2017

CENTER OF PRESSURE EXCURSION DURING A SINGLE LEG STANDING TEST IN AMBULATORY CHILDREN WITH CEREBRAL PALSY

Ryan Thomas Callahan
University of Kentucky, ryan.callahan@uky.edu
Digital Object Identifier: https://doi.org/10.13023/ETD.2017.265

CENTER OF PRESSURE EXCURSION DURING A SINGLE LEG STANDING TEST
IN AMBULATORY CHILDREN WITH CEREBRAL PALSY

_____

THESIS

_____

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science in the
College of Education at the University of Kentucky

By:
Ryan Thomas Callahan
Lexington, Kentucky
Director: Michael Pohl, Ph.D., Assistant Professor
University of Kentucky
Lexington, Kentucky
2017

ABSTRACT OF THESIS
CENTER OF PRESSURE EXCURSION DURING A SINGLE LEG STANDING TEST
IN AMBULATORY CHILDREN WITH CEREBRAL PALSY

INTRODUCTION: Cerebral Palsy (CP) is the most common disabling motor disorder found during childhood, occurring in 2.1-3.2 of every 1,000 births. Motor functionality of children with CP is commonly compromised and is classified with a gross motor function classification score (GMFCS) and with the gross motor function measure (GMFM). Balance ability has typically been assessed using single leg stance test (SLST) time but more recently, center of pressure excursion (COPE) has shown to be a more valid measurement in populations with altered motor abilities. However, COPE has not been used to test balance in the CP population, yet. This study aimed to determine if relationships were present between COPE measurements, functionality measurement scores (GMCS and GMFM) and reported fall frequency. It was hypothesized that i) larger COPE measurements would be associated with a higher GMFCS level and lower GMFM score, and that ii) COPE measurements would be significantly higher in children with a high reported incidence of fall frequency. METHODS: Gross functionality was measured using a GMFM score and GMFCS level. Balance ability was assessed using COPE measurements on a force plate and SLST time. Fall frequency was determined by a short questionnaire. A Pearson correlation analyzed COPE measurements vs. mean GMFM score. A one-way ANOVA was used to compare COPE measures between GMFMCS levels, with a Bonferroni post-hoc test. Lastly, an independent sample t-test analyzed differences in COPE measurements and SLST time between fall frequency groups. RESULTS: Significantly larger COPE velocities were demonstrated in children who reported a greater number of falls in the past month and were considered high risk for falling ($p = 0.02$). No relationships were demonstrated between COPE measurements and GMFM score. GMFCS level III participants demonstrated statistically significant lower COPE velocity compared to GMFCS level II participants ($p = 0.05$). There were no significant differences in SLST between high and low risk fall groups ($p = 0.07$). DISCUSSION: Children with higher reported fall frequencies demonstrated a 60% increase in COPE velocity, compared to those with little to no falls. Clinical GMFM scores did not demonstrate significant correlations to COPE measurements and may not be an appropriate identifier for falling in children diagnosed with CP. This is the first trial to evaluate COPE measurements and reported fall frequencies in children diagnosed with CP. The use of a force plate to determine COPE velocity during a SLST is useful in identifying children with CP who may be at an elevated risk for experiencing a fall. COPE velocity was able to provide intricate quantitative data regarding fall risk that could not be obtained during a normal SLST.

KEYWORDS: Cerebral Palsy, Center of Pressure Excursion, Biomechanics, Fall

Ryan Thomas Callahan

Name

7/7/2016

Date

CENTER OF PRESSURE EXCURSION DURING A SINGLE LEG STANDING TEST

IN AMBULATORY CHILDREN WITH CEREBRAL PALSY

By:

Ryan Thomas Callahan

<u>Michael Pohl, Ph.D.</u>

Director of Thesis

<u>Heather Erwin, Ph.D.</u>

Director of Graduate Studies

<u>7/7/2017</u>

Date

ACKNOWLEDGMENTS

TABLE OF CONTENTS

List of Tables

List of Figures

CHAPTER ONE: INTRODUCTION

The introduction section provides background information about cerebral palsy, gait abnormalities in those living with cerebral palsy, balance related issues in people living with motor disabilities and fall risks in populations with disruptions in normal balance ability. This section also provides information on center of pressure excursion applications and justifies the importance of the trial.

Introduction

Cerebral Palsy (CP) is the most common major disabling motor disorder found during childhood, with a prevalence of 2.1-3.2 cases per 1,000 births (1, 2). CP is considered an umbrella term for permanent disorders of movement and posture, which result in activity limitations. These disorders are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of CP are often accompanied by disturbances in sensation and secondary musculoskeletal disorders (1). When treatments and therapies are provided to individuals who have been diagnosed with CP, the goal normally is not to achieve typical functionality, but rather to sustain mental, motor and social health levels (2).

Consistent with the trend seen in many populations living with disabilities, those with CP are now experiencing a longer life expectancy, which is increasingly closer to that seen in the typically developing (TD) population (3, 4). However, even with this increase in life expectancy, children and young adults with CP still experience a lower quality of life compared to TD individuals (5). In a systematic review exploring the health challenges facing those with CP, it was found that 3 in 4 children were in some form of physical pain, 1 in 2 children had a concurrent intellectual disability, and 1 in 4

had a behavioral disorder. Additionally, it was discovered that children and adults with CP who were unable to walk experienced far greater frequencies of accompanying health impairments (6). This clearly emphasizes the importance of being able to execute planned movement within this population.

Approximately 70% of children with CP are eventually able to ambulate, but most demonstrate gait patterns that differ from the gait of a typical TD child (7). Preserving health and functional mobility in individuals with CP is of great significance in employment, independence, and both health-related and general quality of life. Therefore, it is critical to closely monitor the progression of gait and gross motor ability in a child with CP through adolescence and into adult life (10). Three-dimensional gait analysis testing provides an objective clinical assessment which has proven helpful in producing positive surgical outcomes for children with CP, when done prior to and following a procedure (8). Indeed, significant correlations between gait analysis and gross motor function have been reported in children with CP (9). However, not every clinical setting has the space or equipment to appropriately perform a comprehensive three-dimensional gait analysis. Therefore, many clinicians instead rely on the Gross Motor Function Measure (GMFM) to guide clinical treatment.

The GMFM is an 88-item standardized clinical assessment instrument designed to measure gross motor function over time in children with CP. Within the GMFM test, multiple areas of motor ability are evaluated including; standing, walking, running and jumping. Given the large number of motor tasks that need to be performed during this testing protocol, administration of this scoring system is time consuming. Therefore, it would be of value for clinicians to have a more efficient method of evaluating gross

motor ability in children with CP without sacrificing testing sensitivity. The time saved could be spent performing interventional and therapeutic procedures that would be of greater benefit to pediatric CP patients (11).

Recent research has shown that stability measurements are highly correlated to gross motor function (12). Moreover, the stability testing protocols can be performed in a much shorter time than that seen with a comprehensive three-dimensional gait analysis or GMFM testing. Single leg standing testing (SLST) has already been utilized to evaluate postural stability in multiple clinical populations, including children with CP (13, 14). Although testing is commonly performed by simply measuring the duration a participant is able to successfully stand on one leg, force plates have also been used simultaneously to collect center of pressure excursion (COPE) data during the test. Force plates have the advantage of being more available than a full gait analysis setup and have been shown to be a quantitative and valid predictor for assessing impaired balance in other clinical populations (15). Specifically, studies have demonstrated greater COPE area and COPE velocity for individuals with impaired balance and motor abilities, compared to the TD population (16, 17). However, this testing has not yet been performed with children diagnosed with CP.

Another large concern for any population with impeded balance is the increased risk of falling. This has been widely studied in high-risk fall populations including; stroke, elderly, Parkinson's disease, and Muscular Dystrophy (18-21). Trials have specifically identified balance impairment during clinical testing to be an important risk factor leading to falls (22). SLST has previously been conducted in elderly individuals with one trial reporting that uni-pedal stance testing can be a reliable indicator for risk of

falling in this population (23). It is crucial for clinicians to be able to identify aspects of motor impairment and accurately determine fall factors in order to develop fall prevention programs (24). Measurement of COPE in patients with CP could provide objective and quantitative information pertaining to fluctuations in COM. This information is not currently available from a short timed SLST, as seen during the GMFM testing, and could help clinicians in assessing which children may be at a heightened risk for experiencing a fall.

The primary goals of this study were to examine COPE measurements during a SLST and the following: documented Gross Motor Function Classification Score (GMFCS) level; mean GMFM score; and reported fall frequency in ambulatory children with CP. It was hypothesized that; i) a negative relationship would be seen between COPE measurements and a GMFM scores; ii) significant differences would be seen in COPE measurements between GMFCS levels; iii) significant differences would be seen in balance measurements between high and low frequency fallers. Specifically, this was tested using two different dependent variables, COPE measurements and SLST, and it was postulated that the high fall frequency group would demonstrate smaller COPE values and a shorter SLST time.

If a significant relationship between COPE measurements during a SLST and GMFM score is present, it would allow caregivers the opportunity to evaluate a patient's level of gross motor function without the need to perform a complete GMFM scoring scale. This would provide more time to perform clinical treatment, as opposed to testing and could be more beneficial to the child. Secondly, if a relationship exists between the number of falls and COPE measurements, it would provide caregivers with

supplementary information on children who may be at a heightened risk of falling due to their COPE area or COPE velocity during the SLST.

CHAPTER TWO: METHODOLOGY

The methodology section details the specific steps that were taken to conduct this trial. It contains information regarding the research design, population of interest, instrumentation used, data collection procedures and data analysis procedures.

Experimental Design

This trial was a clinically based, prospective, observational study. The independent variables of the trial were; GMFCS level, GMFM score and self-reported fall frequency. The dependent variables of interest for this trial were COPE area and COPE velocity during a SLST.

Participants

All study screening, recruitment and enrollment was performed in the Motion Analysis Center at Shriners Hospital for Children in Lexington, KY. Children between the ages of 3-21 years of age that presented to the Motion Analysis Center with CP who were ambulatory and scheduled to perform clinical testing were invited to participate. Participants were excluded if they were; unable to self-ambulate, unable to follow simple orders due to intellectual disabilities, had undergone a surgical procedure within the past six months or refused to sign the consent form. Children who used assistive walking devices were included in the trial. All participants between the ages of 12-17 years old signed an assent form, along with their legal guardian signing the informed consent form. Children between 3-11 years old only required inform consent to be signed by their legal guardian. Prior to signing consent, all participants and legal guardians were presented with a detailed description of the study protocol and given the opportunity to ask a study investigator any questions.

Procedures

Participants meeting inclusion criteria visited the Motion Analysis Center at Shriners Hospital for Children (Lexington, KY) for a total of one research visit, which was performed during their clinically scheduled gait evaluation time.

Gross Motor Function Measurement

The Gross Motor Function Measure (GMFM) is a standardized observational clinical test that measures change in gross motor function over a period of time in children with CP (Appendix A). GMFM scoring was completed for all participants during the clinical visit prior to any study specific procedures. This testing comprised of participants performing sections D (standing) and E (walking, running and jumping) that were scored on a 0-3 scale to produce a single uni-dimensional total GMFM score. All GMFM scoring was performed by either a trained Occupational Therapist or Kinesiologist.

Gross Motor Function Classification Score

The Gross Motor Function Classification System (GMFCS) classifies the motor involvement of children diagnosed with CP based on self-initiated movement, specifically sitting and walking. GMFCS levels for each participant were included in the past medical history portion of their clinical visit note. The GMFCS was recorded directly from the clinical note for each participant. For the purposed of this trial, GMFCS levels included were I-III (Appendix B) (27).

Fall Questionnaire

All participants completed a short fall questionnaire administered by study staff. This questionnaire included questions regarding; CP diagnosis, age, gender, dominant leg, fall frequency within the previous 30 days and hospital visits due to recent falls.

Single Leg Standing Test

Participants were asked to stand on an AMTI OR6-5 force plate (AMTI Corporation, Watertown, MA) and perform SLST with both legs. Participants positioned themselves with both feet on one force plate and were then asked to stand on one leg, first with their right foot off the ground for three trials, then their left, for up to ten seconds to familiarize themselves with the testing protocol. If necessary, participants were allowed to use any assisted devices he or she may own to complete the testing, though they were encouraged to use them as little as possible. A study investigator was present during all testing to ensure the participants were not at risk for falling.

Once familiarization was complete, participants completed three ten-second SLST trials with each leg, starting with the right leg off the ground first, then the left as seen in Figure 1. While the participant performed the SLST force plate data was recorded at 960 Hz. Three-dimensional marker kinematic data was collected at 240 Hz using a Motion Analysis System with twelve Eagle digital cameras and Cortex (Version 5.50179) software (Motion Analysis Corporation, Santa Rosa California). Reflective markers were placed on the participants using a modified Cleveland Clinic marker set, totaling 40 reflective markers (Appendix C). Kinematic data was then used in concert with force plate data to define the three phases of the SLST. If the participant was unable to

complete a trial for the full ten seconds each, he or she was informed to stand on one leg for as long as possible.

Data Processing

All marker trajectory data were collected and tracked using Cortex (Version 5.50179) software (Motion Analysis Corporation, Santa Rosa California) and processed using Visual 3-D (Version 5.0123) software (C-Motion Inc., Germantown, MD). Center of pressure data for all SLST trials were exported and divided into three phases using a combination of kinetic COP data and kinematic positional data (Appendix D). These three phases were: stance initiation, single limb support and stance recovery. Only single limb stance phase data was used for subsequent COPE calculations. The longest SLST for each limb was selected and then used to calculate COPE area (m^2) and COPE average velocity (m/s) via the Zumbrunn et al. (2011) method (Appendix D). The values for both limbs were then averaged to create one combined score for COPE area and velocity for each subject.

Statistical Analyses

To test the first hypothesis as to whether a relationship was present between COPE measurements and GMFM level, Pearson correlations were performed for; COPE area vs. mean GMFM score, and COPE velocity vs. mean GMFM score. Interpretation of correlation coefficients (r) was set for very high (r > 0.90), high (r = 0.70 – 0.90), moderate (r = 0.50 – 0.69), low (r = 0.30 – 0.49), and negligible (r = 0.00 – 0.29) (29). To test the second hypothesis and investigate whether differences in COPE measurements existed between the three GMFCS levels, a one-way analysis of variance (ANOVA) was performed in conjunction with Bonferroni post-hoc tests. Lastly, to investigate the third

hypothesis as to whether differences in balance existed between high and low risk fallers, participants were divided into two separate cohorts based on reported fall frequencies. Specifically, the groups were defined as "low frequency" (less than or equal to five reported falls within the last 30 days) or "high frequency" fallers (greater than five reported falls within the last 30 days). Independent sample t-tests were used to test for differences between the high and low frequency fallers for COPE area, COPE velocity, and SLST time. All statistical analyses were performed using SPSS 23 statistical software (SPSS Inc., Chicago, IL) using a significance level of $p < 0.05$.
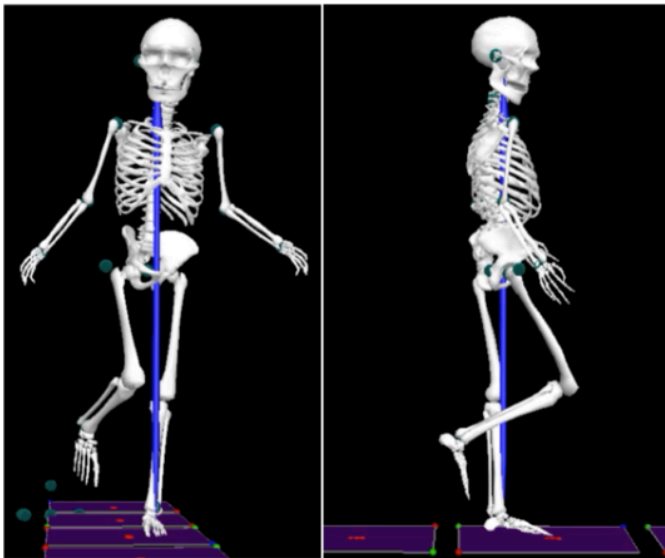
Figure 1 – Medio-lateral and Anterior-posterior Views of SLST via Visual 3-D Software.

CHAPTER THREE: RESULTS

The results section presents the findings of the study, including Pearson correlational analyses, a one-way analysis of variance (ANOVA) with Bonferroni post-hoc test, and an independent sample t-test were conducted on the data collected.

Subject Demographics

A total of 47 children were screened for the trial, with 30 meeting inclusion criteria and enrollment. None of the enrolled subjects were excluded from the trial. Therefore, 30 participants consisting of 16 males and 14 females, of which 23 were independently ambulatory and 7 required assistive ambulatory devices (3 crutch users and 4 walker users) and a total of 27 diplegic CP and 3 hemiplegic CP children, were enrolled. This study enrollment size was similar to multiple other trials that observed COPE measurements in populations with altered postural and gait abilities and characteristics (26). The mean subject age was 14.1 years (+/- 3.8) and mean GMFM score 72.3 (+/- 26.4). Thirteen children were classified as GMFCS level I, 10 were GMFCS level II and 7 GMFCS level III. The division of all participants into groups of +/-5 reported falls created one cohort of 17 individuals (5 falls or less), referred to as the low fall risk group and on of 13 individuals (greater than 5 falls), referred to as the high fall risk group.

COPE Measurements and Gross Motor Function

Pearson correlational testing was performed between mean GMFM score and COPE measurements. No significant correlations where found between mean GMFM score and COPE area (r = 0.33, p = 0.07) or mean GMFM score and COPE velocity (r = 0.19, p = 0.32). The one-way ANOVA analysis demonstrated a significant difference in

COPE velocity values between GMFCS levels ($p = 0.05$). A Bonferroni post hoc test revealed that GMFCS level III participants demonstrated statistically significant lower COPE velocity compared to GMFCS level II participants ($p = 0.05$) (Table 1). No significant differences in COPE velocity were found between GMFCS levels I and II ($p = 0.40$) or levels 1 and 3 ($p = 0.59$). There were no significant differences in COPE area between any of the GMFCS levels.

Table 1. One-way Analysis of Variance for Center of Pressure Excursion (COPE) Measurements and Gross Motor Function Classification Score (GMFCS)

	GMFCS Level	N	Mean	SD
COPE Area (m^2)	1	13	0.0028	0.0016
	2	10	0.0032	0.0029
	3	7	0.0011	0.0019
COPE Velocity (m/s)	1	13	0.2148	0.1388
	2	10	0.2971*	0.1267
	3	7	0.1365*	0.0982

*Denotes significant differences in COPE velocity for GMFCS levels II, III at $p < 0.05$.

COPE Measurements and Reported Fall Frequency

T-tests were performed between COPE measurements and fall risk cohort, demonstrating a significant difference in COPE velocity between the high and low groups ($p = 0.02$) (Figure 2). There were no significant differences ($p = 0.73$) in COPE area between the high and low fall risk cohorts.

Single Limb Support Stance Time and Reported Fall Frequency

Finally, a t-test was performed between fall risk cohort and single-limb support stance time during the SLST. No significant differences ($p = 0.07$) in single limb support stance time was seen between the two fall risk cohorts (Figure 3).
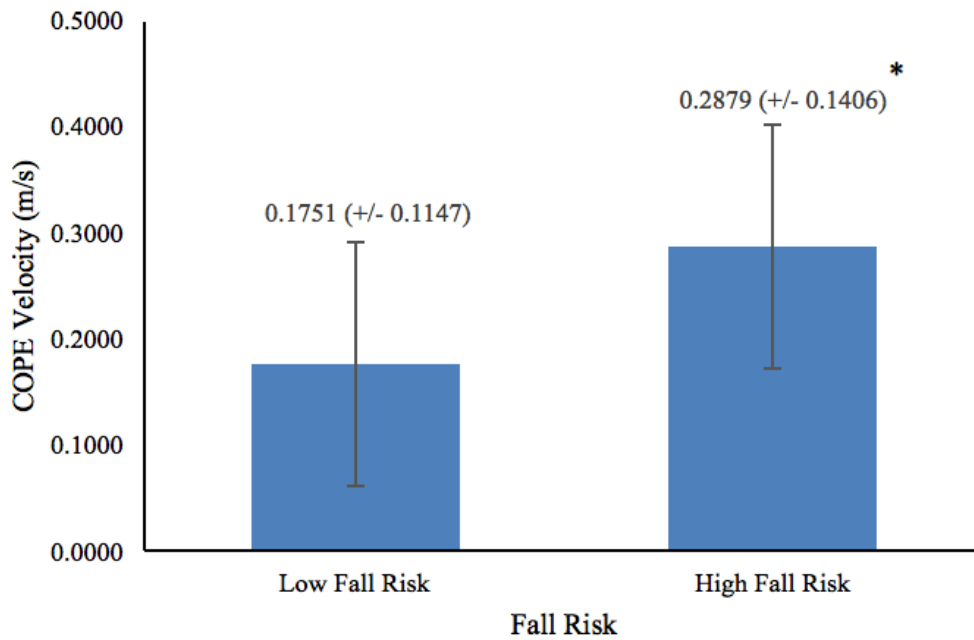
Figure 2 - Mean Center of Pressure Excursion (COPE) Velocities and Standard Deviations for Low and High Fall Risk Groups. *Denotes significance at p < 0.05 level.
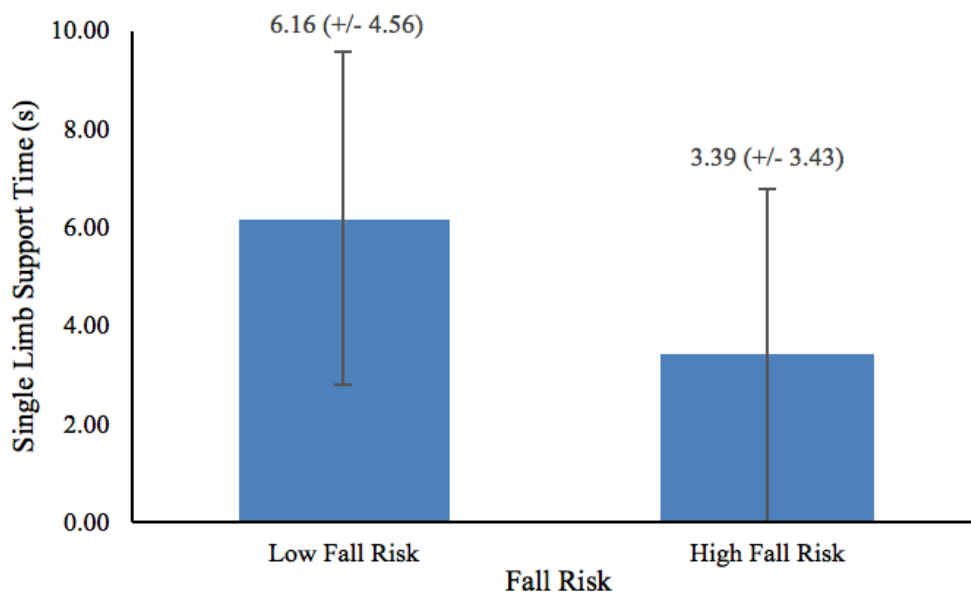
Figure 3 - Mean Single Limb Support Times and Standard Deviations for Low and High Fall Risk Groups. *Denotes significance at p < 0.05 level.

CHAPTER FOUR: DISCUSSION

The discussion section interprets the results that were reported in chapter three. It also includes a discussion of the potential limitations of the study. The discussion aims to contribute new knowledge to the topic in question.

Discussion

The primary aims of this trial were to investigate relationships between COPE measurements during a SLST, GMFM score, GMFCS level and reported fall frequency in ambulatory children with CP. To our knowledge, this is the first trial to evaluate these measurements for children diagnosed with CP who walk independently or with an assistive device.

Consistent with our third hypothesis, significant differences were found in mean COPE velocity between the two fall risk cohorts. Overall, children diagnosed with CP experience greater difficulty maintaining their balance and have been shown to demonstrate greater postural sway than TD children (31). Consistent with the findings of previous research using individuals with ACL injuries, chronic ankle instability and low back pain, the present study indicated that COPE velocity was higher in individuals with impeded balance (32). The use of gross motor function measures such as GMFM and GMFCS were expected to be to be related to COPE measurements in this study, but this was not the case. The heterogeneous nature of CP generates varying physical impairment levels at numerous body structures. The location of spasticity, contracture or weakness can have a significant influence on balance and this may not be reflected by the GMFCS level and/or GMFM score. Given this inability to differentiate impairment location by

uni-dimensional gross motor function score, it is not surprising that COPE measurements were not correlated to GMFCS level and GMFM score in this population.

The poor relationship of the COPE measurements with GMFCS level and GMFM score, suggest that these objective gross function measurement methods are not a valid form of evaluating risk of fall in children with CP. Since previous research has demonstrated that COPE area and COPE velocity are significantly correlated to balance performance in children with altered balance abilities, these measurements may be a more valid method to evaluate the risk for falls in children with CP (17). In this trial, COPE area measures were not different between the high and low frequency fall groups. This may be due to the selected age range of the population used for this trial, which was 3-21 years of age. In a study done examining the variation in postural sway in TD children ages 8-12 years of age, it was discovered that significant differences exist in sway magnitude between children above and below 10 years of age (33). With this information, it is likely that the wide pediatric age range enrollment window may have impacted the COPE measurement results of the SLST. A post hoc analysis displayed a low negative correlation (r = - 0.46, p = 0.01) between age and COPE velocity. No significant correlations were found between age and COPE area. The variation in foot size from the youngest to oldest children enrolled in this trial, likely had an impact on the COPE area calculations. In this study, foot size was not accounted for or normalized during data analysis and it is possible that larger subjects have the potential to produce greater COPE areas, regardless of gross motor ability. Previous research has also failed to account for this variation, however most studies work to avoid this issue by defining smaller enrollment age groups during testing and analysis (17, 31). A smaller enrollment

age window would reduce the large variation in foot size within the subject population. Future studies should consider this extraneous variable during study design.

Additionally, a significant difference in COPE velocity between GMFCS level II and GMFCS level III participants was demonstrated during the SLST. The mean COPE velocity values in the GMFCS level III group were significantly lower than those in GMFCS II, which was opposite to the initial hypothesis. This finding is likely due to the inclusion of ambulatory children who used assistive walking devices into the trial and during testing. The findings in this study suggest that further research done evaluating COPE measurements should aim to cohort individuals based on their use of assistive walking technologies.

A 60% increase in mean COPE velocity was seen in the high fall risk group, compared to the low risk group. This increase in COPE velocity was similar to the difference in COPE velocity reported between congenital talipes equinovarus and TD children by Zumbrunn et al. (2011). Additionally, similar increases in magnitude of COPE velocity during a SLST were found in a study comparing postural control in individuals with and without chronic ankle instability (30). Although differences in COPE velocity were reported between the high and low frequency fallers in the present study, SLST times were not significantly different between the two groups. The greater ability of the COPE velocity to discriminate between high and low frequency fallers highlights the importance and clinical significance these measurements.

It is worth noting that many clinical settings may not have the ability to perform strain gage force plate based COPE measurements at their respective facilities, due to the high cost of these instruments. Recent research has identified the Nintendo Wii Balance

16

Board as an affordable and accurate substitute for determining COPE measurements during a SLST (34). This may present a greater number of clinicians with the ability to accurately evaluate COPE area and COPE velocity, in order to identify individuals at an elevated risk for experiencing a fall.

Limitations and Recommendations for Future Research

Several limitations should be noted in this trial. Firstly, this trial included all children with CP who were ambulatory with or without a walking device, and included the walking device during data collection, if necessary. This was done in an effort to determine if COPE testing would prove valid for all ambulatory children with CP, regardless of ambulatory method. The stability provided by the walking devices during testing would likely have influenced the COPE measurements and future studies should design recruitment procedures to compensate for this variable.

Secondly, children with both hemiplegic and diplegic CP diagnoses were enrolled into this trial. This was done in an effort to evaluate the validity of COPE measurements in all ambulatory children with CP. No statistically significant differences in COPE area or COPE velocity were present between the subjects diagnosed with hemiplegia or diplegia (data not presented). However, it is possible that large intra-participant differences did exist between dominant and non-dominant legs in individuals with hemiplegic CP. Future research may benefit from only including one of these populations and not a combination of both.

Additionally, the calculation of COPE area relied on the four most extreme X, Y coordinates in each direction. Thus, there is a risk of an outlier data point substantially influencing the final COPE area. Finally, differences in SLST balance abilities within the

pediatric population for children aged 3-21 years may differ based on sensorimotor development. Future research my benefit from the design of a smaller inclusive age range.

Conclusion

The results of the study demonstrate that using a force plate to measure COPE velocity during a SLST in ambulatory children diagnosed with CP, can assist in identifying individuals who fall more frequently. These findings were compared to a simple timed SLST, which was unable to separate children who were at a low and high risk for fall. Additionally, the absence of significant relationships between COPE measurements and gross motor function measures (GMFM score and GMFCS level) within this population suggest that these measures may not be appropriate indicators for identifying children with CP who may be at risk for experiencing a fall.

The diversity in clinical appearance of CP presents clinicians with the ongoing challenge of how to best prescribe therapies to combat the risk for decline in gross motor ability. With balance and fall frequency being significant determinants of quality of life and activity inclusion in those diagnosed with CP, it is crucial that clinicians have access to the tools necessary to accurately evaluate these quantitative variables. The use of force plates to calculate COPE velocity has demonstrated its value in being one of these tools.

# Appendix A: Gross Motor Function Measure Sections D & E

Item	D: STANDING	SCORE				NT
* 52.	ON THE FLOOR: PULLS TO STD AT LARGE BENCH	0	1	2	3	52.
* 53.	STD: MAINTAINS, ARMS FREE, 3 SECONDS..	0	1	2	3	53.
* 54.	STD: HOLDING ON TO LARGE BENCH WITH ONE HAND, LIFTS R FOOT, 3 SECONDS	0	1	2	3	54.
* 55.	STD: HOLDING ON TO LARGE BENCH WITH ONE HAND, LIFTS L FOOT, 3 SECONDS	0	1	2	3	55.
* 56.	STD: MAINTAINS, ARMS FREE, 20 SECONDS..	0	1	2	3	56.
* 57.	STD: LIFTS L FOOT, ARMS FREE, 10 SECONDS...	0	1	2	3	57.
* 58.	STD: LIFTS R FOOT, ARMS FREE, 10 SECONDS...	0	1	2	3	58.
* 59.	SIT ON SMALL BENCH: ATTAINS STD WITHOUT USING ARMS	0	1	2	3	59.
* 60.	HIGH KN: ATTAINS STD THROUGH HALF KN ON R KNEE, WITHOUT USING ARMS	0	1	2	3	60.
* 61.	HIGH KN: ATTAINS STD THROUGH HALF KN ON L KNEE, WITHOUT USING ARMS	0	1	2	3	61.
* 62.	STD: LOWERS TO SIT ON FLOOR WITH CONTROL, ARMS FREE	0	1	2	3	62.
* 63.	STD: ATTAINS SQUAT, ARMS FREE	0	1	2	3	63.
* 64.	STD: PICKS UP OBJECT FROM FLOOR, ARMS FREE, RETURNS TO STAND	0	1	2	3	64.

TOTAL DIMENSION D [   ]

| Item	E: WALKING, RUNNING & JUMPING	SCORE				NT
* 65.	STD, 2 HANDS ON LARGE BENCH: CRUISES 5 STEPS TO R...............................	0	1	2	3	65.
* 66.	STD, 2 HANDS ON LARGE BENCH: CRUISES 5 STEPS TO L	0	1	2	3	66.
* 67.	STD, 2 HANDS HELD: WALKS FORWARD 10 STEPS...................................	0	1	2	3	67.
* 68.	STD, 1 HAND HELD: WALKS FORWARD 10 STEPS	0	1	2	3	68.
* 69.	STD: WALKS FORWARD 10 STEPS..	0	1	2	3	69.
* 70.	STD: WALKS FORWARD 10 STEPS, STOPS, TURNS 180°, RETURNS	0	1	2	3	70.
* 71.	STD: WALKS BACKWARD 10 STEPS	0	1	2	3	71.
* 72.	STD: WALKS FORWARD 10 STEPS, CARRYING A LARGE OBJECT WITH 2 HANDS	0	1	2	3	72.
* 73.	STD: WALKS FORWARD 10 CONSECUTIVE STEPS BETWEEN PARALLEL LINES 20cm (8") APART	0	1	2	3	73.
* 74.	STD: WALKS FORWARD 10 CONSECUTIVE STEPS ON A STRAIGHT LINE 2cm (3/4") WIDE........	0	1	2	3	74.
* 75.	STD: STEPS OVER STICK AT KNEE LEVEL, R FOOT LEADING............................	0	1	2	3	75.
* 76.	STD: STEPS OVER STICK AT KNEE LEVEL, L FOOT LEADING	0	1	2	3	76.
* 77.	STD: RUNS 4.5m (15'), STOPS & RETURNS	0	1	2	3	77.
* 78.	STD: KICKS BALL WITH R FOOT	0	1	2	3	78.
* 79.	STD: KICKS BALL WITH L FOOT	0	1	2	3	79.
* 80.	STD: JUMPS 30cm (12") HIGH, BOTH FEET SIMULTANEOUSLY............................	0	1	2	3	80.
* 81.	STD: JUMPS FORWARD 30 cm (12"), BOTH FEET SIMULTANEOUSLY	0	1	2	3	81.
* 82.	STD ON R FOOT: HOPS ON R FOOT 10 TIMES WITHIN A 60cm (24") CIRCLE	0	1	2	3	82.
* 83.	STD ON L FOOT: HOPS ON L FOOT 10 TIMES WITHIN A 60cm (24") CIRCLE	0	1	2	3	83.
* 84.	STD, HOLDING 1 RAIL: WALKS UP 4 STEPS, HOLDING 1 RAIL, ALTERNATING FEET.........	0	1	2	3	84.
* 85.	STD, HOLDING 1 RAIL: WALKS DOWN 4 STEPS, HOLDING 1 RAIL, ALTERNATING FEET	0	1	2	3	85.
* 86.	STD: WALKS UP 4 STEPS, ALTERNATING FEET	0	1	2	3	86.
* 87.	STD: WALKS DOWN 4 STEPS, ALTERNATING FEET..................................	0	1	2	3	87.
* 88.	STD ON 15cm (6") STEP: JUMPS OFF, BOTH FEET SIMULTANEOUSLY	0	1	2	3	88.

TOTAL DIMENSION E [   ]

(35)

19

**Appendix B: Gross Motor Function Classification Score**
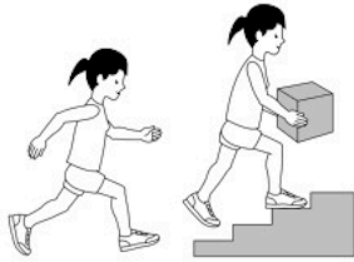
GMFCS Level I

Youth walk at home, school, outdoors and in the community. Youth are able to climb curbs and stairs without physical assistance or a railing. They perform gross motor skills such as running and jumping but speed, balance and coordination are limited.
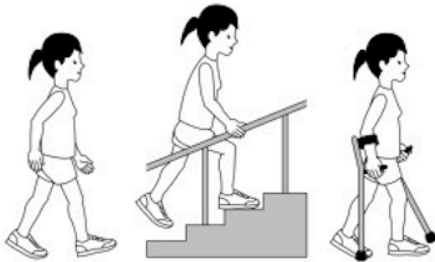
GMFCS Level II

Youth walk in most settings but environmental factors and personal choice influence mobility choices. At school or work they may require a hand held mobility device for safety and climb stairs holding onto a railing. Outdoors and in the community youth may use wheeled mobility when traveling long distances.
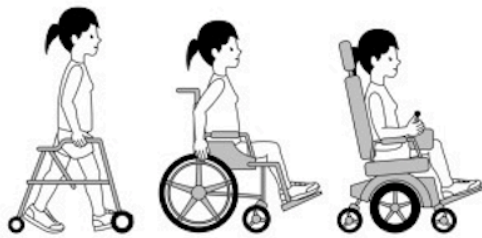
GMFCS Level III

Youth are capable of walking using a hand-held mobility device. Youth may climb stairs holding onto a railing with supervision or assistance. At school they may self-propel a manual wheelchair or use powered mobility. Outdoors and in the community youth are transported in a wheelchair or use powered mobility.
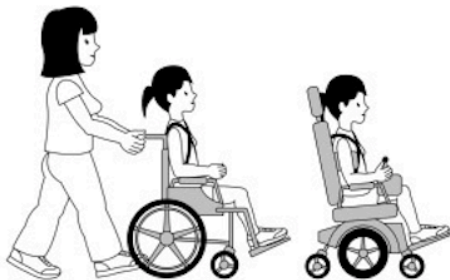
GMFCS Level IV

Youth use wheeled mobility in most settings. Physical assistance of 1-2 people is required for transfers. Indoors, youth may walk short distances with physical assistance, use wheeled mobility or a body support walker when positioned. They may operate a powered chair, otherwise are transported in a manual wheelchair.

GMFCS Level V

Youth are transported in a manual wheelchair in all settings. Youth are limited in their ability to maintain antigravity head and trunk postures and control leg and arm movements. Self-mobility is severely limited, even with the use of assistive technology.

(27)

Appendix C: Marker Set
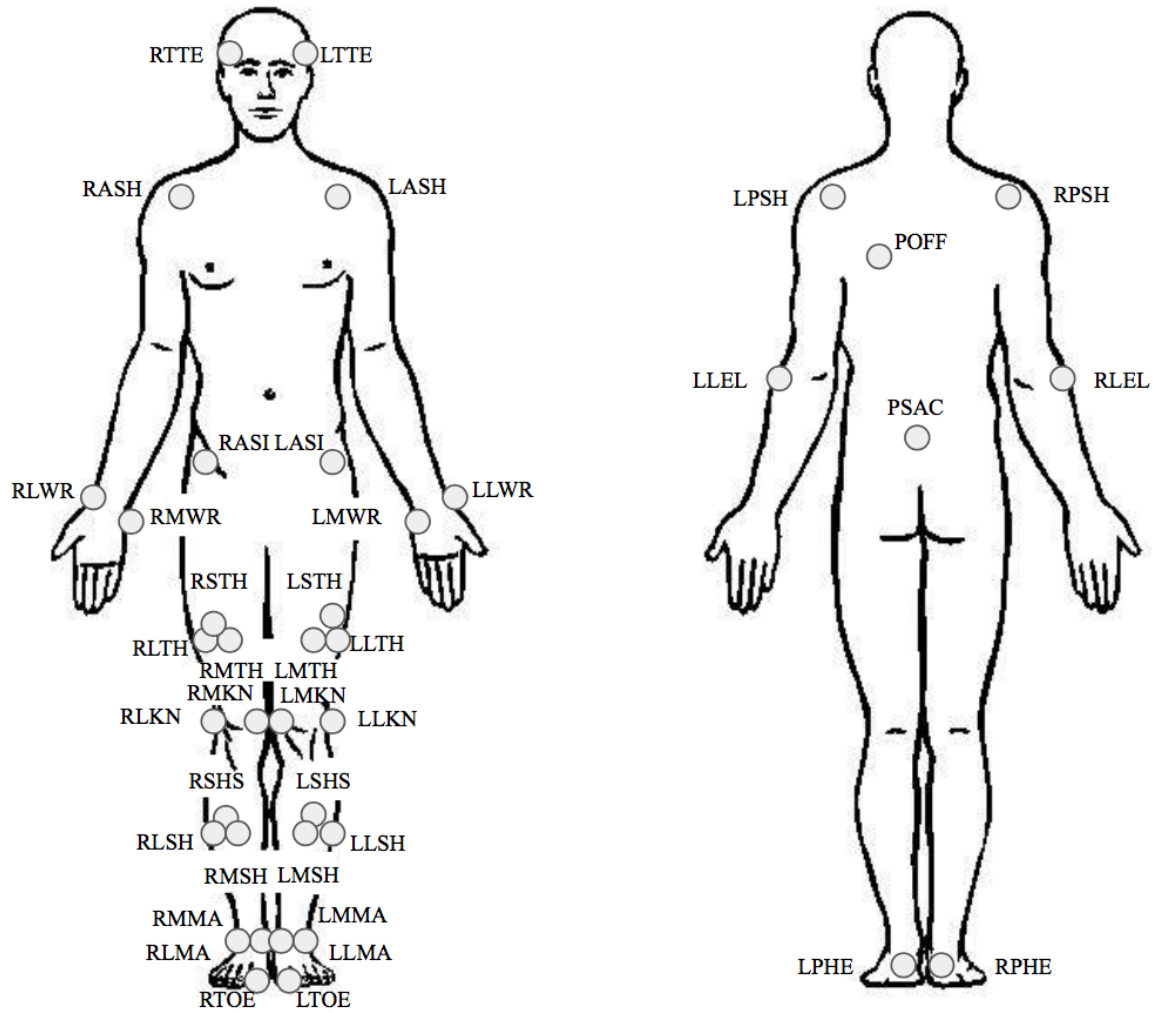
Modified Cleveland Clinic Marker Set

Marker Acronym	Marker Anatomical Description
RTTE	RIGHT TEMPLE
LTTE	LEFT TEMPLE
RASH	RIGHT ANTERIOR SHOULDER
LASH	LEFT ANTERIOR SHOULDER
RASI	RIGHT ANTERIOR SUPERIOR ILIAC SPINE
LASI	LEFT ANTERIOR SUPERIOR ILIAC SPINE
RLWR	RIGHT LATERAL WRIST
RMWR	RIGHT MEDIAL WRIST
LLWR	LEFT LATERAL WRIST
LMWR	LEFT MEDIAL WRIST
RSTH	RIGHT SUPERIOR THIGH
RLTH	RIGHT LATERAL THIGH
RMTH	RIGHT MEDIAL THIGH
LSTH	LEFT SUPERIOR THIGH
LLTH	LEFT LATERAL THIGH
LMTH	LEFT MEDIAL THIGH
RLKN	RIGHT LATERAL KNEE
RMKN	RIGHT MEDIAL KNEE
LLKN	LEFT LATERAL KNEE
LMKN	LEFT MEDIAL KNEE
RSHS	RIGHT SHANK SUPERIOR
RLSH	RIGHT LATERAL SHANK
RMSH	RIGHT MEDIAL SHANK
LSHS	LEFT SHANK SUPERIOR
LLSH	LEFT LATERAL SHANK
LMSH	LEFT MEDIAL SHANK
RLMA	RIGHT LATERAL MALLEOLUS
RMMA	RIGHT MEDIAL MALLEOLUS
LLMA	LEFT LATERAL MALLEOLUS
LMMA	LEFT MEDIAL MALLEOLUS
RTOE	RIGHT TOE
LTOE	LEFT TOE
RPSH	RIGHT POSTERIOR SHOULDER
LPSH	LEFT POSTERIOR SHOULDER
POFF	POSTERIOR OFFSET
RLEL	RIGHT LATERAL ELBOW
LLEL	LEFT LATERAL ELBOW
PSAC	POSTERIOR SACRUM
RPHE	RIGHT POSTERIOR HEEL
LPHE	LEFT POSTERIOR HEEL

Table 2 - Modified Clevelend Clinic Marker Set

Appendix D: Center of Pressure Excursion Calculations

Each participant completed SLST three times on a strain gage force plate with each leg, totaling six trials collected. Tracked kinematic marker data and kinetic data in Cortex (Version 5.50179) software (Motion Analysis Corporation, Santa Rosa California) was exported to Visual 3-D (Version 5.0123) software (C-Motion Inc., Germantown, MD) and divided into three phases; stance initiation, single-limb stance and stance recovery. Phases were determined using a combination of kinetic COP and kinematic data in Visual 3-D. The events used to determine these phases were; foot off, contralateral foot down and termination of COP motion. The beginning of stance initiation was defined by the first mediolateral shift of motion of the COP from a static position paired with the kinematic demonstration of contralateral movement in the direction opposite to the side of the of the body that would be performing the stance position for the SLST. The stance initiation phase terminated, and single-limb stance began, when both kinetic COP data and kinematic activity demonstrated the the transition from a double to single-limb support stance via foot off. The single-limb stance phase continued until both kinetic COP data and kinematic activity confirmed the presence of a double-limb support stance at foot down. Lastly, stance recovery began at the initiation of a double-limb support and ended when kinetic COP data and kinematic activity terminated, at stance termination. Two-dimensional X, Y coordinate COPE data were exported from the AMTI force plate (AMTI Corporation, Watertown, MA) and only single limb stance phase data was used for COPE measurement calculations.

One SLST for each limb was selected to be analyzed for all individuals enrolled, which was chosen based on duration, with the longest trial achieved being used. All 2-D

X, Y coordinate COPE data were exported to Microsoft Excel where COPE area and velocity were calculated via the method used by Zumbrunn et al. (2011):

i. COPE area was determined by creating a rectangular area defined by the absolute maximum and minimum X, Y coordinate data exported from Visual 3-D, as seen in Figure 5. The equation for this calculation is: Area = $(X_{max} - X_{min}) \times (Y_{max} - Y_{min})$ expressed in m². The COPE areas for each selected limb trial were then averaged together and analyzed.

ii. COPE velocity was determined by using the first central difference method. Calculation of the resultant displacement (RD) path of the participant's COPE, using X, Y coordinate data and the quadratic equation: RD = $\sqrt{(X_{i+1} - X_{i-1})^2 + (Y_{i+1} - Y_{i-1})^2}$. This RD was then divided by the change in time to determine the resultant velocity. The mean of all velocity measurements during the SLST was found for each selected limb trial, then averaged together to determine mean COPE velocity expressed in m/s.
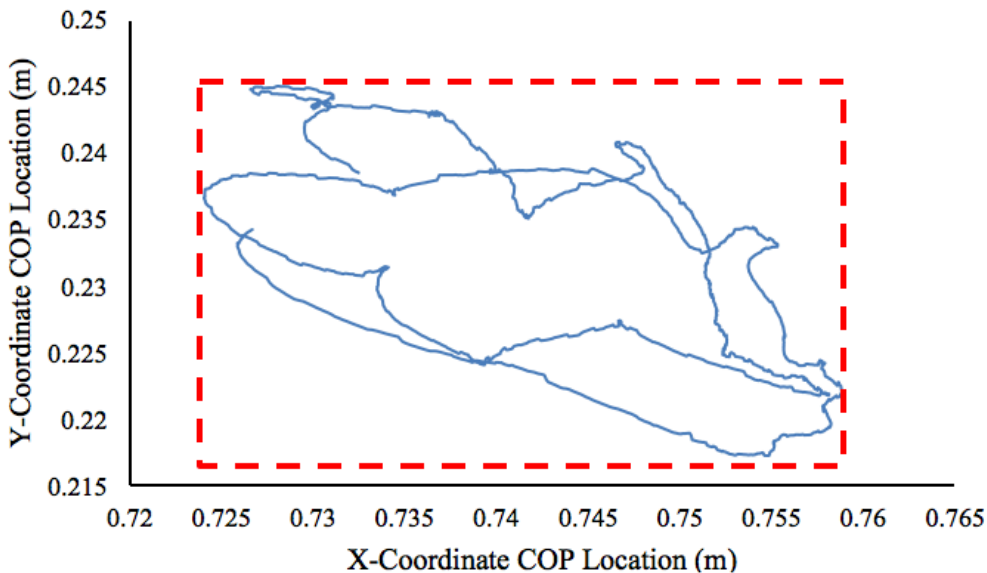

Figure 5 - Center of Pressure Excursion Area Graphed X, Y Coordinate Data Rectangular Formation.

Appendix E: Expanded Literature Review

Cerebral Palsy

Cerebral Palsy is the most common major disabling motor disorder of childhood, as reported by the Centers for Disease Control and Prevention. The prevalence of CP has remained somewhat constant over the last seventy years and continues to be between 1.5-3 cases per 1,000 births. This data is consistent throughout nearly all parts of the world and is not directly affected by race or ethnicity (10). CP is considered an umbrella term for permanent disorders of movement and posture causing activity limitations, which are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of CP are often accompanied by disturbances in sensation, perception, cognition, communication and behavior, by epilepsy, and by secondary musculoskeletal disorders (1). CP is a heterogeneous condition with multiple causes; multiple clinical types; multiple patterns of neuropathology on brain imaging; multiple associated developmental pathologies, such as intellectual disability, autism, epilepsy, and visual impairment; and more recently multiple rare pathogenic genetic variations (36). In most epidemiological studies, males are more at risk of CP than females: 1.3:1 (37).

Preserving health and mobility in adults with CP is of great significance in employment, independence, and both health-related and general quality of life (10). In previous decades, orthopedic surgery was the most popular treatment methodology of all interventions directed toward movement normalization. However, today localized anti-spasticity medications such as botulinum toxin (Botox) and clinical motor learning interventions have become more popular (38). Physical therapy techniques are highly

25

utilized in the pediatric CP population with the goal being motor control maintenance and a heightened functionality into early adulthood. Evidence suggests that physical therapy methods, such as massage, stretching, treadmill exercise and balance training, have significant correlations to positive functional outcomes for children with CP (11). As the mean lifespan of individuals with CP approaches that of the typically developing population, it is critical to provide non-invasive clinical interventions that increase quality of life and lower the risk for future impairment (3). When children with CP have been identified as having poor balance and postural control, therapy based training protocols have demonstrated improvements in these areas (39).

High Risk Fall Populations

Research performed evaluating reported fall frequency in individuals with decreased motor function, and its relation to quality of life, has been done in numerous populations. These populations include and are not limited to; elderly, traumatic brain injury, stroke, multiple sclerosis and Parkinson's Disease populations. The data shows overwhelming evidence that an increased fall frequency, or fear of falling, is correlated to a lower quality of life (40-43). In a trial done with individuals diagnosed with Parkinson's Disease, the fear of falling had a greater detrimental effect on quality of life than the actual act of falling itself (44).

Little research has been performed observing fall frequencies within the CP population, and even less when it comes to the pediatric cohort. In a study done with community dwelling adults living with CP, poor balance was discovered during clinical balance testing, which increased from early adulthood onto later life (45). However, the balance obstacles facing individuals with CP start before early adulthood and can

26

manifest as barriers in a child's life. Research has shown that children with physical disabilities benefit from physical activity, which has been correlated to improved functional independence, social integration and emotional and social well being (46). For children who reported experiencing significant limitations in balance ability, or fear of falling, it was shown to not be directly explained by their self-reported walking deterioration. This raises the question whether gait analyses or questionnaires are an appropriate test for predicting balance ability and risk of fall in children with CP.

Center of Pressure Excursion

Center of pressure is defined as the point at which the pressure of the body under the foot, or feet, centralizes as one single coordinate. Sway of the body, or static posturography, can be measured by calculating the deviations in this single pressure point to generating a total area, referred to as COPE area or a velocity, referred to as COPE velocity, on a force plate (26, 47). These measures have been used in numerous populations to quantitatively evaluate postural stability and balance during single and double limb support testing protocols. Data obtained from these calculations have shown correlations to variables such as; pain experienced during testing, chronic lower extremity instability and ability to maintain posture (30, 48, 49).

COPE testing has been performed in the pediatric CP population, using a double limb stance protocol to test differences in eye open and eye closed excursion values compared to TD children (50). Postural sway, as determined by COPE area, was found to be greater in children with CP, compared to TD. Single leg stance based protocols have also been used in trials to determine COPE. In a study evaluating children with congenital equinovarus, it was found that COPE measurements, specifically COPE

velocity, were correlated to balance (17). These results suggest that the use of a single leg stance test to determine COPE measurements in children with orthopedic impairments may be useful in determining balance ability. The single leg stance testing protocol to determine COPE measurements has not yet been performed in the pediatric CP population.

Gross Motor Function Measure

For approximately three decades the Gross Motor Function Measure (GMFM) has been administered to children with neurologically based disabilities, such as CP, and used as an outcome measure to track rehabilitation techniques (51). There are two versions of the GMFM test, the GMFM-88 and more recent GMFM-66, which are both standardized clinical tools designed to measure gross motor function over time in children with CP (52). Both tests are approved for use in children ages 5 months to 16 years of age. Within the GMFM test, multiple areas of motor ability are evaluated, including; standing, walking running and jumping. Standing function testing is included in the GMFM-D section and walking, running and jumping within the GMFM-E section.

The GMFM-88 includes 88 items of measure to calculate a uni-dimensional determination of gross motor ability. Each item is measured on a scale of 0-3, with three being the highest functional score attainable and zero representing an inability to initiate the measure of the specified test. This test has shown to be reliable and valid in testing the level of gross motor ability in children with CP (53). Interestingly, GMFM scoring systems have shown to be less sensitive in children who are either highly impaired (GMFCS levels IV-V) or only slightly impaired (GMFCS level I). It is recommended that

clinicians use the GMFM, in conjunction with other outcome measures, to determine the comprehensive ability of a child with CP (54).

Summary

In conclusion, children with CP face tremendous obstacles in a plethora of daily functional motor activities, including the ability to maintain balance. These challenges are not unlike those encountered by other populations who live with neuromuscular disabilities, which present a heightened risk for falls. Falling, or the fear of falling, has shown to have a significantly negative impact on quality of life and steps should be taken to diminish this risk whenever possible. COPE measurements have been used in many populations living with decreased balance abilities and could be a viable option for clinicians to use in the pediatric CP population, as well. If validated, COPE measurements could be used to identify those children at an elevated risk for experiencing a fall. This data could provide clinicians with the information necessary to incorporate supplemental balance improvement therapies, which have proven to increase balance abilities and lower fall frequency. This decrease in falls could lead to a higher quality of life, greater functional independence and social involvement.

REFERENCES:

1. Rosenbaum P, Paneth, N., Leviton, A., Goldstein, M., Bax, M., Damiano, D. & Jacobsson, B. A report: the definition and classification of cerebral palsy April 2006. Dev Med Child Neurol Suppl. 2007;109(Suppl 109):8-14.

2. Krigger K, MD. Cerebral Palsy: An Overview. American Family Physician. 2006;71(1).

3. Aisen ML, Kerkovich, D., Mast, J., Mulroy, S., Wren, T. A., Kay, R. M., & Rethlefsen, S. A. Cerebral palsy: clinical care and neurological rehabilitation. The Lancet Neurology. 2011;10(9):844-52.

4. Thomas R, & Barnes, M. Life expectancy for people with disabilities. NeuroRehabilitation. 2010;27(2):201-9.

5. Young NL, Rochon TG, McCormick A, Law M, Wedge JH, Fehlings D. The health and quality of life outcomes among youth and young adults with cerebral palsy. Archives of physical medicine and rehabilitation. 2010;91(1):143-8.

6. Novak I, Hines, M., Goldsmith, S., & Barclay, R. Clinical prognostic messages from a systematic review on cerebral palsy. Pediatrics. 2012;peds-2012.

7. Rosenbaum PL, Russell DJ, Cadman DT, Gowland C, Jarvis S, Hardy S. Issues in measuring change in motor function in children with cerebral palsy: a special communication. Physical Therapy. 1990;70(2):125-31.

8. Lee EH, Goh J, Bose K. Value of gait analysis in the assessment of surgery in cerebral palsy. Archives of physical medicine and rehabilitation. 1992;73(7):642-6.

9. Massaad A, Assi A, Skalli W, Ghanem I. Repeatability and validation of gait deviation index in children: typically developing and cerebral palsy. Gait & posture. 2014;39(1):354-8.

10. Haak P, Lenski M, Hidecker MJC, Li M, Paneth N. Cerebral Palsy and aging. Developmental Medicine & Child Neurology. 2009;51(S4):16-23.

11. Franki I, Desloovere K, De Cat J, Feys H, Molenaers G, Calders P, et al. The evidence-base for basic physical therapy techniques targeting lower limb function in children with cerebral palsy: a systematic review using the International Classification of Functioning, Disability and Health as a conceptual framework. Journal of Rehabilitation Medicine. 2012;44(5):385-95.

12. Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. Developmental Medicine & Child Neurology. 1997;39(4):214-23.

13. Liao H-F, Hwang A-W. Relations of balance function and gross motor ability for children with cerebral palsy. Perceptual and motor skills. 2003;96(3C):1173-84.

14. Liao HF, Mao PJ, Hwang AW. Test-retest reliability of balance tests in children with cerebral palsy. Developmental Medicine & Child Neurology. 2001;43(3):180-6.

15. Ross SE, Linens SW, Wright CJ, Arnold BL. Balance assessments for predicting functional ankle instability and stable ankles. Gait & posture. 2011;34(4):539-42.

16. Nadollek H, Brauer S, Isles R. Outcomes after trans-tibial amputation: the relationship between quiet stance ability, strength of hip abductor muscles and gait. Physiotherapy Research International. 2002;7(4):203-14.

17. Zumbrunn T, MacWilliams BA, Johnson BA. Evaluation of a single leg stance balance test in children. Gait & posture. 2011;34(2):174-7.

18. Cattaneo D, De Nuzzo C, Fascia T, Macalli M, Pisoni I, Cardini R. Risks of falls in subjects with multiple sclerosis. Archives of physical medicine and rehabilitation. 2002;83(6):864-7.

19. Gray P, Hildebrand K. Fall risk factors in Parkinson's disease. Journal of Neuroscience Nursing. 2000;32(4):222-8.

20. Hyndman D, Ashburn A, Stack E. Fall events among people with stroke living in the community: circumstances of falls and characteristics of fallers. Archives of physical medicine and rehabilitation. 2002;83(2):165-70.

21. Woo J, Ho S, Lau J, Chan S, Yuen Y. Age-associated gait changes in the elderly: pathological or physiological? Neuroepidemiology. 1995;14(2):65-71.

22. Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. Physical therapy. 2000;80(9):896-903.

23. Hurvitz EA, Richardson JK, Werner RA, Ruhl AM, Dixon MR. Unipedal stance testing as an indicator of fall risk among older outpatients. Archives of physical medicine and rehabilitation. 2000;81(5):587-91.

24. Vlahov D, Myers A, Al-Ibrahim M. Epidemiology of falls among patients in a rehabilitation hospital. Archives of physical medicine and rehabilitation. 1990;71(1):8-12.

25. Portney LG, Watkins MP. Foundations of clinical research: applications to practice: Prentice Hall Upper Saddle River, NJ; 2000.

26. Ruhe A, Fejer R, Walker B. Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: a systematic review of the literature. European Spine Journal. 2011;20(3):358-68.

27. Rosenbaum P, Palisano R, Walter S, Russell D, Wood E, Galuppi B. Gross Motor Function Classification System (GMFCS). Dev Med Child Neurol. 1997;39:214-23.

28. Schneiders AG, Sullivan SJ, O'Malley KJ, Clarke SV, Knappstein SA, Taylor LJ. A valid and reliable clinical determination of footedness. PM&R. 2010;2(9):835-41.

29. Hinkle DE, Wiersma W, Jurs SG. Applied statistics for the behavioral sciences. 2003.

30. Wikstrom EA, Fournier KA, McKeon PO. Postural control differs between those with and without chronic ankle instability. Gait & posture. 2010;32(1):82-6.

31. Rose J, Wolff DR, Jones VK, Bloch DA, Oehlert JW, Gamble JG. Postural balance in children with cerebral palsy. Developmental Medicine & Child Neurology. 2002;44(01):58-63.

32. Salavati M, Hadian MR, Mazaheri M, Negahban H, Ebrahimi I, Talebian S, et al. Test–retest reliabty of center of pressure measures of postural stability during quiet standing in a group with musculoskeletal disorders consisting of low back

pain, anterior cruciate ligament injury and functional ankle instability. Gait & posture. 2009;29(3):460-4.

33. Mickle KJ, Munro BJ, Steele JR. Gender and age affect balance performance in primary school-aged children. Journal of science and medicine in sport. 2011;14(3):243-8.

34. Huurnink A, Fransz DP, Kingma I, van Dieën JH. Comparison of a laboratory grade force platform with a Nintendo Wii Balance Board on measurement of postural control in single-leg stance balance tasks. Journal of biomechanics. 2013;46(7):1392-5.

35. CanChild Centre for Childhood Disability Research IfAHS, McMaster University. GROSS MOTOR FUNCTION MEASURE (GMFM) SCORE SHEET (GMFM-88 and GMFM-66 scoring) 2013 [Available from: https://canchild.ca/system/tenon/assets/attachments/000/000/218/original/gmfm-88_and_66_scoresheet.pdf.

36. MacLennan AH, Thompson SC, Gecz J. Cerebral palsy: causes, pathways, and the role of genetic variants. American journal of obstetrics and gynecology. 2015;213(6):779-88.

37. Nelson KB, Ellenberg JH. Antecedents of cerebral palsy: I. Univariate analysis of risks. American journal of diseases of children. 1985;139(10):1031-8.

38. Sakzewski L, Ziviani J, Boyd R. Systematic review and meta-analysis of therapeutic management of upper-limb dysfunction in children with congenital hemiplegia. Pediatrics. 2009;123(6):e1111-e22.

39. El-Shamy SM, Abd El Kafy EM. Effect of balance training on postural balance control and risk of fall in children with diplegic cerebral palsy. Disability and rehabilitation. 2014;36(14):1176-83.

40. Anderson V, Brown S, Newitt H, Hoile H. Long-term outcome from childhood traumatic brain injury: intellectual ability, personality, and quality of life. Neuropsychology. 2011;25(2):176.

41. Combs SA, Dugan EL, Passmore M, Riesner C, Whipker D, Yingling E, et al. Balance, balance confidence, and health-related quality of life in persons with chronic stroke after body weight–supported treadmill training. Archives of physical medicine and rehabilitation. 2010;91(12):1914-9.

42. Hartholt KA, van Beeck EF, Polinder S, van der Velde N, van Lieshout EM, Panneman MJ, et al. Societal consequences of falls in the older population: injuries, healthcare costs, and long-term reduced quality of life. Journal of Trauma and Acute Care Surgery. 2011;71(3):748-53.

43. Sosnoff JJ, Socie MJ, Boes MK, Sandroff BM, Pula JH, Suh Y, et al. Mobility, balance and falls in persons with multiple sclerosis. PLoS One. 2011;6(11):e28021.

44. Grimbergen YA, Schrag A, Mazibrada G, Borm GF, Bloem BR. Impact of falls and fear of falling on health-related quality of life in patients with Parkinson's disease. Journal of Parkinson's disease. 2013;3(3):409-13.

45. Morgan P, McGinley J. Performance of adults with cerebral palsy related to falls, balance and function: A preliminary report. Developmental neurorehabilitation. 2013;16(2):113-20.

46. Shields N, Synnot AJ, Barr M. Perceived barriers and facilitators to physical activity for children with disability: a systematic review. Br J Sports Med. 2011:bjsports-2011-090236.

47. Masani K, Vette AH, Abe MO, Nakazawa K. Center of pressure velocity reflects body acceleration rather than body velocity during quiet standing. Gait & posture. 2014;39(3):946-52.

48. Corbeil P, Blouin J-S, Teasdale N. Effects of intensity and locus of painful stimulation on postural stability. Pain. 2004;108(1):43-50.

49. Ogaya S, Ikezoe T, Soda N, Ichihashi N. Effects of balance training using wobble boards in the elderly. The Journal of Strength & Conditioning Research. 2011;25(9):2616-22.

50. Donker SF, Ledebt A, Roerdink M, Savelsbergh GJ, Beek PJ. Children with cerebral palsy exhibit greater and more regular postural sway than typically developing children. Experimental brain research. 2008;184(3):363-70.

51. Boyd R, Dobson F, Parrott J, Love S, Oates J, Larson A, et al. The effect of botulinum toxin type A and a variable hip abduction orthosis on gross motor function: a randomized controlled trial. European Journal of Neurology. 2001;8(s5):109-19.

52. Russell DJ, Rosenbaum PL, Avery LM, Lane M. Gross motor function measure (GMFM-66 and GMFM-88) user's manual: Cambridge University Press; 2002.

53. Ketelaar M, Vermeer A, Helders PJ. Functional motor abilities of children with cerebral palsy: a systematic literature review of assessment measures. Clinical rehabilitation. 1998;12(5):369-80.

54. Alotaibi M, Long T, Kennedy E, Bavishi S. The efficacy of GMFM-88 and GMFM-66 to detect changes in gross motor function in children with cerebral palsy (CP): a literature review. Disability and rehabilitation. 2014;36(8):617-27.

VITA:

Author's Names: Ryan Thomas Callahan

Place of Birth: Beverly, MA

Education:

Harvard University, Cambridge, MA	2015
Coursework: Pre-Medical Sciences	

University of Massachusetts Amherst, Amherst, MA	2010
Major Field of Study: Bachelor of Science - Kinesiology	

Academic Appointments:

Head Graduate Teaching Assistant / Laboratory Director	2016 - 2017
Biomechanics, University of Kentucky	

Graduate Teaching Assistant / Laboratory Instructor	2016
Biomechanics, University of Kentucky	

Guest Lecturer	2016
Biomechanics, University of Kentucky	

Clinical Research Experience:

Senior Clinical Research Coordinator	2013 - 2015
Emergency Medicine, Massachusetts General Hospital	
Clinical Research Coordinator II	2012 - 2013
Emergency Medicine, Massachusetts General Hospital	
Clinical Research Coordinator I	2011 - 2012
Emergency Medicine, Massachusetts General Hospital	
Clinical Research Assistant	2010 - 2011
Muscle Biology and Imaging Laboratory, University of Massachusetts	

Academic Research Experience:

Graduate Research Investigator   2016 - 2017

Motion Analysis Laboratory, Shriners Hospital for Children

Independent Study Undergraduate Research Assistant   2008 - 2009

Muscle Biology and Imaging Laboratory, University of Massachusetts

Professional Affiliations:

Gait and Clinical Movement Analysis Society (GCMAS)   2016 - Present

American Society of Biomechanics (ASB)   2016 - Present

American College of Sports Medicine (ACSM)   2013 - Present

Harvard Extension Pre-Health Society (HEPS)   2013 - Present

Awards and Academic Honors:

University of Kentucky   2016 - 2017

Graduate Certificate Program in Developmental Disabilities

University of Kentucky   2016 - 2017

Graduate Teaching Assistant Fellowship

Massachusetts General Hospital   2014

Partners in Excellence Team Award, MRSA Ambulatory Pilot Program

Massachusetts General Hospital   2013

Partners in Excellence Team Award, Pulmonary Embolism Response Team

Northern Essex Community College   2007

NJCAA All-American, Baseball

Northern Essex Community College   2007

NJCAA All-New England, Baseball

Publications:

1. McCluskey SM, Schuetz P, Abers MS, Bearnot B, Morales M, Hoffman D, Patel S, Rosario L, Chiappa V, Parry B, Callahan RT. Serial Procalcitonin as A Predictor of Bacteremia and Need for ICU Care in Adults with Pneumonia, Including Those with Highest Severity: A Prospective Cohort Study. *Open Forum Infectious Diseases*. 2016 Dec 28 (p. ofw238). Oxford University Press.

2. Marshall AL, Levine M, Howell ML, Chang Y, Riklin E, Parry BA, Callahan RT, Okechukwu I, Ayres AM, Nahed BV, Goldstein JN. Dose-Associated Pulmonary Complication Rates After Fresh Frozen Plasma Administration for Warfarin Reversal. *Journal of Thrombosis and Haemostasis*. 2016 Feb 1;14(2):324-30.

3. Levine M, Marshall A, Howell ML, Thomas SH, Riklin E, Parry BA, Callahan RT, Okechukwu I, Dzik WS, Goldstein JN. 411 Thromboembolism After Emergency Warfarin Reversal with Fresh Frozen Plasma. *Annals of Emergency Medicine*. 2015 Oct 1;66(4):S148.

4. Eyre AJ, Parry BA, Callahan RT, Douglas E, Chang Y, Takayesu JK. Emergency Department Observation Units: An Educational Opportunity. *Academic Emergency Medicine*. 2015 May 1;22:S203-4.

Poster Presentations:

1. Callahan RT, White H, PhD, PT, Wallace JJ, MS, Pohl MB, PhD., Shapiro R, PhD. (2016). Center of Pressure Excursion During a Single Leg Standing Test in Ambulatory Children with Cerebral Palsy. *Center for Clinical and Translational Research Spring Conference*, University of Kentucky.