. Descriptive statistics including mean and standard deviation (SD) were used to characterize continuous variables. Paired t-tests were used to evaluate differences between positive and negative outcomes, in which a positive outcome was defined as a final FPA between 0-10° of external rotation. Additionally physical examination measures were analyzed. Physical examination measures analyzed included ankle dorsiflexion, hindfoot inversion, and hindfoot eversion.

Results: A total of 40 subjects (44 limbs) were included in this study. Demographics were as follows: 26/14 female/male; mean age [SD] (years): 9.8 [3.5]; 30 hemiplegic, 9 diplegic, and 1 triplegic. Of the 44 limbs, 18 limbs had a positive outcome, 4 had no change, and 22 had a negative outcome. For the 18 limbs with positive outcome, an average change of 14.4° ± 13.7° was required to reach a final FPA within 0-10° of external rotation. Of the 22 with a negative outcome, 4 limbs trended towards a positive outcome, but did not meet the threshold to be included in this group. Across all subjects, there was a change in FPA of -10.9° ± 14.7° (p<0.0001). Age at time of surgery, CP diagnosis, pre-operative FPA, and functional ability were not predictors of a positive outcome (p>0.05). There was a statistically significant post-operative change in all physical examination measures aside from ankle dorsiflexion with knee extended (p=0.08). Dorsiflexion with knee flexed had an overall change of +6.5° (p=0.0001), dorsiflexion R1 had an overall change of +7.0° (p=0.0007), inversion changed by -5.1° (p=0.0014), and eversion changed by 3.6° (p=0.0008).
**Discussion:** While the SPOTT significantly affected FPA, both positive and negative outcomes were observed. There were significant changes in passive range of motion that occurred with this procedure as expected. This could be due to the pre-operative severity of the hindfoot varus deformity, the effect of concomitant soft tissue surgeries, or the use of a single segment foot model during gait analysis. Overall the data in this study suggest that there is an expected change in hindfoot mobility both passively on exam, and actively during gait as measured by foot progression angle. Further analysis is required to understand the change in FPA following SPOTT and if other variables can predict this change. This information can be used to determine the amount of rotational correction needed at other anatomic levels.

**References:**

**Figure 1.** Kinematic and physical exam data of patients pre- and post-operatively (* denotes p<0.05) A. Patients who had a SPOTT did not always correct into the target FPA range, nor did they correct in a predictable direction. They did however demonstrate a statistically significant change in FPA post-operatively. B. Patients experienced a significant change in inversion post-operatively. C. Patients experienced a significant change in eversion post-operatively.

**Acknowledgements:** The authors would like to thank the Center for Gait and Movement Analysis and the Musculoskeletal Research Center at Children’s Hospital Colorado for its support of this study.

**Disclosure Statement:** The authors have no conflicts of interest to disclose.
Perioperative management of a case of lower extremity torsional abnormalities undergoing derotational osteotomies

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INTRODUCTION

Lower extremities torsional abnormalities (LETA) include abnormalities in femoral version, tibial torsion, or the combination of both. Anterior knee pain is common and often causes young patients to stop all physical activities (1). Due to a lack of knowledge on LETA, adolescents may consult many health professionals without finding the cause of their pain and may undergo conservative or surgical treatment with disappointing results (2). Once properly diagnosed, the most common treatment for these conditions is femoral and/or tibial derotational osteotomies. There are no clear guidelines regarding the amount of rotation to correct and the optimal site for the osteotomy (e.g. supra vs. infra-tubercle in the tibia). The goal of this procedure is to restore normal limb biomechanics, specifically in transverse plane. This in turn alleviates pain. To date, little is known on the functional status, patients reported outcomes (PRO), perioperative management and on the success of derotational osteotomies for LETAs. Controversies exist about the management of LETA and surgery is sometimes considered as elective for cosmetic rather than for therapeutic purpose. Therefore, the aim of this case report is to describe the perioperative management and the surgery of an adolescent with LETA.

PATIENT HISTORY

An 18 year-old female presented to the senior author with bilateral knee and ankle pain for 3 years. She had no history of trauma or previous surgeries. She had previously been participating in high-level dance, running and basketball, but stopped due to pain. Physical therapy helped reduced pain briefly, but this positive effect of therapy did not last over time.

CLINICAL DATA

On physical examination, she presented with inward pointing patellae. Her foot progression angles were 5° internal bilaterally. A prone-hip rotational assessment revealed excessive internal rotation of the hips with lack of external rotation (85° of internal hip rotation and 15° of external hip rotation bilaterally). The thigh-foot angle was high with 30° and 35° externally on the right and left side respectively. A CT-scan of the bilateral lower-extremities were performed to quantify the torsional deformities in the lower-extremities. The CT scan demonstrated 30° of hip anteversion on the right and 32° on the left, and high tibial torsion of 50° on the right and 43° on the left. The patient had the following muscle weaknesses (right/left): hip flexion= 4/4, hip extension=4+/4, hip abduction=3+/3+ and knee flexion=4+/4. No weaknesses were noted for knee extension and any foot muscles (All 5/5). Her results in the Pediatric Outcome Data Collection Instrument (PODCI), a PRO, were lower than normal (normal score =100): mobility=88, sports=75, pain=33, global function=74 and happiness=70.

MOTION DATA

Pre-operatively, her main gait deviations were in the transverse plane. Kinematic showed major internal hip rotation (R>2SD), internal knee rotation (L>2SD), external foot rotation (bil>1SD) and external foot progression (bil>1SD) (Figure 1).
TREATMENT DECISIONS AND INDICATIONS

The treatment algorithm was discussed with the patient and her family. Surgical treatment was indicated based on chronic hip and knee pain, unresolved with extensive physical therapy. Her physical exam, CT results, and gait lab report were consistent in demonstrating excessive femoral anteversion (internal rotation deformities of both femora). Her foot progression angle (internal) and thigh-foot-angle suggested that her tibial torsion was not a significant contributor to the lower-extremity pathology. The patient underwent bilateral percutaneous femoral osteotomies with rotational correction of 30° on right and 25° on left using intramedullary nails. After the surgery, the patient was weight bearing as tolerated and followed a post-operative physical therapy program.

OUTCOME

At one-year post-surgery, on physical examination, the patient improved from 85° to 50° (norm: 40°) bilaterally for the hip internal rotation and from 15° to 40° (norm: 45°) bilaterally for the hip external rotation. All muscles tested pre-op reached a 5/5 post-op with the exception of left hip extension, bilateral hip abduction and knee flexion for which she had 4+/5. Improvements in the following domains of the PODCI were observed: mobility (88 to 100), physical function (75 to 89), pain (33 to 100), global function (74 to 96), happiness (70 to 80). For kinematic gait (figure 1), she improved towards normalization for all parameters except for knee rotation. For knee rotation, she had increased internal rotation at baseline and external rotation post-surgery.

SUMMARY

We presented a case of an 18-year-old female with excessive femoral anteversion who undertook a thorough pre-operative assessment to determine the transverse plane deformities as a cause of her dysfunction. Pre-op evaluation showed patients had debilitating pain leading to important functional deficits and abnormal gait patterns. Post-op evaluation showed that the selected surgery allowed pain alleviation, restored physical function and normalized gait pattern, to some extent. This case report is suggesting that youth with LETA does not undergo this procedure for cosmetic purpose only, but rather truly have debilitating symptoms that can mostly be taken care of with derotational osteotomy. Our group is prospectively recruiting patients with LETA to determine the preoperative dysfunction as well as demonstrating what improvements in PRO are achieved. The long-term consequences of this surgical approach will be re-evaluated 2 and 5 years post-op.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

REFERENCES

Impact of the COVID-19 Pandemic on Walking Activity in Individuals with Cerebral Palsy

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INTRODUCTION: The COVID-19 Pandemic has had a tremendous effect on our daily lives, drastically changing how individuals access their school, work, leisure and community environments; as a result, Safer at Home orders have led to people having to spend more time indoors. Research has begun to examine self-reported activity levels and lockdown measures in place during the pandemic¹. For individuals with neurological conditions such as cerebral palsy (CP), increasing and maintaining daily activity is an important rehabilitation intervention as research has shown that the tasks children with CP can perform in a clinical setting are influenced by what they actively do in their day-to-day lives². In addition, ambulatory children with CP have limitations in their functional mobility, take fewer steps per day and have decreased habitual daily activity compared to their peers³. The purpose of this study was to assess the impact on the COVID-19 pandemic on walking activity in children, adolescents and adults with CP.

CLINICAL SIGNIFICANCE: The study highlights the importance of further examining the impact of lockdown measures on the activity levels of individuals with neurological conditions such as CP as this significantly impacts their functional mobility and other comorbidities, such as obesity².

METHODS: Fifteen ambulatory participants with CP were asked to wear a StepWatch Activity Monitor (StepWatch, Orthocare Innovations, Mountlake Terrace, WA) on their ankle for 7 consecutive days at an initial assessment and again approximately one year later. One group (6 male subjects; 3 GMFCS level I, 3 GMFCS level II; age 13.4, SD 4.9 years) completed their second visit prior to March 2020 (Non-COVID follow-up). The other group (15 subjects, 7 male; 8 GMFCS level I, 5 GMFCS level II, 2 GMFCS level III; age 17.0, SD 10.5 years) completed their second visit after June 2020, while Safer at Home orders were in place (COVID follow-up). The StepWatch recorded the time history of steps taken over the monitoring period, and average number of steps per day were counted. The change in average steps per day was compared between each participant’s initial and second assessments for each group using nonparametric Wilcoxon sign rank tests. The change in steps per day was compared between groups using the nonparametric Mann-Whitney test.

RESULTS: Steps per day decreased significantly for the COVID follow-up group (p=0.03) but not the non-COVID follow-up group (p=0.75). Twelve of the fifteen participants (80%) in the COVID follow-up group had a decrease in their average steps per day (Fig. 1 and 2). However, of these twelve, only three decreased their walking activity by greater than 1000 steps per day. Four of the six subjects in the Non-COVID follow-up group (67%) had a decrease in their average steps per day. The change in steps per day did not differ significantly between the two groups (p=0.88).
DISCUSSION: A significant percentage of participants had a decrease in their average number of steps per day during the COVID-19 pandemic compared to one year prior, before the pandemic began. However, participants that had their second visit before the pandemic began also had a decrease in their average number of steps per day, making it unclear to what extent staying at home during the pandemic decreased walking activity in the COVID follow-up group. It is possible that we were unable to show a significant difference between the groups due to the small sample size. With more participants, it would be beneficial to examine the effect of GMFCS level or the starting number of average steps per day at their initial visit, as only the COVID follow-up group included GMFCS level III and a number of participants had fewer than 2000 steps per day at their initial visit, which would not allow for much decrease. In addition, in the COVID follow-up group, the greatest decreases were in the GMFCS level I participants who were most active before the pandemic (Fig. 2). Further research should be done to evaluate the impact of the pandemic on the walking activity in individuals with CP.

REFERENCES:


ACKNOWLEDGEMENTS: We would like to acknowledge the rest of our data collection and processing team: Sandi Dennis, Susan Rethlefsen, Alison Hanson, Bitte Healy, Veronica Beltran and Kyle Chadwick.

DISCLOSURES STATEMENT: The authors of this abstract have no disclosures.
INTRODUCTION
The hand is a body segment that allows us to manipulate objects so that we can perform daily living activities that give us independence, these by making eight different types of hand grasp. When the hand is lost, hand prosthesis have been placed on upper limb amputees, in order to restore the lost functions usually they are body-powered, habitually this device is a hook [1]. In recent years there has been an increase in the design and manufacture of 3D printed hands [2], since their benefits include lower cost, speed (their fabrication can be in one day), versatility (different terminal devices can be made with specific needs) and all of them can be customizable [3]. Anyone that wants to create a 3D printed hand can use a search engine to find several options of printable hands that include files and tutorials on how to make and assemble a 3D printed hand [4]. Apparently it offers a viable alternative, however it does not necessarily solve the mobility problem and it does not replace the functions of the original hand, and on the contrary it is not known if these domestic designs could generate injury and frustration with their use. To our knowledge there is a necessity of showing the advantages and disadvantages of this kind of devices to the end-user to make an informed choice of what kind of hand the user is going to have.

CLINICAL SIGNIFICANCE
The current study is aimed to investigate biomechanical factors that change in the performance of daily living activities when using a 3D printed prosthetic hand and determined if there are abnormal movements that could prone the user to an injury compared with the use of the hook and a mechanical prosthetic hand.

METHODS
A third-party 3D printed hand was used. This hand consisted of five fingers that could move as follows, thumb included a rotation and flexion movement, an index finger with independent flexion while the middle, ring, and little fingers move together and only have the ability to flex. All of the hand movements were enabled by independent motors and were activated by an electrical switch. The other two devices were a hook 5X-R, and otobock mechanical hand (8K23). A 60-year-old male patient with 17 years using a hook to perform its daily living activities participated in this experiment. The subject was trained for five sessions of one hour over five days to be familiarized with the device and not measure its learning curve. A functionality test that evaluated three types of grasp was performed. A kinematic test was carried out to analyzed shoulder and elbow articular range of motion (ROM). The subject was instrumented with 15 reflective markers on the prosthetic arm, terminal device, and trunk and measured with a 12 flex13 Optitrack System (Natural Point, Corvallis Oregon, USA), using a modified Plug-in Gait Upper Body model.

RESULTS
For the kinematic analysis we obtained the maximum shoulder abduction and flexion, and elbow’s range of motion for each type of task as seen on Figure 1.
DISCUSSION

Our results show that with the hook the subject performs daily living activities easily, he took less time than with the other two devices. During Grasp activities 3D printed hand showed less shoulder abd-add, flex-ext and elbow flex-ext. For Grasp and weight activities, 3D printed hand spend more time, with less ROM. For Grasp and ability activities the 3D printed hand could not complete the tasks. We do think that it is important to develop functionality test specialized for 3D printed hands and determine their functionality, these with the objective of the developer let know the interested person on acquiring one of their capabilities with each hand.

REFERENCES
4. NIH 3D Print Exchange —National Institutes of Health (NIH).

ACKNOWLEDGMENTS

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DISCLOSURE STATEMENT

All authors have nothing to disclose.
1-SEGMENT TO 2-SEGMENT FOOT MODEL WITH ONE MARKER

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INTRODUCTION

While it is well understood that the internal movement of feet during gait is complex, it is still common practice to simplify the foot as a single vector or segment in gait analysis. Multi-segment foot models can be used, but they often require many additional markers and measurements. This requires more work in exam setup, training, and becomes increasingly difficult with small and pathologic pediatric feet.

Presented here is a method for achieving a 2-segment foot model by adding only one additional marker to a basic 1-segment foot model or two additional markers to the conventional gait model vector foot1. While this 2-segment foot does not offer as much detail as more advanced models such as the Oxford2 or IOR3, it is very simple to implement and should be feasible on any patient. To demonstrate the value of the 2-segment foot, presented are several pediatric pathologic groups where the 2-segment foot model can differentiate clinically important differences that a 1-segment model could not.

CLINICAL SIGNIFICANCE

By better understanding separate midfoot and forefoot movement of the foot, clinicians can better differentiate and treat pathologic feet.

METHODS

The 1-segment foot model adds a 5th metatarsal (MET) marker to the vector foot, and the 2-segment model adds an additional intermediate cuneiform (PROX) marker, making the models backwards compatible (Table 1). Specifically, the vector foot model is defined with a vector between the TOE marker and ankle joint center (AJC), often with a static offset applied using the HEE marker. The 1-segment model adds the MET marker to define a lateral axis and allow full 3-axis tracking (Figure 1, orange). For the 2-segment foot model, the midfoot segment is defined with the primary axis extending from the PROX marker to the AJC and the secondary axis in the
direction of the ANK marker (Figure 1, yellow). The forefoot segment is defined with the primary axis extending from the TOE marker to the PROX marker and the secondary axis in the direction of the MET marker (Figure 1, green).

Midfoot sagittal plane angles are offset 90° in the tibia sagittal plane. The rotation order for all segments is Y-X-Z, following the common pattern of Tilt-Obliquity-Rotation. To match clinical interpretation, midfoot and forefoot angles are presented in the order: Y (Dorsi/Plantarflexion), Z (Inv/Eversion), X (Add/Abduction). The 1- and 2-segment foot models present absolute angles without any static offsets. The HEE marker is not required for 2-segment foot kinematics except for backwards compatibility.

DEMONSTRATION

Four pediatric groups, Typical (n=2), Varus (n=5), Valgus (n=6), and Clubfoot (n=4), were compared using the 1-segment and 2-segment foot models. The results (Figure 2) show that greater differentiation can be made between the groups with 2-segment foot angles than 1-segment foot angles. The Clubfoot group had greater forefoot plantarflexion than all other groups and greater midfoot adduction than the Typical and Valgus groups. The Varus group had more forefoot plantarflexion than the Typical and Valgus groups and more midfoot adduction than all other groups. The Valgus group tended to have greater midfoot eversion, forefoot eversion, and forefoot abduction than all other groups.

SUMMARY

By simply adding one additional marker to a basic 1-segment foot marker set, or 2 markers to the conventional gait model, a 2-segment foot model can be generated that provides greater insight into pathological gait.


DISCLOSURE STATEMENT: KC is a contractor for OpticSurg Inc. This relationship has been reviewed and approved by CHLA IRB in accordance with its policy on objectivity in research. The rest of the authors have no conflicts of interest to disclose.
2-SEGMENT FOOT MODEL: REFINING EVALUATION OF CLUB FEET

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SUBJECTS HISTORY: A case comparison study between a 5y/o female (patient A) and a 3 y/o male (patient B) with histories of idiopathic club foot was initiated to test our novel 2-segment foot model. Patients underwent Achilles tenotomy and Ponseti casting as infants. They presented to our gait lab with concerns for recurrent club foot deformity. Pre-operative surgical considerations were similar for both patients: gastrocnemius recession and split anterior tibialis tendon transfer on the affected side, as well as an adductor hallucis lengthening for patient A.

The 1-segment vector foot used with Plug-In Gait has many significant limitations, including overestimating dorsiflexion due to midfoot break¹,³ and inability to objectively define inversion/eversion of the midfoot or forefoot. Multi-segment foot models exist (Oxford, Milwaukee, Rizzoli, etc.) but they require many additional markers necessitating the motion capture cameras to be moved closer to the subject (particularly with small feet), decreasing data capture volume. We proposed adding two additional markers to the traditional 1-segment vector foot to divide the foot into 2 segments comprised of a hindfoot/midfoot and forefoot. Utilizing our novel 2-segment foot model we aimed to objectively quantify flexible verses fixed forefoot deformities in children with clubfeet.

CLINICAL DATA: Patients had similar ROM measurements of their affected limbs (Table 1). A notable difference was patient B’s Foot-Posture 6-Index score on his affected foot: -9 (indicating pes varus). The foot posture index-6 is a static observational measure that considers the three-dimensional foot and has been shown to have good reliability in both adult and pediatric populations.²,⁴

<table>
<thead>
<tr>
<th>Objective measurements</th>
<th>DF knee extended, inverted</th>
<th>DF knee flexed, inverted</th>
<th>Forefoot Eversion</th>
<th>Hindfoot Eversion</th>
<th>Foot Posture 6-Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient A</td>
<td>-4°</td>
<td>0°</td>
<td>4°</td>
<td>10°</td>
<td>R +2</td>
</tr>
<tr>
<td>Patient B</td>
<td>0°</td>
<td>6°</td>
<td>4°</td>
<td>10°</td>
<td>L -9</td>
</tr>
</tbody>
</table>

Table 1

MOTION DATA: 3D joint kinematic data were collected using a motion capture system (Vicon Motion Systems Ltd., Oxford, UK). Twenty-three retro-reflective markers were placed on the patient’s lower body according to the Plug-In-Gait Model, with modifications of tibial crest markers and patella markers that replace tibia and thigh wands respectively, and the addition of a 5th metatarsal marker and intermediate cuneiform marker to allow formation of a 2-segment foot model. For the 2-segment foot model, the midfoot segment is defined with the primary axis extending from the intermediate cuneiform marker to the ankle joint center and the secondary axis in the direction of the ankle marker from the primary axis. The forefoot segment is defined with the primary axis extending from the toe marker (2nd metatarsal) to the intermediate cuneiform marker and the secondary axis in the direction of the 5th metatarsal marker from the primary axis. The patients walked barefoot along a 15-meter walkway at a self-
selected speed as five to ten trials were recorded and averaged. Data from a typically developing child was used for comparison purposes. (Figure 1)

**TREATMENT DECISIONS AND INDICATIONS:** Utilizing the 2-segment foot model the flexibility of Patient A’s deformity (Green) and the rigidity of Patient B’s deformity (Blue) was identified, as compared to the norm (Black). Patient B’s midfoot and forefoot is rigid, remaining inverted throughout the gait cycle, with little excursion of motion present. (Figure 1a/b) Patient A’s forefoot everts to a nearly normal amount in stance phase, suggesting a more flexible deformity and forefoot inversion isolated to swing phase. (Figure 1b) In the sagittal plane, Patient B has increased forefoot plantarflexion compared to the norm indicating elevated midfoot to forefoot position that is maintained during dynamic activities. (Figure 1c)

**OUTCOME SUMMARY:** Surgical recommendations changed for both patients based on the gait study and 2-segment foot model. Patient A was recommended not to undergo surgery as no split anterior tibialis tendon transfer was indicated since the deformity was isolated to swing phase. Patient B was recommended to have split anterior tendon transfer and gastrocnemius recession. The 2-segment foot model’s ability to differentiate these patients’ midfoot versus forefoot motion during the various gait cycle phases resulted in improved clinical decision making.

**REFERENCES:**

**DISCLOSURE STATEMENT:** KC is a contractor for OpticSurg Inc. This relationship has been reviewed and approved by CHLA IRB in accordance with its policy on objectivity in research. The rest of the authors have no conflicts of interest to disclose.
Effect of initial foot position on postural responses to lateral perturbations during standing in younger and older adults

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Introduction: Age-related deficits in postural control and mobility impact daily living in older adults. An age-related decline in standing balance control in the medio-lateral (ML) direction is associated with increased risk of falling. The choice of initial foot positions (IFPs) could affect neuromuscular and biomechanical control of lateral stability. The purpose of this study was (1) to determine the effect of different IFPs on lower limb muscle activation patterns, kinematics, and kinetics following lateral perturbation and (2) to identify differences in postural reaction between younger and older adults.

Methods: Participants stood on a treadmill and a sudden lateral platform translation (0.043 m, 0.64 m/sec²) was applied. Three foot positions were tested: 1) Reference (REF): feet placed shoulder-width apart with toes pointing forward. 2) Toes-Out with heels together (TOHT): heels together with toes pointing outward to have the same base of support area as REF. 3) Modified Semi-Tandem (M-ST): the heel of the anterior foot was placed by the big toe of the posterior foot. Electromyography (EMG) activity of the gluteus maximus (Gmax), gluteus medius (Gmed), rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), soleus (Sol), and fibularis longus (FL) was recorded along with 3 dimensional whole body kinetic and kinematic data.

Results: No additional step was taken to recover standing balance for all participants for any IFPs. TOHT showed a smaller step increase in M-L variation of the body’s center of mass acceleration (variation of CoMAccel) from pre- to post- perturbation (0.08 ± 0.02 mm/s²) compared to REF (0.15 ± 0.03 mm/s², p = 0.02) and M-ST (0.02 ± 0.02 mm/s², p = 0.01). The activation of the Sol (35.34 ± 7.66 % EMG max, p < 0.01) and FL (24.00 ± 10.61 % EMG max, p < 0.05) muscles in TOHT during balance recovery was greater than REF (Sol: 28.78 ± 7.27 %, FL: 19.76 ± 9.88 % EMG max). Across all IFPs, older adults showed greater variation of CoMAccel in both the A-P
and M-L directions \((p < 0.05)\), and lower FL muscle activation than younger adults (younger: 25.68 \(\pm\) 10.89 \%, older: 18.06 \(\pm\) 6.11 \% EMG max, \(p < 0.01\)).

**Conclusion:** Compared to younger adults, older adults had lower FL muscle activation following perturbation. TOHT increased Sol and FL muscle activity with reduced M-L postural sway during balance recovery. Thus, toes-out IFP could be a viable option to better engage the ankle muscles that contribute to improving balance control from lateral perturbations.
Impact of tendon transfers on shoulder motion in children with brachial plexus injuries

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INTRODUCTION

Children with brachial plexus birth injuries (BPBI) commonly have weakness of muscles that elevate and externally rotate the humerus. Tendon transfers of teres major and/or latissimus dorsi are frequently utilized to improve external rotation and overhead motion in children with brachial plexus birth injuries (BPBI). While the theory is that these tendon transfers increase glenohumeral (GH) and humerothoracic (HT) motion, the impact of these procedures on the scapulothoracic (ST) versus GH joints remains unknown. We hypothesized that transfer of both the teres major and latissimus dorsi or teres major only would increase shoulder external rotation and elevation, decrease internal rotation, and reorient the same total arc of rotational motion.

CLINICAL SIGNIFICANCE: This study will address a current knowledge gap in the understanding of teres major/latissimus dorsi tendon transfers for the treatment of children with BPBI.

METHODS

Motion capture analysis (Vicon Vantage, Oxford, UK) of the ST, GH, and HT joints was performed on ten children before and after transfer of teres major only or both teres major and latissimus dorsi. Children held their arms in 12 positions, including the modified Mallet positions. The scapular markers were re-palpated in each position. The internal/external rotation arc of motion was calculated from the maximum internal and external rotation angles measured across the tested positions. Joint angles in the abduction, external rotation, and internal rotation positions and the internal/external rotation arcs of motion were compared before and after surgery using paired t-tests.

RESULTS

There were no differences in ST, GH, or HT motion in the abduction position after surgery (Table). In the external rotation position, GH and HT external rotation were significantly increased (p=0.019 and p=0.006, respectively) postoperatively. In the internal rotation position, GH internal rotation was significantly decreased (p=0.021), while ST internal rotation was significantly increased (p=0.027). There was no difference (p=0.146) in the total HT internal/external rotation arc after surgery. However, the ST arc was significantly increased (p=0.031), while the GH arc was significantly decreased (p=0.028).
Table 1. Scapulothoracic (ST), glenohumeral (GH) and humerothoracic (HT) joint angles (degrees) and standard deviations before and after surgery. The external/internal rotation arc of motion (ER-IR Arc) in degrees is also shown. (Ns=not significant)

<table>
<thead>
<tr>
<th></th>
<th>ST Preop</th>
<th>ST Postop</th>
<th>p-value</th>
<th>GH Preop</th>
<th>GH Postop</th>
<th>p-value</th>
<th>HT Preop</th>
<th>HT Postop</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abduction</td>
<td>49 ± 12</td>
<td>54 ± 5</td>
<td>Ns</td>
<td>58 ± 18</td>
<td>61 ± 25</td>
<td>Ns</td>
<td>106 ± 21</td>
<td>115 ± 29</td>
<td>Ns</td>
</tr>
<tr>
<td>External Rotation</td>
<td>-42 ± 11</td>
<td>-35 ± 12</td>
<td>Ns</td>
<td>3 ± 30</td>
<td>36 ± 21</td>
<td>0.019*</td>
<td>-36 ± 31</td>
<td>2 ± 27*</td>
<td>0.006</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>39 ± 12</td>
<td>47 ± 8</td>
<td>0.027</td>
<td>9 ± 12</td>
<td>-15 ± 31</td>
<td>0.021*</td>
<td>51 ± 15</td>
<td>34 ± 27</td>
<td>Ns</td>
</tr>
<tr>
<td>ER-IR Arc</td>
<td>20 ± 7</td>
<td>32 ± 9</td>
<td>0.031</td>
<td>60 ± 11</td>
<td>50 ± 10</td>
<td>0.028*</td>
<td>69 ± 16</td>
<td>60 ± 13</td>
<td>Ns</td>
</tr>
</tbody>
</table>

*pre-op difference statistically different p<0.05

Figure. (a) Preoperative elevation (b) Post operative elevation (a) Preoperative external rotation (b) Post operative external rotation. The postoperative elevation image (b) illustrates the increased overhead reach from the more externally rotated position of the humerus.

DISCUSSION

Although tendon transfer surgery is traditionally thought to increase GH motion, the GH arc of motion was significantly decreased after surgery in this cohort. The GH arc of motion was also oriented into greater external rotation postoperatively. Scapulothoracic internal rotation increased postoperatively, which helped maintain the same total arc of HT internal/external rotation. The HT arc of rotation was also more externally rotated postoperatively (Figure). In internal rotation, the scapula was able to compensate for some of the lost GH internal rotation, but HT internal rotation was still significantly lower than before surgery. While no difference in GH or HT elevation was identified postoperatively, the more externally rotated position of the humerus lead to improved overhead reach (Figure). These findings help improve our understanding of shoulder tendon transfer procedures and expected outcomes in the BPBI population.

REFERENCES
A Simple Neural Reward Circuit May Motivate Human Gait Development and Even Explain Cerebral Palsy Gaits

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INTRODUCTION
The assumption that the human bipedal gait emerges from an innate pattern encoded in the motor control system may be incorrect. Instead, our gait may be explained by assuming a mutation that created, in a human ancestor, a simple neural reward circuit. We conjecture a circuit exists that rewards the sensation of Rhythmic Audible Vestibular Jolts (RAVJ). As with operant conditioning, a RAVJ reward will motivate RAVJ producing behaviors. One of those behaviors is learning our bipedal gait since human gaits (from first steps to the adult heel-strike and even cerebral palsy gaits) do generate RAVJ. This occurs because the foot to floor impact creates a compression shockwave in a foot bone that travels via the skeleton to the head [1]. At the head, that shockwave produces a strong vestibular jolt and it is audible (as a click from the fluid mechanics in the cochlea -- as in bone conduction hearing [2]). The periodic nature of our foot-strikes thus generates RAVJ. Additionally, because successfully avoiding an aversive outcome also acts as a reward [3], and falls can be painful, then gait modifications that reduce the aversive sensations of falls will be discovered and learned [4]. Does the literature support this novel RAVJ reward conjecture of gait development?

CLINICAL SIGNIFICANCE
If the RAVJ reward conjecture is correct, then cerebral palsy gaits (such as toe strike and severe crouch) are not brain wiring problems of innate gait patterns, but rather the CP gaits are learned and motivated by the same rewards; rewards from RAVJ and avoiding falls, but under some neurological constraints. CP constrains repeated motion control and impairs reflex development [5]. One walking reflex normally developed stops the forward motion of the foot prior to floor contact; without that reflex developing (as likely in CP), painful slip falls will occur more often [6]. Therefore, in order to prevent slip falls, the CP patient will discover the foot strikes that reliably stop forward foot motion (the toe and crouch strikes); however, to still generate a strong enough shockwave to the head for RAVJ, a high impact strike is required which often leads to skeletal damage. This new gait theory opens novel therapy options which could prevent developing the damaging CP gaits.

METHODS: Literature search of studies on behaviors and gait with data predicted by the RAVJ reward theory. Studies included: infant first steps; gait development and biomechanics; cerebral palsy gaits; slip and trip fall mechanics; reflex plasticity; foot impact mechanics; bipedal gaits by trained monkeys; hominine evolution (Ardi); and other behaviors expected from a RAVJ reward. Preliminary data of vertical head accelerations (jolts) of an infant with one week of walking and a 9 YO simulating a CP toe strike gait was also acquired.

RESULTS
The RAVJ reward conjecture predicts human gaits (in the absence of painful steps) will normally produce RAVJ; it also predicts gait modifications (leading to mature gait) are discovered because they reduce falls (and stop the associated fall sensations) while still producing an adequate shockwave. All data found was consistent with the conjecture’s...
predictions (see discussion). Also, since monkey training shows targeted rewards can produce both upright bipedalism and walking reflexes without needing neural specializations [7], then, for humans, the neural specializations are also unnecessary; targeted rewards will suffice. Also, the origin of the RAVJ reward neural circuit would have made our style of bipedalism immediate in some ancestor; this is consistent with the *Ardipithecus* interpretation [8].

**DISCUSSION**

Crawling will not produce RAVJ, but an infant’s first steps are hard collisions of their feet to the floor (shockwave producing) [9] which is consistent with a RAVJ reward. Infants then quickly learn to prevent painful slip falls by stopping the foot’s forward motion prior to floor contact [6] and are developed into reflexes [10]. Because trip falls can be painful, then trip and falling sensations also become aversive by association; therefore, new gait modifications are adopted which maximize trip recovery time. Maximizing recovery time is accomplished by keeping the body COM (HAT) behind a foot (either stance or the swinging foot) for as much time as possible during the swing phase; however, those new gait modifications must still produce an adequate shockwave to the head. Thus, the new walker’s first learned modifications (within 1 year) is a straight knee (which maximizes shockwave transmission) and with the heel down (which minimizes energy absorption by the heel pad). This gait modification, the *inverted pendulum*, allows a much lower (vertical) velocity foot strike while still producing adequate RAVJ. This gait allows the COM to be further back from the foot strike area which provides more time before the body passes the stance foot; hence, it increases trip recovery time and is thus rewarding when recovering from trips. Discovery of additional gait modifications continues for years until, in the mature gait, the COM is always behind one of the feet [11] while still producing RAVJ. A part of that discovered strategy is to reduce the HAT forward velocity until mid-swing (by the first rocker and knee flex-wave); another is to also propel the swing leg forward as quick as possible without accelerating the HAT [12]. Every adult gait element (even arm-swing and the strong soleus push *prior* to heelstrike) can be shown to maintain a more rearward HAT while still producing an adequate vertical foot velocity at heel impact (needed to produce a strong enough shockwave) [1]. That more rearward HAT rewards by increasing the trip recovery time thus incorporating those new gait elements. The simple and plausible RAVJ reward conjecture provides a complete explanatory and predictive mechanism for human gaits, including cerebral palsy gaits.

**REFERENCES**


**DISCLOSURE STATEMENT:** no conflicts of interest to disclose.
APPRAOH TO THE DIFFERENCES BETWEEN KAYAKING IN A VIRTUAL REALITY ENVIRONMENT AND REAL LIFE.

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INTRODUCTION
Virtual Reality (VR) is a computer environment that can imitate a physical presence in a real or imagined world, when the environment is immersed for the user it means that they feel being present in the virtual environment which has been considered an important feature for rehabilitation [1], [2]. Subjects with Spinal Cord Injury (SCI) have a loss of motor and sensory function, the normal signaling between the brain and the distal muscles will be found partly or completely interrupted resulting in disability, and the damage of the ascending and descending pathways has a direct consequence in the postural control system of the patient, that is the reason why, one of the priorities of the rehabilitation process includes the relearning of movement and upper body balance while being seated [3], [4].

In the last years, Virtual Reality has had an increase in its use, since it has become more accessible. In medicine, it has been used to treat cognitive, emotional and motor functioning and has been reported to enhance the experience for patients motivating them for each session to do it better creating a great adherence to the rehabilitation program [5], [6].

CLINICAL SIGNIFICANCE
The objective of the present project is to determine the differences that exist in healthy and inexperienced people when using a kayak ergometer in real life and using the same ergometer in an immersive virtual reality environment. This will help us to determine the possible kinematic differences and outcomes when we aim to train trunk control to patients with spinal cord injury using the kayak ergometer with virtual reality.

METHODS
We recruited three healthy subjects with an age range between 26 and 31 years old, none of them had any previous experience with kayak technique and provided written informed consent. All the measurements were made on the Movement Analysis Laboratory at the National Institute of Rehabilitation at Mexico City. We recorded two trials: one with immersive VR and one without VR, subjects were instrumented with a modified Plug-in Gait Full body, the trajectories were recorded with a VICON® Nexus System (Oxford, UK) which consisted of 6 Vantage and 8 Vero cameras, for paddling a SpeedStroke from KayakPRO® (Miami, USA) ergometer was used. For the Kayak Virtual Reality Immersive System, we developed an immersive virtual environment in Unreal Engine® (Maryland, USA) with the use of an Oculus® (California, USA) Head-Mounted Device, that consisted of a straight river with mountains on both sides that work as an infinite maze. For the control of the virtual environment we used the position of the subject’s hands with the use of the biomechanical model. The link between the motion capture system and the virtual reality was made using
Motion Builder® (California, USA). For both trials’ subjects were asked to paddle without stopping unless they were told to, the recordings were made at the beginning of the trial and every 2 minutes for 15 seconds for 10 minutes. The kinematic data was processed in Nexus for obtaining the joints' range of motion, afterwards on Visual3D® (Maryland, USA) we obtained the average and standard deviation for each subject.

RESULTS

On Table 1 the ranges of motion for the shoulder, elbow and spine are presented of the three subjects. While on Fig. 1 the differences on paddle trajectories are presented in both trials’ Immersive virtual reality environment and without virtual reality for just one subject.

![Figure 1: Shown the paddle trajectories for a) VR environment and b) without VR](image)

**Table 1: Comparison of Range of Motion for both types of paddling**

<table>
<thead>
<tr>
<th>Type of paddling</th>
<th>Virtual Reality</th>
<th>Without VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Shoulder Flexion</td>
<td>65.11 ± 11.66°</td>
<td>82.05 ± 1.17°</td>
</tr>
<tr>
<td>Elbow Flexion</td>
<td>82.51 ± 6.83°</td>
<td>91.36 ± 6.90°</td>
</tr>
<tr>
<td>Spine Flexion</td>
<td>3.67 ± 0.65°</td>
<td></td>
</tr>
<tr>
<td>Spine Rotation</td>
<td>27.78 ± 6.24°</td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

As seen on the results there exists differences between both types of kayaking even though they are made on the same equipment, and setting. Something to explore is why the upper body have a bigger ROM using the VR environment while the spine has a smaller ROM using the VR. For the trajectories we can see that there are two completely different trajectories within the same subject which also needs to be explore. Even the sample size is small we were able to identify differences between both types of kayaking, it is important to have a bigger sample size in order to determine the possible advantages or disadvantages of practicing kayak using VR in subjects that need to train their trunk balance.

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DISCLOSURE STATEMENT

The authors of this research declare of not having any conflicts of interest.
Implementation of 3D Printed Temporary Orthotics to Reduce Hospital-Acquired Injury in Acute Inpatient Stroke Rehabilitation

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Introduction

The application of orthotics is an essential part of gait rehabilitation process for patients with motor deficits. Temporary prefabricated AFOs are commonly trialed for the gait training during the inpatient rehabilitation stay, however, persistent use of poorly fitted temporary AFOs could possibly lead to increased pain, discomfort, and skin breakdown. Retrospective survey from therapists showed that among 95 stroke patients treated in a two-month span, about 58\% of prefabricated AFOs did not fit well and 42\% of stroke patients experienced pain or skin breakdown associated with the AFOs. A study was proposed by the authors with quality improvement initiative to assess the feasibility of 3D printed AFOs application in stroke patients in physical therapy session to reduce hospital-acquired injuries of pain and skin breakdown during an acute inpatient stroke rehabilitation stay.

Clinical significance:

The purpose of this study is to analyze the production of 3D printed orthotics and its impact on hospital-acquired orthotic injuries. 3D printed orthotics will could possibly allow for a more comfortable inpatient rehabilitation stay, increased confidence for the patient during intensive rehabilitation, easier adjustment to the disability, and overall improvement in function.

Methodology

This study is a prospective feasibility pilot study that analyzes patients with stroke of any chronicity who are admitted to an acute inpatient stroke rehabilitation unit and have orthotic device need. Patients that are screened and eligible for AFO usage with foot drop will be recruited and consented to receive a patient-specific 3D printed AFO for the duration of their inpatient rehabilitation stay. The patient's lower limb would be electronically scanned, modified via CAD imaging, and converted to an .STL file for immediate purposes of 3D printing via fused deposition modeling technology (as showed in picture). The suitable material is under investigation on healthy subject. Bioengineers and orthotists will assist with the overall design and production of the AFO. Nurses and therapists will assess orthotic-related pain and skin changes on a daily basis.
Preliminary Results:
The preliminary data we collected from 14 stroke participants who received temporary prefabricated AFO demonstrated that their potential to cause skin breakdown and discomfort issues during the gait training with physical therapists (as table 1). The modification by padding and wrapping the AFO would consume patients therapy treatment time. The technique and material testing under investigation (as in picture 1) would contribute additional insights for the clinical application of this new approach. The potential benefit of the custom fitted 3D printed AFO will be further studied in this project.

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Limb pain %</th>
<th>Skin issues %</th>
<th>Modification %</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>6(43)</td>
<td>2(14%)</td>
<td>4(28.6%)</td>
</tr>
</tbody>
</table>

Picture 1: Prototype of 3D printed AFO fit test on healthy subject (material Polylactic Acid)

Discussion:
There are very few studies with regard to the feasibility of clinical application of 3D printed AFO. The primary objective of the study is to examine 3D printed orthotic usage in acute inpatient rehabilitation and also evaluate the potential quality improvement on skin breakdown and discomfort caused by traditional prefabricated orthotics for preliminary comparison. 3D printing technology is transforming the medical landscape and there are many exciting opportunities within the field of rehabilitation that providers should become familiar with.


Longitudinal alterations of gait features in growing boys with Duchenne muscular dystrophy

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Introduction: Prolonged ambulation is considered an important treatment goal in children with Duchenne muscular dystrophy (DMD) [1]. Therefore, three-dimensional gait analysis (3DGA) could provide sensitive outcome measures to evaluate the successes of clinical trials [2]. However, quantitative descriptions of the natural history of gait deviations are first required. Sutherland et al. [1] described the gait deterioration based on three stages. These stages were only partially confirmed by later cross-sectional studies [3], which highlight a strong need for longitudinal assessments of gait deviations in the same cohort of growing children with DMD.

Clinical significance: This study contributes to an improved understanding of the gait deterioration in children with DMD.

Methods: 3DGA was collected in 25 boys with DMD, ranging in age between 4.6 and 15.9 years at the time of enrollment, and was repeated at multiple points, one to four times, with an interval of six months, resulting in a data set of 77 3DGA-sessions. A database of 87 typical developing (TD) children between 4 and 18 years old was used as a reference to calculate the gait profile score (GPS) [4]. The spatiotemporal parameters were converted into non-dimensional values. Ten kinematic and three kinetic trials were averaged per 3DGA-session. From the averaged waveforms, discrete parameters (e.g. maxima and minima) were extracted. Linear mixed effect models were used to investigate the effect of age on these gait parameters (α-level=0.05). Random effects were included to correct for the correlation among repeated measurements within subjects. The best fitted regression model after inclusion of random intercepts and slopes was determined. All analyses were performed in MATLAB (R2017A).
Results: The results of the linear mixed effect models are shown in table 1.

Table 1
Linear mixed effect models with age (years) as fixed predictor and gait deviations as expected responses

<table>
<thead>
<tr>
<th>Variables</th>
<th>Fixed effects</th>
<th>Random effects</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression coefficient</td>
<td>Intercept</td>
<td>SD random intercept</td>
</tr>
<tr>
<td>Cadence (steps/s)</td>
<td>-0.07</td>
<td>&lt;0.001*</td>
<td>2.84</td>
</tr>
<tr>
<td>Step length (ℓ)</td>
<td>0.01</td>
<td>&lt;0.001*</td>
<td>0.37</td>
</tr>
<tr>
<td>GPS (°)</td>
<td>-0.01</td>
<td>0.004*</td>
<td>0.85</td>
</tr>
<tr>
<td>Maximal anterior pelvic tilt (°)</td>
<td>1.41</td>
<td>&lt;0.001*</td>
<td>4.99</td>
</tr>
<tr>
<td>Range of motion pelvic obliquity (°)</td>
<td>0.69</td>
<td>&lt;0.001*</td>
<td>4.56</td>
</tr>
<tr>
<td>Range of motion pelvic rotation (°)</td>
<td>1.01</td>
<td>0.004*</td>
<td>5.64</td>
</tr>
<tr>
<td>Maximal hip flexion moment (Nm/kg)</td>
<td>-2.60</td>
<td>&lt;0.001*</td>
<td>26.05</td>
</tr>
<tr>
<td>Maximal hip flexion moment (Nm/kg)</td>
<td>1.49</td>
<td>&lt;0.001*</td>
<td>28.09</td>
</tr>
<tr>
<td>Maximal hip abduction angle in stance (°)</td>
<td>0.46</td>
<td>0.005*</td>
<td>1.76</td>
</tr>
<tr>
<td>Maximal knee flexion angle in stance (°)</td>
<td>0.59</td>
<td>0.028*</td>
<td>27.56</td>
</tr>
<tr>
<td>Plantar flexion angle at initial contact (°)</td>
<td>1.12</td>
<td>&lt;0.001*</td>
<td>-10.20</td>
</tr>
<tr>
<td>Maximal dorsiflexion angle in stance (°)</td>
<td>-0.57</td>
<td>0.043*</td>
<td>18.89</td>
</tr>
<tr>
<td>Maximal dorsiflexion angle in swing (°)</td>
<td>-1.30</td>
<td>&lt;0.001*</td>
<td>15.20</td>
</tr>
<tr>
<td>Maximal internal foot progression angle (°)</td>
<td>1.32</td>
<td>0.002*</td>
<td>-19.04</td>
</tr>
<tr>
<td>Maximal internal hip extension moment (Nm/kg)</td>
<td>-0.04</td>
<td>0.006*</td>
<td>0.86</td>
</tr>
<tr>
<td>Maximal internal knee flexion moment (Nm/kg)</td>
<td>-0.01</td>
<td>0.017*</td>
<td>0.19</td>
</tr>
</tbody>
</table>

GPS, gait profile score; Nm/kg, Newton meter per kilogram bodyweight; SD, standard deviation
The asterisks (*) indicate significance level at p < 0.05

Discussion: Children with DMD deviated 0.50° per year from TD children, indicating the GPS to be a promising, sensitive parameter for longitudinal follow-up. In addition, our results confirmed the three stages previously described by Sutherland et al. [1], because equinus gait, anterior pelvic tilt, hip flexion and internal foot progression angles increased, whereas cadence decreased with age. Furthermore, the pelvic motion increased with age, which could be a compensation for the reduced hip flexion/extension motion. Hip abduction increased with age, which is probably related to the increased step width. Previously, decreased internal hip extension moments were reported in children with DMD [5]. We confirmed the longitudinal increase of this compensation mechanism for weak hip extensors. Unexpectedly, internal knee flexion moments decreased with age. Due to increasing knee flexion contractures [6], the compensation mechanism for weak knee extensors may decrease with increasing age. Therefore, gait parameters may constitute promising markers to evaluate the efficacy of treatments. Studies with longer follow-up, allowing more complex mixed effect models, are required to determine the sensitive parameters that could predict loss of ambulation.

References

Acknowledgements: This study was supported by the Duchenne Parent Project NL: An integrated evaluation platform to explore the interaction between pathological and underlying muscle mechanisms, in growing children with Duchenne muscular dystrophy.

Disclosure Statement: The authors declare that they have no conflict of interest.
STRIDE-TO-STRIDE VARIABILITY OF ADAPTIVE TREADMILL WALKING

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INTRODUCTION
Adaptive treadmill (ATM) control allows the treadmill belt speed to change in real time in response to the user’s step length and anterior ground reaction force (AGRF) [1]. Walking with ATM control may be more similar to overground walking than fixed-speed treadmill (FSTM) walking with respect to kinematic variability, suggesting that ATM walking may be beneficial for rehabilitation [2]. However, it is unknown how people modulate their step length and propulsion during ATM walking to achieve their desired walking speed.

Both kinematic and stride-to-stride (STS) gait variability are believed to be healthy by allowing people to respond to perturbations or obstacles [3]. Detrended fluctuation analysis (DFA) examines the fluctuation of a variable from one cycle to the next and is often applied to gait data [4,5]. DFA calculates an exponent, α, which describes the persistence of the variable, or how likely fluctuations are to be followed by subsequent fluctuations in the same or opposite direction [4,5]. The STS variability of stride time and stride length during overground [4,6] and FSTM [5,6] walking are known, but the STS variability of ATM walking is less clear [7]. The purpose of this study was to determine the STS variability of spatiotemporal and propulsive variables during ATM walking in young healthy adults.

CLINICAL SIGNIFICANCE

This study examines the STS variability of step length and propulsion, which are frequently addressed by rehabilitation. If ATM walking encourages participants to maintain increases in step length or propulsion for subsequent strides, it may be beneficial for post-stroke gait rehabilitation. Furthermore, understanding how people alter their gait to control the ATM may help determine potential benefits of ATM walking during rehabilitation.

METHODS

Three young healthy subjects (3F, 0M; 23 ± 1.63 years; 1.57 ± 0.02 m; 60.53 ± 6.05 kg) participated in this pilot study. Subjects walked on an instrumented split-belt treadmill (Bertec Corp., Worthington, OH, USA) while motion capture data was collected from reflective markers (Motion Analysis Corp., Santa Rosa, CA, USA). Participants walked at their self-selected walking speed on the ATM for 10 minutes as suggested by the literature [6,7]. Speed was monitored to ensure that it did not deviate by more than ± 0.2 m/s. Subjects were given no more than five minutes to familiarize themselves with the ATM before beginning the trial.

The primary variables of interest were propulsive impulse (Ns) and step length (m), as those variables are the main inputs to the ATM controller [1]. Additionally, peak propulsive force (N) and stride time (s) were calculated to allow for further analysis of the ATM controller and comparison to data in the literature [5,7]. DFA was performed on the variables of interest as well as “shuffled” surrogate data to provide a control group [4,5]. Once data collection is complete, two-sample t-tests will be performed with a significance level of 0.05 to compare between the original and shuffled datasets for each variable.
RESULTS

Step length, stride time, peak AGRF, and AGRF impulse during ATM walking all had $\alpha > 0.5$, while all the shuffled data had $\alpha \approx 0.5$ (Figure 1).

DISCUSSION

During ATM walking, step length, stride time, peak AGRF, and AGRF impulse had $\alpha > 0.5$, which suggests persistence. Fluctuations of these variables from their mean values are more likely to be followed by subsequent fluctuations in the same direction. For example, a larger than average propulsive impulse is likely to be followed by additional larger than average propulsive impulses for at least a few strides. Clinically, this would translate to increased propulsion being maintained over consecutive gait cycles, which may be beneficial for post-stroke rehabilitation to combat weakness due to hemiparesis [8]. The uncorrelated shuffled data is consistent with white noise, which is random. The potential difference between the persistent ATM data and the uncorrelated shuffled data suggests that people manipulate their gait in a non-random manner while walking with ATM control. The results for step length and stride time agree with the literature for self-paced treadmill walking [7], while the peak AGRF and AGRF impulse results present one of the first analyses of the STS variability of propulsive mechanics.

Data collection is ongoing, so only three subjects were included, and standard deviations were very large. Power analysis determined that 20 subjects are necessary to determine if $\alpha = 0.5$ (uncorrelated) and $\alpha = 0.8$ (estimated from preliminary analysis) are significantly different at the 0.05 significance level. Future analysis with all subjects will be able to determine the persistence of step length, stride time, peak AGRF, and AGRF impulse during ATM walking.

REFERENCES


ACKNOWLEDGMENTS & DISCLOSURE STATEMENT

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The authors have no conflicts of interest to disclose.
DATA COLLECTION SETTINGS INFLUENCE SPATIOTEMPORAL WALKING PARAMETERS: EFFECTS OF WALKING SPEED AND PARTICIPANT SEX

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INTRODUCTION
Developments in wearable technology enable affordable, quantitative examination of walking outside laboratory settings [1]. Spatiotemporal walking parameters can differ between laboratory and indoor [2] and outdoor settings [3], and between indoor and outdoor settings [4]; however, no studies have made direct comparisons across more than two settings using the same measuring device and group of people. Additionally, previous research from our lab found sex-based differences in spatiotemporal walking parameters persist across multiple walking speeds [5]. The objective of the current study was to explore how spatiotemporal walking parameters are affected by setting and participant sex when walking at different self-selected speeds.

CLINICAL SIGNIFICANCE
Walking speed is a significant clinical measure used to assess functional and health status [6]. Important walking parameters such as gait speed may be dependent on setting, suggesting that assessment location could influence the outcomes and interpretation of clinic-based walking tests. As well, there may be sex-based walking differences among clients that could be clinically important.

METHODS
Healthy young adults walked in four different settings: laboratory (10m); a standard hallway (20m); a large indoor open space (20m); and outdoors along an open pathway (20m). Participants walked at three different self-selected speeds (slow, preferred, and fast) following standardized verbal instructions. The order of settings and walking speed conditions were block-randomized. Participants wore an inertial-based full body kinematic data collection system (Xsens Awinda, Culver City, CA, fs=60Hz). Stride velocity, stride length, cadence, double support percentage, and step width were extracted from the middle strides of each trial (~440 strides/participant). A 4 x 3 x 2 (setting x walking speed x participant sex) RM ANOVA was conducted for each dependent variable. Significant interaction effects were further investigated using multiple RM ANOVAs with adjusted pairwise comparisons. Violations of sphericity were corrected using the Greenhouse-Geiser correction and significance was set at $\alpha = 0.05$.

RESULTS
A total of 14 males (age = 23±4yrs; height = 181±7cm; mass = 79±14kg) and 15 females (age = 22±4yrs; height = 170±7cm; mass = 70±18kg) participated in the study. The main statistical analysis indicated significant setting x speed interactions for stride velocity ($F(4.331,116.944) = 2.916, p = .021$), stride length ($F(3.676,99.265) = 7.579, p < .001$), cadence ($F(3.884,104.857) = 4.580, p = .002$), and double support percentage ($F(3.503,94.573) = 14.790, p < .001$) (see Figure 1.). The walking parameters were not different between the lab and hallway but were generally different between the hallway, the large indoor area and the outdoor setting. There were greater effects of settings on stride parameters at slow and preferred speeds. There was a main effect of walking speed condition for step width (Slow = .26±.04m, Preferred = .28±.05m, Fast = .29±.04m, $F(1.310,35.361) = 24.599, p < .001$). There were significant main effects of participant sex for stride length (Male = 1.6±.1m, Female = 1.5±.1m, $F(1,27) = 5.814, p = .023$) and cadence (Male = 54±3strides/min, Female = 56±3strides/min, $F(1,27) = 7.033, p = .013$).
DISCUSSION

The current study found that basic spatiotemporal walking parameters are different between multiple data collection settings. Participants chose slower velocities in the lab and hallway settings when compared to a larger indoor setting, while the participants always walked faster in the outdoor setting. This aligns with previous work that found step durations to be longer in a laboratory setting compared to an outdoor park setting [3]. Setting-specific effects on stride cadence and length results in different stride velocity between settings. Setting-related differences in double support phase percentage are likely due to the changes in stride velocity [7]. Interestingly, there were no effects of setting for step width, which would suggest that perhaps settings influence walking patterns in the sagittal plane but not the frontal plane. The effect of the difference in length between the lab (10m) and the other settings (20m) warrants further investigation. Settings influenced stride parameters differently depending on the walking speed condition, suggesting that walking speed influences aspects of locomotor control that are affected by settings. These results suggest caution when speed-matching between non-clinical populations and clinical who may walk with slower speeds. There were sex-based differences for stride length and cadence, aligning with our previous work [5] and highlighting the importance of considering sex as an independent factor when interpreting walking data. Sex-based differences should be explored further in clinical populations. Walking is an important and clinically significant task due to its utility for monitoring health and functional status [6]. This study highlights the need for clinicians and researchers to consider the influence of setting when assessing and interpreting measurements of walking.

REFERENCES

Comparing the reliability of assessments of anterior cruciate ligament (ACL) pathology
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Introduction
Cases of ACL re-rupture after reconstruction are on the rise in paediatrics (Geffroy L et al, 2018). One of the issues highlighted with this are poor return-to-sport guidelines. Advice on when it is safe for patients to safely return, focuses on the biomechanical function of the knee by assessing the difference in force between the injured and healthy leg (Arden C et al, 2018). This study compared the reliability of a new assessment of ACL stability to the currently accepted test, the single leg hop for distance (Gokeler et al., 2017). The ‘new’ assessment is a diagonal hop onto a force plate, which assesses the forces applied through the knee in three vectors. Data were collected on two occasions to assess the test-retest repeatability using intraclass correlation coefficients (ICC). In preliminary work, diagonal hop analysis showed poor repeatability. In this study, all data collected from the diagonal hop were assessed using 4 different methods of analysis, in order to see if interpretation of different variables could increase the reliability. These data were compared to that of the single leg hop to compare the reliability of the two tests.

Methods
Participants were recruited from the lead researchers’ peers. They were invited to the gait lab on two occasions. These data were collated with data from a previous study. SPSS version 26 was used to process the data in the four different methods (see table). Each of these methods was chosen, as the research team concluded that analysing the data by looking at these variables may improve the reliability of the test.

Results
Table 1 shows the ICC values for each of the four analysis methods used for the diagonal hop, alongside the single leg hop. These increase in reliability as they approach 1.

Discussion
This indicates that assessing the area under the force-time curve produces the greatest reliability, as all the values are positive. However, no values show good-excellent repeatability (ICC>0.75) compared to the single-leg hop, which, on both legs showed good repeatability (0.75<ICC<0.90) (Koo and Li, 2016).

Single leg hop for distance appears to be a more repeatable outcome measure in a small cohort. Future work in a larger cohort, across different age-ranges would be required to determine if this was a generalisable finding.

References
Table 1: Analysis Methods for Diagonal Hop onto Force Plate and Single Hop

<table>
<thead>
<tr>
<th>LIMB</th>
<th>Axis</th>
<th>TTS (time to stabilisation) per</th>
<th>Using an average threshold to assess the TTS (average threshold calculated by collating the thresholds collected in each axis. This was chosen as using the same thresholds for each participant may increase reliability)</th>
<th>Assessing the TTS between 3-8s (in the Patterson and Delahunt method, the threshold comes from the SD between 7-12 seconds, the research team decided that assessing this earlier in the data in the 3-8 second period may increase the reliability as there was less spikes within the data during this time period)</th>
<th>Area under the force-time curve (A.U.C) (from the force-time curve produced, the AUC can be calculated. This was assessed between 0-2 seconds and standardised for weight, as this would have an impact on the initial ground reaction force)</th>
<th>Single leg hop for distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOMINANT</td>
<td>ML</td>
<td>0.364</td>
<td>0.356</td>
<td>0.262</td>
<td>0.023</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>*</td>
<td>*</td>
<td>0.177</td>
<td>0.166</td>
<td>0.779</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>0.235</td>
<td>*</td>
<td>0.056</td>
<td>0.655</td>
<td>-</td>
</tr>
<tr>
<td>NON-DOMINANT</td>
<td>ML</td>
<td>0.278</td>
<td>*</td>
<td>0.123</td>
<td>.3650</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.378</td>
<td>0.798</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>0.214</td>
<td>0.364</td>
<td>0.180</td>
<td>0.327</td>
<td>-</td>
</tr>
</tbody>
</table>

*SPSS 26.0 software produced an ICC<0
RACIAL DIFFERENCES IN RUNNING AND LANDING MECHANICS

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INTRODUCTION: Running and landing are commonly associated with risk for overuse injuries like stress fractures and impact injuries like tendon ruptures and anterior crucial ligament (ACL) tears. Racial health disparities in the incidence rates of these injuries have been documented between African Americans (AA) and white Americans (WA) ¹,²,³,⁴. It is unknown whether running and landing mechanics differ between racial groups and whether such differences, if they exist, could result in differential injury risk between racial groups and contribute to racial health disparities.

The purpose of this study was to (1) test the hypothesis that racial differences exist in running and landing mechanics between AA and WA, and (2) that such differences could be explained by a combination of anthropometric, strength, and health status factors in females only as these factors were previously unable to account for racial gait differences in males.

CLINICAL SIGNIFICANCE: Equivalency in running and landing mechanics measures between racial groups should not be assumed, especially considering racial disparities in running and landing-related injury rates. Racial diversity of study samples should be a priority to enable consideration of racial differences in research design, development of individualized treatment protocols, and optimization of preventative care across racial groups.

METHODS: 92 participants equally divided between self-identified race and sex were recruited. 3D motion capture and force plate data were recorded during 7 running (3.2 m/s) and 7 drop vertical jump (31cm box height) trials. Stance time and non-normalized time series data were exported from Visual 3D. Heart rate, blood pressure, stress questionnaires, activity level, anthropometry, lower extremity strength, and blood levels of glucose, interleukin-6, C-reactive protein, and cortisol were also collected. Outcome measures included impact peak, peak vertical ground reaction force (pvGRF), average and maximum loading rate (LR), and peak knee flexion (pKFA) and hip adduction angles (pHAdA) during running and pvGRF, average and maximum LR, impulse, pKFA, peak knee abduction angle (pKAbA), and frontal plane knee range of motion (fKROM) during landing.

All analyses were conducted after stratifying data by sex. Independent sample t-tests compared running stances time between AA and WA. Kinetic and kinematic multivariate ANOVA models determined effects of race (SPSS V26, α=0.05). Cohen’s D effect sizes were computed for each effect. For each outcome measure with an observed racial difference, race was locked as a predictor in a stepwise linear regression model. Independent variables
correlated with the outcome measure ($r \geq 0.35$) were included as predictors. If race was no longer significant in the regression model after the inclusion of the independent variable(s), those variables were considered to have explained the effect of race. Landing pvGRF, LR, impulse, and fKROM were log-transformed before analysis due to non-normality.

**RESULTS:** AA females had longer running stance times compared to WA females ($p=0.003$, $d=0.983$). AA males exhibited slower average LR ($p=0.046$, $d=-0.455$) and larger pvGRF ($p=0.036$, $d=0.548$) during running compared to WA males. Racial differences during running were unable to be explained by assessed factors. No racial differences were found during landing in males. AA females landed with greater fKROM compared with WA females ($p=0.033$, $d=-0.677$), which was explained by greater waist circumference and weaker knee extension strength in AA females.

**Table 1: Running [R] and landing [L] outcome measures with racial difference ($p<0.05$)**

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average LR (N/BW*s) [R]</td>
<td>pvGRF (N/BW) [R]</td>
</tr>
<tr>
<td>AA</td>
<td>42.97 (12.80)</td>
<td>2.56 (0.19)</td>
</tr>
<tr>
<td>WA</td>
<td>50.99 (8.68)</td>
<td>2.42 (0.19)</td>
</tr>
</tbody>
</table>

**DISCUSSION:** These results partly support our hypotheses concerning racial differences, although the possibility for additional factors to explain the observed racial differences in running and landing should be investigated further. These findings suggest the need for racially diverse normative running and landing datasets. Modifiable factors such as waist circumference and knee extension strength may provide targets for interventions aimed at injury prevention and targeted rehabilitation. The direction of the racial differences observed in the current study are in mixed agreement with the lower incidence of stress fractures in AA compared to WA but oppose the lower incidence of ACL injury in AA. The latter observation may be explained by lower physical activity levels and potentially limited sport specific landing training in the AA females based on the inclusion criteria. Future investigations should evaluate whether modifiable factors could be targeted to reduce or eliminate racial health disparities in athletes.


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**DISCLOSURES:** none
Comparison of Lower Extremity Dexterity Between Limbs With and Without Anterior Cruciate Ligament Reconstruction

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Introduction
Adolescent athletes are often injured while playing sports. One common non-contact injury is injury to the anterior cruciate ligament (ACL). The repair and rehabilitation for an ACL injury is lengthy, making it impactful to a young athlete’s career. One of the main goals of sports medicine is to prevent injuries and keep athletes on the field, making it important to study and understand these injuries in order to predict them before they happen.

The Lower Extremity Spring Dexterity (LESD) test is intended to measure the neuromuscular control of the lower limb. An unstable spring is compressed with the foot, and the force that can be maintained provides a measure of the limb’s dexterity. Should this test be able to predict injury risk through its ability to measure dexterity, it could be more efficient than current assessments. Current motion analysis tests, although very thorough and accurate, take a lot of time to set up and administer and are not very portable. The LESD test is compact and simple, making it fast and easy to test athletes outside of the lab or during sports team practices.

The purpose of this study was to determine the effectiveness of the LESD test in identifying ACL injuries. We hypothesized that patients post-ACL reconstruction would have lower dexterity than uninjured control participants.

Clinical Significance
Low dexterity scores on the LESD test could be a predictor of future injury risk indicating that preventative actions should be taken to prevent injury from occurring and keep the athlete in sports longer.

Methods
We evaluated 20 post-ACL reconstruction patients and 12 control subjects ages 8-20 years (Table 1). Participants were asked to place their foot flat on a platform and compress a spring to their greatest ability without letting the spring buckle. This was done with the femur at a 90° angle to the torso, and the knee also bent at 90°. The test was completed two times, left and right with the foot flat on the platform. The participants completed five second holds in which they compressed the spring as far as they could and held it. Data was collected for three successful trials of each limb and averaged for analysis. Side-to-side comparison between limbs was evaluated using paired t-tests, and groups were compared using linear regression with sex and age as covariates.
Results
There were no statistically significant differences in LESD scores (force and standard deviation of force) between the control and patient groups (Table 2) or between the reconstructed and contralateral limbs of the patients (Table 3).

Discussion
Contrary to our expectations, the patient group did not have lower dexterity than the control group. This may be a result of the patient group having recovered from surgery long enough to regain dexterity similar to uninjured athletes as the average time post-surgery was 8 months. At this stage in the rehabilitation process, recovered athletes are usually cleared to go back to playing sports, potentially making their abilities equal to or better than those who were not injured. Additional research should investigate whether LESD scores are lower earlier in the rehabilitation process and whether the LESD test can predict future injury risk.

Table 1: Demographics of patient and control groups

<table>
<thead>
<tr>
<th></th>
<th>Control Group</th>
<th>Patient Group</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>12.7 (3.34)</td>
<td>16.5 (1.81)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>Females</td>
<td>8 (33%)</td>
<td>24 (60%)</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>16 (67%)</td>
<td>16 (40%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Comparison of LESD measures between the control and patient groups

<table>
<thead>
<tr>
<th></th>
<th>Control Group (n=41)</th>
<th>Patient Group (n=20)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LESD force</td>
<td>47.2 (8.09)</td>
<td>48.3 (12.4)</td>
<td>0.982</td>
</tr>
<tr>
<td>LESD SD</td>
<td>0.54 (0.24)</td>
<td>0.62 (0.43)</td>
<td>0.31</td>
</tr>
</tbody>
</table>

LESD scores are reported in mean (SD) Newtons

Table 3: Comparison of LESD measures of the injured and non-injured side of the patient group

<table>
<thead>
<tr>
<th></th>
<th>Control Leg (n=18)</th>
<th>Injured Leg (n=18)</th>
<th>Difference</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LESD force</td>
<td>50.8 (8.1)</td>
<td>47.2 (12.6)</td>
<td>3.6</td>
<td>0.417</td>
</tr>
<tr>
<td>LESD SD</td>
<td>0.61 (0.3)</td>
<td>0.59 (0.4)</td>
<td>0.02</td>
<td>0.84</td>
</tr>
</tbody>
</table>

LESD scores are reported in mean (SD) Newtons
Two non-injured legs had no data collected due to fatigue.

References

Acknowledgements
Thank you to the research staff at CHLA. Access to the LESD device/test was provided at no cost by the system manufacturer Neuromuscular Dynamics, LLC. The scientific content of this study is the sole work of the authors and was not influenced or reviewed by the company.

Disclosure
Nothing to disclose.
INTRODUCTION

Less than ten percent of pitching studies focus on athletes younger than 18 years old. Given the lack of investigation, there is a relative paucity of literature focused on establishing correlations between kinematic parameters and athletic performance metrics such as velocity, accuracy, and in particular, spin rate due to its impact on ball flight and pitch trajectory. To this end, our study aimed to investigate the kinematic properties of the wrist during the pitching motion as they correlate to ball spin rate in adolescent subjects. We hypothesized that adolescent pitchers with higher wrist flexion velocity would have higher ball spin rates (as measured by both total and true spin). Additionally, we hypothesized there would be correlating biomechanical parameters upstream in the kinematic chain (i.e. maximal shoulder external rotation angle, elbow extension velocity) with quantifiable changes in wrist kinematics, ultimately impacting ball spin rate.

CLINICAL SIGNIFICANCE

Establishing relationships between wrist kinematics and ball spin-rate, and elucidating the connection between the wrist and elements upstream in the biomechanical chain will help identify potential inefficiencies in youth pitching techniques that can lead to overuse injuries. These findings can be used to inform coaching changes with the goal of preventing injury.

STUDY METHODS

Seventeen adolescent male baseball pitchers (age: 16.1 ± 0.9 years, height: 182.0 ± 5.6 cm, weight: 78.1 ± 9.1 kg) were recruited from a local competitive youth baseball program to participate in this study. Each pitcher had at least 4 years of pitching experience. No pitcher had a current complaint of arm pain or a history of throwing arm surgery. The Institutional Review Board at the Medical College of Wisconsin approved the study. All subjects signed assent forms, and informed consent was obtained from their parents before involvement in the study. Subjects underwent a single testing session involving a biomechanical pitching analysis. Eight Raptor-E Cameras (Motion Analysis Corporation, Santa Rosa, CA) were used to capture the motion of pitchers at 300 frames per second. The motion analysis system was set up surrounding a pitching mound, where each participant threw 10 fastballs. Pitch speed, total spin rate and true spin rate were measured using a Rapsodo Pitching Unit (Rapsodo, Brentwood, MO). The three fastest strikes were analyzed. Marker data was identified and filtered using a 13.4 Hz fourth-order Butterworth low-pass filter in Cortex software (Motion Analysis Corporation, Santa Rosa, CA), and then processed using a biomechanical model in Visual 3D software (C-Motion, Germantown, MD). Statistical analysis was completed using IBM SPSS statistical analysis software (version 26, IBM Corporation, Armonk, NY). Scatterplots were examined for linearity to determine appropriate correlation test. Associations examined were linear, thus two-tailed Pearson correlation coefficients were used to determine correlations between spin rate and biomechanical metrics. A significance level of .05 was used.

RESULTS

The subjects had an average fastball velocity of 77.5 ± 4.0 mph, with an average total spin of 1872.2 ± 122.4 rpm and an average true spin of 1729.9 ± 221.2 rpm. Maximum wrist flexion velocity and maximum external rotation of the shoulder (MER) (Table 1) were within cited ranges for adolescents. A modest positive correlation was found between wrist flexion velocity and true spin rate.
(Table 2), but it did not rise to the level of statistical significance. However, significant negative associations were found between two kinematic metrics at the wrist and true spin rate. At MER, the degree of wrist extension and degree of radial deviation were negatively correlated with the true spin rate (Table 2). Additionally, we found that maximal wrist flexion velocity had a strong inverse relationship with the degree of external rotation of the shoulder (Table 2).

Table 1. Kinematic Data at maximum shoulder external rotation.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Wrist Flexion Velocity (°/s)</td>
<td>1479.3 ± 386.2</td>
</tr>
<tr>
<td>Wrist Extension (°)</td>
<td>-7.2 ± 14.4</td>
</tr>
<tr>
<td>Wrist Radial Deviation (°)</td>
<td>-42.2 ± 9.1</td>
</tr>
<tr>
<td>Shoulder External Rotation (°)</td>
<td>167.1 ± 12.8</td>
</tr>
</tbody>
</table>

Table 2. Significant correlations between pitching biomechanics and spin rate

<table>
<thead>
<tr>
<th>Metric</th>
<th>r</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist Extension (°) and True Spin Rate</td>
<td>-0.291</td>
<td>0.038*</td>
</tr>
<tr>
<td>Wrist Radial Deviation (°) and True Spin Rate</td>
<td>-0.383</td>
<td>0.006**</td>
</tr>
<tr>
<td>Max Wrist Flexion Velocity (°/s) and Shoulder MER (°)</td>
<td>-0.539</td>
<td>0.000**</td>
</tr>
</tbody>
</table>

* Correlation is significant at the P<0.05 level (two-tailed)
** Correlation is significant at the P<0.01 level (two-tailed)

DISCUSSION

The data above suggest a few performance adjustments that can be made in order to ensure a greater degree of spin in adolescent fastball pitches. Limiting the degree of wrist extension at MER could lead to a higher true spin rate. Additionally, the relationship between the degree of radial deviation at MER and true spin rate provides additional evidence for the emphasis on minimal deviation of the wrist for optimal fastball pitch technique. Lastly, the negative correlation between max wrist flexion velocity and shoulder MER suggests a possible compensatory relationship for generating spin and velocity in the absence of significant degree of external rotation. Further investigation into this relationship is required, however, this relationship could help inform coaching changes to emphasize shoulder flexibility to maximize MER with the goal of preventing excess wrist flexor strain. Future research will also investigate subject anthropometrics, such as height and limb lengths, and their correlations with spin rate.

REFERENCES


ACKNOWLEDGEMENTS

This study was funded by the Medical College of Wisconsin Department of Orthopaedic Surgery.

DISCLOSURE STATEMENT

The authors have nothing to disclose.
CHANGES IN LOWER EXTREMITY KINEMATICS BASED ON JUMP DISTANCE OF A DROP VERTICAL JUMP

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INTRODUCTION
Rehabilitation and injury prevention research utilizing motion analysis can be crucial for identifying patient’s underlying biomechanics and highlighting deficiencies in current return-to-play assessments. One task commonly used in functional performance testing and sports medicine research is the drop vertical jump (DVJ). This task requires the subject to perform a dynamic, game-like movement, and has been shown to be a strong predictor of injury [1]. However, numerous variations of the DVJ task are used across motion analysis labs and with various patient populations. In order to use the most appropriate version, it is important to first determine whether kinematic outcomes are altered based on task variations.

CLINICAL SIGNIFICANCE
Motion analysis of high-impact, dynamic tasks can be utilized in sports medicine to inform treatment. However, whether a movement assessment is used to track progress during rehabilitation or to identify injury risk in relatively healthy athletes, it is important to understand the biomechanical response elicited by each task in order to accommodate different populations.

METHODS
Nineteen healthy subjects (10 female, aged 21.6±4.0 years) were prospectively enrolled into an IRB approved study and tested in the Movement Science Lab. Subjects performed three different DVJ tasks that varied by jump distance based on participant height from a plyometric box to two force plates (FPs). Detailed descriptions and task instructions are included in Table 1, and a diagram of the task setup is shown in Figure 1.

Table 1. Description of the different types of DVJ tasks.

<table>
<thead>
<tr>
<th>DVJ</th>
<th>Box Distance (x)</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVJ_{half}</td>
<td>1/2 subject height</td>
<td>Jump horizontally landing with one foot in each FP, then perform a maximal vertical jump</td>
</tr>
<tr>
<td>DVJ_{third}</td>
<td>1/3 subject height</td>
<td>Jump horizontally landing with one foot in each FP, then perform a maximal vertical jump</td>
</tr>
<tr>
<td>DVJ_{drop}</td>
<td>Adjacent to FP</td>
<td>Drop off the box landing with one foot in each FP, then perform a maximal vertical jump</td>
</tr>
</tbody>
</table>

Three successful trials of each DVJ task were captured. Kinematic data were collected at 240hz with a 14-camera motion capture system (Vicon Motion System Ltd, Denver, CO,
USA), and force plate data were collected at 2880hz. Marker trajectories were filtered using a Woltring filter with a predicted mean square error of 10mm². Forceplate data were filtered using a 4th-order low-pass Butterworth filter with a cutoff frequency of 16hz. Kinematic data were calculated at initial contact (IC) and across the first landing phase. To analyze each task, the average of the successful trials for each task was computed. Wilcoxon signed rank tests were performed to compare the differences between task type (α = 0.05).

RESULTS

Hip flexion at initial contact (IC) increased as the box distance increased (Table 2). Alternatively, knee flexion at IC decreased as the box distance increased. Across the full landing phase, maximum hip flexion was reduced during the DVJdrop compared to both the DVJhalf (p = 0.001) and the DVJthird (p = 0.014). Although a difference was seen in maximum hip flexion, maximum knee flexion did not differ during any of the three different box distances. The maximum vertical normalized ground reaction force (vGRF) produced during the landing phase was increased as the box distance increased.

<table>
<thead>
<tr>
<th>Variable</th>
<th>DVJhalf</th>
<th>DVJthird</th>
<th>DVJdrop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Flexion IC (°)</td>
<td>43.6 ± 9.8</td>
<td>41.9 ± 8.2</td>
<td>39.2 ± 10.0</td>
</tr>
<tr>
<td>Knee Flexion IC (°)</td>
<td>14.2 ± 6.0</td>
<td>16.2 ± 7.0</td>
<td>19.5 ± 9.2</td>
</tr>
<tr>
<td>Max Hip Flexion (°)</td>
<td>94.4 ± 12.2</td>
<td>93.8 ± 12.3</td>
<td>90.8 ± 14.3</td>
</tr>
<tr>
<td>Max Knee Flexion (°)</td>
<td>94.4 ± 13.6</td>
<td>94.4 ± 12.6</td>
<td>95.5 ± 13.0</td>
</tr>
<tr>
<td>Max vGRF (Nm/kg)</td>
<td>16.4 ± 3.5</td>
<td>15.4 ± 3.3</td>
<td>14.5 ± 2.3</td>
</tr>
</tbody>
</table>

Note: 3 indicates significant difference from DVJthird task; D indicates different from DVJdrop task

DISCUSSION

The purpose of this work was to determine whether kinematics changed based on task variation. A shift in landing strategy is seen during the horizontal jump, and, as the box distance increases, the legs are more outstretched in front of the body requiring increased hip flexion and a straighter knee. These findings emphasize the importance of understanding the different movement patterns associated when assessing variations in the DVJ. For example, the DVJdrop may be more appropriate early in a patient’s rehabilitation program given that max hip flexion and vGRF were both reduced. In contrast, a patient cleared to return-to-sport who has improved neuromuscular motor control may be tested using the DVJhalf in order to determine how they biomechanically respond to increased impact. While this pilot data was collected in young adults, future work will need to focus on evaluating these task variations in a youth population.


ACKNOWLEDGEMENTS This work originated through collaboration with the Motion Analysis Research Interest Group of the Pediatric Research in Sports Medicine Society. In addition, the authors acknowledge support from the Scottish Rite Research Program.

DISCLOSURE STATEMENT Co-author KTF is a GCMAS executive board member. All other authors have no conflicts of interests to disclose.
Keynote 1

Kenton R. Kaufman, Ph.D., P.E.

What's in your toolbox?

Date/Time: Tuesday June 8th, 11:40-12:40 (UTC-4)

Dr. Kenton R. Kaufman is the W. Hall Wendel Jr Musculoskeletal Research Professor, Professor of Biomedical Engineering, Director of the Motion Analysis Laboratory, and Consultant in the Departments of Orthopedic Surgery, Physiology and Biomedical Engineering at Mayo Clinic. He is a registered professional engineer. Dr. Kaufman's primary area of research is musculoskeletal rehabilitation science. Throughout his career, he has been funded by NIH, NSF, and DOD for projects aimed at improving the mobility of disabled individuals. He has served as the Co-Principal Investigator of a multi-institutional, interdisciplinary network working to develop advanced musculoskeletal rehabilitation for our severely wounded servicemen and women. This broad-based and integrated clinical and translational research program was dedicated to improving the rehabilitation rate and outcome in military service members and veterans who have suffered major limb trauma. He is currently leading a national effort to develop a Limb Loss and Preservation Registry, which will collect data that will improve prevention, treatment and rehabilitation efforts for this population. He is the co-inventor of the SensorWalk, a stance-control orthosis on the commercial market. He has had research funding totaling $62 million, has published over 260 scientific peer-reviewed papers, and holds 6 US patents and one international patent.

Dr. Kaufman has received numerous awards and honors for his work, including the American Society of Biomechanics (ASB) Borelli Award for outstanding career accomplishment, ASB Goel Award for Translational Biomechanics, ASB Young Investigator Award, Excellence in Research Award and the O'Donoghue Sports Injury Research Award from the American Orthopedic Society for Sports Medicine, Clinical Research Award from the American Academy of Orthopedic Surgeons, Research Award from the American Academy of Orthotists and Prosthetists, Best Scientific Paper Awards from the Gait and Clinical Movement Analysis Society, Frank Stinchfield Award from The Hip Society, John Charnley Award from The Hip Society, John Insall Award from The Knee Society, Thranhardt Award from the American Orthotic and Prosthetic Association, and the Clinical Biomechanics Award from the International Society of Biomechanics. He has been recognized as a Distinguished Alumnus (2007) and Distinguished Engineer (2008) at South Dakota State University. The results of his research have also led to many articles for the general population. His work has been cited in the Washington Post, Preventive Medicine, Men's Health, WebMD, and Stars and Stripes. He
Dr. Kaufman has also appeared on the nationally syndicated shows Medical Edge and Bottom Line on Your Health.

Dr. Kaufman currently serves on the Medical Advisory Board for the American Orthotic and Prosthetic Association and the Research Advisory Board for Shriners Hospitals for Children. He serves on the editorial boards of Gait and Posture, and Prosthetic and Orthotics International. Dr. Kaufman has served as a reviewer for NIH, CDC, NIDRR, DOD, and the VA. He has served as chair of review committees for NIH and DOD, on the National Advisory Board for Medical Rehabilitation Research at NIH, and on the National Advisory Council for Nursing Research at NIH. Dr. Kaufman is a Past President of the American Society of Biomechanics. He is a founding member and Past President of the Gait and Clinical Movement Analysis Society. He is a Fellow in the American Institute for Medical and Biological Engineering, American Society of Biomechanics, American Society of Mechanical Engineers, and International Society of Biomechanics.


**Objectives:**

*At the completion of this talk, the audience will be able to*

1. **List 3 methods for quantifying human movement**
2. **Describe the advantages and disadvantages of each method**
3. **Explain when each method should be used.**
Introduction: Improper pitching mechanics has been identified to play a large role in youth baseball pitcher injury risk.\textsuperscript{1,2} Validated clinical movement screens are used to estimate an athlete’s risk of injury and performance. The OnBaseU screen is a clinical assessment tool comprised of 16 movement tests that was developed to identify efficient/deficient movement patterns key to baseball pitching. However, it is unclear how the screen components relate to pitching mechanics. To elucidate the value of this screen, this study will compare portions of the OnBaseU assessment tool with the corresponding pitching kinematic metrics collected using a motion capture system. Additionally, the OnBaseU seated trunk rotation test will be compared to an equivalent test measured using motion capture to determine the reproducibility of using visual assessment to evaluate players according to OnBaseU scoring criteria.

Clinical Significance: The results of this study determine whether portions of the OnBaseU clinical movement screen can be used to estimate corresponding pitching mechanics and evaluate reproducibility of one OnBaseU test.

Methods: OnBaseU and motion capture pitching evaluations were completed for 102 youth pitchers (age = 15.2 ± 1.29 years; height = 70.9 ± 3.41 in; weight = 168 ± 30.4 lbs) on the same day. A motion capture seated trunk rotation test was also conducted on 80 of the 102 youth players (age = 15.2 ± 1.32 years; height = 70.7 ± 3.50 in; weight = 167 ± 30.6 lbs). OnBaseU testing was performed by a certified strength & conditioning coach and OnBase University with over 12 years of experience. Motion data were collected at 250 Hz using the 40 reflective marker set required for PitchTrak (Motion Analysis Corporation, Santa Rosa, California) and a twelve-camera motion analysis system (Qualisys AB, Göteborg, Sweden). Pitches were thrown at regulation distance from a mound that met major league specifications. Participants conducted a normal warmup, followed by 4 fastballs, 4 changeups, and 4 breaking balls. Kinematic data were obtained for 3 fastballs using Visual3D (C-motion, Germantown, MD). For quantitative analysis, OnBaseU evaluations were assigned points where best to worst performance was awarded the most to least points, which were expressed graphically as “excellent,” “good,” “moderate,” “fair,” and “poor”. A non-parametric Kruskal-Wallis test with a Chi-squared approximation and a Dunn’s post-hoc were performed using JMP (JMP, Cary, NC) to test if there were differences between overall tests and individual groups.

Results: Motion capture metrics and OnBaseU screens from 102 pitchers were compared. All OnBaseU and analogous motion capture metric comparisons yielded non-significant differences, except for stride length (%body-height) vs. side step walkout test (p-value < 0.01; Figure 1B). Dunn’s post-hoc results showed a statistically significant difference between the ‘poor’ and ‘excellent’ categories for this comparison (p-value <0.01; Figure 1B). The difference between average OnBaseU seated trunk rotation test and motion capture seated trunk rotation test results were not statistically significant (Figure 2).
Discussion: OnBaseU seated trunk rotation, push-off and shoulder 90/90 tests were not found to be predictive of corresponding pitching mechanics. Stride lengths (% body height) of players who scored “poor” and “excellent” on the OnBaseU side step walkout test groups were statistically significantly different (p<0.01). These two side step walkout test scoring categories may, therefore, have value in predicting pitching mechanics. Non-significant results of OnBaseU and motion capture seated trunk rotation tests indicate that the evaluator cannot visually distinguish trunk rotation angle to the level of precision that is called for by the screen. OnBaseU scoring criteria should be adjusted such that the screen can be conducted correctly. Though not predictive of pitching mechanics, OnBaseU tests may inform the cause of poor pitching mechanics when used in combination with motion capture analysis. The data presented in this study can be used to gauge the value of the OnBaseU clinical assessment screen for baseball pitching mechanics and, therefore, can serve as an aid to coaches, trainers, and players in deciding how this screen should best be applied.

Comparison of Trunk Kinematics at 6 and 24 months in Patients having Scoliosis Correction with Vertebral Body Tethering or Posterior Spine Fusion

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Spencer Warshauer MS, 1 John Gaughan PhD MBA, 2 Ross Chafetz PT DPT PhD1 Email: rchafetz@shrinenet.org

Introduction: 3D motion analysis is powerful tool for evaluating trunk flexibility in patients with adolescent idiopathic scoliosis (AIS). Traditional correction of AIS is a posterior spine fusion (PSF). Although PSF will correct a curve, it has been shown to decrease spine flexibility with more distal lowest instrumented vertebrae (LIV) selection. Anterior vertebral body tethering (VBT) is an alternative treatment that can maintain or reduce curve progression. VBT involves the principle of growth modulation where a flexible cord is attached to the convex side of the curve to asymmetrically compress the vertebral growth plates and gradually correct the deformity as the child grows1-2. In addition to potentially correcting a curve, it is postulated that VBT is superior to PSF for preservation of spine motion.

Clinical Significance: One of the primary concerns patients with AIS have is loss of trunk flexibility, in particular, adolescents participating sports such as gymnastics, cheerleading, baseball, and basketball. This is the only study that compares the trunk flexibility outcomes of PSF and VBT for correction of AIS.

Methods: This is a single center retrospective review of a consecutive series of skeletally immature patients with AIS who underwent motion analysis as standard of care prior to PSF or VBT and again at 6 months (n=193) and 2 years (n=57) post-op. Patients were stratified by LIV: <L1 (VBT n=80; PSF n=34), L2 (VBT n=8; PSF n=12), L3 (VBT n=22; PSF n=24), L4 (VBT n=3; PSF n=13). A Vicon camera system (Vicon Vantage, Oxford, UK) was used to complete 3D kinematic evaluations of trunk forward flexion, sum of bilateral side bending and sum of bilateral rotation. A three-segment model of the pelvis, lumbar segment and thoracic segment was used to evaluate trunk motion3. Marker set included a C7 triad, an L1 triad, 2 clavicle markers, 2 rib markers, 2 ASIS, 2 Iliac crest markers, and 2 PSIS markers For this study, only thoracic to pelvic motion was analyzed. Statistical analysis included an ANOVA for repeated measures between time points and a simple linear regression for changes from preoperative to 6 and 24 months by LIV level for PSF forward flexion.

Table 1: Comparison of Kinematic Trunk Motion at 6 and 24 Months in Patients with AIS undergoing PSF or VBT
Results: Comparing PSF and VBT at six months, there was a statistical difference for each LIV group (p<0.001), except for L4 rotation at 6 months and L1/L2 lateral bending at 2 years (Table 1). For PSF, the motion lost with forward flexion at 6 months postop for each added fused level progressively increased from L1 12º, L2 20 º, L3 28º to L4 35º (Figure 1). Using simple linear regression, 9 degrees of forward flexion motion was lost for each LIV added. A similar relationship at 6 months was found for lateral bending with motion loss increasing from 22º at L1 to 38º at L4 (figure 1). For VBT, there was no relationship between progressive LIV and motion lost. For forward flexion in patients that had VBT, 6 degrees or less of motion was lost for each LIV group. For rotation and side bending, all motion lost was less than 20 degrees for each group.

![Figure 1: Comparison of PSF and VBT changes at 6 months from Pre- to Post-Operative for Forward Flexion and Lateral Side Bending](image)

Discussion: PSF patients lost significant trunk motion in all planes, which increased with each additional LIV from <L1-L4, with the greatest loss in forward flexion. VBT patients experienced some loss of trunk motion at 6 months and 2 years post-op but significantly less than PSF. This study is limited in that it is retrospective, there is a limited number of patients with 24-month follow up, and potential baseline difference due to surgery assignment (selection bias). Despite the study limitations, the results strongly suggest that patients having VBT maintain significant trunk flexibility. Future studies should determine if the motion spared by VBT translates into functional activities such as activities of daily living and participation in sports.

References

Disclosure Statement: the authors declare no conflict of interest
USING REAL-TIME FEEDBACK WITH MOTION CAPTURE TO MEASURE UPPER EXTREMITY WORKSPACE: A PRELIMINARY EVALUATION

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1Pennsylvania State University Harrisburg, Middletown, PA, USA; 2Shriners Hospital for Children, Philadelphia, PA, USA; 3University of Delaware, Newark, DE, USA

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INTRODUCTION

Clinical upper extremity (UE) functional assessments have been criticized for being insensitive to certain meaningful differences in UE function [1]. More precise motion capture measurements are typically constrained to a set of static postures and/or limited dynamic motions relevant to the patient population [2] and may provide an incomplete assessment of a patient’s available UE functionality. Similar to clinical assessments, motion capture analyses are also reliant on patient compliance with traditional task-based data collection protocols, which can be challenging to collect on younger patients.

Assessing UE functionality by utilizing a less prescriptive and more game-like environment may provide the opportunity to obtain precise measures of UE function on young children [3]. The measurement of reachable workspace can be obtained in such an environment. Reachable workspace provides a precise numerical and visual assessment of global UE function by quantifying the surface area or volume that the patient can reach with his or her hand [4] and represents an emerging tool among UE surgeons [5]. Incorporating real-time visual feedback with motion capture into current UE workspace measures can provide an innovative way to engage patients [3] while also ensuring acquisition of the patient’s entire available workspace.

This study provides a preliminary evaluation of a new clinical tool that incorporates real-time visual feedback with motion capture to quantify UE reachable workspace.

CLINICAL SIGNIFICANCE

A reachable workspace tool with real-time feedback may provide a more complete measure of global UE function, facilitate testing in younger patients to obtain previously unavailable pre-operative data, and provide a highly visual and intuitive depiction of patient function for clinicians, patients, and caretakers.

METHODS

Trunk and UE segment orientations of five children with brachial plexus birth injuries (7-12 years) were measured using motion capture (VICON, Centennial, CO). An array of virtual targets surrounding each participant was created using spherical coordinates. Custom LabVIEW software (National Instruments, Austin, TX) displayed targets with real-time feedback from motion capture (Fig. 1). Movements of a red sphere were controlled in real-time based on the position of the subject’s hand marker relative to the trunk (Fig. 1). Once the red sphere moved within a threshold of a target, that target would disappear. Targets throughout the spherical space were displayed sequentially by octant (e.g., upper hemisphere, right side, anterior) until all targets were completed or until Figure 1: Real-time feedback display. Green targets and red real-time sphere.
the subject was unable to reach any more. Participants completed trials on their affected and unaffected limbs under two conditions - with and without real-time feedback. Reachable workspace space was calculated for each hemisphere (e.g., anterior, superior, etc.) as the points reached by the hand expressed as a percentage of the potential reachable points along the outer surface area.

DEMONSTRATION

Unaffected limb workspace was greater than affected limb workspace for all subjects (Fig. 2). Workspace with real-time feedback was greater than workspace without real-time feedback on both limbs for all subjects (Fig. 2). Workspace visualizations showed these differences and facilitated easy identification of regions with the greatest impairments (Fig. 3).

SUMMARY

This preliminary assessment demonstrates the viability of a reachable workspace tool with real-time feedback to facilitate data collection and provide a more complete measure of global UE function that is capable of clearly illustrating areas of impairment.

REFERENCES


ACKNOWLEDGMENTS


DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

Figure 2: Differences in % area reached by region across all subjects (mean ± SD) between limbs (unaffected minus affected) and between conditions (with- minus without real-time feedback).

Figure 3: Unaffected (A [left arm]) and affected (B [right arm]) limb workspace of a representative subject for the anterior and superior hemispheres displaying reduced reach on the affected side, particularly in posterior and across-the-body regions.
ASSESSMENT OF APPROACHES TO ESTIMATE SCAPULAR ORIENTATION IN CHILDREN WITH BRACHIAL PLEXUS BIRTH INJURY

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INTRODUCTION

Glenohumeral (GH) joint dysplasia and range of motion (ROM) deficits as well as scapulothoracic (ST) compensations are commonly observed in children with brachial plexus birth injury (BPBI) [1,2]. Interventions are employed to improve GH function; however, knowledge of dynamic GH orientation is lacking due to challenges in measuring dynamic scapular orientation and the inability to distinguish between GH and ST contributions to humerothoracic (HT) motion. The acromion marker cluster (AMC) has been used to estimate ST motion in healthy adults [3], but was deemed unsuitable for children with BPBI [4]. An updated AMC method using double calibration (D-AMC) to enable interpolation of ST orientations based on HT elevation [5] has been recommended in healthy adults [3], but has yet to be evaluated in children with BPBI. A linear model (LM) approach utilizing measurable HT orientation and acromion process position to estimate ST orientation also has been validated in healthy adults [6], but has not been assessed in children with BPBI. This study evaluates the abilities of the LM and D-AMC to estimate ST orientation in children with BPBI in functional arm postures by comparing to palpation.

CLINICAL SIGNIFICANCE

Accurate measurement of ST motion is needed for objective evaluation of dynamic ST and GH joint motion, which will facilitate surgical planning and outcomes assessment in BPBI.

METHODS

Trunk and upper extremity segment orientations of 17 children with BPBI were measured with motion capture (VICON, Centennial, CO). Participants completed 11 static positions encompassing a full spectrum of shoulder ROM. In each position, two additional scapular markers were placed to determine ST orientation. Helical and Euler YXY HT angles and Euler YXZ ST angles were calculated. Six of the static positions were used as test positions to assess LM and D-AMC accuracy based on their functional relevance to BPBI. Test positions targeted single plane movements of arm elevation (abduction) and rotation (external rotation, internal rotation) as well as more complex functional movements involving a combination of arm elevation and rotation (hand-to-mouth, hand-to-nape, and hand-to-spine). The LM used a “leave one out” approach to develop a unique LM for each test position using multiple linear regression on the data from the other ten positions to generate equations that estimated ST angles based on HT orientation (helical XYZ and Euler Y”) and acromion process position. LM and D-AMC ST angle estimates were compared to palpation using a three-way repeated measures ANOVA (factors: method, test position, ST axis). Average root mean square errors (RMSE) for each approach also were calculated across all subjects and compared against a range of published AMC values for healthy adults that were deemed acceptable for use [3].
RESULTS
The D-AMC was similar to palpation across all positions and ST axes while the LM differed from palpation on ST internal/external rotation in the external rotation position ($p=0.011$, mean diff.=$5.4^\circ$) and on ST anterior/posterior tilt in the abduction and hand-to-mouth positions ($p=0.041, 0.049$, mean diffs.=$2.6^\circ, 4.3^\circ$, respectively). RMSE values of the D-AMC and particularly the LM were mostly at or beyond the upper range of past AMC analyses on healthy adults, especially for more complex, multiplanar arm postures (Fig. 1). The LM and, to a lesser degree, the D-AMC produced errors for some subjects that are likely clinically meaningful (e.g., >$10^\circ$).

DISCUSSION
Despite each method’s statistical similarity to palpation, RMSE values indicate that accurately estimating ST orientation in children with BPBI is more difficult than in healthy adults. Limited HT motion and abnormal ST motion in BPBI likely create a more challenging scenario resulting in larger RMSE values. The LM’s and, to a lesser degree, the D-AMC’s reduced accuracy at test positions involving multiplanar arm movements indicates that both methods are less suitable for assessing more complex functional movements. The LM’s greater likelihood of producing errors that are potentially clinically meaningful for an individual participant showed that this method is less consistent than the D-AMC for assessing BPBI. The D-AMC may be appropriate for estimating ST kinematics in BPBI for certain motions/scenarios, however, caution should be exercised when interpreting results for more complex, multiplanar motions and/or on an individual patient basis.

REFERENCES

ACKNOWLEDGMENTS
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DISCLOSURE STATEMENT
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Upper extremity prosthetic selection influences loading of transhumeral osseointegrated systems
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Introduction: The abandonment rate of prosthetic devices in transhumeral amputees is as high as 40\%, with “too much fuss” being the number one reason for rejection [1]. Recent initiatives to create an upper extremity prosthesis with capabilities similar to a natural limb have enabled amputees to closely achieve pre-amputation function. In parallel, research on percutaneous osseointegrated (OI) endoprostheses for prosthetic attachment has rapidly progressed. By eliminating sockets, OI increases range of motion and humeral rotation that was previously impaired. These advancements allow amputees the possibility of accomplishing more complex motions and improving daily independence. Previous research examined loads on a transhumeral OI system for high demand activities using non-amputee motion to estimate forces and moments on the transhumeral amputation site. Though this gave a better idea of how a high performing individual with transhumeral amputation loads an OI device, it does not look at the impact of a prosthesis on loads during the same activities. In this study, we revisited the data of Drew and Izykowski et al. [2] and modified subject models to reflect the mass distribution of an upper extremity prosthesis after OI endoprosthesis implantation. Models reflecting 4 levels of prosthetic limb complexity, from body powered devices to the state-of-the-art advanced prosthetics, were applied to the previous motion capture data and allowed us to quantify the loads experienced at the simulated bone-implant interface in a transhumeral OI system.

Clinical Significance: Gradual loading of OI implants is recommended during early rehabilitation to ensure bone ingrowth [3], but overloading can damage ingrowth as it forms [4-7]. These data provide clinicians developing post-operative rehabilitation protocols an estimate of how the choice of prosthesis changes the load experienced at the transhumeral OI attachment.

Methods: Upper extremity motion capture data from Drew and Izykowski et al. [2] was used for the present study. This included 40 non-amputee subjects performing six activities: jumping jack, jug lift, underhand toss, jogging, rapid internal rotation, and briefcase carry. Virtual amputations were created at 25, 50, and 75\% humeral length. A single prosthetic arm model was created in Visual3D for each of four categories of limbs based on hand type as a surrogate for overall complexity: body powered, myoelectric hook, myoelectric hand, and advanced prosthetic limb. Elbow width, wrist width, hand length, forearm mass, hand mass, forearm center of mass, and hand center of mass were altered for each prosthetic arm category. A pylon connection was implemented for all models. All prosthetic arm models were applied to each subject’s motion data for all three virtual amputation lengths (Fig 1).

We examined loading estimations (bending and torsional moments and axial forces) in the same manner as Drew and Izykowski et al. [2] for the intact model and each prosthetic model (body powered, myoelectric hook, myoelectric hand and advanced prosthetic) at different amputation levels (25\%, 50\% and 75\%, Fig 1). We then employed the multivariate regression approach to simultaneously model force measurements. To assess the differences, we estimated the
percentage difference in the force measurements (1) between each prosthetic model to the intact model, (2) between prosthetic models, and (3) between amputation lengths. All statistical comparisons were performed using statistical software R at an a priori significance of 0.05.

**Results:** For all activities that did not have a weight in hand, the body powered prosthesis decreased bending moments 67-87% (range of means for each activity including the 25%, 50%, and 75% lengths), torsional moments 85-88%, and axial pullout forces 60-70% compared to the intact loading values (p≤0.001). The myoelectric hand model showed the most overall similarity to the intact model with a decrease in bending moment of 1-11%, torsional moment 3-56%, and axial pullout force -1-25% (axial pullout force increased at the 75% amputation level for jogging). The advanced prosthetic increased bending moments 77-101%, torsional moments 64-226%, and axial pullout forces 33-85% (p≤0.001). Prosthetic models had a smaller impact on change in force from the intact model during activities with a weight in hand.

**Discussion:** These results reveal a ranked order in loading magnitude according to complexity of the prosthetic device. When comparing the results of this study to those of initial stability failure load measurements on transhumeral OI systems [8], we see axial failure occurs at 4.8x maximum estimated forces, but there is overlap between bending and torsional failure and estimated moments. This overlap highlights the need to further constrain loading and employ protective measures during the early post-operative period when failure occurs at lower loads. Also, it highlights the fact that prosthetics used are an added component to this risk and should be considered when prescribing rehabilitation. OI increases range of motion and advanced prosthetics increase functionality opening the possibility of performing higher demand activities that impart more force on the bone, but this also increases the risk for fracture for individuals with OI attachment systems.

**References:**

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**Disclosure Statement:** We have nothing to disclose.
INTRODUCTION
As lifespans increase, objective methods of assessing how well a person is ageing become necessary. This is especially important for those affected by chronic diseases. Many central nervous system (CNS) disorders are chronic in nature and have systemic effects on the patient; affecting the way the entire body functions, especially during movement. Historically, normal and abnormal gait in patients with CNS disorders have been appraised using clinical assessment and observation with the naked eye. These approaches are appealing because of their simplicity, rapidity, and low cost. However, visual gait assessments are limited by the fact that they only provide subjective information about outward appearances of gait [1]. Further, there is considerable variation in observer agreement for the most common clinical assessments [2]. Quantitative gait analysis is well established as a means of objective monitoring of neurologic disease progression and therapeutic interventions [3]. Literature reflects the efficacy of temporal distance (TD) gait measures for CNS conditions [4, 5]. TD gait metrics such as velocity, single limb support times, symmetry, step width and step lengths are valid measures that provide insight into a patient’s health status, energy consumption during gait, fall risk, and survival [6-10]. Unfortunately, many providers do not objectively measure gait in patients with CNS disorders.

CLINICAL SIGNIFICANCE
People with CNS disorders visit their healthcare providers for medication management, mitigation of fall risk, and overall symptom management. Evidence based practice necessitates the use of objective TD metrics to assess the efficacy of clinical treatments. An objective gait study yielding TD factors will provide insight into the patient’s mobility. The provider may modify medications to control disease related symptoms; then have the patient return for a follow up gait study to determine efficacy of the medication change. An instrumented walkway rather than a conventional gait study reduces appointment length and analysis time to provide faster reports to the provider.

METHODS
Our lab has instituted an instrumented walkway (Zeno™ walkway, ProtoKinetics, Havertown, PA) to objectively measure TD parameters during over-ground walking. The patient is asked to come to the gait lab appointment with their assistive device. A physical examination is completed by a licensed physical therapist. The patient is then instructed to walk in their typical manner across an instrumented walkway while wearing their usual footwear. The patient’s gait metrics are collected and reduced by an engineer. The engineer creates a report detailing the patient’s TD metrics. This information, combined with the physical exam, is analyzed by the physical therapist, and documented in the medical record. The objective gait metrics are referenced for future comparison.

DEMONSTRATION
An example of the TD metrics report is illustrated below (Fig. 1). This report demonstrates the pre-intervention and post-intervention metrics for a 72 year old female who underwent ventriculo-peritoneal shunt placement for treatment of normal pressure hydrocephalus. Gait metric changes are the objectively measureable outcome to demonstrate improvement or lack of improvement after treatment. The pre/post intervention metric changes are readily apparent to the provider, demonstrating the efficacy of intervention. Lack of improvement in gait metrics may indicate to the provider that shunt setting adjustment is necessary.

Figure 1: An example of a TD report detailing gait metrics before and after surgical intervention for treatment of normal pressure hydrocephalus. Red triangles denote pre-operative metrics; blue dots denote metrics six months post-operatively. The box for each gait metric shows the 5th and 95th percentile of normative data. The patient’s data is reported for each gait metric in addition to being plotted to give a graphical representation of the patient’s performance relative to the normative data.

SUMMARY
Objective gait metrics provide important insight into the functional mobility of patients, medication efficacy, and symptomology related to disease progression. Temporal distance parameter analysis via an instrumented walkway is an efficient, non-invasive way to objectively measure gait. These measurements inform providers of a patient’s current functional status and changes following medical and surgical intervention.

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DISCLOSURE STATEMENT
Neither author has any conflicts of interest to disclose.
RACIAL DIFFERENCES IN GAIT MECHANICS

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INTRODUCTION: Race has rarely been investigated in biomechanics studies despite racial health disparities in the incidence of musculoskeletal injuries and diseases1-3. Racial differences in gait mechanics could drive disease progression and their examination may enable the identification of factors associated with racial health disparities. As race is a social construct, differences in gait mechanics between racial groups could be driven by specific factors other than racial classification itself.

The purpose of this study was to (1) test the hypothesis that racial differences in fundamental gait measures between African Americans (AA) and white Americans (WA) exist and (2) that these differences would be explained by a combination of anthropometric, strength, and health status factors.

CLINICAL SIGNIFICANCE: Equivalency in gait measures between racial groups should not be assumed. Racial diversity of study samples should be a priority to enable consideration of racial differences in the development of future research and individualized treatment protocols.

METHODS: 92 participants were equally divided by self-identified race and sex. Self-selected walking speed was measured, and 3D motion capture and force plate data were recorded during 7 walking trials at regular (1.35 m/s) and fast (1.6 m/s) speeds. Step length and width, peak vertical ground reaction force (pvGRF), and peak hip extension (pHEA), knee flexion (pKFA), and ankle plantar-flexion angles (pAPfA) were obtained. Heart rate, blood pressure, stress questionnaires, activity level, anthropometry, lower extremity strength, and blood levels of glucose, interleukin-6, C-reactive protein, and cortisol were also assessed.

Separate multivariate ANOVA models were fit for spatiotemporal, kinetic, and angular measures in both regular and fast walking speed trials to determine main and interaction effects of race and sex (SPSS V26, α=0.05). For each significant MANOVA finding, post-hoc univariate ANOVA models were fit and partial eta squared effect sizes were computed for all effects. Further analyses were run after separating data by sex. Stepwise linear regression models were fit including race and all independent variables correlated with the outcome measure (r ≥ 0.25); this was done for each outcome measure with an observed racial difference. If race was no longer significant in the regression model after the inclusion of the independent variable(s), those variables were considered to have explained the effect of race.
RESULTS: MANOVA findings were significant for spatiotemporal \((p<0.001)\) and angular (regular: \(p=0.001\), fast: \(p<0.001\)) models, but not for kinetic models (regular: \(p=0.895\), fast: \(p=0.200\)). No significant interactions between race and sex were found. Self-selected walking speed was slower in AA \((p=0.004)\) (Table 1). pHEA [fast: \(p=0.007, \eta_p^2=0.08\)] and pAPfA [regular: \(p=0.012, \eta_p^2=0.07\] | fast: \(p<0.001, \eta_p^2=0.14\)] were smaller in AA (Table 1). In males, no racial differences in gait were explained. In females, slower self-selected walking speed in AA was explained by larger Q-angle and decreased ankle dorsiflexion strength. Smaller pAPfA during gait in AA females was explained by weaker ankle plantarflexion strength.

### Table 1: Outcome measures with significant effect of race \((p<0.05)\) in MANOVA models

<table>
<thead>
<tr>
<th></th>
<th>AA males</th>
<th>WA males</th>
<th>AA females</th>
<th>WA females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Selected Walking Speed (m/s)</td>
<td>1.23 (0.15)</td>
<td>1.34 (0.21)</td>
<td>1.21 (0.17)</td>
<td>1.33 (0.15)</td>
</tr>
<tr>
<td>pAPfA (^\circ) [Regular]</td>
<td>14.74 (3.85)</td>
<td>18.32 (5.48)</td>
<td>13.92 (4.06)</td>
<td>15.27 (4.87)</td>
</tr>
<tr>
<td>pHEA (^\circ) [Fast]</td>
<td>10.77 (6.99)</td>
<td>15.05 (5.34)</td>
<td>10.84 (5.65)</td>
<td>13.07 (5.10)</td>
</tr>
<tr>
<td>pAPfA (^\circ) [Fast]</td>
<td>15.73 (4.44)</td>
<td>20.48 (5.61)</td>
<td>14.48 (4.44)</td>
<td>17.51 (5.42)</td>
</tr>
</tbody>
</table>

DISCUSSION: These results support our hypothesis that racial differences in gait mechanics exist and that a combination of anthropometric, strength, and health status factors contribute to their explanation, however, these observations were only in women. The possibility for additional factors to explain the observed racial gait differences should be investigated further, especially in men. For women, a mix of innate and modifiable factors explained racial differences. Innate metrics such as Q-angle contributing to racial differences suggests the need for racially diverse normative datasets. Modifiable factors such as ankle dorsiflexion and plantarflexion strength that are associated with racial differences could provide targets for interventions aimed at injury prevention and optimizing rehabilitation. Identified targets may also be useful in reducing or potentially eliminating racial health disparities in musculoskeletal injury and disease.

REFERENCES:  

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DISCLOSURES: none
Long term impact of DBS on gait in PD: a Kinematic study

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Introduction

Deep Brain Stimulation (DBS) provides considerable symptomatic relief to patients with Parkinson’s Disease (PD). While it is well established that DBS improves tremor, slowness, rigidity, and dyskinesia, its long-term effects on gait are less well understood.

Clinical Significance

Although many studies consider the acute effects of DBS on gait, evidence regarding longitudinal changes in gait is sparser (Collomb-Clerc et al 2015, Cossu et al 2017, Roper et 2016). This study investigates the effect of DBS on gait parameters before and after surgery.

Methods

Database review from our kinematics laboratory between 2015 to 2018 identified 22 patients that had gait parameters measured before and after DBS procedures and at nominal 12-month follow-up. DBS targets were as follows: globus pallidus internus, N=14 (8 unilateral / 6 bilateral); subthalamic nucleus, N = 9 (6 / 3). After excluding incomplete records, data of N=19 PD patients were analyzed.

On two separate visits (pre-surgical and follow-up), each patient was assessed with a full-body 3-dimensional optical motion capture system (Motion Analysis Corporation, Santa Rosa, CA) using a customized configuration of 60 reflective kinematic markers. Patients completed a standardized battery of gait tasks including multiple replicates of self-selected walking over a distance of 4.7 m. Ten standard gait outcomes, including gait speed, step length, and cadence, were extracted from kinematic marker data using OrthoTrack 6.6.0. Other clinical variables including Movement Disorder Society-Unified Parkinson Disease Rating Scale (MDS-UPDRS) and levodopa equivalent doses (LEDD) were also recorded.

Pre-surgical assessments were performed in the “medication on state.” Follow-up assessments were performed in the “DBS stimulation on” and “medication on” state. This was expected to simulate a real-world scenario and changes in gait while the patient was on optimal therapy. Statistical significance of changes in study variables over time was assessed with paired t-tests. Type-I error was controlled with a Bonferroni procedure. For visualization of the relative sizes of effects of time on each study variable, changes from pre-surgical to
follow-up were expressed as average differences / standard deviation (referred to as Cohen’s $d$; Cohen 1992).

Results
Average age was 61.2±7.8 years and disease duration, 10.5±3.9 years. Five were female. The average time between pre-surgical and follow-up visits was 15.4±4 months. At follow-up, there were significant reductions in MDS-UPDRS-III “on” state score (13.9±8.6 vs. 19.8±10.7 points, p=0.004) and in LED (942±491 vs. 1437±513 mg, p<0.001), consistent with overall improvement in parkinsonian symptoms. However, there was worsening of gait parameters after DBS surgery when compared to preoperative baseline. There was a significant deficit (reduction) in gait velocity (94±25 vs. 111±21 cm/s; p=0.001). This was not correlated with DBS target location, disease duration, severity of motor symptoms or levodopa dose adjustments. There was also an increase in total support time (p=0.003), double support time (p=0.002) with decrease in cadence (p=0.003), decrease in swing phase (p=0.003) and decrease in single support time (p=0.003). Other gait parameters such as step width, stride length or step length did not show significant changes. Figure 1 demonstrates the pattern of changes in which overall symptom severity and LED improved, but gait measures declined as relative effect sizes.

Discussion
Our study reveals overall worsening gait for in PD patients that have undergone DBS procedures despite improvement in other motor symptoms. A possible explanation may be disease progression given a long period between assessments. Further study is warranted to better understand the efficacy and neurophysiology of DBS and its effect on gait.

References

Disclosure Statement
Authors have no relevant disclosures or acknowledgements.
Deriving Muscle Pathway of the Gastrocnemius Using Motion Capture and Ultrasound for Musculoskeletal Modeling

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INTRODUCTION
The moment arms muscles have about a joint play an important role in determining the joint torques they generate. This dictates how muscle activations relate to force generation in musculoskeletal models. Since the moment arm is heavily affected by the volume, insertion and origin of muscle, it is crucial to acquire reliable muscle pathway data. Previously, muscle pathways were measured from cadavers or with magnetic resonance imaging (MRI) and cadaver analysis. However, compared to these methods, using a combined ultrasound and motion capture method is inexpensive and readily available to gait analysis labs. Thus, the aim of this study is to develop a reliable method for measuring the muscle pathway using an ultrasound probe, a motion capture system, and musculoskeletal modeling.

CLINICAL SIGNIFICANCE
The proposed methodology accurately measures the gastrocnemius's muscle pathway, improving the accuracy and accessibility of musculoskeletal modeling. These models are useful in assessing pathologic muscle behavior and in development of assistive devices.

METHODS
Our ultrasound method was applied to a young healthy male, 27 yrs, 1.6 m and 56.6 kg. The experiment consisted of three trials for both the lateral and medial gastrocnemius on the participant’s left leg. Three reflective markers were placed onto the ultrasound probe to establish the ultrasound’s coordinate and five reflective markers were attached, following a modified Helen Hayes marker set, on the participant’s leg to identify the joint angle and reconstruct shank and thigh segments with a motion capture system throughout the experiment. During the experiments, the participant laid prone, with their leg elevated at a knee angle of 50 degrees and an ankle angle of 20 degrees. The ultrasound, running at 8 to 9 frames per second, was then drawn from the knee, distally, toward the ankle over the target muscle. The image sequence produced by the ultrasound was processed in ImageJ to find the location of the muscle’s centroid. The ultrasound data was interpolated to match the 100Hz sampling rate of the motion capture system. Using a scaled Thelen model in OpenSim, the muscle centroid data was transformed from the 2D ultrasound image coordinates into the 3D coordinates of the motion capture environment, representing the position of the centerline of the muscle in reference to the origin of the tibia. Each series of coordinates was compared against our other trials as well as the Thelen and Rajagopal [1,2] musculoskeletal models.

DEMONSTRATION
Each muscle pathway was averaged and compared against the Thelen and Rajagopal [1,2] models (Fig. 1). When comparing our experimental pathway to that of our reference models we interpolated the coordinates for both the Thelen and Rajagopal models to match our
Proximal/Distal values. This allowed us to find the RMSE for both the Anterior/Posterior and Medial/Lateral coordinates for the medial and lateral gastrocnemii (Table 2).

![Graphs showing Lateral Gastrocnemius Sagittal Plane and Lateral Gastrocnemius Coronal Plane](image)

**Figure 1**: Position of experimental centerline compared to that of both the Rajagopal and Thelen models.

**Table 1**: The root mean squared error between the experimental coordinates and that of the reference models

<table>
<thead>
<tr>
<th>Gastrocnemius</th>
<th>Coordinate</th>
<th>Thelen (cm)</th>
<th>Rajagopal (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial</td>
<td>Anterior/Posterior</td>
<td>0.3703</td>
<td>3.0423</td>
</tr>
<tr>
<td>Medial</td>
<td>Medial/Lateral</td>
<td>0.4221</td>
<td>0.4832</td>
</tr>
<tr>
<td>Lateral</td>
<td>Anterior Posterior</td>
<td>0.2363</td>
<td>2.0901</td>
</tr>
<tr>
<td>Lateral</td>
<td>Medial Lateral</td>
<td>0.4706</td>
<td>0.5215</td>
</tr>
</tbody>
</table>

**SUMMARY**

This new method allows for the fast and affordable analysis of a muscle’s pathway. With an average RMSE for the Rajagopal and Thelen models being 1.5342 cm and 0.3748 cm respectively, one could conclude that the Thelen model is more accurate. However, a better explanation for the discrepancies between modeled pathways and measured pathway is the differences between individual subjects’ muscle architecture. This highlights the importance of methods for measuring individual muscle pathways that cannot be estimated with the scaling of a general model. In order to further develop this study more markers need to be used to define additional body segments with motion capture, a larger sample size needs to be obtained, and more muscles need to be measured.

**REFERENCES**


**DISCLOSURE STATEMENT**: The authors have no conflicts of interest to disclose.
BEWARE THE TRANSVERSE PLANE: VARIABILITY OF “NORMAL GAIT” IN TYPICALLY DEVELOPING CHILDREN

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INTRODUCTION

A critical step in the analysis of the gait data is the choice of stride for interpretation. The Gait Variable Standard Deviation (GVSD) has been published as a measure of stride-to-stride kinematic variability, but the study did not evaluate the range of values or the trunk segment kinematics.1 The goal of this study is to quantify stride-to-stride variability in typically developing (TD) children using three-dimensional gait analysis (3DGA) in an expanded set of 14 kinematic variables.

CLINICAL SIGNIFICANCE

A better understanding of inherent stride-to-stride variability in TD children will improve the interpretation of three-dimensional and observational gait data for surgical decision-making.

METHODS

Ambulatory TD children were recruited for this prospective cohort diagnostic IRB approved study. 3DGA was performed using a 12-camera infrared system. To measure stride-to-stride variability, a custom MATLAB program calculated two summary measurements:

1) *Gait Variable Standard Deviation (GVSD)* – This measurement is the root mean square of the standard deviation of all strides at each of the 101 gait cycle time points for a given variable and is represented by the following equation: \( \text{GVSD} = \sqrt{\frac{\sum_t (\sigma(i,t))^2}{T}} \), where \( \sigma = \text{standard deviation}, i = \text{gait variable of interest}, t = \text{time point}, \) and \( T = \text{total number of time points} \).

2) *Gait Variable Range (GVR)* – This measurement is the root mean square of the range of all strides at each of the 101 gait cycle time points for a given variable and is represented by the following equation: \( \text{GVR} = \sqrt{\frac{\sum_t R(i,t)^2}{T}} \), where \( R = \text{Range}, i = \text{gait variable of interest}, t = \text{time point}, \) and \( T = \text{total number of time points} \).

Paired t-tests and unpaired t-tests were performed to analyze the GVSD and GVR between each limb and between sexes, respectively. Linear regression analyses were used to identify the effect of age on GVSD and GVR. A one-way ANOVA with Tukey’s honest significant test explored the differences between planes of motion for kinematic variables for each limb segment.

RESULTS

Thirty-seven patients (ages 5.3 – 16.8 years; 20F, 17M) each had an average of 7 gait cycles analyzed using 3DGA. Foot progression angle demonstrated the greatest variability (GVR = 10.4° right and 12.0° left; GVSD = 3.8° right and 4.1° left). Statistically and clinically significant kinematic variability was the greatest in the transverse plane in all body segments.
except for the knee, where kinematic variability was greatest in the sagittal plane [Table 1]. There was no statistically significant difference in variability between right and left limbs for all kinematic variables except for knee flexion, where the difference was not clinically significant (GVR 1.3° and GVSD 0.3°). Kinematic variability decreased with increasing age. There was no statistically significant difference between sexes for any kinematic variable.

Table 1: GVSD and GVR for Kinematic Measurements.

<table>
<thead>
<tr>
<th>Kinematic Measurement</th>
<th>GVR (deg)</th>
<th>GVSD (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Trunk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk Rotation</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>9.5**</td>
<td>9.4**</td>
</tr>
<tr>
<td>Trunk Tilt</td>
<td>6.7</td>
<td>6.4</td>
</tr>
<tr>
<td>Trunk Lateral Bend</td>
<td>4.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Pelvis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvic Rotation</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>7.8**</td>
<td>7.8**</td>
</tr>
<tr>
<td>Pelvic Tilt</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Pelvic Obliquity</td>
<td>3</td>
<td>2.9</td>
</tr>
<tr>
<td>Hip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip Rotation</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>8.3**</td>
</tr>
<tr>
<td>Hip Flexion</td>
<td>6.6</td>
<td>6.3</td>
</tr>
<tr>
<td>Hip Adduction/Abduction</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee Rotation</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Knee Flexion</td>
<td>10.1†</td>
<td>8.8†</td>
</tr>
<tr>
<td>Knee Varus/Valgus</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Ankle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foot Progression Angle</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>12*</td>
<td>10.4*</td>
</tr>
<tr>
<td>Ankle Dorsiflexion</td>
<td>8.3</td>
<td>7</td>
</tr>
<tr>
<td>Ankle Dorsiflexion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significance was determined by ANOVA with Tukey’s Post Hoc (p < 0.05). ** Significant Difference between Transverse and Sagittal/Coronal Planes. † Significant Difference between Sagittal and Transverse/Coronal Planes. * Significant Difference between Transverse and Sagittal Planes

DISCUSSION

Typically developing children have consistency in gait kinematics, but do show the greatest stride-to-stride kinematic variability in the transverse plane. In particular, the foot progression angle can have up to a 12° GVR, indicating that orthopaedic surgeons should not place emphasis on a single trial in isolation for treatment of pathological conditions such as femoral anteversion and tibial torsion. Gait consistency increases with age, suggesting that determination of fixed pathological gait patterns may be more accurate as children reach skeletal maturity.

REFERENCES


DISCLOSURE STATEMENT

None of the authors had any disclosures to report.
BIOMECHANICAL IMPACT OF HOSPITAL BED HEIGHT AT THE EGRESS OF PATIENT WITH PARKINSON DISEASE

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INTRODUCTION
Falls are the most frequently reported safety incident within hospitals which increase the length of hospital stay, the risk of mortality and the health care costs [1]. About 60% to 70% of these falls happen at the hospital bedside, such as when getting into or out of bed, especially for the patients with gait impairments and balance limitations. To our knowledge, the effects of hospital bed height on the natural transition during bed egress in patients with PD is still largely unknown. Therefore, the aim of this study was to evaluate the influence of different hospital bed heights in patients with PD during bed egress.

CLINICAL SIGNIFICANCE
This information could improve the understanding of biomechanical changes that occur during bed egress for patients with PD and may reduce the risk of fall for this high-risk population by setting proper bed height.

METHODS
Twelve patients with PD (age 68.9±8.4 years, height 1.72±0.09 m, weight 82.3±12.6 kg) and fourteen healthy elderly adults (HEA) (age 63.4±8.8 years, height 1.70±0.11 m, weight 78.0±20.1 kg) were recruited. Participants were required to sit on the edge of the bed and rise in an unconstrained, natural manner without using side rails, and walk several steps to a chair. The space was surrounded by an 18-camera motion capture system. Two force plates were installed on the floor to collect ground reaction forces (GRF). The target height of hospital bed for each participant was set as low bed (LB), medium bed (MB) and high bed (HB), from 95%, 110% and 125% of a participant’s lower leg length.

The temporal and GRF variables, kinematics variables, pelvis center and center of mass (CoM) variables were processed using Visual3D software. Two-factor repeated ANOVA was used to determine the effects of hospital bed height (LB, MB and HB) and group (PD and HEA). Post-hoc tests were performed for multiple comparisons. The results were considered statistically significant when P < 0.05.

RESULTS
The patients with PD showed a significantly longer time of bed egress than HEA. The bed height had a significant effect for the peak of vertical and medial GRFs, which both showed smaller values on LB than MB. The bed height effect was also significant for several peak joint kinematics variables, including trunk flexion, pelvis obliquity, hip flexion, knee flexion and ankle plantarflexion. Post-hoc tests indicated that the peak flexion of trunk, hip and knee joints were smaller on HB compared with MB and LB, respectively. Additionally, the patients with PD manifested increased peak trunk lateral flexion, but decreased peak pelvis anterior tilt.
and hip flexion compared with HEA. The maximum distance between pelvis center and CoM in the anteroposterior direction was significantly affected by bed height and group, which indicated a smaller value on HB than MB and LB, and the patients with PD showed a smaller value than HEA.

Table 1 The parameters expressed as mean (SD) for PD and HEA groups

<table>
<thead>
<tr>
<th>Temporal and GRF variables</th>
<th>Low bed</th>
<th></th>
<th>Medium bed</th>
<th></th>
<th>High bed</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of bed egress (s)†</td>
<td>3.55(1.18)</td>
<td>1.71(0.30)</td>
<td>3.08(1.04)</td>
<td>1.54(0.27)</td>
<td>2.88(0.76)</td>
<td>1.69(0.47)</td>
</tr>
<tr>
<td>Max vertical GRF (%BW) *</td>
<td>100.50(3.68)</td>
<td>99.36(6.86)</td>
<td>103.17(2.89)</td>
<td>101.86(6.52)</td>
<td>103.50(3.85)</td>
<td>100.14(4.31)</td>
</tr>
<tr>
<td>Max posterior GRF (%BW) *</td>
<td>6.49(2.02)</td>
<td>6.61(2.51)</td>
<td>7.06(3.86)</td>
<td>5.20(1.96)</td>
<td>5.67(2.08)</td>
<td>4.96(1.40)</td>
</tr>
<tr>
<td>Max medial GRF (%BW) *</td>
<td>4.12(1.21)</td>
<td>3.69(1.39)</td>
<td>5.09(2.57)</td>
<td>4.77(1.71)</td>
<td>4.24(2.72)</td>
<td>4.91(1.89)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak joint motion</th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk flexion *</td>
<td>55.61(10.21)</td>
<td>60.03(7.39)</td>
<td>51.85(11.14)</td>
<td>57.52(7.50)</td>
<td>48.52(6.69)</td>
</tr>
<tr>
<td>Trunk lateral flexion †</td>
<td>7.65(5.75)</td>
<td>3.43(2.40)</td>
<td>5.15(4.11)</td>
<td>3.95(2.45)</td>
<td>5.70(3.50)</td>
</tr>
<tr>
<td>Pelvis anterior tilt †</td>
<td>12.00(13.07)</td>
<td>30.07(13.19)</td>
<td>14.42(14.71)</td>
<td>30.71(14.30)</td>
<td>14.75(13.41)</td>
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<tr>
<td>Pelvis obliquity *</td>
<td>3.74(5.88)</td>
<td>3.42(2.18)</td>
<td>6.80(5.56)</td>
<td>2.50(2.25)</td>
<td>8.17(7.94)</td>
</tr>
<tr>
<td>Hip flexion *†</td>
<td>72.75(20.92)</td>
<td>97.36(17.77)</td>
<td>72.50(20.04)</td>
<td>94.36(17.46)</td>
<td>66.33(19.73)</td>
</tr>
<tr>
<td>Knee flexion *‡</td>
<td>101.68(9.23)</td>
<td>95.77(8.03)</td>
<td>90.24(8.17)</td>
<td>89.05(8.16)</td>
<td>83.83(7.86)</td>
</tr>
<tr>
<td>Ankle plantarfexion *</td>
<td>17.17(9.53)</td>
<td>20.86(11.73)</td>
<td>21(11.01)</td>
<td>24.57(12.92)</td>
<td>27.83(10.21)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pelvis-CoM distance (%height)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Anteroposterior *</td>
<td>6.54(2.39)</td>
<td>8.91(1.79)</td>
<td>6.31(2.52)</td>
<td>8.84(2.10)</td>
<td>6.13(2.36)</td>
</tr>
</tbody>
</table>

* Significant bed height effect (P < 0.05); † Significant group effect (P < 0.05);

DISCUSSION

Several different strategies were shown following the changes of bed height and also between the adults with PD and HEA. Patients with PD showed a more conservative movement strategy than HEA during bed egress, such as significantly increased bed egress time, decreased peak of pelvis anterior tilt, hip flexion and decreased anteroposterior distance between pelvis center and CoM, which tended to decompose bed egress into two distinct subtasks or phases (sit to stand and walk) [2]. The LB condition created a more challenging posture and balance condition in older adults, particularly for the PD group, who employed a similar compensation strategy as HEA including increasing the peak of trunk, hip and knee flexions to generate a greater forward CoM momentum and joint torque to rise from the LB. However, these strategies may also pose a greater risk of fall for those who have impaired postural control such as individuals with PD [3]. we suggested that the caregivers should consider the height of the hospital bed before egress and avoid the LB condition during egress for elderly persons if possible.

REFERENCES


DISCLOSURE STATEMENT

There are no conflicts of interest to disclose.
WALKING IN A WIDTH-CHANGING VIRTUAL CORRIDOR AFFECTS STEP WIDTH VARIABILITY

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INTRODUCTION
Mediolateral visual perturbations during treadmill walking impact gait variability in the frontal plane. However, this effect was shown for randomly or discretely changing visual perturbations and remains unknown for continuously changing visual perturbations [1,2]. The purpose of this study was to investigate whether continuous changes in the width of a virtual corridor could affect step width variability during treadmill walking.

CLINICAL SIGNIFICANCE
A width-changing virtual corridor could be eventually utilized for rehabilitation purposes when step width variability is targeted.

METHODS
Nine healthy adults (26 ± 5 years; height: 168 ± 14 cm; body mass: 69 ± 21 kg) performed three 6-min treadmill walking conditions while kinematics was acquired. The conditions were the following: one with a fixed-width corridor (1.91 m) presented as the Control condition, and two with different width sizes of the corridor where the width of the corridors was expanding and then narrowing sinusoidally during each condition (Fig. 1). The step width time series from all participants/conditions was identified from the kinematics and was evaluated using i) the standard deviation to identify changes in the amount of variability, and ii) the fractal scaling exponent estimated with detrended fluctuation analysis to identify changes in the temporal structure of variability (Fig. 2). We compared the variability measures among width-changing virtual corridor conditions using a linear mixed effects model with width-changing virtual corridor condition as a fixed effect and the blocking factor (participant) as a random effect. Significance level was set at α = 0.05.

RESULTS
The standard deviation of the step width time series significantly increased in the Wide condition (2.06 ± 0.50 cm) as compared to the Narrow (1.87 ± 0.37 cm) condition (p = 0.015). The fractal scaling exponent of the step width time series significantly decreased (p < 0.001) for the Wide condition (0.68 ± 0.09) as compared to the Narrow condition (0.79 ± 0.09); and
significantly increased (p = 0.03) for the Narrow condition as compared to the Control condition (0.73 ± 0.11).

**DISCUSSION**

Overall, our findings demonstrate that continuous change in the width of the virtual walking path affect step width variability in healthy young adults. When the virtual corridor was expanding in a wider fashion, the amount of step width variability increased, and its temporal structure became less persistent. Our results suggest that the gradual transition from a wide to a narrow visual field may reweight visual information (from motion) as a function of corridors’ width. As a result, step width variability during walking could be modulated continuously through visual information.

**REFERENCES**


**ACKNOWLEDGMENTS**

This work was supported by the Center for Research in Human Movement Variability, the NIH (P20GM109090, R15AG063106, and R01NS114282), and the University of Nebraska Collaboration Initiative.
INTRODUCTION
COVID-19 led to social distancing restrictions across the US. For children, this included the closing of schools and public playgrounds, cancellation of organized sports and ultimately prevented peer interaction beyond household siblings. Health guidelines recommend children 5-17 years-of-age achieve 60 minutes of moderate-to-vigorous physical activity (MVPA) daily [1], or approximately 12,000 steps [2]. Physical activity (PA) can improve physical fitness [1] and mental health [3] and is vital for social development of school-aged children [4]. Early COVID-19 studies have shown reduced PA in children based on parent-report [5], and decreased step counts in children with congenital heart disease using wrist-worn accelerometers [6]. However, the impact of stay-at-home orders on the PA of children in America remains unclear. The aim of this study was to assess quantitative PA using wearable ankle sensors during a COVID-19 Stay-at-Home mandate.

CLINICAL SIGNIFICANCE
Physical activity is a vital component to the physical, social and emotional health of American youth, however, there is scarce quantitative data that describes the impact and/or severity of change in PA in American children during COVID-19 restrictions.

METHODS
This study was conducted using a convenience sample of 33 children living in the Dallas-Fort Worth metroplex during stay-at-home orders in April 2020. Children between 5-10 years of age with no current orthopedic, neuromuscular or cardiorespiratory condition/injury that may affect PA were provided a StepWatch Activity Monitor (SAM) and a log to track donning/doffing times. SAMs were pre-programmed per manufacturer guidelines using the participants’ estimated height. Participants were asked to wear the SAM above the ankle on their dominant leg for 5 consecutive days (3 weekdays and 2 weekend days), during all waking hours, excluding bathing and swimming. Single-sided strides were doubled to approximate total steps.

Retrospective SAM data collected from age-matched children pre-pandemic were used as a historical control set. Mann-Whitney U and/or Pearson chi-square tests were used to determine differences for SAM variables between groups. Wilcoxon Signed Rank Test was used to determine within-group differences between weekdays and weekend days. Post-hoc power analysis revealed that a total sample of 28 participants, with 14 in each group, was required to achieve a power of .80 using a two-tailed test, medium effect size (d=.50) and an alpha of .05. Statistical significance was set at $\alpha < .05$. 

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RESULTS

Demographic comparison between 33 stay-at-home (15F) and 26 pre-pandemic children (14F) showed no significant difference in age (7.4±0.3 vs. 8.0±0.2, \( p=.09 \)). Children during stay-at-home orders had 77 minutes less active time \((p=.001)\) and took 3,737 less steps daily \((p<.001)\) compared to children tested pre-pandemic. Texas stay-at-home orders resulted in severely reduced PA in children, with only 36% of children averaging the 12,000 steps per day compared to a pre-pandemic historical group at 85%. The pre-pandemic cohort also had reduced step counts on weekend days compared to weekdays \((p=.04)\), with no significant difference seen in the stay-at-home cohort \((p=.58)\).

DISCUSSION

Significantly reduced physical activity levels were in children during COVID 19 stay-at-home orders when compared to pre-pandemic age-matched cohort. While steps per day is not a direct equivalent measure, it has been shown to be an accurate proxy to identify if children reach minimal MVPA recommendations \cite{1}. The effect of school closures, and subsequent loss of physical education classes, recess, and peer play appear significant as the percentage of children meeting 12,000 steps per day dropped from 92% on weekdays (school days) in the pre-pandemic group to only 27% during stay-at-home orders. Differences typically seen between weekdays and weekends pre-pandemic were not present during stay-at-home orders. This cross-sectional study comparing two small, homogeneous samples at different points in time may not be representative of all US children.

Step count comparisons pre- vs. during the COVID-19 pandemic in this study suggest structured, school-based activity is an important means for children to achieve daily PA goals. Prolonged decreased activity levels may have detrimental effects on the physical and social development of school-aged children. Findings from this study suggest that schools should assure that quality physical education remain an essential part education, whether that is in-person or virtual instruction. It is imperative that pediatricians and school leaders educate parents on the importance of physical activity outside of the classroom, and offer suggestions for home-, neighborhood- and community-based options that follow local, state and national guidelines for social distancing and COVID-19 safety.

REFERENCES


ACKNOWLEDGMENTS The authors wish to acknowledge the SRC Research Program.

DISCLOSURE STATEMENT Co-author KTF is a GCMAS executive board member. All other co-authors have no disclosures.
CLINICAL EFFICACY OF INSTRUMENTED GAIT ANALYSIS: SYSTEMATIC REVIEW 2019 UPDATE

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INTRODUCTION

In 2011, we published a systematic review evaluating the literature related to the clinical efficacy of 3D instrumented gait analysis (3DGA) [1]. This topic is still important since debate persists regarding the use of 3DGA for clinical patients and with the increasing emphasis on evidence-based medicine. The current study is an update to our previous review.

CLINICAL SIGNIFICANCE

Evidence of efficacy is needed to support the utilization and reimbursement of instrumented motion analysis in clinical care.

METHODS

A literature review was conducted to identify English language articles related to human gait analysis published from September 2009 to October 2019. Papers had to investigate human walking using 3D kinematics, kinetics, ground reaction force, plantar pressure, and/or electromyography (EMG) obtained using typical motion analysis laboratory methods. Review articles, commentaries, protocols, and short conference abstracts were excluded.

Initial screening for inclusion/exclusion criteria was performed by 1 of 5 experienced gait laboratory personnel. Secondary screening was then performed by at least 2 evaluators to identify the level of efficacy, if any, addressed by each paper. Levels of efficacy were defined similar to our previous publication: level 1 (technical), level 2 (diagnostic accuracy), level 3-4 (diagnostic thinking and treatment), level 5 (patient outcome), level 6 (societal). An additional level (2b) identified papers on the effects of treatments at a group level.

RESULTS

Overall results are presented in Fig. 1. The level 1 studies primarily dealt with development of improved technology for data collection and modeling, including reliability and validity studies. The level 2 studies generally compared different diagnostic or demographic groups, related gait measures to other gait measures, participant characteristics, or testing conditions, or developed methods to advance data interpretation. The level 2b studies mainly evaluated the effects of treatments such as surgery, bracing, prosthetics, or rehabilitation programs or compared the outcomes of different treatments.

The level 3-4 studies showed that 3DGA changes treatment plans and increases clinicians’ confidence in their treatment decisions for patients with cerebral palsy (CP) [2], spina bifida [3], and post-stroke [4]. There is little agreement in problem identification and surgical planning between clinical examination and 3DGA [5]. However, agreement among clinicians in problem identification and goal setting increases with 3DGA [6].
The level 5 articles included two from a randomized controlled trial (RCT). The first [8] showed little difference in 1-year outcomes between children with CP randomized to receive a pre-operative 3DGA report and controls who underwent surgery without the report. The lack of difference was attributed to low adherence to the 3DGA recommendations, which was only 42% in the group receiving the report compared with 35% in the control group [7]. This is much lower than the 77-97% adherence typical of clinical referrals [8]. To investigate this effect, a second paper subdivided the group receiving the gait report according to whether or not a particular recommendation for femoral derotation osteotomy was followed and found significant improvements into the normal range only when the 3DGA recommendations were both received and followed [9]. A final level 5 study [10] found that the incidence of severe crouch gait dropped impressively, from 25% to 4%, in the years following practice changes including the addition of 3DGA and single event multilevel surgery, which requires 3DGA.

DISCUSSION

The volume of studies on 3DGA has exploded over the last decade. Thousands of articles contribute to continued development of methods for improved data collection and interpretation. Six new studies in level 3-4, including a RCT, support the findings of 11 similar studies from the previous review period, clearly demonstrating the efficacy of 3DGA in changing and reinforcing treatment decisions, increasing clinicians’ confidence in treatment planning, and increasing agreement among different clinicians. Three new studies in level 5, including two from a RCT, demonstrate the potential of 3DGA to improve patient outcomes.


DISCLOSURE STATEMENT: The authors have no conflicts of interest to disclose.
Title: Joint Kinetics 101: Understanding Gait Pathology, Treatment Decision-making and Outcomes Evaluation Using Joint Kinetic Data.

Instructors: Sylvia Öunpuu, Kristan Pierz, Jennifer Rodriguez-MacClintic

Intended Audience: All personnel who are involved in the interpretation for treatment decision-making as well as the collection and processing of joint kinetic data. This includes, but is not limited to, physicians, physical therapists, kinesiologists, biomechanists and engineers.

Prerequisite Knowledge: Participants should have the basic understanding of how clinical gait analysis supports treatment decision-making, familiarity with gait analysis output and terminology especially joint kinematic data.

Outline of Course Content: Joint kinetic data collection as part of comprehensive motion analysis procedures is the most difficult component of clinical gait analysis to understand and utilize. The overall goal of this course is to provide the background knowledge and skills needed to use joint kinetic data as an integral part of assessment of pathological gait so that the most informed treatment decision is possible. The course will review the basic concepts needed to interpret joint kinetic data and provide examples of how kinetic data provides the clinician with clinically relevant information for understanding the impact of joint level impairment on gait pathology. Through case examples, we will demonstrate how joint kinetics can improve our understanding of gait pathology, facilitate treatment decisions and improve understanding of treatment outcomes for a variety of gait pathologies.

The course will begin with an overview of the methods used to collect joint kinetics and the basic principles of joint kinetic calculations, which are an essential part of understanding joint kinetic data. Typically developing joint kinetic patterns will then be reviewed followed by an interactive exercise in identification of atypical joint kinetics. Possible conclusions that can be made about the gait pathology based on the joint kinetic plots will be discussed. Finally, the impact of trunk positioning on lower extremity joint kinetics will be demonstrated and data from patient examples will then be discussed to verify understanding of interpretation concepts.

In the second half of the course, pathological gait will be defined initially by identifying common atypical joint kinetic patterns for a variety of diagnoses. This will be followed by a variety of case examples. In each case, the impact of the joint kinetic information on the understanding of the pathomechanics of the specific gait problem and the treatment decision will be reviewed. Examples from a wide variety of gait pathologies will be included for both children and adults.

The content of this course will be based upon the knowledge gained from over 35 years of experience in using joint kinetics in the evaluation of gait pathology, treatment decision-making and treatment outcomes evaluation in a clinical setting. We will also
draw from our published research outcomes to highlight the possible changes in joint kinetic data pre and post-surgical intervention.

**Learner-based Course Objectives:** At the completion of the course, the participant should:

1) be familiar with data collection methods needed to interpret kinetic data
2) be familiar with typically developing and common atypical kinetic patterns
3) be familiar with the relationship between trunk position and joint kinetics
4) understand the clinical utility of joint kinetics for improving treatment outcomes

**Schedule**

**Introduction:** (2 minutes) - Sylvia Ōunpuu

**Background:** (35 minutes) - Sylvia Ōunpuu

- Fundamentals in methods and conventions
- Typical patterns
- Interactive exercise in understanding principles

**Implications of Trunk Position on Joint Kinetics** (10 minutes) - Sylvia Ōunpuu

- Audience stands (if able) to experience impact of trunk position
- Examples of impact of trunk motion on lower extremity function (kinematics and kinetics)

**Questions and answers** (5 minutes)

**Case Examples:** (40 minutes) - Sylvia Ōunpuu, Kristan Pierz, Jennifer Rodriguez-MacClintic

(specific examples of atypical joint kinetic data in a variety of pathologies)
- barefoot vs. orthoses (AFO’s and UCBL’s)
- quadriceps avoidance
- pre versus post-surgical assessment, etc.

**Questions and answers** (8 minutes)
COMPARISON OF INJURY RISK FACTORS BETWEEN LIMBS WITH AND WITHOUT ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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E-mail: twren@chla.usc.edu

INTRODUCTION

Motion analysis is being used increasingly to assess sports biomechanics and injury risk. Dynamic limb valgus and stiff landing are two known risk factors for anterior cruciate ligament (ACL) injury. We have developed a scoring system to assess these risk factors based on kinematics and kinetics. The purpose of this study was to compare risk scores between limbs with recent ACL reconstruction and uninjured (contralateral and control) limbs.

CLINICAL SIGNIFICANCE

Rehabilitation programs post-ACL reconstruction appear to be effective in improving biomechanics and decreasing injury risk factors.

METHODS

Sports motion analysis data were reviewed for 177 pediatric patients after recent primary ACL reconstruction (ACLR) and 63 uninjured control subjects ages 8-17 years. 3D motion analysis data were collected while subjects performed the following sports tasks: heel touch from 6” or 9” step (depending if height >155 cm), drop jump from 41 cm height, lateral shuffle, forward-backwards deceleration, single leg hop, and 45° cutting. Each limb was scored for components of dynamic limb valgus (hip stability, pelvis stability, trunk stability) and stiff landing (shock absorption, hip strategy) based on the kinematic and kinetic measures in Table 1. Each scoring category was rated for each applicable task (Table 2) as adequate (2), borderline (1), or inadequate (0). Percentage scores by scoring category and task was compared among reconstructed, contralateral, and control limbs using chi-square tests and ANOVA.

Table 1: Kinematic and kinetic variables used for each scoring category

<table>
<thead>
<tr>
<th>Scoring Category</th>
<th>Scoring Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Limb Valgus</td>
<td>Hip Stability • Mean hip internal rotation • Max hip adduction • Mean knee valgus • Min knee valgus moment</td>
</tr>
<tr>
<td>Pelvis Stability</td>
<td>• Pelvic obliquity</td>
</tr>
<tr>
<td>Trunk Stability</td>
<td>• Trunk lateral lean</td>
</tr>
<tr>
<td>Stiff Landing</td>
<td>Shock Absorption • Max knee flexion • Max hip flexion • Peak GRF</td>
</tr>
<tr>
<td>Hip Strategy</td>
<td>• AP position of knee axis relative to ankle &amp; toe • AP position of hip joint center relative to heel • Max forward trunk lean • Ratio of knee flexion moment / hip flexion moment</td>
</tr>
</tbody>
</table>
Table 2: Maximum score per limb for each task and scoring category

<table>
<thead>
<tr>
<th>Task</th>
<th>Hip Stability</th>
<th>Pelvic Stability</th>
<th>Trunk Stability</th>
<th>Shock Absorption</th>
<th>Hip Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel Touch</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Drop Jump</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lateral Shuffle</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Deceleration</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Single Leg Hop</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cutting</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

RESULTS

Scores differed significantly among groups for all tasks except lateral shuffle (p=0.30) and drop jump (p=0.07). Task scores were generally lower for the control group but were similar between the patient reconstructed and contralateral limbs. Shock absorption (p<0.001), hip strategy (p<0.001), and trunk stability (p=0.005) scores differed significantly between groups. Shock absorption and hip strategy were both worse in the control group compared with the patient groups, while trunk stability was best in the control group and worst in the ACLR group. For the overall risk factors, stiff landing was worse in controls compared with both limbs of patients (p<0.001), but dynamic limb valgus was worse in the ACLR limbs (p≤0.03) (Figure 1).

DISCUSSION

Post-operative ACLR patients generally demonstrated better biomechanics than controls on both the reconstructed and contralateral limbs, particularly for shock absorption. This may reflect training in proper biomechanics during physical therapy and rehabilitation. Motion analysis is useful for identifying risky movement patterns so biomechanics can be corrected prior to return to play.

DISCLOSURE STATEMENT: The authors have no conflicts of interest to disclose.
KINEMATIC ANALYSIS OF THE STEP DOWN TAP TASK: AN ASSESSMENT OF METHODOLOGY FOR A SPORTS PROTOCOL

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INTRODUCTION
The incidence of lower extremity injuries in adolescent athletes is increasing as rates of participation and sports specialization grow. Development of rehabilitation and injury prevention programs have incorporated the use of motion analysis to better analyze movement patterns and identify potential injury risk. Specific tasks have been used to isolate and identify deficient movement patterns in hopes of retraining or improving lower extremity biomechanics. Variations of a single leg squat task have been used to identify inadequate movement patterns of the trunk, pelvis, hip, and knee [1-2]. Due to the variability in the performance of a single leg squat, the step down tap (SDT) has been used to standardize a unilateral squatting maneuver across subjects. However, while the SDT provides a more uniform technique for performing a single leg squat, there are still variations of this task that need to be evaluated prior to its implementation into a standard sports motion capture protocol.

CLINICAL SIGNIFICANCE
Development of a standardized sports motion capture protocol would offer clinicians an invaluable tool for assessing injury risk in the youth athlete. Determining which SDT variation is most appropriate for biomechanical evaluations is a crucial first step towards this development and widespread, multicenter injury prevention research.

METHODS
Participants were prospectively enrolled into an IRB approved study and seen for a single visit in the Movement Science Lab. During the testing session, subjects performed a series of dynamic tasks that included 5 variations of the SDT task (Table 1). For all variations, subjects began standing on top of a bench and were instructed to extend one foot (in front or to the side) of the bench, lower the extended heel so it gently taps the ground, and return to the standing position. Bench height was set to either 15 or 21cm based on the subjects’ height and ability to perform the task successfully. For each task, 3 trials were performed per leg. Kinematic variables were evaluated at maximum squat depth for each successful trial and averaged for each leg/task. Wilcoxon signed rank tests were used to compare task variations (α = 0.05). Clinical significance was determined as differences greater than 3 degrees.

### Table 1. Description of SDT Task Variations (Note: ANT = Anterior, LAT = Lateral)

<table>
<thead>
<tr>
<th>SDT Variation</th>
<th>Body Position</th>
<th>Arm/Foot Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANT Free</td>
<td>Facing forward, leg extends in front</td>
<td>Self-selected arm/foot position</td>
</tr>
<tr>
<td>ANT Arms Fixed</td>
<td>Facing forward, leg extends in front</td>
<td>Self-selected foot position with hands on hips</td>
</tr>
<tr>
<td>ANT Foot Fixed</td>
<td>Facing forward, leg extends in front</td>
<td>Self-selected arm position with foot fixed forward</td>
</tr>
<tr>
<td>LAT Free</td>
<td>Facing sideways, leg extends out to side</td>
<td>Self-selected arm/foot position</td>
</tr>
<tr>
<td>LAT Arms Fixed</td>
<td>Facing sideways, leg extends out to side</td>
<td>Self-selected foot position with hands on hips</td>
</tr>
</tbody>
</table>
RESULTS

Nineteen subjects (10 female, 21.6±4.0y) were tested. The primary comparison was between the ANT Free and LAT Free variations of the SDT. Kinematic differences observed are presented in Table 2. With the ANT SDT, there was increased knee flexion ($p<0.001$), greater external pelvic rotation ($p<0.001$), and less anterior pelvic tilt ($p<0.001$) compared to the LAT SDT. No clinically significant differences were observed in trunk/hip kinematic variables or coronal knee position. Secondarily, no clinically significant differences were seen when comparisons were made to determine whether controlling the arm or stance foot position would influence kinematics for ANT and LAT variations.

Table 2. Kinematic variables at Maximum Squat Depth

<table>
<thead>
<tr>
<th>Variable (degrees)</th>
<th>ANT Free</th>
<th>ANT Arms</th>
<th>ANT Foot</th>
<th>LAT Free</th>
<th>LAT Arms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk Tilt</td>
<td>17.1 (8.1)</td>
<td>16.1 (8.4)</td>
<td>15.6 (9.2)</td>
<td>19.1 (8.0)</td>
<td>19.3 (8.2)</td>
</tr>
<tr>
<td>Trunk Lean</td>
<td>-6.8 (5.7)</td>
<td>-6.8 (6.0)</td>
<td>-5.7 (5.5)</td>
<td>-6.0 (5.7)</td>
<td>-5.2 (5.0)</td>
</tr>
<tr>
<td>Pelvic Tilt</td>
<td>24.7 (6.7)</td>
<td>25.0 (6.3)</td>
<td>25.1 (6.4)</td>
<td>28.9 (8.2)</td>
<td>28.6 (7.0)</td>
</tr>
<tr>
<td>pelvic Obliquity</td>
<td>0.9 (4.5)</td>
<td>1.6 (4.3)</td>
<td>2.3 (4.3)</td>
<td>2.5 (3.8)</td>
<td>4.9 (4.4)</td>
</tr>
<tr>
<td>Pelvic Rotation</td>
<td>-11.2 (5.6)</td>
<td>-12.1 (6.5)</td>
<td>-10.0 (5.8)</td>
<td>-3.1 (6.1)</td>
<td>-3.2 (5.8)</td>
</tr>
<tr>
<td>Hip Flexion</td>
<td>61.3 (10.4)</td>
<td>59.2 (8.4)</td>
<td>61.0 (9.1)</td>
<td>63.9 (11.4)</td>
<td>62.0 (7.9)</td>
</tr>
<tr>
<td>Hip Adduction</td>
<td>14.5 (6.3)</td>
<td>16.1 (5.3)</td>
<td>15.9 (6.4)</td>
<td>13.3 (6.7)</td>
<td>15.8 (6.2)</td>
</tr>
<tr>
<td>Hip Rotation</td>
<td>3.3 (6.2)</td>
<td>4.4 (6.8)</td>
<td>4.1 (6.4)</td>
<td>3.4 (6.5)</td>
<td>4.5 (5.9)</td>
</tr>
<tr>
<td>Knee Flexion</td>
<td>85.6 (12.5)</td>
<td>84.0 (7.6)</td>
<td>86.3 (8.0)</td>
<td>78.1 (12.1)</td>
<td>77.1 (8.9)</td>
</tr>
<tr>
<td>Knee Varus</td>
<td>3.7 (4.9)</td>
<td>4.7 (4.7)</td>
<td>4.2 (4.7)</td>
<td>3.6 (4.8)</td>
<td>4.4 (4.7)</td>
</tr>
</tbody>
</table>

mean (standard deviation) Note: Clinical significance in bold (ANT vs LAT)

DISCUSSION

The objective of this study was to determine kinematic differences across variations in the SDT in order to standardize a motion analysis sports protocol and allow for widespread data collection across motion capture facilities. During the ANT SDT there was increased external (stance limb) pelvic rotation as the athlete rotated their body to extend the limb in front of them, with greater knee flexion needed to reach the floor as the foot was farther away from the bench. While the LAT SDT allows the athlete to keep the non-stance more neutrally aligned, minimizing pelvic rotation, they were more inclined to increase pelvic tilt, and as well as trunk tilt, although the latter did not reach significance. In the future, differences between the ANT and LAT SDT methods should be considered in order to best standardize research protocols. While this pilot data was collected in young adults, future work will need to focus on evaluating these task variations in a youth population.


ACKNOWLEDGEMENTS This work originated through collaboration with a Motion Analysis Research Interest Group of the Pediatric Research in Sports Medicine Society study group. In addition, the authors acknowledge support from the Scottish Rite Research Program.

DISCLOSURE STATEMENT Co-author KTF is a GCMAS executive board member. All other co-authors have no conflicts of interests to disclose.
LOWER EXTREMITY ASYMMETRY INCREASES BASED ON PROVIDED INSTRUCTIONS AND TARGET USE DURING A DROP VERTICAL JUMP TASK

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² The University of Texas Southwestern Medical Center, Dallas, TX, USA
E-mail: sophia.ulman@tsrh.org

INTRODUCTION
Numerous efforts have been made to develop reliable return-to-play (RTP) criteria for youth athletes [1]. Consequently, comparisons between common RTP measures and patients’ underlying biomechanics during functional tests have been investigated to provide a better understanding of movement quality. Recent work has shown that these measures do not reflect the kinematic asymmetries recorded using 3D motion analysis [2-3]. This evidence suggests that more advanced measures of movement quality are necessary to better estimate RTP readiness, emphasizing the need for a standardized motion analysis protocol to capture patients’ biomechanics during dynamic tasks, such as the drop vertical jump (DVJ). The DVJ captures a game-like movement, specifically a preparatory landing for a maximum vertical jump. Given that this task highlights indicators of injury risk, including asymmetry between limbs, it is commonly used in RTP functional testing and injury-risk research [3]. However, the procedure for this task is not standardized across labs. Therefore, the purpose of this study was to determine whether variations in jump distance, verbal instructions, or target use would influence symmetry in landing mechanics.

CLINICAL SIGNIFICANCE
Motion analysis is a valuable resource that can be utilized in sports medicine to inform return-to-play decision-making. However, in order to use 3D movement assessments clinically across multiple institutions, researchers should determine the most appropriate tasks for analysis and develop a standardized protocol for testing.

METHODS
Nineteen healthy subjects (10 female, 18 right-leg dominant, aged 21.6±4.0 years) were asked to perform six different DVJ tasks, which required subjects to “drop” or jump from a 31 cm plyo-box onto two force plates. Lower extremity kinematics and bilateral ground reaction forces (GRF) were collected during the first landing. Three tasks varied by jump distance (i.e., distance from the box to the center of the force plates): zero distance (typical drop jump, DROP), one-third (THIRD) and one-half (HALF) of the subject’s height. To test whether verbal instructions would reduce the variability in movement strategies of a typical drop jump, the zero distance task was used. During the DROP task, subjects were asked to “drop off the box onto the force plates” followed by modified instructions to “slightly bend their knees to ‘pop-off’ the box with both feet at the same time” (POP). The last two task variations investigated whether the use of a target positioned above the force plates would alter symmetry in landing mechanics. For this assessment, a target was added to the HALF (H-TAR) and POP (P-TAR) DVJ tasks.

Wilcoxon signed rank tests were performed to assess side-to-side differences in hip and knee kinematics for each DVJ task (α = 0.05). Symmetry between limbs was assessed by
comparing the dominant limb (D) to the non-dominant limb (N) determined by asking each subject which foot they would use to kick a ball. In addition, clinical significance was only determined when statistically significant joint angle differences were greater than three degrees.

RESULTS

Hip abduction at initial contact (IC) \((p = 0.033 \ P, 0.044 \ H-T, 0.033 \ P-T)\) and max hip abduction \((p = 0.040 \ P, 0.013 \ H-T, 0.022 \ P-T)\) were increased on the non-dominant limb during the POP and target tasks. Additionally, max GRFs in the THIRD \((p = 0.003)\) and target tasks \((p = 0.049 \ H-T, 0.007 \ P-T)\) were increased on the dominant side. No significant differences in knee kinematics were found.

Table 1: Side-to-side differences by DVJ task. Note: Statistical significance in bold.

<table>
<thead>
<tr>
<th>Variable</th>
<th>DROP</th>
<th>THIRD</th>
<th>HALF</th>
<th>POP</th>
<th>H-TAR</th>
<th>P-TAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Abd IC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>((degrees))</td>
<td>N</td>
<td>7.1±3.7</td>
<td>7.3±3.9</td>
<td>6.7±4.2</td>
<td>8.2±4.2</td>
<td>7.9±3.4</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>6.3±4.6</td>
<td>6.0±3.5</td>
<td>6.7±3.5</td>
<td>5.1±4.3</td>
<td>5.7±3.7</td>
</tr>
<tr>
<td>Hip Abd Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>((degrees))</td>
<td>N</td>
<td>13.9±8.8</td>
<td>14.0±7.7</td>
<td>13.6±8.1</td>
<td>14.8±8.3</td>
<td>14.9±8.2</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>10.7±5.5</td>
<td>10.9±5.3</td>
<td>11.5±5.5</td>
<td>10.9±5.9</td>
<td>10.6±5.4</td>
</tr>
<tr>
<td>GRF Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>((Nm/kg))</td>
<td>N</td>
<td>14.0±2.4</td>
<td>14.3±2.2</td>
<td>15.5±2.4</td>
<td>14.4±2.5</td>
<td>15.0±3.2</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>15.0±3.1</td>
<td>16.5±3.9</td>
<td>17.2±4.3</td>
<td>15.4±3.0</td>
<td>16.8±5.1</td>
</tr>
</tbody>
</table>

DISCUSSION

While similar trends in hip abduction and GRFs were present across all DVJ tasks, clinically significant asymmetry between limbs was observed when subjects were provided further instructions during the POP and when a target was used. Differences in kinematics between limbs due to verbal instructions highlight the need of consistency when testing patients. Additionally, asymmetry observed during the target tasks is likely due to the subjects shifting their weight to their dominant side through the landing phase of the DVJ task in preparation of jumping and reaching for the target, implying that target use may not be appropriate for clinical RTP assessments. In conclusion, these findings emphasize the need for a standardized DVJ procedure. Repeating this analysis for all dynamic tasks utilized in a single sports protocol would allow for multi-center collaborations and widespread collection of biomechanical data that could be used to inform treatment.

REFERENCES


ACKNOWLEDGMENTS This work originated through collaboration with the Motion Analysis Research Interest Group of PRiSM. The authors also acknowledge support from the Scottish Rite Research Program.

DISCLOSURE STATEMENT Co-author KTF is a GCMAS executive board member. All other authors have no conflicts of interest to disclose.
**Proof of Concept:** Response surface methodology reveals changing motor control strategies during a single leg squat.

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**Affiliations:** University of Colorado Anschutz Medical Campus  
**Corresponding Author:** beth.warren@cuanschutz.edu  
**Category:** New Tools and Techniques

**Introduction**
Response surface methodology (RSM) is a technique relating the interaction of two variables to an output and is classically used to optimize crop yield and chemical processes \(^{[1]}\). Stergiou et al. introduced the application of this technique for analyzing motor controls strategies during single leg hopping \(^{[2]}\). Our study seeks to further explore RSM as a technique to characterize joint stiffness and compare motor control strategies between healthy controls and subjects with hemophilia during a single leg squat.

**Clinical Significance**
Hemophilia is a bleeding disorder resulting from clotting factor deficiency. Joint bleeding and long-term damage can occur in a person with hemophilia (PwH), leading to movement alterations from pain, swelling, and arthritis in weight-bearing joints that reduce range of motion and increase joint stiffness. To determine how motor control may change in PwH, pilot data from control subjects were collected to characterize the motor control strategies during repeated single leg squats (SLS).

**Methods**
Controls (n = 13) and a PwH (n=1) performed 20 SLS, with rest as needed to avoid fatigue effects. Trajectories from the Vicon full body marker set were recorded using eight Vicon Vantage cameras and kinetics recorded using a Bertec force plate. Kinematic and kinetic data was temporally normalized, and the concentric and eccentric phases of the hop identified using joint angles. Joint stiffness was calculated for each subject’s dominant leg’s hip, knee, and ankle by dividing joint moment by joint angle. Total leg stiffness is the sum of the hip, knee, and ankle stiffnesses. Pairings of joint’s stiffness data (hip-knee, hip-ankle, knee-ankle) were then fitted using 2\(^{nd}\) order, nonlinear regression in Mathematica. Surfaces were categorized based on calculated eigenvalues as a maximum (maximizing variables to optimize the response), minimum (minimizing variables), or saddle (mixed behavior of variables) \(^{[3]}\).

A two-tailed, unpaired t-test was performed comparing the respective joint and total leg stiffnesses between the control cohort and the PwH for both the concentric and eccentric phases of the SLS.

**Figure 1:** Response Surfaces for Eccentric Phase of Squat.  
Row 1: Control Subjects, Row 2: PwH
Demonstration
There was no significant difference (p > 0.1) between the individual joint and total leg stiffnesses between the controls and PwH. However, RSMs revealed that different motor control strategies were adopted (Figure 1). The surfaces for the eccentric phase of the squat for the PwH was different than what was seen in the control cohort. For these subjects, the majority of the surfaces for the eccentric phase were saddles while the PwH had a minimum, maximum, and saddle surface. Upon further investigation of the individual surfaces in the control cohort, some subjects had a maximum surface. However, none of the controls had a minimum surface in the eccentric phase of the squat and was only seen in the PwH (Figure 2). Although more subjects with hemophilia will be studied in this ongoing investigation, the differences in stiffness strategies during the eccentric phase of the SLS between controls and the PwH suggest RSM may offer clinically useful insights. RSM may elucidate motor control strategies adopted to compensate for hemophilia caused joint damage by reducing multiple joints’ kinematic and kinetic variables into a low dimensional descriptor.

Summary
This investigation explored the use of RSM to evaluate motor control strategies in control subjects compared to a PwH. While traditional kinematic and kinetic data may not detect changes in motor control, RSM shows promise in revealing changes in movement strategies for populations with movement impairments relating to joint stiffness.

References

Acknowledgements
This study was funded by a pilot grant from the University of Colorado Department of Orthopedics and by grant 2H30MC24049 (HRSA/MCHB/Mountain States Hemophilia Network).

Disclosures
The authors have no relevant conflicts of interest to declare.
EFFECT OF AUTOGRRAFT TYPE ON RECOVERY OF KNEE EXTENSOR MECHANISM FUNCTION FOLLOWING PEDIATRIC ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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E-mail: TWren@chla.usc.edu

INTRODUCTION
While multiple studies have shown clear benefits of autograft over allograft for anterior cruciate ligament reconstruction (ACLR) in young athletes, disagreement remains regarding the optimal autograft choice [1]. Recovery from ACLR may be influenced by the type of autograft used, which is typically based on skeletal maturity, surgeon preference and the athlete’s post-surgical goals. This study compared knee joint function, specifically in the sagittal plane, among pediatric athletes with different ACLR autograft types, including iliotibial band (IT), hamstring tendon (HT), quadriceps tendon (QT), and patellar tendon (PT).

CLINICAL SIGNIFICANCE
In the return to sport timeframe following ACLR, young athletes with IT band autografts exhibited the greatest engagement of the knee extensors during dynamic loading among all autograft types studied, supporting the use of IT band as a viable autograft option in young athletes undergoing ACLR.

METHODS
145 pediatric athletes (76 female; mean age at surgery 15.0, SD 2.2, range 7-21 years) with recent (3-18 months) unilateral ACLR performed drop-jump landing (41 cm box) and 45° cutting. Kinematics and kinetics were collected using a 6-degree of freedom model [2] and an 8-10 camera Vicon motion capture system with AMTI force plates. Knee extensor mechanism function (maximum knee flexion angle, maximum internal knee extensor moment, energy absorption at the knee) during the loading phase (foot contact to peak knee flexion) was compared among graft types (20 IT, 29 HT, 39 QT, 57 PT) and sides (ACLR or contralateral) using linear mixed models with sex, age, and time since surgery as covariates.

RESULTS
Of all graft types tested, dynamic knee extensor function was greatest in the IT band group. Knee flexion was significantly lower on the operated vs. contralateral side for HT, QT, and PT during both drop jump (p≤0.02) and cutting (p≤0.006). All graft types exhibited lower knee extensor moments and energy absorption on the operated side during both movements (p<0.001). This asymmetry was most pronounced for QT and PT and least pronounced for IT (Figure 1). Loading on the operated limb decreased in order from IT to HT to QT and PT, while loading on the contralateral limb increased similarly. Asymmetry of kinetics was significantly lower for IT compared with both QT and PT during both movements (p≤0.005). Similar patterns were observed for HT but were less pronounced and not always statistically significant (p≤0.07). Few differences in asymmetry were observed between IT and HT or between QT and PT.
FIGURE 1: Comparison of operated (red) and contralateral (blue) limbs by graft type (model predicted average and 95% confidence interval)

DISCUSSION
In the return to sport timeframe following ACLR, young athletes with IT band autografts exhibited the greatest engagement of the knee extensors during dynamic loading among all autograft types studied. This was evidenced by both higher loading of the reconstructed knee and lower loading of the contralateral knee, resulting in decreased asymmetry. Interestingly, these effects were much more prominent for kinetics compared with kinematics. This highlights the importance of objective, quantitative assessment using motion analysis technology since the kinematic asymmetry could be difficult to discern visually.


ACKNOWLEDGMENTS: We would like to thank Henry Lopez and Kyle Chadwick for their work in the Motion Analysis Laboratory.

DISCLOSURE STATEMENT: There are no disclosures from any of the authors.
JOINT KINETICS IN UNDERSTANDING POSSIBLE CAUSES FOR PAIN AND REDUCED RUNNING PERFORMANCE: A CASE STUDY
S. Õunpuu and K. Pierz
Connecticut Children’s Medical Center, Farmington, CT, USA
E-mail: souenuu@connecticutchildrens.org, Web: www.connecticutchildrens.org

PATIENT HISTORY
Patient is a 17-year-old male, who had a transverse fracture of his tibia and fibula two years prior when playing baseball. Surgical fixation took place 4 days following the injury with plate and screws in both the tibia and fibula followed by casting and crutch walking for two weeks and boot for two months with full healing. He had 8 months of PT following surgery before approval to return to baseball. However, he had ongoing pain while loading during running and was unable to perform at his pre-injury level. He was seen for a comprehensive gait analysis to gain insight into possible biomechanical mechanisms for the ongoing pain. Parent and patient goal was pain resolution and to attain preinjury running speed and agility.

CLINICAL DATA
A comprehensive gait analysis was completed both walking and running. Selected clinical exam findings are summarized in Table 1. Pain was located 1/3 the way down the anterior portion of the right shank and was graded 3-4/10 when at its worst. Additional assessments revealed difficulty with single leg hopping and squatting (eccentric loading of the quadriceps) on the right side only.

Table 1: Selected clinical exam and temporal findings.

<table>
<thead>
<tr>
<th></th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion strength</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Knee flexion strength</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Knee extension strength</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Ankle plantar flexion strength</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Knee extension (deg)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Popliteal angle (deg)</td>
<td>-55</td>
<td>-45</td>
</tr>
<tr>
<td>Ankle dorsiflexion knee 0deg flexion (deg)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Ankle plantar flexion strength</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Ankle dorsiflexion strength</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Quads Girth (20 cm prox to patella) (cm)</td>
<td>57.8</td>
<td>60.0</td>
</tr>
<tr>
<td>Toe off walking range (% gait cycle)</td>
<td>62.2-62.5</td>
<td>59.3-61.7</td>
</tr>
<tr>
<td>Toe off running range (% gait cycle)</td>
<td>33.7-34.1</td>
<td>34.1-35.7</td>
</tr>
</tbody>
</table>

MOTION DATA
During level shod walking, motion analysis data showed a reduction in knee flexion loading and associated quadriceps avoidance knee moment pattern (no internal knee extensor moment) on the right in comparison to the left side (Fig. 1). When running, this asymmetry was more remarkable with no right knee flexion in loading and a continued quadriceps avoidance pattern during loading of the right side only (Fig. 1). Kinematic and kinetic data was very consistent stride to stride. The right side ankle showed no compensatory increased power absorption during the loading phase (not shown). Following visual review of sagittal plane kinetic data asymmetries, patient was videoed during unilateral squat movements.
**TREATMENT DECISION AND INDICATIONS**

Physical therapy to work on eccentric strengthening of the right quadriceps. **Indications:** reduction in right knee loading response flexion in comparison to the left and associated quadriceps avoidance during walking and more significantly during running. Ankle kinematics and kinetics were symmetric during running (not shown) indicating no ankle compensation for reduced knee loading on the right side. **Goal:** to improve eccentric loading capacity of the quadriceps muscle and distribute loading impact through both the knee and ankle thus reducing possible load on the right tibia.

![Graphs showing knee kinematics and kinetics during walking and running.](image)

**TREATMENT OUTCOMES**

The patient is currently undergoing rehabilitation to address the asymmetry in knee eccentric strength to allow muscle based absorption of landing loads during running on the right side.

**SUMMARY**

Comprehensive gait analysis allows objective measurement of walking and running function that is not possible in the clinic setting. The patient showed asymmetry in knee sagittal plane kinematics and kinetics both in walking and more so in running. The decreased eccentric loading at the right knee was not absorbed by increased right ankle absorption. These gait findings led to assessment of eccentric strength immediately following the gait analysis testing. The isometric strength symmetry did not provide evidence of this isokinetic strength asymmetry. The gait analysis results, specifically knee sagittal plane kinetics, helped to identify ongoing impairment that required rehabilitation.

**DISCLOSURE STATEMENT**

The authors have no conflicts of interest to disclose.
Similar Biomechanics During Change of Direction in Adolescents with Contact Versus Non-Contact Anterior Cruciate Ligament Injury

Mia J. Katzel, PT¹, Adriana Conrad-Forrest, MS¹, Curtis D. VandenBerg, MD¹, Tishya A. L. Wren, PhD¹
¹Children’s Hospital Los Angeles
Email: twren@chla.usc.edu

Introduction

Patients who sustain non-contact anterior cruciate ligament (ACL) injuries are thought to be predisposed to injury due to deficient biomechanics or neuromuscular control¹. In contrast, patients who sustain contact ACL injuries may have been injured due to unlucky trauma and may not have poor biomechanics. The purpose of this study was to compare biomechanics during change of direction movements between patients who injured their ACL through a contact mechanism and those who were injured with a non-contact injury mechanism. We hypothesized that patients who sustained an ACL tear with a contact injury mechanism would demonstrate better biomechanics (greater shock absorption and less dynamic limb valgus) than patients with a non-contact injury mechanism.

Clinical Significance

The results of this study suggest that all patients post ACL reconstruction have potentially modifiable biomechanical risk factors for re-injury regardless of injury mechanism. Motion analysis can be used to evaluate movement patterns prior to return to sport so any deficiencies in biomechanics or neuromuscular control can be identified and addressed.

Methods

15 adolescents (age 10-18 years) with contact ACL injury (4 female; mean age 15.5, standard deviation (SD) 2.1 years) and 94 with non-contact ACL injury (11 female; mean age 15.6, SD 1.9 years) underwent biomechanical assessment in our sports and motion analysis laboratory 6-12 months (mean 7.5, SD 1.3) after ACL reconstruction. Subjects performed forward-backwards (deceleration) and lateral (side shuffle) change of direction tasks while 3D motion analysis data were collected using a 10-camera Vicon motion capture system and AMTI force plates. A 6-degree of freedom marker set was used, and modeling was performed in Visual3D. Kinematic and kinetic variables reflecting dynamic limb valgus (frontal and transverse plane) and shock absorption (sagittal plane) were compared between patients who had contact vs. non-contact injury mechanisms using 2-tailed t-tests.

Results

No significant differences were observed in any of the kinematic or kinetic measures between the contact and non-contact groups (Table 1).
Table 1: Comparison of kinematics and kinetics between contact and non-contact ACL injury groups

<table>
<thead>
<tr>
<th></th>
<th>Deceleration</th>
<th>Lateral Shuffle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Contact</td>
<td>Contact</td>
</tr>
<tr>
<td><strong>SHOCK ABSORPTION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max hip flexion</td>
<td>75.3 (15.2)</td>
<td>76.9 (16.4)</td>
</tr>
<tr>
<td>Max knee flexion</td>
<td>65.2 (14.1)</td>
<td>68.8 (20.9)</td>
</tr>
<tr>
<td>Max ankle dorsiflexion</td>
<td>-5.5 (7.1)</td>
<td>-2.3 (2.2)</td>
</tr>
<tr>
<td>Max hip flexion moment</td>
<td>2.8 (1.5)</td>
<td>2.5 (0.9)</td>
</tr>
<tr>
<td>Max knee flexion moment</td>
<td>1.3 (0.5)</td>
<td>1.2 (0.7)</td>
</tr>
<tr>
<td>Max ankle dorsiflexion moment</td>
<td>0.84 (0.22)</td>
<td>0.82 (0.29)</td>
</tr>
<tr>
<td>Energy absorption at hip</td>
<td>0.66 (0.43)</td>
<td>0.56 (0.39)</td>
</tr>
<tr>
<td>Energy absorption at knee</td>
<td>0.50 (0.35)</td>
<td>0.44 (0.38)</td>
</tr>
<tr>
<td>Energy absorption at ankle</td>
<td>0.17 (0.11)</td>
<td>0.14 (0.06)</td>
</tr>
<tr>
<td><strong>DYNAMIC LIMB VALGUS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max hip internal rotation</td>
<td>7.8 (7.4)</td>
<td>5.1 (7.8)</td>
</tr>
<tr>
<td>Max hip adduction</td>
<td>1.9 (6.4)</td>
<td>2.6 (4.5)</td>
</tr>
<tr>
<td>Min knee varus</td>
<td>-1.1 (4.8)</td>
<td>-3.8 (6.6)</td>
</tr>
<tr>
<td>Min knee varus moment</td>
<td>-0.34 (0.34)</td>
<td>-0.32 (0.32)</td>
</tr>
</tbody>
</table>

External moments are reported. Angles are expressed in degrees, moments in N/kg, energy absorption in J/kg.

**Discussion**

Contrary to expectations, in patients recovering from ACL reconstruction, the contact injury group did not have better biomechanics than the non-contact injury group. This may be due to both groups engaging in similar physical therapy and rehabilitation programs, focusing on improving their strength and movement patterns. It may also be due to the contact injury group having similar pre-injury biomechanics to the non-contact group but happening to be injured by a contact mechanism. These results suggest that all patients post ACL reconstruction have potentially modifiable risk factors for re-injury and should have their biomechanics evaluated so any deficiencies in movement patterns, biomechanics, and neuromuscular control can be rectified prior to return to sport regardless of injury mechanism.

**References**


**Acknowledgements**

We would like to acknowledge all staff members in the Motion and Sports Analysis Laboratory at Children’s Hospital Los Angeles.

**Disclosure Statement**

The authors of this abstract have no disclosures.
Tuesday Night Social

One of the challenges of hosting an online conference is providing social spaces in which participants can interact outside of the formal bounds of the meeting. To this end, we’ll be opening one of our Zoom rooms during large parts of the meeting for informal gatherings. I’ll discuss that more in a later post.

But meetings are also a place where one can gather with friends and colleagues to have fun. Often this is in the form of a banquet on the next to last night, but it can also take other forms in person. In our original meeting in 2020, this was scheduled to be on one of West Chester’s “Swinging Summer Thursdays” in which restaurants give discounts, and the streets are blocked off so that restaurants can put out tables. Gay Street has a super-high density of restaurants, so the feel is like the downtown of a European city. We had planned a roof-top a-la-carte Mexican dinner in West Chester with encouragement to get out and try all the local pubs and breweries that you hadn’t yet encountered.

So in light of this, we felt that providing this element online would be a challenge. The programming committee discussed virtual beer tastings (yum!) as a pale imitation of the in person experience, but these came with large price tags due to shipping costs, and after polling random people including spouses, lab mates, and teaching colleagues, we figured that given the cost (over $100 per person) people would probably rather drink whatever they had on hand and experience something else.

The solution (we hope!) presented itself, when my family attended an online show by an improv comedy troupe we had previously seen in person: Better Than Bacon. This group started out in the early 2000s taking improv classes together, and then moved on to start giving shows. For the past several years they have been a fixture at the local performing arts centers. Furthermore, they often donate their proceeds to non-profits in the area via their Bacon Gives Back initiative.
Better Than Bacon will be providing our Tuesday night (June 8th, 2021) entertainment from 6.30-7.30pm via Zoom. We hope that you will consider donating to a worthy cause as they are donating their time to our organization!
Breakfast Session 2

Advances in Upper Extremity Motion Capture for Clinical Assessment

Date/Time: Wednesday, June 9: 9-10am EDT (UTC-4)

Presenters:

- Jason Long, PhD - Cincinnati Children’s
- Ross Chafetz, PT, DPT, PhD, MPH - Shriners Hospital for Children - Philadelphia
- Tyler Richardson, PhD - Penn State Harrisburg
- Stephanie Russo, MD, PhD - Shriners Hospital for Children - Philadelphia

Objectives:

1. Acknowledge limitations of upper extremity motion capture assessments
2. Understand the proposed recommendations for upper extremity motion capture assessments
3. Learn about novel upper extremity motion capture techniques and recognize the potential for integration of technology into data collections

Description:

Upper extremity motion capture clinical assessments are far less common than lower extremity analyses due to a variety of challenges. Our group of surgeons, therapists, and researchers dedicated to improving the care of children with brachial plexus injuries (Plexus Nexus - https://www.plexusnexus.org/) has been working to address these challenges common to all upper extremity assessments. We have developed a standardized set of recommendations for clinical and motion analysis evaluation procedures in order to expedite data sharing and apples-to-apples comparisons between sites. Additionally, we are creating novel real-time motion capture tools to facilitate data collection on younger patients and exploring new ways to quantify and visualize upper extremity function. Keeping in line with collaborative spirit of this endeavor, we would like to disseminate this information and provide open access to the tools utilized to any interested upper extremity clinicians or researchers. During this session we will describe our proposed recommendations for upper extremity motion analysis, provide a demonstration new tools and approaches, and facilitate an open discussion between upper extremity clinicians and researchers in attendance.
Title:

Markers, Models and Methods: Technical Factors to Consider When Initiating Clinical Sports Medicine Protocols in Traditionally Non-Sports Clinical Motion Analysis Labs

Instructor(s):

Sophia Ulman, PhD¹, Tishya Wren, PhD², Mia Katzel, DPT, OCS, CSCS² Ross Chafetz, PT, PhD³, Kirsten Tulchin-Francis, PhD⁴ and a PRiSM Motion Analysis RIG Study Group

¹Scottish Rite for Children
²Children’s Hospital Los Angeles
³Shriners Hospital, Philadelphia
⁴University of Texas Southwestern Medical Center

Purpose:

To provide an overview of the technical planning and aspects involved in initiating a new clinical sports medicine protocol in a traditionally non-sports clinical motion analysis lab.

Intended Audience:

Any individual involved in motion analysis (orthopedists, sports medicine specialists, biomechanists, physical therapists, athletic trainers, kinesiologists and engineers) who may consider participating in the functional evaluation of pediatric, adolescent or adult athletes in a motion analysis lab.

Prerequisite Knowledge:

No particular prerequisite knowledge is required.

Abstract:

As a collaboration through the Pediatric Research in Sports Medicine (PRiSM) Motion Analysis Research Interest Group (RIG), our study group has been working to establish standard methods to biomechanically study pediatric and adolescent sports medicine patients who sustain lower limb injuries through multi-center collaboration. Each center had independently initiated, either clinically or through research, protocols to evaluate adolescent patients with ACL and/or other knee injuries. While each center used similar methods for standard clinical gait analysis, we found that methodology varied in our sports methodology. Our study group did extensive pilot testing to develop standard operating procedures (SOP) which focused on marker placement, model definitions and functional task instructions.

The aim of this tutorial is to twofold: 1) to provide an overview of kinematic and kinetic differences during sports medicine functional tasks based on biomechanical modeling and marker placement, and 2) to provide basic guidelines and best practices that can be followed in developing comprehensive procedures when implementing multi-task protocols in motion analysis.
**Learning objectives:**

At the completion of this course, attendees will:

- Understand the basics of biomechanical modeling using 3D motion capture
- Discuss the relationship between marker placement, segment definitions, and tracking, both static and dynamic
- Understand how variations in biomechanical models may alter kinematics and kinetics differently during different athletic tasks
- Understand the clinical and technical content that should be included in a comprehensive multi-task motion capture standard operating procedure

**Outline of course content:**

I. Introduction to course (5 mins)
   
   This will include the course outline, introduction of speakers, and learning objectives.

II. Overview of Biomechanical Modeling (20 mins)

   This section will include a review of basic biomechanical modeling theory, followed by descriptions of the traditional CGM marker placement/model and the cluster/6-DOF technique.

III. Model-Based Differences in Lower Extremity Kinematics and Kinetics: Applications Across Multiple Sports Medicine Functional Tasks (60 mins)

   During this section of the tutorial we will present multiple functional tasks, such as drop vertical jump, single limb hops, etc., and will present how kinematic and kinetic data may change based on biomechanical model.

IV. What is a comprehensive, multi-task, motion analysis Standard Operating Procedure (SOP)? (20min)

   The protocol developed will only be as good as its SOP. What information goes into a SOP, and how much detail do you really need to include?

V. Question/Answer (15min)

*Handout will include a sample SOP based on that which was developed for our study group.*
Keynote 2

Freeman Miller, MD
Diagnostic Clinical Gait Analysis: Where are we and Where should we go?
Date/Time: Wednesday June 9th, 11:40-12:40 (UTC-4)

Dr. Miller graduated from the University of Colorado Medical School in 1978. A Residency in Orthopedic surgery was completed in 1983, followed by a fellowship in Pediatric Orthopedics at the Hospital for Sick Children in Toronto, Ontario.

Dr. Miller was Co-director of the Cerebral Palsy Program and the Clinical Director of the Gait Analysis Laboratory at the A.I. duPont Hospital for Children for 30 years. He continues as an emeritus staff member at AI duPont Hospital for Children providing consultative services and is active in the research program. His clinical practice of pediatric orthopedics is limited to children with cerebral palsy. For the past 25 years, Dr. Miller has held Adjunct Professor appointments in the Departments of Mechanical Engineering and Physical Education at the University of Delaware. He is also a member of the University BIOMS program, which is an interdisciplinary graduate program in biomedical engineering. Dr Miller has been actively involved in supervision of graduate and undergraduate students at Delaware through these programs. Current and past research interests include investigation of surgical outcomes of CP surgery through gait analysis; mathematical modeling of the hip joint in children with CP, hip monitoring and management for children with CP, and management of spinal deformity in CP. Almost all my clinical practice has been focused on orthopedic management of children with neurologic disability, especially on improving gait and managing disabling deformity.

Dr. Miller has published approximately 200 articles in peer reviewed journals, has published a book Cerebral Palsy: A Guide for Caregiving directed at families and none medical careproviders which was published in 1995, and in 2017 was revised and released as the third edition. A medical textbook, Cerebral Palsy with 1080 pages outlining musculoskeletal care of the child with cerebral palsy was written by Dr. Miller and published in 2005 by Springer-Verlag. The second edition of this book is will be released in mid 2020.

Objectives:

At the completion of this talk, the audience will be able to
1. Understand the current deficits in our use of gait analysis data for clinical decision making.
2. To be able to conceptualize new options for future clinical applications of gait data to improve patient outcomes.
3. Appreciating the longterm nature of childhood gait treatment and its lifetime implications in the context of the international framework of understanding disability.
Declines in Strength, Motor Function, and Gait in a Child with Cerebral Palsy Following Multiple Botox Injections: A Case Report

Lennon, N; Miller, F; Shrader, MW; Church, C; Salazar-Torres, J; Kalisperis, F; Howard, J

Subject History: This case study presents gait lab data over seven years of childhood for a patient whose birth history, developmental profile, and gait presentation are consistent with spastic diplegic cerebral palsy (CP) GMFCS II who received care at two specialty centers. The first center promoted early physical therapy, orthoses, and gait monitoring, with consideration for orthopedic surgery when development plateaus. The second institution had a common practice of repeat Botox injections to spastic muscles throughout childhood.

Clinical Data: Table 1 presents serial clinical measures of muscle strength, spasticity, lower extremity PROM, gait kinematics, and gross motor function collected in the gait analysis lab from age three to ten.

Motion Data: Figure 1 presents data from gait lab visits at age 5, 9, and 10 years (10---9---5.5---).

Treatment Decisions and Indications: At age 3.5, there was hamstring spasticity with poor flexibility and mild gastrocnemius spasticity with normal ankle DF, corroborating a Rodda gait classification of apparent equinus driven by hamstring spasticity. At that stage, the patient had Botox injections from the first center to bilateral hamstrings. At age 5.5, there was improved hamstring flexibility, reduced hamstring spasticity, and gains in the GMFM, including independent walking. He received two larger doses of Botox from the second center to multiple muscle groups at age eight and nine. The clinical exam measures prior to those injections do not support treatment of the hip adductors and gastrocnemius, where spasticity measures were relatively mild. Following the Botox injections, at age nine, stiffness in the hip adductors increased and flexibility decreased. Hamstring spasticity and PROM had no change, and gastrocnemius contracture (relative to soleus) got worse. MMT measures had no meaningful change; however, gait kinematics showed a loss of controlled second rocker at the ankle, perhaps related to functional calf weakness. There was excess DF, which likely contributed to excess knee flexion and hip flexion. After the fourth round of Botox injections from center two, at age ten, the MAS ratings peaked and the degree of soft tissue contractures was clinically concerning and unimproved. At this stage, there was a clear loss of strength in the ankle PFs. Gait Kinematics persisted in crouch, with excess hip and knee flexion, although ankle DF was less severe. There was a loss in GMFM-D score, from 76% to 69%, and most concerning, report from the family that the patient started crawling rather than walking around the house.

Outcome Summary: After improvements from age three to seven, the patient’s gait and motor function declined from age eight to ten with no improvement in spasticity or range of motion measurements. Muscle testing and gait kinematics define a loss of plantarflexion strength. The decline in gross motor skills and gait seen in this patient may have been prevented if interventions at the second specialty center had been guided by objective data. Treatment decisions should be informed by a comprehensive battery of measures intended to define functional goals and evaluate outcomes. Absent this approach, families risk less favorable outcomes.
Table 1: Longitudinal Data on Spasticity, Contractures, Strength, Gross Motor Function, and Gait (m = missing)

<table>
<thead>
<tr>
<th>Botox timing &amp;</th>
<th>Patient Age</th>
<th>Side</th>
<th>3.5 years old</th>
<th>5.5 years old</th>
<th>8 years old</th>
<th>9 years old</th>
<th>10 years old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle groups</td>
<td></td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
</tr>
<tr>
<td>Hip adductors</td>
<td>2</td>
<td>2</td>
<td>1+</td>
<td>2</td>
<td>1+</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Hamstrings</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>1</td>
<td>1</td>
<td>1+</td>
<td>1+</td>
<td>2</td>
<td>1+</td>
<td>1+</td>
</tr>
</tbody>
</table>

Spasticity (MAS)

<table>
<thead>
<tr>
<th>PROM</th>
<th>Hip extension</th>
<th>-5°</th>
<th>-5°</th>
<th>10°</th>
<th>10°</th>
<th>-5</th>
<th>-5</th>
<th>-10°</th>
<th>-10°</th>
<th>-5°</th>
<th>-5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip abduction</td>
<td>12°</td>
<td>15°</td>
<td>15°</td>
<td>20°</td>
<td>20</td>
<td>18</td>
<td>15°</td>
<td>13°</td>
<td>13°</td>
<td>16°</td>
<td></td>
</tr>
<tr>
<td>Knee extension</td>
<td>-10°</td>
<td>-10°</td>
<td>-11°</td>
<td>-7°</td>
<td>-10</td>
<td>-15</td>
<td>-11°</td>
<td>-15°</td>
<td>-13°</td>
<td>-21°</td>
<td></td>
</tr>
<tr>
<td>Popliteal angle</td>
<td>100°</td>
<td>90°</td>
<td>68°</td>
<td>70°</td>
<td>75</td>
<td>80</td>
<td>75°</td>
<td>75°</td>
<td>78°</td>
<td>80°</td>
<td></td>
</tr>
</tbody>
</table>

| DF (knee flexed)| 35° | 25° | 15° | 15° | 20 | 0 | 20° | 15°  | 22°  | 15° |
| DF (knee ext)   | 10° | 10° | 0°  | 10 | -8| -3°| -7° | 0°   | -5°  |

Strength (MMT)

<table>
<thead>
<tr>
<th>Strength (MMT)</th>
<th>Hip extensors</th>
<th>m</th>
<th>m</th>
<th>3+</th>
<th>3+</th>
<th>3+</th>
<th>3+</th>
<th>4-</th>
<th>4-</th>
<th>4</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee extensors</td>
<td>m</td>
<td>m</td>
<td>3+</td>
<td>3+</td>
<td>3+</td>
<td>3+</td>
<td>4</td>
<td>4</td>
<td>4+</td>
<td>4+</td>
<td></td>
</tr>
<tr>
<td>Knee flexors</td>
<td>m</td>
<td>m</td>
<td>3+</td>
<td>3+</td>
<td>3+</td>
<td>3+</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td></td>
</tr>
<tr>
<td>Ank plantarflexors</td>
<td>m</td>
<td>m</td>
<td>3+</td>
<td>3+</td>
<td>3+</td>
<td>3+</td>
<td>3-</td>
<td>3-</td>
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Kinematics (maximum values during stance)

<table>
<thead>
<tr>
<th>Kinematics (maximum values during stance)</th>
<th>Hip extension</th>
<th>m</th>
<th>m</th>
<th>-3°</th>
<th>0°</th>
<th>m</th>
<th>m</th>
<th>-17°</th>
<th>-20°</th>
<th>-18°</th>
<th>-13°</th>
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<tbody>
<tr>
<td>Knee extension</td>
<td>m</td>
<td>m</td>
<td>-30°</td>
<td>-32°</td>
<td>m</td>
<td>m</td>
<td>-48°</td>
<td>-50°</td>
<td>-50°</td>
<td>-60°</td>
<td></td>
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<tr>
<td>Ankle DF</td>
<td>m</td>
<td>m</td>
<td>10°</td>
<td>5°</td>
<td>m</td>
<td>m</td>
<td>28°</td>
<td>23°</td>
<td>14°</td>
<td>7°</td>
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Gross Motor Function

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Walking Speed</td>
<td>m</td>
<td>75 cm/sec</td>
<td>m</td>
<td>32 cm/sec</td>
<td>76 cm/sec</td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION: Progressive foot deformity is often seen in children with cerebral palsy (CP)\cite{1,3} and can adversely affect a child’s gait and function as they age. The odds of pes valgus and out-toeing increase with age and history of prior surgery in children with CP.\cite{1} In ambulatory patients, correction of pes valgus is performed to relieve pain and improve transverse plane alignment with the hope of improving stance phase stability and functional ambulation.\cite{1,3} At our facility, medial calcaneal sliding osteotomy (CS) and (LCL) are the two main osseous surgeries performed for the correction of pes valgus deformity. Medial column surgery, most commonly talonavicular joint capsulorrhaphy (TNCC) or talonavicular joint fusion (TNF), is often performed concomitantly with the calcaneal osteotomy. We have anecdotally observed postoperative development of pes varus deformity after LCL and have replaced it with CS with the aim of preventing this unintended result.

CLINICAL SIGNIFICANCE: The purpose of this study was to compare the effectiveness of CS and LCL procedures for correction of valgus foot deformities in ambulatory children with CP. We hypothesized that the two approaches would be equivalent with respect to deformity correction and improvement in gait characteristics, but that the incidence of post-operative pes varus would be higher after LCL than CS.

METHODS: Retrospective medical record review (including 3D gait analysis data) of patients with CP functioning at GMFCS levels I-III, who underwent LCL or CS at our facility. Data extraction included complications (modified Clavien-Dindo system), change in standing foot position (modified Yoo system)\cite{2}, and change in gait kinematics and kinetics pre- to post-operatively. Groups were compared using paired t-tests, Fisher’s exact test, and survivorship analysis using Cox proportional hazard models.

RESULTS: Seventy-two eligible participants (119 limbs) were identified, 41 male (57%) and 31 female (43%). Average age at surgery was 11.1 (SD 2.5) years. All participants were ambulatory with or without assistive devices, and 38 (53%) functioned at GMFCS level III at the time of surgery. Age at surgery, sex distribution, and distribution of GMFCS levels were similar between groups. The CS group had significantly shorter follow-up time than the LCL group (p=0.0004). The CS group had a higher rate of concomitant TNF (48% vs. 0%, p<0.001), while the LCL group had a higher rate of TNCC (89% vs. 22%, p<0.001). Complication rates were acceptably low (≤ 23%) in both groups and did not differ significantly between groups (p=0.14). Successful maintenance of deformity correction was achieved according to the modified Yoo\cite{2} ratings in 52/73 limbs (71%) in the CS group and 16/44 limbs (36%) in the LCL group (p<0.001). Recurrent pes valgus was more common in the LCL group (p=0.003), as was the need for repeat foot surgery (p=0.001). Development of pes varus was more common in the LCL group than the CS group, but the difference did not reach the level of statistical significance and
the rate was low in both groups (13% for LCL, 4% for CS). (Table 1) To account for the
difference in length of follow-up between the two groups, survivorship analysis was performed
to predict the occurrence of recurrent valgus, development of varus, and repeat foot surgery as a
function of time since surgery. Because TNF had a significant effect on outcomes, the
survivorship analysis compared three groups: LCL (no TNF was done with LCL), CS (without
TNF), and CS+TNF. This analysis confirmed that the risk of recurrent pes valgus was
significantly lower when TNF accompanied CS (p<0.04) but did not differ significantly between
the LCL and CS groups without TNF (p=0.58). Similar results were observed for repeat foot
surgery. The risk of developing pes varus did not differ significantly between groups (p>0.20).
Ankle kinematics and kinetics showed no significant change pre- to post-operatively in either
group, and the amount of change was not significantly different between groups.

Table 1: Frequency of recurrent pes valgus, development of pes varus and repeat foot surgery

<table>
<thead>
<tr>
<th></th>
<th>Lateral column lengthening (46 limbs)</th>
<th>Calcaneal sliding osteotomy (73 limbs)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recurrent pes valgus</td>
<td>15 (33%)</td>
<td>7 (10%)</td>
<td>0.003</td>
</tr>
<tr>
<td>Development of pes varus</td>
<td>6 (13%)</td>
<td>3 (4%)</td>
<td>0.09</td>
</tr>
<tr>
<td>Repeat foot surgery</td>
<td>14 (30%)</td>
<td>5 (7%)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

DISCUSSION: Successful correction was maintained in 71% of limbs after CS and 36% of
limbs after LCL. However, this difference appears to be due to longer follow-up in the LCL
group rather than a true difference in outcome between the two surgical procedures. This study
highlights the frequent need for concomitant medial column surgery at the time of CS or LCL in
children with CP, due to the frequency of midfoot breaks in this population. None of the patients
who underwent CS with concomitant TNF experienced recurrent valgus. In fact, survivorship
analysis showed no recurrent pes valgus and very little need for repeat foot surgery up to 15
years after initial intervention. Despite excellent results of patients who underwent TNF, we only
advocate this in three main groups of patients: 1) lower functioning patients, 2) those who are
obligate brace wearers, and 3) those whose midfoot breaks are so severe that sufficient correction
would not be feasible without TNF. For children with CP functioning at GMFCS levels I-III,
both CS and LCL result in long-term (up to 15 years) maintenance of correction of pes valgus.
Concomitant talonavicular fusion is key to success of CS for lower functioning patients with
severe deformities, and obligate brace wearers.


DISCLOSURES STATEMENT: Robert Kay, MD owns stock in Pfizer, Johnson & Johnson,
Medtronic and Zimmer-Biomet. All other authors have no disclosures.
The relationship between pelvis-hip musculature and functional ambulation in patients with Myelomeningocele

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INTRODUCTION
Myelomeningocele (MM) is a neuromuscular disorder that results in bulging of the spinal cord and subsequent muscle paralysis and/or weakness. The lower the level of defect, the more function is preserved. Consequently, patients with defects at the lower lumbar level and below preserve their walking ability. However, our clinical observations suggest that a group of them maintains the ability to walk independently with the use of orthotics (IAs), while another group requires the use of external support, i.e., assistive devices, such as walkers or crutches (NIAs). Currently, to the best of our knowledge, there does not exist any comprehensive literature explaining the underlying cause of this discrepancy. Therefore, the purpose of this study was to investigate if the ambulatory status of patients with lower lumbar MM, IAs compared to NIAs, is related to their muscle strength.

CLINICAL SIGNIFICANCE
Currently, to the best of our knowledge, there does not exist any comprehensive motion analysis studies relating the ambulatory status of patients with lower lumbar level MM to their muscle strength. If this information were known, then more targeted interventions could be identified so that, potentially, NIAs can progress to IAs.

METHODS
This is a retrospective study involving 50 patients with MM who underwent three-dimensional gait analysis (3DGA) in our laboratory as part of their health care plan. For the purposes of this investigation, we focused on their walking pattern characteristics, along with the lower extremity Manual Muscle Test (MMT) portion of their physical exam. Muscle strength from the MMT was translated from the clinical scale [1] to a continuous scale from 1 to 24, where a score of 1 is the equivalent of 0 in the clinical scale, defining the lack of any ability to contract the muscle. A score of 24 in the continuous scale is the equivalent of 5 in the clinical scale, meaning that the patient can move the distal end of the joint it attaches to, through the full range of motion of that joint against maximum manual resistance. Kinematic and temporal-spatial characteristics were determined by the 3DGA involving implementation of a modified Helen-Hayes marker set using specific anatomical landmarks of the segments of the lower body (pelvis, thighs, lower legs, and feet). The averages from each parameter for each group were statistically analyzed using an ANOVA. Statistical significance was achieved at $\alpha \leq 0.05$.

RESULTS
Table 1 shows the relationship between muscle strength for specific muscle groups and ambulatory status. Of the muscle groups investigated, the iliopsoas, sartorius, and gluteus maximus were stronger in the IAs group ($p=.0003$, $p = 0.014$, and $p=.0002$, respectively). Additionally, the group of IAs demonstrated a higher velocity and cadence ($p=.02$ and $p=.005$, respectively). Of the kinematic variables assessed, pelvic protraction was greater for IAs ($p=.02$) and downward pelvic obliquity was greater for the NIAs ($p=.02$) (Table 2).
Table 1: Statistical output comparing the muscle strength between patients who ambulate independently and those who do not. Muscles tested: adductors (Add); quadriceps (Quad); iliopsoas (Ilio); sartorius (Sar); gluteus maximus (Glut Max); gluteus medius (Glut Med).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Add</th>
<th>Quad</th>
<th>Ilio</th>
<th>Sar</th>
<th>Glut Max</th>
<th>Glut Med</th>
<th>Vel</th>
<th>Cad</th>
<th>Stride Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA Average</td>
<td>18.10 ± 4.99</td>
<td>20.79 ± 3.36</td>
<td>20.12 ± 3.58</td>
<td>18.11 ± 4.23</td>
<td>10.69 ± 4.37</td>
<td>7.48 ± 3.31</td>
<td>0.798 ± 0.03</td>
<td>0.944 ± 0.02</td>
<td>0.852 ± 0.03</td>
</tr>
<tr>
<td>NIA Average</td>
<td>17.45 ± 4.10</td>
<td>19.71 ± 3.16</td>
<td>15.25 ± 2.99</td>
<td>15.00 ± 1.85</td>
<td>5.92 ± 2.19</td>
<td>6.88 ± 2.50</td>
<td>0.643 ± 0.03</td>
<td>0.761 ± 0.17</td>
<td>0.833 ± 0.02</td>
</tr>
<tr>
<td>p-value</td>
<td>0.7008</td>
<td>0.3661</td>
<td>0.0003</td>
<td>0.0136</td>
<td>0.0002</td>
<td>0.5607</td>
<td>0.0243</td>
<td>0.0049</td>
<td>0.7504</td>
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</table>

Table 2: Comparison of the kinematics of pelvic rotation and pelvic obliquity between IAs and NIAs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pelvic Protraction</th>
<th>Pelvic Retraction</th>
<th>Pelvic Obliquity Upward</th>
<th>Pelvic Obliquity Downward</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA Average</td>
<td>18.26 ± 7.41</td>
<td>-16.70 ± 8.24</td>
<td>6.74 ± 3.49</td>
<td>-2.88 ± 4.11</td>
</tr>
<tr>
<td>NIA Average</td>
<td>13.74 ± 5.54</td>
<td>-12.54 ± 6.51</td>
<td>8.44 ± 4.42</td>
<td>-6.56 ± 4.90</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0229</td>
<td>0.0652</td>
<td>0.1997</td>
<td>0.0178</td>
</tr>
</tbody>
</table>

DISCUSSION

The purpose of this study was to investigate the relationship between ambulatory status of patients with lower lumbar MM who are IAs or NIAs and their respective muscle strength. The stronger hip flexors and extensors seen in the IAs group can provide greater hip stability which can facilitate independent ambulation. Furthermore, the greater velocity of the IAs, which, however, appears to be a function of increased cadence, may be further reflective of the improved ability of the IAs to control their gait compared to the NIAs. The greater excursion range for pelvic rotation in the IAs group may reflect that they achieve their stride length, partly, from pelvic rotation. The assisting devices, on the other hand, may be the limiting factor for the decreased pelvic rotation seen in the NIAs group. The decreased pelvic obliquity in the cohort of IAs may suggest that they have greater pelvic control while ambulating. One limiting factor of this investigation may be the discrepancy in sample sizes between the groups (35 IAs versus 15 NIAs). It is possible, therefore, that there may be some outliers influencing the results.

REFERENCES

ACKNOWLEDGEMENTS

Andrew Moseley-Gholl and Shannon Villegas have been instrumental to this study for the data extraction from patient records.

DISCLOSURE STATEMENT

The authors have nothing to disclose with respect to this investigation.
The Association Between Gait Performance and Cognitive Function, Physical Activity, and Functional Ability in Adults with Cerebral Palsy

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²Physical Medicine & Rehabilitation, Univ. of Colorado Anschutz Medical Campus, Aurora, CO

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Introduction

For individuals free of pathology, gait performance, specifically gait speed, has been associated with a healthy lifestyle, onset of secondary health conditions, and overall cognitive function. Gait speed has also been associated with cognitive decline, in which it is currently being used as a health indicator for the onset of cognitive decline and dementia in the aging population¹. While gait speed and cognition have been reported to be strongly correlated in the able-bodied people, there is limited knowledge of whether this applies for individuals with musculoskeletal disabilities, specifically cerebral palsy (CP).

In the CP population, gait has mostly been associated with functional and social aspect of life. Improved gait performance has been associated with maintaining muscle length, bone density, and cardiovascular fitness, while also allowing individuals to become more independent and have a more positive social view. However, there is limited knowledge about the association between cognitive function with gait speed, functional status, and/or physical activity in the adult CP population. As such, our study aims to analyze these associations in the adult CP population.

Clinical Significance

Based on the Patient-Reported Outcomes Measurement Information System (PROMIS) with standardized psychometric and functional measures we evaluated if there is an association between gait speed and cognitive and physical function in our cohort. Our study aim was to find out whether gait speed could be used as a biomarker that precedes both physical and cognitive decline in the adult CP population, who are at a higher risk of showing signs of accelerated aging and the onset of secondary health conditions.

Methods

The current study represents a secondary analysis of data collected as part of the Cerebral Palsy Adult Transition Study (CPAT), in which the methodology has been previously published²,³. Cognitive function was evaluated with the Wechsler Memory Scale IV (WMS-IV), the Wechsler Adult Intelligence Scale IV (WAIS-IV), and the Short Test of Mental Status (STMS). The Instrumented Gait Analysis (IGA) included temporal-spatial measures, such as walking speed adjusted for stature, and a functional status assessment, as measured by the Gross Motor Functional Classification System (GMFCS). Physical Activity Levels were assessed using the PROMIS-57 physical function sub-domain. Linear regression was used to assess the association between all outcome variables using the Spearman’s correlation coefficients, r, at a significance level of p<0.05.

Results

A total of 66 adults with CP (age range: 18.5-48 years; mean age [STD]: 24.9[5.4]; 30 Male, 36 female) participated in the study and completed the IGA, cognitive assessment,
functional status assessment, and the physical activity assessment. These results are summarized in Table 1.

Table 1: Gait Speed Correlations.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable</th>
<th>Spearman r</th>
<th>p-value for Spearman r</th>
</tr>
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<tr>
<td>Total Logical Memory I - Immediate Recall Raw Score</td>
<td>WMS-IV</td>
<td>0.11</td>
<td>0.389</td>
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<tr>
<td>Total Logical Memory II - Delayed Recall Raw Score</td>
<td>WMS-IV</td>
<td>0.06</td>
<td>0.626</td>
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<tr>
<td>Total Logical Memory II - Recognition Raw Score</td>
<td>WMS-IV</td>
<td>0.15</td>
<td>0.242</td>
</tr>
<tr>
<td>Total Verbal Paired Associates I - Immediate Recall Raw Score</td>
<td>WMS-IV</td>
<td>0.15</td>
<td>0.209</td>
</tr>
<tr>
<td>Total Verbal Paired Associates II - Delayed Recall Raw Score</td>
<td>WMS-IV</td>
<td>0.15</td>
<td>0.219</td>
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<tr>
<td>Total Verbal Paired Associates II - Recognition Raw Score</td>
<td>WMS-IV</td>
<td>0.20</td>
<td>0.106</td>
</tr>
<tr>
<td>Total Visual Reproduction I - Immediate Recall Raw Score</td>
<td>WMS-IV</td>
<td>0.31</td>
<td>0.010*</td>
</tr>
<tr>
<td>Total Visual Reproduction II - Delayed Recall Raw Score</td>
<td>WMS-IV</td>
<td>0.29</td>
<td>0.017*</td>
</tr>
<tr>
<td>Total Visual Reproduction II - Recognition Raw Score</td>
<td>WMS-IV</td>
<td>0.18</td>
<td>0.146</td>
</tr>
<tr>
<td>Total Block Design Raw Score</td>
<td>WAIS-IV</td>
<td>0.37</td>
<td>0.002*</td>
</tr>
<tr>
<td>Total Digit Span Raw Score (forward+backward+sequencing)</td>
<td>WAIS-IV</td>
<td>0.35</td>
<td>0.004*</td>
</tr>
<tr>
<td>Total Picture Completion Raw Score</td>
<td>WAIS-IV</td>
<td>0.35</td>
<td>0.003*</td>
</tr>
<tr>
<td>Total Symbol Search Raw Score</td>
<td>WAIS-IV</td>
<td>0.54</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Category Test Raw Score</td>
<td>WAIS-IV</td>
<td>0.27</td>
<td>0.031*</td>
</tr>
<tr>
<td>STMS Total Score</td>
<td>WMS-IV</td>
<td>0.30</td>
<td>0.013*</td>
</tr>
<tr>
<td>Physical Function Assessment (PROMIS-57)</td>
<td>WMS-IV</td>
<td>0.68</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>GMFCS Level</td>
<td>WMS-IV</td>
<td>-0.81</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

WMS-IV = Wechsler Memory Scale IV, WAIS-IV = Wechsler Adult Intelligence Scale IV, STMS = Short Test of Mental Status, WS = Walking Speed Adjusted for Statures, * = statistically significant

Discussion and Conclusion

This study provides evidence that gait speed showed moderate to weak associations with cognitive function. Specifically, gait speed was associated with all measures in the WAIS-IV sub-test and the STMS tool, which assess a person’s general cognitive ability, whereas the WMS-IV only had a few statistically significant correlations, which assesses a person’s memory. These results appear to reveal that gait speed is correlated with general cognitive ability in the adult CP population. Additionally, gait speed was strongly associated with PROMIS-57 physical function sub-domain and GMFCS levels. Since both the PROMIS-57 physical function domain and the GMFCS levels are validated instrument to assess physical and functional status respectively in the CP population, this confirms that improved gait is associated with better overall physical function and functional ability in this cohort. These results support the importance of integrating such assessment tools in the care of individuals with CP, as to evaluate and prevent further health decline. The findings of this study have the potential to impact current healthcare practices and prevention approaches for adults with CP.

References

3) Baer HR, Thomas SP, Pan Z, Tagawa A, Carollo JJ, Heyn PC. Self-reported physical function is associated with walking speed in adults with cerebral palsy. J Pediatr Rehabil

Acknowledgments: This project was supported by grants from NIDILRR (#90IF0055-01) and the J. T. Tai Foundation.
The Effect of Medial versus Medial and Lateral Hamstrings Lengthening on Transverse Gait Parameters in Cerebral Palsy.

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*louisb@ualberta.ca

Introduction:
Hamstrings lengthening is a common procedure for improving flexed knee gait patterns in children with cerebral palsy. Its benefits to sagittal plane abnormalities are well established. However, the impact of hamstrings lengthening on transverse plane kinematics and alignment are less well understood. Furthermore, while the medial and lateral hamstrings have a common origin, they insert distally on opposite sides of the knee joint center, potentially contributing differentially towards transverse gait kinematic patterns. Preservation of the lateral hamstrings during isolated medial hamstrings lengthening is likely to cause a relative external rotation moment on the tibia compared to combined medial and lateral hamstrings lengthening. In this retrospective cohort study, we compare the short- and long-term outcomes in the transverse plane alignment and kinematics of patients with isolated medial hamstrings lengthening to those with combined medial and lateral hamstrings lengthening to determine if this biomechanical effect is present clinically.

Clinical Significance:
This study demonstrates the differential effects of lengthening both medial and lateral hamstrings compared to isolated medial lengthening.

Methods:
We retrospectively identified patients with hemiplegic or diplegic cerebral palsy who have had hamstrings lengthening as part of a single event multilevel surgery along with preoperative and postoperative three-dimensional gait analysis. Patients were excluded if they had concurrent osteotomies or tendon transfers, were GMFCS level IV or V preoperatively, did not have preoperative gait analysis within 12 months of surgery, or did not have at least one gait analysis one year or later postoperatively. The patients were divided into two groups, the first with medial hamstrings lengthening (MHL) only, and the second with combined medial and lateral hamstrings lengthening (MLHL). Patients were evaluated on a per-limb basis. Changes between preoperative and short term (1-2 years), and long term (3+ years) postoperative gait parameters including GDI, range of motion, and kinematics were compared between groups to identify any differences. One way ANOVA and post-hoc Bonferroni tests were calculated to determine any significant differences between pre-operative, short term and long-term transverse plane alignment and kinematics and unpaired t-tests were completed to determine the relative change in transverse plane outcomes measures between the 2 surgical groups.
Results:
One hundred and fifty children (234 limbs, 110 with MHL, 124 with MLHL) were evaluated at age 9.4±4.1, 12.2±4.9 and 13.8±4.1 years (pre-op/ST/LT), with GMFCS levels I (21% MHL, 15% MLHL), II (52%,44%), and III (27%,40%). Tibial external rotation increased after hamstrings lengthening (p<0.05). The external rotation change was greater with MHL compared to MLHL (p=0.045; see Table 1), and this change was statistically significant in short term follow up. The relative difference diminished in long term follow up. In addition to the transverse plane, there were significant improvements in the sagittal gait parameters over short- and long-term follow-up, including knee flexion at initial contact, and maximum knee extension in stance in both surgical groups (p<0.05). Pelvic tilt changed by less than 2 degrees in both groups at both short- and long-term visits.

<table>
<thead>
<tr>
<th></th>
<th>Change (Short Term)</th>
<th>Change (Long Term)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>M+L</td>
</tr>
<tr>
<td>GDI</td>
<td>9.06 (14.6)</td>
<td>7.75 (12.8)</td>
</tr>
<tr>
<td><strong>Transverse plane kinematics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvic rotation (° Leading)</td>
<td>0.60 (6.8)</td>
<td>0.34 (7.0)</td>
</tr>
<tr>
<td>Hip rotation (° IR)</td>
<td>-0.32 (10.9)</td>
<td>-0.83 (9.6)</td>
</tr>
<tr>
<td>Tibial rotation (° IR)</td>
<td>-8.93 (15.9)</td>
<td>-4.35 (14.5)</td>
</tr>
<tr>
<td>Ankle rotation (° IR)</td>
<td>-0.14 (12.0)</td>
<td>0.032 (8.7)</td>
</tr>
<tr>
<td>Foot orientation (° IR)</td>
<td>-8.58 (12.9)</td>
<td>-5.23 (13.0)</td>
</tr>
</tbody>
</table>

Table 1: Short- and long-term transverse plane alignment and gait kinematics outcome changes between pre- and post-operative medial, and medial and lateral hamstring surgeries. All values listed as mean (standard deviation).

Discussion:
Biomechanically, the external rotation moment of the lateral hamstrings should result in increased external rotation of the tibia in isolated medial hamstrings lengthening compared to medial and lateral hamstrings lengthening. This was confirmed clinically in this study. However, the effect was most pronounced in short term (1-2 year) follow up and diminished in long term follow up. There was no detectable relative impact on hip or pelvis rotation.

References:

Disclosure Statement: The authors have nothing to disclose.
THE IMPACT OF PREOPERATIVE FACTORS AND SURGICAL BURDEN ON POSTOPERATIVE RECOVERY OF WALKING ACTIVITY IN CHILDREN WITH CEREBRAL PALSY

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INTRODUCTION

Cerebral palsy (CP) describes a group of disorders of the development of movement and posture that are attributed to non-progressive disturbances in the developing fetal or infant brain [1]. Children with CP have decreased walking activity (WA) compared with typically developing youth [2]. Multilevel orthopedic surgery (MLS) can improve gait pattern for children with CP [3]. However, our previous study showed no change in WA 1-2 years after MLS [4]. Additionally, the patient and family should expect a temporary decrease in WA during rehabilitation after surgery. Our specific aims were:

1) To determine how the dose, or surgical burden, of orthopedic surgery affects the recovery of daily WA after MLS.

2) To examine how preoperative factors affect recovery of WA after MLS.

CLINICAL SIGNIFICANCE

Previous studies have demonstrated that MLS improves gait pattern in children with CP. However, previous research has not used WA to monitor postoperative recovery.

METHODS

This was an IRB-approved retrospective study. Inclusion criteria were a diagnosis of CP, gait correction surgery at Nemours/Alfred I. duPont Hospital for Children, WA monitoring using a StepWatch device within 12 months before and 24 months after surgery, and at least 3 days with an average of at least 8 hours of wear per day from each collection period. Normalized strides per day were calculated by dividing mean total strides per day by reference values according to age and GMFCS level [5, 6, 7]. A LOESS alpha adjusted serial t-tests (LAAST) analysis was performed using change in normalized strides per day as the outcome measure to determine when participants in each surgical burden group returned to baseline WA [8]. A regression analysis was also performed using mean total strides per day as the outcome measure. Predictors included surgical burden (low burden = soft tissue surgery and up to 1 osteotomy and high burden = 2 or more osteotomies), age at surgery, and preoperative gait velocity, average GDI, GMFM-D, single strength sum, hip and ankle power, and VO2 (walk).

RESULTS

178 children (Age 12.8±8.6, GMFCS I (22), II (110), III (39), IV (7)) with 613 StepWatch collection periods and 197 surgeries (127 low, 70 high burden) met the inclusion criteria.
LAAS analysis showed that children returned to baseline WA 3.3 months after a low burden surgery and 13.2 months after a high burden surgery (Fig. 1). However, there was significant variation in postoperative WA, with 41% improving, 18% having no change, and 41% declining. Younger age at surgery, low surgical burden, higher gait velocity, higher GDI ($p<0.001$), higher single strength sum ($p<0.01$), and higher GMFM-D ($p<0.05$) predicted higher postoperative WA. Hip and ankle power and VO$_2$ (walk) were not significant predictors of postoperative WA.

**DISCUSSION**

Postoperative recovery of WA is prolonged after high burden MLS. Older children and those with more severe gait and gross motor impairments according to preoperative gait velocity, GDI, strength, and GMFM-D are less likely to increase WA postoperatively. Previous studies have demonstrated that MLS improves gait in children with CP, but its effect on activity and participation is inconsistent. This study demonstrates the feasibility of using WA as an objective measure of activity that could help providers to set expectations for families preparing for MLS.

**REFERENCES**


**DISCLOSURE STATEMENT**

None of the authors have any disclosures to make.
UNDERSTANDING FAMILY PRIORITIES ACROSS FUNCTIONAL LEVELS USING THE GAIT OUTCOMES ASSESSMENT LIST (GOAL) QUESTIONNAIRE

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INTRODUCTION: A family-centered approach to care for children with cerebral palsy (CP) has been shown to improve motivation and outcomes, [1,2] yet inclusion of patient and family priorities is not routine in most functional assessments. The Gait Outcomes Assessment List (GOAL) Questionnaire is an assessment of gait priorities and functional mobility for ambulatory children with CP designed to address the gap in understanding of patient and family priorities for gait and intervention [3,4]. Priorities and concerns for gait-related interventions have been found to be different based on Gross Motor Function Classification (GMFCS) level [5-7]. The purpose of this study is to describe family priorities using the GOAL Questionnaire across GMFCS levels.

CLINICAL SIGNIFICANCE: Understanding priorities by level of function will assist clinicians in providing optimal family-centered care and may improve outcomes when incorporated into treatment planning.

METHODS: Caregivers of or adult patients with a diagnosis of CP, GMFCS levels I-IV completed the parent-version 5.0 of the GOAL Questionnaire during a standard-of-care quantitative gait analysis visit. Questionnaires with a total GOAL score available were included in the analysis (missing domain and item scores were permissible). The proportion of respondents who indicated items to be at least ‘difficult’ to perform and ‘very important’ to improve was calculated. The five top priorities were tabulated for the entire group and for each GMFCS level.

RESULTS: Data from 321 individuals (193 M, 128 F, mean age 10.1±4.2 years, range 3-25 years) were included. GMFCS sample sizes were as follows: I: 73, II: 134, III: 86, IV:28. The five top priorities and proportions were different based on GMFCS level. The GMFCS I group had the smallest proportions in their five top priorities (.32-.43) and the GMFCS IV had the largest (.62-.73). The most represented domain for priorities was Gait Pattern and Appearance with at least 2-4 items among the five top priorities for each GMFCS level. Activities of Daily Living & Independence, Physical Activities Sports & Recreation and Use of Braces and Mobility Aids domains were the least represented (one item for a single GMFCS level; Table & Figure).

DISCUSSION: Gait Pattern and Appearance concerns are the most highly prioritized by families across GMFCS levels. One or two concerns represented in the top five priorities at GMFCS levels I & II were from different domains than those at GMFCS levels III & IV consistent with different gross motor ability. Understanding the unique priorities at each
GMFCS level and incorporating them into treatment planning will contribute to improved family-centered care.

<table>
<thead>
<tr>
<th>MOST COMMON PRIORITIES ACROSS GMFCS LEVELS (BY PROPORTION)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domain</strong></td>
</tr>
<tr>
<td>Pain Discomfort &amp; Fatigue</td>
</tr>
<tr>
<td>Gait Pattern &amp; Appearance</td>
</tr>
<tr>
<td>Gait Pattern &amp; Appearance</td>
</tr>
<tr>
<td>Gait Pattern &amp; Appearance</td>
</tr>
<tr>
<td>Gait Pattern &amp; Appearance</td>
</tr>
<tr>
<td>Body Image &amp; Self Esteem</td>
</tr>
<tr>
<td>Gait Pattern &amp; Appearance</td>
</tr>
<tr>
<td>Gait Function &amp; Mobility</td>
</tr>
<tr>
<td>Gait Function &amp; Mobility</td>
</tr>
<tr>
<td>Gait Function &amp; Mobility</td>
</tr>
<tr>
<td>Physical Activities Sports &amp; Recreation</td>
</tr>
<tr>
<td>Gait Function &amp; Mobility</td>
</tr>
<tr>
<td>Activities of Daily Living &amp; Independence</td>
</tr>
<tr>
<td>Use of Braces &amp; Mobility Aids</td>
</tr>
</tbody>
</table>

Proportion of respondents indicating an item was a “very important” goal to improve and at least “difficult” to perform.

Table: Bolded proportions represent the top five priorities across all GMFCS levels or within a specific GMFCS level.
Figure: The average proportion across GMFCS levels is indicated by the red bars, and individual shapes indicate proportions for each GMFCS level.

REFERENCES

DISCLOSURE STATEMENT
ERB’s position is supported by the Gait & Motion Outcomes Fund of Gillette Children’s Specialty Healthcare.
CHILDREN WITH CEREBRAL PALSY GENERATE MINIMAL NET WORK BY TRICEPS SURAE ABOUT THE ANKLE

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INTRODUCTION
Children with cerebral palsy (CP) are notably inefficient in generating ankle power and work during the pushoff phase of gait [1]. However, net joint measures do not necessarily reflect the output of individual muscle-tendon units, particularly when contractures and co-contraction are present. Our labs are investigating the use of shear wave tensiometry to track muscle-tendon force during walking [2]. Tensiometers measure fluctuations in wave propagation speed along the tissue, which is used to infer the tensile load transmitted by the tendon [3]. Tendon force can be plotted against muscle-tendon length to visualize a work-loop which characterizes the functional behavior of the muscle-tendon unit. We investigated the work done by the triceps surae about the ankle in children with CP who exhibit equinus and/or crouch gait.

CLINICAL SIGNIFICANCE
The data illustrate how tensiometry can facilitate the quantitative assessment of muscle-tendon behavior in gait pathologies which could prove useful in planning treatments for gait disorders.

METHODS
Eleven children with CP (4F, 8-16 yrs) and 15 typically developing controls (9F, 8-17 yrs) participated. Children with CP were included if they had spastic diplegia, GMFCS Level I or II status, and evidence of equinus (<5° dorsiflexion angle) and/or crouch (>20° knee flexion angle) gait patterns. Reflective markers and EMG sensors were placed over the lower limbs. A shear wave tensiometer was secured over the Achilles tendon. All subjects walked overground at their preferred speed; controls additionally walked at slower and faster than preferred speeds [4]. A subject-specific calibration procedure was used to estimate Achilles tendon force from shear wave speed [2]. The excursion of the triceps surae about the ankle was calculated from ankle angle and tendon moment arm [2]. Forces were normalized to body weight and excursion to leg length. Work-loop plots [5] were used to evaluate net work of the triceps surae about the ankle.

RESULTS
Net work was significantly lower in children with CP compared to controls walking at their slow speed (p = 0.02) (Fig 1). Controls did more positive net work with increased speed (p < 0.001). Children with CP showed an altered work-loop pattern as well as earlier medial gastrocnemius EMG activation compared to controls (Fig 2).

Figure 1. Average net work by triceps surae (SD error bars).
**DISCUSSION**

This study utilized shear wave tensiometry, kinematics, and EMG to assess the triceps surae work patterns underlying gait in children with CP. These analyses revealed substantial and profound differences in triceps surae behavior among a heterogenous group of children with CP. Controls showed a net positive work-loop over the gait cycle, indicating the triceps surae about the ankle is acting like a motor [5]. In contrast, the children with CP showed an upward sloped force-length curve with no net work, indicative of more spring-like behavior. The timing of muscle activation is particularly important in the efficiency of gait [6]. Thus, the diminished work production could, in part, arise from spasticity and deficiencies in selective motor control [7]. Indeed, the net work loop plots of individuals with CP often exhibited early gastrocnemius activation relative to controls (Fig. 2). This work-loop approach provides new insight about functional muscle-tendon behavior by integrating excitation, kinematic and novel tendon kinetics, which are challenging to infer from traditional joint kinematics and kinetics plots.

**REFERENCES**


**ACKNOWLEDGMENTS**

Funding provided by NIH HD092697. Our thanks to Stacy Ngwesse and Andy Ries.

**DISCLOSURE STATEMENT**

J.A.M. and D.G.T. are co-inventors on a patent for tensiometer technology.
STANCE AND SWING PHASE ANKLE PHENOTYPES IN YOUTH WITH CHARCOT-MARIE-TOOTH DISEASE

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2 Children’s Hospital Los Angeles, Los Angeles, CA, USA
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INTRODUCTION
Charcot-Marie-Tooth disease (CMT) is a hereditary neuropathy that causes muscle weakness and gait deviations, particularly at the ankle. CMT is heterogeneous in its origin and presentation, and it is unclear whether the gait patterns in CMT are determined by CMT type or whether they vary within a single CMT type. The aim of this study was to document the variation in stance and swing phase ankle motion and compensatory gait deviations in children and adolescents with CMT type 1 (CMT1), the most common type of CMT.

CLINICAL SIGNIFICANCE
Youth with CMT1 demonstrate substantial variation in ankle phenotypes in both the stance and swing phases of gait. These phenotypes cannot be determined based solely on clinical examination measures like strength and range of motion (ROM). Gait analysis can help to differentiate these groups, which is needed to determine appropriate treatment options.

METHODS
Twenty-five youth with CMT1 (20 males, mean age 14.0 years, SD 2.8, range 7-19) underwent comprehensive gait analysis using the conventional gait model during barefoot walking at a self-selected pace. Assessment included standard clinical examination (strength, ROM, anthropometrics), kinematics and kinetics, temporal-spatial parameters, and the 6-minute walk test. Each limb was classified into a stance phase ankle phenotype based on peak dorsiflexion in terminal stance (45-55% gait cycle, GC) and a swing phase ankle phenotype based on peak ankle angle in mid-swing (70-90% GC) compared with normative values from a typically developing (TD) control group (Fig. 1). Groups were compared using analysis of variance with Bonferroni-adjusted post-hoc tests and Fisher’s exact test as appropriate.

RESULTS
Patients with CMT1 presented with all combinations of the stance and swing phase phenotypes (Table 1). Eleven patients (44%) had their feet classified into different stance phase groups, and 9 patients (36%) had their feet classified into different swing phase groups.

The limbs with decreased dorsiflexion (DF) in stance had higher plantar flexion (PF) strength, greater PF at initial contact, greater peak internal PF moment and positive work generated in stance, greater peak ankle power generation during push-off, and lower mean knee extensor moment in stance compared with the other stance phase groups. The limbs with increased DF in stance had weaker PF strength, delayed peak DF in stance, greater knee flexion at initial contact and average over stance, and greater mean knee extensor moment in stance compared to compared with the other stance phase groups.
The limbs with increased PF in swing had reduced passive DF ROM and lower DF strength with 10/31 limbs (29%) demonstrating < 5/5 strength compared with 1 of 19 limbs (5%) in the typical swing DF group.

Walking performance was primarily related to stance phase ankle phenotype. Patients with decreased peak DF in terminal stance walked significantly faster (p ≤ 0.001) with longer step length (p ≤ 0.05) than the other two stance phase groups. Patients with increased peak DF in terminal stance walked a shorter distance than the other two groups during the 6-minute walk test (p ≤ 0.01). Temporal-spatial parameters and 6-minute walk test results did not vary among the swing phase groups (p ≥ 0.17).

**Table 1:** Classification of ankle phenotypes for stance and swing. (# of sides and % total)

<table>
<thead>
<tr>
<th>Ankle Angle Terminal Stance</th>
<th>Decreased Dorsiflexion</th>
<th>Typical Dorsiflexion</th>
<th>Increased Dorsiflexion</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical or Increased DF</td>
<td>5 (10%)</td>
<td>7 (14%)</td>
<td>7 (14%)</td>
<td>19 (38%)</td>
</tr>
<tr>
<td>Increased PF</td>
<td>16 (32%)</td>
<td>12 (24%)</td>
<td>3 (6%)</td>
<td>31 (62%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>21 (42%)</td>
<td>19 (38%)</td>
<td>10 (20%)</td>
<td>50 (100%)</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The gait phenotypes examined in this study provide information about dynamic ankle function beyond what is revealed by strength measurement and passive ROM. Increased PF in swing can be due to dorsiflexor weakness and/or plantar flexor contracture/tightness. Increased dorsiflexion during stance is typically a sign of plantar flexor weakness. Stance phase ankle phenotypes may help to identify the specific bracing needs of these patients despite their similar “drop foot” presentation in swing. Since gait patterns vary even within a single CMT type, gait analysis can be useful to characterize dynamic function and to determine appropriate treatment.

**DISCLOSURE STATEMENT:** The authors have no conflicts of interest to disclose.
Instrumented Gait Analysis for the Clinical Management of Children with Cerebral Palsy: A Scoping Review

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INTRODUCTION

Although use of Instrumented Gait Analysis (IGA) for the clinical management of individuals with cerebral palsy (CP) has increased in recent years, there is significant variability in data collection protocols, as well as reporting and interpretation strategies. Appreciating this variability is difficult with an ever-growing body of literature. Previous investigators have performed systematic reviews of the literature to evaluate and summarize the evidence related to the efficacy of IGA. Wren et al (2011) identified 1528 manuscripts related to IGA and categorized them based on a framework used to evaluate the efficacy of diagnostic tests (Fryback and Thornbury, 1991). This comprehensive work included applications of IGA for all patient populations. However, children with CP present with unique clinical presentations and gait characteristics that affect data collection, and the methods of reporting and strategies for interpretation justify a more focused review of the literature. Therefore, the purpose of the current work was to perform a scoping review of the existing literature to describe and categorize the range of existing literature about IGA as applied to the clinical management of children with CP.

SIGNIFICANCE

This scoping review will provide clinicians and clinical researchers with a resource to summarize the roles of IGA in the clinical management of children with CP. Results will be beneficial to clinical researchers by identifying gaps in the existing scientific literature. This review was undertaken in preparation for development of a clinical practice guideline (CPG) on this topic.

METHODS

A health sciences librarian developed the search strategy with 4 key inclusion criteria: a) original peer-reviewed research study; b) population included children with CP; c) used IGA to investigate gait; and d) available in English. Records were identified by a search of Medline (via Ovid) completed in April 2019. Once studies were identified, to ensure reliability, individual sets of 10 titles and abstracts were screened by all 6 reviewing authors for inclusion. After 100% agreement was achieved between the 6 reviewers, individual investigators screened the remaining studies. The included studies were classified into nine categories developed based on Wren et al.’s 2011 systematic review about IGA (Table 1.0). To ensure reliability of categorization, individual sets of 10 full text articles were categorized by 6 authors. After 100% agreement was achieved, individual investigators categorized the remaining studies. To describe the methodological characteristics of the existing literature about IGA and how it has been used for the clinical management of children with CP, frequency (percentages) of the categories was then calculated.
Table 1. Study Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Frequency N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reliability and validity testing of IGA or IGA measures</td>
<td>315 (53%)</td>
</tr>
<tr>
<td>2. Validation of IGA measures for diagnosis and/or Identification of</td>
<td>298 (50%)</td>
</tr>
<tr>
<td>sub-groups via IGA analysis</td>
<td></td>
</tr>
<tr>
<td>(Includes documenting kinematic patterns using IGA)</td>
<td></td>
</tr>
<tr>
<td>3. Effectiveness of IGA or IGA measures to determine treatment</td>
<td>29 (5%)</td>
</tr>
<tr>
<td>approach</td>
<td></td>
</tr>
<tr>
<td>4. Effectiveness of using IGA or IGA measures to improve patient</td>
<td></td>
</tr>
<tr>
<td>outcomes</td>
<td></td>
</tr>
<tr>
<td>5. Cost-effectiveness or cost-benefits of using IGA or IGA measures</td>
<td></td>
</tr>
<tr>
<td>within clinical care</td>
<td></td>
</tr>
<tr>
<td>6. IGA or IGA measures used as a tool to investigate the effectiveness</td>
<td></td>
</tr>
<tr>
<td>of some intervention</td>
<td></td>
</tr>
<tr>
<td>7. Commentary or review</td>
<td></td>
</tr>
<tr>
<td>8. Did not involve gait analysis or did not use IGA or did not include</td>
<td></td>
</tr>
<tr>
<td>children with CP</td>
<td></td>
</tr>
<tr>
<td>9. Insufficient information available in English</td>
<td></td>
</tr>
</tbody>
</table>

RESULTS

1296 citations were screened, and 599 included studies were categorized. Analysis of study purposes and designs showed a wide range of prospective and retrospective designs analyzing a myriad clinically important gait features (Table 2.0). The most common study designs included those that develop/evaluate the clinimetric properties of quantitative metrics used to evaluate the gait of children with CP and those that identify specific atypical gait characteristics of children with CP. The least commonly reported categories included studies that evaluated the cost-effectiveness or cost-benefits of IGA.

DISCUSSION

As a key technology for documenting gait dysfunction, IGA provides the basis for a wide range of approaches to the examination, evaluation, and measurement of outcomes for gait dysfunction, as well as forming a crucial step in clinical decision making for treatment for children with CP related gait dysfunction. By identifying and characterizing a substantial body of peer-reviewed research on these topics, this scoping review has begun to describe the spectrum of existing literature on IGA for children with gait dysfunction related to CP. As such, this scoping review can form the basis to begin developing Clinical Practice Guidelines (CPG) about the use of IGA for the clinical management of children with CP. Additional steps such as a search of additional databases and analysis of the studies identified, stakeholder surveys, development of precise PICO(T) questions for the CPG and quality assessment of the literature are progressing under sponsorship of the Academy of Pediatric Physical Therapy.


DISCLOSURE STATEMENT - We have no conflicts of interest to disclose.
Factors Associated with Walking Activity in Adults with Cerebral Palsy

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Introduction: This IRB approved prospective study uses instrumented gait analysis, patient reported outcomes (PROs), and portable accelerometers to examine walking activity (WA) and factors with associated WA in adults with cerebral palsy (CP).

Clinical Significance: Previous studies have looked at WA in children with CP, but few have explored factors that influence WA in adulthood using gait analysis and patient reported outcome measures. The aim of this work is to inform pediatric and adult specialty practice by providing objective data of levels of WA and factors that influence activity in adults with CP.

Methods: We identified adults with CP who in 2017 were between the ages of 25-45 and had a previous gait analysis at our institution. 109 participants returned to the lab to complete a 3D gait analysis, self-report outcomes (PROMIS physical function, Satisfaction with Life Score (SWLS) and demographic information), and wear a StepWatch™ to monitor community WA. The StepWatch™ is a device that fits around the ankle and measures the number of strides taken by that leg in a day. Average stride data based on GMFCS classification was compared with a group of 193 nondisabled adults (NDA) age 30-39 years [1] utilizing Welch’s t-tests with Bonferroni corrections. We evaluated correlations, stratified by GMFCS level, between WA and gait deviation index (GDI), gait speed, level of physical function (PROMIS), quality of life (SWLS), Body Mass Index (BMI), employment rate, and caretaker need.

Results: 109 adults with CP, age 29±4 years, returned to participate. GMFCS levels were: 20% level I, 54% level II, 22% level III, and 4% level IV. PROMIS physical function, GDI, and gait speed had positive correlations with strides/day and showed some significant differences compared to adults without disability (Tables 1 & 3). WA (strides/day) was moderately correlated with GMFCS level (r = -0.63). Compared to nondisabled adults, WA was higher in the GMFCS I group, no different in the GMFCS II group, and lower in the GMFCS III and IV groups (Table 1). Employment and caretaker needs had small correlations with GMFCS level (r = -0.32 and r= 0.35), while quality of life score and BMI had less association with GMFCS level (Table 2).

<table>
<thead>
<tr>
<th>GMFCS</th>
<th>NDAs</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA (strides/day)</td>
<td>2564(1417)</td>
<td>4324(2003)*</td>
<td>2705(1568)</td>
<td>890(569)*</td>
<td>130(33)*</td>
</tr>
<tr>
<td>PROMIS physical Function</td>
<td>55(8)</td>
<td>50(9)</td>
<td>41(9)*</td>
<td>34(10)*</td>
<td>32(5)</td>
</tr>
<tr>
<td>GDI</td>
<td>100(10)</td>
<td>85(10)*</td>
<td>73(11)*</td>
<td>64(10)*</td>
<td>55(15)*</td>
</tr>
<tr>
<td>Gait Speed</td>
<td>124(18)</td>
<td>113(12)*</td>
<td>82(21)*</td>
<td>48(22)*</td>
<td>27(14)*</td>
</tr>
</tbody>
</table>

Table 1: Average strides/day, Gait pattern/velocity and self-reported physical function by GMFCS level compared with nondisabled adults. The mean and standard deviation (SD) are
shown. A p-value of <0.0125 denotes a statistically significant value due to 4 comparisons with Bonferroni correction. Statistical significance is marked by an asterisk (*).

<table>
<thead>
<tr>
<th>GMFCS</th>
<th>NDAs</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Employed</td>
<td>96</td>
<td>83</td>
<td>54</td>
<td>38</td>
<td>25</td>
</tr>
<tr>
<td>% with Caretaker</td>
<td>n/a</td>
<td>8</td>
<td>31</td>
<td>46</td>
<td>80</td>
</tr>
<tr>
<td>Average SWLS</td>
<td>20-24 (Average)</td>
<td>27(7)</td>
<td>24(7)</td>
<td>23(8)</td>
<td>23(8)</td>
</tr>
<tr>
<td>Average BMI</td>
<td>22(2)</td>
<td>25(8)</td>
<td>26(7)</td>
<td>28(6)</td>
<td>29(4)</td>
</tr>
</tbody>
</table>

Table 2: percent employment, percentage with caretaker needs, SWLS, and BMI. As of Oct. 2019, the US unemployment was 4% [3]. The SWLS score range for nondisabled adults is shown [2]. The BMI of a NDA adult is from a normal weighted adult living a mostly sedentary lifestyle [4].

<table>
<thead>
<tr>
<th>Variable</th>
<th>r with WA (strides/day)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROMIS (Physical Function)</td>
<td>0.42</td>
<td>6.4e-6 *</td>
</tr>
<tr>
<td>GDI</td>
<td>0.48</td>
<td>1.2e-7 *</td>
</tr>
<tr>
<td>Gait Velocity</td>
<td>0.58</td>
<td>2.8e-11 *</td>
</tr>
<tr>
<td>Employment</td>
<td>0.27</td>
<td>0.0046 *</td>
</tr>
<tr>
<td>Care</td>
<td>-0.22</td>
<td>0.020</td>
</tr>
<tr>
<td>SWLS</td>
<td>0.22</td>
<td>0.029</td>
</tr>
<tr>
<td>BMI</td>
<td>-0.17</td>
<td>0.078</td>
</tr>
</tbody>
</table>

Table 3: Correlations between WA (strides/day) and gait and self-reported factors with Bonferroni corrections (significance* at p < 0.0071).

Discussion: WA in adults functioning at GMFCS I or II met or exceeded the WA of an age-matched nondisabled sample. Clear association was noted between physical function and walking activity as there was a significant correlation between strides per day and the PROMIS physical function score.

Adults functioning at GMFCS levels III and IV took significantly fewer strides per day compared to nondisabled adults. Significant associations were found between walking activity and employment. Despite limited physical function and the presence of gait deviations, adults with CP demonstrated levels of satisfaction with life that were no different from nondisabled adults.

References:
EVALUATION OF PLANTAR PRESSURE AUTOMATED MASKING AND TEMPORAL SPATIAL GAIT PARAMETERS IN CHILDREN WITH SPINA BIFIDA
Brandon Euker1, Amy Bodkin1,2, Aaron Powell2, James Carollo1,2
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Introduction
Plantar pressure (PP) measurements capture differences in foot pressure distribution and are typically segmented into different regions by manually applying a mask. A key part of these masks is the foot progression angle (FPA), which bisects them longitudinally. Temporal spatial gait parameters are used clinically to determine overall gait performance, and both PP and temporal spatial measures can be used to track disease progression over time. Motion capture systems serve as the current best-practice for FPA and temporal-spatial parameters, although use of a plantar pressure mat has advantages such as ease of access and speed of data processing, in addition to acquiring PP distributions unavailable from motion capture. This study aims to compare the accuracy of FPA and temporal spatial data generated from a plantar pressure mat (Novel emed XL, Munich, Germany) to that of a 3D optical motion capture system (Vicon Vantage, Oxford, UK) in a group of children with spina bifida.

Clinical Significance
Previously, automated plantar pressure masks and temporal spatial parameters obtained from a plantar pressure mat were tested in subjects without foot pathology. Validation of these techniques in a patient population with atypical foot presentation is necessary to evaluate the automated masking technique in subjects expected to have changes in PP over time.

Methods
Thirty-five participants (mean age 10.7 years, SD 4.4 years) with a diagnosis of spina bifida were recruited from the Spinal Defects Clinic at Children’s Hospital Colorado. The participants walked in a motion analysis lab wearing reflective markers on their feet in a fashion similar to the Oxford Foot Model. Optical motion capture cameras tracked 3D locations of the markers while a plantar pressure mat simultaneously recorded foot pressures. Five trials with at least two steps on the mat were collected for each participant as they passed through the motion capture volume and over the PP mat. Marker trajectories were labelled, gap-filled, and filtered in Vicon Nexus and then imported into MATLAB (Mathworks, Natick, MA). Motion capture of steps recorded on the PP mat were matched to the corresponding PP data.

Raw pressure data were imported into MATLAB where foot pressures were automatically identified and centers of pressure (CoPs) were calculated for each step. All viable steps were masked using one manual and five automated techniques. (Image Processing, Heel-Centroid, Full, CoP, 66% CoP, CoP Inter-Peak) These masks were previously applied to subjects without foot pathology.

The timing of foot-floor contact was calculated by identifying steps and using the first and last moments of pressure applied. Foot pressures were automatically identified, and a base heel location was assigned. The heel base point was used to determine step width and length.

Results/Demonstration
Cadence (-0.27 (6.76,-7.30) steps/min, Mean Difference, (Limits of Agreement)) gait speed (-0.01 (0.06,-0.09) m/s), step length (-0.31 (2.09,-3.58) cm), and step width (1.16 (4.73,-2.41) cm) each had low mean differences between systems and were comparable to our previous study. The limits of agreement indicated room for improvement in plantar pressure analysis of step width.
however, as 4.73 is 43% of the average motion capture calculated step width. Manual FPA mean difference is below the average kinematic minimal detectable change of ~4 degrees. All automated techniques produced mean difference above four degrees with large standard deviations.

Figure: Bland-Altman plots of the temporal spatial parameters evaluated for the series. The solid line indicates the mean difference between the measurement systems. The dotted lines set the limits of agreement.

Table: Mean difference and standard deviation between optical motion capture and the plantar pressure mat for foot progression angle.

<table>
<thead>
<tr>
<th></th>
<th>Participants with Spina Bifida</th>
<th>Participants with Typical Gait</th>
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<tbody>
<tr>
<td></td>
<td>Image Processing</td>
<td>Full CoP</td>
</tr>
<tr>
<td>Mean FPA Difference (Degrees)</td>
<td>3.67</td>
<td>5.69</td>
</tr>
<tr>
<td>Standard Deviation (Degrees)</td>
<td>2.45</td>
<td>6.90</td>
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</table>

Summary
The results show that the plantar pressure mat was able to produce temporal spatial gait parameters with a low mean error in a cohort with spina bifida that is clinically acceptable and similar to the system errors shown in our previous study of normal subjects. FPA mean error was acceptable for manual masking, but unacceptably high for automated masks. This indicates that the complex pressures produced by the spina bifida population will require a different automated masking technique if automation is to replace manual masking.

References
1. Pimentel, R. et al. (2019), GCMAS
2. Tomes, E. et al. (2019), GCMAS

Acknowledgements
Thank you to the participants who donated their time for this study. Additional thanks to Richard Pimentel for his work on the software used for this project and for Patrick Carry for his statistics help. Funding for this project was received from the Department of Physical Medicine and Rehabilitation at University of Colorado and J.T. Tai & Co. Foundation.

Disclosure Statement
The authors have no conflicts of interest to disclose.
Long-term outcomes of femoral derotation osteotomy in individuals with cerebral palsy

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INTRODUCTION
Individuals with cerebral palsy (CP) often have abnormal femoral anteversion, internal hip rotation or intoeing during gait. An external femoral derotation osteotomy (FDO) may normalize hip rotation in the short- and long-term, though previous outcome studies have design limitations to objectively assess its potential benefit compared to no FDO [1-4]. The purpose of this study is to address these limitations by assessing long-term outcomes in individuals with CP who had an FDO in childhood compared to matched-individuals who did not have an FDO. The secondary purpose was to compare outcomes within groups. Outcome assessments were guided by the domains of the International Classification of Functioning, Disability, and Health. This abstract focuses on body structure and function outcomes.

CLINICAL SIGNIFICANCE
There is a paucity of evidence as to whether childhood surgeries improve or maintain function, activity, and participation into adulthood compared to a control group. These long-term outcomes can help clinicians more comprehensively counsel families.

METHODS
For this cohort study, eligible individuals were identified within our gait lab database who met the following criteria: 1) diagnosed with bilateral CP, 2) had an FDO when 5-12 years old (10-90th percentile for historic patients), 3) had a pre-operative gait analysis (Pre) or a gait analysis at which they met all other criteria (non-FDO group), and 4) currently ≥25 years old. The non-FDO group was matched to the FDO group based on their anteversion and Pre hip rotation in gait. Participants returned for a Long-term analysis, which included various measures from gait analysis, physical exam, radiographs and functional tests. Statistics were performed using Matlab. The non-FDO group only included individuals in GMFCS levels I-II (determined at Long-term), so between-group comparisons were only performed for these individuals.

RESULTS
Sixty-one individuals participated (50 FDO, 11 non-FDO; Table). Groups were matched at Pre (p≥0.083) on all variables except hip abductor moment (p=0.048; Figure). Anteversion by physical exam, mean stance hip rotation, and Tonnis angle improved in all groups (p≤0.047). Reimer’s Index only improved in the FDO group (p=0.003). Hip abductor moment did not change in any group (p≥0.310). At Long-term, there were no differences between the FDO and non-FDO group in hip rotation, hip abductor moment, number of hip abductor repetitions, Reimer’s Index or Tonnis angle (p≥0.657). Anteversion was smaller in the FDO group (p=0.016).

Table. Demographics of participants (mean (SD) [min-max])

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre Age (yrs)</th>
<th>Long-term Age (yrs)</th>
<th>Sex (M/F)</th>
<th>GMFCS level</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDO</td>
<td>8(2) [5-12]</td>
<td>29(3) [25-35]</td>
<td>25/25</td>
<td>I II III IV</td>
</tr>
<tr>
<td>Non-FDO</td>
<td>9(2) [5-11]</td>
<td>28(4) [25-36]</td>
<td>4/7</td>
<td>4 7 0 0</td>
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DISCUSSION

Both groups had decreased hip rotation and anteversion at Long-term compared to Pre, in agreement with our retrospective study [4]. This suggests natural femoral remodeling (non-FDO) and maintenance of surgical correction (FDO group). GMFCS level I-II groups were matched at Pre on the radiographic measures, so the small improvements in Reimer’s may be due to the FDO, whereas improvements in Tonnis angle are not. Radiographic improvements are also evident in individuals in GMFCS levels III-IV. Normalized anteversion theoretically improves frontal plane hip abductor moment arm; however, this was not reflected in the data. The groups had similar hip abductor moment and performed a similar number of hip abductor repetitions. In summary, an external FDO results in lasting normalization of anteversion, which exceeds improvements without an FDO. However, the data suggest that an FDO may not be necessary for patients in GMFCS levels I-II if their goal is to maintain or improve functional parameters, such as hip rotation, abductor moment, or work capacity. Alternatively, an FDO will help patients achieve neutral hip rotation quicker.

REFERENCES


ACKNOWLEDGEMENTS

The Gait and Motion Outcomes Fund of Gillette Children’s Foundation supported this work.

DISCLOSURE STATEMENT

No author has any conflicts of interest to disclose.
INTRODUCTION
Pes planovalgus (PPV) is the most common foot deformity among individuals with bilateral cerebral palsy (CP) and the likelihood of it developing increases with age [1]. Surgery is indicated if the deformity is not reducible with more conservative methods. The aim of surgery is to reduce the subluxed talar head and restore the forefoot and midfoot alignment to achieve a stable plantigrade foot with improved functional ability during walking and standing [2]. A variety of surgical options are available to treat PPV including tendon transfers, osteotomy, arthroereisis and arthrodesis. Calcaneal osteotomies are powerful reliable surgical procedures also used for the correction of PPV foot deformity. Multiple osteotomy techniques are currently used to correct segmental malalignment associated with PPV. Lateral calcaneal lengthening osteotomy (LCL) and the translational medial calcaneal sliding osteotomy (MCSO) are two techniques used to correct hindfoot alignment. Unfortunately, the decision over which calcaneal osteotomy is to be performed is often based on physician preference and no current indications exist for one procedure over the other. Furthermore, reports of post-operative follow-up have not evaluated long-term surgical outcomes once these individuals have transitioned to adulthood and entered the workforce. Therefore, the purpose of the current work was to evaluate the longer-term effectiveness of surgery for PPV and identify the most effective technique that minimizes gait impairment for adults with CP.

CLINICAL SIGNIFICANCE
Long-term assessments of surgical outcomes for children with CP are important because continued growth and weight gain throughout puberty can affect short-term improvements when surgery is performed at a younger age. Continued research and development for surgical techniques and outcomes are indicated, as calcaneal osteotomy will foreseeably remain an important reconstructive option in the correction of foot deformity.

METHODS
Eighteen individuals with bilateral CP treated with either LCL or MCSO for PPV during childhood (13 males, Average age: 24.3 ± 7.9 yrs, Average years since surgery: 10.9 ± 8.4 yrs, GMFCS I: 1, GMFCS II: 7, GMFCS III: 10) participated in a single instrumented gait analysis for the current, IRB approved, prospective study. Additionally, 11 healthy adults with a rectus foot type (3 males, Average age: 26.0 ± 3.5) participated as a Control Group for comparison. One foot was analyzed per subject based on surgical site and/or dominance. The Milwaukee Foot Model (MFM), a segmental foot model, provided kinematic data for four foot and ankle segments [3]. Three representative trials were selected for analysis. Average kinematic curves were calculated and between group comparisons were assessed using the method of locally weighted regression smoothing with alpha-adjusted serial Welsch t-tests (LAAST) [4]. Comparisons were made among each surgical group and the Control Group.

RESULTS
In the coronal plane of the hindfoot, the MCSO Group more closely resembled the Control Group. The LCL Group showed residual hindfoot eversion with compensatory forefoot varus. In the transverse plane...
of the forefoot, the LCL Group presented with less forefoot abduction. Both groups showed a combination of decreased hindfoot dorsiflexion and lack of forefoot plantarflexion.

**DISCUSSION**

These preliminary long-term results showed that the MCSO Group more closely resembled the Control Group for the coronal plane alignment. Consistent with the goals of a calcaneal lengthening osteotomy, the LCL Group demonstrated less long-term forefoot abduction. Future studies should consider including pre-operative data to truly evaluate surgical correction.

**DISCLOSURE STATEMENT:** None of the authors have conflicts of interest to disclose.

Title: Consistent Interpretation of Gait Analysis Data: A Case-Based Quality Assurance Approach

Instructors: Tom F. Novacheck, MD, Andrew G. Georgiadis, MD, Jean L. Stout, PT, MS

Purpose: The purpose of this course is to demonstrate a quality improvement process used to assess consistency gait interpretation. Participants will have opportunity for "hands on" experience interpretation consistency process for problem identification and treatment recommendations with other participants. Gait analysis case studies in conjunction with an audience response system/survey monkey system will be employed.

Intended Audience: Pediatric orthopaedists, physical therapists, physical medicine and rehabilitation physicians, biomechanics, kinesiologists, engineers, and other professionals who participate in the interpretation of gait analysis data.

Prerequisite Knowledge: Intermediate. Gait analysis interpretation skills are used.

Course Summary: This course will summarize our experience with the design and success of an interpreter consistency quality assurance program and certification process. Use of an audience response system/mobile technology will allow participants to be interactive in assessing their own consistency among other participants and responses from Gillette Children’s interpretation staff. A series of case studies will be used to illustrate problem identification and treatment recommendations. The controversies surrounding gait interpretation consistency within and across centers and its impact on the utility of gait analysis will be discussed.

Course Format:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time</th>
<th>Speaker</th>
</tr>
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<tbody>
<tr>
<td>Introductions and Cases</td>
<td>5 minutes</td>
<td>Stout</td>
</tr>
<tr>
<td>Controversies Surrounding Interpretation Consistency of</td>
<td>10 minutes</td>
<td>Georgiadis</td>
</tr>
<tr>
<td>Gait Analysis and Recent Evidence</td>
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<tr>
<td>Design of an Interpreter Consistency and Certification QI program</td>
<td>15 minutes</td>
<td>Novacheck</td>
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<tr>
<td>Case 1: Audience Participation of Problem Identification</td>
<td>20 minutes</td>
<td>All</td>
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<tr>
<td>Questions &amp; Answers</td>
<td>10 minutes</td>
<td>All</td>
</tr>
<tr>
<td>Break</td>
<td>5 minutes</td>
<td></td>
</tr>
<tr>
<td>Review Study Data: Problem Identification MD &amp; PTs</td>
<td>10 minutes</td>
<td>Stout</td>
</tr>
<tr>
<td>Case 2: Audience Participation: Problem Identification &amp; Treatment Recommendations</td>
<td>25 minutes</td>
<td>All</td>
</tr>
<tr>
<td>Review Study Data: Treatment Recommendations</td>
<td>10 minutes</td>
<td>Georgiadis</td>
</tr>
<tr>
<td>Wrap Up, Questions &amp; Answers</td>
<td>10 minutes</td>
<td>All</td>
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GYROSCOPIC SENSORS VERSUS OPTOELECTRONIC MOTION TRACKING FOR EVALUATING EFFECTS ON PASSIVELY UNSTABLE SURFACE BALANCE

Peter M. Quesada, Benjamin J. Eckert and Jacob M. Puthoff
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INTRODUCTION
Angular velocities (AVs) have been used to quantify movement of passively unstable surfaces (PUSs) and body segments, for assessing effects on PUS balance performance and mechanisms\(^1\). A PUS has previously been defined as a non-fixed surface whose movements are dynamically linked to an individual’s motion responses\(^2\). Mean AV (over specified durations, e.g. 45 sec) of PUS/foot contact interface has been an overall PUS balance performance metric, in conjunction with instruction to keep a PUS as still as possible; while, mean AVs of body segments (particularly middle/upper) have been metrics for assessing PUS balance strategy.

Investigators at this institution have previously used reflective marker coordinates, obtained via an optoelectronic motion tracking system (OMTS), to compute AVs of PUS/foot contact interface(s) and middle/upper body segments. Such approach has been found to be effective at generating the desired AVs. However, OMTSs are typically ingrained within fixed laboratory environments, such that participants in PUS balance studies must travel to a specific facility.

Wearable gyroscopic sensor (GS) measurements provide alternative means, of obtaining AV metrics, which are not limited to a fixed location and which can be quickly placed on persons. Applications of wearable sensors, including GSs, have become more common for a variety of biomechanical activities/tasks. The current study’s purpose was to compare AV metrics obtained from GSs versus those obtained from an OMTS, in a context involving assessing the effects of manipulating specified PUS balance task conditions.

CLINICAL SIGNIFICANCE
The need to visit a fixed location with an OMTS tends to pose limitations on biomechanical study enrollments. Pre-testing preparation (particularly placing reflective markers) can be time consuming and contribute to extensive experimental session durations. Moreover, issues associated with transportation to a laboratory can range from mild inconvenience to substantial impracticality, particularly for some potential subject populations that are of specific interest regarding impacts of interventions/impairments on PUS balance performance and mechanisms.

Knowledge that use of GSs and use of an OMTS can yield similar assessments, regarding task manipulation effects on PUS balance performance/mechanisms, could facilitate increased volume of experimental data collection by mitigating need for an OMTS to conduct such studies.

METHODS
Six healthy elderly subjects (4 m, 2 f; >55 years) participated, after providing informed consent. For all trials, subjects were directed to keep a BOSU board, placed on varying thicknesses of supporting foam, as still as able for 45 seconds. Trajectories of markers, placed on both the BOSU board surface and subjects, were recorded by an OMTS (Qualisys) at 100 Hz. Synchronous AV measurements were obtained, at 2000 Hz, from GSs (Delsys) placed on the BOSU ball surface and placed on the trunk, pelvis, right/left upper arms, and right/left lower arms. Subject performed 2 trials with each permutation of 5 supporting foam thickness (1-5 inches), and 2 concurrent cognitive task conditions (no cognitive task, NC; verbal fluency task, VF). The primary performance metric (based on task instruction) was mean board AV. Secondary measures were mean AVs of pelvis, trunk, upper arms, and lower arms.
RESULTS

With respect to foam thickness, both OMTS and GS based values generally indicated greater mean AVs, for the BOSU board surface and for all body segments, with lower thickness of supporting foam (Figs 1 and 2; upper arms not shown). However, some variations were observed, regarding specifically where statistically significant thickness differences occurred. With respect to cognitive task conditions, both OMTS and GS based values generally indicated greater mean AVs, for the BOSU board surface and for all body segments, with concurrent VF tasks (Figs 1 and 2; upper arms not shown). While indications of foam thickness and cognitive task effects appear to generally agree for OMTS and GS based mean AVs, it was observed that GS based values tended to be higher than OMTS based values (note scale changes in figures).

DISCUSSION

General agreement between GS and OMTS results, regarding effects of supporting foam thickness variation and concurrent cognitive tasks, suggests that GSs are a viable alternative for obtaining AVs when investigating impacts of experimental condition variations on PUS balance performance and mechanisms. Future investigations should, subsequently, be able to conduct experimental sessions outside of the fixed laboratory sessions. Such freedom would enable investigators to travel to subjects, rather than the reverse. That capacity would include going to potential locations where larger numbers of desired subject types may exist. For example, assisted living facilities might encompass large numbers of elderly persons, while fitness centers might contain substantial volumes of recreational athletes. Moreover, the number of GS placements will generally be less than the number of marker placements (when using an OMTS); and GS locations typically do not need to be as meticulously determined. It is noted, however, that caution would be warranted when attempting direct comparisons of future GS based values with existing OMTS based values, due to apparent tendency for larger GS based values.

REFERENCES

1. Quesada, P.M. and Geiger, J.T. (2017) Cogent Engineering, 4:1, 1311440. [Crossref]

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.
COMPARISONS OF INTER-SEGMENT COORDINATION STABILITY BETWEEN LEADING AND TRAILING OBSTACLE-CROSSING LIMBS DURING WALKING IN YOUNG ADULTS

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INTRODUCTION
The dynamical system approach, such as a continuous relative phase analysis, can be used to quantify the locomotor system’s inter-segment coordination stability during cyclical multi-joint movements, such as walking and obstacle crossing [1]. Some research has indicated that the leading limb provides the required whole-body dynamic-related stability, while the trailing swing limb must cross the obstacle with sufficient toe clearance [2]. Both of these tasks require adequate inter-segment coordination, and if insufficient or unstable could result in a trip, loss of whole-body stability, and a fall. However, Lu et al, demonstrated that the trailing limb might contribute better to inter-segment stability than the leading limb while crossing an obstacle [3]. The differences between leading and trailing limb inter-segment stability difference are still unclear. Hence, the purpose of this study was to investigate potential leading and trailing limb inter-segment stability during obstacle crossing. It was hypothesized that the leading and trailing limbs would exhibit differences in inter-segment coordination stability of the pelvis-thigh, thigh-leg, and leg-foot when crossing the obstacle, thereby indicating a mechanism by which altered limb control affect in fall risk.

CLINICAL SIGNIFICANCE
Since differences between and changes in leading and trailing limb inter-segment coordination stability with obstacle crossing can reflect different neuromuscular control adaptation understanding these differences can be important to reduce fall risk.

METHODS
Seventeen subjects (age:23yr ± 2.4, height = 1.66 m ± 0.08, body mass = 56.4 kg ± 15.4) voluntarily participated in this study. Subjects walked approximately 6 m at a self-selected speed in each of two obstacle conditions: 1) normal walking with no obstacle, and 2) stepping over a 20 cm height obstacle positioned at the walkway’s midpoint. This obstacle height was chosen to represent the typical heights of curbstones separating cars in parking lots and stair risers. Subjects were required to perform successfully five consecutive walking trials in each condition. Condition order was randomized. A customized lower body marker system adapted from literature was used to determine retro-reflective marker placement for motion capture [4][5]. Three-dimensional motion capture data were recorded using an 8-camera Vicon system (Nexus 2.9.3, Vicon system, Centennial, CO; 100 Hz). Three-dimensional raw marker trajectories were low-pass filtered (6 Hz; Butterworth, 4th order) and then processed using a custom Matlab (The Mathworks, Inc., Natick, MA, USA) program that modeled the body and calculated sagittal plane segment angle and angular velocity variables.
The continuous relative phase (CRP) was calculated and used to represent inter-segmental coordination between adjacent lower extremity segments (i.e., pelvis-thigh, thigh-leg, leg-foot). The CRP’s variability, called the deviation phase (DP), was used to quantify the inter-segment coordination stability [1]. A higher DP value indicates less stability in the movement [1]. A 2x2 repeated measures ANOVA (α=0.05) was used to determine differences between the trailing and leading limbs in the two obstacle crossing conditions. A paired-samples t-test was used to compare DP values between trailing and leading limbs in each walking condition due to a significant limb by obstacle interaction. Statistical analysis was performed using SPSS (version 27.0, Chicago, Illinois). All parametric assumptions were met.

RESULTS
Descriptive statistics for DP during the obstacle stepping task were calculated (Table 1). There was a significant (p = 0.026) interaction between the obstacle and limb conditions. During obstacle crossing, the leading limb exhibited significantly greater pelvis-thigh (36.8% difference; t (16) = 4.04, p = 0.001), and leg-foot (34.5% difference; t (16) = 4.38, p = 0.001) DP values when compared with the trailing limb. There were no limb inter-segment stability differences (p > 0.05) during normal walking.

Table 1: Descriptive statistics for DP in the leading and trailing limbs while walking with and without obstacle crossing (mean ± SD).

<table>
<thead>
<tr>
<th>Inter-Segment Variable</th>
<th>Normal Walking</th>
<th>Obstacle Crossing Walking</th>
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<tbody>
<tr>
<td></td>
<td>Leading Limb</td>
<td>Trailing Limb</td>
</tr>
<tr>
<td>Pelvis-Thigh</td>
<td>31.0 ± 4.96</td>
<td>30.1 ± 5.09</td>
</tr>
<tr>
<td>Thigh-Leg</td>
<td>21.2 ± 2.82</td>
<td>22.5 ± 4.93</td>
</tr>
<tr>
<td>Leg-Foot</td>
<td>14.7 ± 4.66</td>
<td>14.32 ± 5.30</td>
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a = Leading limb significantly (p < .001) different from the trailing limb.

DISCUSSION
The results support the hypothesis that subjects presented significantly different inter-segment coordination stability in the leading limb during obstacle crossing. The obstacle induced significant differences between trailing and leading limbs that were not present during normal walking. The results are consistent with a previous study that showed the trailing limb has greater inter-segment stability than the leading limb during obstacle crossing [3]. Additionally, the obstacle-crossing leading limb exhibited less inter-segment stability, which could result from the required large muscular demand from the hip, leg, and foot to avoid tripping over the obstacle [3]. This reduced stability could indicate an increased difficulty in controlling the segment to modulate whole-body stability. These results suggest that an increase in leading limb inter-segment coordination stability could be an important factor in successful obstacle stepping.

REFERENCES
DEVELOPMENT OF AN INNOVATIVE RESEARCH PROTOCOL TO ASSESS GAIT, BALANCE, AND MUSCLE STRENGTH AMONG BREAST CANCER SURVIVORS WITH CHEMOTHERAPY-INDUCED PERIPHERAL NEUROPATHY (CIPN)

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INTRODUCTION
Persistent CIPN is a significant, common, and understudied consequence of taxane-chemotherapy for breast cancer treatment [1]. CIPN symptoms include numbness combined with tingling sensations, persistent shooting, stabbing, or burning pain even in the absence of painful stimuli, lower extremity muscle weakness, and impaired balance [2]. CIPN symptoms often persist for a long time after completion of chemotherapy, causing significant loss of functional abilities, compromising the quality of life, and increased risk of falls [3]. The purpose of this study was to develop an innovative research protocol to assess gait, balance, and lower extremity muscle strength in breast cancer survivors with CIPN and to determine the intra-rater reliability of these assessment tools.

CLINICAL SIGNIFICANCE
Research focused on the assessment of gait, balance, and lower extremity strength in breast cancer survivors with CIPN is a necessary step to prevent debilitating sensory and motor neuropathy in these patients, thus preserving physical function.

METHODS
A total of 7 subjects (2 males, 5 females, age 34.7 ± 15.2 years, weight 81.5 ± 12 kg, height 1.7 ± 0.1 m) with no signs of neurological or orthopedic impairments participated in the study protocol development. The assessment of gait included spatiotemporal metrics (gait speed, stance percent, swing percent, gait cycle time, stride length, cadence, and step duration) and lower extremity joint kinematics (hip, knee, and ankle). The APDM Opal inertial measurement units (IMU) were used to assess gait. The APDM IMUs are wireless sensors for measuring motion that allow clinicians to perform gait assessments in a simple and quick manner [4]. IMUs were placed at specific body landmarks to reduce intra-subject variability. Balance was assessed using the Sensory Organization Test (SOT) using a NeuroCom Balance Master and the EquiTest System. to assess visual, vestibular, and somatosensory balance information. Strength of hip, knee, and ankle flexor and extensor muscles was assessed using an isokinetic dynamometer. Participants performed two visits to the laboratory with a minimal interval of two days. In each visit, they were asked to perform the gait, balance, and muscle strength assessments. Standardized instructions were provided to minimize intra-subject variability. To determine the reliability of the measurement, we
calculated Pearson’s correlations (r) and intraclass correlations coefficients. Agreement was considered poor if ICC < 0.50, moderate if ICC = 0.50–0.74, good if ICC = 0.75–0.90, and excellent if ICC > 0.90 [5].

RESULTS
No significant differences were observed between tests performed (p>0.05 for all comparisons). As shown in Table 1, spatiotemporal metrics of gait measures all demonstrated excellent test-retest reliability (r > 0.86; ICC > 0.90), whereas good to excellent reliability was found for gait kinematics measures (r > 0.7; ICC > 0.75). SOT composite equilibrium scores demonstrated a moderate reliability (r = 0.87; ICC = 0.67). Lower extremity muscle strength measures demonstrated good to excellent reliability (r > 0.7; ICC > 0.80).

DISCUSSION
Declines in peripheral nerve function secondary to neurotoxic chemotherapy have been well documented. Evidence-based assessment tools with clinical utility are needed. Spatiotemporal and kinematics assessment of gait using APDM Opal IMU’s, SOT using NeuroCom Balance Master, and isometric muscle strength using Biodex BX Advantage provide reliable information on gait, balance, and strength in patients with persistent CIPN induced by taxanes.

REFERENCES

Table 1: Reliability of spatiotemporal metrics and kinematics of gait, balance, and strength measures

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<tr>
<th></th>
<th>Cadence (steps/min)</th>
<th>Double Support (%)</th>
<th>Elevation at Midswing (cm)</th>
<th>Gait Cycle Duration (s)</th>
<th>Gait Speed (m/s)</th>
<th>Foot Strike Angle (degrees)</th>
<th>Toe Off Angle (degrees)</th>
<th>Single Limb Support (%)</th>
<th>Stance (%)</th>
<th>Step Duration (s)</th>
<th>Stride Length (m)</th>
<th>Swing (%)</th>
<th>Terminal Double Support (%)</th>
<th>Toe Out Angle (degrees)</th>
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<tr>
<td>Gait Kinematics</td>
<td>Hip Flexion Angle (degrees)</td>
<td>0.70</td>
<td>0.82</td>
<td>Hip Extension Angle (degrees)</td>
<td>0.70</td>
<td>0.82</td>
<td>Knee Flexion Angle (degrees)</td>
<td>0.71</td>
<td>0.77</td>
<td>Knee Extension Angle (degrees)</td>
<td>0.82</td>
<td>0.86</td>
<td>Ankle Dorsiflexion Angle (degrees)</td>
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</tr>
<tr>
<td>Balance</td>
<td>Somatosensory Score (%)</td>
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<td>0.48</td>
<td>Visual Score (%)</td>
<td>0.19</td>
<td>0.28</td>
<td>Vestibular Score (%)</td>
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<td>0.77</td>
<td>Reliance on Visual Preference (%)</td>
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<td>0.94</td>
<td>Composite Equilibrium Score (%)</td>
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<tr>
<td>Isometric</td>
<td>Knee extension (Nm)</td>
<td>0.94</td>
<td>0.96</td>
<td>Knee Flexion (Nm)</td>
<td>0.95</td>
<td>0.97</td>
<td>Ankle Plantarflexion (Nm)</td>
<td>0.92</td>
<td>0.94</td>
<td>Ankle Dorsiflexion (Nm)</td>
<td>0.91</td>
<td>0.96</td>
<td>Hip extension (Nm)</td>
<td>0.74</td>
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r (Pearson’s correlation), ICC (intraclass correlation)

DISCLOSURE STATEMENT
The authors have no conflicts of interest to disclose.
Association between pain and patella alta in patients with cerebral palsy and crouch gait

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²Universidade de Caxias do Sul, Caxias do Sul, Brasil
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INTRODUCTION
Crouch gait is defined as an increased knee flexion during stance phase with ankle dorsiflexion and hip flexion. This pattern of gait is frequently found in individuals with diplegic cerebral palsy. We also found patella alta in this group of patients, mostly of them associated with crouch gait. We hypothesized that crouch gait results from a progressive deterioration of gait associated with knee pain. Several authors related knee pain in this cases due to an overload in the femoropatellar joint or even with an inadequate contact between this joints in case the patient present patella alta.

CLINICAL SIGNIFICANCE
The aim of this study is to report the presence of knee pain in diplegic spastic cerebral palsy individuals and crouch gait and how its related or not with patella alta.

METHODS
Our sample was composed by 70 patients with diagnose of spastic diplegic cerebral palsy and crouch gait, all patients was assessed with full instrumented gait analysis between July 2014 and December 2019. We excluded patients with GMFCS I and IV and those who did not complete the knee pain questionnaire properly. The final sample was 52 patients with a mean age of 12 ± 6 years old. The patients were categorized according age (older than 12 years or up to 12 years old), knee pain (presence or not), GMFCS (II or III), patella (alta or not) and gender.

A chi-square association analysis was performed between each combination of two categorical variables (Age versus Pain versus GMFCS versus Patella versus Sex), making a total of 10 association analyzes. The degree of Phi association (φ) was also corrected for each analysis. The significance index adopted was $\alpha < 0.05$. When there was an association between the variables, the risk factor was also included.

RESULTS
No significant associations were found between the combinations of analysis with the categorical variables GMFCS and Sex with respect to the other variables. Pain and age showed a significant association, where 38% of patients older than 12 years old have knee pain versus only 15% of patients below 12 years old. In the risk analysis, it was found that patients older 12 years old and crouch gait are 7.5 times more likely to develop knee pain than patients under 12 years of age. Pain was also associated with the type of patella, 46% of patients had patella alta and pain versus 8% of patients with patella alta without pain. Regarding the risk analysis for this association, it was found that patients with patella alta and crouch gait are 5.1 times more likely to develop knee pain than patients without patella alta.
Effect of Evan’s Calcaneal Lengthening Osteotomy on Foot Progression Angle in Children with Cerebral Palsy

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1. University of Colorado School of Medicine; 2. Children’s Hospital Colorado Center for Gait and Movement Analysis; 3. Orthopedics Institute, Children's Hospital Colorado 4. University of Colorado Anschutz Medical Campus 5. University of Michigan School of Medicine 6. Donald and Barbara Zucker School of Medicine at Hofstra, Hempstead, NY

Introduction: Pes planovalgus deformity is commonly associated with cerebral palsy (CP). The Evan’s calcaneal lengthening osteotomy (Evan’s) has been successfully used to treat pes planovalgus. Its success has been demonstrated by clinical observation, radiographic, and pedobarographic data, but it’s effect on foot progression angle (FPA) has not been explored. This information is necessary for orthopedists planning multilevel surgeries for children with CP.

Clinical Significance: We aim to characterize the effect that the Evan’s procedure has on foot kinematics in children with CP to assist orthopedists planning single event multi-level surgeries.

Methods: Following IRB approval, we completed a retrospective analysis of children with CP who underwent an Evan’s from 2009-2019 at Children’s Hospital Colorado. All patients included had a pre- and post-operative instrumented gait analysis. Patients were not excluded based on concomitant procedures. FPA was calculated as an average over stance phase of the gait cycle. Target FPA was set as a range of 0-10° of external rotation, based on our institution's database of typically developing individuals.

Results: 65 subjects (123 feet) met inclusion criteria. Demographics were as follows: 38/27 male/female; mean age [SD] (years) 9.3 [2.7]; 19 hemiplegic, 29 diplegic, 6 triplegic, 6 quadriplegic; 9 Gross Motor Function Classification System (GMFCS) 1, 23 GMFCS II, 24 GMFCS III, 1 GMFCS IV. Of the 123 feet, 32 (26%) had a post-op change within the target. The 32 feet that corrected experienced a 13.4° ± 10.6° change to attain the target FPA. Of the 91 feet that did not correct to the target, 57 (68%) feet moved towards the target range. Across all feet there was no significant post-operative FPA change (p>0.05). Predictors of positive outcomes were assessed using odds ratios. GMFCS I/II, and hemi/diplegic CP diagnoses were predictors of a positive outcome (p=0.01, p=0.02 respectively). Gender, age at time of surgery, or concomitant interventions were not predictors of a positive outcome (p>0.05)

Discussion: The Evan’s was not shown to change FPA, but it did result in an improvement. Most patients who did not have a target outcome did correct towards the target range. This lack of complete correction could be due to the pre-operative severity of pes planovalgus deformity and concomitant bony surgeries. This procedure did not generate a significant FPA change. There is no clinically relevant effect that should not be considered by orthopedic surgeons when planning a single event multi-level surgery to correct multilevel malalignments in children with CP.

References:


Figure 1. Kinematic data of patients pre- and post-operatively. A. Patients who had an Evan’s did not always correct into the target FPA range. B. Patients who corrected to the target range typically had a change in FPA of 13.4° ± 10.6° when they did correct to the target range. C. Patients who did not fully correct did move towards the target range in the 68% of cases.

Table 1. Summary of predictive variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reference Group</th>
<th>OR(95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female</td>
<td>1.1 (0.48-2.5)</td>
<td>0.88</td>
</tr>
<tr>
<td>Preop time before surgery</td>
<td></td>
<td>1.02 (1.0-1.1)</td>
<td>0.44</td>
</tr>
<tr>
<td>Time after surgery</td>
<td></td>
<td>0.99 (0.97-1.02)</td>
<td>0.71</td>
</tr>
<tr>
<td>Cerebral palsy diagnosis</td>
<td>Hemiplegic vrs Diplegic</td>
<td>3.45 (1.3-9.0)</td>
<td>0.01</td>
</tr>
<tr>
<td>Triplicate/Quadruplicate vrs Diplegic</td>
<td></td>
<td>1.1 (0.33-3.5)</td>
<td>0.90</td>
</tr>
<tr>
<td>Wedge size</td>
<td>&gt;10 vrs ≤ 10</td>
<td>0.74 (0.32-1.7)</td>
<td>0.48</td>
</tr>
<tr>
<td>Preop FPA</td>
<td></td>
<td>0.99 (0.97-1.01)</td>
<td>0.25</td>
</tr>
<tr>
<td>GMFC level</td>
<td>(1 or 2) vrs (3 or 4)</td>
<td>2.97 (1.2-7.5)</td>
<td>0.02</td>
</tr>
<tr>
<td># of concomitant interventions</td>
<td></td>
<td>1.50 (0.9-2.6)</td>
<td>0.14</td>
</tr>
<tr>
<td>Botox</td>
<td></td>
<td>1.82 (0.41-8.1)</td>
<td>0.43</td>
</tr>
<tr>
<td>Phenol</td>
<td></td>
<td>0.97 (0.2-5.1)</td>
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<tr>
<td>Strayer gastrocnemius lengthening</td>
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<td>0.96 (0.39-2.3)</td>
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</tr>
<tr>
<td>DFEO</td>
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<td>0.77 (0.20-3.0)</td>
<td>0.70</td>
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</table>

Acknowledgements: The authors would like to thank the Center for Gait and Movement Analysis and the Musculoskeletal Research Center at Children’s Hospital Colorado for its support of this study.

Disclosure Statement: The authors have no conflicts of interest to disclose.
Title: Longitudinal fluctuation of Rodda classification in individuals with Spastic Diplegic Cerebral Palsy

Bidzina Kanashvili MD; Freeman Miller MD; Jason Howard MD; Kenneth Rogers PhD; Chris Church, MPT; Nancy Lennon MS, PT, DPT; John Henley, PhD; Timothy Niiler, PhD; M Wade Shrader MD

Introduction and Clinical Significance: To examine longitudinal alterations in gait, as defined by the Rodda classification, in children with spastic diplegic cerebral palsy (CP) who were treated at a single institution, and to evaluate if the Rodda classification would be helpful with predicting outcomes.

Methods: We performed a retrospective longitudinal examination of Rodda classification of children with spastic diplegic CP who had been treated at our hospital and who had instrumented gait analysis (IGA) before they were 8 and after they were 15 years old. Children who had gait-related surgeries before their initial IGA were excluded from this study. We used a modified Rodda Classification that was based on the mean knee flexion and mean ankle plantar-flexion of individual limbs during the stance phase of gait.

Welch’s t-tests were utilized to compare select gait variables from early childhood to young adult and to compare knee angles in patients who had plantar-flexor lengthening surgeries to those patients who did not.

Results: 105 individuals with spastic diplegic CP were evaluated through IGA at a mean age of 6.0(±1.2) and 19.6(±4.5) years. The distribution of GMFCS levels was I (10.5%), II (55.2%), III (28.6%), and IV (5.7%). 45% of the individuals in this study had asymmetric gait patterns. At the initial IGA, a majority of limbs were in either true equinus (28%) or jump-knee gait (29%) (Figure 1). In the interval between IGAs, musculoskeletal treatment of these individuals included PT, orthoses, and orthopedic surgery that focused on soft-tissue lengthening and lever arm correction. There were 259 total operative events that included a total of 1169 surgical procedures performed on the patients between the IGAs. At the second IGA, crouch gait was the most common classification (54%) (Figure 1) of which 50% were mild (defined as range of z-score between 1 and 3)(19-28°). There was no change in the mean knee flexion during stance over the treatment. 27.30(±14.48)° at initial evaluation and 26.71(±11.47)° at the second evaluation, normal 17(±6)° (p=0.5234). Nor was there a change in passive passive knee flexion contracture was -3.46(±7.83)° and -3.62(±7.90)° (p=0.842). Dorsiflexion in stance increased from 0(±12)° to 9(±6)° (p<0.0001); normal 6(±3)°. There was no difference in stance phase knee flexion between patients who underwent plantar-flexor lengthening versus those who did not, regardless of the walking pattern at the final visit, (p>0.18). Overall 83% of the limbs had a different Rodda classification in the second visit compared to the first.

Discussion: Based on our analysis of the Rodda classification assignment at both the initial and final visits, there was little stability in sagittal gait patterns in spastic diplegic cerebral palsy CP over time. Even though the patients were classified as diplegic a large proportion had...
asymmetrical gait patterns. With time, we found that the most common sagittal plane trajectory was towards a crouch gait pattern, albeit with a high degree of variability with most participants being sub-classified into a ‘mild crouch’ group mainly due to an increase in stance phase dorsiflexion. Plantarflexor lengthenings were not a significant factor in the progression of stance phase knee flexion.

**Significance:** Rodda classification may assist in understanding gait pathology but it did not reveal a simple prescriptive model for surgical procedures or outcomes. Surgical intervention, informed by IGA was more individualized and complex. Only a small percentage of patients were classified as having normal gait at the final visit and a mild crouch gait may represent a positive and sustainable outcome in adulthood.

**Figure 1:**


Disclosure Statement: The authors have nothing to disclose
A FRAMEWORK FOR COMMUNITY MOBILITY ASSESSMENT USING INTEGRATED SMARTPHONE SENSORS

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² Shriners Hospitals for Children, Chicago, IL, USA
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INTRODUCTION
Community mobility and participation metrics seek to describe the level of physical activity and community participation quantitatively in the real-world setting (the patient’s home, school, if applicable, and community) [1]. The intent of this type of analysis is to improve upon or supplement other methodologies, such as laboratory-based biomechanical mobility assessments, and qualitative, survey-based mobility and participation metrics. This development study presents a proof-of-concept demonstration that smartphones have the capacity to track community mobility and participation effectively using only built-in sensors.

CLINICAL SIGNIFICANCE
Improved mobility and community participation has been shown to lead to improved physical and psychological health [2]. By better understanding community participation and mobility, more effective rehabilitation protocols and activity promotion can be achieved. Smartphones are ubiquitous and, if effective, could provide needed data without additional burden on the patient (as opposed to body-attached sensors or extra devices to carry).

METHODS
Most smartphones have movement and position tracking sensors built-in to the electronic mainboard, typically used to detect smartphone. This study used a combination of both motion and positional sensors (accelerometer, gyroscope, magnetometer, and GPS sensors of an Android phone) to develop a mobile application. The motion sensor types are very similar to those used in commercial inertial measurement units (IMUs), which are applied clinically and in research to study the biomechanics of human motion. Our use of location data (GPS) is specifically targeted to assessing community participation. By tracking the number of unique locations an individual visits outside of the home, and correlating motion data from those locations, we can determine how actively a user is participating in their community, a technique supported by recent work by Brusilovskiy et al. [3].

The app registers and acquires data from all sensors and displays the acquired data on its user interface (UI). Simultaneously, it transmits the acquired data to a secure, encrypted cloud-hosted database. Data is automatically logged in real-time, then can then be stored or analyzed to indicate longitudinal or real-time community mobility and participation.

DEMONSTRATION
The mobile application was successfully developed for the Android smartphone platform, including the ability to collect real-time data from integrated IMU and GPS sensors, and display, store, and transmit the collected data to a database. Figure 1 (left), below, depicts the mobile application research interface. The sensor data results can be used to reconstruct and
identify movement and cycle events in ambulatory or wheeled mobility. To demonstrate the appearance of the raw sensor data in ambulation, we performed a simple 10-second laboratory data collection simulation, and collected and transmitted the data (Figure 1, right).

Results of this demonstration indicate that the data is properly stored in the database in time-series form and has sufficient resolution to identify individual mobility cycles for ambulatory or wheelchair mobility. This includes the motion cycles, as well as spatiotemporal parameters such as mobility cadence and cycle time. Ultimately, this system produces data that is appropriate to study community mobility and participation of a variety of users.

SUMMARY
This study shows the viability of applying the existing sensors in smartphones to monitor and track the mobility and movement of people with disabilities. This could, in the future, enable rehabilitation practitioners to monitor how different techniques and interventions can improve community mobility. While much work is still to be done by future studies for this method of rehabilitation monitoring, it is a significant step in the right direction and will greatly simplify the research methodology (and improve participant compliance & ease of use) in future research. Our group’s next step will be to validate the app against a laboratory motion capture system and community participation outcomes tools.

REFERENCES

ACKNOWLEDGMENTS
The authors acknowledge partial funding support of this work through the University of Wisconsin-Milwaukee, Support for Undergraduate Research Fellows.

DISCLOSURE STATEMENT
The authors have no conflicts of interest to disclose.
INTRODUCTION
State of the art technologies in motion capture used for instrumented gait analysis generate a large amount of information on patients’ gait patterns. Analyzing these large volumes of motion data might become cumbersome for traditional data analytics methods. To this end, a growing number of techniques for data parameterization have been developed over the past decades. A reliable overview allowing for comparison and identification of the advantages and disadvantages of these methods is, however, lacking.

CLINICAL SIGNIFICANCE
The number of clinical applications of statistical kinematic models has substantially grown in the past two decades. The applications range from data compression to automated diagnosis, treatment planning and patient follow up. In the present manuscript, we aim to benchmark the latest methods and make suggestions for their optimal use in clinical applications.

METHODS
The periodicity of gait data can be exploited in two ways. Either one can isolate and analyze single motion cycles or one can study a repeated series of motion cycles in time. Both approaches are appraised separately in this study. To compare the different methodologies applicable to single cycle analysis, we use the comprehensive gait database from Schreiber et al. (2019) [1]. For the evaluation of parameterization techniques on series of cycles, the instrumented treadmill gait data set from Morgan et al. (2018) is used [2]. Knee flexion curves from both data sets were utilized for comparison of the different parameterization methods.

Parameterization of Single cycle data
Before parameterization can be performed, a single motion cycle must be isolated, normalized and aligned. Three different aligment techniques are evaluated, namely Linear Length Normalization (LLN), Piecewise Linear Length Normalization ( PLLN) and continuous registration. Following, data parametrization by means of Principal Component Analysis (PCA), Principal Polynomial Analysis (PPA) and Functional Principal Component Analysis (FPCA) are compared based on the following features: in-sample error (accuracy), out-of-sample error (generalization), compactness and overall computational cost.

Parameterization of Series of cycles
Parameterization is evaluated for PCA on Fourier coefficients (FC) and FPCA on aligned curves. Before alignment of the curves can be performed, compensation for the difference in the fundamental frequency of the curves is applied. To do so, a Fourier Series is fitted to approximate the mean gait waveform of a series of cycles. Principal Component Regression (PCR) is used to remove the dependency of the FC on the fundamental frequency. Subsequently, the curves are aligned with a template curve in an iterative process by time-shifting the curves to maximize cross-correlation with the template curve. Following, PCA is applied on the FC and FPCA is applied on the aligned curves. The same outcome parameters as described above were used to evaluate both methods.
RESULTS

Figure 1: The in- and out-of-sample error for PCA, PPA and FPCA for the knee flexion curve.

Figure 2: The in- and out-of-sample error for PCA on FC and FPCA on aligned curves for the knee flexion curve.

Aligning by continuous registration results in a notable lower data variance. For a single cycle, the in- and out-of-sample error for PCA, PPA and FPCA are provided in figure 1. On a data set of 2200 training samples, it is found that PCA, PPA and FPCA provide comparable findings. The computational cost for FPCA and PCA is similar and largely lower than PPA (ratio 1-20).

For a series of cycles, the in- and out-of-sample error for PCA on the FC and FPCA on the aligned curves are given in figure 2. To retain 94.04% of the variance, the PCA on the FC technique is less compact, requiring 5 components, while the FPCA technique needs only 4 components. Further, PCA on the FC shows to be significantly more accurate and generalizing as opposed to FPCA.

DISCUSSION

Over the last decades, different techniques have been developed to parameterize curves and simplify data analysis. Depending on the application, different criteria are important. For data compression, the in-sample error and model compactness are crucial. For classification and feature extraction purposes, the out-of-sample error is of greater importance. Alignment appears a crucial first step for single cycle analysis. LLN or PLLN remove less unwanted data variance as compared to continuous registration. Non-linear techniques for parameterization are interesting from a mathematical point of view and appear to perform well. Yet, on large datasets the difference with the gold standard PCA is minimal.

For a series of cycles, FPCA has a larger in- and out-of-sample error as compared to PCA on the FC but requires fewer components to capture the same variance.

REFERENCES

DISCLOSURE STATEMENT
There are no disclosures to report.
An Ensemble Machine Learning Approach for the Estimation of Lower Extremity Kinematics Using Shoe-Mounted IMU Sensors

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INTRODUCTION

Evaluating human body movement is an essential step for biomechanical analysis and assessing a disease's condition and progression. The infrared light motion capture system is a standard method for assessing joint kinematics. However, the motion capture system requires a specific setup in a confined area, leading to challenges with quantitative assessment of walking conditions found in daily living. Using multiple inertial measurement units (IMU) sensors allows for the evaluation of movement outside the lab. Still, they are too burdensome for daily living due to needing sensors in specific locations on each limb. There is a need for an accurate kinematics assessment with a reduced number of sensors---this paper focuses on the setting where only one sensor is mounted on each shoe. Machine learning has been used to estimate joint kinematics with a reduced number of IMU sensors [1], but the resultant joint angle errors are not minor enough for applying movement evaluation. This paper proposes a new machine learning algorithm that provides highly accurate and real-time hip, knee, and ankle joint angle estimations in the sagittal plane using two shoe-mounted IMU sensors. We adapted five deep learning networks by implementing various configurations of Convolutional Neural Networks (CNNs) or Long-Short Term Memory (LSTM) Networks and ensembled them all together to leverage the advantage of each model. Our ensemble technique provides high correlation between predicted joint kinematics and kinematics measured with an infrared light motion capture system.

CLINICAL SIGNIFICANCE

Optimal control of wearable devices requires the input of different gait-related parameters. Our algorithm helps produce kinematics using a small number of sensors, which can be used to control patients' devices.

METHODS

Nine healthy subjects (six male and three female) participated in the study. The Institutional Review Board (IRB) of the University of Central Florida (UCF) approved the study protocol. We placed two IMU sensors on the participants' shoes. The participants walked on the treadmill at four different speeds: slow, normal, fast, and very fast, for approximately 2 minutes per setting. We set up four different non-dimensional walking speeds; slow, normal, fast, and very fast from their leg length [2]. Then, the participants walked on the treadmill for 2 minutes in each speed setting. Thirty-six reflective markers were placed on the participant based on a modified Helen-Hayes marker set [3]. Three-dimensional marker trajectories were captured with twelve infrared light cameras at a sampling rate of 100 Hz. The accelerometer and gyroscope data were recorded with a sampling frequency of ~148 Hz. We used OpenSim [4], an open-source musculoskeletal analysis tool to calculate joint angles during the walking conditions. Our study considers the hip, knee, and ankle angle on the sagittal plane for both legs, which results in six joint angle coordinates. The performance of multiple neural networks
may not be the same for a specific dataset. There are variances in the prediction due to the different structure of those networks. Ensembling different neural networks can be used to take advantage of better performing networks. In our work, we take the prediction average of five deep learning models. Our proposed ensemble network outperforms all the neural networks individually. We have used two metrics to evaluate the performance of the model. The Root Mean Square Error (RMSE) and the Pearson correlation coefficient were calculated between the ground truth kinematics and the deep learning model’s prediction.

**DEMONSTRATION**

From the result shown in Table 1, our proposed ensemble technique outperforms all single networks. RMSE of hip flexion angle has decreased 2-10% and 4-8% on average for the right and left leg, respectively. For knee angle, the RMSE reduction is 7-10%, 6-12% for right and left leg. For ankle angle, RMSE improvement is 3-11%, 1-12% for left and right leg, respectively. The correlation was slightly improved for the ensemble method in all joint angles for both left and right leg.

<table>
<thead>
<tr>
<th>Model</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hip</td>
<td>Knee</td>
</tr>
<tr>
<td>Conv2D-net</td>
<td>4.01</td>
<td>4.18</td>
</tr>
<tr>
<td></td>
<td>(0.982)</td>
<td>(0.985)</td>
</tr>
<tr>
<td>Bi LSTM-net</td>
<td>4.15</td>
<td>4.16</td>
</tr>
<tr>
<td></td>
<td>(0.981)</td>
<td>(0.985)</td>
</tr>
<tr>
<td>Hybrid Conv1D-LSTM-net</td>
<td>4.35</td>
<td>4.24</td>
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<td>(0.985)</td>
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<td>(0.981)</td>
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<td></td>
<td>(0.980)</td>
<td>(0.986)</td>
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<tr>
<td>Ensemble (Proposed)</td>
<td>3.94</td>
<td>3.83</td>
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<tr>
<td></td>
<td>(0.984)</td>
<td>(0.988)</td>
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</tbody>
</table>

Table 1: RMSE (Correlation) of different models for joint angles

**SUMMARY**

We presented a machine learning technique to estimate lower extremity joint angles in treadmill walking in this work. Previous work estimated the joint angle directly from IMU sensors on each leg segment. This method is less practical as it requires many sensors on the body. Machine learning can be used to map data from a reduced number of sensor with joint angles. In our method, two IMU sensors are fixed on the shoes. As a result, our method can more readily be applied to monitor gait outside of the lab and in daily living conditions.

**REFERENCES**


**DISCLOSURE STATEMENT.** The authors have no conflicts of interest to disclose.
Proof of Concept: A Novel Approach to Stride Identification in Inertial Measurement Unit Data Using Instantaneous Frequency Estimates

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Introduction

Traditional motion capture system analysis has inherent precision and accuracy advantages but is limited by expense, need to travel to a specialized lab, short duration of analysis, and activity limitations of a controlled environment. Inertial measurement units (IMUs) are inexpensive and more flexible, potentially allowing for identification of some pathologies more apparent in daily activity. We have developed a technique to identify strides in acceleration data from a XSENS Dot IMU ($105 per unit), utilizing a novel step detection algorithm.

Clinical Significance

Hemophilia causes joint and muscle bleeding, which can precipitate changes in gait.¹,² In order to better understand the biomechanical contributors to joint bleeds in persons with hemophilia (PwH), we are developing techniques for IMU-based motion analysis that can be done anywhere with low-cost hardware.

Methods

XSENS Dot IMUs were placed on the subjects’ shanks, above the center of the tibia, secured with 3M Coban. Though the XSENS Dot outputs a variety of data from a proprietary sensor fusion algorithm, this analysis focused on local axis acceleration in the direction parallel to the subject’s tibia. All data were streamed over Bluetooth to the XSENS iOS app at 60 Hz, then transferred into Matlab 2020b for analysis.

Two types of trials were used to ascertain algorithm effectiveness in 2 able-bodied adult volunteers. The first involved walking at 2.6 mph on a Bertec Instrumented Treadmill as a reference for step identification. The number of strides identified in the treadmill data in a given time period was compared to the number of strides found by the algorithms in the IMU data in the same time period, testing overall agreement between the two methods. The second set of trials involved a free walk overground to validate stride identification accuracy using the assumption that the number of strides detected on the left and right should be equal.

Demonstration

Shank acceleration data shows foot on and foot off acceleration peaks, which can be distinguished based on their frequency content. Foot on signals (green lines) have lower frequencies...
than foot off (purple lines) (figure 1a). The timing of signal peaks was determined using the raw acceleration data, with foot on and foot off signal types distinguished using two methods: (1) a low-pass (LP) filter technique using a 2 Hz cutoff (figure 1b), and (2) a novel instantaneous frequency (IF) approach, which applies a Gaussian window to 12 points before and after the point of interest to emphasize points near the center, then applies a Fast Fourier Transform (FFT) to determine the percentage of local frequencies over a set threshold. Figure 1c shows the percentage of the local acceleration data contained in frequencies greater than 9.2 Hz, which was empirically determined to best delineate peak types.

Treadmill studies evaluated 3 separate trials in 1 participant, with 200-400 steps in each trial. Treadmill and IMU stride times correlated well, with an intraclass correlation of 0.956 (95% confidence interval 0.950-0.962, p<0.0001), and complete agreement between LP and IF methods. Free walk studies included 7 trials in another participant, with 5000-9000 total steps per trial. Though the LP and IF approaches produced identical results in the short treadmill trials, the IF approach showed greater similarity between right and left step counts in long free walk trials (table 1). The overground trials are far longer, with greater variance in stride length and stride time because the walk is not limited to the space and speed of the treadmill, leading to greater differentiation between IF and LP results. Though two are similar, the IF approach shows consistently higher contralateral accuracy, with this difference potentially amounting to hundreds of additional steps detected during a longer trial.

**Summary**

Accurate stride identification in IMU data opens new avenues of analysis for identifying gait abnormalities in PwH and is likely to be a valuable complement to traditional motion lab analysis. Through calculation of the instantaneous frequency of shank acceleration throughout the stride, strides can be more accurately discerned compared to low pass filtering. Though additional work will be required to find the full capabilities of these devices with regards to detecting gait events, step identification is a crucial first step. Future directions will focus on detecting step asymmetry, which is expected in hemophilia pathology.

**References**


**Acknowledgements**

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**Disclosures**

The authors have no relevant conflicts of interest to declare.
Ankle Assistive Device Stiffness Test: A Novel Method for Quantifying Stiffness of Ankle-Foot Orthoses

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INTRODUCTION

Ankle-foot orthoses (AFOs) are braces that improve walking pattern by providing support to people with spastic or contracture muscle disorders [1]. Previous studies have shown prescribing appropriate AFO stiffness in the sagittal plane can improve pathologic gait patterns and increase the operating length of the affected muscle [2]. Thus, it is important to have an accurate and consistent method for determining the AFO stiffness to achieve optimal results for each patient.

Current devices to quantify AFO stiffness use a loadcell with only a single axis measurement. While these studies are suitable for measuring dorsiflexion of AFOs with hinge joints, they do not fully capture the complex moment of the other types of AFOs and they often require the destruction of the AFO being tested. Our unique method, the Ankle Assistive Device Stiffness (AADS) Test, will provide a consistent and accurate way of determining the stiffness of patient AFOs and other assistive devices for clinical modification and prescription.

CLINICAL SIGNIFICANCE

In clinical practice, quantitative stiffness is not accounted for when patients are given AFOs, as they are prescribed at orthotists’ discretion. A procedure to measure the stiffness of the AFO can help orthotists prescribe AFOs based on individualized needs, supported by records of the patients’ treatment histories and recovery patterns. An easy-to-replicate yet consistent, reliable, and non-destructive method would allow all orthotists to measure the stiffness of the AFO they are prescribing, generating custom fit and fine-tuning availability for patients.

METHOD

The Ankle Assistive Device Stiffness (AADS) Test was designed to replicate a human’s lower extremity. Our AFO was individualized by editing a 3D scan of the patient’s foot in the 3D CAD software, Meshmixer (Autodesk, CA). The scan was modified to the AFO shape and 3D printed, with a foot and shank portion connected by the commercially available Camber Axis joint. A spring-loaded AFO was selected as the gold-standard in preliminary AFO research studies.

The trials of the AADS Test were conducted using a motion capture system (Vicon, UK) with a force plate (AMTI, MA) to measure the ground reaction forces and moments in three dimensions, the center of pressure, and the angle measurements. Reflective markers were placed in a modified Helen Hayes marker set to define the foot and tibia. Three springs provided tension in the amounts of 9,900 N/m, 15,600 N/m, and 25,100 N/m. In each trial, a user applied force to the superior pylon of the AADS Test to bend the AFO in the sagittal plane without (Fig. 1).

Collected data from the trials were imported to the OpenSim software to calculate AFO stiffness [3]. A static test was recorded prior to the start of each trial for use in scaling the AADS

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The AFO dorsiflexion angle was acquired from inverse kinematics. To account for unknown external loads from the operator, static optimization (SOP) was used to find the ankle torque by minimizing the summation of the axes of the external forces and moments. SOP results were evaluated for accuracy through comparison to computed muscle control (CMC) calculations. CMC uses a closed loop of running SOP and forward dynamics. This repeatedly checks the calculated external loads, via SOP, against the application of the external loads, via forward dynamics, thereby minimizing error. From the torque results of SOP or CMC, the AFO stiffness in the sagittal plane was determined (Fig. 2). To evaluate the SOP and CMC results, the stiffness of the AFO was hand calculated by multiplying the orthogonal joint-to-spring distance by the tensile force of the spring (Fig. 2).

The AADS Test was evaluated for accuracy and consistency in both intra-user and inter-user situations. For intra-user accuracy, the same operator performed three trials on each spring. For inter-user consistency, three different operators each performed a set of three trials, and the average of the trials were compared. The results from both intra-user and inter-user trials were statistically evaluated to determine the variation between circumstances.

**DEMONSTRATION**

**SUMMARY**

This study aims to verify the effectiveness of the AADS Test using SOP, inverse kinematics, and CMC to provide AFO stiffness in dorsiflexion. Future work will incorporate the use of other AFO joints, such as flexure joints with data in multiple planes. The evaluation of intra-user and inter-user scenarios ensures that the variation in data was negligible for the AADS Test to be applicable as a standard clinical procedure. The similarity in trends and stiffness values among the CMC, SOP, and hand calculated results proves that this method provides accurate stiffness measurements. In future studies, only SOP calculations will be required to calculate stiffness, as this is proven to be the more efficient and equally accurate method. The AADS Test will provide a quantitative method of prescribing and evaluating AFOs, thus aiding orthotists in AFOs prescription with an individualized approach.

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ELECTROMYOGRAPHIC VALIDATION OF INDIVIDUAL MUSCLE CONTRIBUTIONS PREDICTED IN TWO MUSCULOSKELETAL MODELS

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INTRODUCTION
The validation of human musculoskeletal models has remained a challenge for the scientific community because direct measurement of muscular forces in the body is highly invasive. One such model was developed by Arnold et al. [1] using muscle architecture data collected by Ward et al. [2] from cadaveric subjects. More recently, Rajagopal et al. suggested another model which redefines the muscle volumes based on magnetic resonance images (MRI) of healthy young adults [3]. In the updated model, Rajagopal et al. hoped to improve upon the Arnold model by decreasing its computational demands while correcting some of its inaccuracies that stem from muscle parameters based on cadaveric specimen data instead of in-vivo human data. Both the Arnold and Rajagopal musculoskeletal models were validated with experimental walking data. As walking requires complex joint movements and dynamic muscle functions, it is difficult to identify the role of individual muscles and their association with specific joint movements. Simulations involving the isokinetic movements of a single degree of freedom (SDoF) can reduce unwanted variables and provide intuitive analyses.

CLINICAL SIGNIFICANCE
In this study, we evaluate the Arnold model and the Rajagopal model in single degree of freedom isometric and isokinetic flexions by comparing their predictions for individual muscle contribution to electromyographic data. Thus, the methods are validated in a way that examines the effects of the muscle moment arms and muscle co-contraction.

METHODS
A 21-year-old healthy male performed maximal effort isometric knee flexions at knee angles of 10, 30, 45, and 60 degrees and maximal effort isokinetic knee flexions with an angular velocity of 60 and 120 degrees/second in a Biodex System 4 human dynamometer (Biodex Medical Systems, NY). Each trial consisted of the condition repeated 3 times with 5 seconds of rest between activations and 5 minutes of rest between each trial. During these trials, surface electromyographic (EMG) sensors were placed over the muscle bellies of the rectus femoris (RECF), the semitendinosus (SEMT), the vastus lateralis (VASL), and the medial gastrocnemius (MGAS) while digital goniometers were placed across the hip, knee, and ankle joints (Avanti™ wireless EMG, Delsys, MA).

Two OpenSim models (developed by Arnold et al. and Rajagopal et al.) were adapted to model the participant seated in the Biodex System 4. Using measurements taken of the subject’s segment lengths, a scaled model of the subject was created. A computed muscle control (CMC) algorithm is used to estimate individual muscle contribution to the joint torques based on the
goniometer measured kinematics and the dynamometer measured external forces. The activations predicted by the CMC algorithm with the Arnold and Rajagopal models during the isometric knee flexions are compared to normalized EMG activations. The EMG activations are normalized with data from maximum voluntary contractions of each of the muscles.

RESULTS
The plateaus of each trial’s EMG activation are averaged for each isometric knee angle condition and plotted along with the CMC predicted activations (Fig. 1). The SEMT activation in both the Rajagopal and Arnold models follow the parabolic trend observed in the EMG activations in each different isometric trial, except the 30 degree trial (Fig.1). Both models show 0.02 activations on antagonist muscle due to the minimum activation setting of CMC, suggesting there are no co-contractions.

The individual muscle contributions during the isokinetic knee flexions are plotted with the normalized EMG activations (Fig. 2). They are plotted with respect to the percent completion of the flexion, starting at a knee angle of 20 degrees and ending at a knee angle of 70 degrees.

DISCUSSION
The Arnold model predicted greater activations in all isometric test conditions compared to the Rajagopal model due to the smaller maximum muscle force capacity that was estimated based on muscle volumes of cadavers. The Arnold model has greater increases in SEMT and MGAS activation at higher knee angular velocities. This may be due to different muscle wrapping constraints and the usage of different muscle models.

REFERENCES

DISCLOSURE STATEMENT
There are no conflicts of interest to disclose.
GENDER DIFFERENCES IN ANKLE & FOOT KINEMATICS DURING TREADMILL RUNNING

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INTRODUCTION
Running is a recreational sport pursued by people of all ages, with an estimated 30 million who regularly participate [1,2]. The variability in training schedules and running form place some runners at risk of injury. Injury incidence ranges from 20-80%, with more injuries occurring in novice runners [3]. The most common injuries involve joints of the lower extremity, but causality is multifactorial and complex. Gender differences in functional anatomy may affect biomechanical stresses applied during running, but there is limited data regarding three-dimensional ankle/foot kinematic differences [4,5]. The Plug-in-Gait (PiG) and Oxford Foot (OF) models have been used extensively to assess walking kinematics [6,7,8], with limited running data, particularly comparisons between genders. Our purpose was to compare foot and ankle running kinematics between genders from a healthy population.

CLINICAL SIGNIFICANCE
Statistical and clinically meaningful differences, with women tending to demonstrate more mobility, existed in sagittal and frontal plane motion at tibia/hindfoot and hindfoot/forefoot during the stance phase of running. These differences may provide clues distinguishing predisposition for particular running-related injuries for male and female recreational runners.

METHOD
This study was approved by the Institutional Review Board at Grand Valley State University (17-222-H). Sixteen healthy recreational runners, aged 18 to 42 years (6 males; 25.2 ± 4.1 yrs., height 177.9 ± 7.2, weight 71 ± 10.2; BMI 22.3 ± 1.1 kg/m2; 10 females, 25.2 ± 8.0 yrs., height 168.2 ± 4.3, weight 62.3 ± 7.8, BMI 22.3 ± 2.8 kg/m2), who ran at least 15 miles/wk. participated. Fifteen Vicon (Oxford Metrics, UK) cameras (120 Hz) were synchronized with an AMTI instrumented (1200 Hz) treadmill (Advanced Mechanical Technology, Inc, Watertown, MA, USA). Markers were placed according to the PiG full body and OF models by a trained, graduate physical therapy student, verified by an experienced faculty member. Foot markers were placed through pre-cut holes in standardized running shoes (Mizuno Wave Runners). Data were collected at three speeds (6.21mph, 7.45mph, and 8.60mph; only the 7.45 mph speed was analyzed), reduced using Vicon Nexus, v 2.9.1., and exported to Visual 3D (C-Motion, Inc., Germantown, MD) to determine joint kinematics and kinetics. A two-way ANOVA (JMP® Pro 14, SAS Institute Inc., Cary, NC), with significance set at α = 0.05, was utilized to assess differences in selected foot segment kinematic peaks and range of motion means between genders during stance. Based on ANOVA post hoc analysis, an effect size was defined as the difference between group means, which is more clinically relevant than standardized effect size values.

RESULTS & DISCUSSION
Thirteen of the 16 runners were rearfoot strikers. For tibia/hindfoot motion, females demonstrated greater dorsiflexion (DF) at initial contact (IC), and pronation (PRON) at both
initial contact and toe off (TO); females also showed greater peak DF and PRON range of motion (ROM). At the hindfoot/forefoot females were more plantarflexed and supinated at IC and TO; females also had greater mean supination ROM. Our findings are consistent with those reported by Sinclair et al. [5], except that Sinclair reported greater DF in females than males.

### REFERENCES


### DISCLOSURE STATEMENT

There are no conflicts of interest to disclose.

### ACKNOWLEDGEMENTS

Barbara Hoogenboom, PT, EdD, SCS, ATC and Yunju Lee, PhD
Evaluation of Gait Pattern and Lower Extremity Kinematics of Children with Morquio Syndrome (MPS IV).

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Introduction: This IRB approved retrospective study aims to describe lower limb physical characteristics and kinematic function, using instrumented gait analysis in patients with Morquio Syndrome, also known as mucopolysaccharidosis IV (MPS IV). This study compares these values to those of an age matched group of typically developed children. MPS IV is a rare progressive genetic disorder commonly affecting bone and joint development, growth, gait patterns, and posture, with presentation of symptoms occurring within the first couple years of life (White, K. K., et al., 2014; Yasuda, E, 2016; Yilmaz, G. 2014). Previous research on a small number of children with MPS IV has shown reduced cadence and stride length, slower walking speeds, and multiplanar lower extremity boney malalignment when compared to typically developed children (Dhawale, A. 2013).

Clinical Significance: Morquio syndrome and other similar forms of mucopolysaccharidosis are a group of rare genetic disorders with relatively limited research available regarding the effects of the associated symptoms on kinematic and kinetic gait patterns during childhood and adolescence. We aim to expand upon existing research and communicate the outcomes to the specialty pediatric population in order to help provide the best evidence-based care for children with MPS IV.

Methods: A retrospective chart review was conducted to identify children with MPS IV who underwent instrumented gait analysis between 1992 and 2020. Inclusion criteria consisted of diagnosis of Morquio syndrome, age between 2 and 18 years old (inclusive) at time of baseline gait analysis, and no lower extremity surgery prior to baseline gait analysis. Outcome measures include temporal spatial data and 3D lower extremity kinematics collected during walking at a self-selected speed and knee varus/valgus and transmalleolar axis measured in non-weightbearing during a physical exam. Outcome measures were compared to normative data using a two sample t-test with unequal variance.

Results: The retrospective database search revealed forty-seven possible children for inclusion. Twelve of the forty-seven children met exclusion criteria. Gait patterns and lower extremity kinematics of the remaining thirty-five children (70 limbs) with MPS IV were compared to an age matched cohort of typically developing children (Table 1). In summary, children with MPS IV had an average height of 101.3 cm (±13.0), an average weight of 19.9 (±6.4) kilograms, and an average age at the time of gait analysis of 8.8 years (±4.0). When compared to the typically developing group, children with MPS IV had increased trunk and pelvic forward tilt (p-value <0.001) and increased knee valgus alignment and excessive external tibial torsion (p-value <0.001). Children with MPS IV also had decreased forward velocity, decreased cadence decreased stride length (All p-value < 0.001; both absolute and normalized values) and GDI values p<0.001.
<table>
<thead>
<tr>
<th></th>
<th>Morquio Syndrome (MPS IV)</th>
<th>Typically Developed</th>
<th>P value</th>
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<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range (Min-Max)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Forward Velocity Avg. (cm/s) (n=35)</td>
<td>76.4 (24.5)</td>
<td>10.3 - 121.4</td>
<td>117.3 (10.8)</td>
</tr>
<tr>
<td>Normalized Velocity (cm/s) (n=35)</td>
<td>0.75 (0.25)</td>
<td>0.14 - 1.26</td>
<td>0.90 (0.09)</td>
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<tr>
<td>Cadence Avg. (steps/min) (n=35)</td>
<td>123.0 (23.6)</td>
<td>58.8 - 162.4</td>
<td>135.9 (12.8)</td>
</tr>
<tr>
<td>Normalized Cadence (steps/min) (n=35)</td>
<td>1.23 (0.28)</td>
<td>0.65 - 1.75</td>
<td>1.05 (0.25)</td>
</tr>
<tr>
<td>Stride Length Avg (cm) (n=35)</td>
<td>73.0 (17.4)</td>
<td>19.5 - 112.6</td>
<td>105.2 (18.3)</td>
</tr>
<tr>
<td>Normalized Stride Length (cm) (n=35)</td>
<td>0.72 (0.15)</td>
<td>0.26 - 0.98</td>
<td>0.80 (0.03)</td>
</tr>
<tr>
<td>Knee Varus-Valgus Position (Gait) (n=70)</td>
<td>17 (11.6) (val)</td>
<td>53.7 (val) - 2.14 (var)</td>
<td>4 (2.8) (val)</td>
</tr>
<tr>
<td>Knee Varus-Valgus Position (PT) (n=70)</td>
<td>17.4 (10.9) (val)</td>
<td>40.0 (val) - 12(var)</td>
<td>5.0 (3.0)**</td>
</tr>
<tr>
<td>Tibial Rotation (Gait) (n=70)</td>
<td>26.0 (15.9) (ext)</td>
<td>17.8 (int) - 60.1 (ext)</td>
<td>3.1 (4.3) (ext)</td>
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<tr>
<td>Transmalleolar axis (PT) (n=70)</td>
<td>25.9 (9.59) (ext)</td>
<td>5.0 (ext) - 45.0 (ext)</td>
<td>16.0 (5.9) (ext)**</td>
</tr>
<tr>
<td>Gait Deviation Index (n=70)</td>
<td>68.9 (19.5)</td>
<td>20.5 - 102.4</td>
<td>100.0 (10.0)**</td>
</tr>
</tbody>
</table>

Table 1: Temporal/spatial, kinematic, kinetic, GDI [4]* and physical examination values recorded during the gait analysis session of children with Morquio Syndrome, compared with a cohort of typically developed children. Typically developed knee varus-valgus and transmalleolar axis values were obtained from the literature (53 children with an age range of 4 to 16 years)[5]**.

**Discussion:** Gait patterns in children with MPSIV are often affected due to the progressive skeletal dysplasia and joint stiffness or laxity. This study provides quantitative information on the abnormal physical characteristics and dynamic gait patterns in this population. Children with MPS IV present with multiplanar lower extremity boney malalignment, most commonly with excessive knee valgus and external tibial torsion though variation is present between patients. Accuracy of the evaluation of multiplanar malalignment using traditional 2D methods of assessment (x-rays) is limited so utilization of 3D motion capture is an important part of surgical planning in this population.

**References:**
OPTIMIZING GAIT OUTCOMES IN PARKINSON’S DISEASE WITH AUDITORY CUES: THE EFFECTS OF SYNCHRONIZATION AND GROOVE

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Introduction: Walking is a naturally rhythmic pattern with a regular and repetitive cycle, much like that of music. The rhythmic nature of gait and music has been capitalized on in neurological rehabilitation to support natural and safe walking patterns among people with impaired gait, in particular in Parkinson’s disease (PD). Rhythmic auditory stimuli (RAS), such as metronomes or music, provide temporal information to which a person can entrain their gait. Much work supports that RAS can produce longer, faster strides with increased stability when played at a rate faster than baseline cadence; however, these findings are variable in the literature and consequently pose a barrier to appropriate clinical implementation [1]. Some of this variability may stem from properties of the music and how users interact with the cue. Perceiving more groove in music, or feeling greater desire to move with music, consistently elicits faster gait with larger strides in healthy adults [2-4]. Furthermore, this appears to depend in part on whether users are actively trying to synchronize with cues or not [4-5]. To date, no work has investigated how groove and synchronization together impact gait outcomes in PD.

Clinical Significance: Gait impairments are a debilitating aspect of PD that are associated with increased fall risk, decreased quality of life, and feelings of social isolation [6-9]. To enable safe and functional mobility, a better understanding of how to reliably optimize gait outcomes with RAS in PD is required.

Methods: 21 people with idiopathic PD (Hoehn and Yahr stages 2-3, independent walkers) were included in the study and tested during the peak “ON” phase of their medication cycle. Participants were randomized to one of two instruction conditions: free walking (instructed to walk comfortably) or synchronized walking (instructed to synchronize with music). In both conditions, participants walked 8 passes across a 16-foot pressure sensor walkway (Zeno\textsuperscript{TM}) to determine baseline gait parameters. Participants then walked to high- and low-groove music that was adjusted to be 10% faster (in beats per minute) than individual baseline cadence. In each condition, participants performed four trials to low groove music (does not induce desire to move), and four trials to high groove music (induces desire to move). Step length, stride width, stride velocity, cadence, and double-limb support time were examined. Coefficient of variation for step length and time were assessed as measures of gait variability.

Results: Overall, high groove cues produced more favourable gait outcomes than low groove cues and, in many cases, metronome cues. Greater step length \(F (1.8, 34.7) = 5.19, p = .013, n_p^2\)
cadence \[ F(1.6, 30) = 11.5, p < .001, n_p^2 = .38 \], stride velocity \[ F(1.7, 32.2) = 11.30, p < .001, n_p^2 = .37 \], and lower double-limb-support time \[ F(1.5, 27.7) = 7.74, p < .01, n_p^2 = .29 \] was observed in the high groove compared to low groove condition. In other words, faster gait speed with larger steps and more steps per minute resulted from music that induced desire to move (high groove) compared to music that did not induce desire to move (low groove). In addition, higher stride velocity was observed among synchronized walkers compared to free walkers \[ F(1, 19) = 7.47, p = .013, n_p^2 = .28 \], regardless of perceived groove. No significant effects were observed for stride width, step length variability, nor step time variability.

**Discussion:** These findings support that perceived groove in music and intention to synchronize significantly impact gait outcomes in people with PD while walking to music-based RAS. Larger steps and faster gait are observed with higher groove music, while instructions to synchronize facilitate faster overall gait speed. These findings suggest that controlling for groove and task instructions may foster better, more controlled, clinical outcomes.

**References**


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The effect of reducing anxiety on improving freezing of gait symptoms in Parkinson’s disease patients

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Introduction:
Freezing of gait (FOG) is a disabling and incapacitating motor symptom that results in falls and impairs the quality of life of more than 50% of later-stage Parkinson’s disease (PD) patients. FOG consists of brief episodes of an inability to initiate or continue walking and is characterized by short, stuttering steps, occurring particularly at gait initiation or upon turning. This symptom is relatively intractable, with minimal response to dopaminergic therapy. Anxiety has been suggested to worsen FOG symptoms by increasing their frequency and severity (Witt, Ganjavi, & Macdonald, 2019). This is consistent with patients’ subjective reports of anxiety during episodes of FOG, as well as the fact that stressful or anxiety-inducing situations seem to provoke FOG (Martens, Ellard, & Almeida, 2014).

Benzodiazepines acutely and effectively decrease various forms of anxiety including generalized anxiety, social anxiety, phobias, and panic attacks. Further, benzodiazepines are first line treatment in patients with hyperekplexia, a neurological condition in which excessive startle to tactile or acoustic stimuli leads to increased tone and freezing that at least on the surface bears some resemblance to FOG in PD. Finally, benzodiazepines have been shown to be safe and effective in the treatment of anxiety in PD. Taken together, the objective of this experiment is to test the potential of the anxiolytic medication alprazolam, a short-acting benzodiazepine, to improve FOG in PD. Benzodiazepines have not previously been tested for their effect on FOG in PD. The aim is to empirically test the hypothesis that reducing anxiety improves FOG.

Clinical Significance:
Reducing anxiety using a known anxiolytic, alprazolam, is expected to decrease FOG symptoms severity and frequency. This, in turn, might reduce the burden associated with FOG on PD patients and their caregivers.

Methods:
We investigated the effect of the benzodiazepine alprazolam versus placebo, tested in counterbalanced order across participants, on FOG in patients with PD. Both alprazolam (0.25mg) and placebo (i.e., cornstarch), were administered in identical capsules. Patients diagnosed with PD by a neurologist, who are treated with dopamine-modulating therapy, were recruited through the Movement Disorders Database, London Health Sciences Centre. All participants were evaluated in two nearly identical sessions at the Brain and Mind Institute, University of Western Ontario. Half of the participants received alprazolam at their first session followed by placebo at their second session, and the other half received the reverse order. Alprazolam and placebo caplets were provided an hour prior to tests of gait. During both sessions, participants completed standardized questionnaires assessing FOG, anxiety, depression, and other cognitive and neurological abilities. Ten patients with PD and FOG walked on a pressure sensitive walkway (Zeno™) in virtual
environments that were designed to be either low- or high-anxiety settings. Virtual environments were created using WorldViz software and presented via Oculus Rift virtual-reality goggles. Trials were completed in a randomized order (10 low-anxiety, 10 high-anxiety total). In the low-anxiety condition, participants walked on a plank that appeared level with the floor; in the high-anxiety condition, the plank appeared raised over a deep (virtual) pit.

**Results:**

Preliminary results have shown an increase in the frequency of FOG episodes on the high anxiety (28 episodes) situation compared to the low anxiety ones (zero episodes). Additionally, alprazolam managed to reduce the number of FOG episodes in the high anxiety situations (21 episodes). Moreover, administering alprazolam reduced gait variability (stride length, stride time, and stride velocity variability) and increased swing time. In addition, blood pressure (which is highly correlated with anxiety), was reduced on alprazolam compared to the OFF state.

**Discussion:**

Our results support a notion that 1) anxiety aggravates FOG in patients with PD and 2) that alprazolam, an anxiety-reducing medication can reduce FOG symptoms as well as improve gait measures associated with freezing. The outcome of this research confirms that anxiety is a causal factor behind FOG in Parkinson’s patients. Moreover, one dose of a short-acting anxiolytic was able to ameliorate FOG symptoms, which opens the floor to future clinical trials on other anxiolytics with more prolonged duration as a way to control FOG in patients with PD.

Keywords: Parkinson's Disease, Freezing of Gait, Anxiety, Alprazolam, Virtual reality.

**References:**


**Acknowledgments:**

We would like to acknowledge the help with data analysis from by Dr. Emily Nichols. In addition, we want to thank our volunteers Téa Sue, Jackshani Jeevaretnam, and Roja Ahimsadasan for their help with data collection.

**Disclosure statement**

The authors have no conflicts of interest to disclose.
MATERIAL TESTING OF 3D-PRINTED LOWER LIMB PROSTHETIC SOCKETS

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INTRODUCTION

Fabrication methods for lower limb prosthetic sockets has remained nearly static for decades - despite it being time-consuming, messy, somewhat expensive, and labor intensive. Advances in 3D printing technology present the possibility to reduce fabrication time, labor and cost, make the process more uniform and objective, and provide a perfect digital copy for any subsequent fabrications. Some preliminary work has begun to be published about this process and the resulting product but many methodological and performance questions remain. Computer modeling (CAD) design choices, material selection and 3D printing parameters can significantly influence comfort, safety, fabrication time and cost. The present work attempts to shed light on the impact of these choices. In this paper, we describe initial findings on the effect of material and 3D printing parameter choices on print speed, post-fabrication modification (i.e. workability) and strength of 3D printed sockets.

CLINICAL SIGNIFICANCE

Though a few commercial services exist for 3D printed socket fabrication, the basic socket design methodology, choices associated with materials and final socket fit and structural properties have not been scientifically, if at all, well described. Clarifying the role and impact of these measures is essential to ensure a safe and appropriate socket can be delivered to patients, to develop consensus on best practices and to quantify the benefits of this new approach.

METHODS

To gauge the suitability of print materials on workability (i.e. post-fabrication modifications), sample of 8 common 3D printing materials were cut, heated, flared and buffed by a CP0 – exactly as is done on sockets during fitting and delivery. A qualitative rating was then given by the prosthetist to each material. We tested PLA (Polylactic Acid), CPE (Co-Polyester), PVA (Polyvinyl alcohol), PP (Polypropylene), ABS (Acrylonitrile Butadiene Styrene), PETG (Glycol-modified Polyethylene Terephthalate), PC-MAX (Polycarbonate) and HIPS (High Impact Polystyrene). Plates (2in x 2in x 0.25in) of each material were printed at 30% infill. To gauge the effect of printing parameters on socket fabrication time, print time estimates by the slicing software were recorded as material, infill percentage, printing pattern, printing orientation, and layer height were varied. Initially, sockets were actually printed while the independent parameters varied. It was found that the slicer time estimates were accurate to within 5% of actual print times, which was deemed sufficient for this work. All subsequent time data were obtained by these printing simulations but not actually printing the sockets in those configurations. Jigs were designed and machined to allow proper loading to be applied by a testing machine (Tinius Olsen, Fig. 1 Strength testing setup.)
H10KS, Horsham, PA USA). Per general guidelines adapted from ISO10328 (Conditions I&II, static load test), sockets were to be tested at various angles and loads to represent those that may occur during walking. The experimental setup is shown (Fig.1). To evenly distribute the load, the socket was filled with a polymeric sand before loading was applied. Since variability in the strength of conventional (and a few 3DP) sockets is emerging [1-4], we will follow the core testing techniques described to date to facilitate comparison to those results. Sockets will be tested to proof and ultimate failure levels. This testing is currently ongoing.

RESULTS

The material workability evaluations (Table 1) and photos (Fig. 2) help clarify these results. Testing for the other four materials is underway. The effect of print settings on socket fabrication times is reported in Table 2.

<table>
<thead>
<tr>
<th>Material</th>
<th>Workability</th>
<th>Heat Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>CPE</td>
<td>Great</td>
<td>Good</td>
</tr>
<tr>
<td>PVA</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>PP</td>
<td>Good</td>
<td>Great</td>
</tr>
</tbody>
</table>

Fig 2. Left) PLA – showing warping during heating; Right) PP – showing excellent heat tolerance and good workability

DISCUSSION

We believe this is the first report on the effect of print settings and materials on the properties of 3DP sockets. It serves amputees to have well described specifications that are evaluated and debated by care providers, engineers and patients – to reach consensus on best practices. We have benchmarked the effect of numerous printing parameters (layer height, material, infill percentage, printing pattern, printing orientation) – and determined that layer height has one of the most significant impacts on print speed. As it stands this has potential to reduce socket delivery times considerably. Further improvements may allow sockets to be ready the same day – significantly reducing travel burden on the patient. Our testing has shown that one of the most common 3DP materials, PLA, is not suitable for sockets but other fairly common materials (PP, CPE) may well be – pending strength testing. Other materials are still being evaluated. Strength testing is in early stages but shows our general method for design and fabrication produces high quality strong sockets (static testing loads>1000lbs). Subjective fit testing of socket to residual limb has been very positive.

REFERENCES


ACKNOWLEDGMENTS - Julio Aira, IV; Angelo Russelo and Howard Brand
Velocity-Matched Normative Comparison of Gait Patterns of Individuals with Chronic Traumatic Brain Injury

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INTRODUCTION
A proper framework for evaluating TBI gait data can clarify understanding of deficits and guide treatment decisions. Past research to describe and understand gait deficits in the TBI population has attempted to frame TBI gait data in such a way, but the reference data to allow this do not seem to exist. Walking speed has a significant influence on magnitude and timing of many gait parameters. Consequently, many prior evaluations of TBI walking data have been compared to available or convenience (i.e. not velocity matched) gait data.

CLINICAL SIGNIFICANCE
Lack of appropriate reference data can lead to misconceptions about TBI gait as well as unrealistic expectations or treatment goals.

METHODS
Data were obtained from a prior trial of twenty-three participants with waking limitations due to chronic TBI participated in a trial to determine the efficacy of a variety of gait training interventions on follow up gait performance [1]. The data presented here were prior to any interventions were administered. Participants were at least 18 years of age and had a traumatic brain injury (≥12 months). All subjects provided informed consent. Prior to enrollment, participants were able to ambulate at least 10 meters at a self-selected velocity between 0.2 m/s and 0.6 m/s. If needed, braces (ankle/foot, knee orthoses) or upper extremity assistive devices (canes, walkers) were allowed. Overall, one subject used a MAFO, and all but three used upper limb support (parallel bars) during walking trials. Subjects were instrumented with bilateral lower extremity and trunk markers and walked across the 20-meter laboratory walkway that included 5 embedded forceplates at their self-selected velocity. Subjects typically were able to take at least 2-3 steps prior to entering the calibrated recording volume. Subjects had to wait on the order of 5 seconds once reaching the end of the walkway and turning around – which minimized the discontinuity and contributed to the steady-state nature of the data collected.

RESULTS
Bilateral 3D joint kinematics and kinetics were computed. Sagittal findings are reported here – a sample of which are shown in the below figures.

DISCUSSION
This is the first report, to our knowledge, of a systematic data collection of gait data from individuals with chronic TBI along with comparison to velocity matched reference normal data. Data were collected using the same system, same staff and processed using the same biomechanical model. Our data support that there is, as has been speculated, increased variability in TBI gait. Nearly all of the basic patterns observed in healthy normal gait were present in the
TBI group – a finding that could not be made unless comparisons to appropriate velocity-matched data. Timings and magnitudes of specific phases were altered and these can have important consequences on subsequent interventions and strategies to improve walking. We believe these data can serve as an important tool for the clinicians as they evaluate and develop treatment plans for this population.

Figure 1. Sagittal Knee Angle Data for Both TBI and Normal Groups Walking at ~0.3m/s along with Healthy Normal Subjects Walking at 1.2m/s.

Figure 2. Sagittal Hip Moment of TBI Group Referenced to Velocity-Matched Normative Data

REFERENCES

ACKNOWLEDGMENTS
The subjects, their families and the laboratory staff who helped to obtain these data.

DISCLOSURE STATEMENT
No authors have any conflicts of interest to disclose.
**Effects of Posterior Spinal Fusion Surgery on Gait Biomechanics in Patients with Adolescent Idiopathic Scoliosis**

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**INTRODUCTION:**

Scoliosis is a complex multidimensional spinal deformity which affects spinal anatomy, quality of movement and walking, and trunk symmetry. Posterior spinal fusion (PSF) is usually performed to stop curve progression, to reduce back pain and to restore asymmetric upper body \(^{[1]}\). Previous studies indicate that, there is an alteration of gait patterns in patients with Scoliosis and this gait pattern is substantially altered after surgical intervention. In India, these deformities are often neglected and present at a very late and much more deformed state (mean cobb angle \(\geq 60^\circ\)). So, we have planned a study to investigate the effects of posterior spinal fusion surgery on spatio-temporal and lower and upper body kinematics in severe Adolescent Idiopathic Scoliosis (AIS) patients during gait.

**CLINICAL SIGNIFICANCE:** Postoperative gait analysis may allow in the evaluation of surgical outcome and functional limitation in daily life of subjects with complex spinal deformities.

**METHODS:** This clinical prospective study after written informed consent included 15 subjects (mean age 16.3 Years) diagnosed with thoraco-lumbar/lumbar AIS (cobb angle MT 78.62 ± 8.10, TL/L 60.52 ± 7.42). Spatio-temporal parameters and upper and lower body kinematics were evaluated preoperatively and after 6 months of surgery using instrumented 3D gait analysis (BTS, Italy). Student T test was performed to find significant differences between pre and post operative AIS.

**RESULTS:** Gait speed, cadence, stride length were improved significantly after 6 months of surgery. Step width, gait profile score (GPS) and gait deviation index (GDI), were not changed significantly postoperatively. No significant changes in mean angle \((^\circ)\) of knee flex extension, hip Ab-adduction, hip flex-extension, ankle dorsi-planterflexion, spine flex extension were observed postoperatively.
Table 1: Comparisons of spatiotemporal and kinematics gait variables in AIS patients preoperatively and after 6 months of surgery. Values are in mean (SD).

<table>
<thead>
<tr>
<th>Variables</th>
<th>AIS Preoperative</th>
<th>AIS Postop 6 M</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spatio temporal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gait Speed (m/s)</td>
<td>0.94 (0.13)</td>
<td>1.06 (0.11)</td>
<td>0.012</td>
</tr>
<tr>
<td>Cadence</td>
<td>105.92 (6.02)</td>
<td>111.93 (6.01)</td>
<td>0.001</td>
</tr>
<tr>
<td>Stride Length (m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>1.06 (0.16)</td>
<td>1.14 (0.15)</td>
<td>0.0395</td>
</tr>
<tr>
<td>LT</td>
<td>1.06 (0.16)</td>
<td>1.14 (0.15)</td>
<td>0.0455</td>
</tr>
<tr>
<td>Step Width (m)</td>
<td>0.06 (0.02)</td>
<td>0.06 (0.02)</td>
<td>0.9177</td>
</tr>
<tr>
<td><strong>Kinematic analysis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gait Profile Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>7.69 (1.86)</td>
<td>7.72 (1.80)</td>
<td>0.93</td>
</tr>
<tr>
<td>LT</td>
<td>7.46 (1.91)</td>
<td>7.43 (2.17)</td>
<td>0.82</td>
</tr>
<tr>
<td>Gait Deviation Index</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>91.53 (7.91)</td>
<td>91.29 (9.02)</td>
<td>0.14</td>
</tr>
<tr>
<td>LT</td>
<td>90.46 (5.70)</td>
<td>91.93 (8.21)</td>
<td>0.72</td>
</tr>
<tr>
<td>Knee Flex- Extn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>23.63 (4.09)</td>
<td>24.79 (6.44)</td>
<td>0.56</td>
</tr>
<tr>
<td>LT</td>
<td>25.82 (4.59)</td>
<td>24.32 (5.44)</td>
<td>0.56</td>
</tr>
<tr>
<td>Hip Ab-Add</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>-2.89 (3.03)</td>
<td>-2.55 (3.39)</td>
<td>0.27</td>
</tr>
<tr>
<td>LT</td>
<td>-2.62 (4.19)</td>
<td>-2.15 (2.81)</td>
<td>0.23</td>
</tr>
<tr>
<td>Hip Flex-Extn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>16.04 (7.91)</td>
<td>17.61 (9.74)</td>
<td>0.54</td>
</tr>
<tr>
<td>LT</td>
<td>17.52 (8.53)</td>
<td>16.26 (8.14)</td>
<td>0.67</td>
</tr>
<tr>
<td>Ankle Dor-plan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>6.21 (2.85)</td>
<td>5.60 (3.16)</td>
<td>0.45</td>
</tr>
<tr>
<td>LT</td>
<td>6.50 (2.72)</td>
<td>5.90 (2.40)</td>
<td>0.42</td>
</tr>
<tr>
<td>Spine Flex-Extn</td>
<td>-19.45 (13.58)</td>
<td>-21.15 (16.68)</td>
<td>0.66</td>
</tr>
</tbody>
</table>

**DISCUSSION:** The results of our study suggest that Surgical intervention did not cause any significant changes in the upper and lower limb kinematics during gait, despite of large part of spinal fusion. Postoperative significant improvements in spatio-temporal parameters explain the well functioning in daily life of subjects with Adolescent Idiopathic Scoliosis. A comprehensive study involving long-term post-operative follow-up of a large sample of AIS is needed to draw decisive conclusions regarding alteration in gait of scoliosis.


**DISCLOSURE STATEMENT:** Authors has no conflicts of interest to disclose.
Title: Effect of Manual Therapy and Exercise on Motor Strategies During Gait in People with Hyperkyphosis

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ABSTRACT

Purpose: The purpose of this study was to assess whether older adults with Hyperkyphosis, who exhibit improved posture after a manual therapy and exercise intervention, would also demonstrate improved gait performance and postural control. Methods: A total 21 participants (13 females and 8 males; mean age: 66.2 ± 9.3 y.o.; mean BMI: 28.8 ± 5.0 kg/m²) were recruited from a local community. This study is a single group prospective clinical intervention trial with pre-treatment, 2-weeks, and 4 weeks measures of spatiotemporal gait parameters and vertical ground reaction forces in people with hyperkyphosis. The Kyphotic index (KI) and Block Test (BT) were conducted to assess the degree of thoracic kyphosis at pre-intervention, 2-weeks (mid-intervention), and 4 weeks
(final intervention). This study used Friedman’s ANOVA and Wilcoxon Signed Ranks test to analyze for changes in KI, BT, and double stance time during gait initiation \((DST_{GI})\), variables that did not meet the test for normality or homogeneity. Repeated measure ANOVA with one fixed factor (time) was conducted for steady state walking speed, shock dissipation rate, and duration of anticipatory postural adjustment (APA). \(p <0.05\). **Results:** Friedman test showed a statistically significant therapeutic effect for improving thoracic kyphosis on both KI and BT \((p = 0.00)\). One-way repeated analysis of variance and Friedman test showed significant improvement after the 4-week MT and exercise intervention on steady state walking speed \((p=0.000)\), shock dissipation \((p = 0.03)\), and \(DST_{GI}(p=0.031)\). However, better postural alignment did not improve APA \((p=0.296)\) during the task of GI. **Conclusion:** People with HK showed improved posture pre- to post-intervention and demonstrated significant improvements in SSWS, shock dissipation during mid-stance, and a shortened DST suggesting that improved alignment provides better gait performance. However, APA was not significantly improved, suggesting that the feedforward motor strategies of GI remain unaffected after treatment.
TEMPOROSPATIAL PARAMETERS IN PEDIATRIC HIP PATHOLOGY PATIENTS: PRE AND POST-SURGICAL INTERVENTION

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INTRODUCTION

Temporospatial parameters are consistently used in clinical settings through quantitative observations in order to evaluate gait deviations, recommend clinical interventions, and monitor patient progress over time. Self-selected gait speed, when compared to an aged-matched control group, can help determine overall gait function. Symmetry is an important evaluation tool used to assess gait efficiency, balance, and can provide insight on an impaired limb compared to the non-impaired leg during rehabilitation progression. Lower limb gait symmetry may provide clinicians a snapshot in overall function, particularly in hip pathology patients. The purpose of this study was to compare the temporospatial parameters of a large hip pathology cohort to an aged-matched control group as well as determine the impact of post-surgical intervention.

CLINICAL SIGNIFICANCE

Investigating temporospatial parameters in a large cohort of adolescent patients undergoing hip preservation surgery may assist in rehabilitation.

METHODS

A retrospective analysis of data collected through an IRB-approved prospective surgical hip preservation registry (HPS) was conducted on adolescent and young adult patients with non-neurological, non-syndromic hip pathology (data pulled from 1996-2020). An over-ground, self-selected gait analysis was conducted on all patients prior to surgery. Three hundred and twelve (N=312) pre-operative patients (aged 16±3yrs, BMI 25±6kg/m^2) were included with the following diagnoses: Acetabular Dysplasia (AD) (n=133), Femoracetabular Impingement (FAI) (n=90), Legg-Calve-Perthes disease (LCP) (n=58), and Slipped Capital Femoral Epiphysis (SCFE) (n=31). Ninety patients (n=90) were diagnosed with a bilateral hip deformity and 124 patients had previous hip surgery. A healthy aged-matched control sample (control) of 91 individuals (aged 17±5yrs, BMI 22±6kg/m^2) were utilized for comparison. In addition to cadence, normalized speed, stride time, and stride length, a limb comparison symmetry index was calculated for step time, step length, single and double limb support [3]. A higher symmetry index value indicates greater asymmetry. Non-parametric (Mann-Whitney and Kruskal Wallis) tests were used (alpha=0.05).

RESULTS

Overall: In the patient group (Patient), there were significant differences in cadence (Patient: 112±9, Control: 117±9 steps/min, p<0.001), normalized speed (Patient: 0.29±0.04, Control: 0.33±0.04, p<0.001), stride time (Patient: 1.08±0.09, Control: 1.03±0.08s, p<0.001, and stride length (Patient: 1.25±0.12, Control: 1.33±0.13m, p<0.001). A sub-analysis of 210 patients were used to compare post-operative changes in function. The latter time point was used in the analysis if a patient had both 1-year and 2-year post-op gait data. There was a statistical
difference between the pre-operative (PRE) and post-operative (POST) groups across normalized speed (pre: 0.29±0.04, post: 0.30±0.04, p<0.001) and stride length (pre:1.25±0.12, post:1.30±0.12, p<0.001).

**Previous Surgery Group:** There were no significant differences across cadence, normalized speed, stride time, and stride length in the previous surgery group (PS) compared to the no previous surgery group (No PS) (p>0.05), however, the PS group had significantly greater asymmetry across step length (No PS:3.75±3.87, PS:4.77±4.38, p=0.031), single limb support (No PS:3.95±4.01, PS:5.80±5.86, p=0.002), double limb support (No PS:4.06±3.76, PS:4.58±3.52, p=0.047), and step time (No PS:3.64±3.80, PS:4.82±4.51, p=0.021).

**Comparison Across Diagnoses:** AD patients (0.30±0.04) ambulated at a faster speed compared to FAI patients (0.29±0.03, p=0.020), LCP patients (0.28±0.03, p=0.013), and SCFE patients (0.28±0.04, p=0.004). Pre- to post-operative analysis across diagnoses revealed a significant, yet marginal, difference in normalized speed in AD (pre: 0.30±0.04, post: 0.31±0.03), FAI (pre:0.29±0.03, post:0.31±0.04), and LCP (pre:0.28±0.03 post:0.30±0.04) as well as stride length in AD (pre:1.25±0.12, post: 1.29±0.12m), FAI (pre:1.28±0.11, post: 1.32±0.12m), LCP (pre:1.22±0.11, post:1.27±0.12m).

**DISCUSSION**

Pre-operatively, adolescents undergoing hip preservation surgery have significantly impaired temporospatial parameters when compared to age-matched controls, but show significant improvement post-operatively. Patients with previous surgery tend to have a greater temporospatial gait asymmetry pre-operatively. Furthermore, hip preservation surgery may improve or optimize walking efficiency with an increase in walking speed and stride length post-operatively. Kinematic and kinetic changes in adolescents and young adults with hip disorders have varied in the literature, dependent on age, diagnosis and treatment. However, this is the first to report relatively consistent changes in ambulatory function across a variety of young active patient populations following hip preservation surgery.

**Table 1.** Temporospatial parameters in hip pathology patients at the pre-operative (Pre-Op) and post-operative (Post-Op) visits compared to a healthy control group (Control); SI – Symmetry Index; Mean (SD)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>Pre-Op</th>
<th>Post-Op</th>
<th>Variable</th>
<th>Control</th>
<th>Pre-Op</th>
<th>Post-Op</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadence (Steps per min)</td>
<td>116.82±8.90</td>
<td>112.38±9.44</td>
<td>113.42±8.24</td>
<td>SI Step Length</td>
<td>Control</td>
<td>Pre-Op</td>
<td>Post-Op</td>
</tr>
<tr>
<td>Normalized Speed</td>
<td>Control 0.33±0.04</td>
<td>Pre-Op 0.29±0.04</td>
<td>Post-Op 0.30±0.04</td>
<td>SI Single Limb Support</td>
<td>Control 2.54±2.01</td>
<td>Pre-Op 4.68±4.91</td>
<td>Post-Op 5.08±6.99</td>
</tr>
<tr>
<td>Stride Time (s)</td>
<td>Control 1.03±0.08</td>
<td>Pre-Op 1.08±0.09</td>
<td>Post-Op 1.06±0.08</td>
<td>SI Double Limb Support</td>
<td>Control 4.65±5.13</td>
<td>Pre-Op 4.27±3.67</td>
<td>Post-Op 5.12±7.44</td>
</tr>
<tr>
<td>Stride Length (m)</td>
<td>Control 1.33±0.13</td>
<td>Pre-Op 1.25±0.12</td>
<td>Post-Op 1.30±0.12</td>
<td>SI Step Time</td>
<td>Control 2.86±2.44</td>
<td>Pre-Op 4.11±4.13</td>
<td>Post-Op 3.87±3.68</td>
</tr>
</tbody>
</table>

**REFERENCES**


**ACKNOWLEDGEMENT** The authors wish to acknowledge Scottish Rite Research Program for support.

**DISCLOSURES** Co-author KTF is on the GCMAS executive board. The other authors have no disclosures.
INTER AND INTRA RATER RELIABILITY OF THE IMAGE BASED CRITERIA
OF THE FOOT POSTURE INDEX IN PEDIATRIC POPULATIONS

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INTRODUCTION
The Foot Posture Index-6 (FPI) is a clinical tool to address the supination, neutrality, or
pronation of the foot based on the sum of six individual measurements for each foot [1]. The
FPI was originally designed to evaluate and palpate the foot in person. However, assessment
using photographs, in feet without pathology, has also been found to be a reliable form of rating
the foot, broadening the opportunities for inter and intra rater reliability [2]. This study seeks to
evaluate the repeatability and reliability of the FPI through the use of photographs in a variety
of pediatric flatfeet that encompass a wide range of foot postures.

CLINICAL SIGNIFICANCE
The FPI is a non-invasive rating scale to quickly assess the posture of the foot. The repeatability
and reliability of the scale has been demonstrated on patients evaluated in person, but
photographic repeatability and reliability can provide greater flexibility for measurement
assessment.

METHODS
Foot photographs were collected for patients enrolled in a prospective IRB approved study.
Photos of 10 feet (5 patients; 15.4±2.3 years; 85.4±40.6 kg; 175.1±12.9 cm) over a range of
foot postures (including cavovarus, clubfoot, plantar fasciitis, and flatfeet) were used to rate the
feet on a scale of –2 to 2 for five image-based measures of the FPI, including curvature of the
supra and infra lateral malleoli (Malleoli), calcaneal frontal plane position (Calcaneus),
prominence of the talonavicular joint (TNJ), congruence of the medial longitudinal arch (Arch),
and abduction/adduction of the forefoot on the rearfoot (Abd/Add). Five raters ranging in
experience and familiarity with the FPI rated the feet on two separate days, with at least one
day between each rating session. All raters met on two separate occasions to review the FPI
measures and review example foot photographs prior to independent rating. Intraclass
correlation coefficients (ICC) were calculated to determine intra/inter-rater reliability for
individual FPI ratings as well as a summed FPI total score (mFPI, modified as it doesn’t include
the talar head palpation). ICCs were described as poor (0.0-0.50), moderate (0.51-0.75), good
(0.76-0.90), or excellent (0.91-1.00).
RESULTS
Intra-rater reliability was assessed for each rater between the first and second rating sessions. The intra-rater reliability for mFPI score totals was found to be excellent (ICC > 0.91) for 3 of the 5 raters and good for the remaining raters. However, the intra-rater reliability for the individual FPI scores was found to range in agreement (-0.025-0.979). The individual with the lowest ICCs had the least clinical experience with patients with foot deformity. Removal of the 5th rater resulted in an improved range of ICCs (0.372-0.979).

Based on the intra-rater reliability results, inter-rater reliability was recalculated (see Table 1) after removing the 5th rater. All ICC’s improved, with the mFPI total found to have excellent agreement (ICC=0.945). Individual FPI measures had moderate to good agreement. The TNJ had moderate agreement (ICC=0.645) and the Malleoli (ICC=0.772), Arch (ICC=0.829), Calcaneus (ICC=0.868) and Abd/Add (ICC=0.849) had good inter-rater agreement.

DISCUSSION
Evaluation of adolescent feet with foot deformity using the mFPI by means of photographic measurements provides a repeatable measure of the feet by multiple raters. The FPI traditionally requires rating to take place in person, due to the measurement of the talar head through palpation. However, rating using photographs provides greater flexibility in assessing the posture of the foot, allowing for easy reliability testing amongst multiple raters. Furthermore, photography allows for long-term documentation, and later assessment as needed.

To our knowledge only one study has previously validated a similar method of rating the FPI using photography, however this was in healthy volunteers and evaluated by certified athletic trainers [2]. Our cohort of patients presented in a complex adolescent foot and ankle clinic with a variety of foot pathologies including cavovarus and planovalgus foot deformities, recurrent clubfoot, and plantar fasciitis.

Intra-rater ICC total scores between sessions had good to excellent agreement, indicating that the mFPI score using photographs is reliable between sessions. However, it was noted that the least clinically experienced rater had the lowest intra-rater reliability which may highlight the importance for proper initial training and continued competency evaluation when utilizing the photo method. Future work will include application of this method to a larger cohort of patients across a range of foot pathologies and the development of a documented training plan.


ACKNOWLEDGEMENTS The authors wish to acknowledge the TSRHC Research Program.

DISCLOSURE STATEMENT Co-author KTF is a GCMAS executive Board member. All other authors have no conflicts to disclose.
FUNCTIONAL DEFICITS IN THE NON-OPERATIVELY TREATED SKELETALLY MATURE CHILD WITH CLUBFOOT: MOVEMENT QUALITY ASSESSMENT USING ACCELEROMETRY DATA

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INTRODUCTION

A nonoperative treatment paradigm for children with clubfoot is widely accepted as a standard course of care. Functional outcome assessments of children treated primarily nonoperatively have been performed using various technologies including three-dimensional gait analysis, pedobarography, objective strength measures and community ambulation [1]. Advancements in technology, including highly sensitive accelerometers, have broadened the capabilities of researchers to further investigate functional outcomes and gather in-depth assessments on sided differences and overall movement mechanics (quality) in both healthy children and those with a physical disability [2]. When utilizing a dynamic agility test to assess movements and overall function, integrating accelerometry data in these assessments could be a useful tool to researchers. Children with clubfoot who remained non-operative at 10 years of age have been shown to have deficits in sagittal plane ankle ROM and push-off power during gait [1]. The question remains whether these non-operatively treated children at skeletal maturity have sided differences when asked to perform a dynamic agility task and whether ankle plantarflexion/dorsiflexion strength influences the quality of movement during the task.

CLINICAL SIGNIFICANCE

At skeletal maturity, children treated nonoperatively for clubfoot may show deficits in ankle strength which may translate to poorer movement quality during a sport specific dynamic agility task.

METHODS

As part of this prospective IRB approved study, isokinetic strength and performance during the Edgren Side Step Test (modified) were collected at 16 years of age in unilateral patients treated nonoperative (NO) for idiopathic CF (surgically treated and bilateral patients were excluded). Isokinetic dorsi- and plantar-flexion strength were collected in the prone position (Biodex, NY, USA). Five consecutive trials were collected and the maximum effort on each side (peak torque, N-m/kg) was used for analysis. Each child performed a modified version of the Edgren Side Step Test (mESST) which incorporates lateral coordination, power, speed and agility. This modified protocol allows for time-based assessments of the functional demand on the leg rather than a singular distance-based evaluation. At the “go” command subjects side stepped laterally across 4-meters toward the opposite end-line, quickly gathered themselves and side stepped laterally in the opposite direction. “Down-and-back” was counted as one repetition and this was performed three times. If the individual did not touch the end lines, did not maintain their trunk and pelvis positions parallel to the path, or crossed their legs during the test, the trial was deemed unsuccessful. Subjects were given three attempts and the fastest successful trial was used for analysis. To determine time based metrics and sided movement patterns, an Actigraph GT3X accelerometer (Pensacola, FL, USA,), sampled at 100 Hz, was worn above the lateral malleolus of each ankle. The acceleration signals were plotted to determine each pass and foot contact/off events at the end of each repetition.
were identified using previously established methods [3]. The overall time of the attempt was calculated for each repetition, and the Split time (travel time between end lines) and Lag time (transition times at the end lines) were also calculated based on the lead foot. Leg movement was assessed by calculating the peak acceleration (peak G), integral of the vector magnitude of acceleration signal in the frontal/mediolateral planes (VMag Int) and stride frequency (Stride Freq). Side to side differences were analyzed by separating the accelerometry data based on whether the movement was driven by the affected and unaffected sides and an average of the measures (time/accelerometry measures) was taken. Signed rank test were performed comparing the affected (Aff) to the unaffected side (unAff). Spearman rank correlations were performed between isokinetic ankle strength of the affected and unAff sides and the time/accelerometry measures. Alpha was set to 0.05.

RESULTS
17 non-operatively treated unilateral clubfoot patients were tested. The affected side had significantly weaker dorsi- and plantarflexion strength when compared to the unAff side (p<0.001). There was no significant difference in Split, Lag time, Peak G or Stride Freq between sides (p>0.05). VMag Int was significantly higher on the affected side (Aff 168.7 vs. 156.9, p=0.04). unAff feet with greater plantarflexion had a quicker overall time on the test (p= -0.669, p<0.01), quicker Split time (p= -0.655, p<0.01), higher Peak G (p=0.532, p=0.03) and higher VMag Int (p=0.581, p=0.01). Greater affected side plantarflexion strength correlated with a quicker Lag time (p= -0.620, p<0.01) indicating less time was needed to change directions at the end-lines of each pass.

DISCUSSION
Children with unilateral clubfoot who remained nonoperative by skeletal maturity did not appear to show a significant amount of sided differences in time/accelerometer measures when performing a sport specific dynamic agility test, though sided differences in ankle strength were observed. Interestingly, the affected limb adopted a strategy where velocity (VMag Int) was sustained, while traveling between end lines to maintain a similar split time, as compared to the unaffected limb.

Correlations to ankle strength were mainly observed in the unaffected feet as greater strength in those feet resulted in better performance on the agility test and greater movement quality. Integration of accelerometry measures during agility testing further enhances the functional assessment of children treated for clubfoot and allows a more in-depth movement profile that could help describe functional deficits and the relationship to ankle strength. Movement quality can now be quantified outside of the typical lab environment as accelerometry measures provide information on leg movement that have an association to the preservation of ankle strength. Further work is necessary to utilize accelerometry data to describe the movement profile of children with clubfoot across the treatment outcome spectrum (poor/good outcomes; nonoperative/surgical feet).

REFERENCES

DISCLOSURE STATEMENT Co-author KTF is on the GCMAS executive board. All other authors have no conflicts of interest to disclose.

ACKNOWLEDGEMENTS: The authors wish to acknowledge the TSRHC Research Program.
INTRODUCTION
Dynamic joint stiffness (hereafter referred to simply as “stiffness”) is a descriptive metric commonly used for numerous joints in the body, particularly lower-limb joints [1]. It is most often defined as the slope of the linear regression of a joint’s net moment vs. angle throughout all or part of a defined motion, such as walking or running. Metatarsophalangeal (MTP) joint stiffness is important because it affects contra- and ipsilateral lower limb dynamics in prosthetic users, and play an important role in user comfort [2]. In running biomechanics, MTP stiffness is suggested to influence the performance of energy storing-and-releasing footwear [3]. The benefit provided by elastic foot orthoses is added support to the natural foot structures (plantar aponeurosis, intrinsic muscles) that store and release energy about the MTP joint [4].

To date, no study to our knowledge has thoroughly examined how MTP stiffness changes during terminal stance – when the joint’s moment and angular excursion are greatest – or how stiffness changes with gait speed. The purpose of this study was to provide a normative baseline for MTP stiffness during distinct portions of terminal stance and understand how it changes with walking speed in a healthy population. We hypothesized that MTP joint stiffness would increase in magnitude with speed during both early and late terminal stance.

CLINICAL SIGNIFICANCE
As previously mentioned, MTP joint stiffness influences lower limb biomechanics in prosthesis users, and potentially plays an important design role in tuning running shoe stiffness. These highlight its importance for both patient-based and healthy populations. Having a normative baseline of MTP stiffness values across a wide range of speeds is valuable information for prosthetic and orthotic device designers and manufacturers seeking to quickly estimate what a user might need, rather than go through a lengthy trial-and-error process to tune device’s properties to the user’s preference.

METHODS
10 young, healthy individuals (average (Std.Dev.): age=24.2 (2.86) yrs, height=1.71 (0.07) m, mass=69.63 (10.71) kg, 6 female) participated. Subjects traversed a 20m-long level walkway with four force plates while wearing a six-degree-of-freedom marker set. Force plates measured ground reaction forces (GRFs) while 3D kinematics were captured with a motion capture camera system. Subjects walked at 0.4, 0.6, 0.8, and 1.0 statures/s (±0.02 statures/s tolerance), or very slow to brisk.
walking. Eight foot strikes per condition (four per limb) were captured per subject. Terminal stance (a.k.a. toe rocker or push-off) was the only phase of stance analyzed. It was defined as the period from when the anterior/posterior (A/P) position of the foot’s center of pressure (CoP) crossed the location of the MTP joint center (2nd metatarsal head) (Fig. 1). This was further divided into early push-off (EP) and late push-off (LP), which were separated by the instant of peak MTP joint moment (Fig. 2). The foot-to-floor angle was used as the joint angle, and MTP moments were calculated as the A/P distance from the 2nd met. head to the CoP multiplied by the GRF (Fig. 1). Linear regressions of the MTP joint moment vs. MTP joint angle during EP and LP determined the stiffness for each phase. Multilevel linear models (MLMs) were used to identify statistically significant differences in EP or LP stiffness across walking speeds.

**RESULTS**

EP had a higher stiffness magnitude for each condition than LP, by a factor of 2-3 (Table 1). MLMs showed that EP stiffness was significantly different ($p<0.014$) between every speed except 0.4/0.8 stat/s ($p<0.066$), and LP stiffness was significantly different between every speed ($p<0.002$).

**DISCUSSION**

This is the first study to our knowledge to quantify dynamic MTP joint stiffness during the toe rocker phase of stance while walking across a range of controlled walking speeds. These findings support our hypothesis that MTP stiffness would increase in magnitude with walking speed.

**Table 1**: EP and LP stiffness values

<table>
<thead>
<tr>
<th>Walking speed</th>
<th>0.4 stat/s</th>
<th>0.6 stat/s</th>
<th>0.8 stat/s</th>
<th>1.0 stat/s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EP stiffness (N*m/deg/BW)</strong></td>
<td>7.02E-04 ±3.70E-04</td>
<td>7.91E-04 ±3.26E-04</td>
<td>9.00E-04 ±3.43E-04</td>
<td>1.09E-03 ±3.80E-04</td>
</tr>
<tr>
<td><strong>LP stiffness (N*m/deg/BW)</strong></td>
<td>-2.56E-04 ±1.32E-04</td>
<td>-3.52E-04 ±1.53E-04</td>
<td>-4.07E-04 ±1.57E-04</td>
<td>-5.10E-04 ±1.83E-04</td>
</tr>
</tbody>
</table>

**REFERENCES**


**ACKNOWLEDGMENTS & DISCLOSURE STATEMENT**

Luke Nigro acknowledges the National Science Foundation’s Graduate Research Fellowship grant no. 1940700 for funding. None of the authors have conflicts of interest to disclose.
FUNCTIONAL OUTCOMES IN ACETABULAR DYSPLASIA PATIENTS: 
A 10-YEAR POST-OPERATIVE CASE SERIES
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INTRODUCTION
Acetabular Dysplasia (AD) refers to an abnormal skeletal morphology of the hip with a
range of deficiencies including shape, size and/or orientation. The lateralized hip joint center
leads to poor femoral head coverage, an increase in mechanical stress, and degenerative changes
at the joint [1].

Previous studies have reported a decrease in the hip abductor moment during stance
phase in adolescent patients with AD pre-operatively, however, this has been shown to increase
one-year following a Ganz periacetabular osteotomy (PAO) [2]. Furthermore, isokinetic hip
flexion strength has been reported to decrease at six-month post-surgical intervention when
compared to pre-operative measurements and improve by the one-year post-operative visit [2].

Despite these previous studies, long-term outcomes related to the hip abductor moment
and hip strength have not been clearly differentiated in adolescent and young adult patients with
AD. Therefore, the purpose of this study was to evaluate the changes in temporospatial
parameters, hip mechanics, and hip strength over time in adolescent and young adult patients
with AD following a traditional PAO in order to better understand longitudinal outcomes.

CLINICAL SIGNIFICANCE
It is important to understand the long-term outcomes of the Ganz periacetabular
osteotomy (PAO) in adolescent patients with acetabular dysplasia (AD).

METHODS
Data collected through an institutional review board (IRB) approved surgical hip
preservation registry (data collected 1999-2020) were retrospectively reviewed. Adolescent and
young adult patients clinically diagnosed with AD, who underwent a traditional PAO (modified
Smith-Peterson method) and completed an instrumented gait analysis (Vicon Nexus) prior to
surgical intervention as well as one, two, five, and ten-year (range 10-17yrs) post-surgical
intervention visits were identified for analysis.

Nine (N=9) patients (surgical age: 16±4yrs, BMI: 21±3kg/m²), were included for
analysis. Seven patients (n=7) were diagnosed with a bilateral hip deformity, and four patients
(n=4) had hip surgery prior to their PAO. Temporospatial parameters (normalized speed,
cadence, stride time and stride length) were calculated at each visit. Functional hip flexion range
of motion was determined across the gait cycle, however, hip abductor moment, hip abductor
impulse, and hip flexion power were determined across stance phase. Peak isokinetic flexion and
abduction strength (torque) was normalized to body weight (Biodex System 3). The change in
each variable was calculated between each subsequent time point, for each patient’s affected
limb, then averaged across the cohort.
RESULTS

Out of the temporospatial parameters, cadence revealed the greatest difference in mean changes (-4 to 2 steps per min). Interestingly, between the five-year and ten-year visit there was a decrease in cadence (-4 steps per min). There were marginal differences seen in normalized speed (-0.02 to 0.01), step time (-0.01s to 0.02s), and step length (-0.02m to 0.02m).

Hip flexion range of motion revealed minimal mean differences ranging from -1.29º to 1.40º. Changes in hip power in the sagittal plane ranged from -0.37 to 0.07 W/kg. Decreased hip pull off power of -0.37 W/kg was seen between the five and ten-year visit. Hip abductor moment impulse changes ranged from -0.04 to 2.62 Nm/kg*s. The largest increase in change occurred between pre-op and the one-year visit (2.62 Nm/kg*s), with no change seen between the five-year and ten-year visits (0.04 Nm/kg*s). Similarly, the largest increase in average hip abductor moment change ranged from 0.01 to 0.08 Nm/kg with the greatest change reported from pre-op to the one-year visit (0.08 Nm/kg).

While there were marginal differences seen in isokinetic hip flexion strength (-3.5 to 3.89 Nm/kg), interestingly, there were slight decreases in strength seen between the two-year to five-year visits (-1.22 Nm/kg) and the five-year to ten-year visits (-3.51 Nm/kg). Isokinetic hip abductor strength demonstrated greater changes ranging early, with an increase from pre-op to one-year (10.93 Nm/kg) and one-year to two-year (10.38 Nm/kg). However, a large decline was seen between the five-year and ten-year visits (-10.09 Nm/kg).

DISCUSSION

In this series of patients with long-term follow-up, there were no clinically significant differences in temporospatial parameters. Patients did not appear to develop hip stiffness post-operatively long-term. However, there was a reduction in hip flexion power and strength, as well as a decline in hip abduction strength, at the ten-year visit compared to their five-year visits, which had not been seen previously. This early pilot case series may suggest that as these adolescent patients age into adulthood, and formal rehabilitation has long ended, they should be encouraged to continue at home exercise programs with a focus on hip flexor and abductor strength. Furthermore, future work should also focus on the Rectus-Sparing approach to the PAO [3] with similar long-term follow-up data to fully understand longitudinal outcomes.

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DISCLOSURES
Co-author Kirsten Tulchin-Francis is on the GCMAS executive board. All other authors have no disclosures to report.
Sagittal Plane Motion during Different Squat Tasks in Patients with Femoroacetabular Impingement

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INTRODUCTION
Femoroacetabular impingement (FAI) is a condition in which extra bone grows on either the acetabulum or the femoral head. This causes the bones to not fit properly together which can limit the range-of-motion (ROM) that can be achieved by the hip. Biomechanically, squatting is used to replicate daily tasks and can be used to test the overall ROM of the hip and knee joint. The purpose of this study was to determine which squatting technique would elicit the greatest amount of hip and knee ROM and the greatest squat depth for biomechanical assessments.

CLINICAL SIGNIFICANCE
Participants may restrict the depth of their squat to maintain comfort and avoid pain. If squatting is used as a functional assessment or outcome measure, it is important to consider which squat technique elicits the largest amount of hip and knee motion.

METHODS
All participants were enrolled in an IRB approved research study and scheduled to undergo unilateral hip preservation surgery for FAI. Pre-operative kinematic data were collected while participants completed three squatting techniques. During the hold squat, participants were instructed to maintain the squat at their lowest possible position for three seconds. For the standard squat, each participant squatted to their lowest possible position and immediately returned to standing upright. For the target squat, a 15.5cm platform was placed behind the participant who was instructed to attempt to reach but not sit on the platform. Peak sagittal plane kinematics of the trunk, pelvis, hip, knee, and ankle were determined during the squat. Maximum squat depth was calculated by dividing the displacement of the hip joint center (HJC) by the highest position of the HJC. Parametric statistics were used to evaluate comparisons between squatting techniques for Group 1. A One-way Repeated Measures ANOVA followed by a post-hoc paired t-test was used for comparison of Group 2 (α = 0.05).

RESULTS
Forty-six participants that completed the hold and standard squats were included in Group 1 (16.5 ± 1.7 years, 35 females). Group 2, a subgroup of Group 1, consisted of twenty-five participants (16.5 ± 2.2 years, 20 females) who completed all three types of squats. The surgical breakdown of Group 2 (21 arthroscopic, 3 surgical hip dislocation, and 1 combined approach) was not as balanced as Group 1 (23 arthroscopic, 22 surgical hip dislocation, and 1 combined approach).

Overall, Group 1 sagittal plane motion of the hip, knee and ankle were significantly different between the two squatting techniques (Table 1). During the standard squat, maximum sagittal plane motion was greater than the hold squat for the hip (4.2°), knee (10.2°) and ankle (1.4°). While peak ankle dorsiflexion is statistically, due to the minimal difference we do not consider it clinically significant. Maximum squat depth was also greater during the standard squat with participants achieving 6.6% more HJC displacement. Comparing the hold and standard squat types, Group 2 showed similar results as Group 1 at the hip, knee, and ankle with all displaying increased peak values during the standard squat. (Table 2). While the standard
squat had increased trunk tilt when compared to the hold squat, the greatest amount of trunk tilt was seen during the target squat in Group 2. The least amount of squat depth was achieved during the hold squat and the greatest during the target squat.

**DISCUSSION**

Participants may have restricted the depth of the hold squat to assure comfort and ability as they held the squatting position for three seconds. The amount of joint ROM and overall squat depth noticeably progressed with the deep squat, however, it was greatest in the target squat. Providing a target maximizes overall squat depth which may elicit different mechanics and compensations which may not be present during an untargeted hold or standard squat. Therefore, if biomechanical testing is used as a functional assessment or outcomes measure, a target squat maybe used to achieve the deepest squat and the greatest amount of hip flexion.

**REFERENCES**


**DISCLOSURE STATEMENT**

All authors have no conflicts of interests to disclose.

**Table 1.** Kinematic data of the affected limb of Group 1 during the squatting tasks.

<table>
<thead>
<tr>
<th>AFFECTED LIMB</th>
<th>Group 1 mean (SD)</th>
<th>Hold vs Standard</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hold</td>
<td>Standard</td>
<td></td>
</tr>
<tr>
<td>Max Trunk Tilt (*)</td>
<td>28.5 (12.0)</td>
<td>29.8 (13.2)</td>
<td>0.312</td>
</tr>
<tr>
<td>Max Pelvic Tilt (*)</td>
<td>2.7 (3.8)</td>
<td>2.3 (3.4)</td>
<td>0.062</td>
</tr>
<tr>
<td>Max Hip Flexion (*)</td>
<td>87.7 (14.8)</td>
<td>91.9 (14.1)</td>
<td>0.005</td>
</tr>
<tr>
<td>Max Knee Flexion (*)</td>
<td>90.2 (20.6)</td>
<td>100.4 (19.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Max Ankle Dorsiflexion (*)</td>
<td>32.0 (6.0)</td>
<td>33.4 (5.9)</td>
<td>0.001</td>
</tr>
<tr>
<td>Max Squat Depth (%)</td>
<td>36.0 (13.0)</td>
<td>42.6 (12.8)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Table 2.** Kinematic data of the affected limb of Group 2 during the squatting tasks.

<table>
<thead>
<tr>
<th>AFFECTED LIMB</th>
<th>Group 2 mean (SD)</th>
<th>One-way Repeated ANOVA</th>
<th>Hold vs Standard</th>
<th>Target vs Hold</th>
<th>Target vs Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hold</td>
<td>Standard</td>
<td>Target</td>
<td>p-value</td>
<td>p-value</td>
</tr>
<tr>
<td>Max Trunk Tilt (*)</td>
<td>27.9 (12.5)</td>
<td>31.5 (12.9)</td>
<td>39.2 (13.8)</td>
<td>&lt;0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Max Pelvic Tilt (*)</td>
<td>2.6 (2.7)</td>
<td>2.2 (2.5)</td>
<td>2.8 (2.6)</td>
<td>0.323</td>
<td></td>
</tr>
<tr>
<td>Max Hip Flexion (*)</td>
<td>87.2 (17.1)</td>
<td>94.5 (14.4)</td>
<td>100.9 (14.4)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Max Knee Flexion (*)</td>
<td>85.0 (18.4)</td>
<td>97.9 (19.7)</td>
<td>108.0 (21.2)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Max Ankle Dorsiflexion (*)</td>
<td>30.4 (5.6)</td>
<td>32.0 (5.5)</td>
<td>29.8 (5.3)</td>
<td>0.003</td>
<td>0.016</td>
</tr>
<tr>
<td>Max Squat Depth (%)</td>
<td>34.0 (12.0)</td>
<td>42.7 (12.9)</td>
<td>50.4 (14.2)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
The Effect of Augmented Plantar Feedback on Walk Ratios

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INTRODUCTION

Barefoot and shod gait has been shown to display considerable differences in kinematics, kinetics, and muscular activation [1, 2]. A possible source of these changes is the alteration in plantar feedback during shod gait. For instance, Sacco et al. found changes in plantar sensory information during shod and barefoot walking resulted in alterations in the lower extremity muscle activity in both healthy individuals and those with peripheral neuropathy. While the exact mechanism(s) that cause these differences has been a point debated in the literature, it is apparent that the successful integration of sensorimotor information is vital to control mechanisms during gait, especially in populations with decreased capabilities (e.g. older adults, pathology).

More recent research has indicated the ability of augmented tactile feedback to significantly alter spatiotemporal gait parameters and gait symmetry measures (e.g., stance phase, single support, and swing phase) in young, healthy adults, while others have reported a reduced stride length and walking velocity when older adults wore a textured as opposed to a smooth insole [4, 5]. Likewise, the research by Nurse et al. (2005) has indicated the ability of augmented tactile feedback to alter gait mechanics and muscle activity during walking.

Given the influence of plantar sensory information on motor control strategies, analysis of spatiotemporal gait patterns utilizing the velocity independent variable, walk ratio (step length (mm) / cadence (steps*min⁻¹)), may assist in better understanding motor control changes resulting from diminished plantar feedback while shod [7-8]. Specifically, previous research has found that the walk ratios are altered in populations with neuromuscular dysfunction (e.g. Parkinson’s disease), older adults, and during the execution of dual tasks [8-10]. Therefore, the purpose of the present study was to compare the influence of augmented plantar feedback while shod and barefoot on stride length, stance width, and the walk ratios during free walking (i.e. self-chosen). A secondary purpose was to examine potential gender differences in walk ratios which has not been previously reported.

CLINICAL SIGNIFICANCE

Walk ratios have been utilized as an indicator of alterations in motor control strategies during walking [7-8]. Given the potential influence of plantar sensory information, as well as footwear, on motor control strategies, examining walk ratios during gait may provide a rather simple variable to calculate that would assist clinicians in quickly identifying changes in neuromuscular strategies during gait.

METHODS

Fifty healthy participants (25 male, 25 female) walked across an instrumented walkway (GAITRite, CIR Systems, Inc., Havertown, PA, USA) at a normal, self-selected pace during four footwear conditions: barefoot (BF), insole-only (IN), a minimalist running shoe (SH), and a minimalist running shoe with the textured insole (INSH). Spatiotemporal variables were...
averaged across six trials of normal walking for each of the footwear conditions. The mass of the insole-only, shoe, and insole/shoe combination was 31.5g, 143g, and 162g, respectively. A two-way (IV’s: Footwear, Gender) repeated measures ANOVA’s with Bonferonni post hoc analyses were performed with dependence on Walk Ratios and Walking Velocity. Stride length (mm) and cadence (steps*min\(^{-1}\)) were collected to calculate the walk ratio (step length (mm) / cadence (steps*min\(^{-1}\))) during each condition.

RESULTS
Statistical analyses revealed a significant main effect for gender \((p < 0.001)\) as well as footwear condition \((p < 0.001)\); no significant effect was noted for velocity. Specifically, results indicate that females display significantly smaller walk ratios as compared to males (Figure 1).

With respect to walk ratios (Figure 2), follow-up analyses indicated that participants displayed significantly greater \((p < 0.001)\) walk ratios when Shod (SH) as compared to Barefoot (BF) as well as when Shod with a textured Insole (INSH) as compared to BF \((p < 0.001)\). Finally, results indicate that there was no significant difference in the walk ratios of individuals with BR as compared to the insole-only condition (IN).

DISCUSSION
Previous research has found walk ratios to be a reliable measure for identifying changes in motor control strategies during gait [7-10]. Furthermore, research has previously reported significant differences in barefoot and shod gait, including altered efferent muscular activation patterns, as well as the ability of augmented plantar feedback to alter gait patterns in a variety of populations [1-6]. The present study suggests that while footwear does indeed alter the walk ratios of individuals, augmented plantar feedback has a minimal effect on gross motor control strategies. Furthermore, it has been previously reported that a smaller walk ratio may be an indicator of potential pathology; however, the present study suggests that females with no pathology will often display significantly lower walk ratios as compared to males [7-8]. While not altogether unexpected given the smaller stature of females, this finding does indicate the potential need for gender specific norms.

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